Design of First FRP Reinforced Concrete Bridge in Florida

Halls River Project

Presenters

FDOT District 7 Structures Design Office:

- Elisha Masséus, P.E.
  Structures Design Engineer
- David Pelham
  Structures Designer & D7 Geotechnical Coordinator
- Cristina Suarez
  Structures Designer

Outline

- Introduction
  - Corrosion Issue
  - Fiber Reinforced Polymer (RFP) Reinforcing
  - Prevention Methods
  - References
- Halls River Project
  - Project Overview
  - Construction

Introduction

- Corrosion Issues
- FRP (Fiber Reinforced Polymer) Reinforcing
- Prevention Methods
- References

Corrosion Issues

- Corrosion of steel reinforcing
  - Premature deterioration of concrete structures
  - Reduction in capacity and service life
  - High costs for rehabilitation and/or replacement




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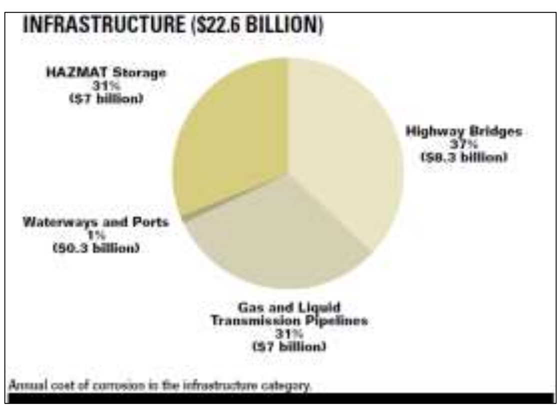
Corrosion Costs



Source: "Costs & Preventive Strategies in the U.S.", FHWA/NACE 2002

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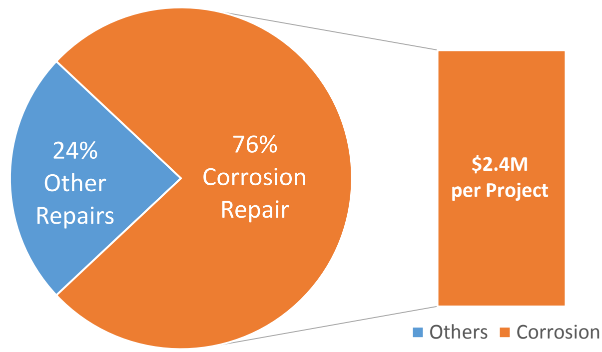
Corrosion Costs

District 7 (FY 02/03 to Present)

54 Total projects:
- 20 Steel
- 34 Concrete



Source: FDOT D7 District Structures Maintenance Office (DSMO) & T.Y. Lin

Corrosion Issues

- Concrete Alkalinity:
  - Provides initial corrosion protection for steel bars
  - Reduces in aggressive environments
    - Highway Deicers
    - Marine/Coastal Environments
    - Contaminated soils (high chloride/sulfate concentration)
- Concrete Cracks:
  - Due to shrinkage, creep, temperature, settlement, etc.
  - Localized corrosion (where crack intersects rebar)

Prevention Methods

- Existing Concrete Structures
  - Pile Jacket
  - FRP Wrapping
  - Cathodic Protection
- New Concrete Structures
  - Adequate Concrete Cover
  - Concrete Quality
  - Corrosion Inhibiting Admixtures
  - Prefabricated FRP beam: **Hybrid Composite Beam**
  - Alternative Reinforcements
    - Galvanized
    - ECR
    - Z-bar
    - Stainless
    - Epoxy
    - FRP

FRP Reinforcing

- FRP Bar: Fiber-Reinforced Polymer rebar
- Rebar made of fibers embedded in polymeric resin
  - Superior to either component alone
  - Each component retains its own chemical and physical properties

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FRP Reinforcing

- Fibers purpose:
  - Strength
  - Stiffness
  - Toughness
  - Durability
- Resin purpose:
  - Holds fibers together
  - Protects fibers from environment/abrasion
  - Transfers load between fibers (shear)

FRP Reinforcing

- Fiber types:
  - ✓Glass
  - Carbon
  - Aramid
  - Basalt

Preferred choice for RC applications:
- Balance between cost and strength

- Resin (Thermoset) types:
  - ✓Vinyl ester
  - Polyester
  - Epoxy

Preferred choice for RC applications:
- Good alkali resistance
- Good adhesion to concrete

FRP Reinforcing

Advantages:

- Corrosion Resistant
- High Strength
- Lightweight
- Fatigue Endurance
  - Aramid FRP bars susceptible to fatigue
- Nonmagnetic
- Low Thermal and Electrical Conductivity

FRP Reinforcing

Main Disadvantages:

- High initial cost
- Brittle failure

FRP Reinforcing

Design Considerations:

- Low shear strength relative to tensile strength
- Low modulus of elasticity
- Creep under sustained loading
- Elevated Temperature
- Moisture
- Ultra-Violet Radiation

FRP Reinforcing

Factors Affecting Material Properties:

- Fiber type
- Fiber volume ratio
- Fiber orientation
- Manufacturing process and quality control
- Rate of resin curing
- Temperature
- Void content

FRP Reinforcing

Table 5.2—ASTM standard reinforcing bars

Bar size designation		Nominal diameter, in. (mm)	Area, in.^{2} (mm^2)
Standard	Metric conversion		
No. 2	No. 6	0.250 (6.4)	0.05 (31.6)
No. 3	No. 10	0.375 (9.5)	0.11 (71)
No. 4	No. 13	0.500 (12.7)	0.20 (129)
No. 5	No. 16	0.625 (15.9)	0.31 (199)
No. 6	No. 19	0.750 (19.1)	0.44 (284)
No. 7	No. 22	0.875 (22.2)	0.60 (387)
No. 8	No. 25	1.000 (25.4)	0.79 (510)
No. 9	No. 29	1.128 (28.7)	1.00 (645)
No. 10	No. 32	1.270 (32.3)	1.27 (819)
No. 11	No. 36	1.410 (35.8)	1.56 (1006)

Source: ACI 440.1R

FRP Reinforcing

Table 3.1—Typical densities of reinforcing bars, lb/ft^3 (g/cm^3)

Steel	GFRP	CFRP	AFRP
493.00 (7.90)	77.8 to 131.00 (1.25 to 2.10)	93.3 to 100.00 (1.50 to 1.60)	77.80 to 88.10 (1.25 to 1.40)

Source: ACI 440.1R

FRP Reinforcing

Table 5.1—Minimum modulus of elasticity, by fiber type, for reinforcing bars

	Modulus grade, × 10^3 ksi (GPa)
GFRP bars	E5.7 (39.3)
AFRP bars	E10.0 (68.9)
CFRP bars	E16.0 (110.3)

Source: ACI 440.1R

FRP Reinforcing

Table 3.2—Typical coefficients of thermal expansion for reinforcing bars*

Direction	CTE, × 10^{-6}/°F (× 10^{-6}/°C)			
	Steel	GFRP	CFRP	AFRP
Longitudinal, α_L	6.5 (11.7)	3.3 to 5.6 (6.0 to 10.0)	–4.0 to 0.0 (–9.0 to 0.0)	–3.3 to –1.1 (–6 to –2)
Transverse, α_T	6.5 (11.7)	11.7 to 12.8 (21.0 to 23.0)	41 to 58 (74.0 to 104.0)	33.3 to 44.4 (60.0 to 80.0)

*Typical values for fiber volume fraction ranging from 0.5 to 0.7.

Source: ACI 440.1R

FRP Reinforcing

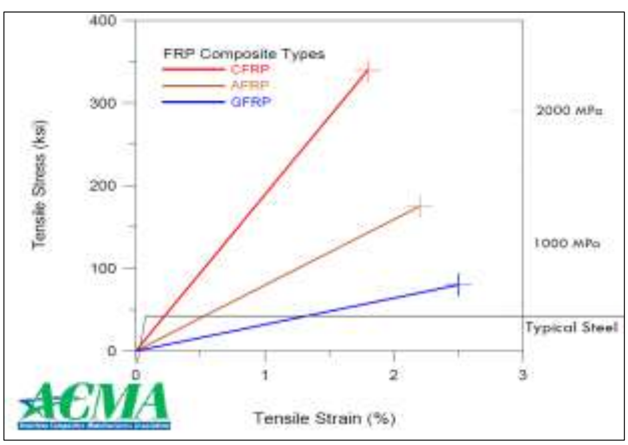
Table 3.3—Usual tensile properties of reinforcing bars*

	Steel	GFRP	CFRP	AFRP
Nominal yield stress, ksi (MPa)	40 to 75 (276 to 517)	N/A	N/A	N/A
Tensile strength, ksi (MPa)	70 to 100 (483 to 690)	70 to 230 (483 to 1600)	87 to 535 (600 to 3690)	250 to 368 (1720 to 2540)
Elastic modulus, $\times 10^3$ ksi (GPa)	29.0 (200.0)	5.1 to 7.4 (35.0 to 51.0)	15.9 to 84.0 (120.0 to 580.0)	6.0 to 18.2 (41.0 to 125.0)
Yield strain, %	0.14 to 0.25	N/A	N/A	N/A
Rupture strain, %	6.0 to 12.0	1.2 to 3.1	0.5 to 1.7	1.9 to 4.4

*Typical values for fiber volume fractions ranging from 0.5 to 0.7.

