2017 FDOT – Halls River Bridge FRP Workshop

May 3, 2017

Tampa, FL

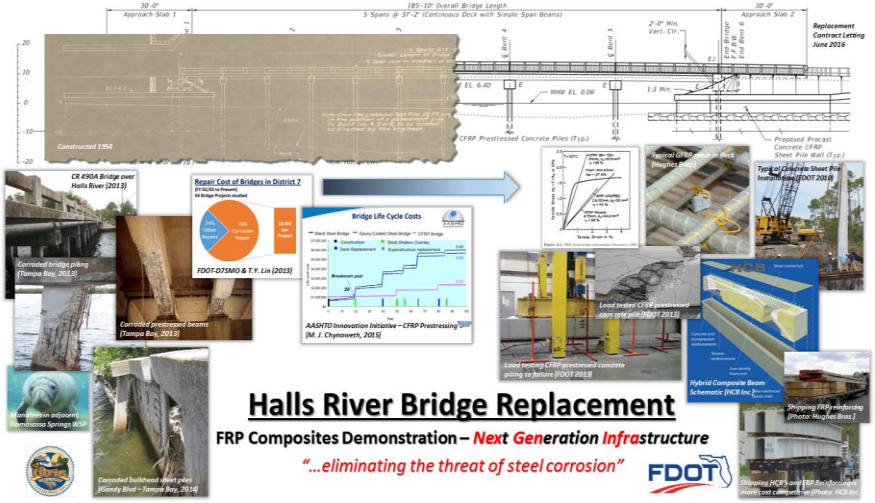
# HRB-FRP Workshop (Part 2)

## Developmental Design Standards


Presenter: **Steve Nolan**

*State Structures Design Office*

*Design Technology – Standards Group*

# Outline:

**Part 1 –** Bridge Design (1:15 – 2:30pm) (Pelham, Masseus, Siddiqui)

1. Halls River Bridge Project Overview
2. Hybrid Composite Beams
3. GFRP-RC Deck Design
4. GFRP-RC Bent Cap Design
5. Challenges & Lessons Learn

*(15 min. break)*

**Part 2 -** Developmental Standards:

5. CFRP Prestressed Concrete Bearing Piles - (Nolan)
6. Cantilever Sheet Pile Walls (Bulkhead/Seawall) - (Nolan/Hunter)
7. Gravity Walls - (Nolan)
8. GFRP-RC Traffic Railings & Approach Slabs - (Nolan)

**Part 3 -** Research Project & Monitoring - (Roddenberry/Knight)

**Part 4 -** CEI's Insights and Recommendations - (D7 Construction)

**Part 5** - Open Discussion

# CFRP Prestressed Concrete Bearing Piles

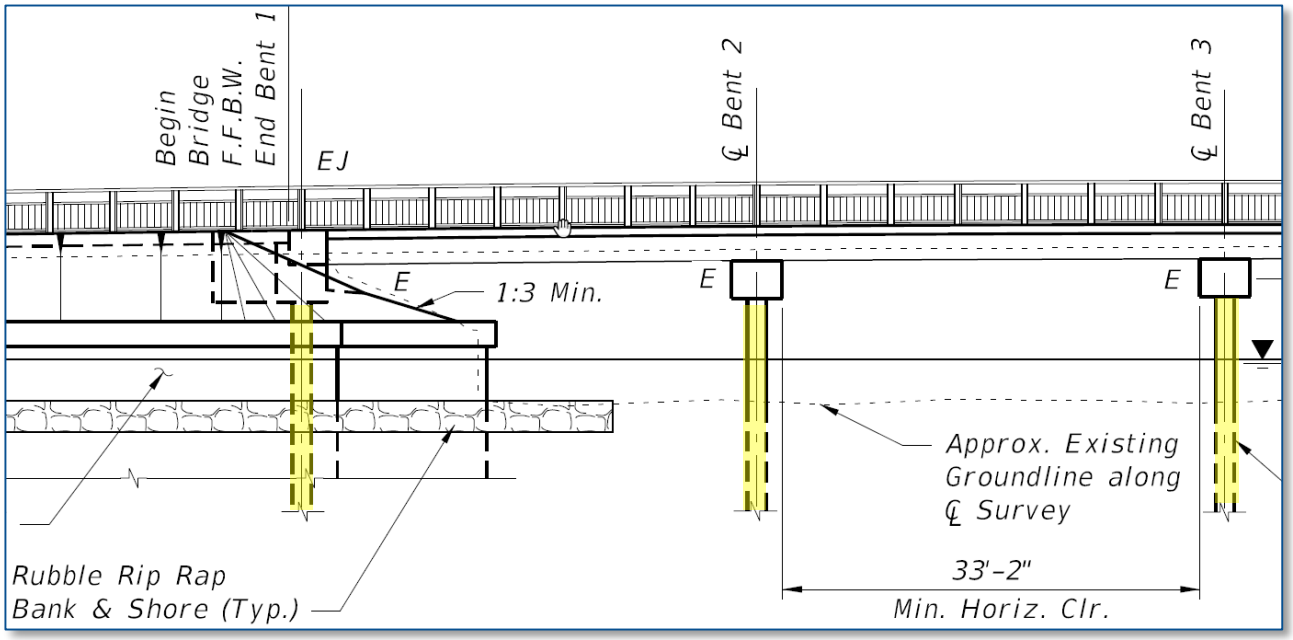
# CFRP Prestressed Bearing Piles

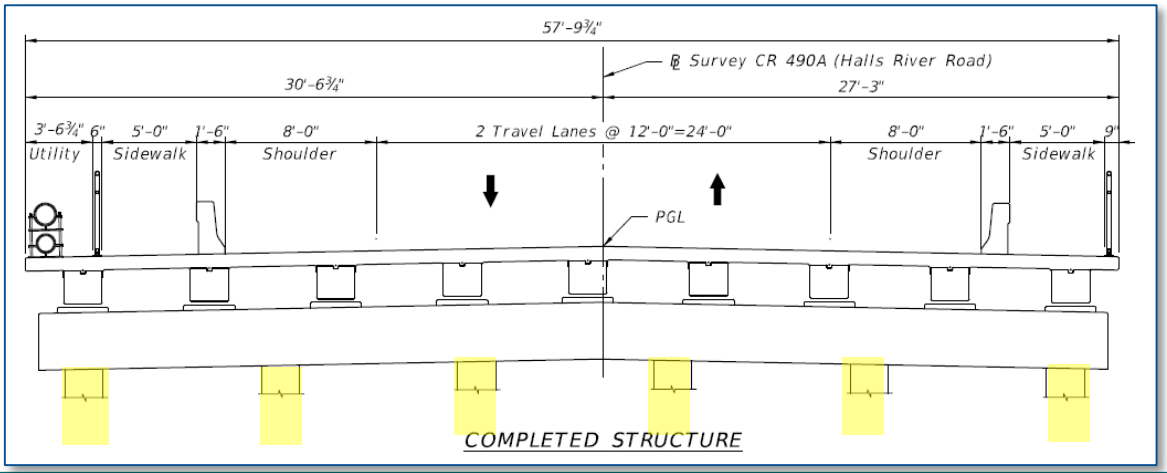
- 18”x18” Square Concrete Prestressed Piles;

- 6 Piles per End Bents;

- 6 Piles per Intermediate Bents;

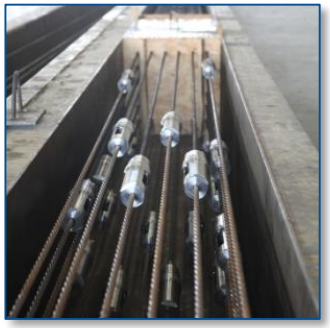
- Total 36 piles, (test pile lengths 55’ to 70’)

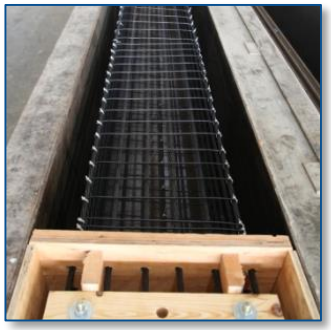


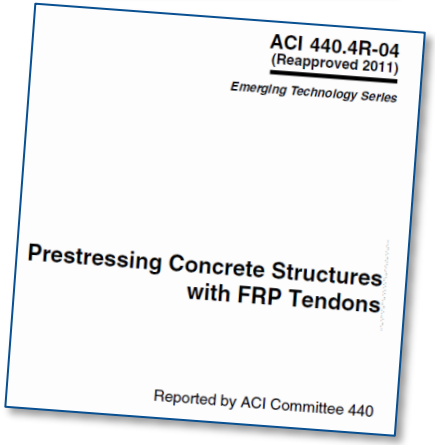



# CFRP Prestressed Bearing Piles

A. Standardization
   i. Square CFRP Prestressed Bearing Piles
   ***ii.*** ***Developmental*** Index D22600 & D22618 (*now conventional* ***Design Standards***)
B. Development Basis
   i. Research at FAMU/FSU
C. Design Criteria - ***ACI 440.4R***
D. FDOT Material Specifications – (***Dev) 932*** & ***933***
E. Usage Criteria – ***SDG*** 3.5.1
F. Challenges
   i. No ***AASHTO*** CFRP Prestressing Design Specifications
   ***ii.*** ***ACI 440.4R*** jacking forces limits (65% $f_{pu}$) may be too conservative for bearing piles
   iii. Cracking at pile cut-offs observed.



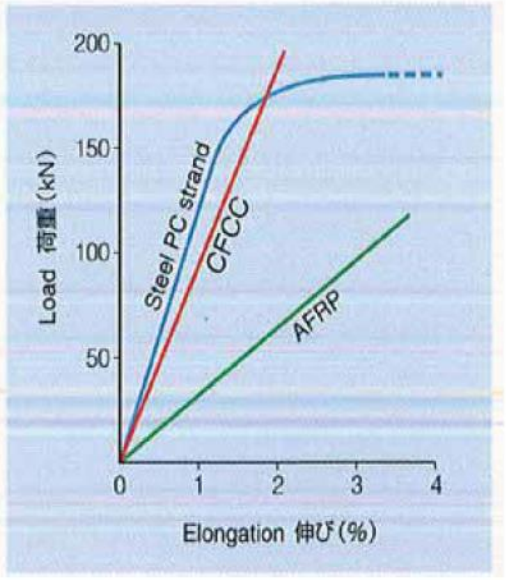




# CFRP Prestressed Pile Research:

- Roddenberry M, Mtenga P, Joshi K, (2014). "Investigation of Carbon Fiber Composite Cables (CFCC) in Prestressed Concrete Piles", FAMU-FSU College of Engineering, for FDOT Project BDK83-977-17, April 2014.

  http://www.dot.state.fl.us/structures/structuresresearchcenter/Final%20Reports/2014/FDOT-BDK83-977-17-rpt.pdf




Load and elongation diagram (Source: Tokyo Rope

Figure 5.4: EDC installation

# CFRP Prestressed Pile Research:

- Roddenberry M, Mtenga P, Joshi K, (2014). "Investigation of Carbon Fiber Composite Cables (CFCC) in Prestressed Concrete Piles", FAMU-FSU College of Engineering, for FDOT Project BDK83-977-17, April 2014.

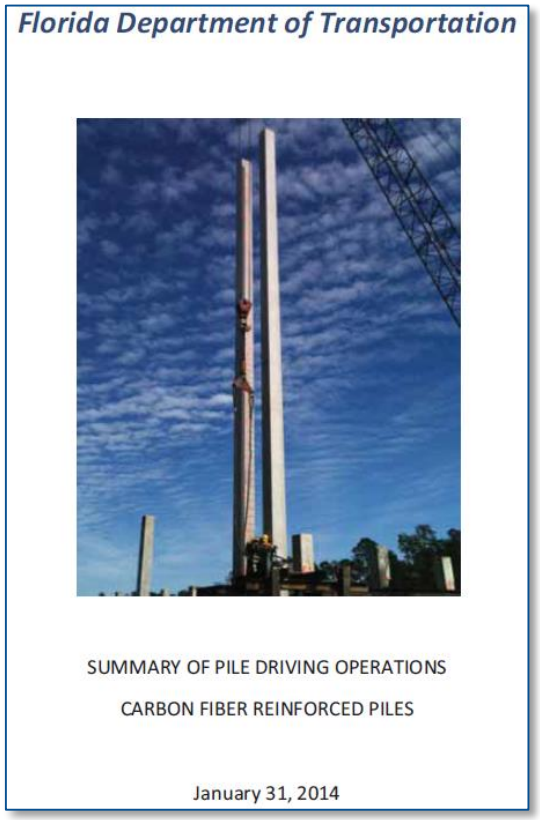


Figure 12 – Diesel Covered Pile with Spalled Sections

# CFRP Prestressed Pile Research

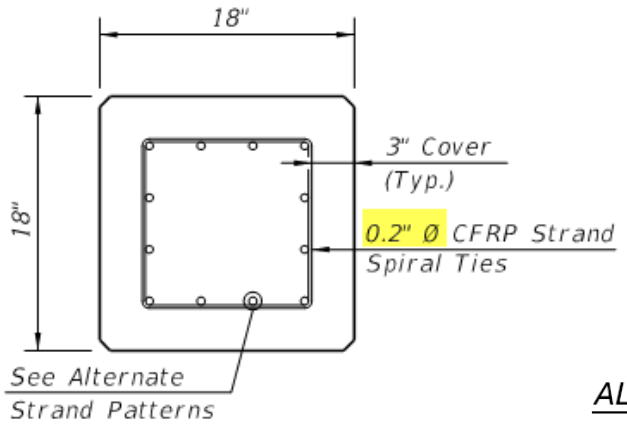
Other past pile research (referenced ***ACI 440.4R)***:

1. Iyer, S. L., 1995, "Demonstration of Advanced CompositeCables for use as Prestressing in Concrete WaterfrontStructures," Final report submitted to U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, Champaign, Ill., Nov.
2. Arockiasamy, M., and Amer, A., 1998, "Studies on CFRP Prestressed Concrete Bridge Columns and Piles in Marine Environment," Final Report Submitted to FDOT, Tallahassee, Fla., July. *http://www.fdot.gov/structures/structuresresearchcenter/Final%20Reports/1998/B-9076%20-%20Final%20Rpt.pdf*
3. Schiebel, S., and Nanni, A., 2000, "Axial and Flexural Performance of Concrete Piles Prestressed with CFRP Tendons," *Proceedings of the Third International Conference on Advanced Composite Materials in Bridges and Structures (ACMBS3)*, Ottawa, Canada, Aug., pp. 471-478

# Standardization – ***Developmental Design Standards*** *(2014-2016)*

## - Prestressed Concrete Piles (with CFRP only)

- ***Indexes D22600, D20601, D22614, 22618 & 22624***
  - New corrosion resistant piling for intermediate bridge pile bents in Extremely Aggressive Environments (splash zone);
  - Used for Halls River Demonstration Project.




SECTION A-A

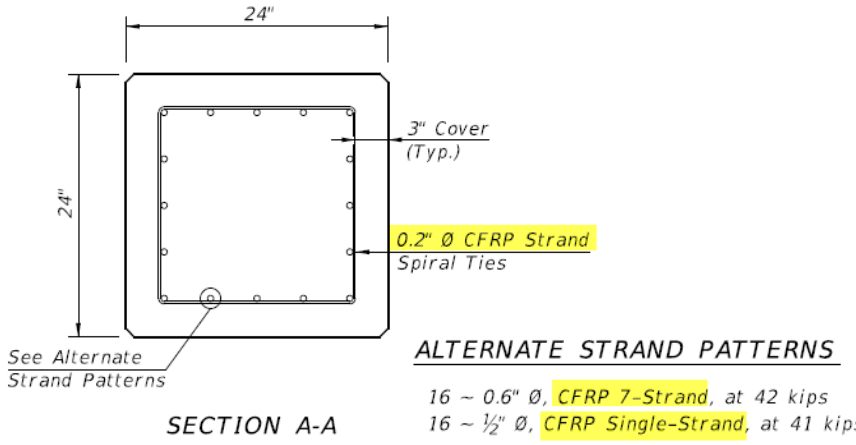
ALTERNATE STRAND PATTERNS

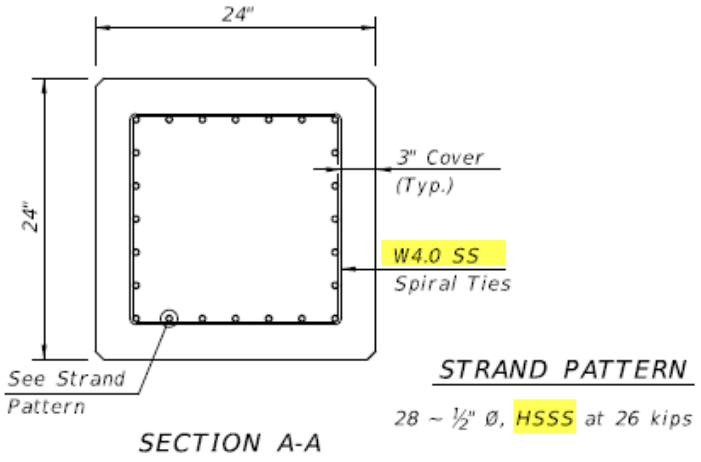
12 ~ 0.6" Ø, CFRP 7-Strand, at 34 kips
12 ~ ½" Ø, CFRP Single-Strand, at 33 kips

# Standardization – ***Design Standards*** *(2016-2017)*

## - Prestressed Concrete Piles (with CFRP or SS)

- ***Indexes*** 22600, 20601, 22612, 22614, 22618, 22624, & 20630
  - New corrosion resistant piling for intermediate bridge pile bents in Extremely Aggressive Environments (marine)
    - *see* ***Structures Design Bulletin 15-10*** *for more information and*
    - ***SDG*** *Table 3.5.1-1 for application.*
  - Carbon-FRP strands (single or 7-strand) & spiral reinforcing or Stainless Steel strand (7-wire) and spiral reinforcing *(at contractor's/producer's option)*

