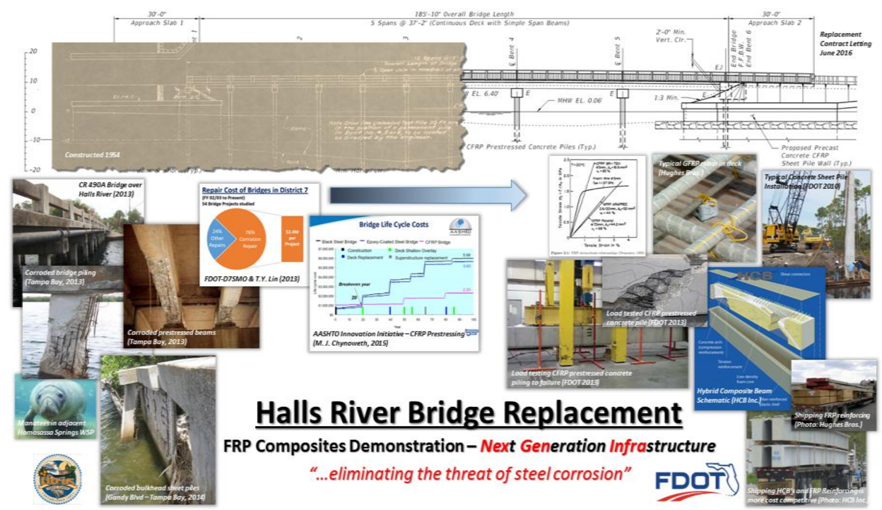
HRB-FRP Workshop (Part 2)

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

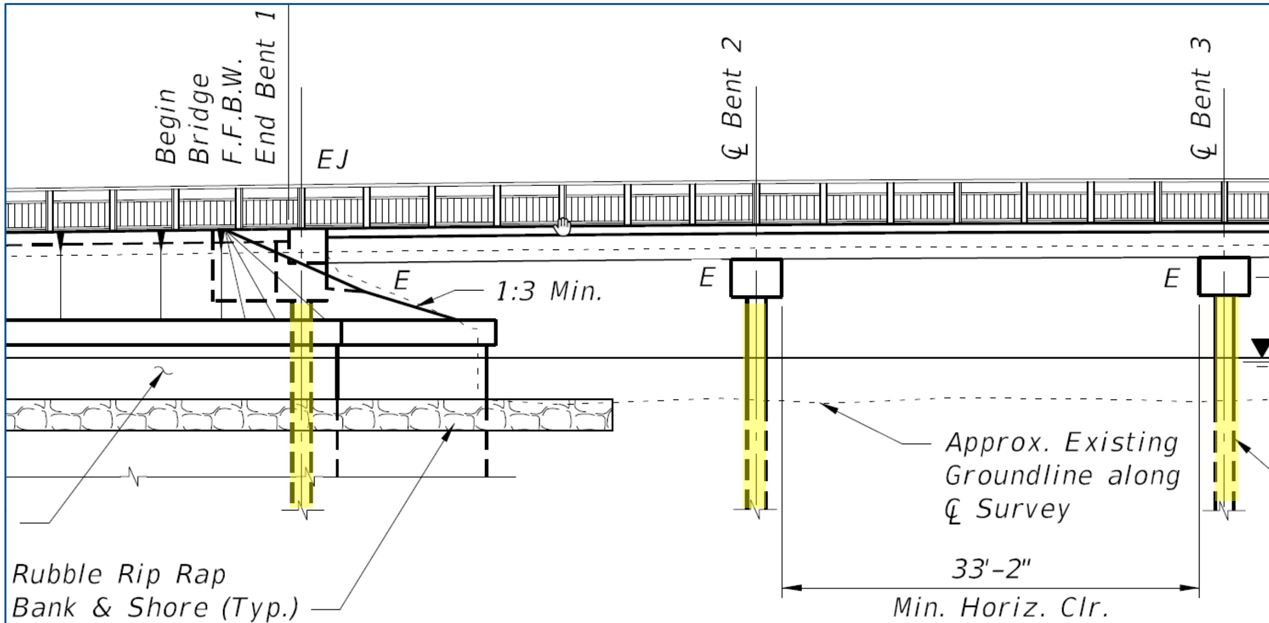
CFRP Prestressed Bearing Piles

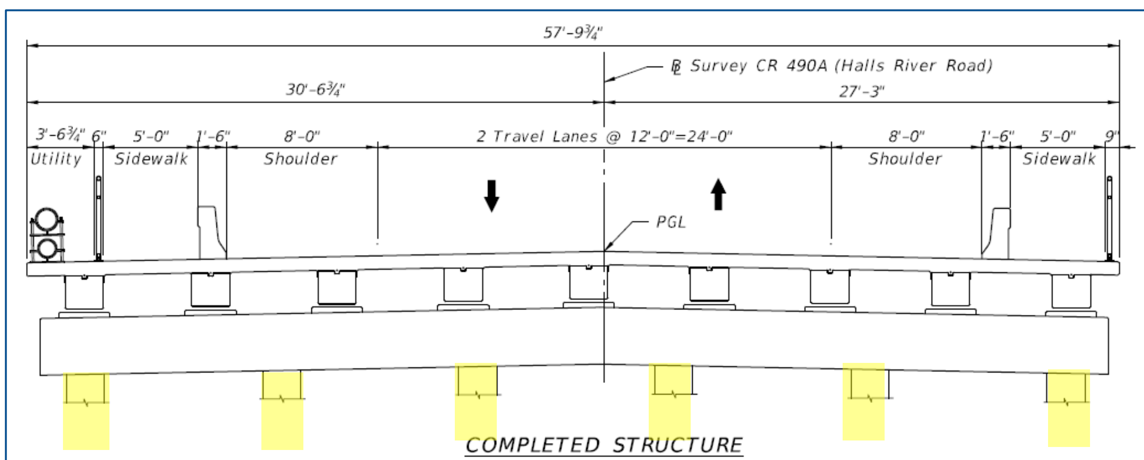
- 18”x18” Square Concrete Prestressed Piles;

- 6 Piles per End Bents;

- 6 Piles per Intermediate Bents;

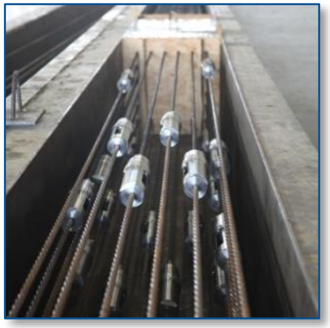
- Total 36 piles, (test pile lengths 55’ to 70’)

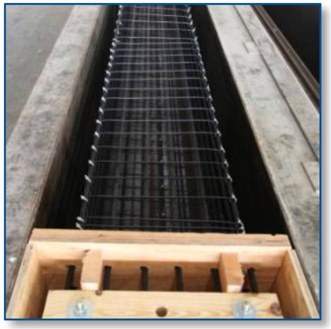


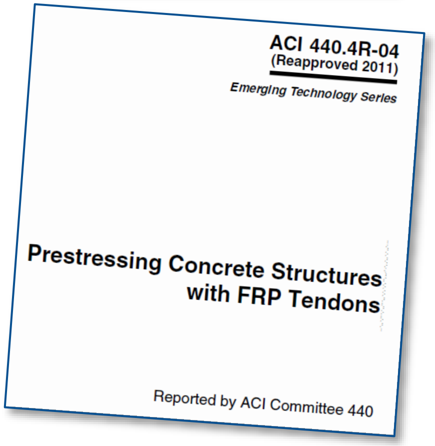


CFRP Prestressed Bearing Piles

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.





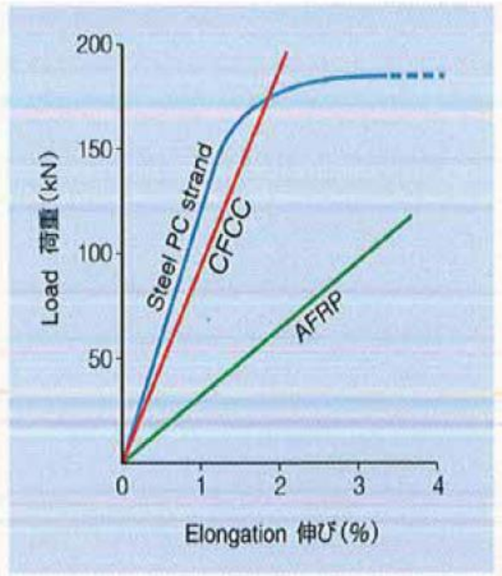

ACI 440.4R-04
(Reapproved 2011)
Emerging Technology Series

Prestressing Concrete Structures with FRP Tendons

Reported by ACI Committee 440

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

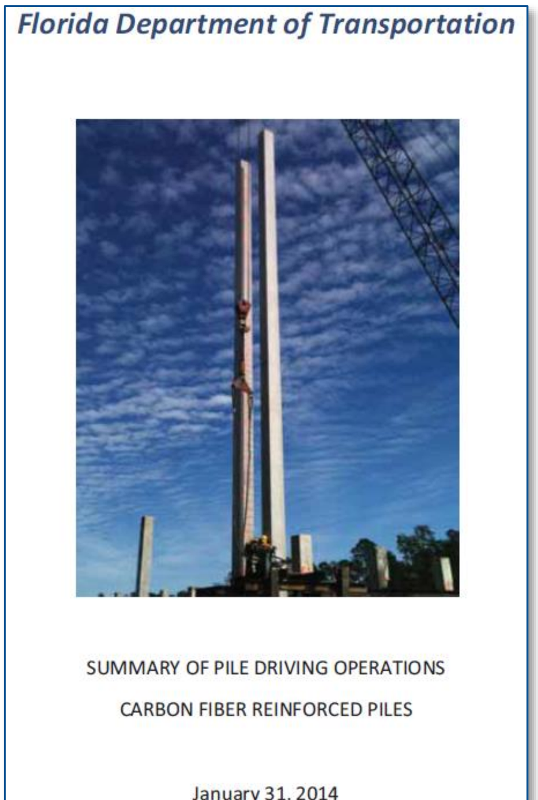


Load and elongation diagram (Source: Tokyo Rope

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.


Florida Department of Transportation

SUMMARY OF PILE DRIVING OPERATIONS

CARBON FIBER REINFORCED PILES

January 31, 2014

Figure 12 – Diesel Covered Pile with Spalled Sections

CFRP Prestressed Pile Research

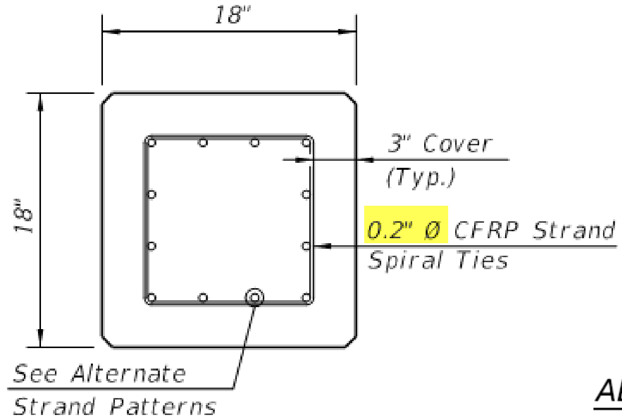
Other past pile research (referenced ***ACI 440.4R)***:

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

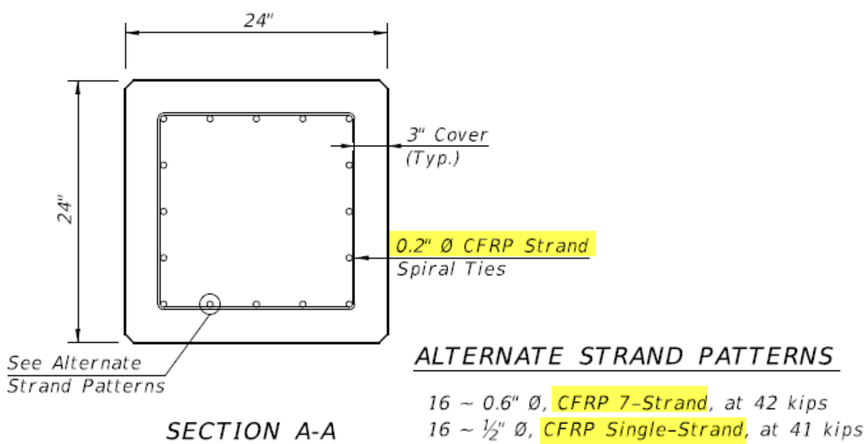
ALTERNATE STRAND PATTERNS

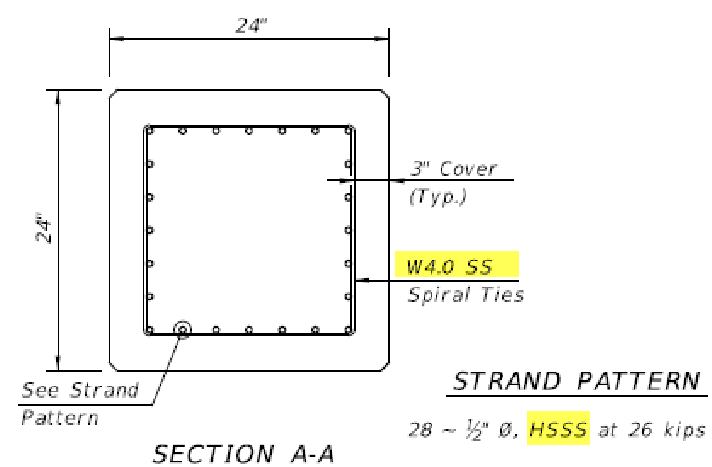
12 ~ 0.6" Ø, CFRP 7-Strand, at 34 kips
12 ~ ½" Ø, CFRP Single-Strand, at 33 kips

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

- Prestressed Concrete Piles (with CFRP or SS)

