2017 FDOT – Halls River Bridge FRP Workshop

May 3, 2017

Tampa, FL

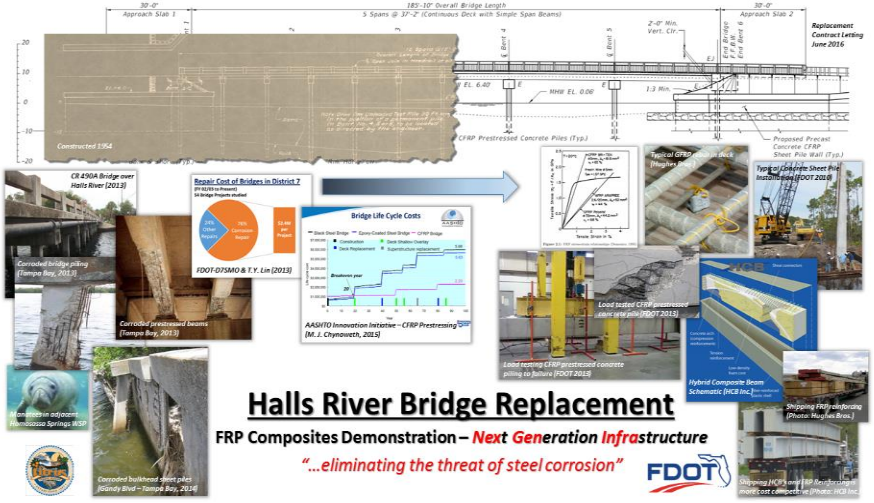
HRB-FRP Workshop (Part 1)

Presenters:

Mamunur Siddiqui, EOR, FDOT D7

David Pelham, FDOT D7

Elisha Masseus, FDOT D6



Outline:

Part 1 – Bridge Design

1. Halls River Bridge Project Overview
2. Hybrid Composite Beams (HCB)
3. GFRP-Reinforced Concrete
4. Challenges
5. Lessons Learned

1. Project Overview

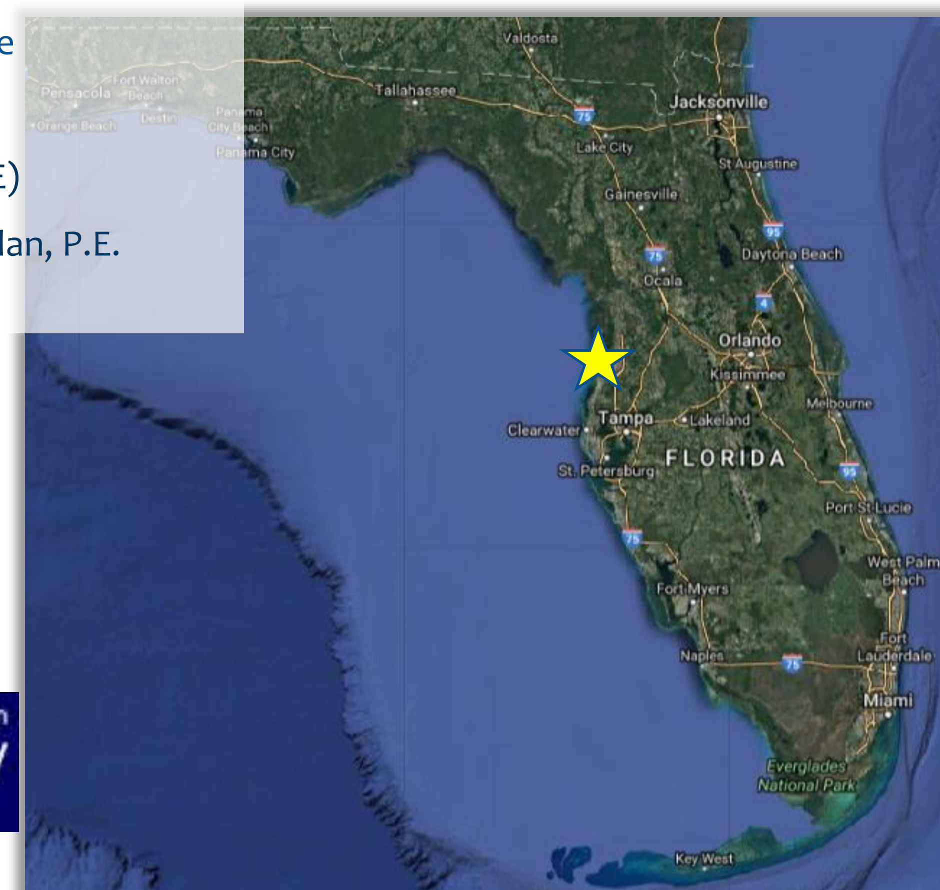
Project Overview –
Halls River Bridge Replacement

Designer: FDOT District 7 Structures Design Office

Bridge EOR: Mamunur Siddiqui, P.E.

Bulkhead/Seawall EOR: Richard Hunter, P.E. (ACE)

FDOT Developmental Standards EOR: Steven Nolan, P.E.



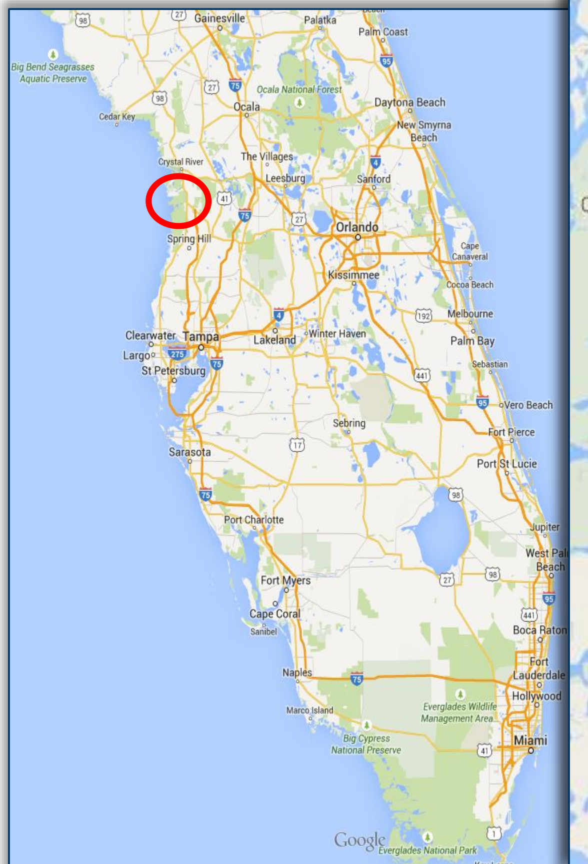
Owner & Maintaining Agency

Design & Bi-Annual Inspection

Collaboration Research

Funding & Oversight

Project Overview



Project Location
(Contract Letting 06/15/2016)

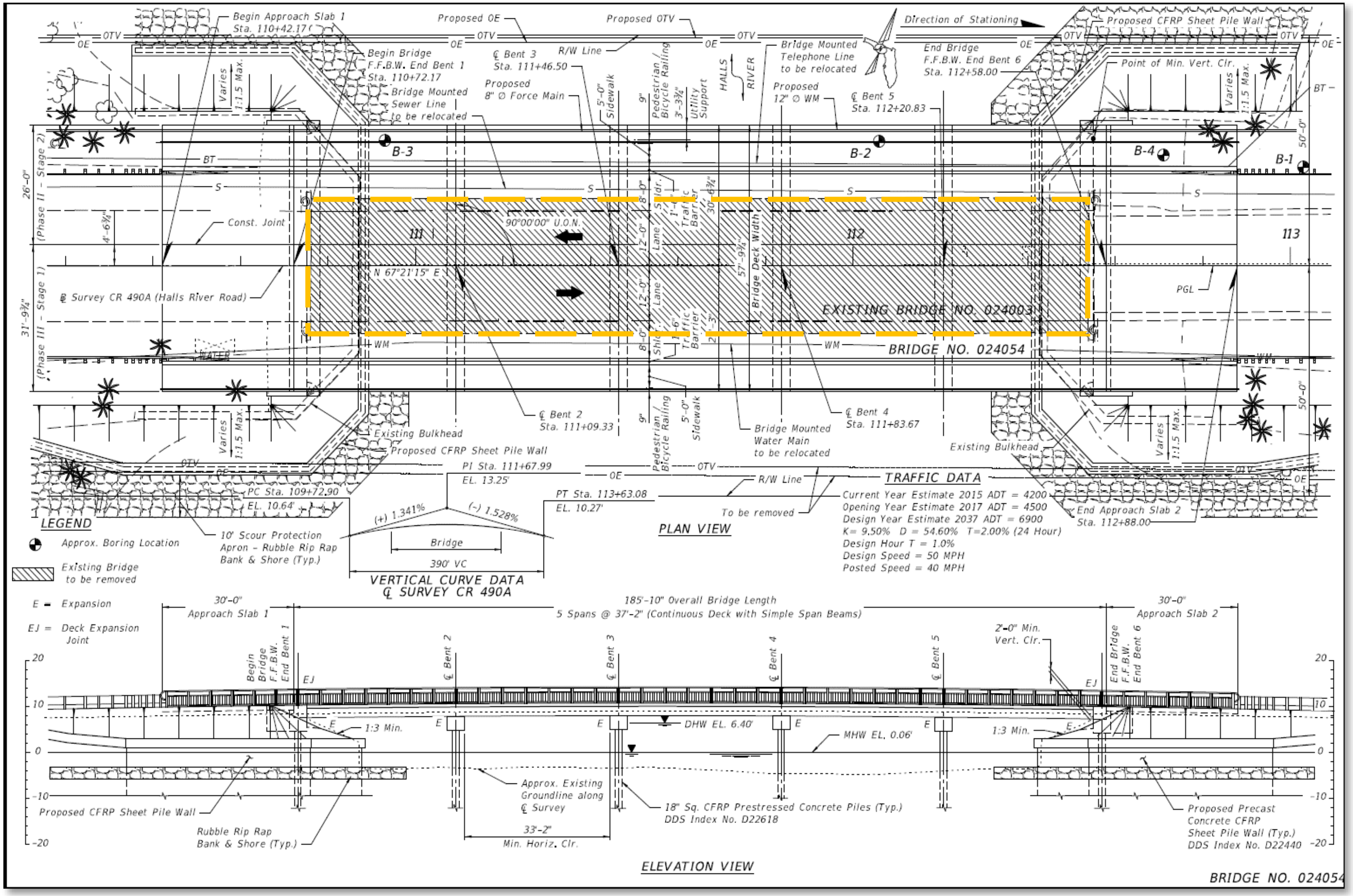
Ellie Schiller Homosassa Springs Wildlife State Park

Wild Manatees reside in the park year round.

Lu the hippo, honorary citizen of Florida since 1991.