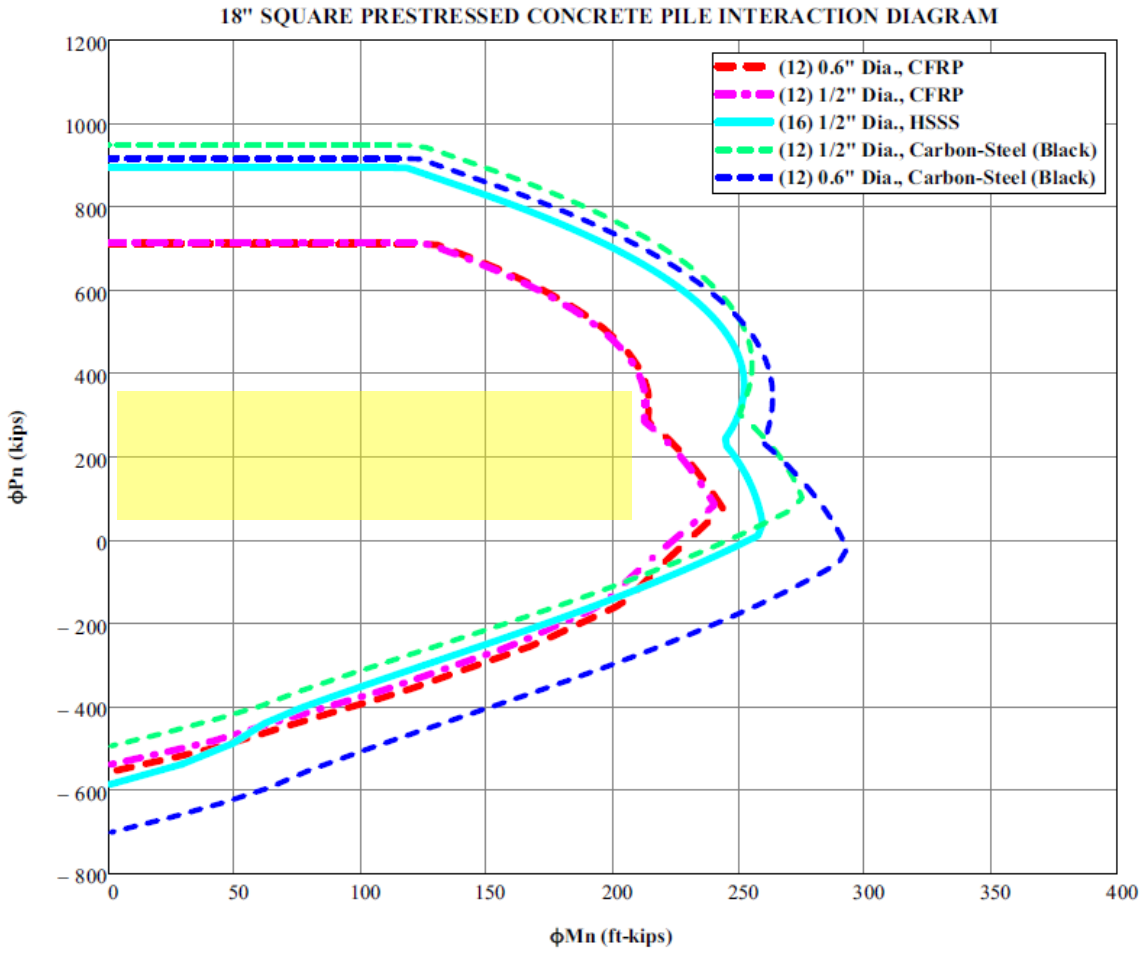


# Standardization – ***Design Standards***

## - Prestressed Concrete Piles (with CFRP or SS)

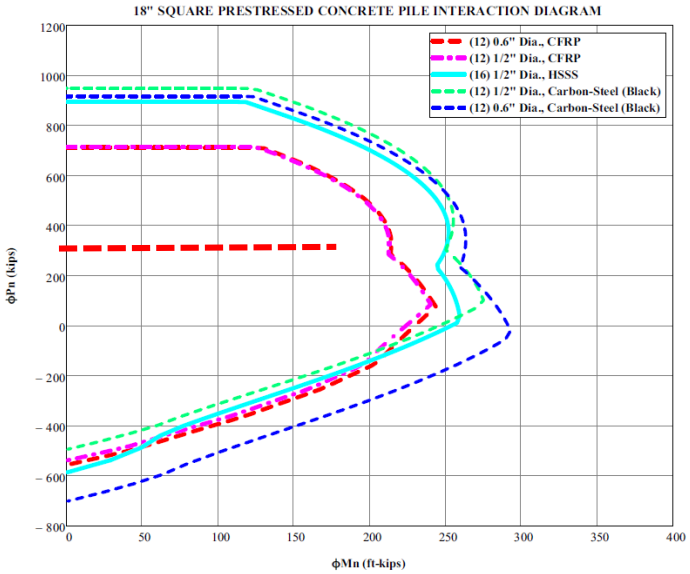
- ***Instructions – IDS-22600***
- Nominal 1,000 psi uniform compression
- Slight differences in Strength Limit States mainly due to reduced resistance factors for CFRP prestressing. Refer to the ***Design Aid*** M-N Charts



# Standardization – ***Design Standards***

## - Prestressed Concrete Piles (with CFRP or SS)

- ***HRB Pile Data Table***
- Max. Axial Load = 288 kips



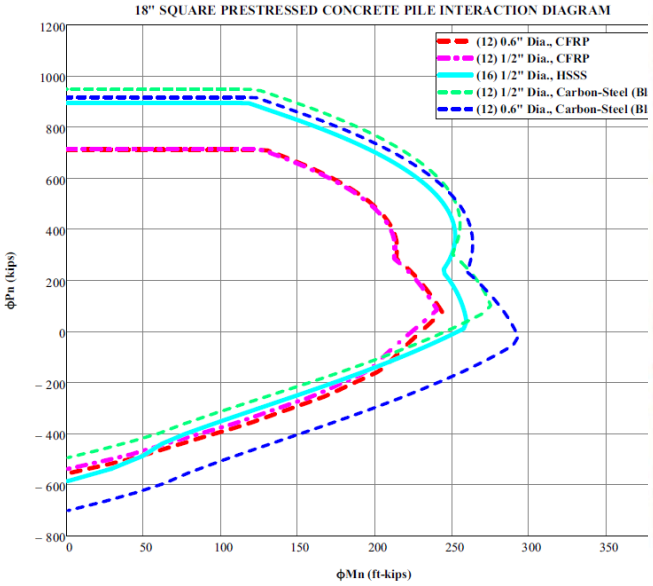

PILE DATA TAB

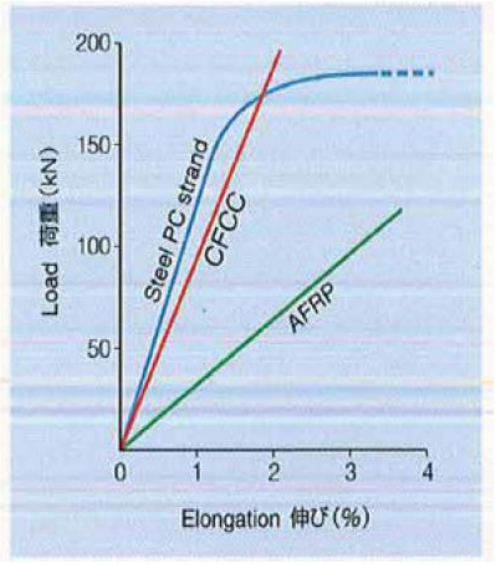
| INSTALLATION CRITERIA | | | | | | | | DE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PIER or BENT NUMBER | PILE SIZE (in.) | NOMINAL BEARING RESISTANCE (tons) | NOMINAL UPLIFT RESISTANCE (tons) | MINIMUM TIP ELEVATION (ft.) | TEST PILE LENGTH (ft.) | REQUIRED JET ELEVATION (ft.) | REQUIRED PREFORM ELEVATION (ft.) | FACTORED DESIGN LOAD (tons) | FACTORED DESIGN UPLIFT LOAD (tons) | DOWN DRAG (tons) | TO SC RESIS (to | |
| EB1 | 18 | 183 | N/A | — | 55 | N/A | — | 119 | — | — | N/A | N/A |
| 2 | 18 | 222 | N/A | -27 | N/A | N/A | -27 | 144 | — | — | 22 | 0 |
| 3 | 18 | 222 | N/A | -27 | 66 | N/A | -27 | 144 | — | — | 22 | 0 |
| 4 | 18 | 222 | N/A | -27 | N/A | N/A | -27 | 144 | — | — | 8 | 0 |
| 5 | 18 | 222 | N/A | -27 | 70 | N/A | -27 | 144 | — | — | 8 | 0 |
| EB6 | 18 | 183 | N/A | — | 64 | N/A | — | 119 | — | — | N/A | N/A |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

# Standardization – ***Strength Design Modelling***

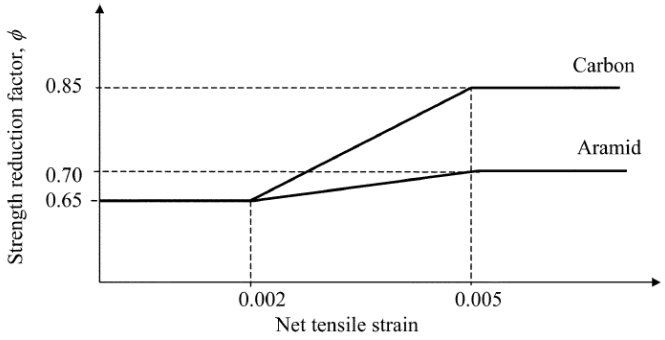
## - Prestressed Concrete Piles (with CFRP or SS)

- CFRP strands linear-elastic to failure
- CFCC (0.6”~7-cord)
  - $E_p$ = 22,480 ksi
  - $f_{pu}$ = 339 *ksi*
- CFRP (1/2”~single-rod)
  - $E_p$ = 18,000 ksi
  - $f_{pu}$ = 300 ksi
- Resistance Factor
  - $\phi$ = 0.65 to 0.85
- Use strain compatibility method
- Environmental Reduction Factor ($C_E$) not addressed in ACI 440.4R. **Used 0.9 for Interaction Diagrams**

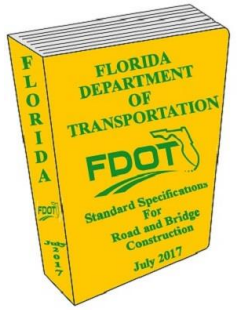


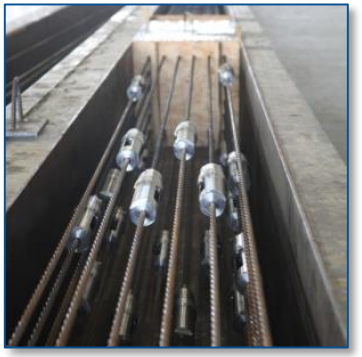

Load and elongation diagram (Source: Tokyo Rope)



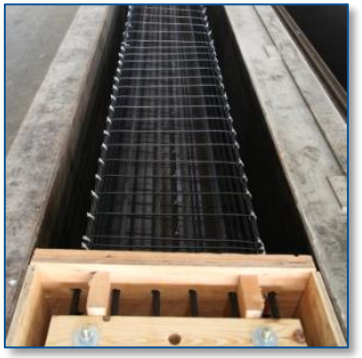
# FDOT Specifications




a) ***Standard Specifications*** (effective July 2016):
   - Implemented previous ***Developmental Specifications*** for FRP materials;
   - Added Stainless Steel Bar, Wire & Strand;
   - ***931*** Metal Accessory Materials for Concrete Pavement and Concrete;



b) Previous ***Developmental Specifications***:
   - ***Dev400FRP*** Concrete Structures – Fiber Reinforced Polymer Reinforcing;
   - ***Dev410FRP*** Precast Concrete Box Culvert;
   - ***Dev415FRP*** Reinforcing for Concrete;
   - ***Dev450FRP*** Precast Prestressed Concrete Construction – Fiber Reinforced Polymer (FRP);
   - ***Dev932FRP*** Nonmetallic Accessory Materials for Concrete Pavement and Concrete Structures;
   - ***Dev933FRP*** Prestressing Strand;



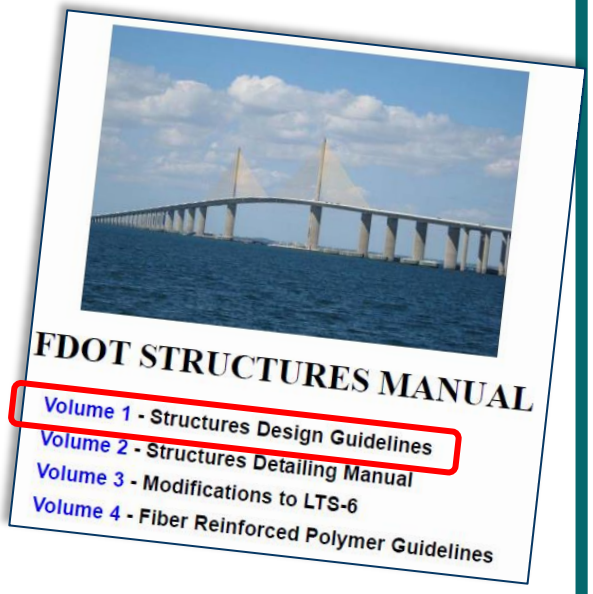
# Usage Criteria

## - Prestressed Concrete Piles (with CFRP or SS)

- ***SDG Table 3.5.1-1***
  - Piles in the "splash zone" (= Intermediate Pile Bents in marine environments), preferred use of Carbon FRP strands & spiral reinforcing or Stainless Steel strand and spiral reinforcing.

**Table 3.5.1-1 Concrete Pile Size and Material Requirements**

| Pile Location | | | Minimum Square Pile Size (inches) | | Minimum Cylinder Pile Diameter (inches) | Material Properties for All Pile Sizes[1] | | |
|---|---|---|---|---|---|---|---|---|
| | | | Vehicular Bridges | Pedestrian Bridges & Fishing Piers | | Strand Type | Spiral Type | Reinforcing Bar Type |
| Pile Bents | On land or in water in environments that are Extremely Aggressive due to chlorides | Widenings | 24[2] | 18 | 54 | Carbon steel, Spec 933 | Carbon steel, Spec 931 | Carbon steel, Spec 931 |
| | | New Construction | 24[3] | 18[3] | 54[3] | Carbon steel, Spec 933 | Carbon steel, Spec 931 | Carbon steel, Spec 931 |
| | | | 18 | 14 | 54 | CFRP, Spec 933 | CFRP, Spec 932 | GFRP or CFRP, Spec 932 |
| | | | | | | Stainless steel, Spec 933 | Stainless steel, Spec 931 | Stainless steel, Spec 931 |
| | On land or in water in all other environments | | 18 | 14 | 54 | Carbon steel, Spec 933 | Carbon steel, Spec 931 | Carbon steel, Spec 931 |
| Footings | In water (waterline or mudline) in environments that are Extremely Aggressive due to chlorides | | 24[2] | 18 | 54 | Carbon steel, Spec 933 | Carbon steel, Spec 931 | Carbon steel, Spec 931 |
| | On land or in water (waterline or mudline) in all other environments | | 18 | 14 | 54 | Carbon steel, Spec 933 | Carbon steel, Spec 931 | Carbon steel, Spec 931 |

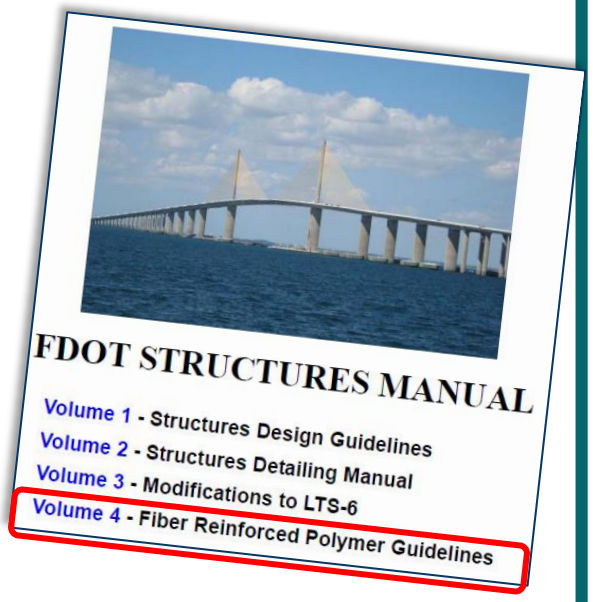



[3] The use of FRP or stainless steel strand and reinforcing is preferred for use in splash zones.

# Usage Criteria

## - General FRP guidelines

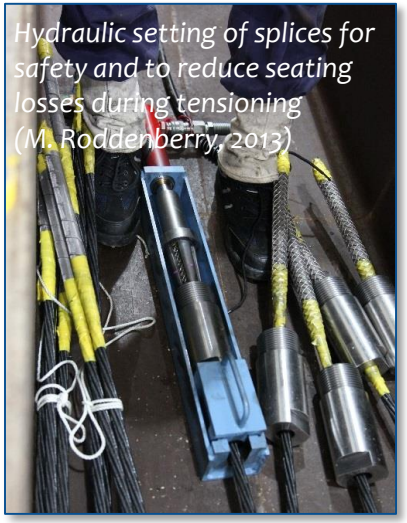
- ***Structures Manual Vol. 4 – Fiber Reinforced Polymer Guidelines (FRPG)***.
  - Overall commentary on FRP;
  - Specific design criteria, plan content and Specification requirements;
  - Design review requirements;
  - Approval of use process;
  - Permitted uses for each type of FRP.