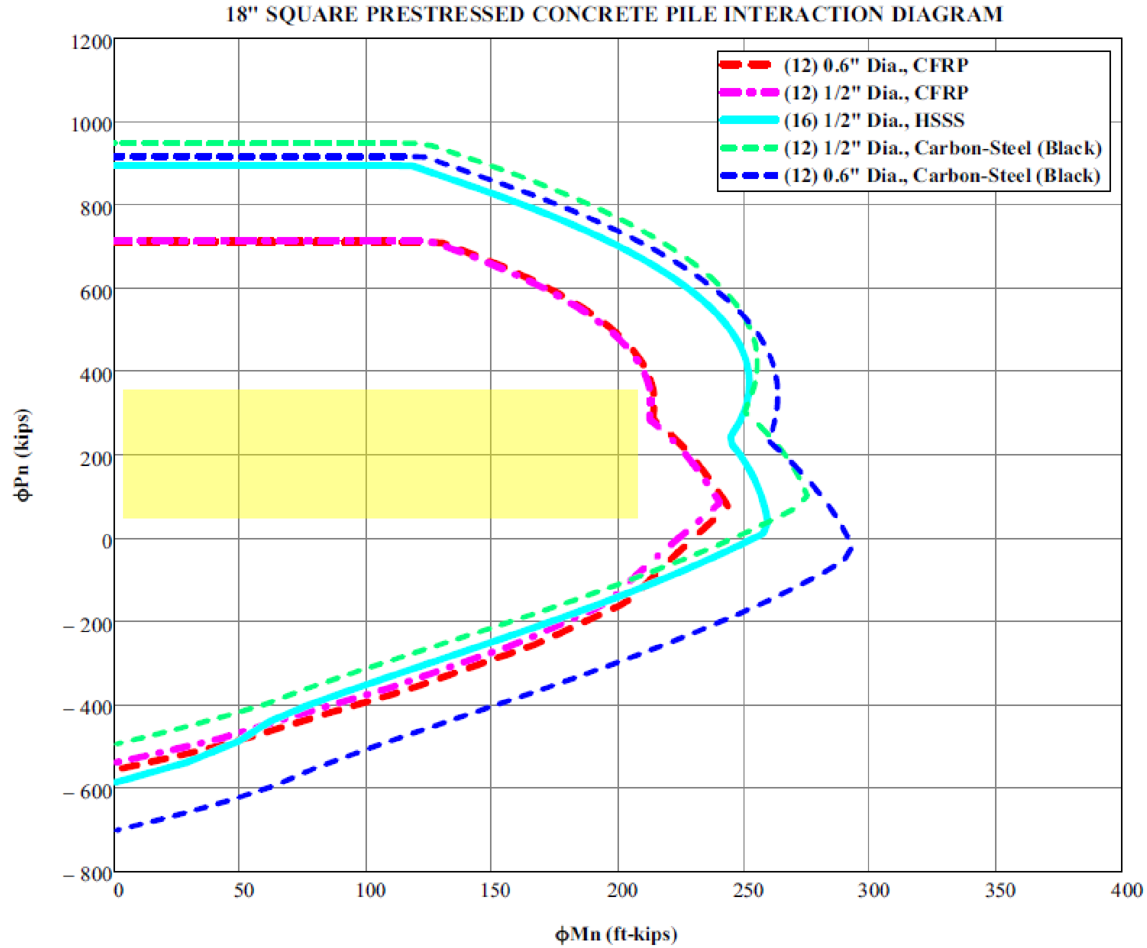
- ***Indexes 22600, 20601, 22612, 22614, 22618, 22624, & 20630***
  - New corrosion resistant piling for intermediate bridge pile bents in Extremely Aggressive Environments (marine)
    - *see **Structures Design Bulletin 15-10** for more information and*
    - *SDG Table 3.5.1-1 for application.*
  - 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)

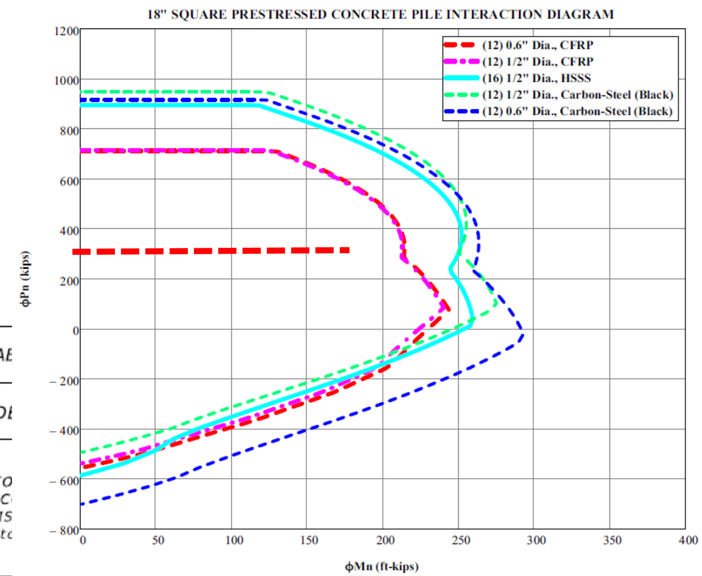
- ***Instructions – IDS-22600***
- Nominal 1,000 psi uniform compression
- Slight differences in Strength Limit States mainly due to reduced resistance factors for CFRP prestressing. Refer to the ***Design Aid*** M-N Charts



Standardization –
Design Standards

- Prestressed Concrete Piles (with CFRP or SS)

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



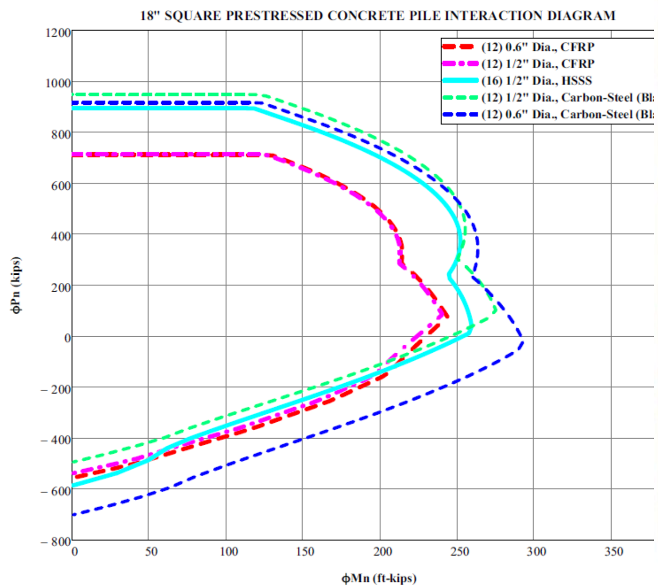
PILE DATA TAB...

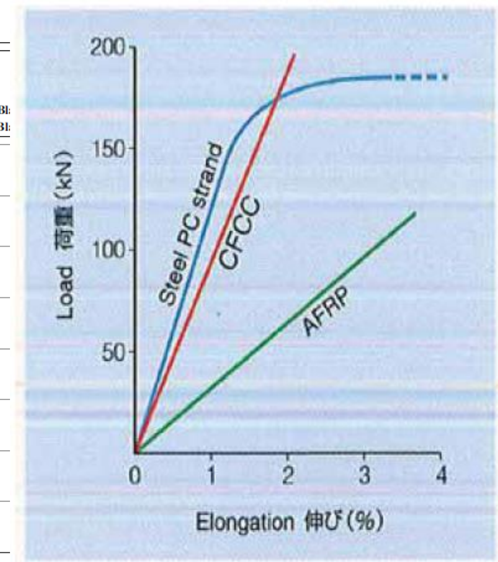
INSTALLATION CRITERIA								DE...				
PIER or BENT NUMBER	PILE SIZE (in.)	NOMINAL BEARING RESISTANCE (tons)	NOMINAL UPLIFT RESISTANCE (tons)	MINIMUM TIP ELEVATION (ft.)	TEST PILE LENGTH (ft.)	REQUIRED JET ELEVATION (ft.)	REQUIRED PREFORM ELEVATION (ft.)	FACTORED DESIGN LOAD (tons)	FACTORED DESIGN UPLIFT LOAD (tons)	DOWN DRAG (tons)	TO... SC... RESIS... (t...	
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***

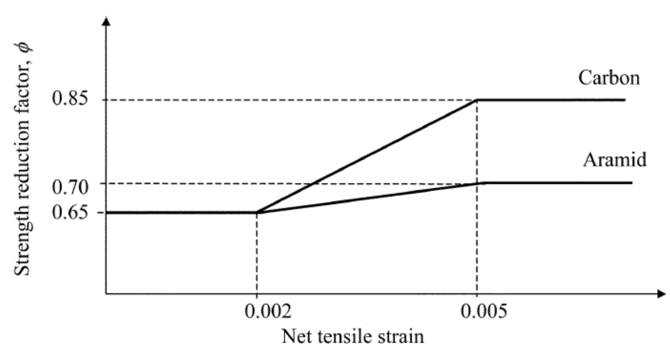
- Prestressed Concrete Piles (with CFRP or SS)

- 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
  - ϕ = 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**

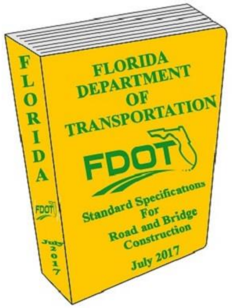




Load and elongation diagram (Source: Tokyo Rope)



FDOT Specifications

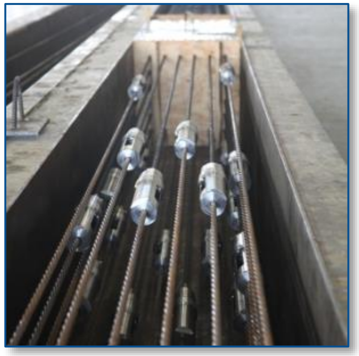


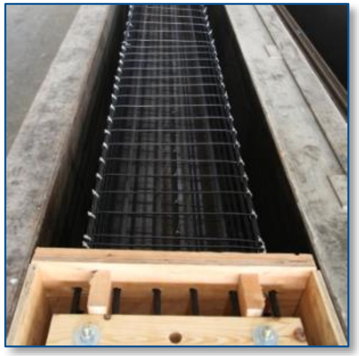
a) ***Standard Specifications*** (effective July 2016):

- 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;





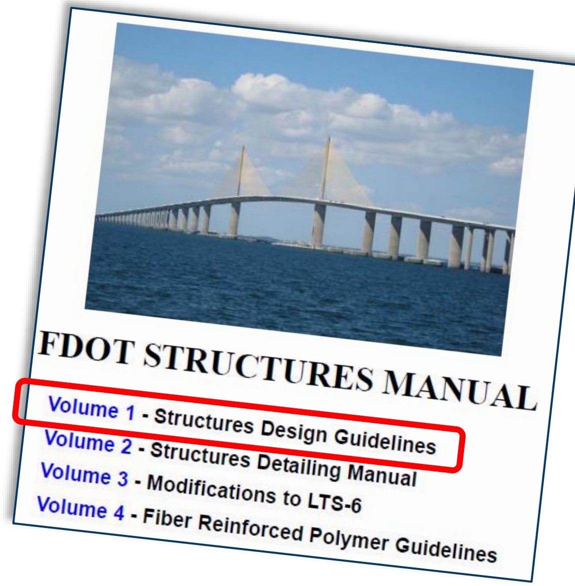
Usage Criteria

- 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

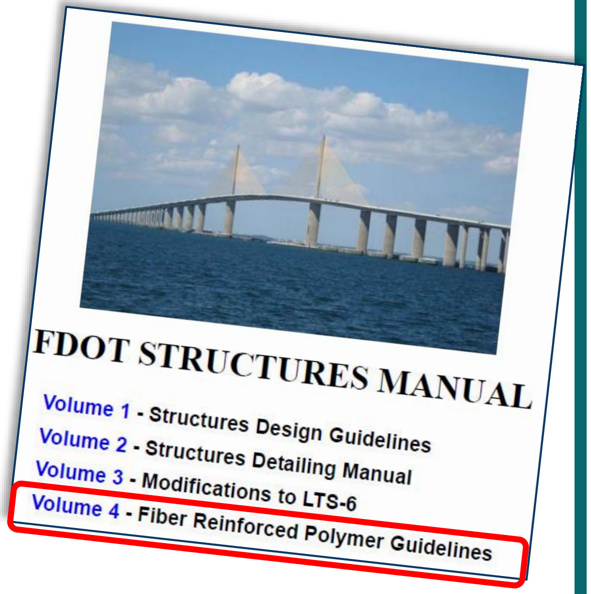


[3] The use of FRP or stainless steel strand and reinforcing is preferred for use in splash zones.

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.*

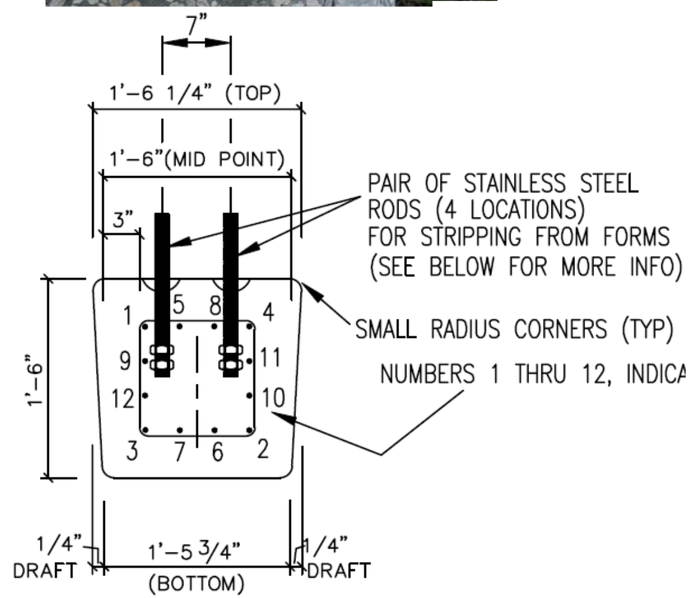
(photograph) FDOT. *CFRP Pile Casting with SCC.*

Challenges with CFRP Strands

(Halls River Bridge):

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

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



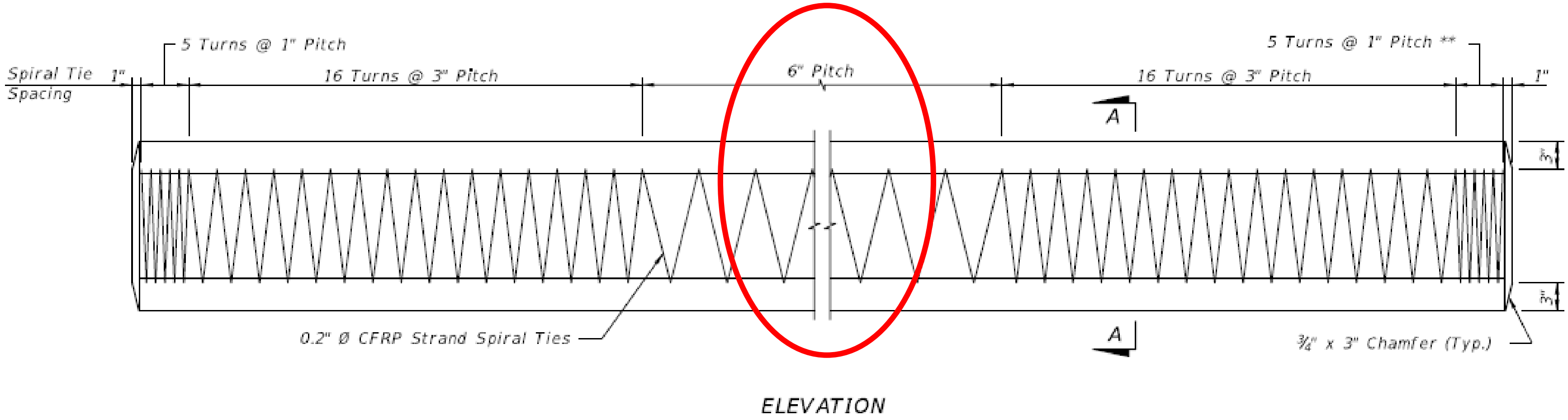
(Figure) *Corrosion resistance lifting device from Shop Drawings* (Gate Precast)