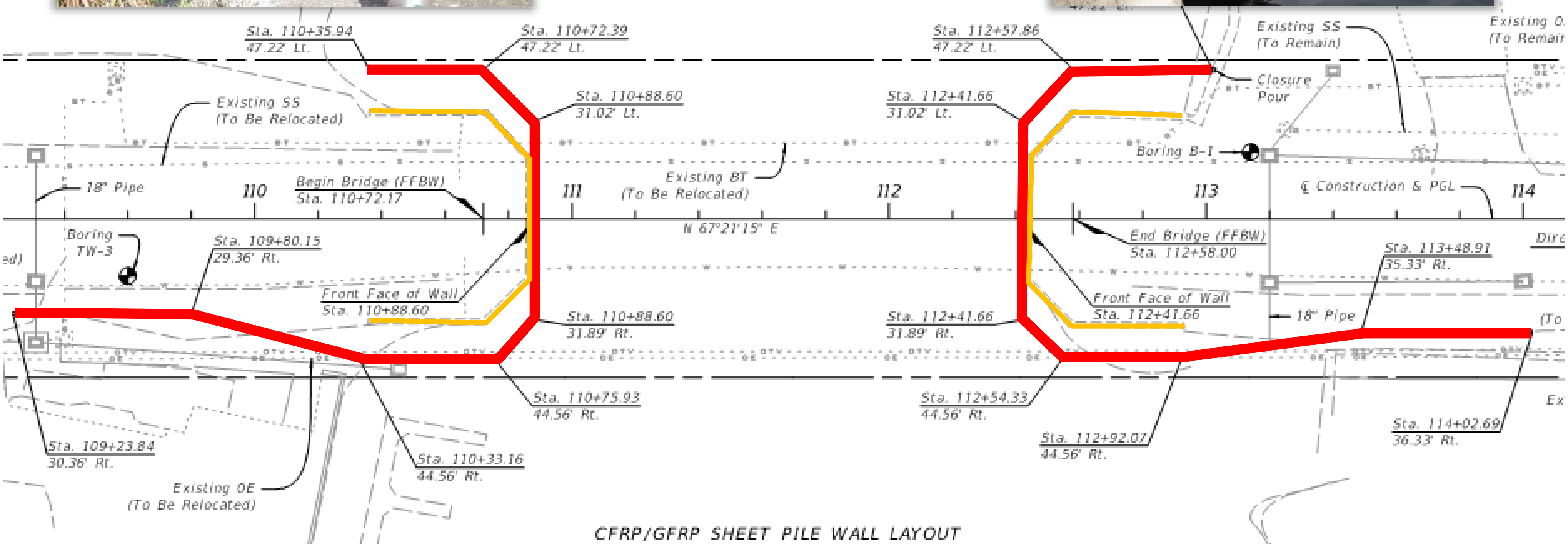
Vintage Postcard: "T.V.'S Gentle Ben makes his home at the Ivan Tors Animal Actors Training Academy here, and is on hand to greet visitors when not on filming location." *Homosassa Springs.*

Project Overview



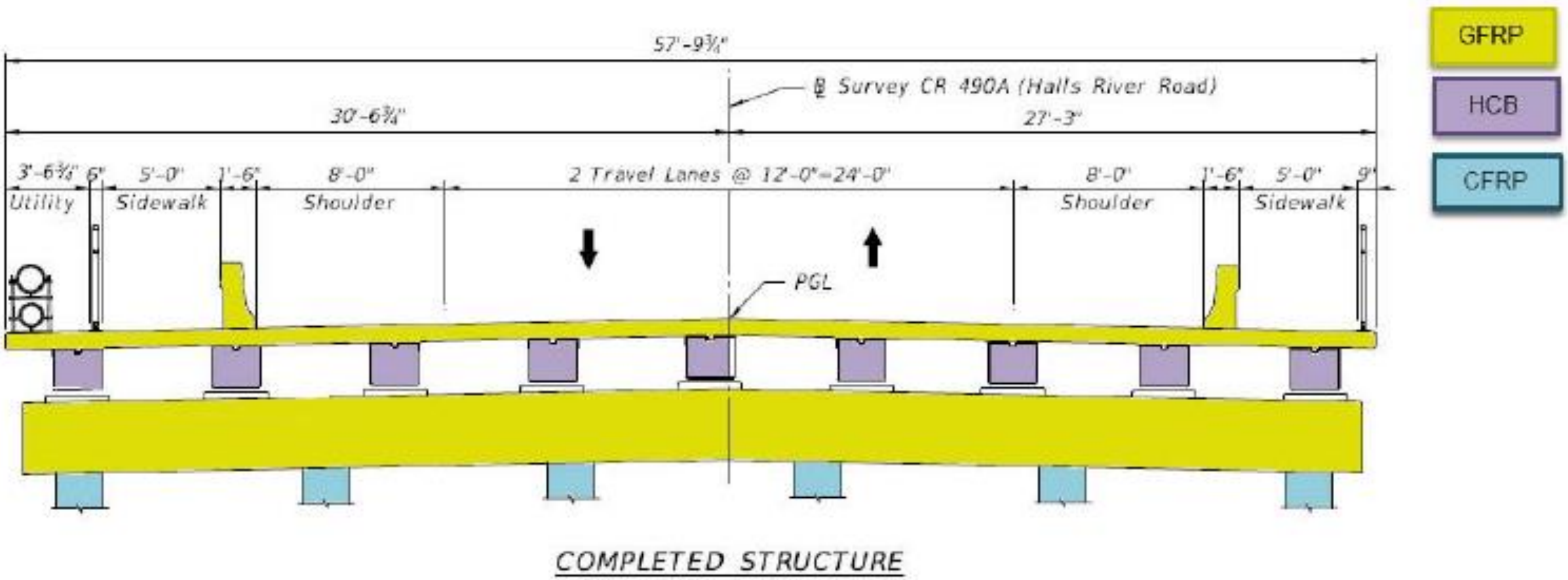
Existing (orange) and Proposed Layout

Project Overview



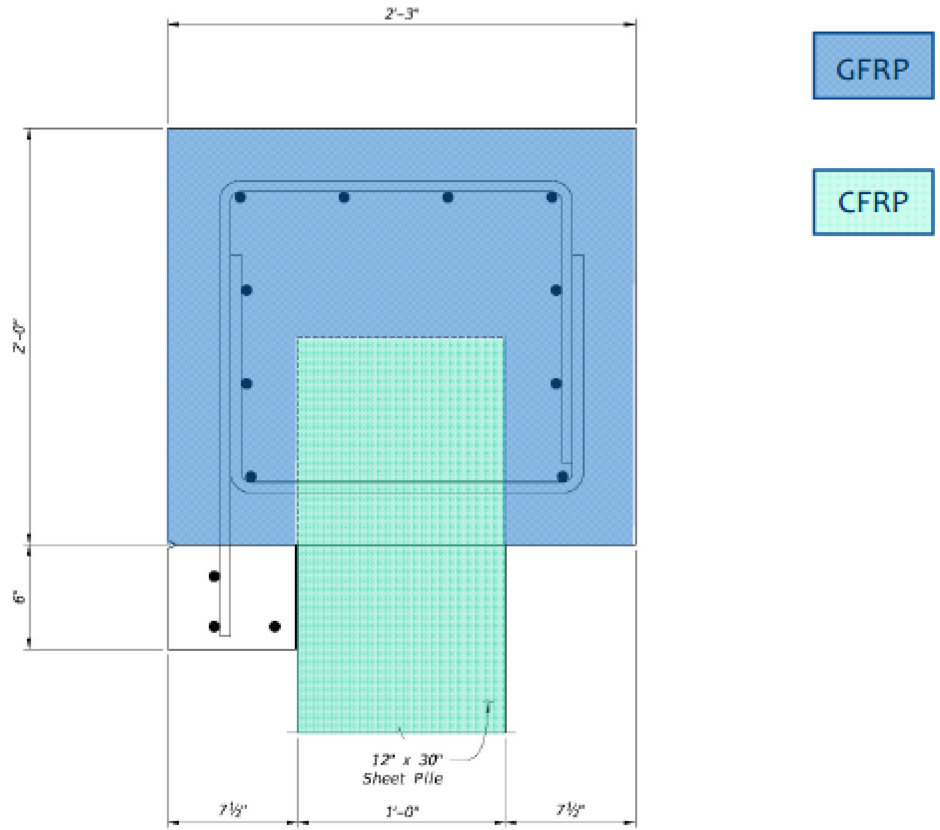
Existing (orange) and Proposed Bulkhead (Red) Layout

Project Overview



Project Overview

CFRP/GFRP Sheet Pile Walls



2. Hybrid Composite Beams (HCB)

Hybrid Composite Beams (HCB)

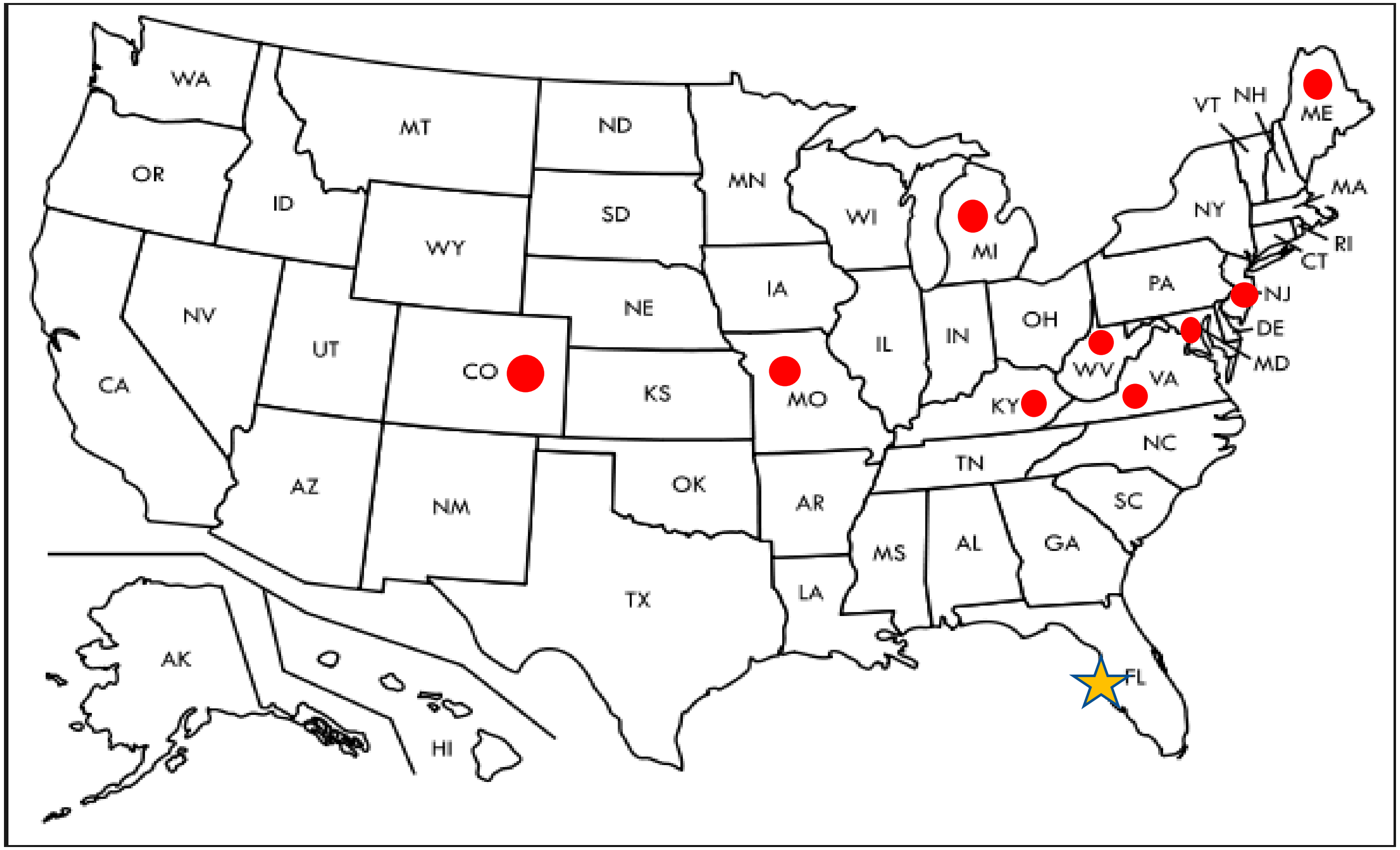
A. Overview
B. Components
C. Design
D. Specifications

Hybrid Composite Beams (HCB)

A. HCB Overview

   i. Proprietary Product background (Hillman Composite Bridge, Inc.)

   ii. Other Projects: DOT's (Maine, …), Railroads …



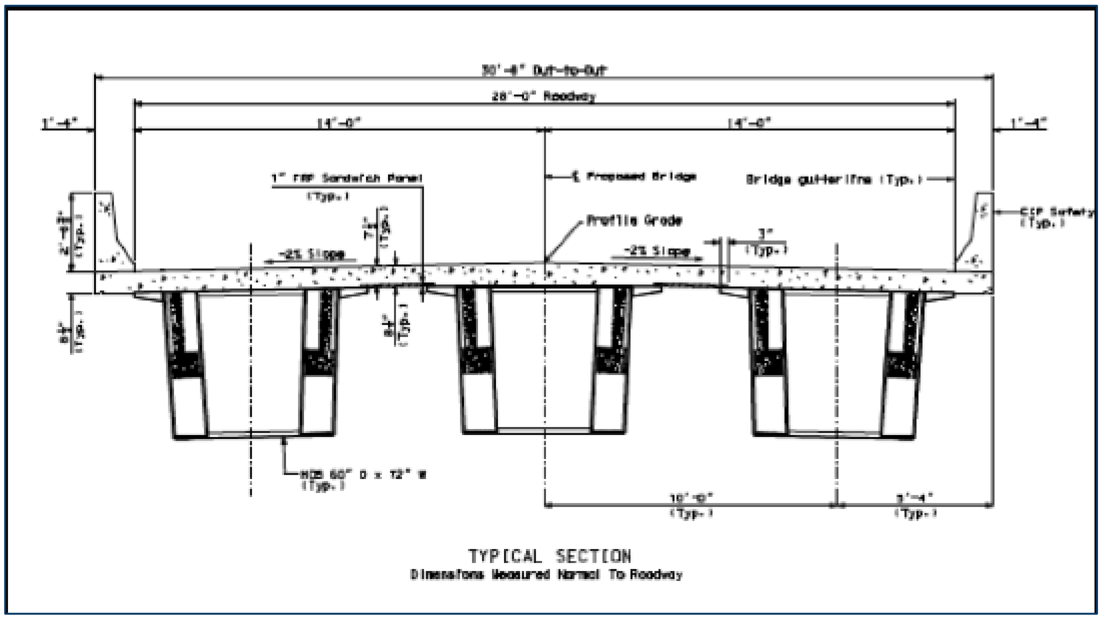
Source: HCB, Inc.