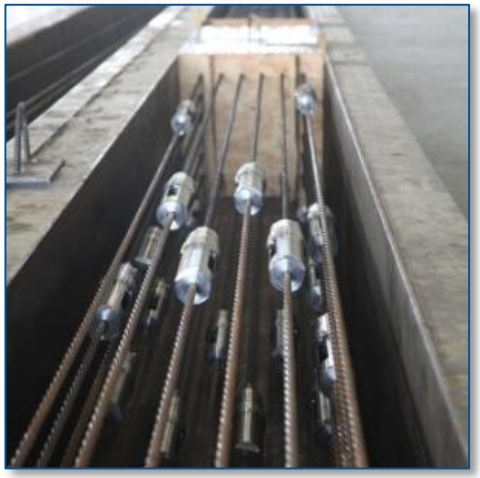

http://www.fdot.gov/structures/StructuresManual/CurrentRelease/StructuresManual.shtm

# Fabrication Challenges with CFRP Strands *(Spec. Section 450 & 933):*

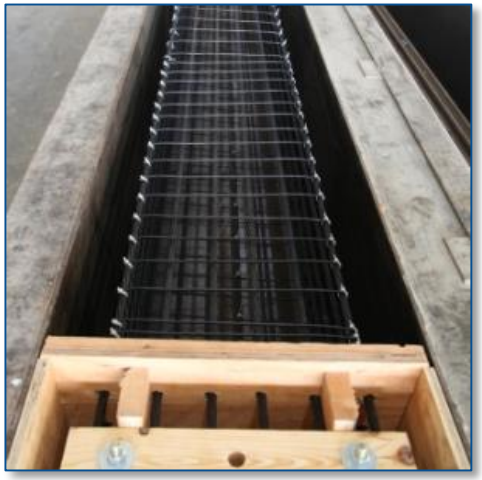
- Use self-consolidating concrete only;
- No flame or shear cutting of CFRP strand;
- Tie using plastic coated wire or zip ties;
- Spirals for CFRP reinforced piling must also be CFRP;
- Headers must be wood, or steel with rubber grommets.
- Coupling to steel strand tails for stressing



*Hydraulic setting of splices for safety and to reduce seating losses during tensioning (M. Roddenberry, 2013)*



(photograph) FDOT. *Coupling CFRP Strands to Steel Strands.*



(photograph) FDOT. *Wooden Headers For CFRP Strands.*

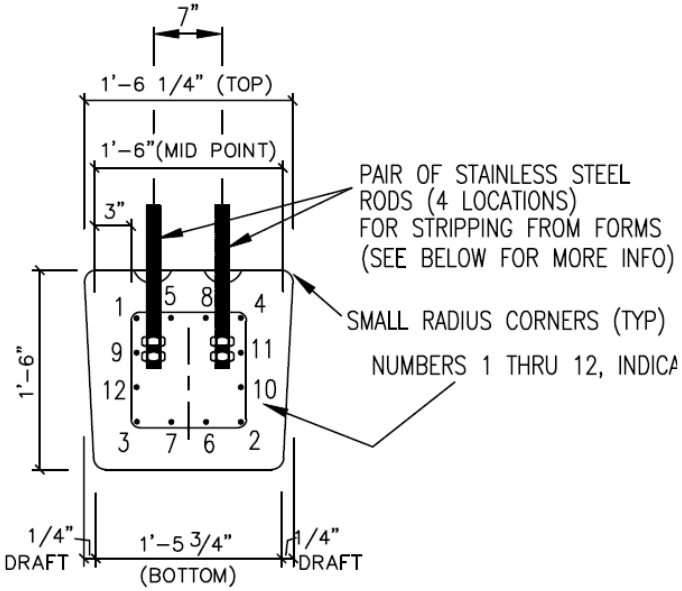
(photograph) FDOT. *CFRP Pile Casting with SCC.*

# Challenges with CFRP Strands

*(Halls River Bridge):*

- Cracking at cut-offs
- Lifting Devices (form removal)

(Photographs - FDOT). *Strand contraction and cracking at cut-offs.*



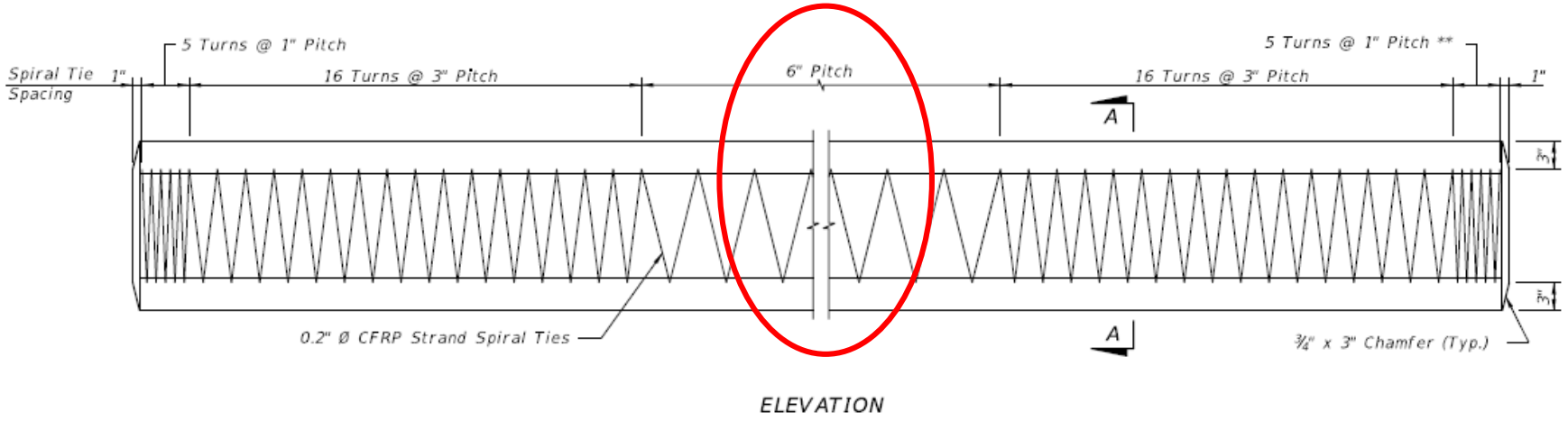

(Figure) *Corrosion resistance lifting device from Shop Drawings* (Gate Precast)

# Challenges with CFRP Strands

*(Halls River Bridge):*

- Cracking at cut-offs – possible actions:
  - Decrease spiral pitch << 6”
  - Increase spiral size > 0.2” to 0.3” dia.
  - Reduce prestressing force ☹
  - Seal cracks at exposed faces as needed
  - Or do nothing for now and monitor

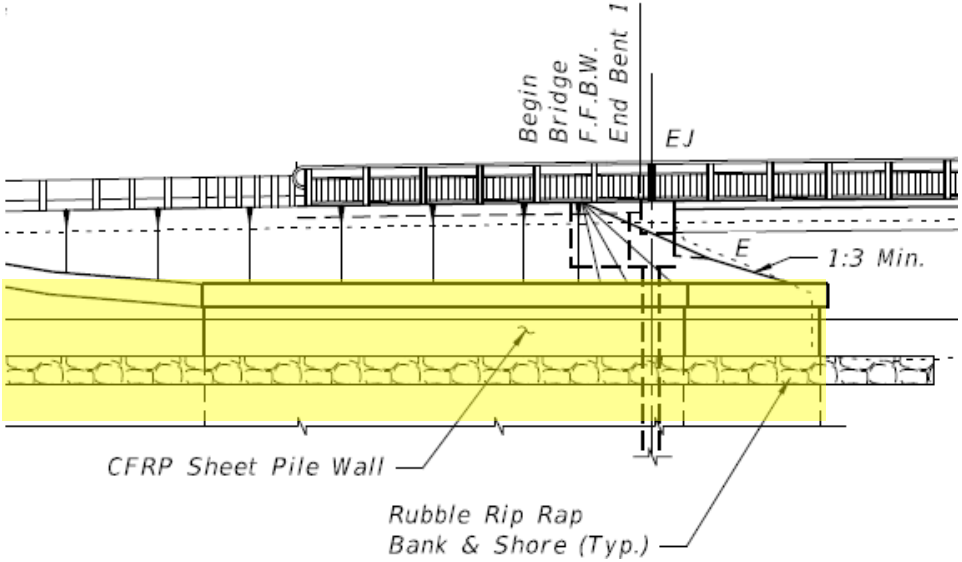
(Photographs - FDOT). *Strand contraction and cracking at cut-off.*




(Figure) *Spiral reinforcing from FDOT Index D22618*

# Cantilever Concrete Sheet Pile Walls (Bulkhead/Seawall)

# Concrete Sheet Pile Walls

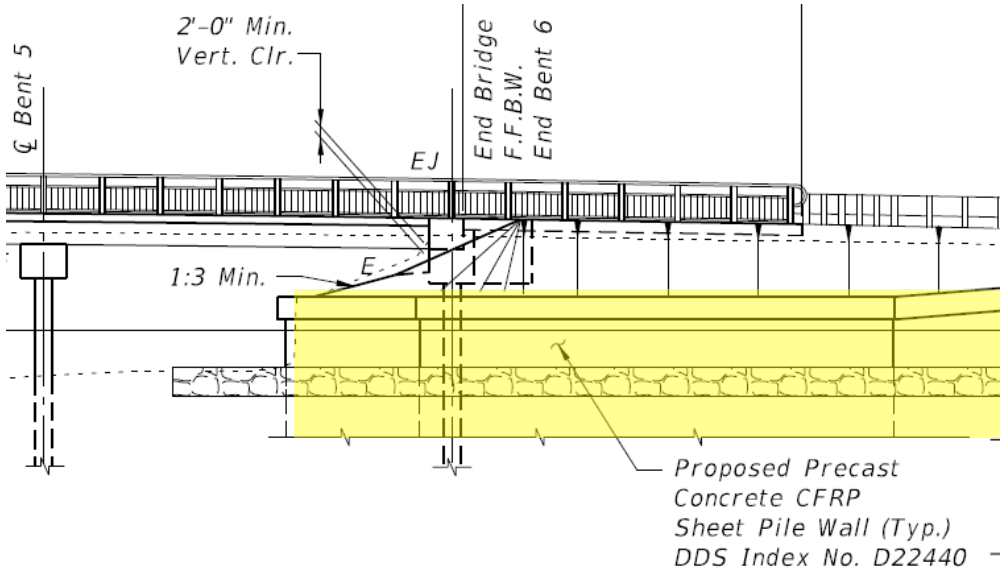



**Sheet Piles:**

- 12" x 30" Concrete Prestressed Sheet Section;
- 8 CFRP prestressing strands ;
- GFRP #4 stirrups and #5 supplemental reinforcing;
- Lengths vary 24' to 29';
- Total 235 piles (12 corner piles)

**Caps:**

- 24" x 27" Concrete Section;
- GFRP #5 stirrups and #5 longitudinal reinforcing;
- Total Length 575'
- Integral Test Blocks

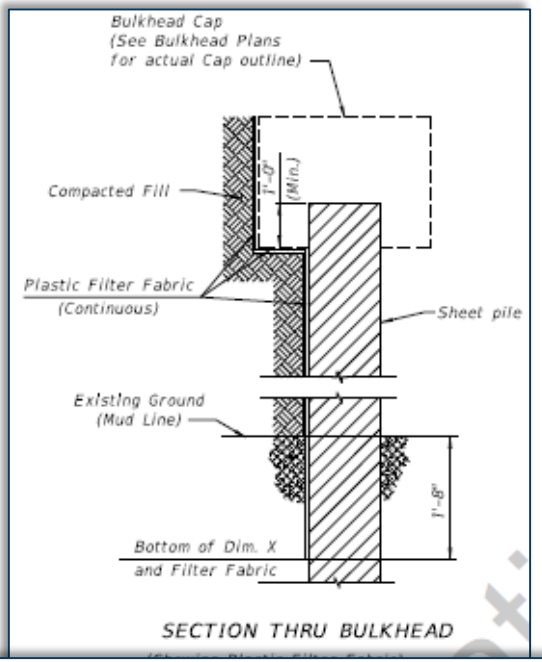


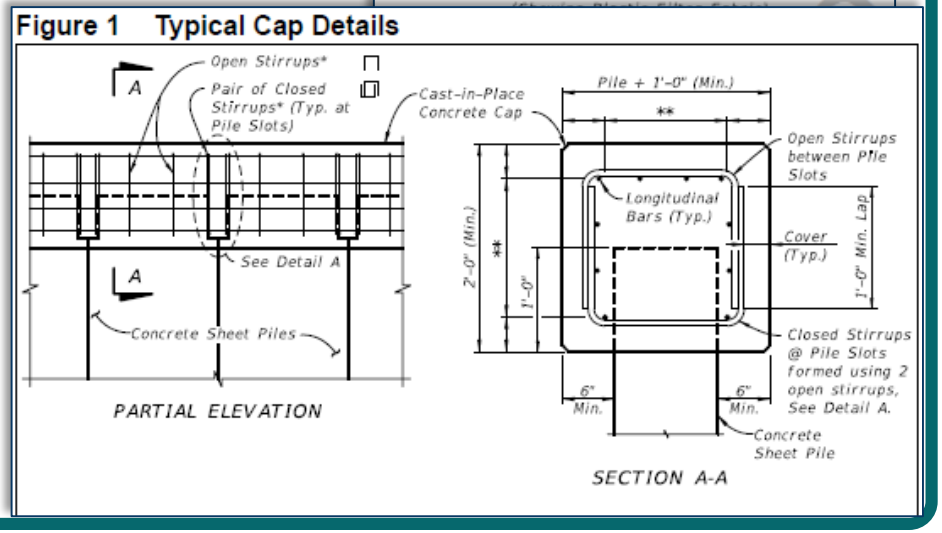
# Concrete Sheet Pile Walls
## (with CFRP/GFRP)

A. Standardization
   i. CFRP/GFRP Prestressed Concrete Sheet Piles (***Index D22440***)
   ii. GFRP-RC Bulkhead Cap (***FDOT Instructions – IDDS-22440,*** *see Figure 1 below*)
   iii. GFRP-RC Guidelines (***Structures Manual*** –Vol. 4 ***Fiber-Reinforced Polymer Guidelines***)

B. FDOT ***Material Specifications*** for strands and bars
   i. FRP Bars – ***Section 932 (Dev)***
   ii. FRP Strands - ***Section 933 (Dev)***

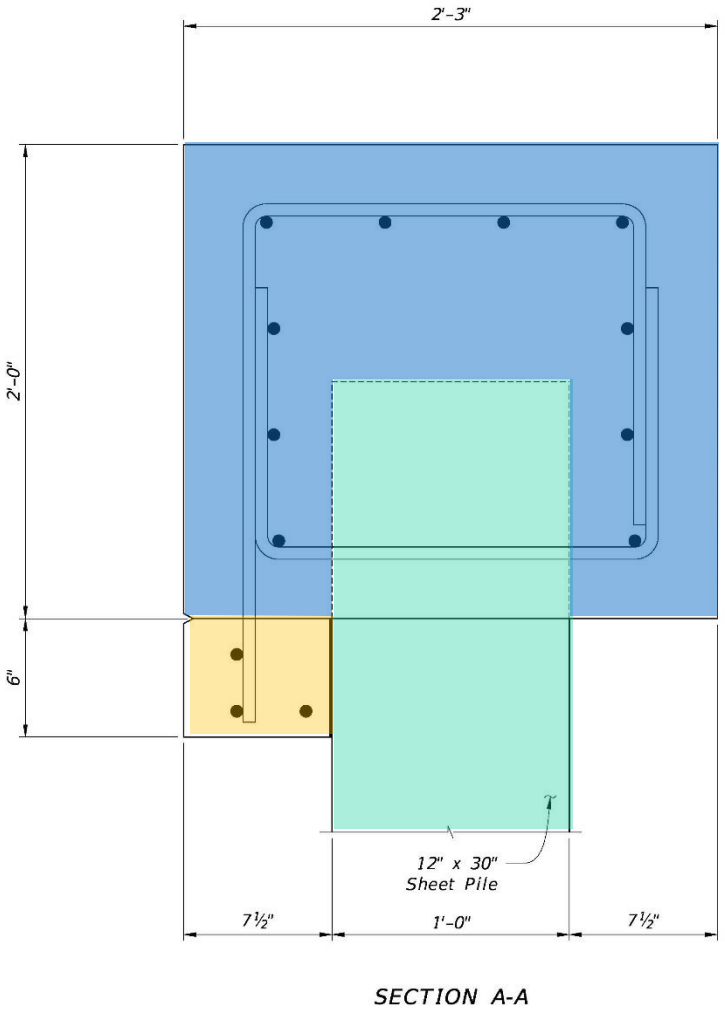
C. Design Criteria - ***ACI 440.1R*** & ***440.4R***
   i. 700 psi min. pre-compression
   ii. Allow 6√f'c tension for Service Limit State.
   → *Equivalent to 1,165 psi pre-comp. when no tension allowed.*



# Concrete Sheet Pile Wall Caps
## (with GFRP)

Example Original Plan Sheet Details:




SECTION A-A

GFRP

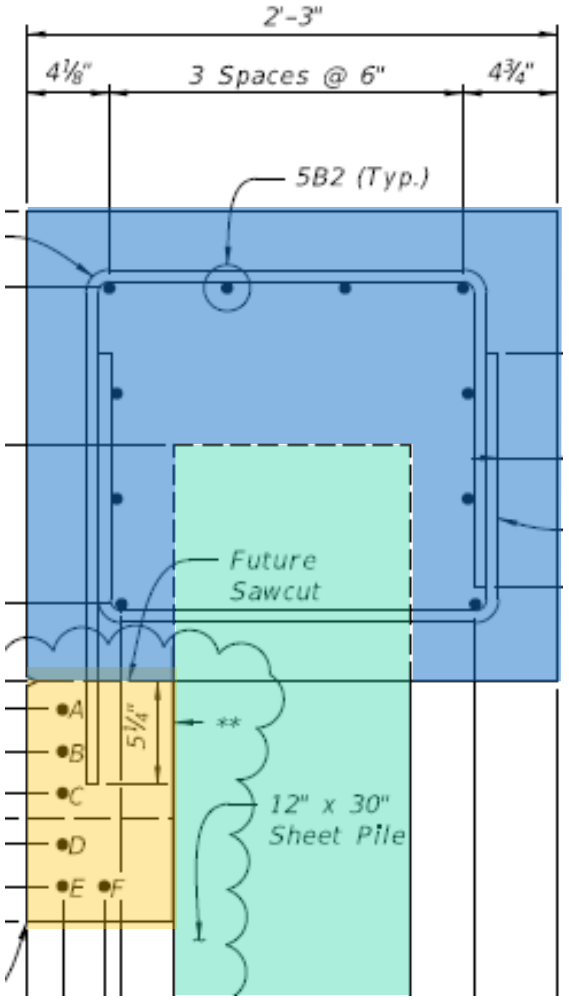
CFRP/ GFRP

Test Block

Note:

1. Bulkhead caps and test blocks are to be cast monolithically with same concrete mix.
2. Concrete cover reduced in test blocks