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

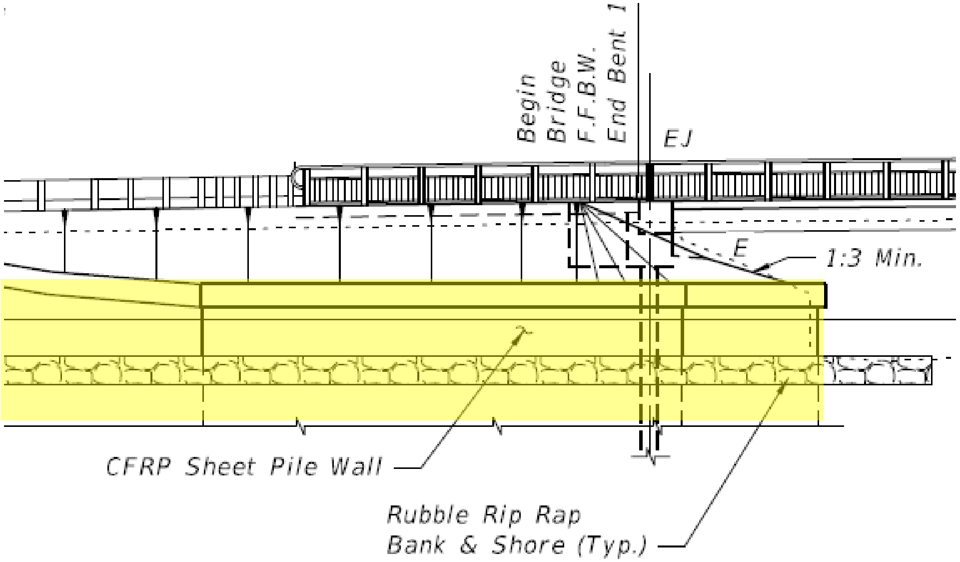
(Photographs - FDOT). *Strand contraction and cracking at cut-off.*



(Figure) *Spiral reinforcing from FDOT Index D22618*

Cantilever Concrete Sheet Pile Walls (Bulkhead/Seawall)

Concrete Sheet Pile Walls

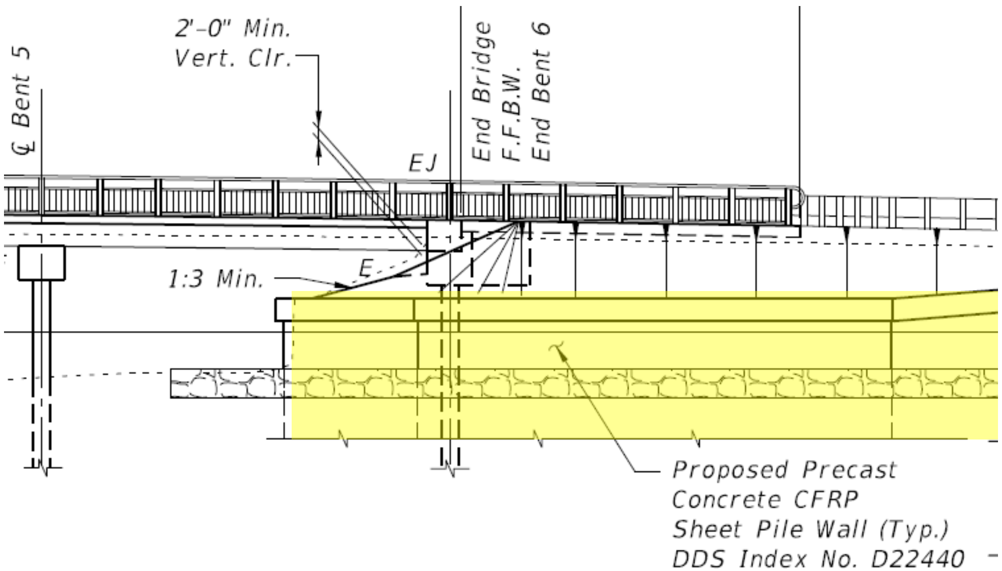


Sheet Piles:

- 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.*

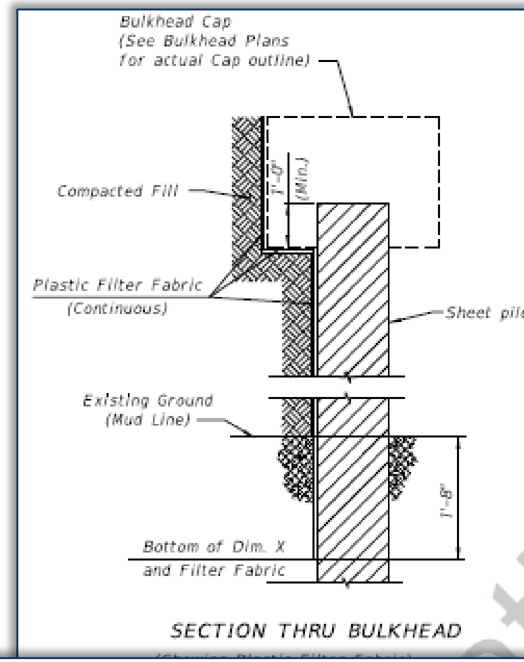
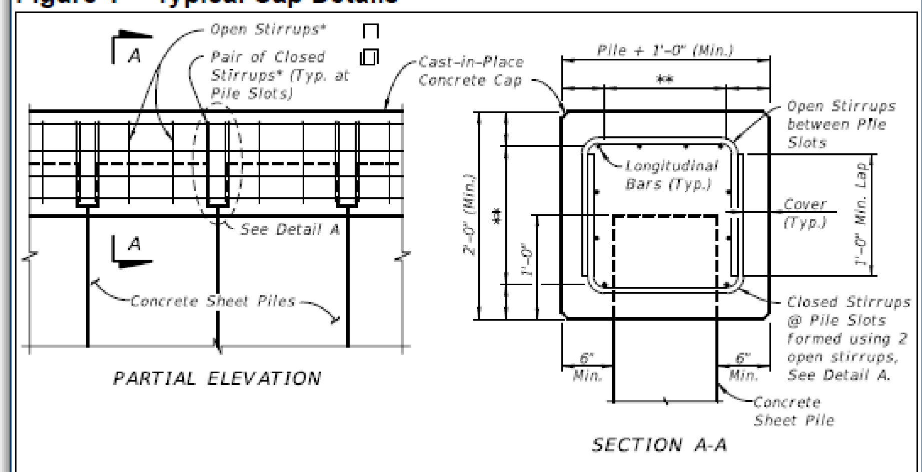


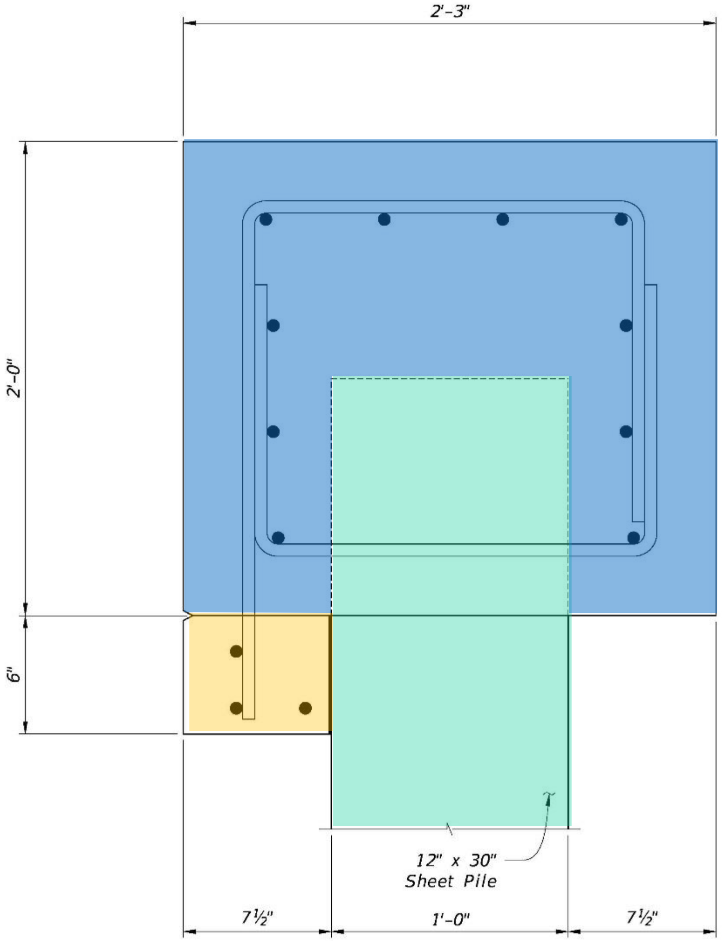
Figure 1 Typical Cap Details



Concrete Sheet Pile Wall Caps

(with GFRP)

Example Original Plan Sheet Details:



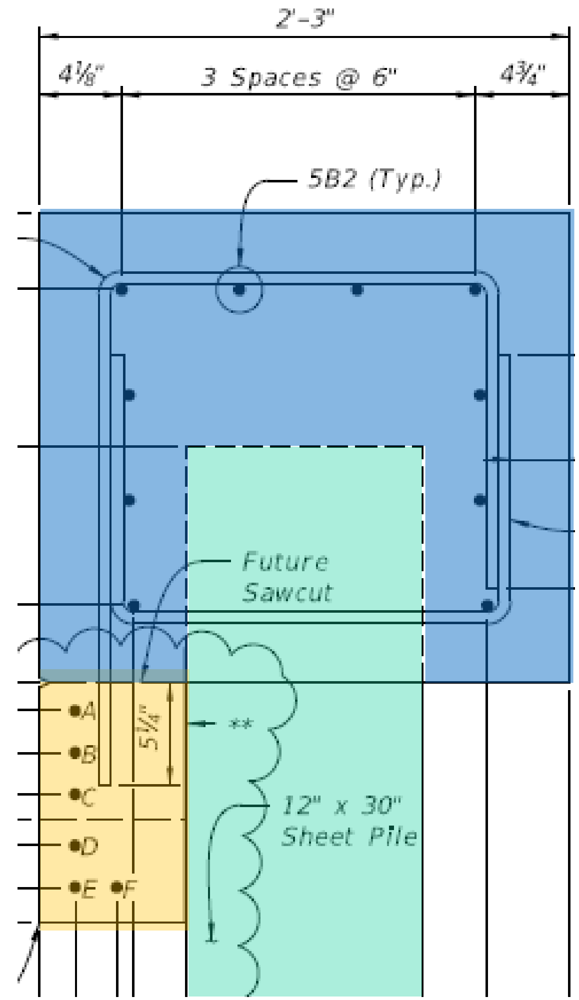
SECTION A-A

GFRP

CFRP/ GFRP

Test Block

Revised Plan Test Block Details:



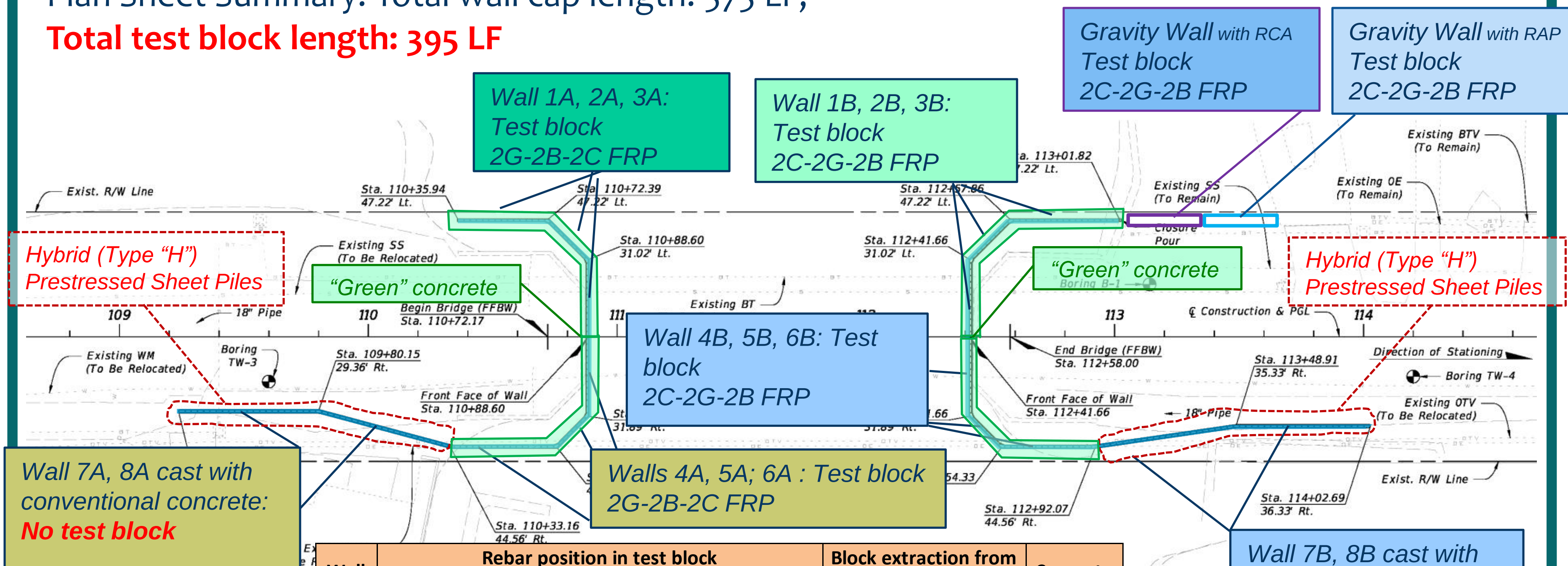
Note:

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

Concrete Sheet Pile Walls

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

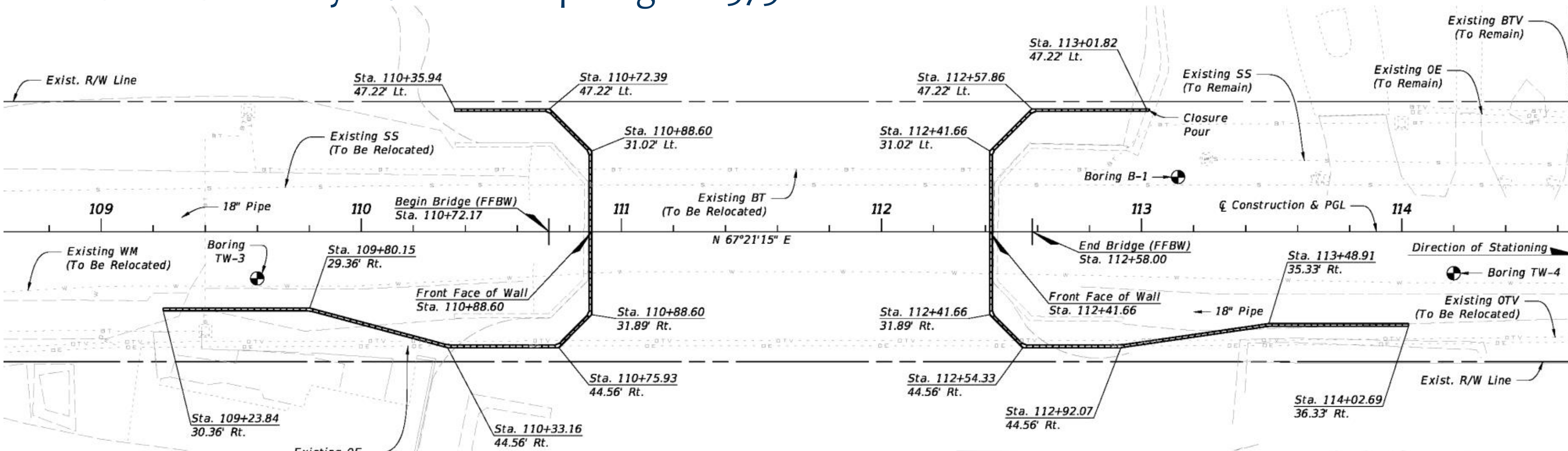
Total test block length: 395 LF



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

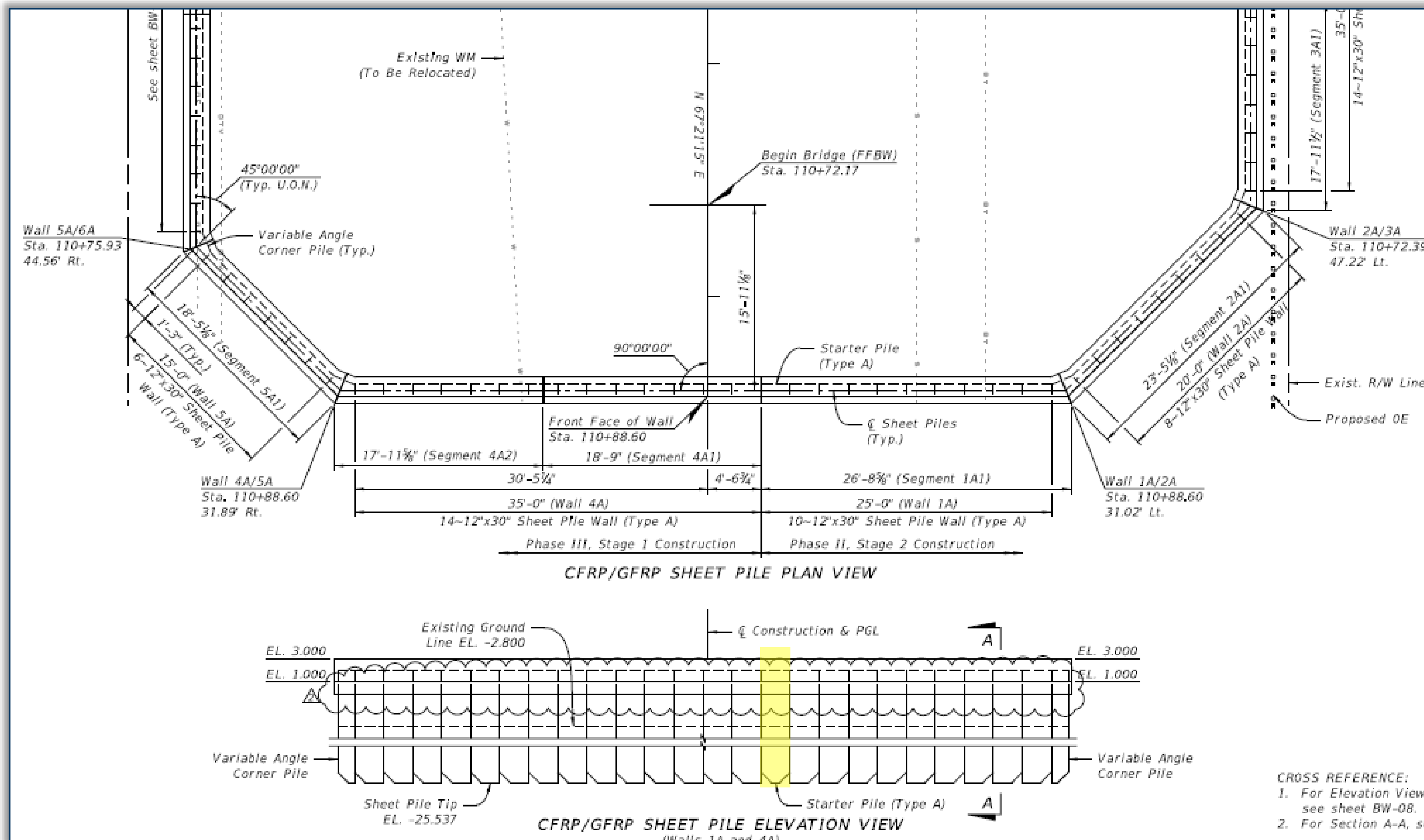
Plan Sheet Summary: Total wall cap length = 575 LF



CFRP/GFRP SHEET PILE WALL LAYOUT

Concrete Sheet Pile Walls

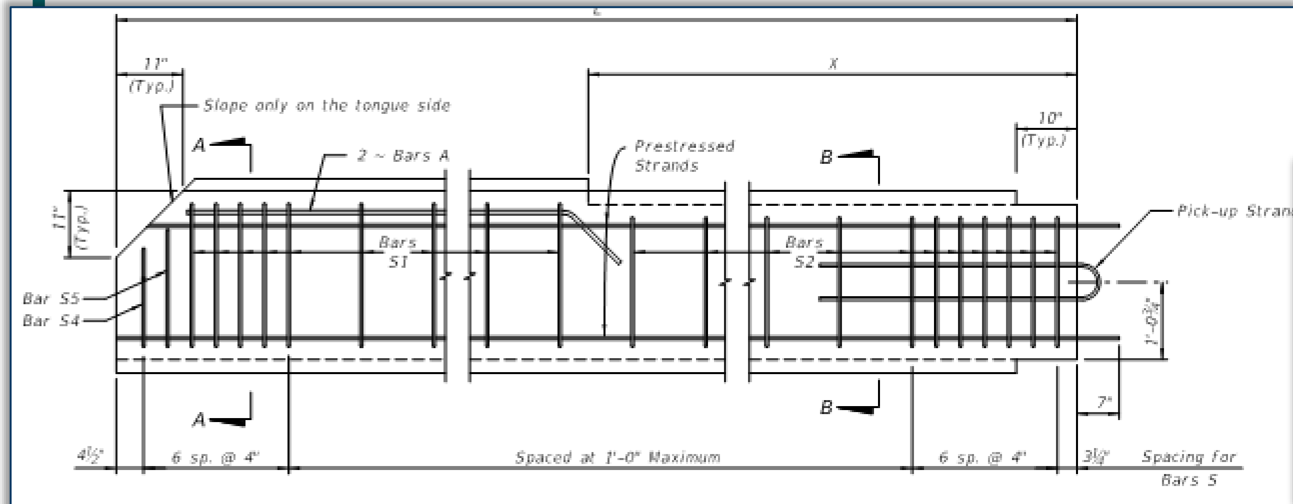
Example Plan Sheet Details:



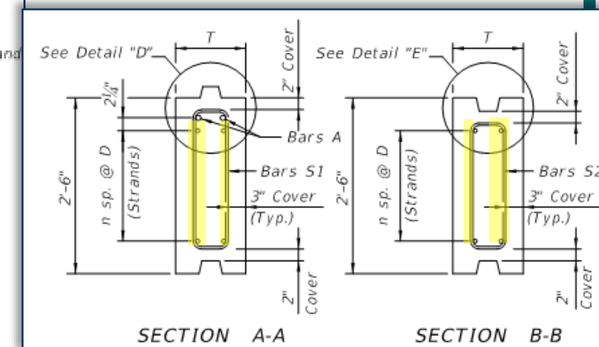
Concrete Sheet Pile Walls

(with CFRP/GFRP – Type "A")

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



TYPICAL PILE



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

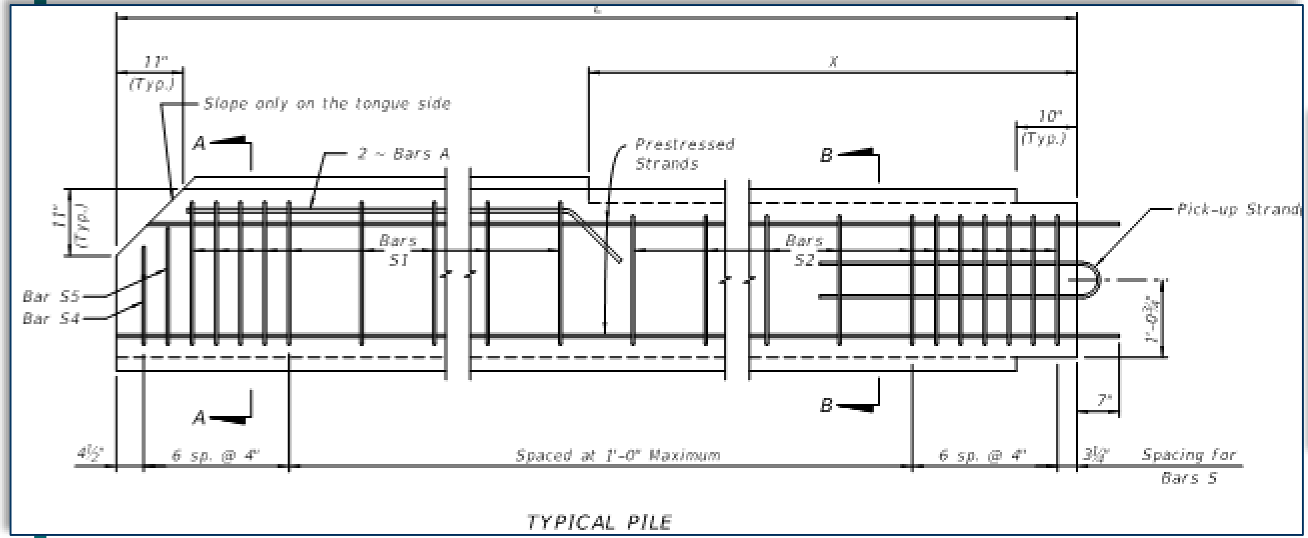
* Unit Prestress after losses.
** Based on lifting using single point pick-up.

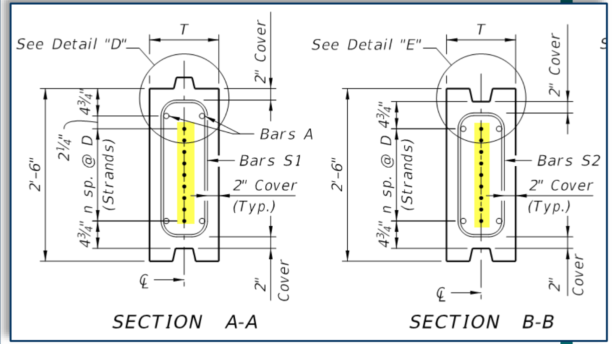
Alternate symmetrical strand patterns:
(1) 4 sp. @ 2" & 1 sp. @ 8"
(2) 2 sp. @ 4" & 1 sp. @ 8"

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).