Source: ACI 440.1R

FRP Reinforcing



References

FDOT

FIBER REINFORCED POLYMER GUIDELINES (FRPG)

FDOT STRUCTURES MANUAL
VOLUME 4
JANUARY 2015

ACI

ACI 440.1R-06

Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars

Reported by ACI Committee 440

AASHTO

References

Developmental Specifications

Dev932FRP

NONMETALLIC ACCESSORY MATERIALS FOR CONCRETE PAVEMENT AND CONCRETE STRUCTURES.
(REV 7-16-14)

Specifications and Estimates/Specifications/

Materials Manual Section 12.1, Volume II

FIBER REINFORCED POLYMER COMPOSITES

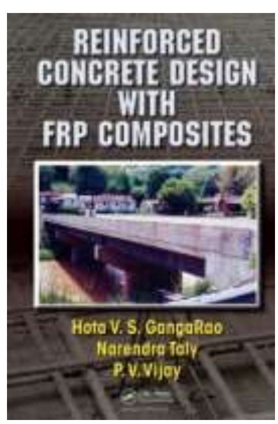
Section 12.1, Volume II

Technical Specification Provision for HCB

References

* FIBER REINFORCED POLYMER BAR BENDING DETAILS *					
021310 Certification Statement	FRP Bar Bending Details Permitted Projects FPID No(s): 430021-1, 432194-1-52-01	[illegible]	[illegible]	-	[illegible]
* FRP REINFORCED PILES *					
022440 Certification Statement	Precast Concrete CFRP/GFRP Sheet Pile Wall Permitted Projects FPID No(s): 430021-1-52-01, 432194-1	[illegible]	[illegible]	CEL-022440-CSPSA CEL-022440-CSPDA CEL-022440-CSPC	
022600 Certification Statement	Notes and Details For Square CFRP Prestressed Concrete Piles Permitted Projects FPID No(s): 430021-1-52-01				[illegible]
022601 Certification Statement	Square CFRP Prestressed Concrete Pile Splices Permitted Projects FPID No(s): 430021-1-52-01				
022614 Certification Statement	14" Square CFRP Prestressed Concrete Pile Permitted Projects FPID No(s): 430021-1-52-01	[illegible]	[illegible]	[illegible]	
022624 Certification Statement	24" Square CFRP Prestressed Concrete Pile Permitted Projects FPID No(s): 430021-1-52-01				

References



Halls River Project

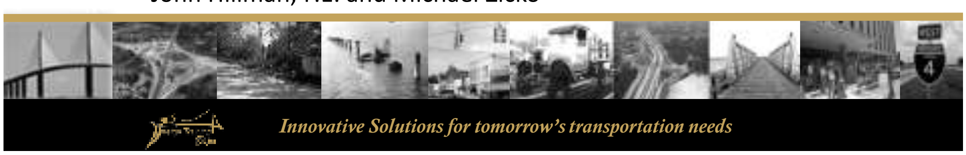
- Project Overview
- Construction

Project Overview

- Collaboration
- Information
- Existing Bridge
- Proposed Bridge
- GFRP, CFCC, and HCB Projects
- Cost Estimates

Project Overview: Collaboration

- FDOT Structures Design Office
  - Steve Nolan, P.E.
  - Tom Waits, P.E.
- FDOT Structures Research Center
  - Will Potter, P.E.
- FDOT Materials Office
  - Chase Knight, Ph.D.
- University of Miami – Composite Research Center
  - Antonio Nanni, Ph.D., P.E.
- HCB inventors
  - John Hillman, P.E. and Michael Zicko



Project Overview: Information

- Category II Structure
  - New bridge using FRP composite materials (1st in Florida)
- FRP Composite Materials
  - Glass FRP reinforcement (deck, bent cap, and bulkhead)
  - Carbon FRP reinforcement (square and sheet concrete piles)
  - Hybrid Composite Beams