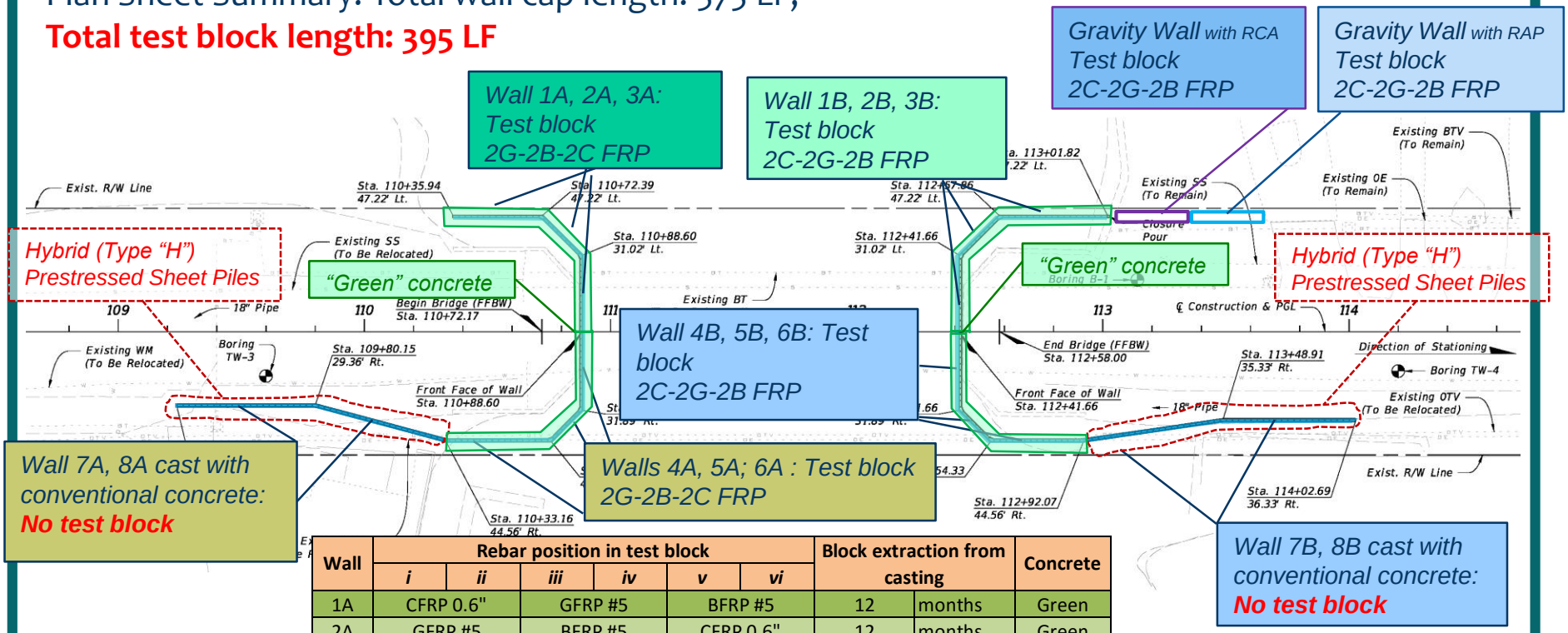
Revised Plan Test Block Details:



# Concrete Sheet Pile Walls

Plan Sheet Summary: Total wall cap length: 575 LF;

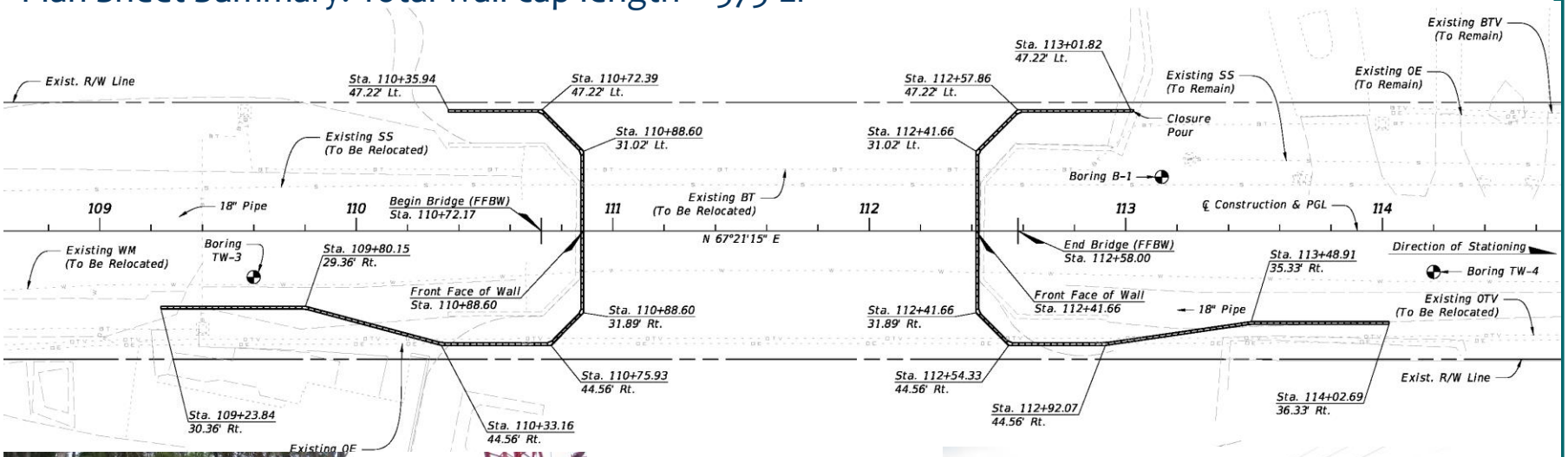
**Total test block length: 395 LF**




| Wall | Rebar position in test block | | | | | | Block extraction from casting | | Concrete |
|---|---|---|---|---|---|---|---|---|---|
| | *i* | *ii* | *iii* | *iv* | *v* | *vi* | | | |
| 1A | CFRP 0.6" | | GFRP #5 | | BFRP #5 | | 12 | months | Green |
| 2A | GFRP #5 | | BFRP #5 | | CFRP 0.6" | | 12 | months | Green |
| 3A | BFRP #5 | | CFRP 0.6" | | GFRP #5 | | 28 | days | Green |
| 1B | BFRP #5 | | CFRP 0.6" | | GFRP #5 | | 24 | months | Green |
| 2B | CFRP 06" | | GFRP #5 | | BFRP #5 | | 24 | months | Green |
| 3B | GFRP #5 | | BFRP #5 | | CFRP 0.6" | | 6 | months | Green |
| 4A | CFRP 0.6" | | GFRP #5 | | BFRP #5 | | TBD | | Green |
| 5A | GFRP #5 | | BFRP #5 | | CFRP 0.6" | | TBD | | Green |
| 6A | BFRP #5 | | CFRP 0.6" | | GFRP #5 | | TBD | | Green |
| 4B | BFRP #5 | | CFRP 0.6" | | GFRP #5 | | TBD | | Green |
| 5B | CFRP 0.6" | | GFRP #5 | | BFRP #5 | | TBD | | Green |
| 6B | GFRP #5 | | BFRP #5 | | CFRP 0.6" | | TBD | | Green |
| GW | CFRP 0.6" | | GFRP #5 | | BFRP #5 | | 12 months | 24 months | RCA |
| GW | CFRP 0.6" | | GFRP #5 | | BFRP #5 | | 12 months | 24 months | RAP |

# Concrete Sheet Pile Walls

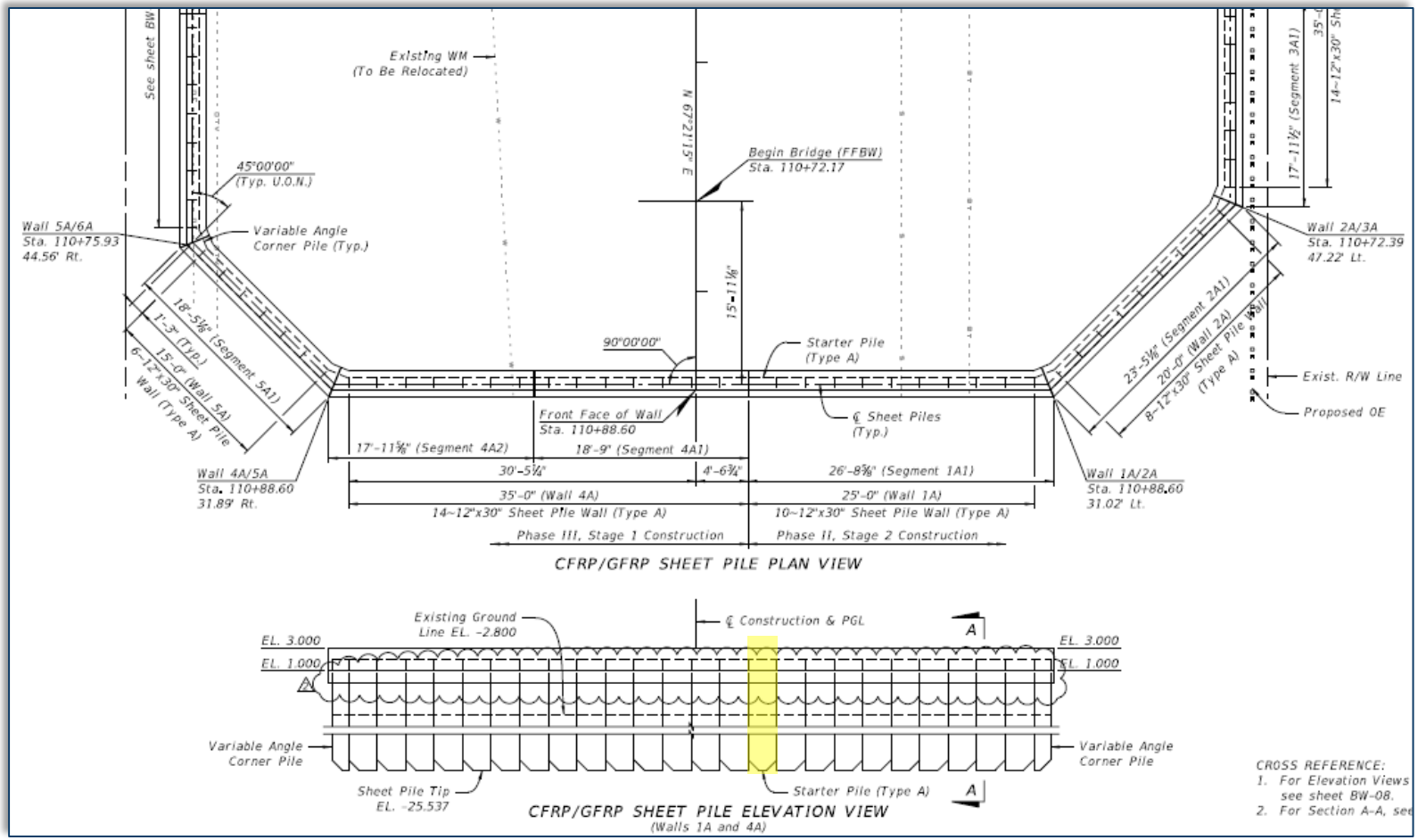
Plan Sheet Summary: Total wall cap length = 575 LF



CFRP/GFRP SHEET PILE WALL LAYOUT

# Concrete Sheet Pile Walls

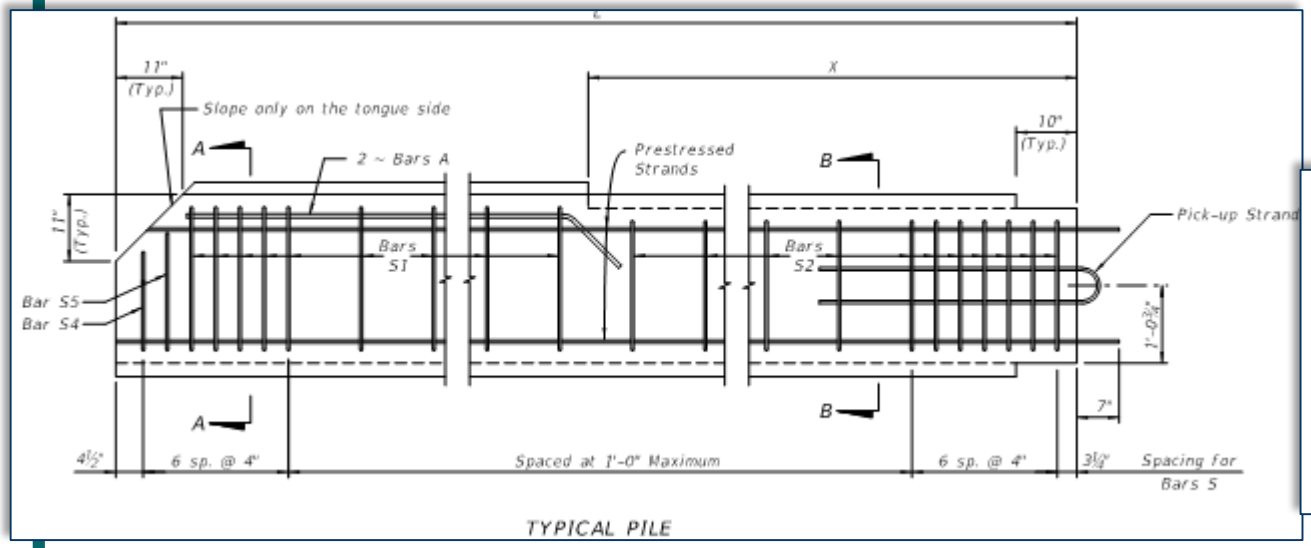
## Example Plan Sheet Details:

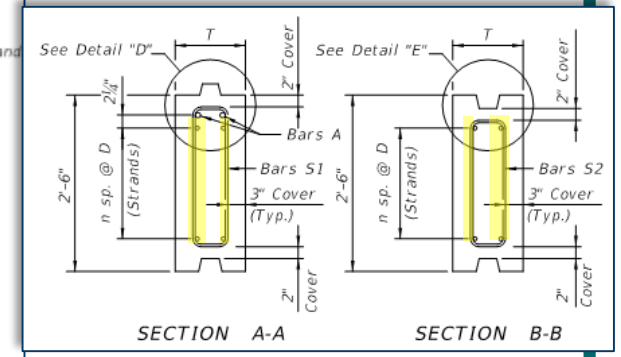


# Concrete Sheet Pile Walls

## (with CFRP/GFRP – Type "A")

### Example Project Details (***Index D22440***):




| Wall Thickness | CFRP STRAND DIA. (in.) | MAXIMUM L ** | n | D (in.) | TOTAL # OF STRANDS | SECTION MODULUS (in.³) | * STRESS (psi) |
|---|---|---|---|---|---|---|---|
| T=10 in. | 0.49 (12.5mm) | 26'-0" | 4 | 4 | 10 | 500 | 730 |
| | 0.5 (12.7mm) | 27'-0" | 3 | 5¼ (2) | 8 | 500 | 830 |
| | 0.6 (15.2mm) | 27'-0" | 3 | 5¼ (2) | 8 | 500 | 840 |
| T=12 in. | 0.49 (12.5mm) | 31'-0" | 5 | 3¼ (1) | 12 | 720 | 730 |
| | 0.5 (12.7mm) | 31'-0" | 3 | 5¼ (2) | 8 | 720 | 700 |
| | 0.6 (15.2mm) | 31'-0" | 3 | 5¼ (2) | 8 | 720 | 710 |

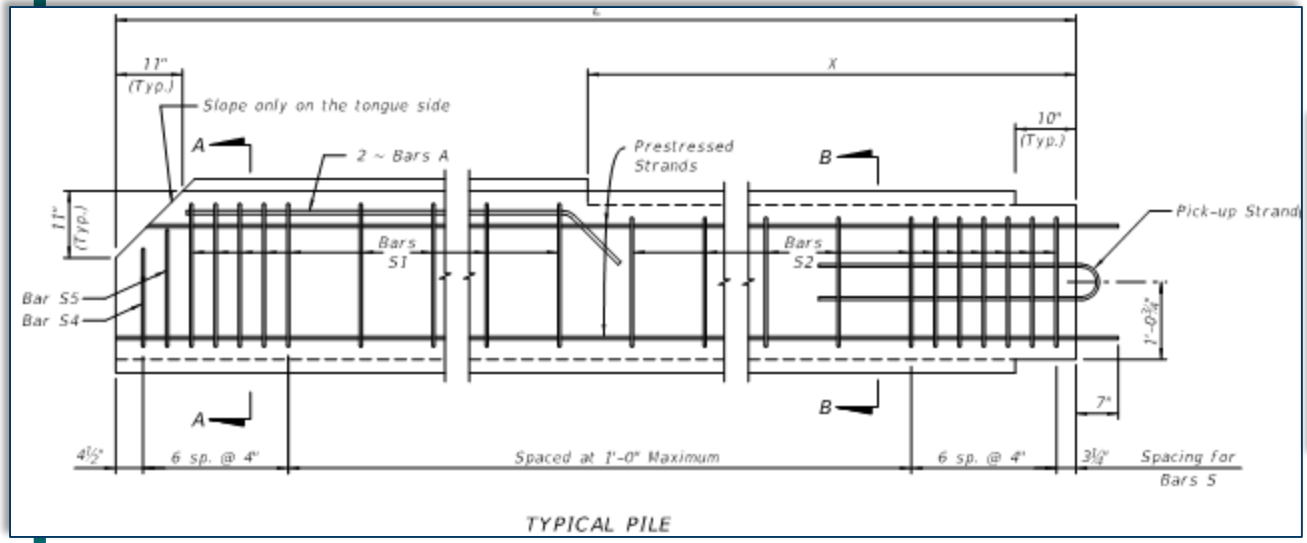
* Unit Prestress after losses.
** Based on lifting using single point pick-up.

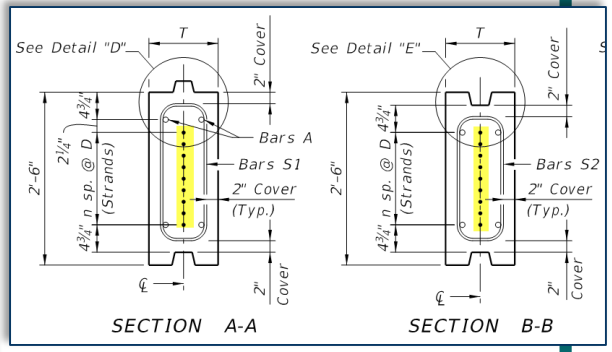
Alternate symmetrical strand patterns:
(1) 4 sp. @ 2" & 1 sp. @ 8"
(2) 2 sp. @ 4" & 1 sp. @ 8"

# Concrete Sheet Pile Walls

## (Hybrid with steel strands/GFRP stirrups - Type "H")

Example Project Details (***Index D22440***):




| Wall Thickness | STEEL STRAND DIA. (in.) | MAXIMUM L | n | D (in.) | TOTAL # OF STRANDS | SECTION MODULUS (in.³) | * STRESS (psi) |
|---|---|---|---|---|---|---|---|
| T=10 in. | 0.6 | 26'-0" | 8 | 2 | 9 | 500 | 920 |
| T=12 in. | 0.6 | 29'-0" | 8 | 2 | 9 | 720 | 800 |

* Unit Prestress after losses.