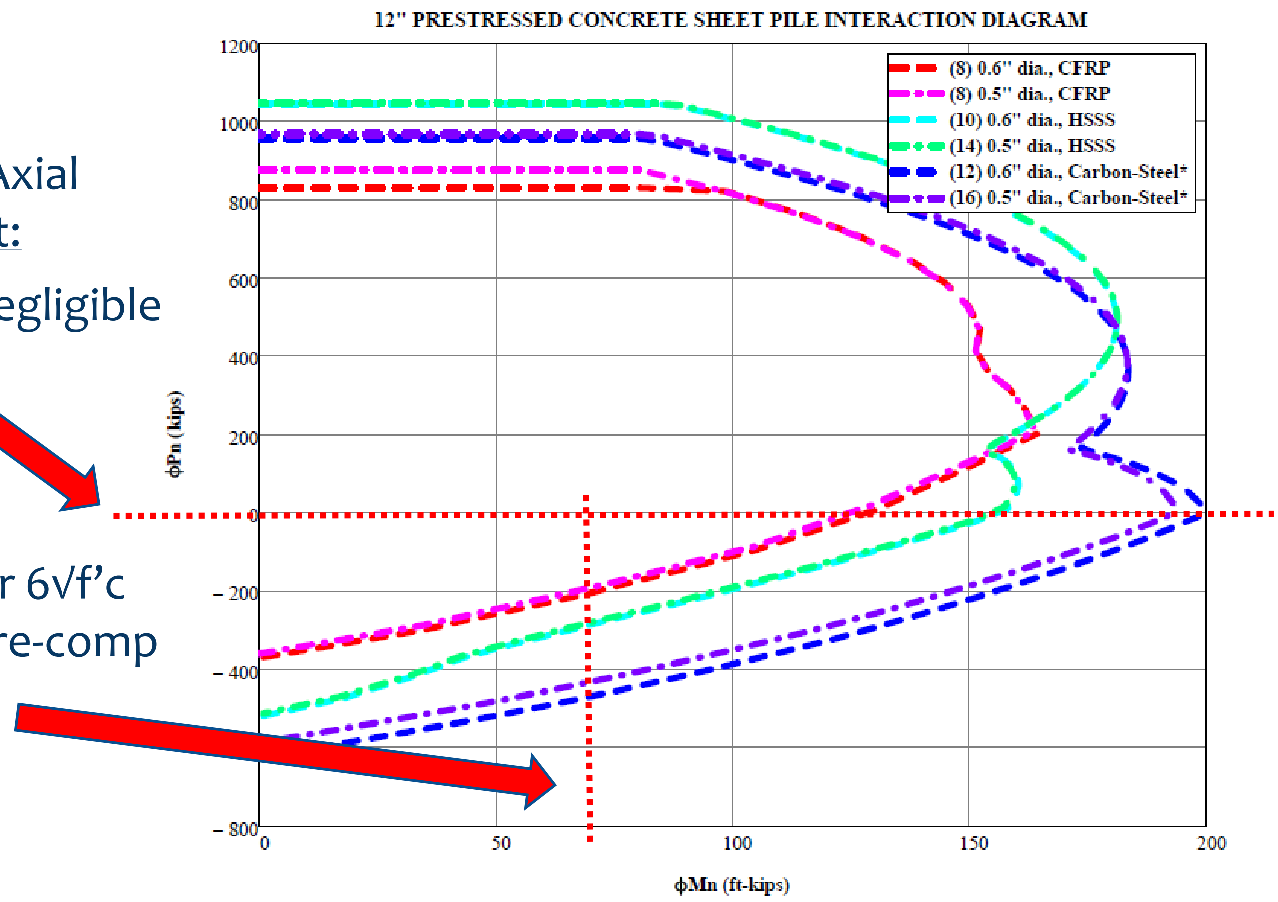
Cantilever Concrete Sheet Pile Walls

(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

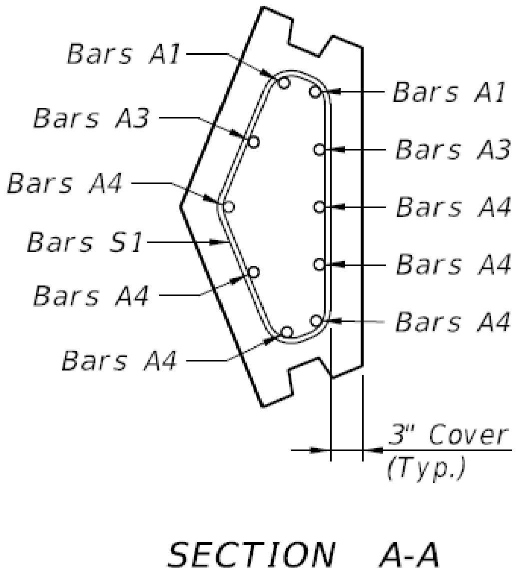


Concrete Sheet Piles

(Corner Piles)

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

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



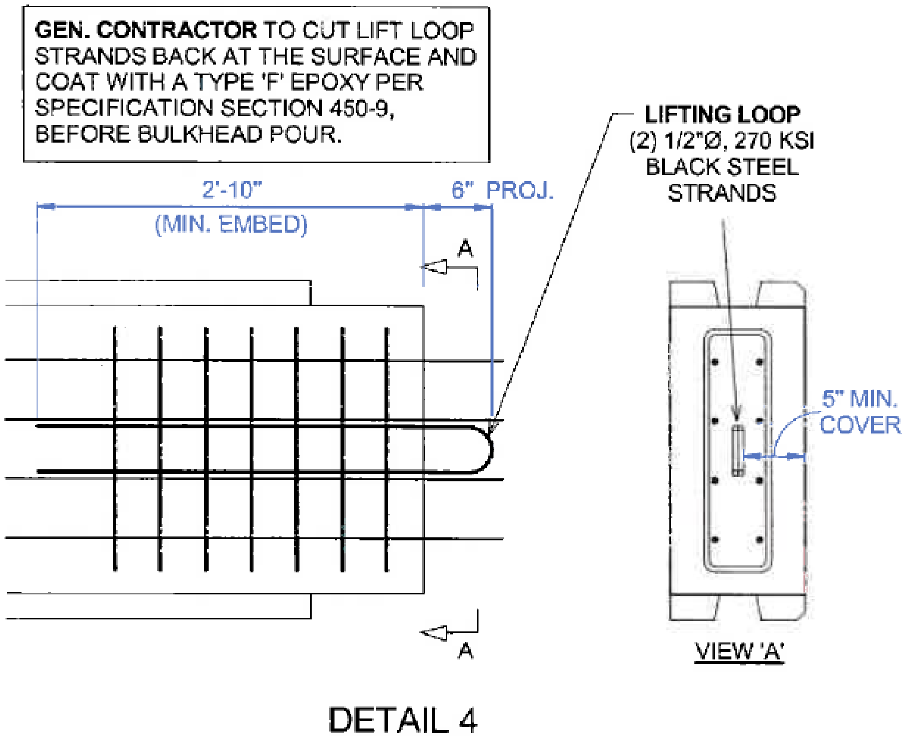
(Photographs - FDOT). *Corner Sheet Piles stored on site*

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 %

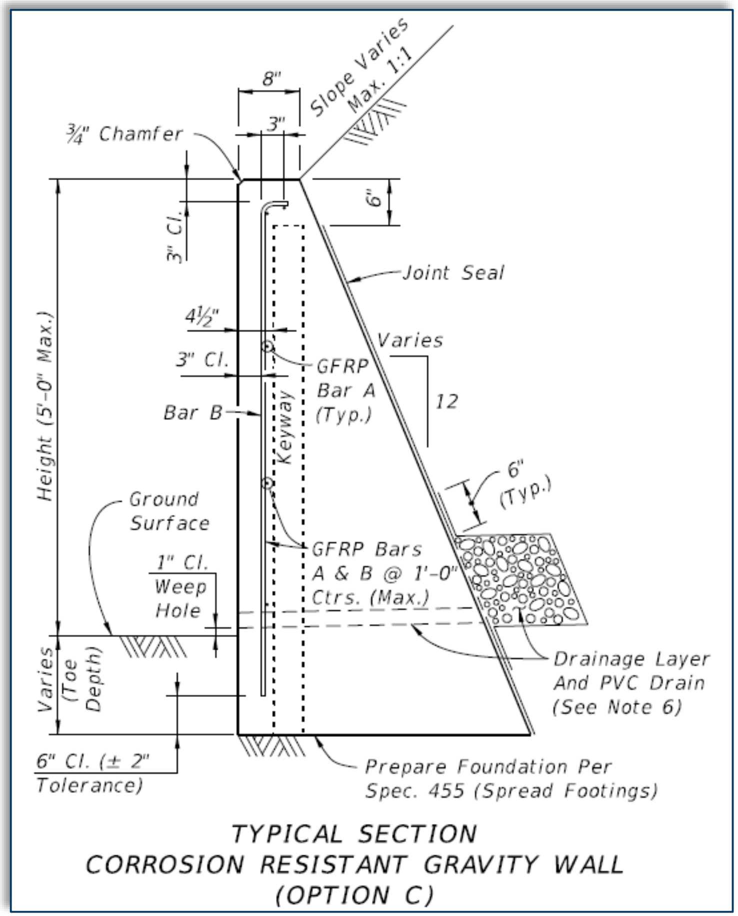


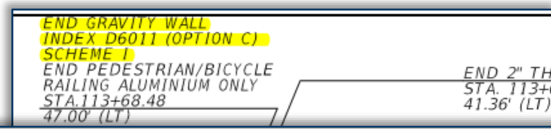
Figure from Index D6011c (2016)

PROJECT NOTES:

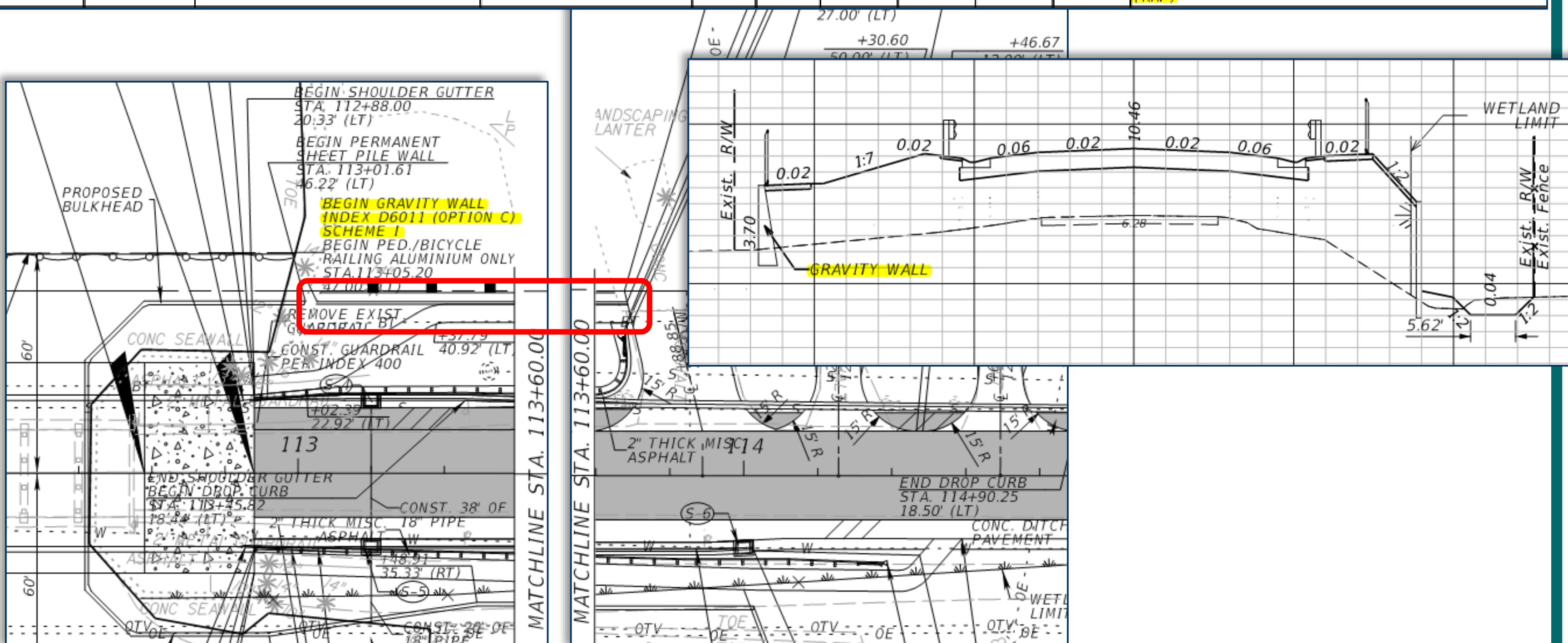
1. Class NS concrete must contain between 10% and 20% content of Recycled Concrete Aggregate (RCA) in Section 1, and between 10% and 20% content of Recycled Aphalt Pavement (RAP) in Section 2.

Gravity Walls (with GFRP)

Example Plan Sheet Details:



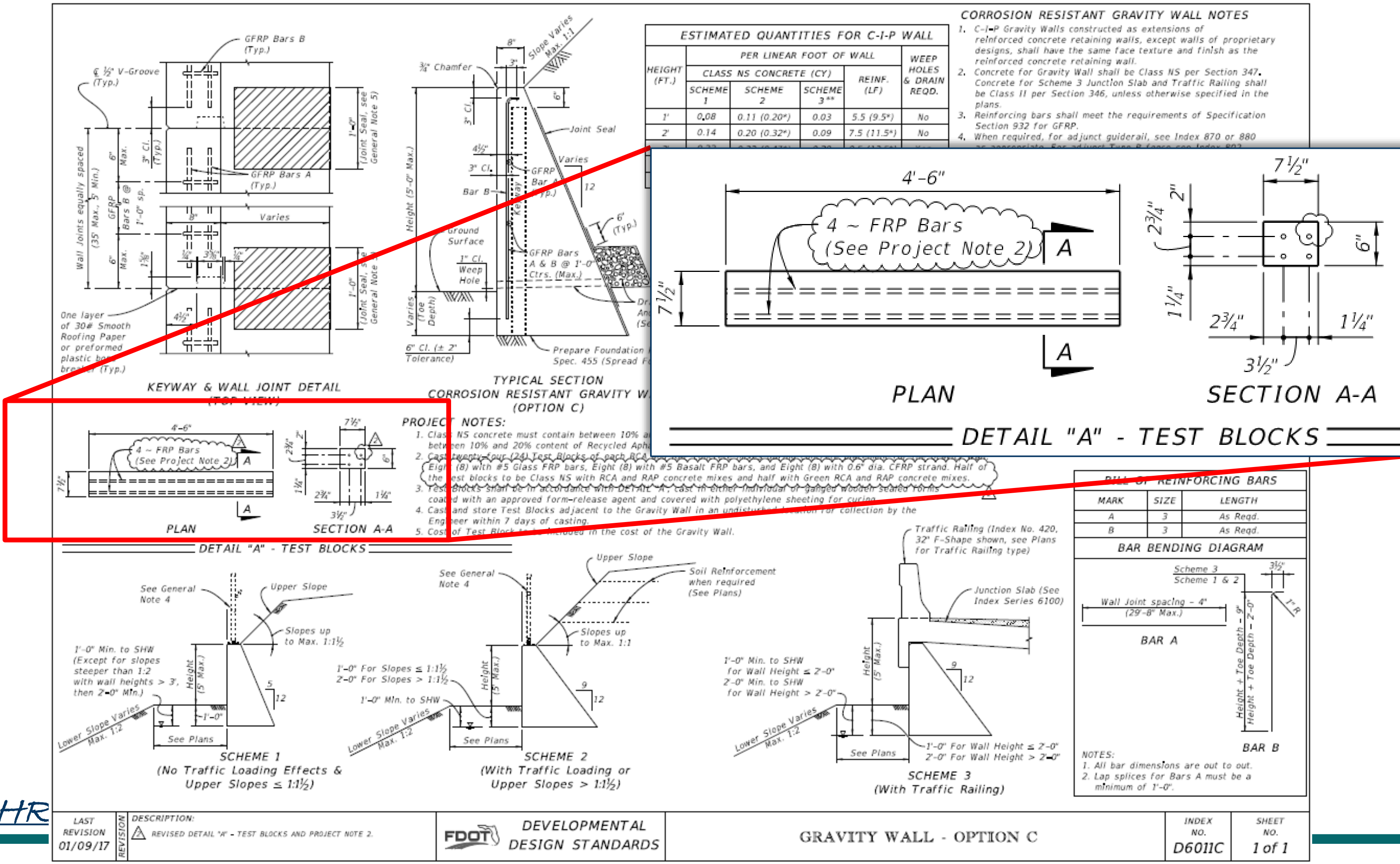
SUMMARY OF WALLS										
WALL NO.	PAY ITEM NO.	PAY ITEM DESCRIPTION	LOCATION STA. TO STA.	SIDE	UNIT	QUANTITY P	QUANTITY F	TOTAL P	TOTAL F	DESIGN NOTES
1	400 0 11	CONCRETE CLASS NS, GRAVITY WALL	113+05.00 to 113+37.20	LT	CY	10.4		20		USING 20% RECYCLED CONCRETE AGGREGATE (RCA)
			113+37.20 to 113+68.48	LT	CY	10.0				USING 20% RECYCLED ASPHALT PAVEMENT AGGREGATE (RAP)