Hybrid Composite Beams (HCB)

A. HCB Overview

Other Projects: Double Web Box HCB – Missouri

- 60 in depth, 120 ft long



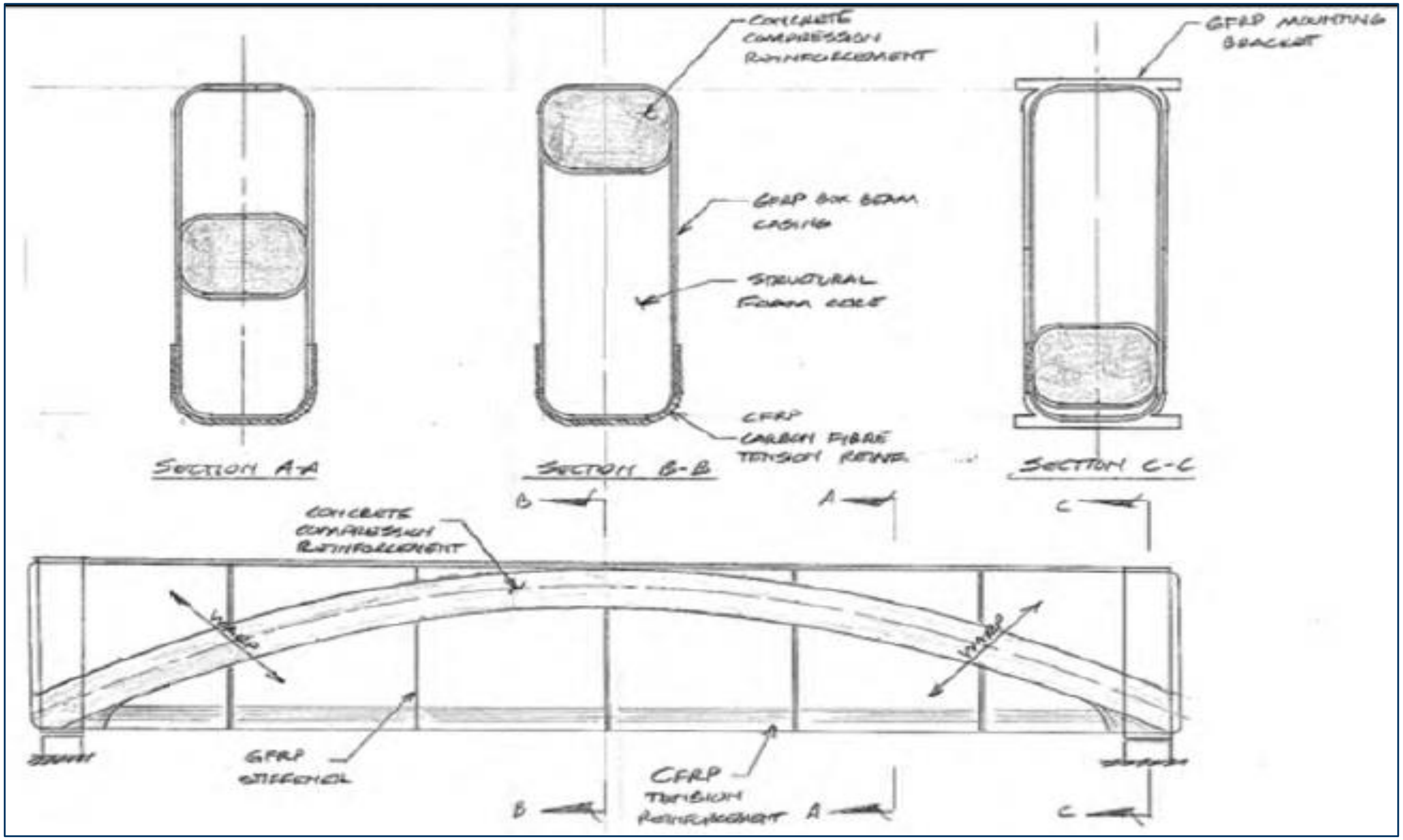
Source: HCB, Inc.

Source: HCB, Inc.

Hybrid Composite Beams (HCB)

A. HCB Overview

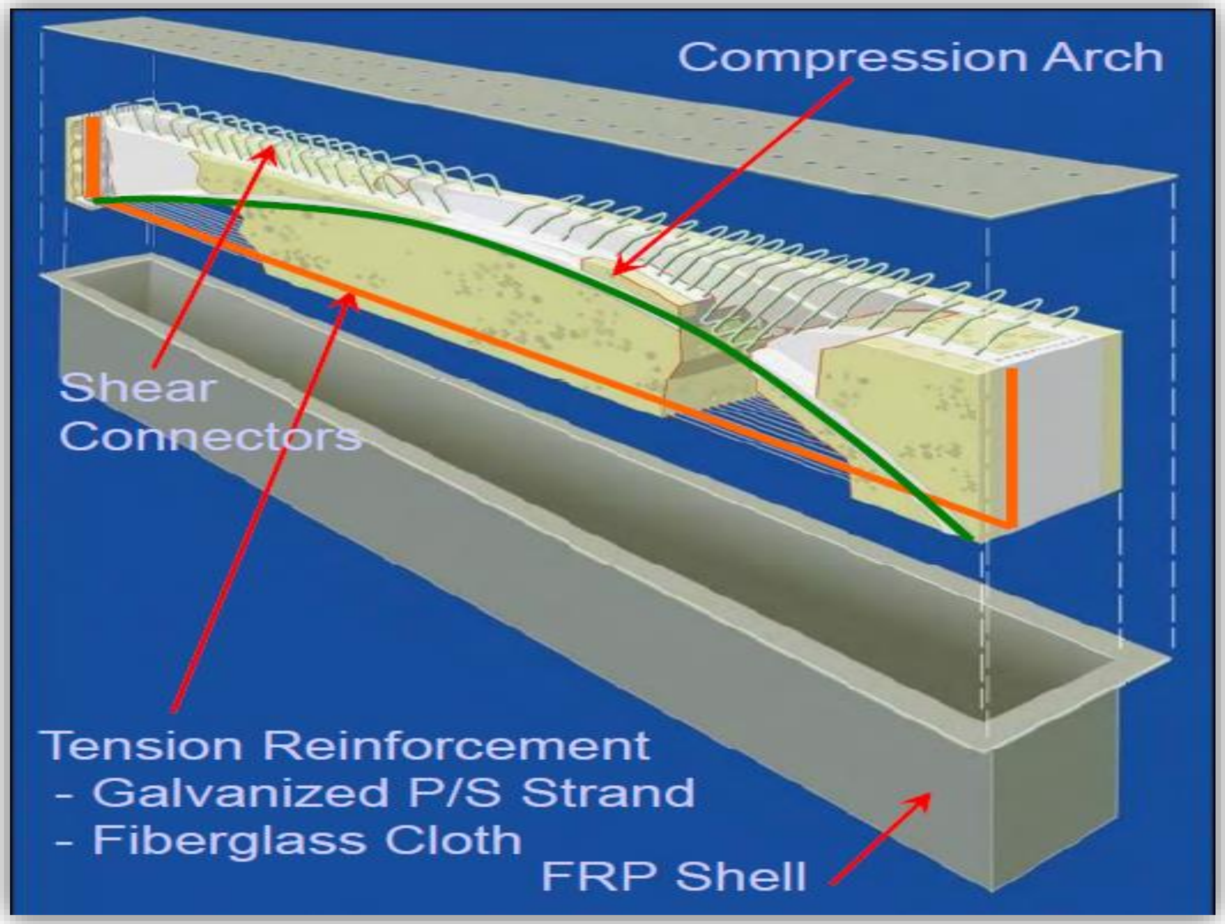
Original Sketches – 1996



Source: HCB, Inc.

Hybrid Composite Beams (HCB)

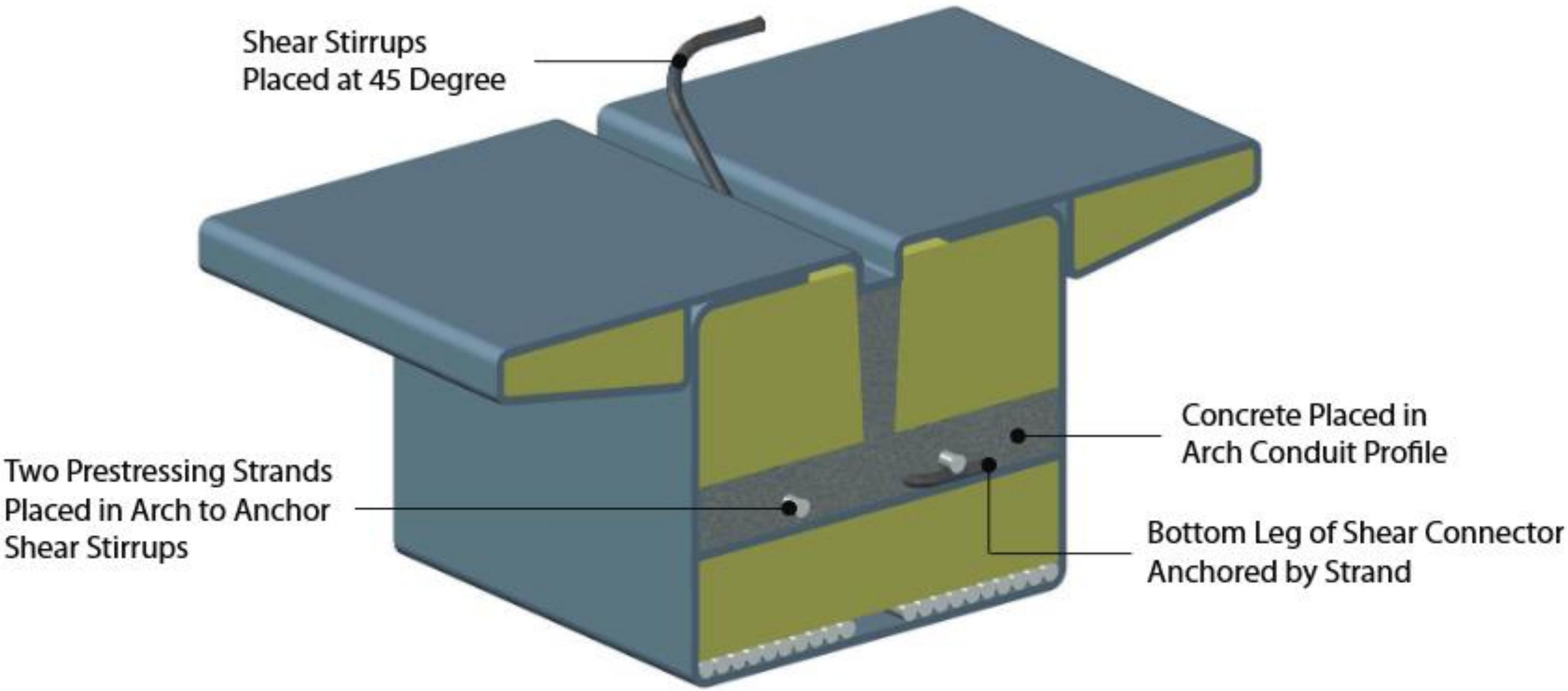
B. Components



HCB Design and Maintenance Manual (HCB, Inc.)