# Cantilever Concrete Sheet Pile Walls

(Design Considerations)

Currently lower capacity compared to conventional sheet piles under ***Index 6040***:

- Strength Limit State – Flexural or M-N Interaction Diagrams tools ?
- Service Limit State – $6\sqrt{f'c}$ allowable tension (FDOT) vs. $3\sqrt{f'c}$ for steel strands, but lower pre-compression provided 700 psi vs. 1,000 psi:
  - We can add more CFRP strands, but at cost (approx. $4/ft.)
  - OK for HRB… but do we need this for other projects?
- Deflections should be similar for uncracked condition (gross section)
- Non-prestressed versions with GFRP have unresolved viability questions:
  - Durability of cracked section?
  - Sustained load limits for cracked section 0.2 $f_u$ (very low)
  - Crack width limits (0.02") … are these reasonable for buried side?
  - Deflections may become more critical (cracked section).

# Cantilever Concrete Sheet Pile Walls

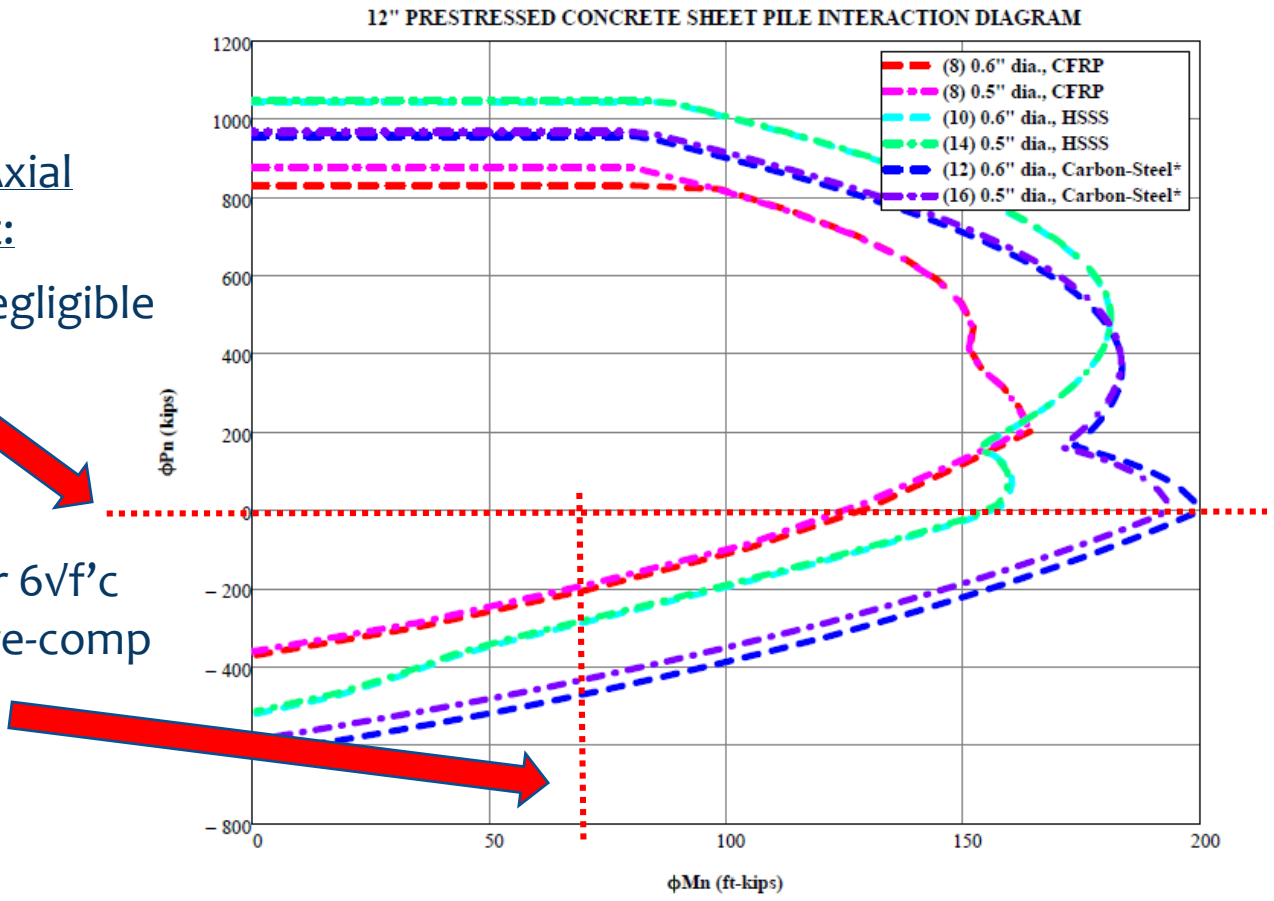
(Design Considerations)

- Strength Limit State – Flexural or M-N Interaction Diagrams tools?

Preliminary Moment-Axial Load Interaction Chart:

- axial load usually negligible for sheet pile

- Service moment for 6√f'c tension + 700 psi pre-comp = 70kips

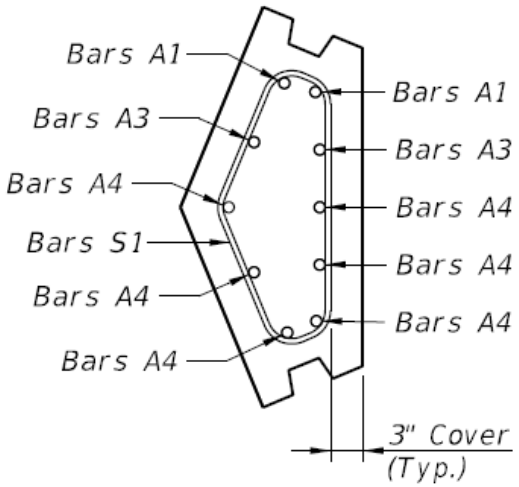


# Concrete Sheet Piles

## (Corner Piles)

Example Project Details (***Index D22440***):

- #8 GFRP Bars longitudinally
- #4 GFRP Transverse Ties




SECTION A-A

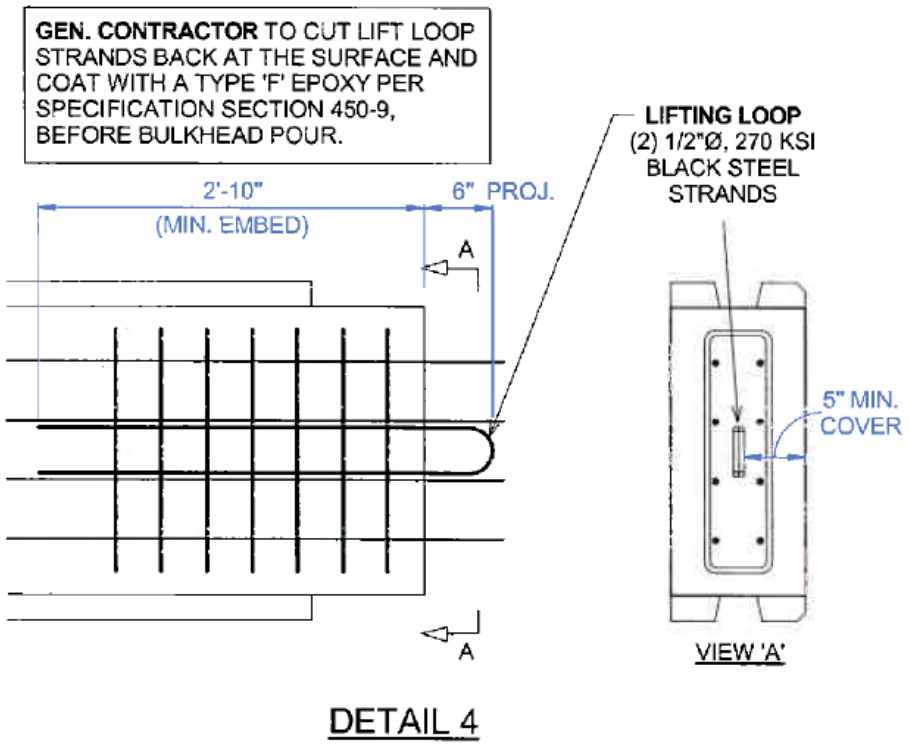
(Photographs - FDOT). *Corner Sheet Piles stored on site*

# Concrete Sheet Piles

## (Lifting Device)

Lifting devices installation:

- Do these need to be corrosion resistant if deeply embedded and sealed in cast-in-place cap?
- CFRP strands not practical;
- Stainless steel strands have low ductility – could be safely concern;
- SS manufactured lifting devices can be expensive.




(Figure) Shop Drawings details for lifting loops

# Gravity Walls

# Gravity Walls (with GFRP)

A. General Information
   i. Average 4 feet exposed height
   ii. 32’ length using RCA concrete
   iii. 32’ length using RAP concrete

B. Concrete – Coarse Aggregate replacement:
   i. Class NS = 2,500 psi 28-day strength
   ii. 10-20% Recycle Asphalt Pavement (RAP)
   iii. 10-20% Recycle Concrete Aggregate (RCA)

C. Structural System
   *i.* ***Index D6011c*** ***Gravity Wall - Option C***
   ii. Nominal GFRP exposed face reinforcement. (#3’s at 1’-0” spacing)

   *Less than minimum temperature and shrinkage reinforcing design. Equivalent tensile strength to steel reinforcing version.*

D. FDOT Material Specifications
   - **Section *347*** (since 7/1/16 allows RAP substitution)
   - ***Section 901*** (allows RCA substitution for Class 347 concrete for may years)
   - Halls River Bridge used a “Plan Note” to define %

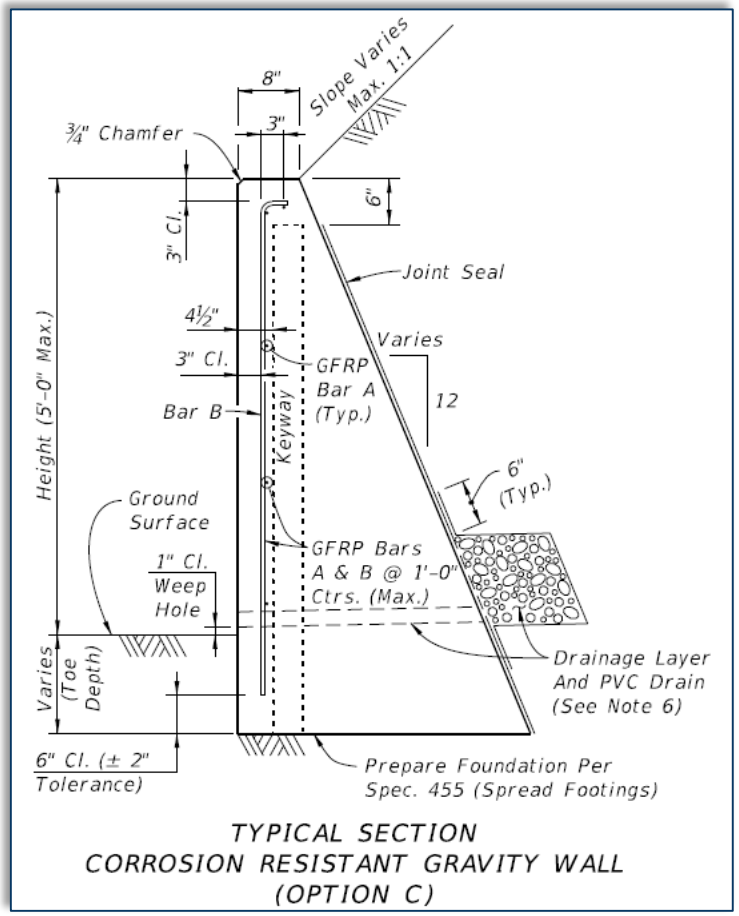


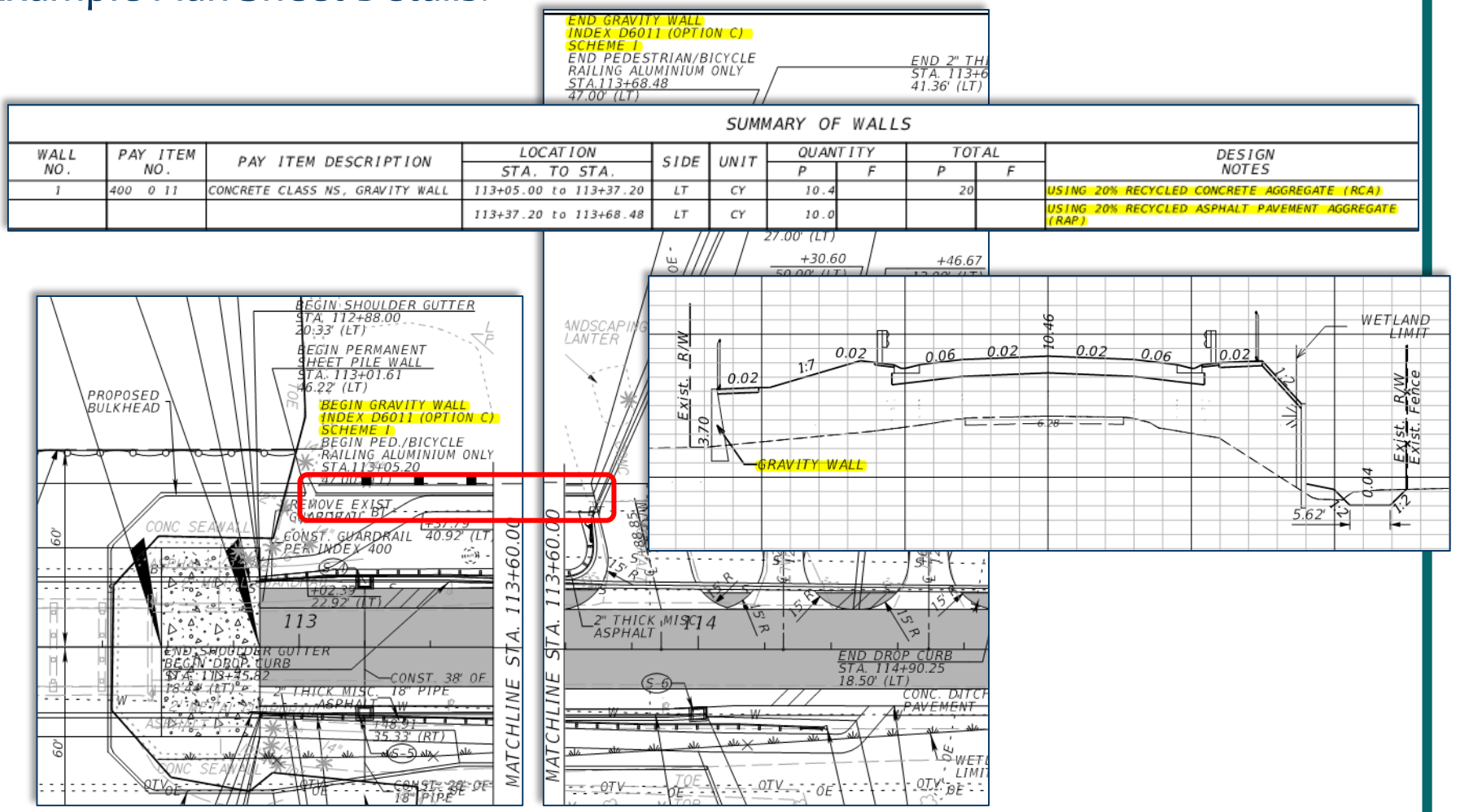

**Figure from Index D6011c** (2016)

*PROJECT NOTES:*

1. *Class NS concrete must contain between 10% and 20% content of Recycled Concrete Aggregate (RCA) in Section 1, and between 10% and 20% content of Recycled Aphalt Pavement (RAP) in Section 2.*

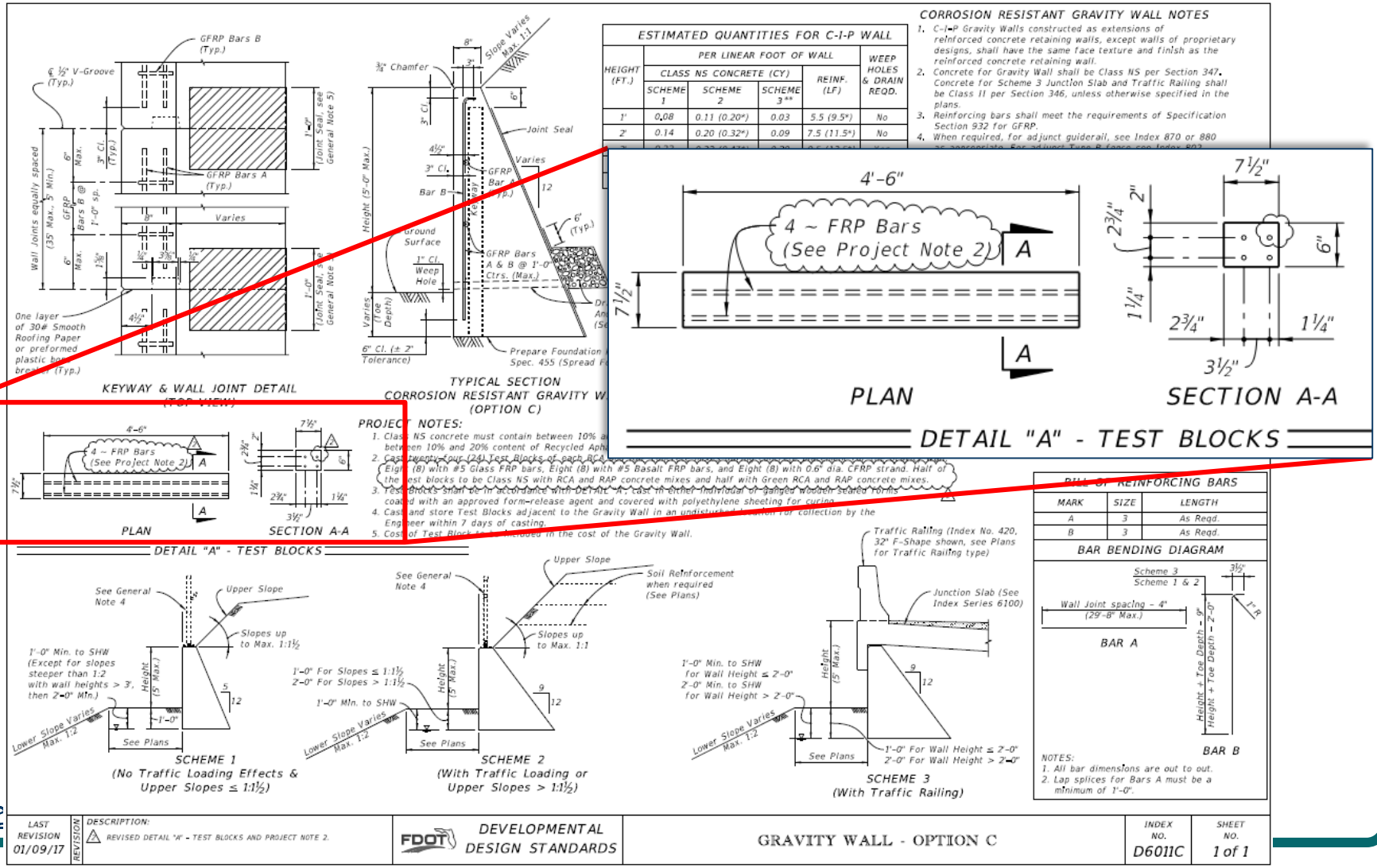
# Gravity Walls (with GFRP)