HRB-FRP Workshop

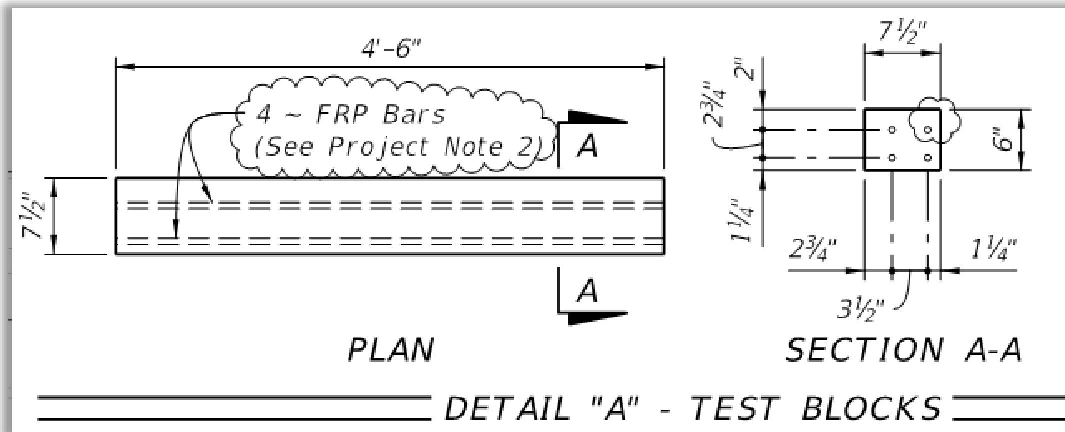
Gravity Walls (with GFRP)

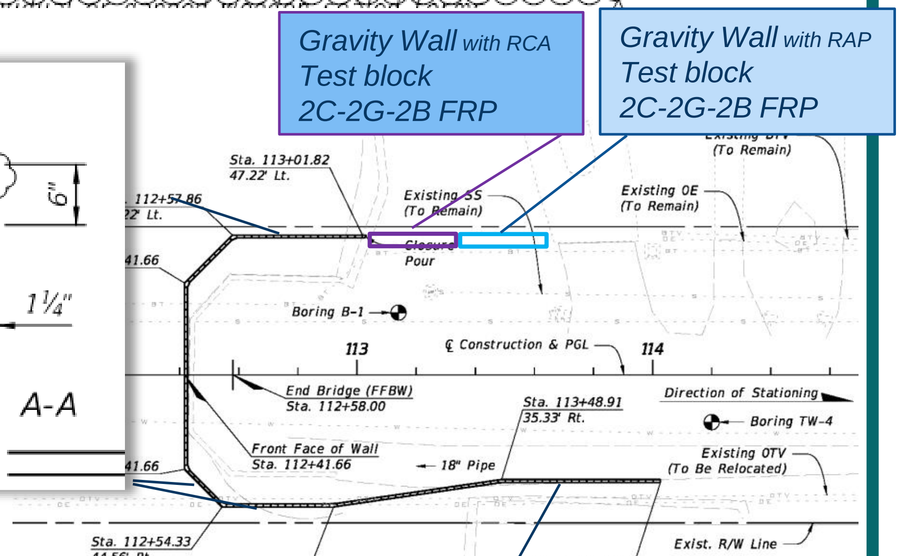
Index D6011c (*project version*):



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

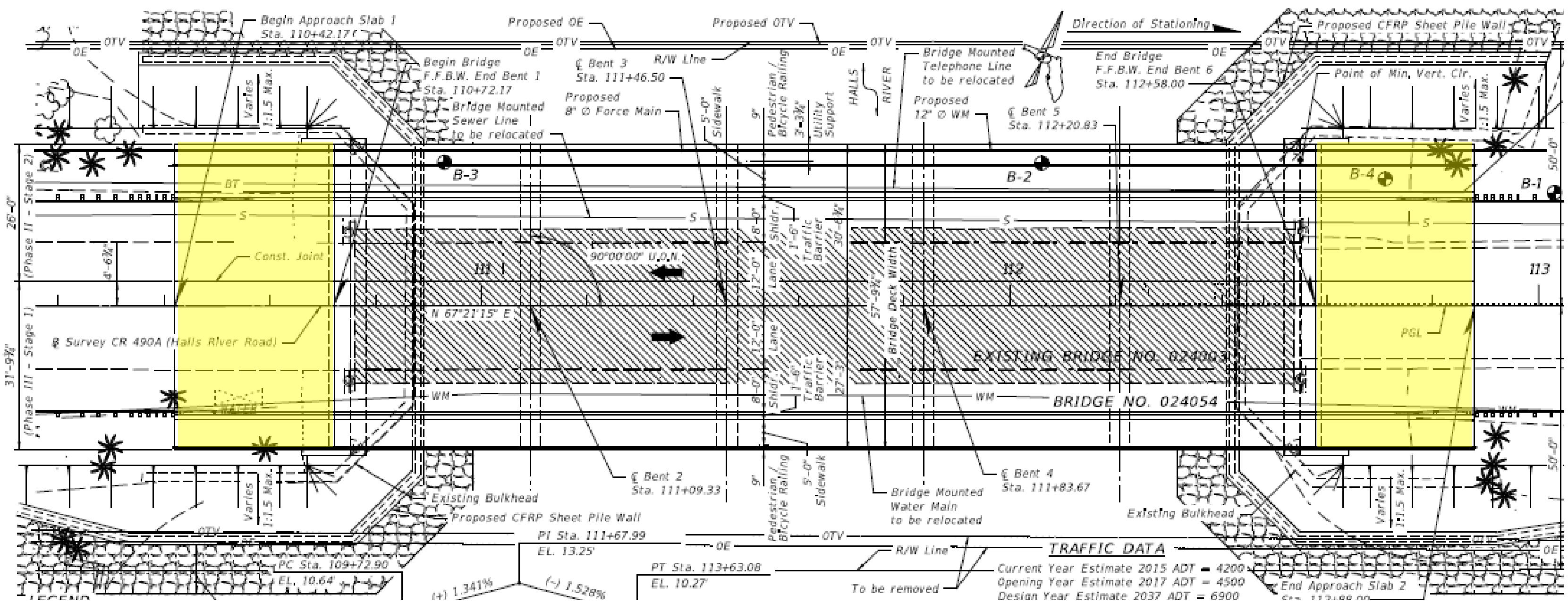
2 blocks with CFRP strands – "Green"-RCA

2 blocks with GFRP bars – "Green"-RAP

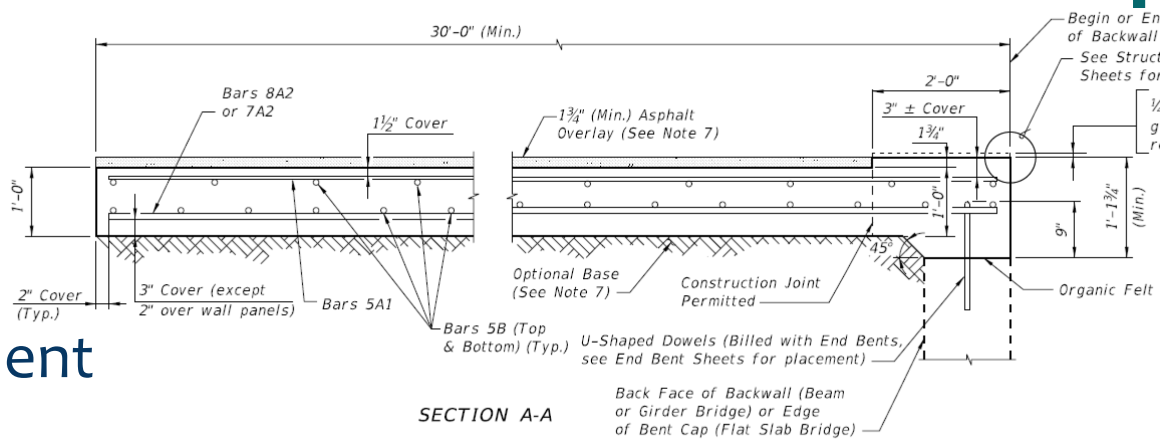
2 blocks with BFRP bars – "Green"-RAP

2 blocks with CFRP strands – "Green"-RAP

GFRP-RC Approach Slabs



Approach Slabs



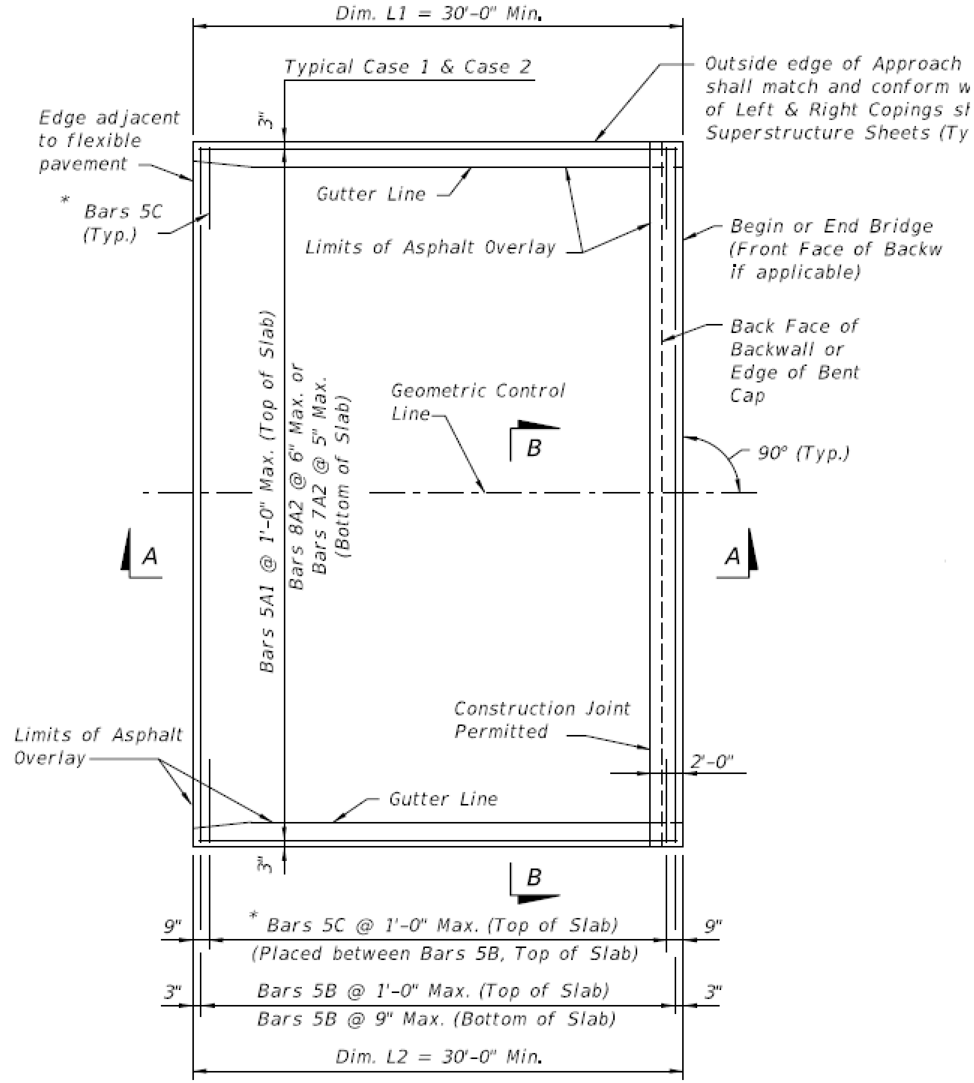
A. General
   i. 30ft length
   ii. GFRP reinforcement
B. Structural System
   i. ***Developmental Design Standard*** *Index D22900*
C. Design Criteria
   i. ***ACI 440.1R / AASHTO Guide Spec.*** *(without service limit state checks) – For slab-on-grade neither may not be applicable.*
   ii. Emulates 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 ϕM_n = 32 ft-kips, based on f_y = 60 ksi and ϕ_f = 0.9

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

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

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

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

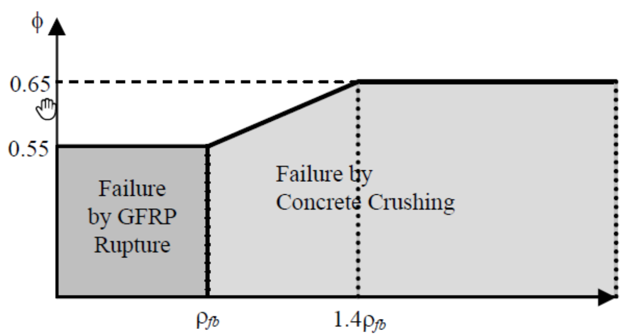
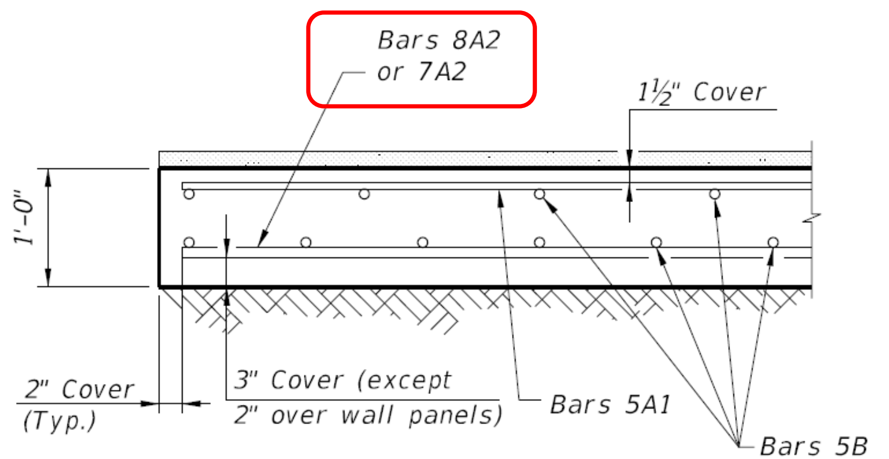