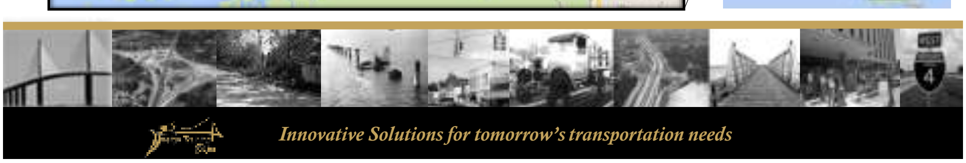
Project Overview: Information

- Owner
- Maintaining Agency

- Bi-Annual Inspection
- Design and Build Proposed Bridge

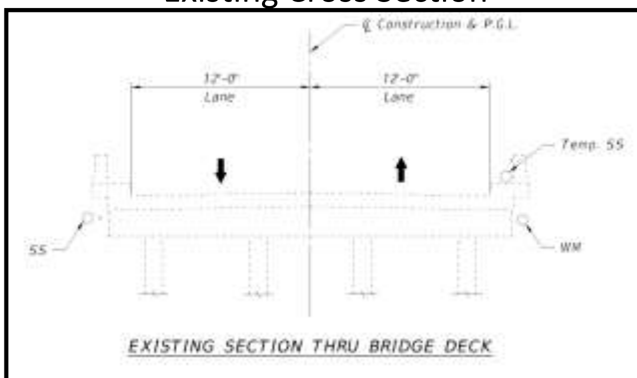
Project Overview: Existing Bridge

Bridge Location



Project Overview: Existing Bridge

Existing Cross Section



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Project Overview: Existing Bridge

Existing Spans Configuration

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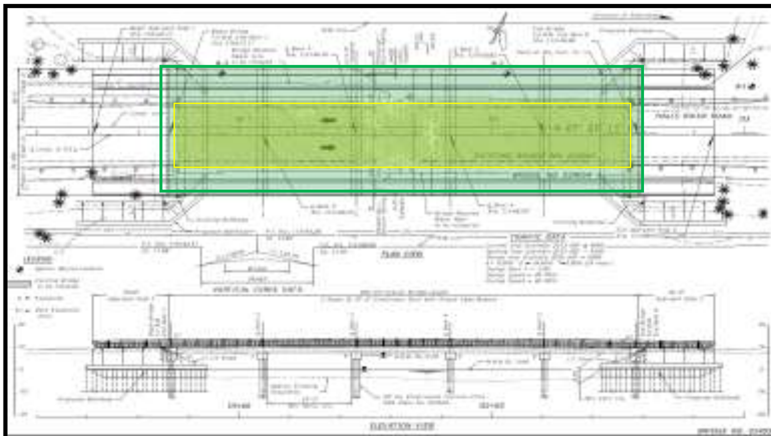
Project Overview: Proposed Bridge



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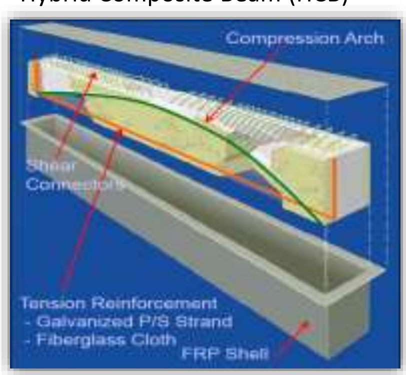
Project Overview: Proposed Bridge

Glass Fiber Reinforced (GFRP) Bars

Carbon Fiber Composite Cable (CFCC)

Hybrid Composite Beam (HCB)



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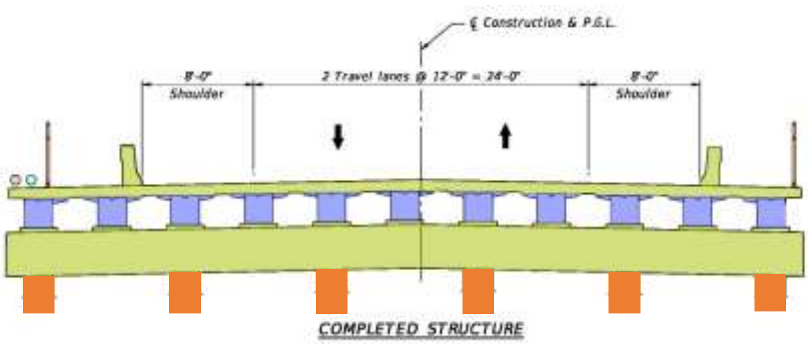
HYBRID COMPOSITE BEAM (HCB)

http://www.hcbridge.net/4801.html

Project Overview: Proposed Bridge



GFRP HCB CFCC

Project Overview: GFRP Projects

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Project Overview: CFCC Projects