## Example Plan Sheet Details:



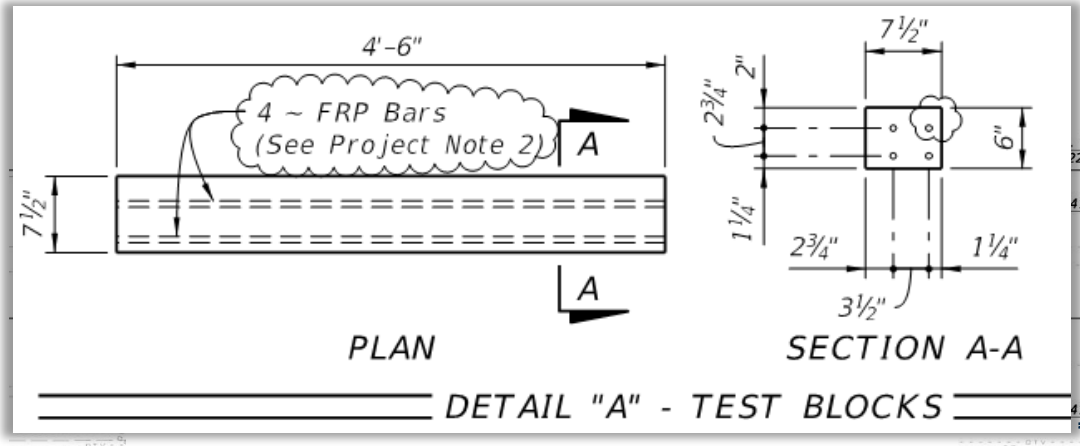
# Gravity Walls (with GFRP)

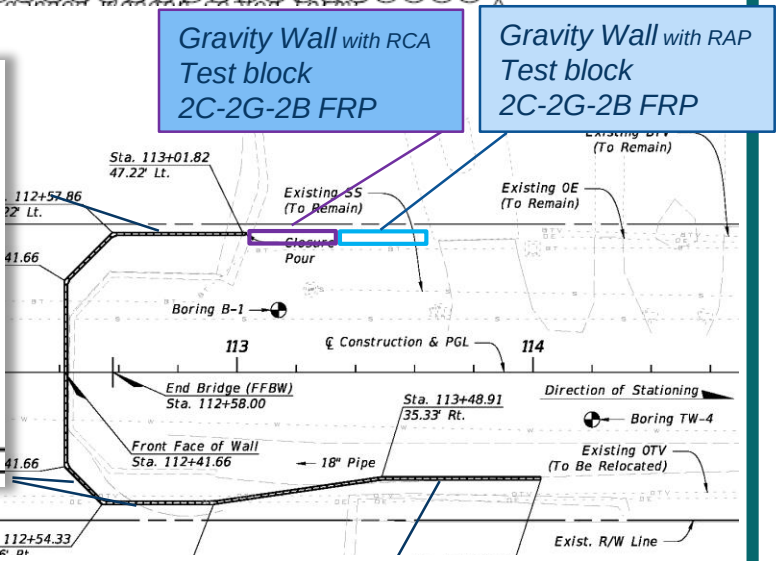
## Index D6011c (*project version*):



# Gravity Wall Test Blocks

2. Cast twenty-four (24) Test Blocks of each RCA and RAP concrete mixes during concrete placement for the Gravity Wall. Eight (8) with #5 Glass FRP bars, Eight (8) with #5 Basalt FRP bars, and Eight (8) with 0.6" dia. CFRP strand. Half of the test blocks to be Class NS with RCA and RAP concrete mixes and half with Green RCA and RAP concrete mixes.




**Gravity Wall Test Blocks:**

- 24 Total Blocks:

- 12 with FDOT Class NS concrete:

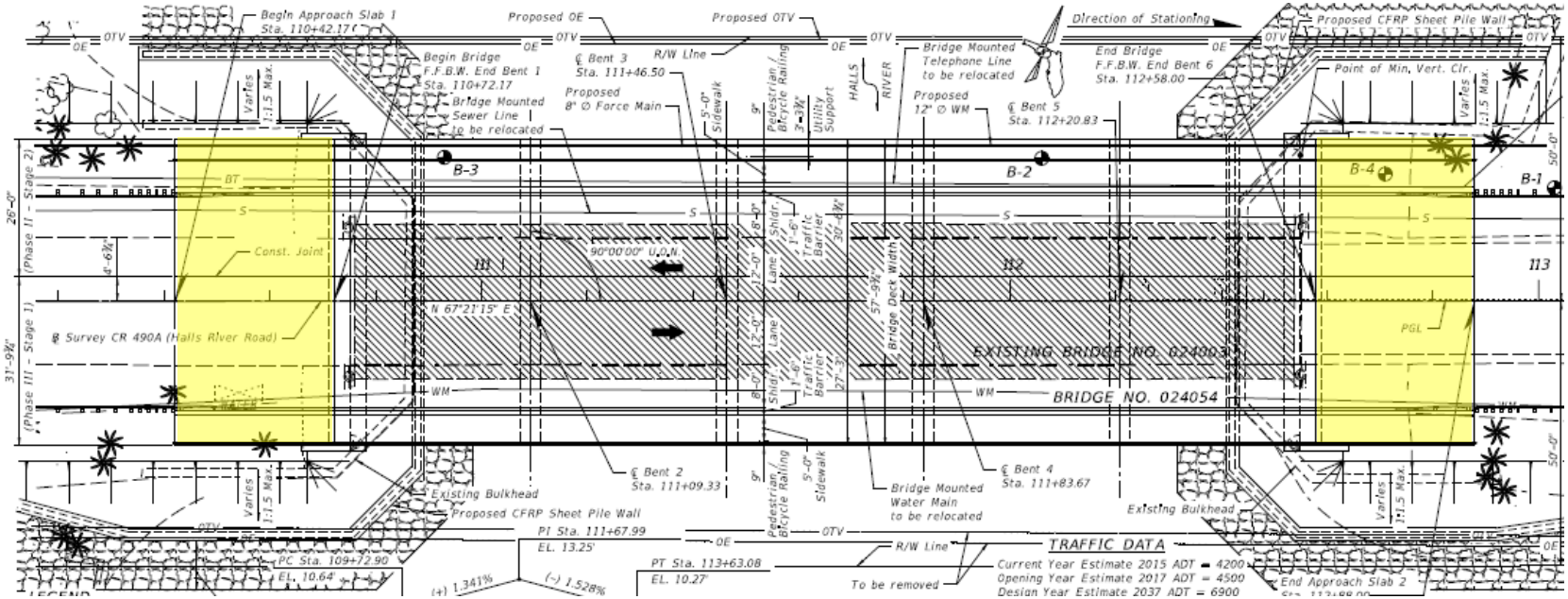
2 blocks with GFRP bars – Class NS-RCA
2 blocks with BFRP bars – Class NS-RCA
2 blocks with CFRP strands – Class NS-RCA
2 blocks with GFRP bars – Class NS-RAP
2 blocks with BFRP bars – Class NS-RAP
2 blocks with CFRP strands – Class NS-RAP

- 12 with SEACON "Green" concrete:

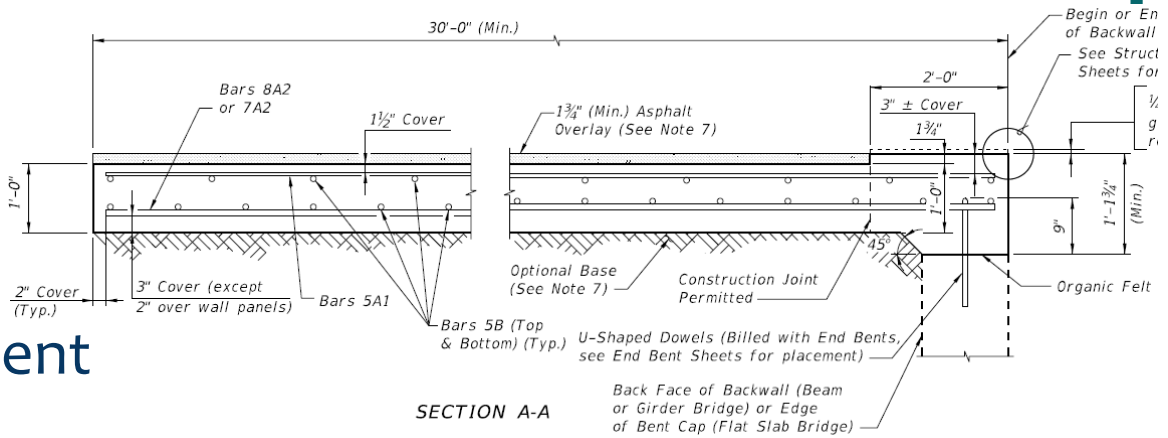
2 blocks with GFRP bars – "Green"-RCA
2 blocks with BFRP bars – "Green"-RCA
2 blocks with CFRP strands – "Green"-RCA
2 blocks with GFRP bars – "Green"-RAP
2 blocks with BFRP bars – "Green"-RAP
2 blocks with CFRP strands – "Green"-RAP

HRB

# GFRP-RC Approach Slabs



# Approach Slabs



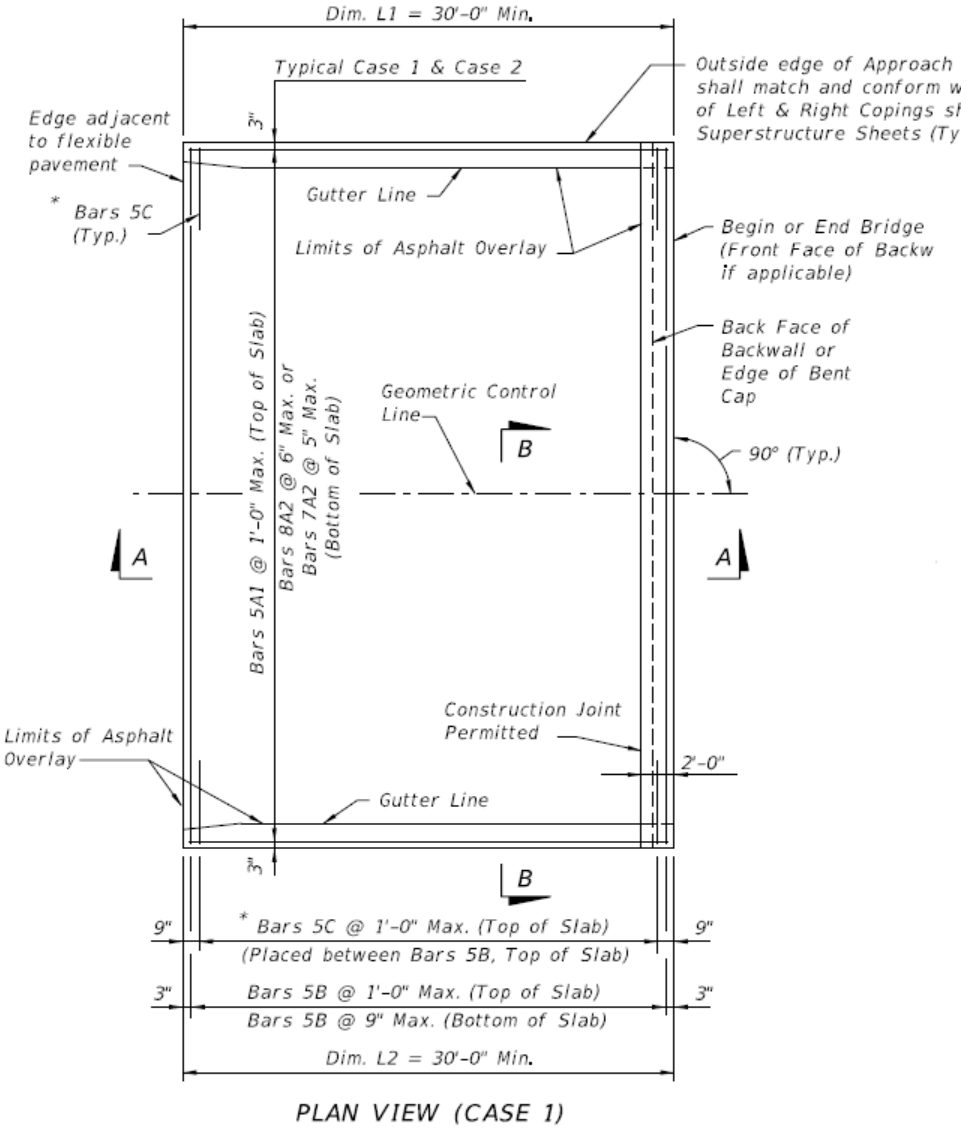

A. General
   i. 30ft length
   ii. GFRP reinforcement
B. Structural System
   i. ***Developmental Design Standard*** *Index D22900*
C. Design Criteria
   i. ***ACI 440.1R / AASHTO Guide Spec.*** *(without service limit state checks) – For slab-on-grade neither may not be applicable.*
   ii. Emulates FDOT standard Approach Slab (*Index 20900*)
D. FDOT Material Specifications – ***Section 932 (Dev)***

# Approach Slabs

A. Main longitudinal bottom reinforcing increased:
   i. #8's or #7's based on equivalent strength.

B. Allows reduction on concrete cover from ***Index 20900***:
   i. Reduce from 1 ¾" to 1 ½" at Top;
   ii. Reduced from 4" to 3" at Bottom;

C. Transverse top reinforcing needs to resist traffic railing impact (extreme event)




PLAN VIEW (CASE 1)

# Approach Slabs

A. Main longitudinal bottom bar (Strength Limit State):

- Steel Rebar (Index 20900) = #8's @ 9" spacing ($A_s$ = 1.05 in²/ft);

  Flexural Resistance $\phi M_n$ = 32 ft-kips, based on $f_y$ = 60 ksi and $\phi_f$ = 0.9

- GFRP Rebar (option 1) = #8's @ 6" spacing ($A_f$ = 1.58 in²/ft);

  Flexural Resistance $\phi M_n$ = 32 ft-kips, based on $f_{fu}$ = 85 ksi x 0.70 Environmental Factor and $\phi_f$ = 0.6 *(transition concrete crushing)*

- GFRP Rebar (option 2) = #7's @ 5" spacing ($A_f$ = 1.44 in²/ft);

  Flexural Resistance $\phi M_n$ = 31.4 ft-kips, based on $f_{fu}$ = 90 ksi x 0.70 Environmental Factor and $\phi_f$ = 0.6 *(transition concrete crushing)*

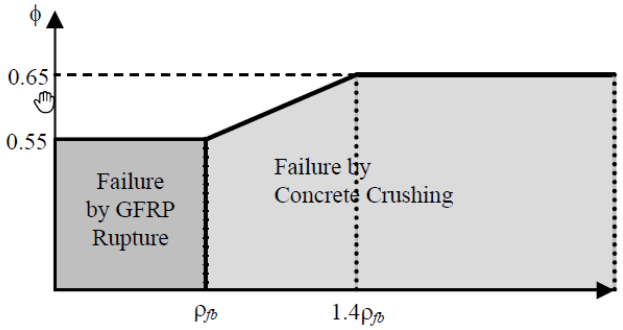
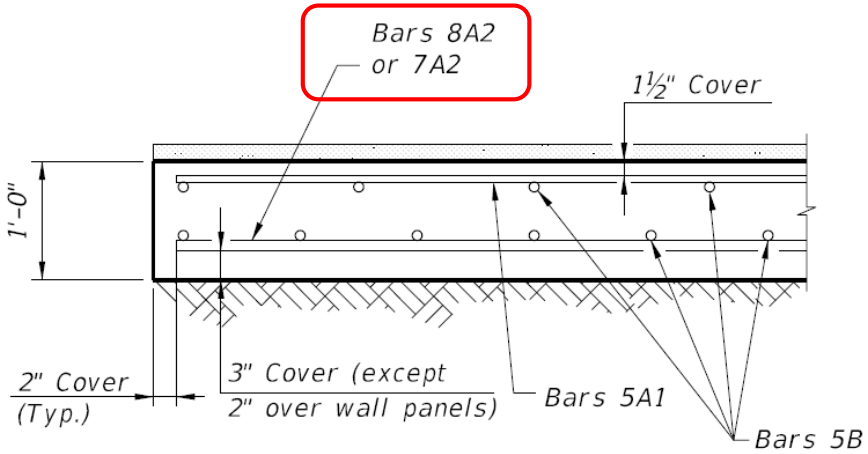



**Figure 2.7.4.2-1—Resistance factors for flexure**



# Approach Slabs

C. Transverse top reinforcing (Extreme Event Limit State):

- Steel Rebar (Index 20900) = #5's @ 6" spacing ($A_s$ = 0.62 in²/ft);

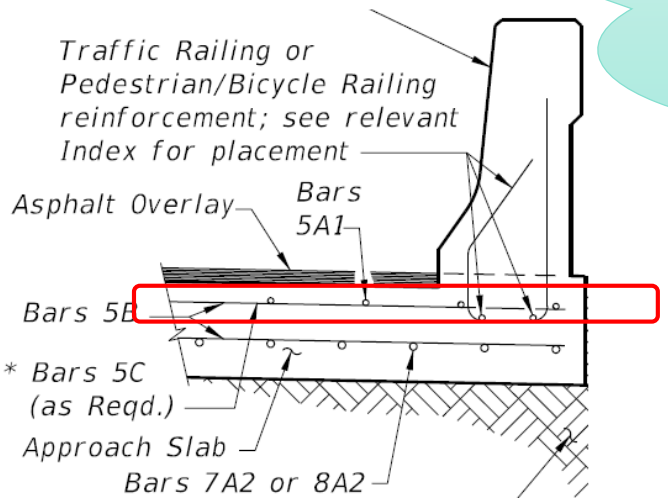
  Flexural Resistance $\phi M_n$ = 28 ft-kips, based on $f_y$ = 60 ksi and $\phi_{ee}$= 1.0

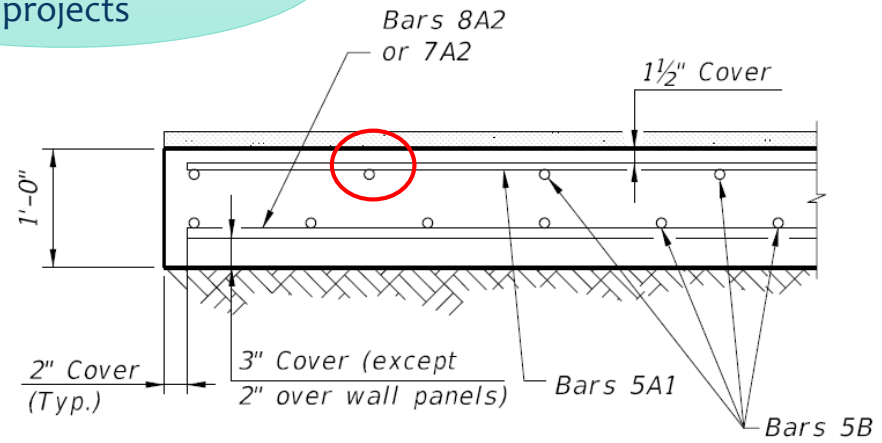
- GFRP Rebar (Index 22900) = #5's @ 6" spacing ($A_f$ = 0.62 in²/ft);

  Flexural Resistance $\phi M_n$ = 29 ft-kips, based on $f_{fu}$ = 95 ksi x 0.70 Environmental Factor and $\phi_{ee}$ = 1.0 *(using flexure FRP rupture $\phi_f$ = 0.55 ➔ need #7's @ 6" spacing)*

  *… for $\phi_f$ = 0.55 ➔* $\phi_f M_n$ = 15.9 ft-kips > $M_c$ = 15.7 ft-kips required in ***SDG*** Table 4.2.5-2.