Hybrid Composite Beams (HCB)

B. Components



Virginia Tech –Tide Mill Bridge (Shainur)

Hybrid Composite Beams (HCB)

B. Components

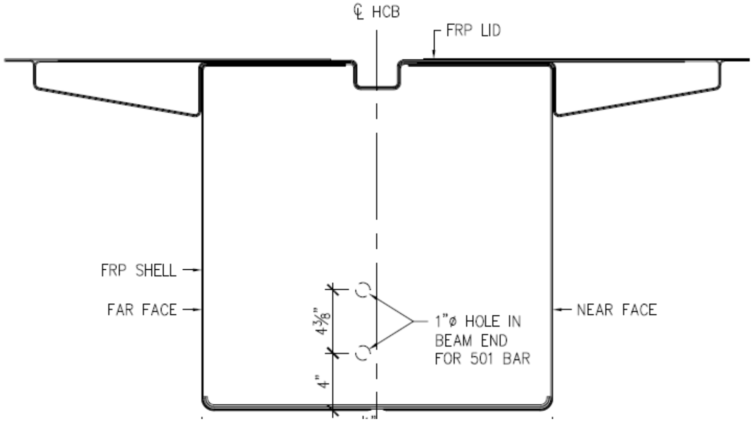
i. Wings vs. No wings

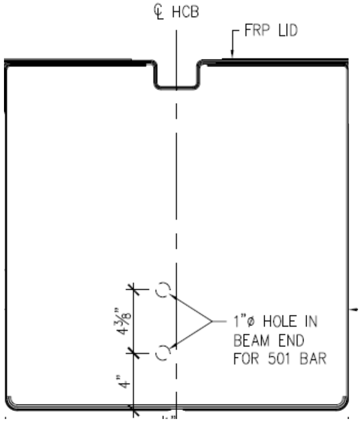
- Savings in HCB costs
- SIP Metal
- hangers and overhang brackets for overhang forming

ii. CIP compression arch

- Self-Consolidating Concrete (Dev346SCC)
- Ease of HCB Transport, Erection and Installation

HCB, Inc.





Hybrid Composite Beams (HCB)

B. Components

iii. Shell

- Glass + resin matrix
- 0°, 90° and ± 45° fibers orientation
- Mechanical Properties
  - **Rules of mixture** (micro-mechanics)
  - **Experimental** (ASTM panels tests)

iv. 0.5”ø, 7-wire low-lax galvanized strands, 270-ksi, unstressed

iii. Interface shear reinforcing

- MMFX → grade 60 → zinc-coated (galvanized)

Hybrid Composite Beams (HCB)

C. Design
   i. Beam cross section
   ii. Section Properties
   iii. Deflection
   iv. Camber
   v. Flexural Stress
   vi. Flexural Strength
   vii. Vertical Shear
   viii. Horizontal Shear
   ix. Fatigue
   x. Load Rating

Hybrid-Composite Beam (HCB®)
Design and Maintenance Manual

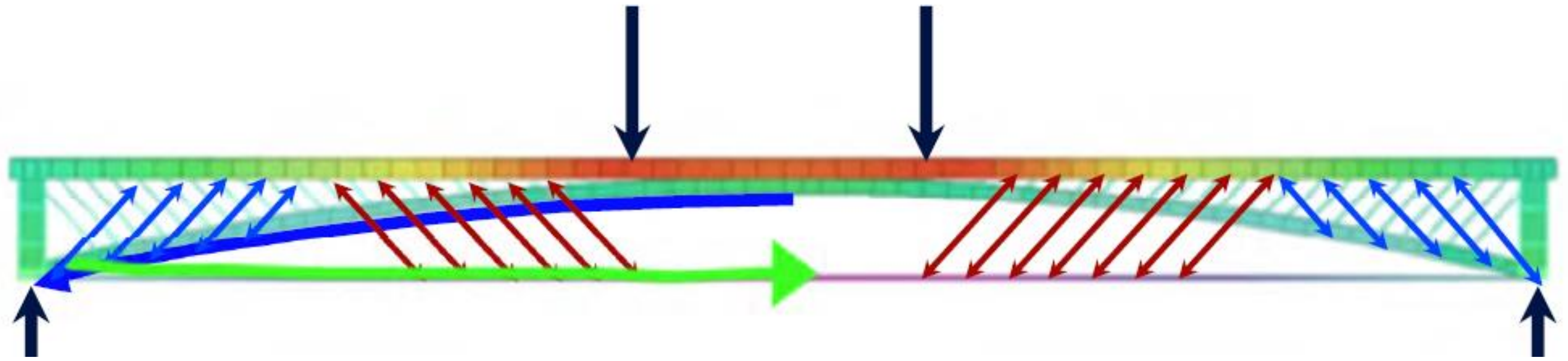
RTE 205 (RIDGE RD.)
Over Tide Mill Stream, Westmoreland Co.
State Project No.: 0205-096-101, B601
Federal Aid Project No.: BR-096-6(015)
NBIS No. 27818

Prepared for
The Virginia Department of Transportation

John R. Hillman, PE, SE
HCB, Inc.

Hybrid Composite Beams (HCB)

B. Typical Load Path



Source: HCB, Inc.

Hybrid Composite Beams (HCB)

C. Design

i. Beam cross section

- Depth: span/18 to span/25
- Width: depth/3 to depth/2
- Coordinate with HCB, Inc.

ii. Section Properties

- 10 points along beam
- All components transformed to equivalent FRP web

iii. Deflection

- Serviceability governs → LL deflections
- FRP materials → low elastic modulus → larger deflections
- Concrete + steel → used to meet deflection criteria

Hybrid Composite Beams (HCB)

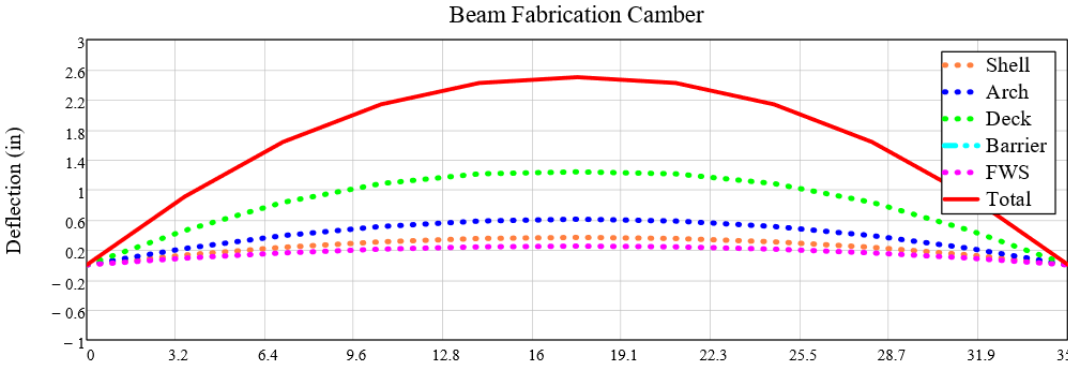
C. Design

iv. Camber

- Total = $^{shell}DL.camber_i + {}^{arch}DL.camber_i + \Delta Deck_i + \Delta SDL_i + \Delta allow_i$
- Allowance = 0.25" (creep and net positive camber)
- Check arch pour and deck casting stages

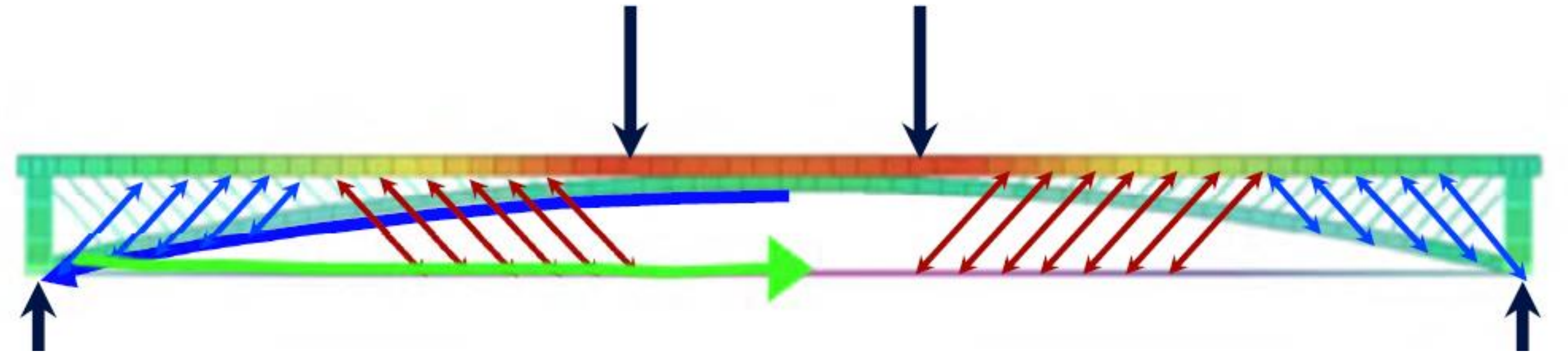
v. Flexural Stress

- Use individual moment inertia of each material
- Check construction stages: FRP shell, SW, SDL, LL
- Check service conditions



Hybrid Composite Beams (HCB)

B. Typical Load Path



Source: HCB, Inc.

Hybrid Composite Beams (HCB)

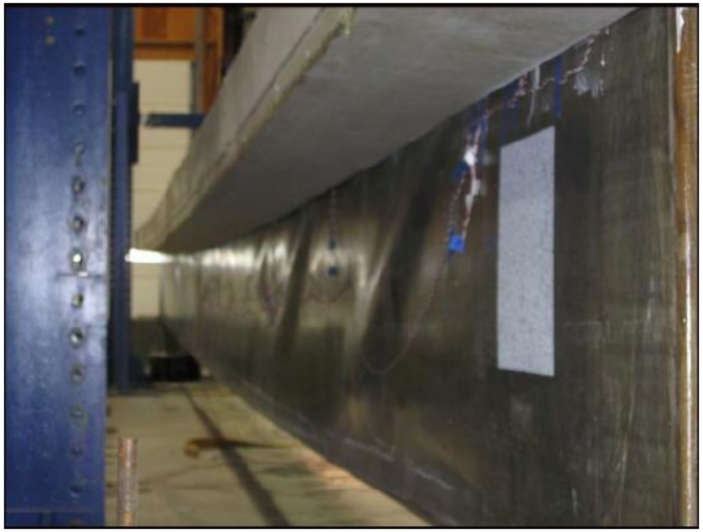
C. Design

vi. Flexural Strength

- Over-reinforced→ required steel from deflection criteria
- Strain compatibility method → moment strength
- Additional $\varphi = 0.9$ → FRP laminates (ACI 440.1)

vii. Vertical Shear → Virginia Tech Research

- Demand:
  - FRP Shell + Concrete
- Capacity:
  - FRP web
  - Concrete
- Beam casting check for FRP webs



Hybrid Composite Beams (HCB)

C. Design

viii. Horizontal Shear

- ACI Shear-Friction Method (ACI 318, 11.6.4)
- Connector capacity
- Coefficient of friction → steel beam with headed studs
  - 0.6 (roughness of FRP, conservative)
- Angle of inclination of shear connectors