Figure 2.7.4.2-1—Resistance factors for flexure



Approach Slabs

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

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

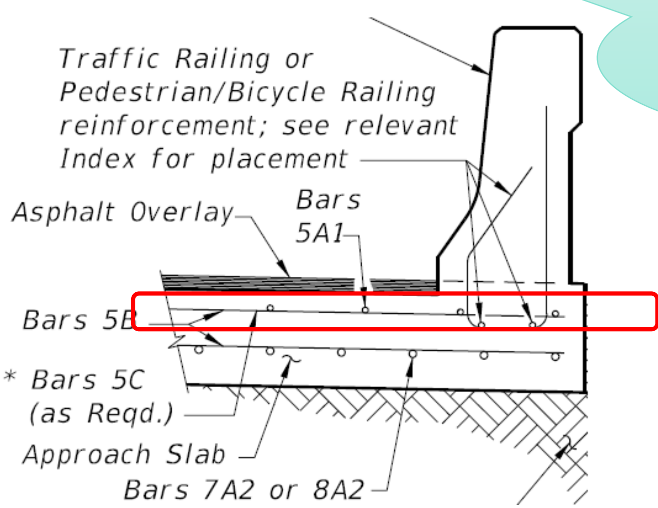
  Flexural Resistance ϕM_n = 28 ft-kips, based on f_y = 60 ksi and ϕ_{ee}= 1.0

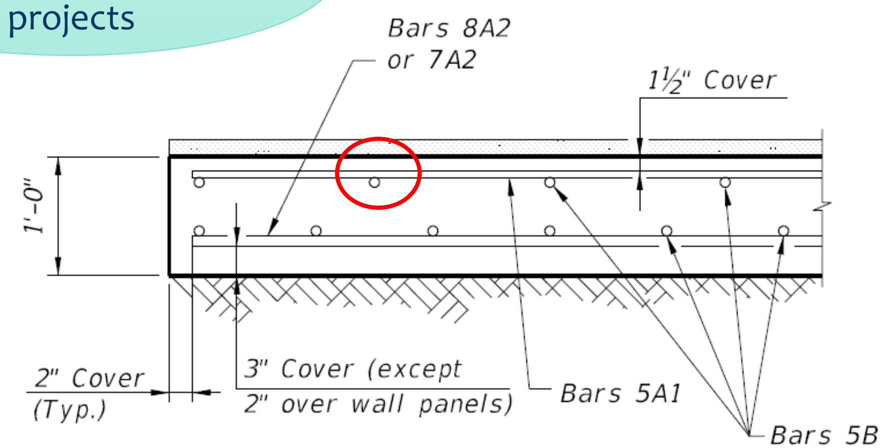
- GFRP Rebar (Index 22900) = #5's @ 6" spacing (A_f = 0.62 in²/ft);

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

  … for ϕ_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



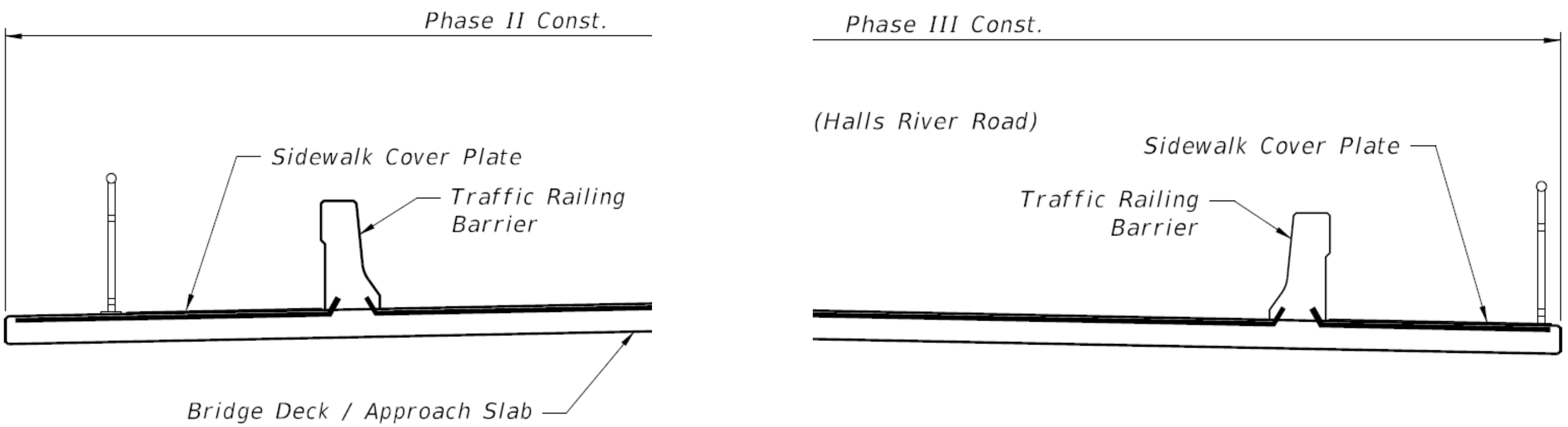


Approach Slabs

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. $\leq$ 0.0036 $\rho_{f,st}$ per face → A_f = 0.52 in²/ft.

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

Need consensus on approach for future projects

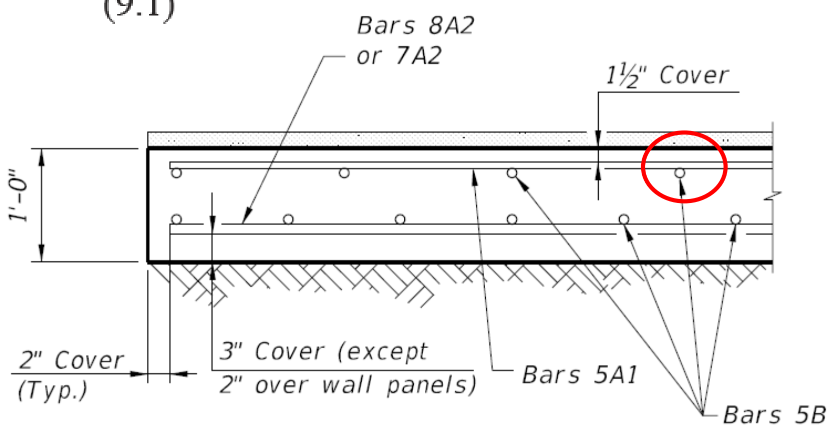
ACI 440.1R Guide Spec . $\leq$ 0.0036 $\rho_{f,ts}$ total → A_f = 0.26 in²/ft. top & bottom face

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

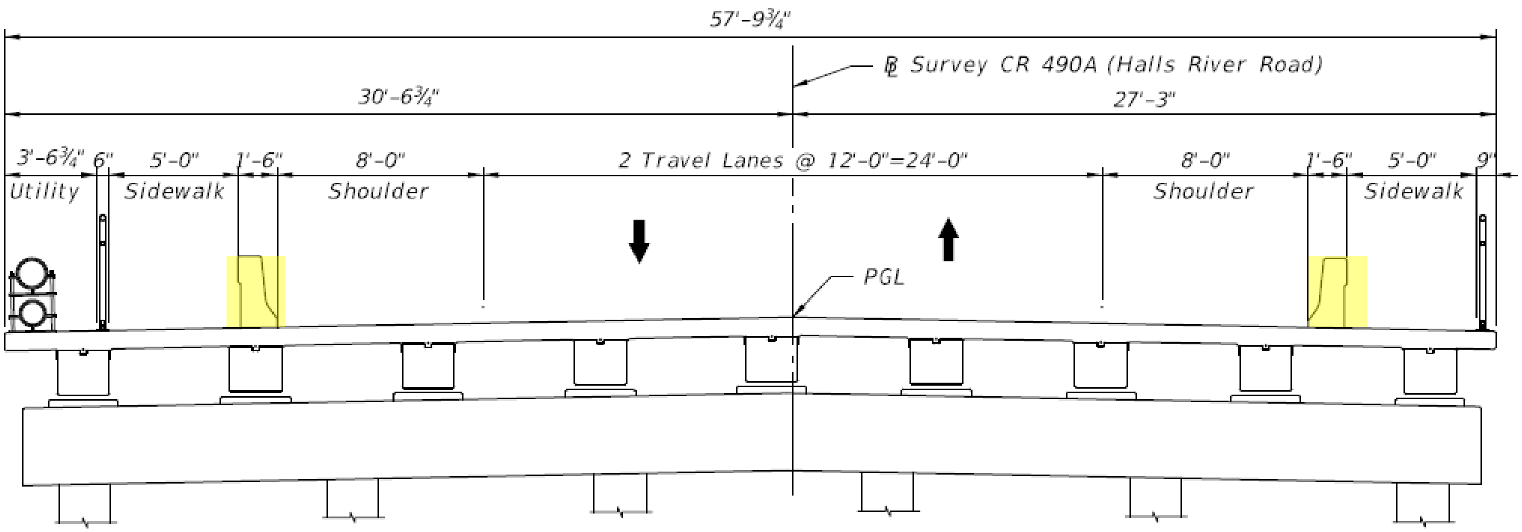
ACI 318-14 Commentary R24.4.3.2:

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

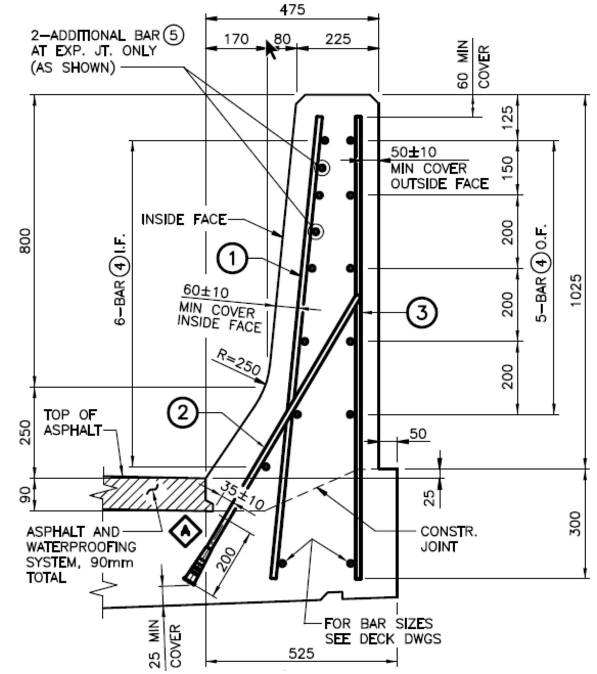
ii. Vertical reinforcing equivalent to #5's @ 12" spacing away open joint.

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??)

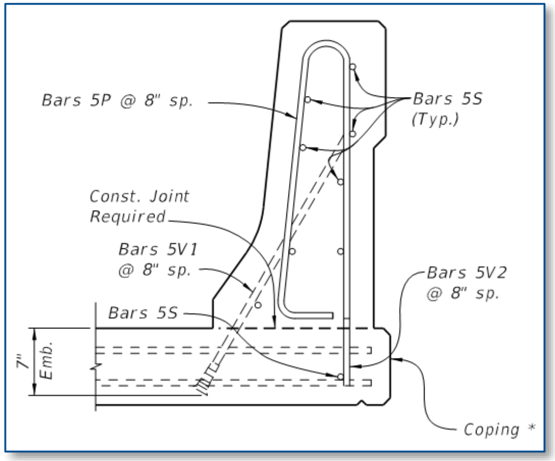
v. Halls River Bridge only needed TL-3 (since off-system roadway)

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



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

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



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)

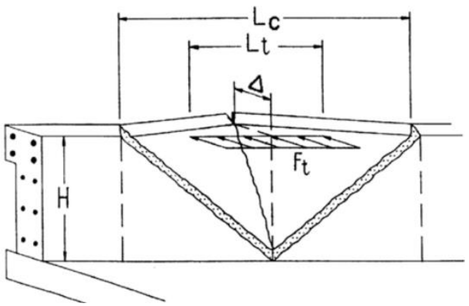


Table A13.2-1—Design Forces for Traffic Railings

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 Angle: 20° Weight: 1,809 lb.	Speed: 62 mph Angle: 25° Weight: 2,420 lb.
TL-3	Pickup	Speed: 62 mph Angle: 25° Weight: 4,409 lb.	Speed: 62 mph Angle: 25° Weight: 5,000 lb.
TL-4	Single Unit Truck	Speed: 50 mph Angle: 15° Weight: 17,636 lb.	Speed: 56 mph Angle: 15° Weight: 22,000 lb.
TL-5	Tractor Trailer	Speed: 50 mph Angle: 15° Weight: 79,366 lb.	Speed: 50 mph Angle: 15° 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)

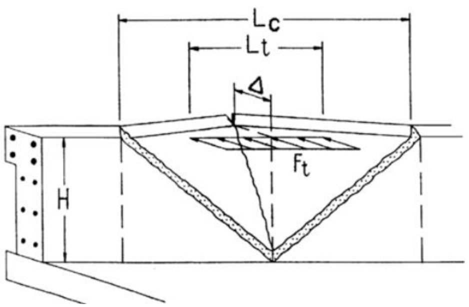


Table A13.2-1—Design Forces for Traffic Railings

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

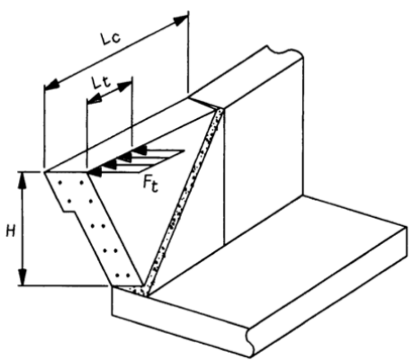


Figure CA13.3.1-2—Yield Line Analysis of Concrete Parapet Walls for Impact near End of Wall Segment

Near End of Wall Segment:

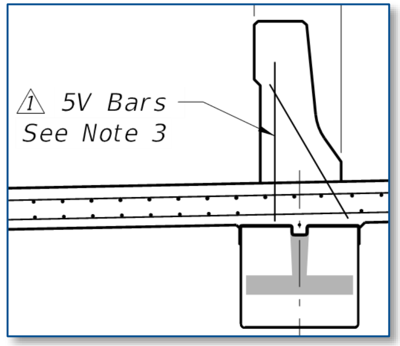
- Nominal Resistance = 76 kips (ϕ = 1.0 ***AASHTO-BDS***)
- Using ϕ_f = 0.55 per ***AASHTO Guide Spec.*** commentary C3.4, Factored Resistance = 42 kips at joint (= 80 kips away from joint)