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Project Overview: HCB Projects

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Project Overview: Estimated Cost

Cost Per Unit Deck Area

Bridge Type	$/SF
Conventional Concrete Bridge (PSB, Steel Reinforcement)	166.00
Proposed Composite Bridge (HCB, FRP Reinforcement)	282.00

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Construction

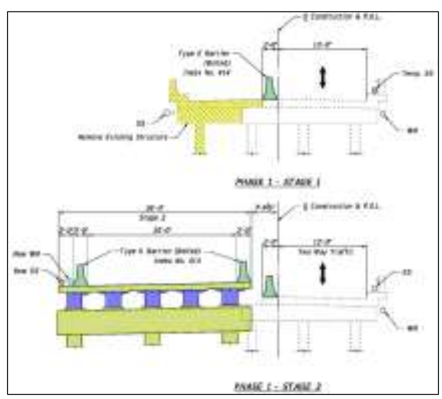
- Halls River Bridge: Phase Construction
- CFCC Piles
- Hybrid Composite Beam (HCB)
- FRP Bars
  - Handling and Storage
  - Placement and Assembly

Construction: Phase Construction

Phase 1 Sequence

Stage 1:
- Setup traffic (1 lane-2 way) and install Type K Barrier.
- Relocate Sewer Line to temporary location.
- Remove portion of Existing Bridge.

Stage 2:
- Construct Phase 1 of New Bridge.
- Install new Water and Sewer Lines in permanent location.
- Install Type K Barriers for Phase 2 Traffic.



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Construction: Phase Construction

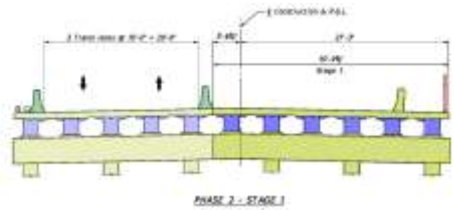
Phase 2 Sequence

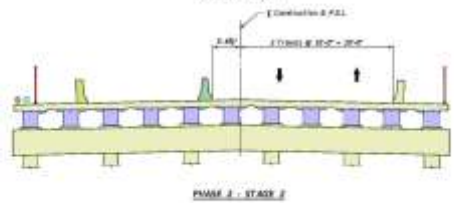
Stage 1:

- Shift traffic to Phase 1 of new Bridge (2 lane-2way).
- Construct Phase 2 of New Bridge with Traffic Railing and Pedestrian Railing.

Stage 2:

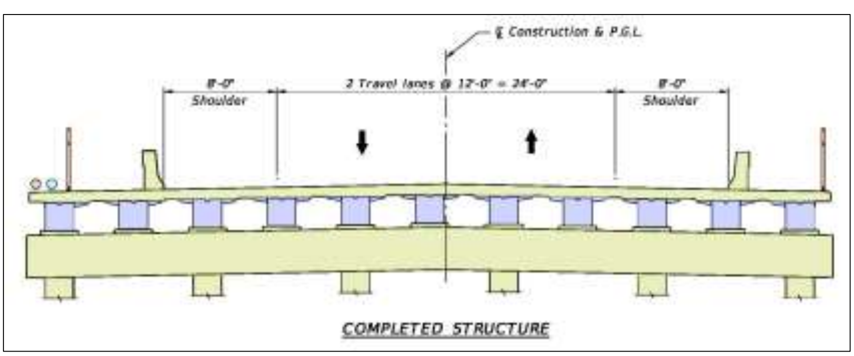
- Shift traffic to Phase 2 of new Bridge (2 lane-2way).
- Construct Traffic Railing and Pedestrian Railing on Phase 1 portion of new Bridge.