ix. Fatigue

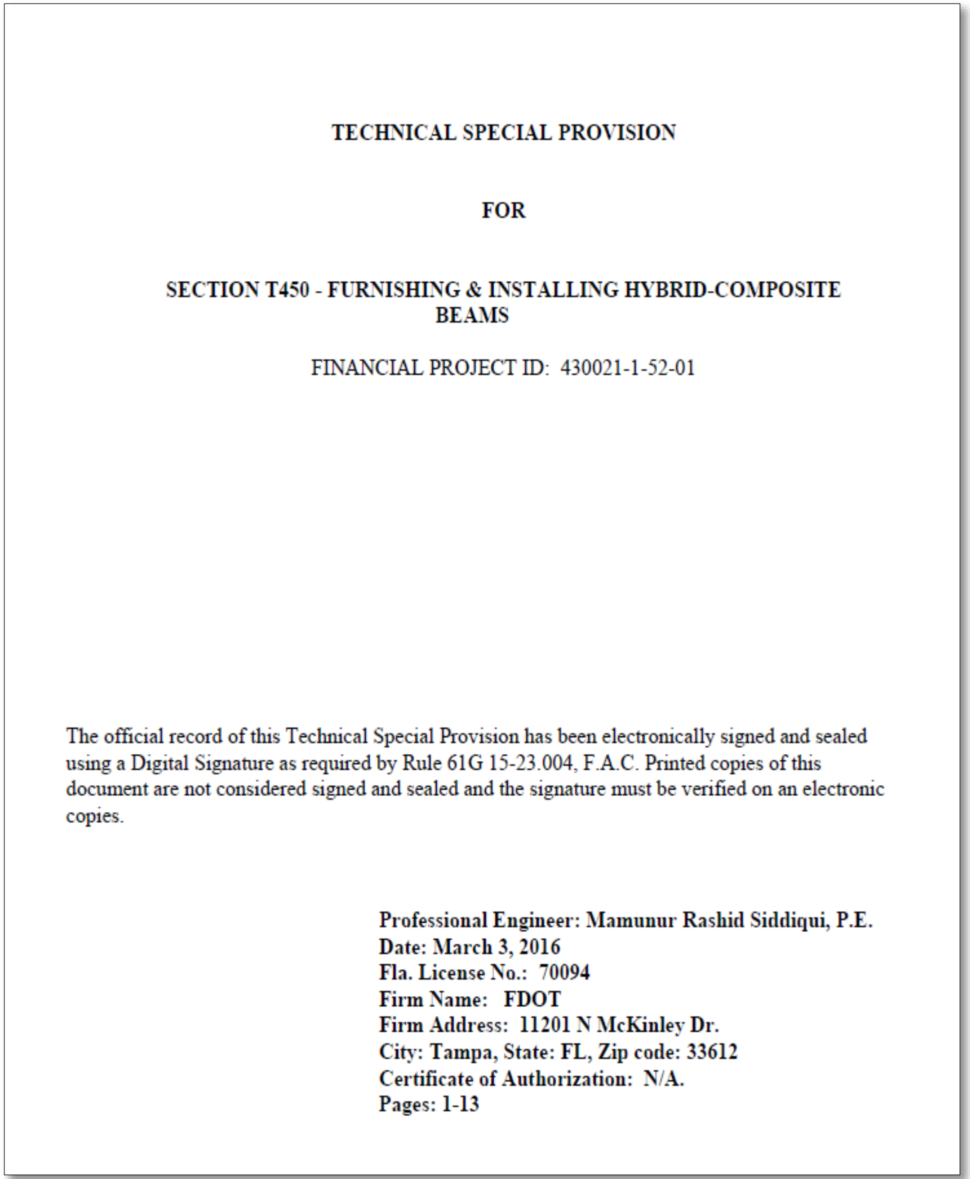
- Tested to Class 1 freight rail traffic → 500,000 to 2,000,000 cycles
- FRP and steel → Tensile stress ranges 10% ultimate capacities

x. Load Rating

- Similar to reinforced concrete beams

Hybrid Composite Beams (HCB)

D. Technical Special Provisions(TSP)



TECHNICAL SPECIAL PROVISION

FOR

SECTION T450 - FURNISHING & INSTALLING HYBRID-COMPOSITE BEAMS

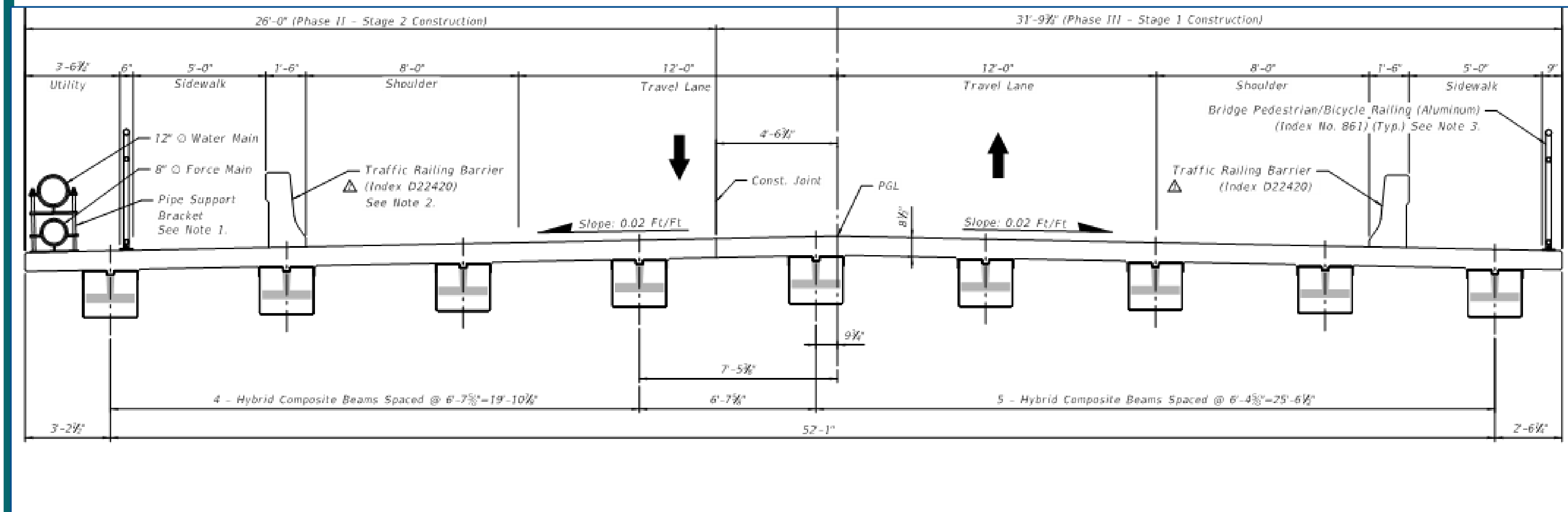
FINANCIAL PROJECT ID: 430021-1-52-01

The official record of this Technical Special Provision has been electronically signed and sealed using a Digital Signature as required by Rule 61G 15-23.004, F.A.C. Printed copies of this document are not considered signed and sealed and the signature must be verified on an electronic copies.

Professional Engineer: Mamunur Rashid Siddiqui, P.E.
Date: March 3, 2016
Fla. License No.: 70094
Firm Name: FDOT
Firm Address: 11201 N McKinley Dr.
City: Tampa, State: FL, Zip code: 33612
Certificate of Authorization: N/A.
Pages: 1-13

Hybrid Composite Beams (HCB)

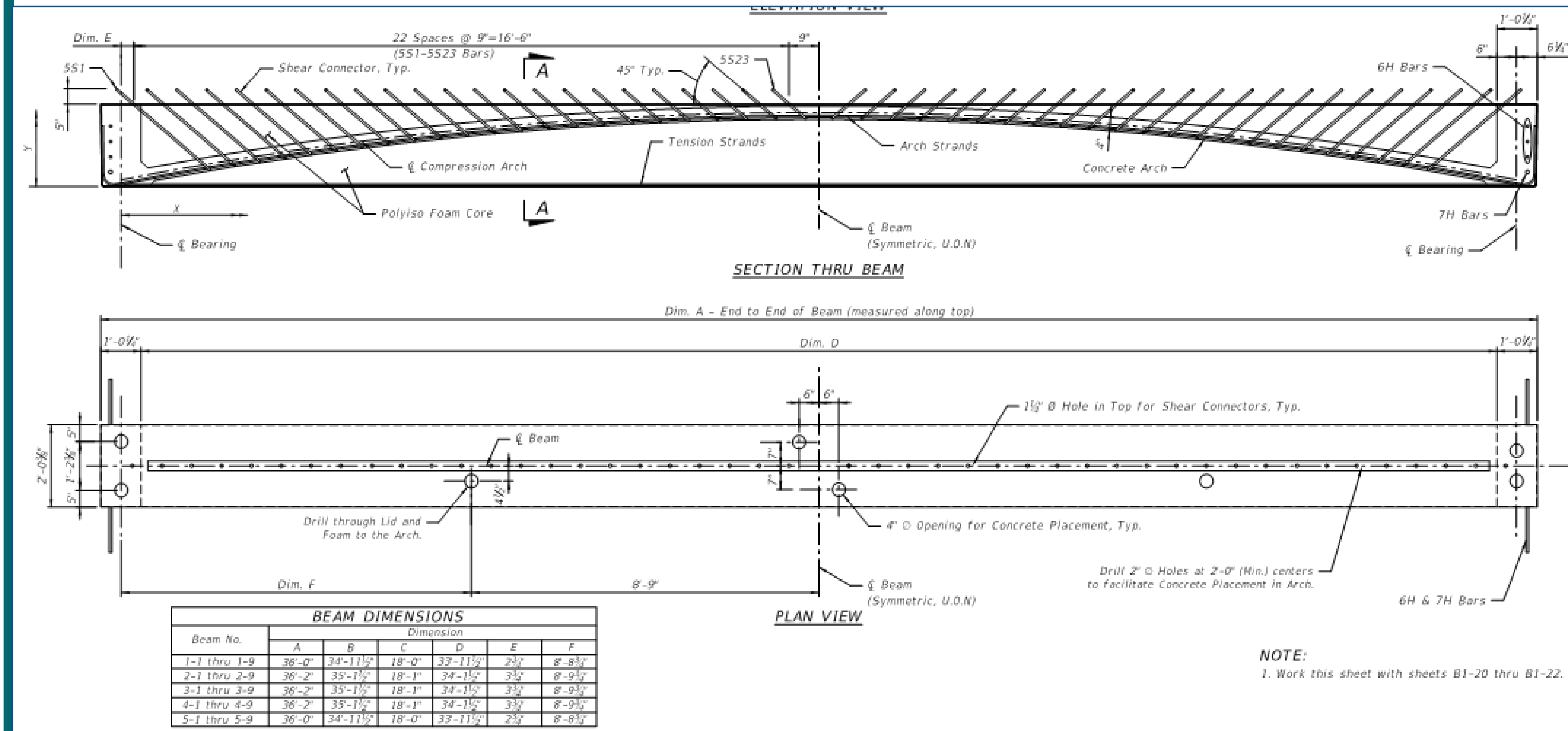
Example Plan Sheet Details:



TYPICAL SECTION THRU BRIDGE DECK

Hybrid Composite Beams (HCB)

Example Plan Sheet Details (cont.):



BEAM DIMENSIONS

Beam No.	Dimension					
	A	B	C	D	E	F
1-1 thru 1-9	36'-0"	34'-11½"	18'-0"	33'-11½"	2[illegible]"	8'-8[illegible]"
2-1 thru 2-9	36'-2"	35'-1½"	18'-1"	34'-1½"	3[illegible]"	8'-9[illegible]"
3-1 thru 3-9	36'-2"	35'-1½"	18'-1"	34'-1½"	3[illegible]"	8'-9[illegible]"
4-1 thru 4-9	36'-2"	35'-1½"	18'-1"	34'-1½"	3[illegible]"	8'-9[illegible]"
5-1 thru 5-9	36'-0"	34'-11½"	18'-0"	33'-11½"	2[illegible]"	8'-8[illegible]"

3. GFRP Reinforced Concrete

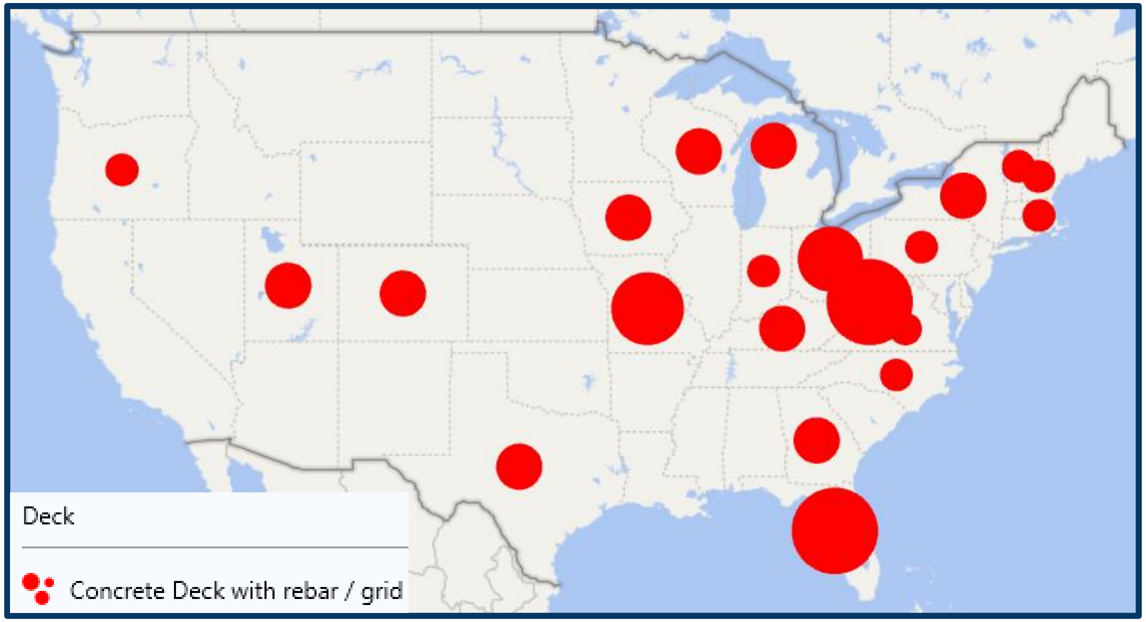
GFRP Reinforced Concrete

A. Overview
B. Components
C. Design
D. References, Codes and Specifications

(Photographs) Hughes Bros. *GFRP Bars*.