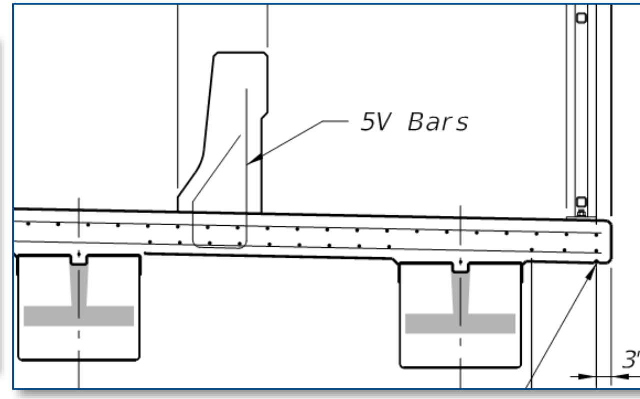
Crashworthiness of reinforced concrete traffic railing greatly depends on its stiffness when subjected to transverse load. This should be accounted for by limiting the strength reduction factor for flexure to 0.55 when the internal forces computed through inelastic analysis are associated with a strain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

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

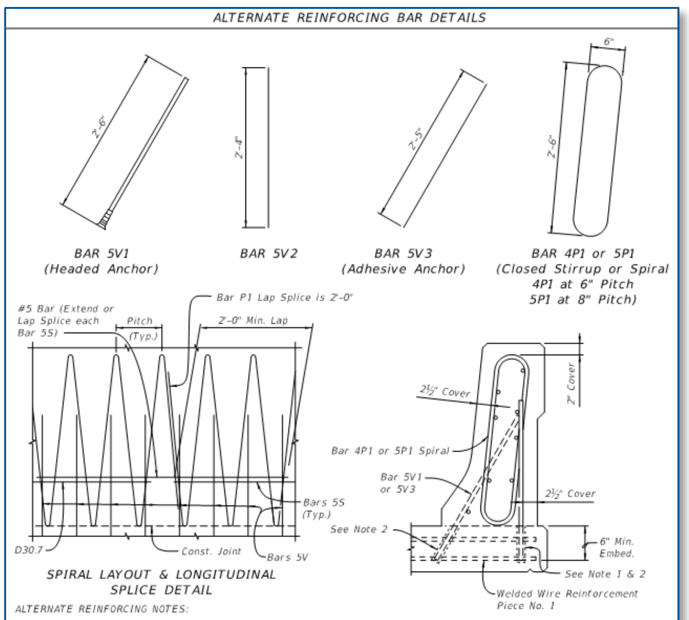
Traffic Railings

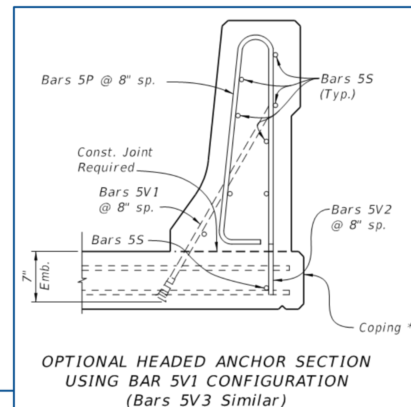
Example Plan Sheet Details:

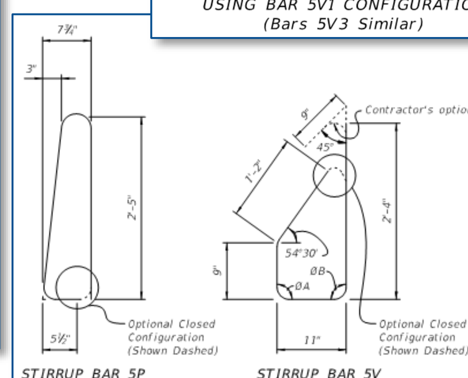


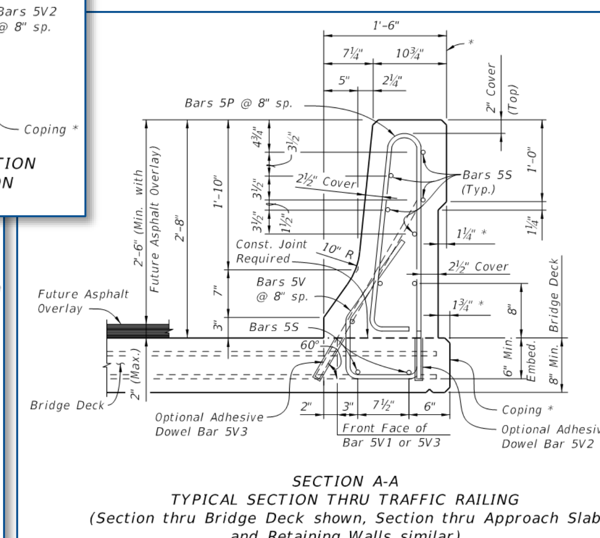


Index D22420 various rebar options:



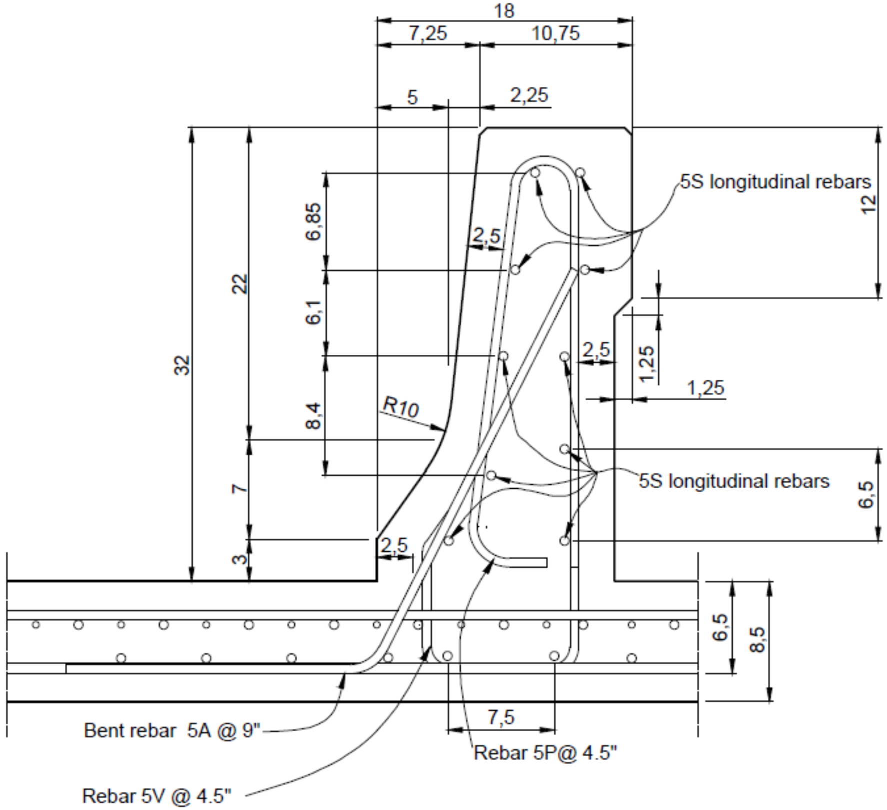




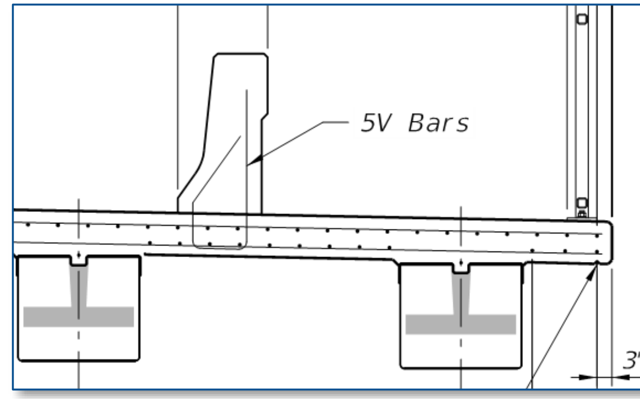


Traffic Railings

Contractor’s revised Reinforcing Details (south side):



SECTION A-A
TYPICAL SECTION THRU TRAFFIC RAILING

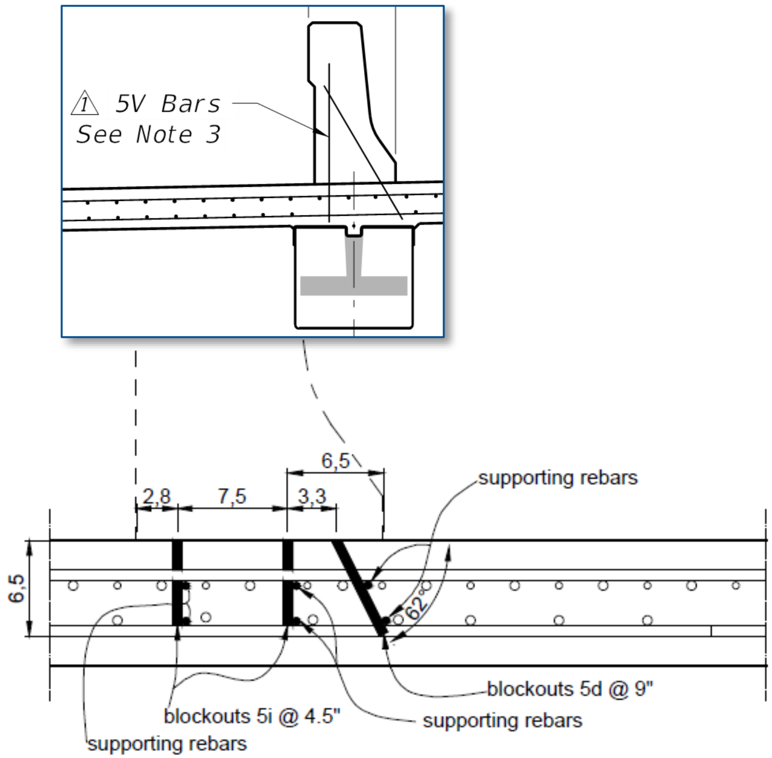


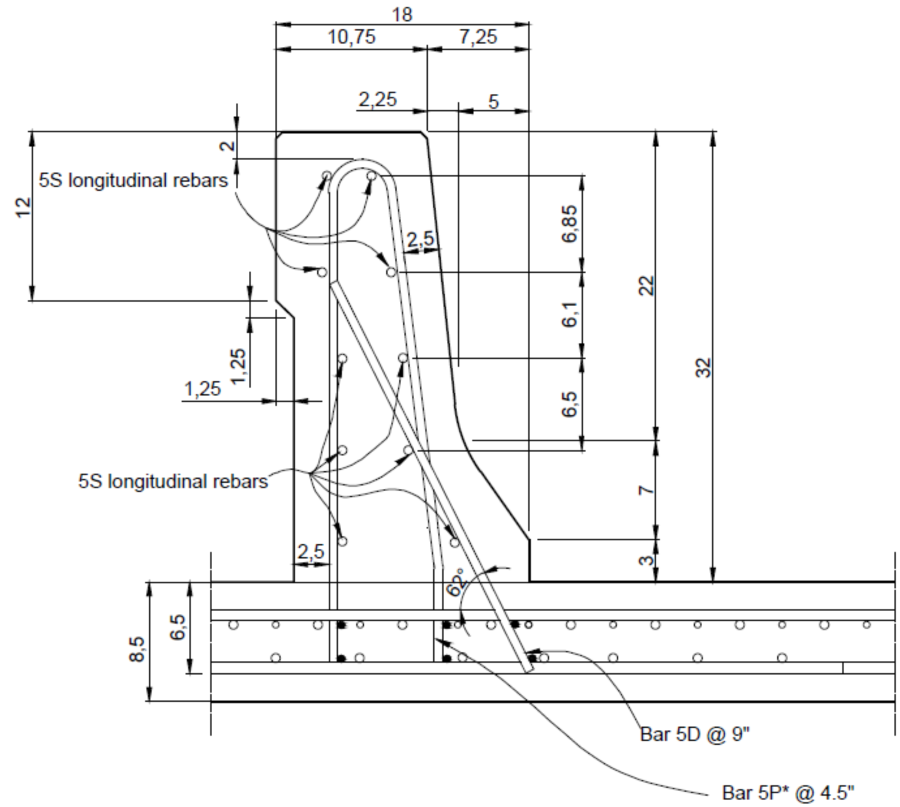
Vertical spacing adjusted to 4.5” increments to match deck rebar spacing

Traffic Railings

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

Contractor’s revised Reinforcing Details (north side):





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.

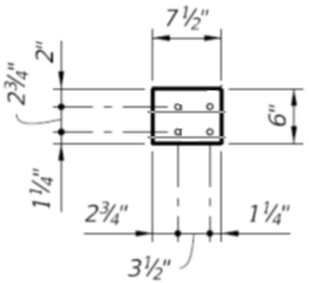
- White-cement mix to be used on Southside railing;
- 60% slag mix to be used on Northside railing;
- Lehigh and SEACON team partnering with the contractor to offset the additional cost;
- Future monitoring to be determined.

Photos courtesy of Lehigh White Cement Company promotion brochure.

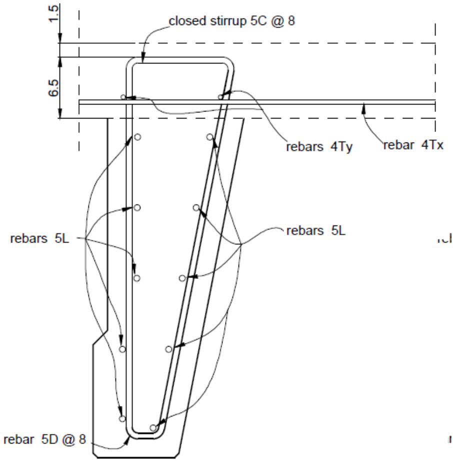
Traffic Railings

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

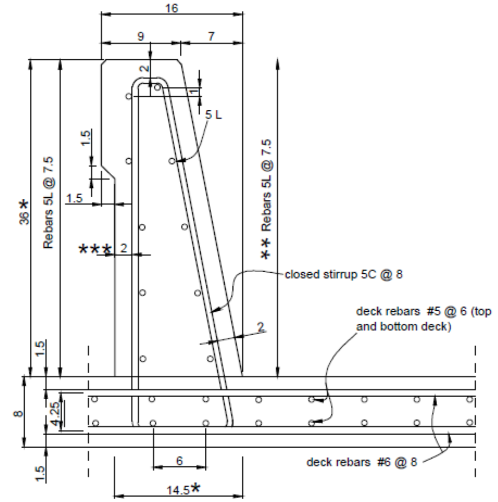
- White-cement and 60%-slag concretes have a lower alkalinity, but should not be a problem for GFRP durability;
- Casting FRP reinforced test blocks for performance monitoring by SEACON team;
- Three 12-ft specimens to cast based on new 36" Single-Slope Traffic Railing;
- Possible for pendulum impact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



SECTION A-A



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

steven.nolan@dot.state.fl.us

(850) 414-4272