Need to review approach for future projects



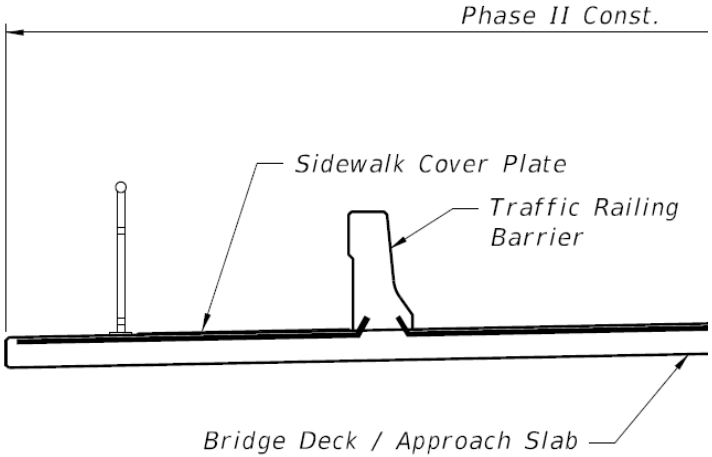



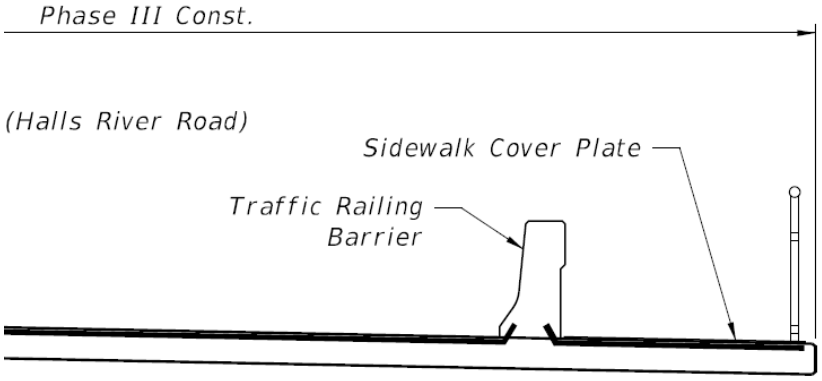
# Approach Slabs

C. Transverse top reinforcing (Extreme Event Limit State):

- Halls River Bridge Traffic Railings are not located at the edge of the slab -

  Therefore flexural moment in supporting slab is significantly reduce due to distribution in both directions (approx. 50% each side) and contribution of both bottom and top reinforcing



# Approach Slabs

D. Shrinkage and Temperature Reinforcement (Transverse):

- Steel Rebar (Index 20900) = #5's @ 12" spacing ($A_{s.top}$ = 0.31 in²/ft.);

- GFRP Rebar provided = #5's @ 12" spacing ($A_{f.top}$ = 0.31 in²/ft.);

  AASHTO Guide Spec. ≤ 0.0036 $\rho_{f,st}$ per face → $A_f$ = 0.52 in²/ft.

Need consensus on approach for future projects

$$\rho_{f,st} = 0.0018 \frac{60\ \text{ksi}}{f_{fd}} \frac{E_s}{E_f} \qquad (2.11.5\text{-}1)$$

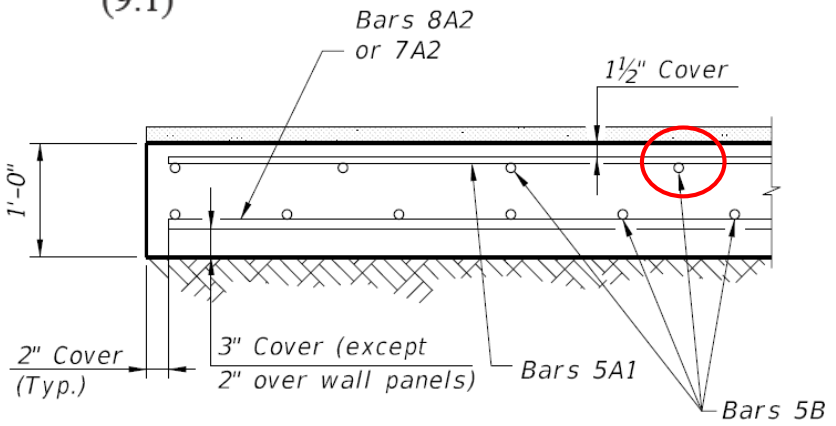
ACI 440.1R Guide Spec . ≤ 0.0036 $\rho_{f,ts}$ total → $A_f$ = 0.26 in²/ft. top & bottom face

$$\rho_{f,ts} = 0.0018 \times \frac{60{,}000}{f_{fu}} \frac{E_s}{E_f} \qquad (9.1)$$

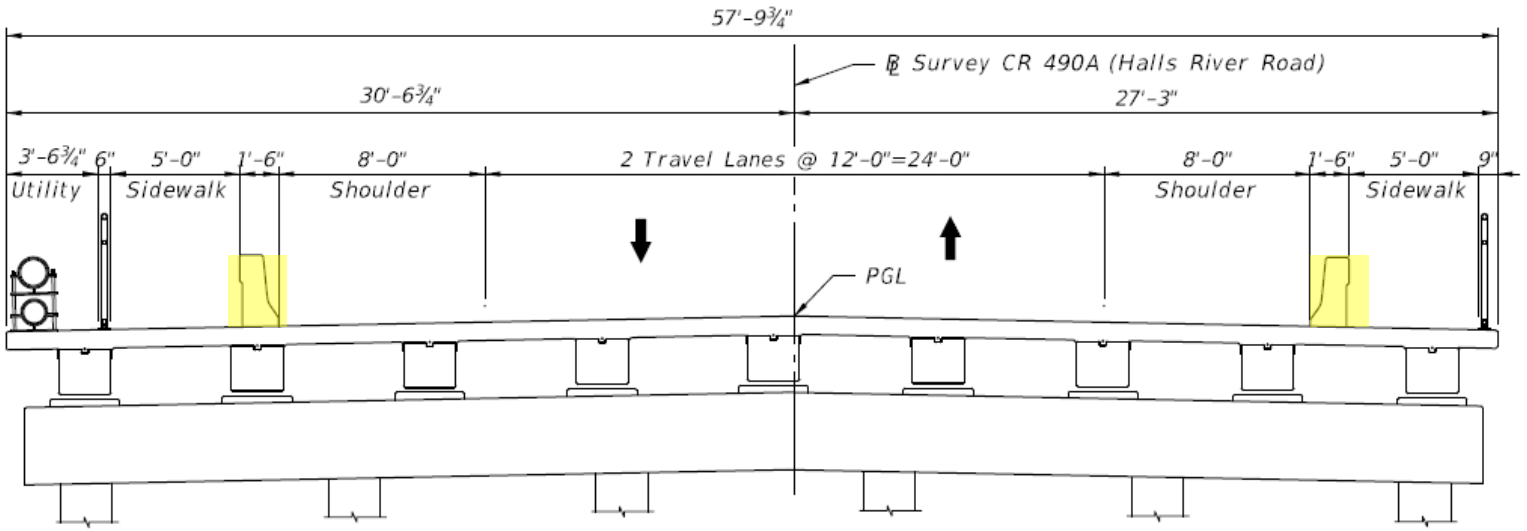
ACI 318-14 Commentary R24.4.3.2:

**COMMENTARY**

many years. The resulting area of reinforcement may be distributed near the top or bottom of the slab, or may be distributed between the two faces of the slab as deemed appropriate for specific conditions.



# GFRP-RC Traffic Railings




COMPLETED STRUCTURE

# Traffic Railings

A. General
   - *i.* ***DDS*** Index D22420 - GFRP-RC 32” F-Shape
   - ii. Supplemental plan details required for post-installed anchorage (north side).

B. Similar crash tested designs
   - i. Pultrall (V-Rod), Schoeck (ComBAR), & Temcorp (TemBar): MASH TL-5, 42" Safety-Shape
   - ii. GFRP Adhesive Anchor Pullout Tests by Hilti/Canadian Researchers.

C. Design Criteria
   - *i.* ***AASHTO Guide Spec.***
   - ii. NCHRP Report 350 (but MASH pending)

D. FDOT Material Specifications - ***Dev932***

E. Challenges
   - i. Phased construction
   - ii. Bridge deck cantilever design for traffic railing impact support.

*Photograph: GFRP reinforced traffic railing from successful TL-5 crash test (Pultrall)*

*Photograph: GFRP Bars in retaining walls railing combination (Hughes Bros.)*

# Traffic Railings

B. Similar crash tested designs

i. 42" Safety-Shape based on ***MTO*** standard for PL3 requirement ≤ MASH TL-5

ii. Vertical reinforcing equivalent to #5's @ 12" spacing away open joint.

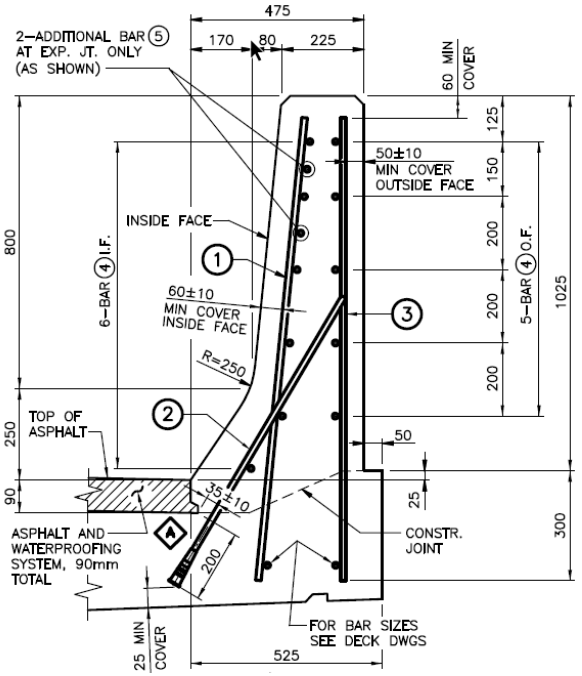
iii. Within 4 feet of open joint #5's @ 6" spacing

iv. TL-5 equivalent static lateral load = 124 kips (NCHRP 350, MASH = 160 kips??)

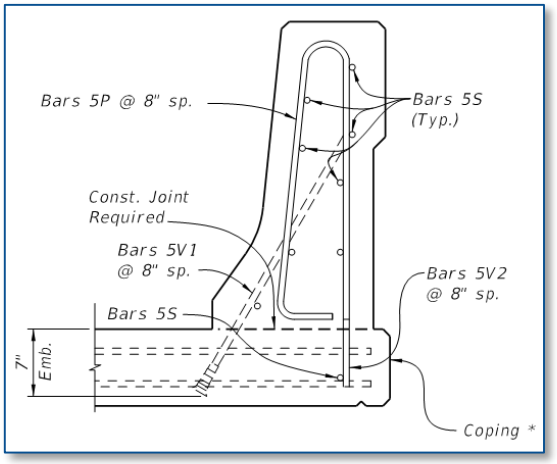
v. Halls River Bridge only needed TL-3 (since off-system roadway)

vi. TL-3 & 4 equivalent static lateral load = 54 kips (NCHRP 350, MASH = 54 & 80 kips??)

Therefore we used standard FDOT 32" F-Shape with #5 bars at 8" spacing for similar section thickness (conservative)




Typical Section from **Standard SS110-92** (Ministry of Transportation, Ontario)



# Traffic Railings

## vii. TL3 vs. TL-4 vs. TL-5

Extract from ***AASHTO LRFD Bridge Design Specifications*** Chapter 13 – Appendix A (based on NCHRP Report 350)

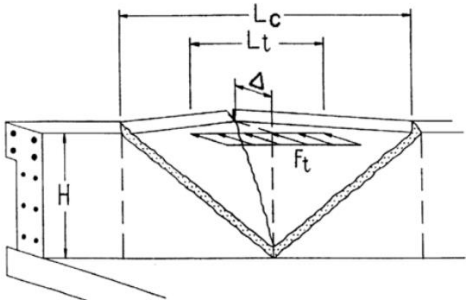



**Table A13.2-1—Design Forces for Traffic Railings**

| Design Forces and Designations | Railing Test Levels | | | | | |
|---|---|---|---|---|---|---|
| | TL-1 | TL-2 | TL-3 | TL-4 | TL-5 | TL-6 |
| $F_t$ Transverse (kips) | 13.5 | 27.0 | 54.0 | 54.0 | 124.0 | 175.0 |
| $F_L$ Longitudinal (kips) | 4.5 | 9.0 | 18.0 | 18.0 | 41.0 | 58.0 |
| $F_v$ Vertical (kips) Down | 4.5 | 4.5 | 4.5 | 18.0 | 80.0 | 80.0 |
| $L_t$ and $L_L$ (ft) | 4.0 | 4.0 | 4.0 | 3.5 | 8.0 | 8.0 |
| $L_v$ (ft) | 18.0 | 18.0 | 18.0 | 18.0 | 40.0 | 40.0 |
| $H_e$ (min) (in.) | 18.0 | 20.0 | 24.0 | 32.0 | 42.0 | 56.0 |
| Minimum $H$ Height of Rail (in.) | 27.0 | 27.0 | 27.0 | 32.0 | 42.0 | 90.0 |

| Test Level | Test Vehicle | NCHRP 350 | MASH - 2009 |
|---|---|---|---|
| TL-3 | Small Car | Speed: 62 mph<br>Angle: 20°<br>Weight: 1,809 lb. | Speed: 62 mph<br>Angle: 25°<br>Weight: 2,420 lb. |
| TL-3 | Pickup | Speed: 62 mph<br>Angle: 25°<br>Weight: 4,409 lb. | Speed: 62 mph<br>Angle: 25°<br>Weight: 5,000 lb. |
| TL-4 | Single Unit Truck | Speed: 50 mph<br>Angle: 15°<br>Weight: 17,636 lb. | Speed: 56 mph<br>Angle: 15°<br>Weight: 22,000 lb. |
| TL-5 | Tractor Trailer | Speed: 50 mph<br>Angle: 15°<br>Weight: 79,366 lb. | Speed: 50 mph<br>Angle: 15°<br>Weight: 79,300 lb. |

# Traffic Railings

Halls River Bridge minimum traffic railing requirements (TL-3):

- Off-system Bridge ("*Florida Greenbook*" criteria)
- Design Speed = 50 mph

**TRAFFIC DATA**

CURRENT YEAR = 2015 AADT = 4200
ESTIMATED OPENING YEAR = 2017 AADT = 4500
ESTIMATED DESIGN YEAR = 2037 AADT = 6900
K = 9.50% D = 54.60% T = 2% (24 HOUR)
DESIGN HOUR T = 1%
DESIGN SPEED = 50 MPH
POSTED SPEED = 40 MPH

**C.3.c Railings**

All traffic, pedestrian, and bicycle railings shall comply with the requirements in Section 13 of LRFD. Traffic railings shall meet the crash requirements of at least Test Level 3 (TL-3) for bridges with design speeds greater than 45 mph and at least TL-2 for design speeds less than or equal to 45 mph.