GFRP Reinforced Concrete

A. Overview
   i. Background
   ii. Other projects *(sourced from ACMA)*
      i. 67+ USA
      ii. 200+ Canada



Source: University of Miami

GFRP Reinforced Concrete

B. Components

i. RC Deck

ii. RC Bent Cap

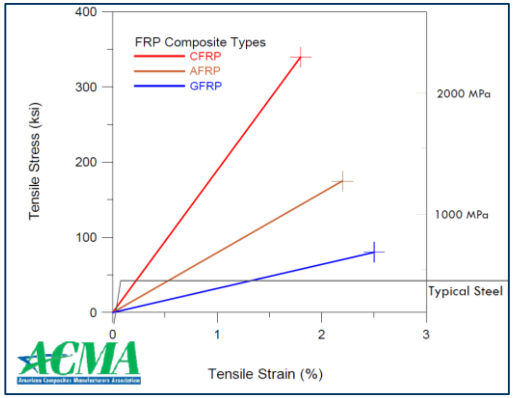
iii. RC Back and Wing Walls

iv. RC Diaphragms

GFRP Reinforced Concrete

C. Design - Principles:

i. Based on
- Equilibrium
- Compatibility of Strains
- Stress-strain characteristics of the material



ii. Brittle behavior of the FRP reinforcement

i. Linear-to-failure stress-strain relationships must be used

ii. Design mainly controlled by crack width, bond factor k_b or min reinforcement requirement, w_{lim}= 0.02 inch, k_b =0.9 to 1.4

GFRP Reinforced Concrete

C. Design – Failure Mode:

   i. If the FRP reinforcement ruptures, sudden and catastrophic failure can occur

   ii. Concrete crushing has typically been considered

   iii. The margin of safety against failure for FRP is higher than the conventional steel,

   iv. FRP reinforced sections are designed based on required strength considerations and check for creep rupture stress limits, and serviceability criteria

GFRP Reinforced Concrete

C. Design – FRP Rebar:

i. A direct substitution between FRP and steel reinforcement is not possible

- differences in the mechanical properties of the two materials
- f_{fu} =70ksi to 110ksi with reduction (Ce=0.7) used $f_{fd.pr.slab}$ =63ksi

ii. Modulus of elasticity much lower than steel, E_f = 6500ksi

iii. FRP reinforced concrete sections do not show ductility

i. Steel yield first → Ductile failure mode

iv. Resistance Factors:

- Flexure and tension: ϕ_f = 0.55 to 0.65
- Shear and torsion: ϕ_v = 0.75

GFRP Reinforced Concrete

C. Design - Deck *(AASHTO LRFD)-2009*

- Design Tensile strength and strain

$$f_{fd} = C_E f_{fu}$$

$$\varepsilon_{fd} = C_E \varepsilon_{fu}$$

Table 2.6.1.2-1—Environmental Reduction Factors

Exposure Condition	Environmental Reduction Factor, C_E
Concrete not exposed to earth and weather	0.80
Concrete exposed to earth and weather	0.70

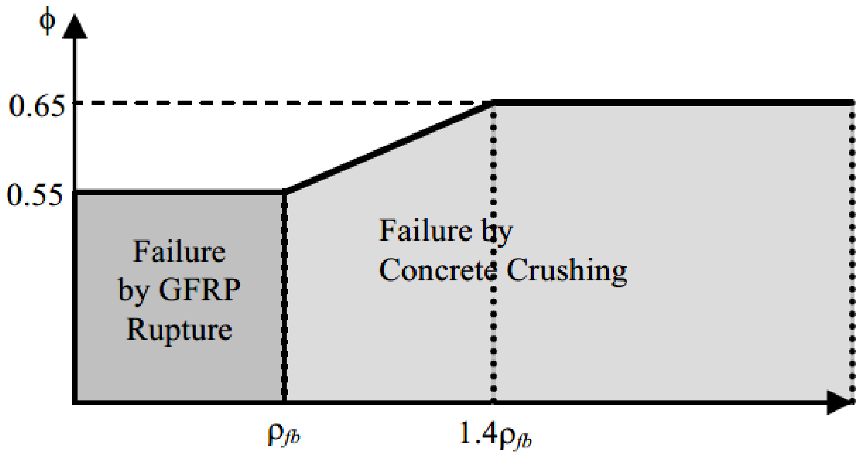
GFRP Reinforced Concrete

C. Design - Deck and Cap

- Resistance Factors

$$\phi = \begin{cases} 0.55 & \text{for} \quad \rho_f \le \rho_{fb} \\ 0.3 + 0.25\dfrac{\rho_f}{\rho_{fb}} & \text{for} \quad \rho_{fb} < \rho_f < 1.4\rho_{fb} \\ 0.65 & \text{for} \quad \rho_f \ge 1.4\rho_{fb} \end{cases}$$

$$\rho_{fb} = 0.85\beta_1 \frac{f_c'}{f_{fd}} \frac{E_f \varepsilon_{cu}}{E_f \varepsilon_{cu} + f_{fd}}$$



GFRP Reinforced Concrete

C. Design - Deck and Cap (ACI, AASHTO LRFD)

- Flexural Resistance (Rectangular sections)

When $\rho_f > \rho_{fb}$:

$$a = \frac{A_f f_f}{0.85 f_c' b} \qquad f_f = \sqrt{\frac{(E_f \varepsilon_{cu})^2}{4} + \frac{0.85\beta_1 f_c'}{\rho_f} E_f \varepsilon_{cu}} - 0.5 E_f \varepsilon_{cu} \le f_{fd}$$

$$M_n = A_f f_f \left(d - \frac{a}{2} \right)$$

When $\rho_f < \rho_{fb}$:

$$c_b = \left(\frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_{fd}} \right) d \qquad f_{fd} = C_E f_{fu}$$

$$M_n = A_f f_{fd} \left(d - \frac{\beta_1 c_b}{2} \right)$$

GFRP Reinforced Concrete

C. Design - Cap (ACI 440.1R)

- Shear Resistance

$$V_n = V_c + V_f$$

$$V_c = 0.16\sqrt{f_c'}\,b_w c \quad \text{not be larger than } 0.32\sqrt{f_c'}\,b_0 c$$

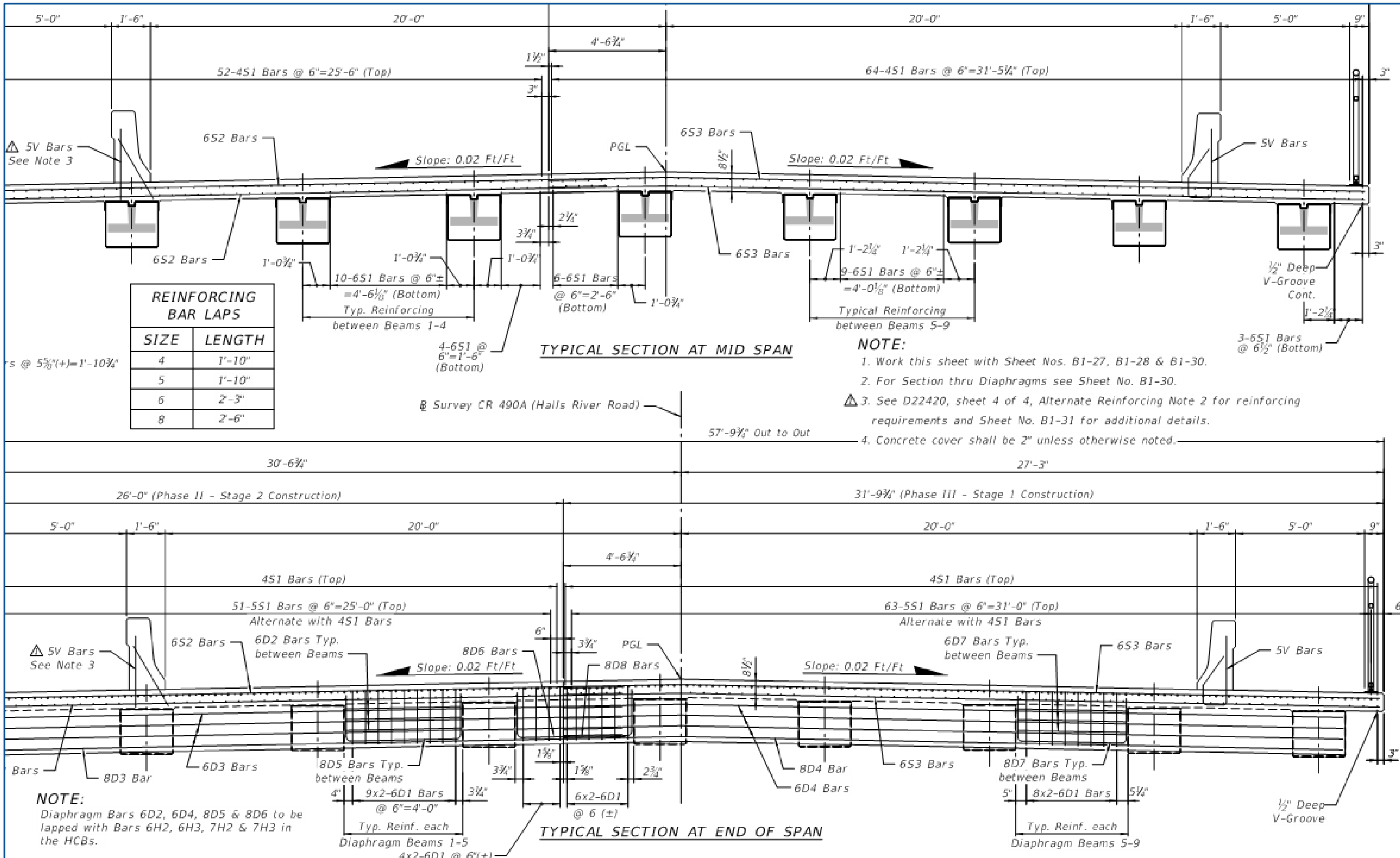
$$V_f = \frac{A_{fv} f_{fv} d}{s}$$

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

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

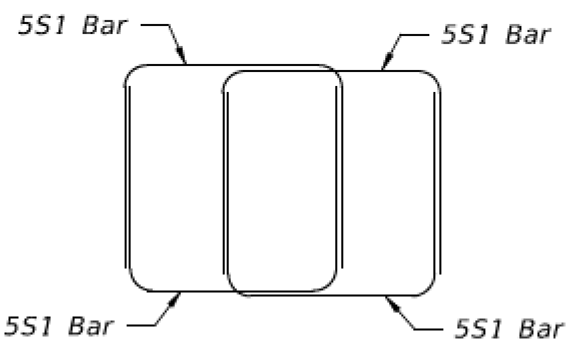
GFRP -RC Deck

Plan Sheet Details:

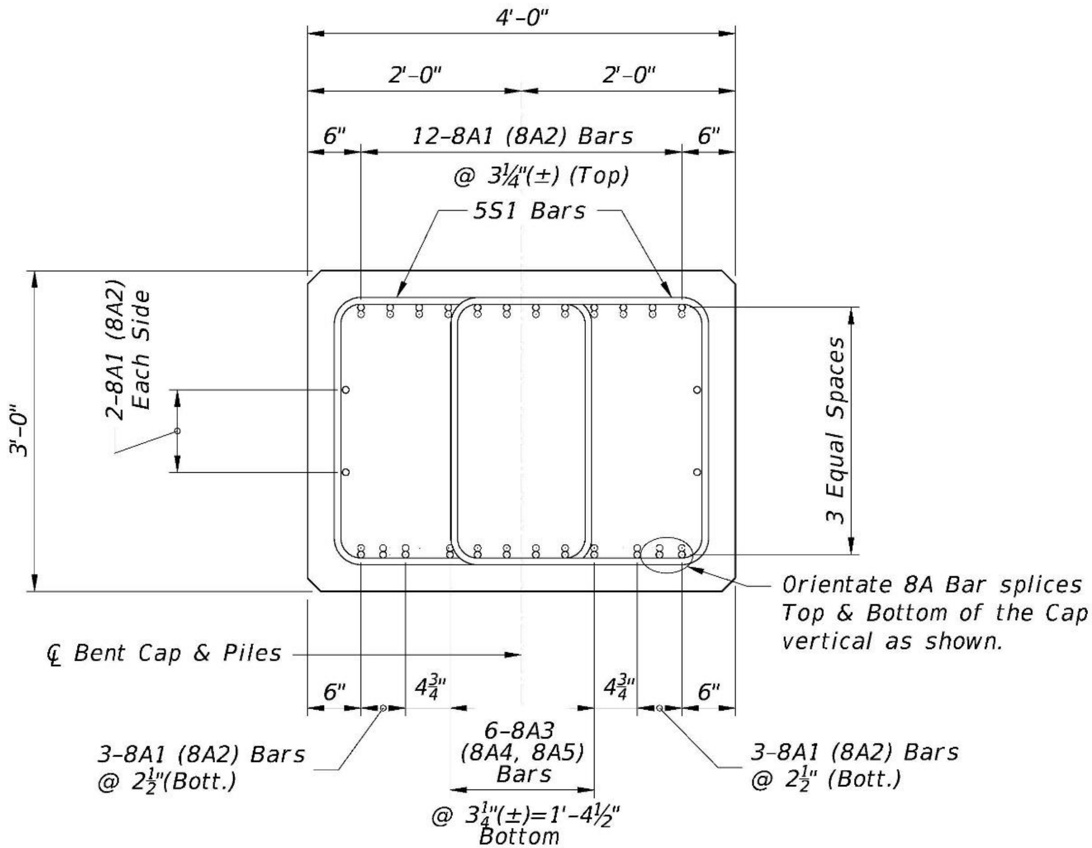


GFRP Reinforced Concrete

Plan Sheet Details:



5S1 BARS
Schematic Layout



SECTION A-A

GFRP Reinforced Concrete

D. References, Codes and Specifications

i. There are a limited number of standards and codes

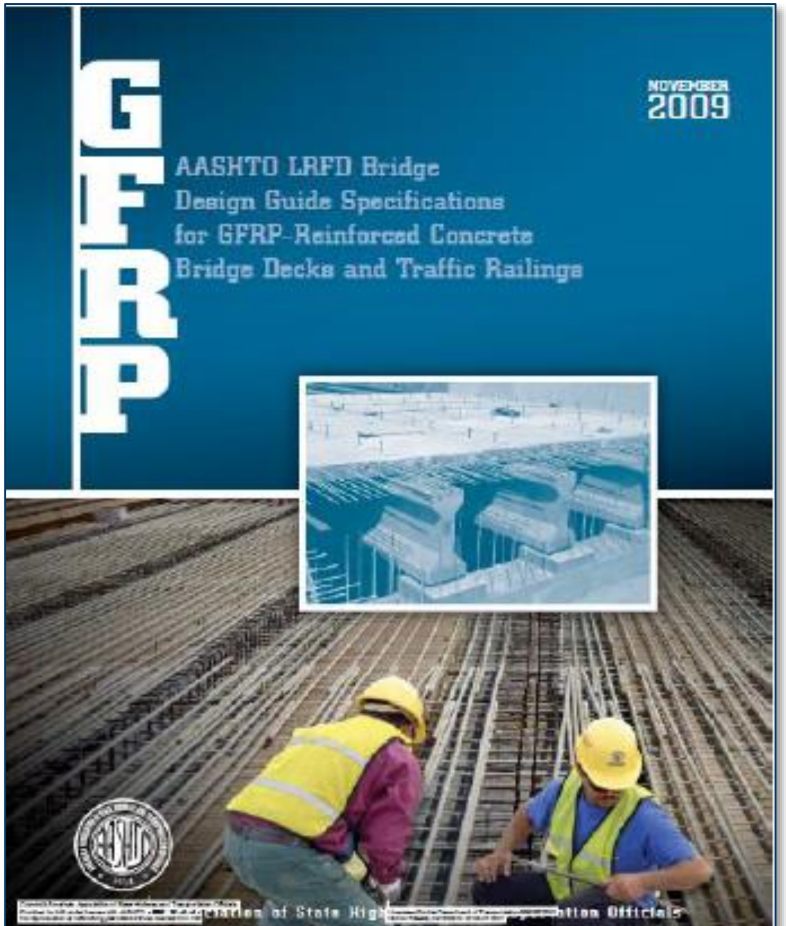
ii. The lack of accepted design guidelines and code language

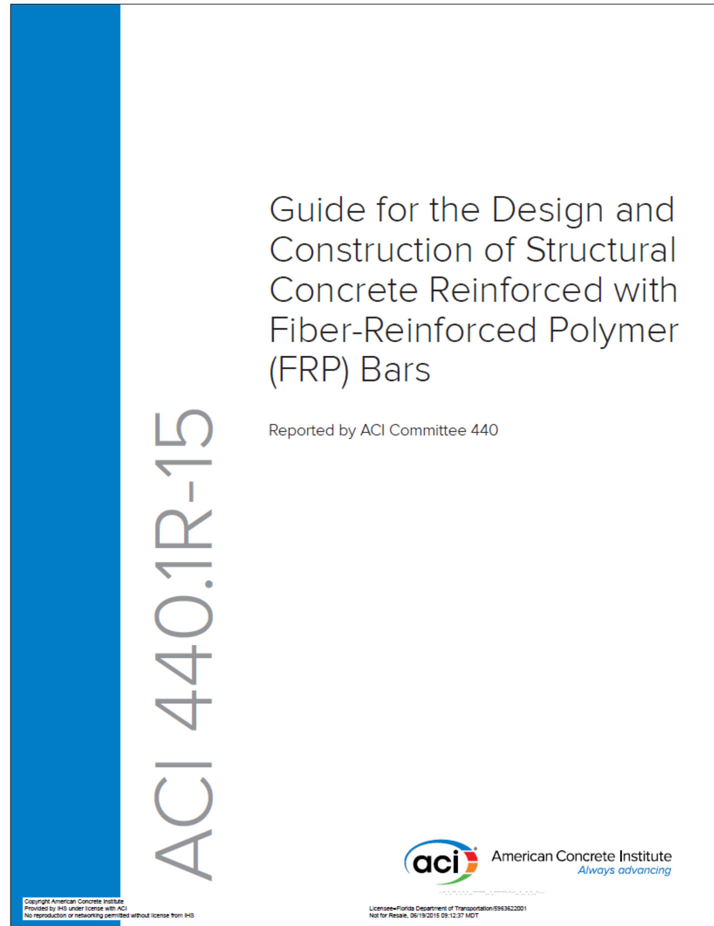
iii. Design Manuals:

- ***ACI 440.1R***
  - *Guide for the Design and Construction of Structural Concrete Reinforced with Fiber-Reinforced Polymer*
- ***AASHTO LRFD GFRP-2009***
  - *Design Guide Specifications for GFRP-Reinforced Concrete Bridge Decks and Traffic Railings*

GFRP Reinforced Concrete

D. References, Codes and Specifications





GFRP Reinforced Concrete

D. References, Codes and Specifications

iv. FDOT Manuals and Standards:

- ***FDOT SM Volume 4***
  - *Fiber Reinforced Polymer Guidelines (FRPG)*
- ***Material Manual Section 12.1 Volume II***
  - *Fiber Reinforced Polymer Composites*
- ***Developmental Design Standards***
  - *Square Piles, Sheet Piles, Traffic Railings, Approach Slabs, Bar Bending Details*

v. FDOT Developmental Specifications:

- ***Dev932***
  - *Nonmetallic Accessory Materials for Concrete Pavement and Concrete Structures*
- ***Dev933***
  - *Prestressing Strand (CFRP)*

GFRP Reinforced Concrete

D. References, Codes and Specifications

Specifications and Estimates/Specifications/

Materials Manual Section 12.1, Volume II

FIBER REINFORCED POLYMER COMPOSITES

Section 12.1, Volume II

2016

FDOT

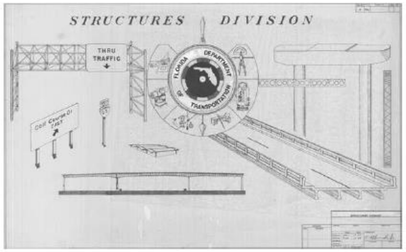
Design Standards

For Construction and Maintenance Operations on the State Highway System

Topic No. 625-010-003

State of Florida Department of Transportation
Office of Design
Mail Station 32
605 Suwannee Street
Tallahassee, Florida 32399-0450

FLORIDA DEPARTMENT OF TRANSPORTATION



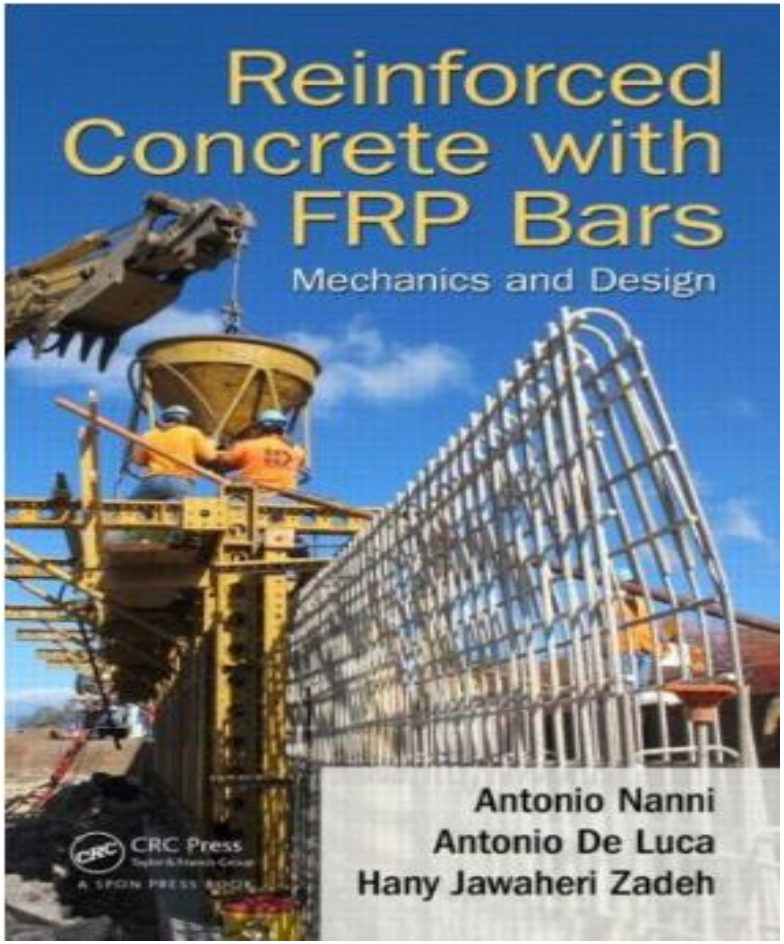
FIBER REINFORCED POLYMER GUIDELINES (FRPG)

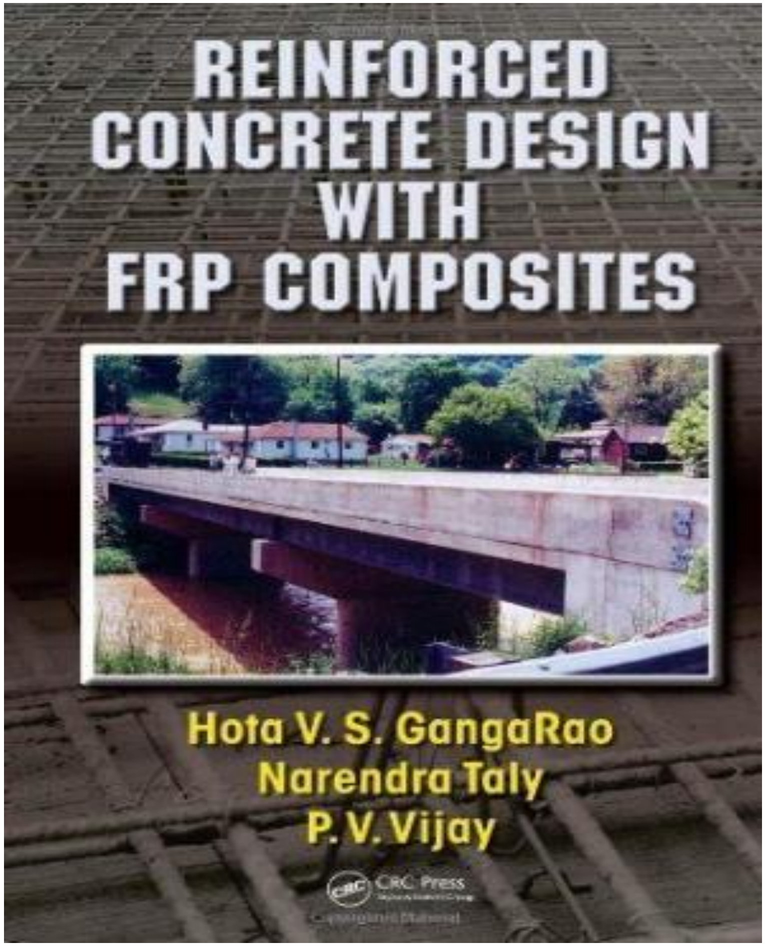
FDOT STRUCTURES MANUAL
VOLUME 4
JANUARY 2016