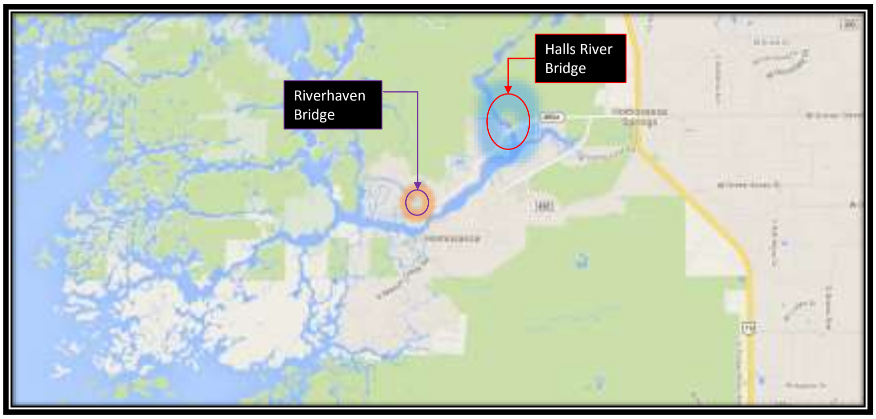


Construction: Phase Construction

Final Configuration



Construction: Phase Construction



Construction: Phase Construction

Riverhaven Bridge: Construction Phasing

Construction: Phase Construction

Riverhaven Bridge: Utility Accommodation

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Construction: CFCC Piles

- FDOT Research:
  - Field Testing:
    - Installation and Behavior.
  - Lab Testing
    - Material and Capacity.
- Pile Production
  - Similar to conventional piles.
  - Handling of CFCC strands to prevent damage.
- Installation
  - Driving method and behavior similar to conventional piles.
  - Research found strength and capacity similar to conventional piles.

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Construction: HCB

- Lightweight:
  - 33% less weight than standard concrete beam (includes concrete fill).
  - 80% less concrete than standard concrete beam.
  - 75%-80% fewer trucks required for shipping.
  - Smaller cranes for placement.
    - ➢ Accelerated beam installation.

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Construction: HCB

- Fabrication
  - Current Locations:
    - ➢ Maine
    - ➢ Texas
  - New Approved Locations:
    - ➢ North Carolina
    - ➢ South Dakota
    - ➢ Seattle
  - Currently no fabrication plants in Florida.

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Construction: HCB

Fabrication

HYBRID COMPOSITE BEAMS

STANDARD CONCRETE BEAMS

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Construction: HCB

Handling and Storage

HYBRID COMPOSITE BEAMS

STANDARD CONCRETE BEAMS

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Construction: HCB

Transportation

HYBRID COMPOSITE BEAMS (Union Street, ME)
9.0 kips x 4= 36 kips Total
70 ft. beams

PRESTRESSED SLAB BEAMS (Gospel Island, FL)
25 kips x 2 = 50 kips Total
39 ft. beams

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Construction: HCB

Installation

HYBRID COMPOSITE BEAMS

STANDARD CONCRETE BEAMS

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Construction: FRP Bars

- Minimize damage to FRP bars
- Handling, storage, and placement
  - Similar to coated bar (epoxy or galvanized)
- ACI 440.5-08 “Specification for Construction with FRP Bars”

Construction: FRP Bars

Handling & Storage

- FRP bars vulnerable to surface damage

Checklist: Handling and Storage of FRP Rebars	
☑	Store bars in a clean environment
	Protect bars against:
☑	- UV radiation
☑	- High temperature
☑	- Damaging chemicals
☑	Lift bundles of bars with care
☑	Do not shear bars when cutting
SAFETY*	Work gloves should be worn at all times

* In addition to typical safety precautions and procedures

Construction: FRP Bars

Placement & Assembly

- Follow Manufacturers' guidelines

	Checklist: Placement and Assembly of FRP Rebars
☑	Oil, grease, dirt, removed from bars
☑	Bars placed as specified by Engineer
☑	Ties type as specified by Engineer
☑	Rebar chair type as specified by Engineer
☑	No direct contact between CFRP and steel
☑	No mechanical bar splices (lap splices only)
☑	Reinforcement tied down to prevent floating
☑	Care taken during concrete vibrating
☑	No walking on bars (sometimes permitted)
☑	Bends/hooks may not be fabricated on-site
SAFETY	[illegible]

* In addition to typical safety precautions and procedures

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Summary:

- Pilot project
  - Pilot/Experimental project
  - First of its kind in Florida
  - FDOT Central Office and FHWA oversight
  - Long-term monitoring
    - FDOT Structures Research Center and State Materials Office
- Use of corrosion resistant materials
  - Glass FRP rebar
  - Carbon FRP strands
  - Hybrid Composite Beams
- $3.2M estimated costs

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Thank you.

Questions?