Extract from 2013 ***"Florida Greenbook"*** (Manual for Uniform Minimum Standards For Design, Construction and Maintenance For Streets an Highways)

# Traffic Railings

## viii. Yield-Line Analysis

Extract from ***AASHTO LRFD Bridge Design Specifications*** Chapter 13 – Appendix A (based on NCHRP Report 350)

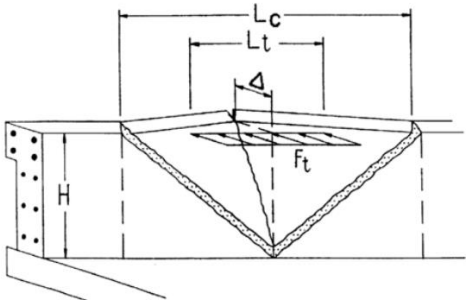



**Table A13.2-1—Design Forces for Traffic Railings**

| Design Forces and Designations | Railing Test Levels | | | | | |
|---|---|---|---|---|---|---|
| | TL-1 | TL-2 | TL-3 | TL-4 | TL-5 | TL-6 |
| $F_t$ Transverse (kips) | 13.5 | 27.0 | 54.0 | 54.0 | 124.0 | 175.0 |
| $F_L$ Longitudinal (kips) | 4.5 | 9.0 | 18.0 | 18.0 | 41.0 | 58.0 |
| $F_v$ Vertical (kips) Down | 4.5 | 4.5 | 4.5 | 18.0 | 80.0 | 80.0 |
| $L_t$ and $L_L$ (ft) | 4.0 | 4.0 | 4.0 | 3.5 | 8.0 | 8.0 |
| $L_v$ (ft) | 18.0 | 18.0 | 18.0 | 18.0 | 40.0 | 40.0 |
| $H_e$ (min) (in.) | 18.0 | 20.0 | 24.0 | 32.0 | 42.0 | 56.0 |
| Minimum $H$ Height of Rail (in.) | 27.0 | 27.0 | 27.0 | 32.0 | 42.0 | 90.0 |

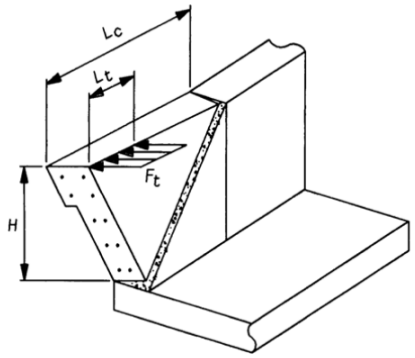



**Figure CA13.3.1-2—Yield Line Analysis of Concrete Parapet Walls for Impact near End of Wall Segment**

### Near End of Wall Segment:

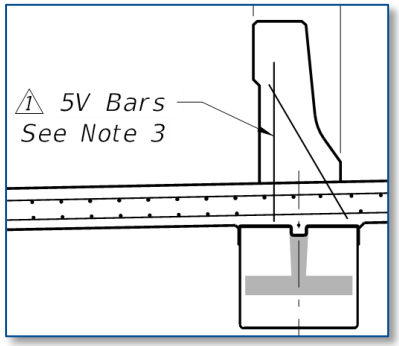
- Nominal Resistance = 76 kips ($\phi$ = 1.0 ***AASHTO-BDS***)
- Using $\phi_f$ = 0.55 per ***AASHTO Guide Spec.*** commentary C3.4, Factored Resistance = 42 kips at joint (= 80 kips away from joint)

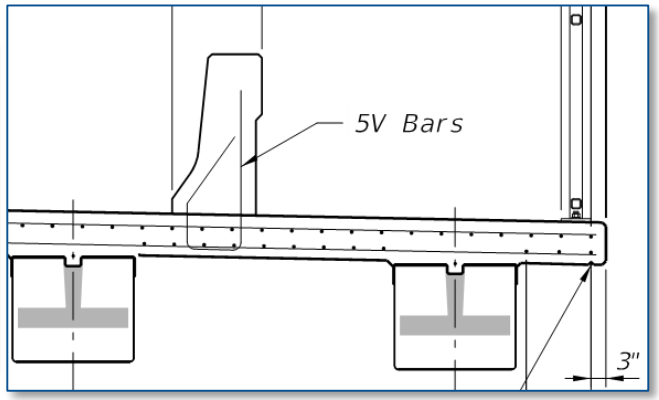
> Crashworthiness of reinforced concrete traffic railing greatly depends on its stiffness when subjected to transverse load. This should be accounted for by limiting the strength reduction factor for flexure to 0.55 when the internal forces computed through inelastic analysis are associated with a strain in the GFRP bars of 0.005 or greater.

- Could reduce vertical stirrup bar spacing to 6” near joints for Factored Resistance = 54 kips.

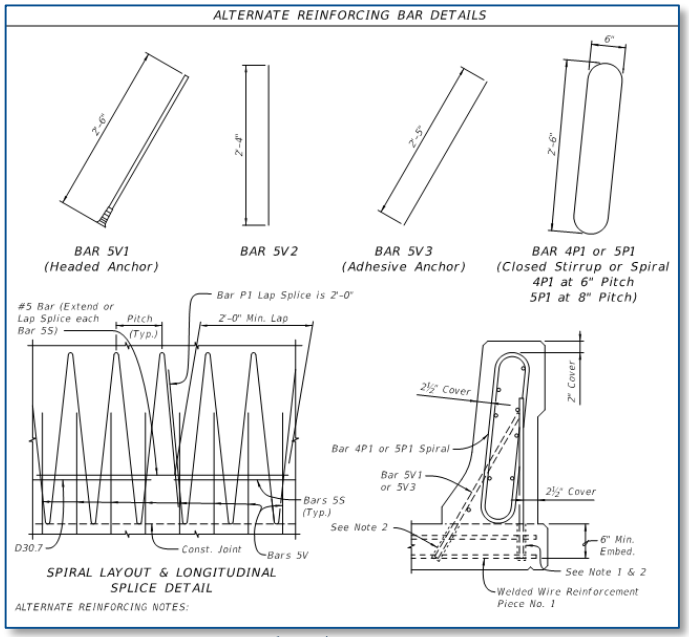
# Traffic Railings

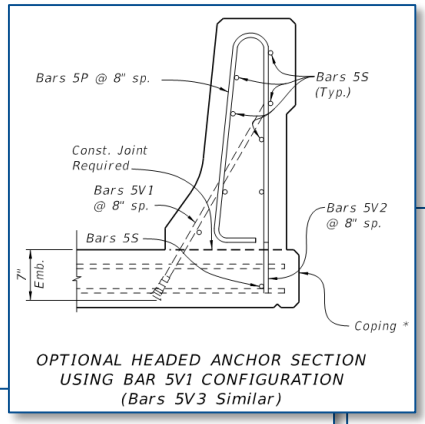
Example Plan Sheet Details:

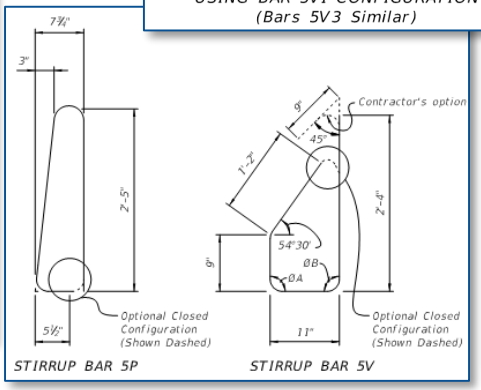


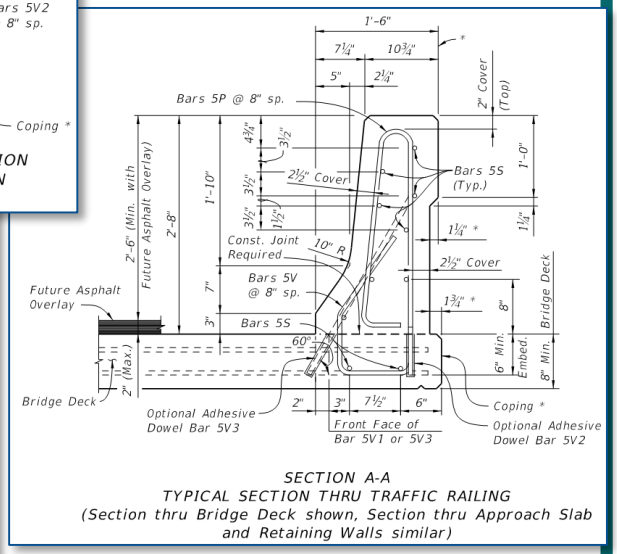




***Index D22420*** various rebar options:



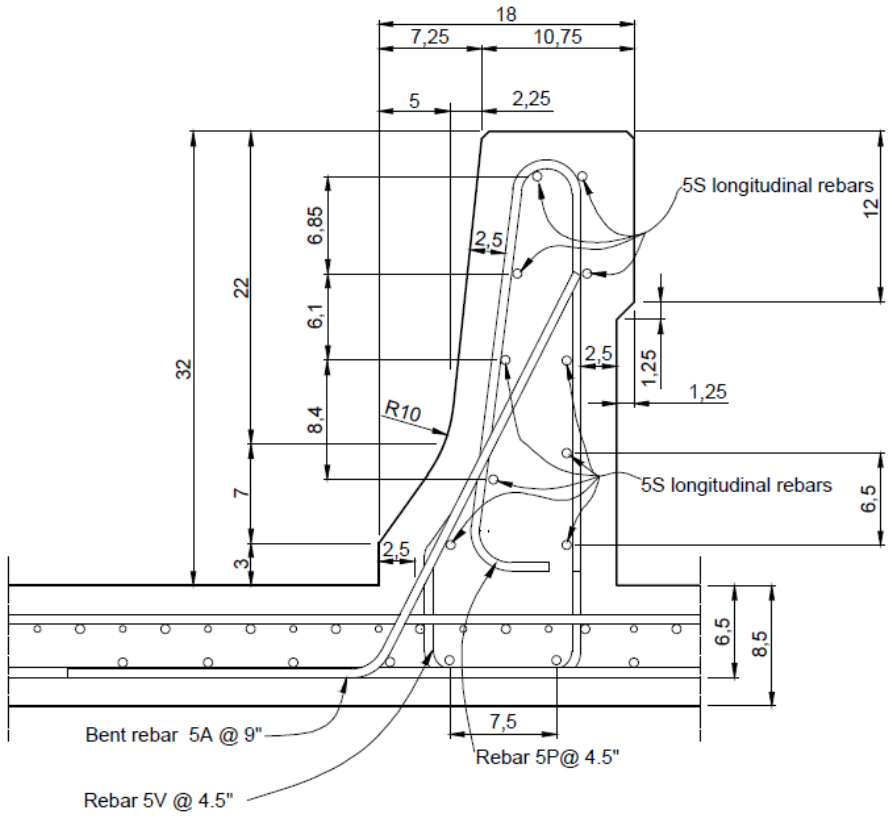



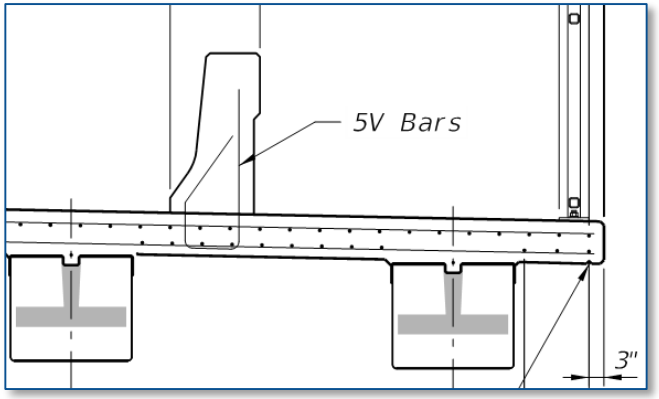



# Traffic Railings

Contractor's revised Reinforcing Details (south side):




SECTION A-A
TYPICAL SECTION THRU TRAFFIC RAILING

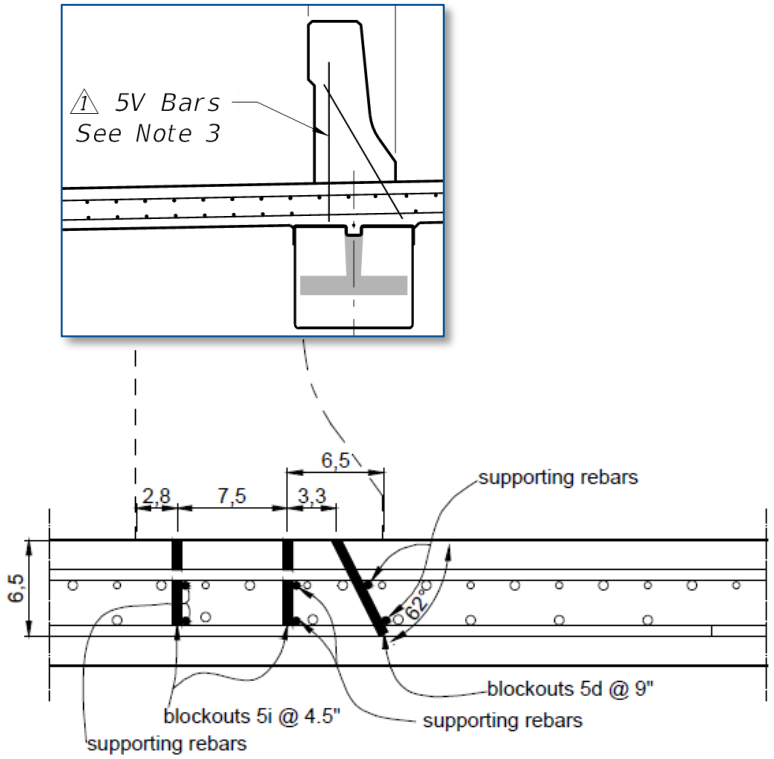


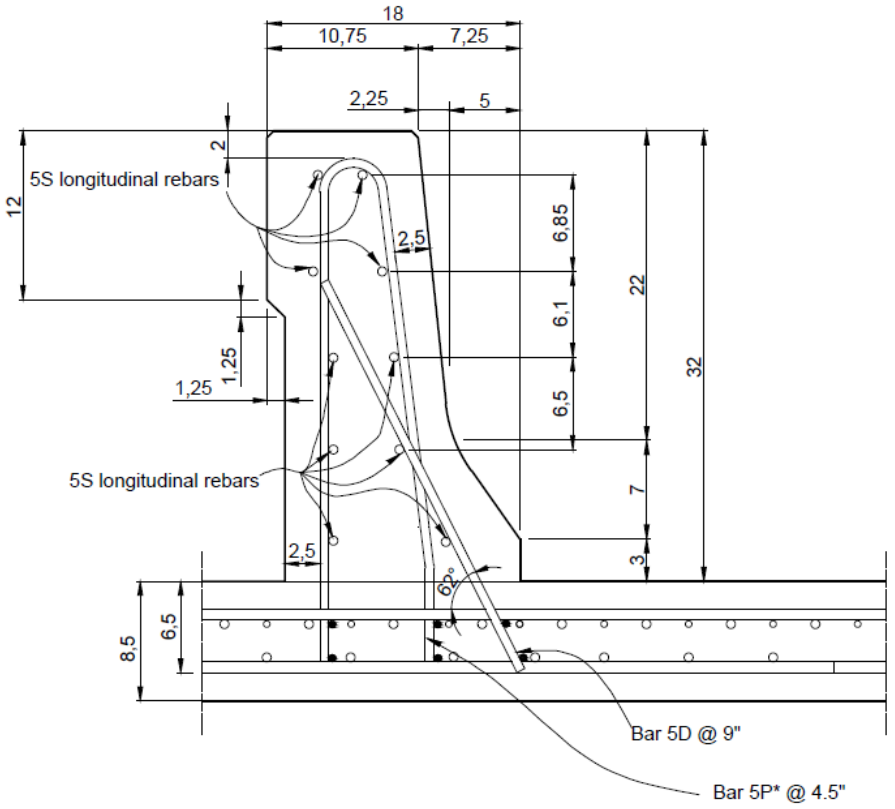

Vertical spacing adjusted to 4.5" increments to match deck rebar spacing

# Traffic Railings

Contractor's revised Reinforcing Details (north side):

Vertical spacing adjusted to 4.5" increments to match deck rebar spacing




SECTION A-A
TYPICAL SECTION THRU TRAFFIC RAILING

**Question: Is there a better solution for phased construction ?**

# Traffic Railings

Investigating use of White Cement & 60%-Slag concrete for enhanced visibility.

- White-cement mix to be used on Southside railing;
- 60% slag mix to be used on Northside railing;
- Lehigh and SEACON team partnering with the contractor to offset the additional cost;
- Future monitoring to be determined.

In wet weather

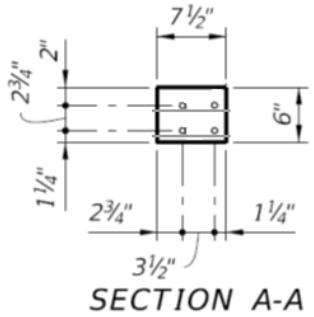
In dry weather

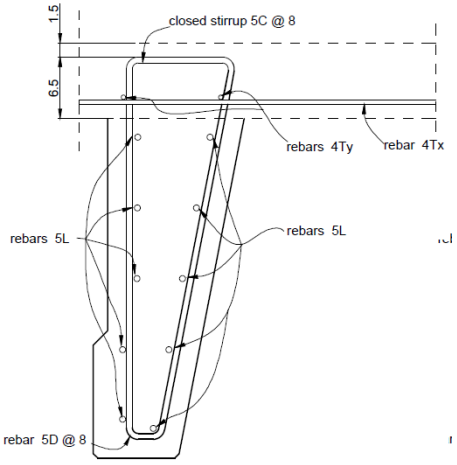
Photos courtesy of Lehigh White Cement Company promotion brochure.

# Traffic Railings

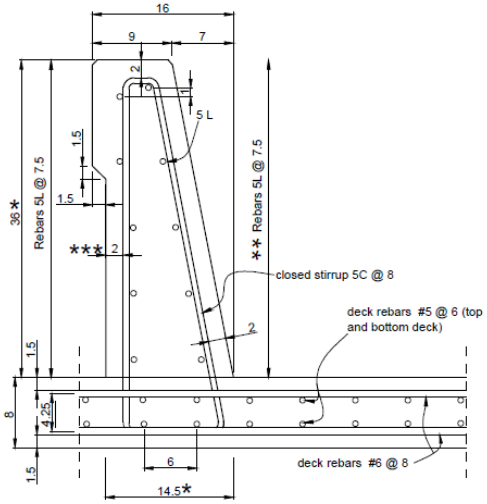
Investigating use of White Cement & 60%-Slag concrete for enhanced visibility.

- White-cement and 60%-slag concretes have a lower alkalinity, but should not be a problem for GFRP durability;
- Casting FRP reinforced test blocks for performance monitoring by SEACON team;
- Three 12-ft specimens to cast based on new 36” Single-Slope Traffic Railing;
- Possible for pendulum impact test ???






Cast test specimens upside down




Mount on deck system at test site

# Research Project & Monitoring

# CEI's Insights and Recommendations

# Contractor's Perspective

# Questions ?

**SDO Contact Information:**

Steve Nolan, P.E.

State Structures Design Office

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(850) 414-4272