FDOT

GFRP Reinforced Concrete

D. References, Codes and Specifications

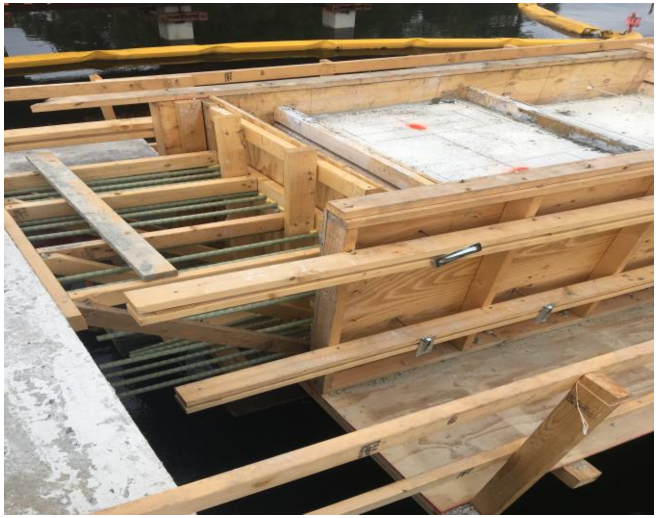




4. Challenges

Challenges

A. HCB
  i. Proprietary product
  ii. Design Criteria
  iii. Inspection for closed system
  iv. Durability verification
  v. Fabrication QA/QC



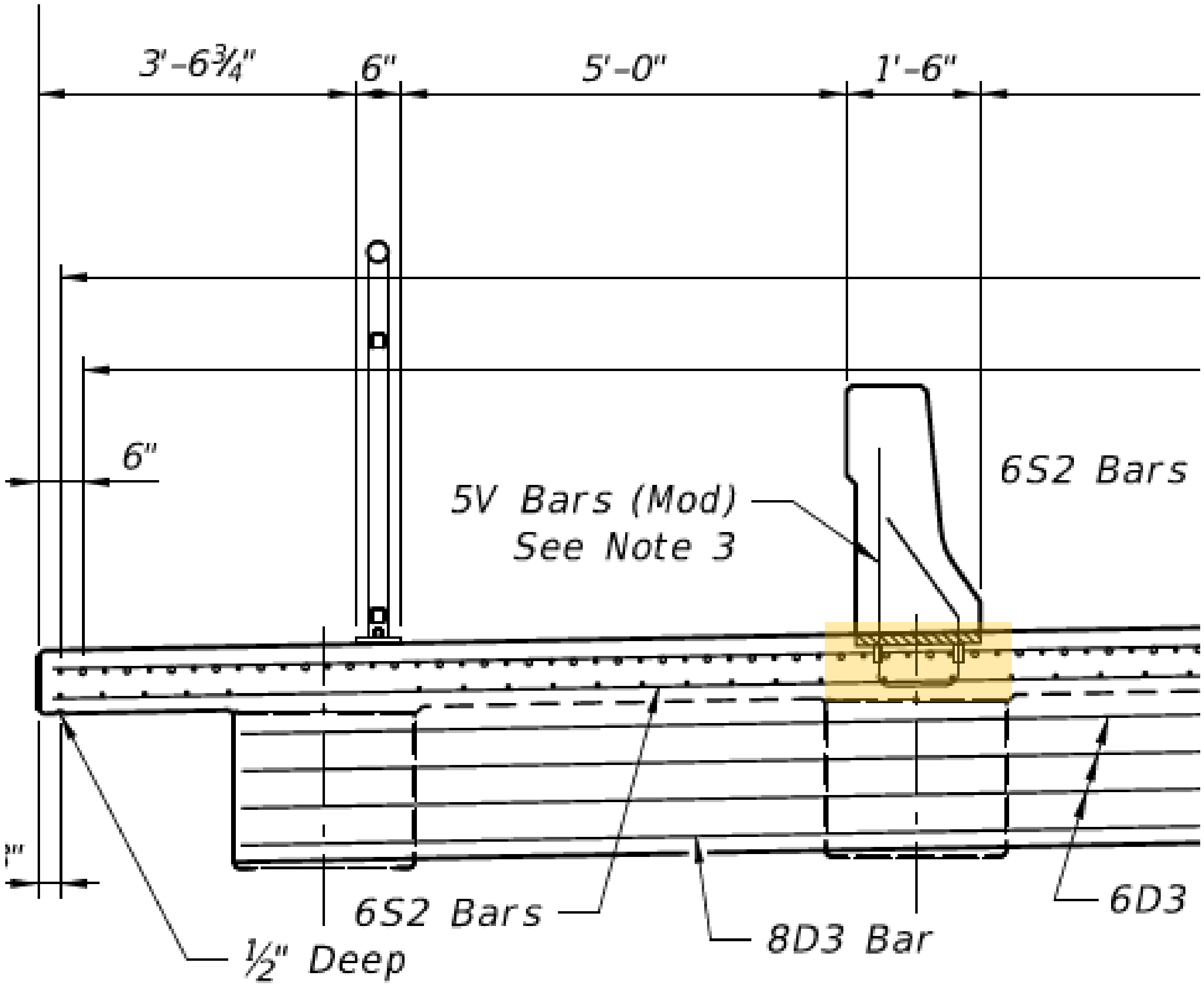
B. GFRP Reinforced Concrete
  i. Lap Splice: deck, cap, and diaphragm
  ii. Rebar unit price
  iii. Reinforcing Bar List

REINFORCING BAR LAPS	
SIZE	LENGTH
4	1'-10"
5	1'-10"
6	2'-3"
8	2'-6"

C. Funding and Costs
  i. FHWA and County

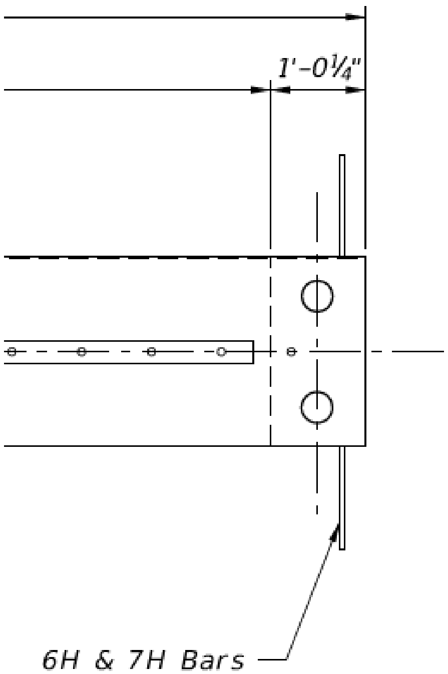
Challenges

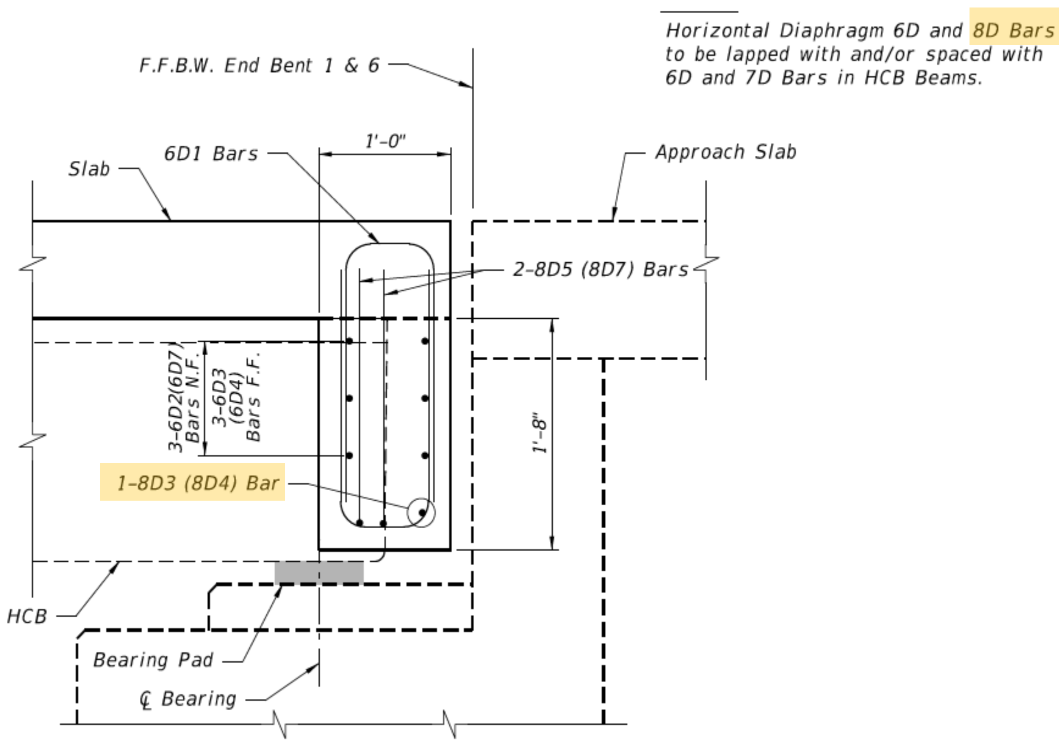
Plan Sheet Details post Installed Traffic Railing:



Challenges

Diaphragms Plan Sheet Details:





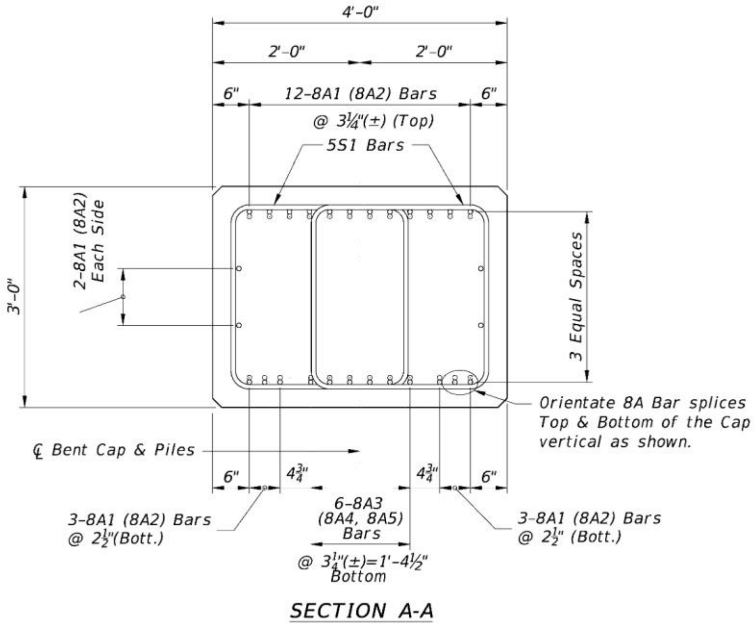
SECTION AT END DIAPHRAGM

END BENTS 1 & 6

5. Lessons Learned

Lessons Learned

- To develop standard details and specifications
- Design for Phase Construction
- Rebar arrangement – no mechanical coupler
- Lead time, Sole source of CFCC (Tokyo Rope)
- HCB QA/QC plan
- Sheet pile wall driving
- Pile capacity



Summary

- **Demonstration Project with Innovative Materials – First in Florida**
  - ✓ Superstructure: Hybrid Composite Beams; GFRP Bars: Deck, Barriers & Approach Slabs
  - ✓ Substructure: CFRP Pre-stressed Piles; Bent Caps: GFRP Bars
  - ✓ Sheet Pile Walls: CFRP/GFRP Sheet Piles; Wall Cap: GFRP Bars

- **Contractor Bid Cost - $6.016 Million (Structures = $4.06 Million)**
  - Bridge Cost = **$218 / sq. ft.**

    (Conventional Construction = **$166 / sq. ft.**)

- **Accelerated Construction**
  - Lighter Materials – Beams and Rebar
  - Faster Transportation and Delivery – reduced construction time

Questions ?

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