FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

PUT IT DOWN
IT'S THE LAW

FDOT FRP Rebar Implementation – Current status and updates

Steven Nolan, PE.

Florida Department of Transportation

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FDOT

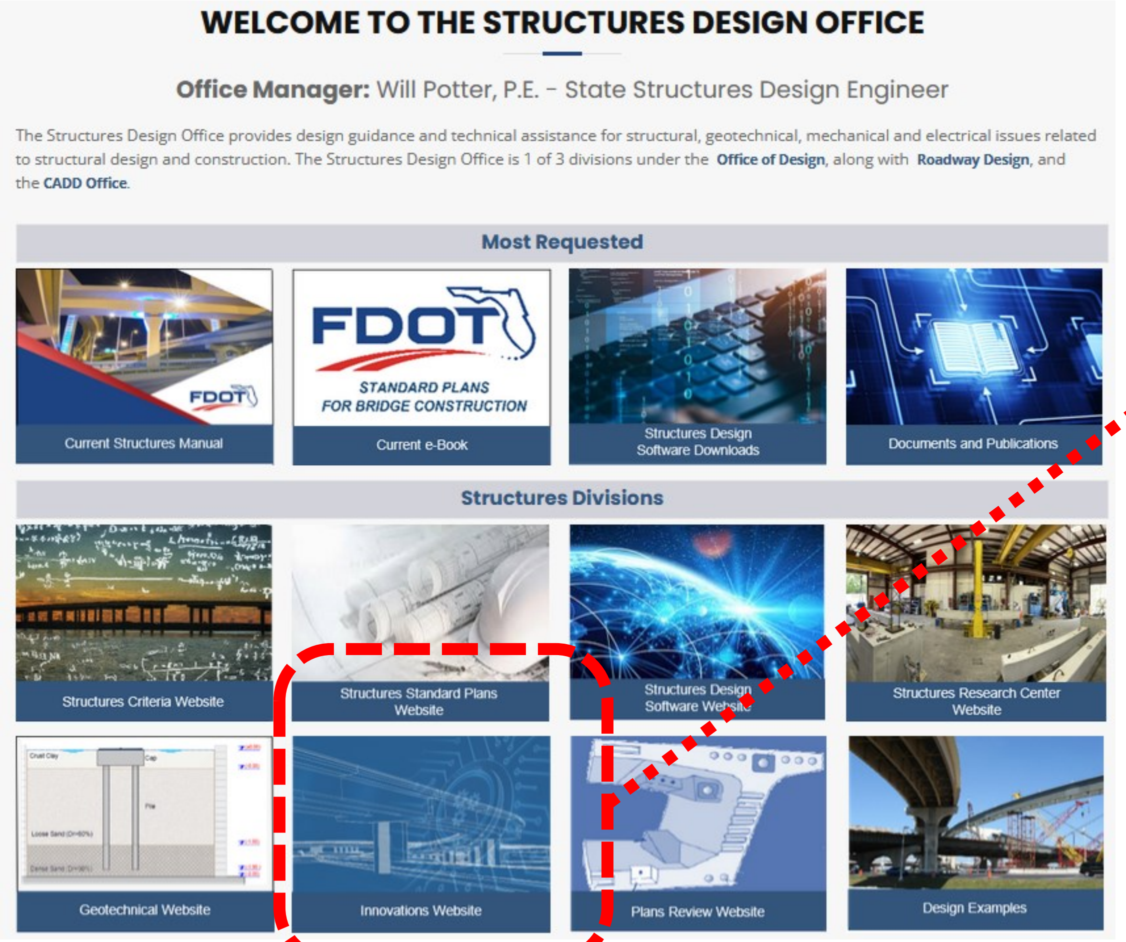
Speaker Bio: Steven Nolan, P.E.

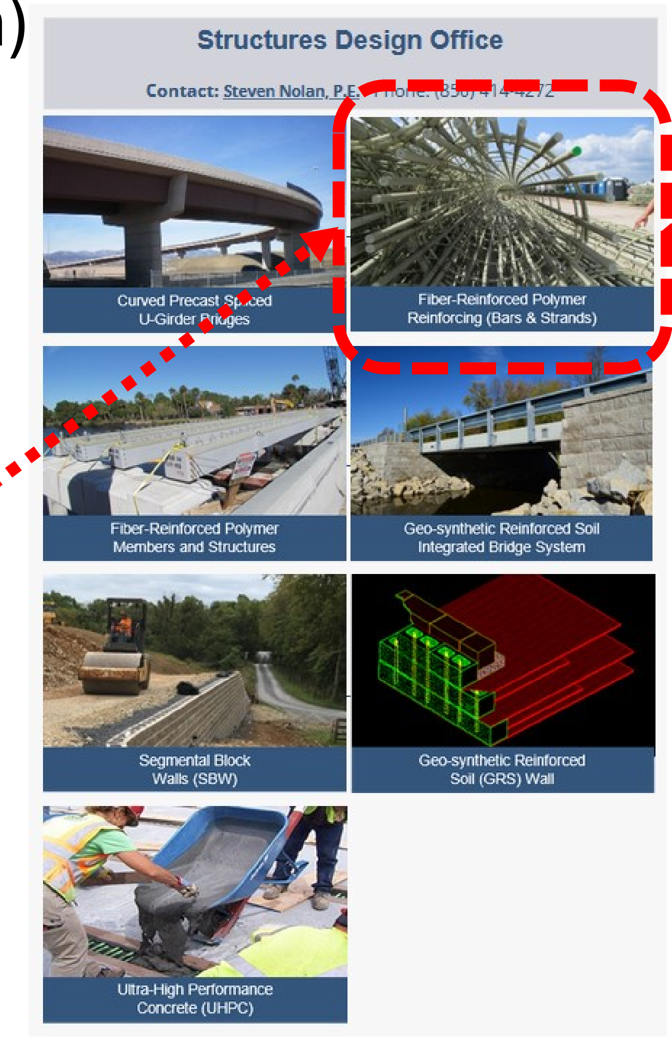
Professional Engineer in Florida since 2003, current technical lead coordinator for Florida DOT for implementation of Fiber-Reinforced Polymer reinforcing and prestressing, stainless-steel prestressing, and UHPC for structural applications. 10-years' experience with development of design guidance for FRP, 30-years' experience with concrete design and construction including 25-years with bridge design specification and standards development. Current member of ***TRB*** committee **AKB10**-Innovative Highway Structures, ***ACI*** 440C & CSAO, ***ASCE***-Structural Engineering Institute, Bridge Engineering Institute, and ***fib*** *(International Federation for Structural Concrete).*

Background:

- FDOT introduced guidance for the implementation of Fiber-Reinforced Polymer-Reinforced and Prestressed Concrete (FRP-RC & FRP-PC) at the ***2014 Design Training Expo***. We highlighted the planned release of ***Standard Specifications***, ***Structures Manual***, and ***Materials Manual*** updates, and the early design work for the seminal demonstration project - Halls River Bridge.
- Reflecting on 10 years of implementation and the evolution of design guidance, standard specifications and plans, many projects have now been successful completed and continue to be monitored with the goal of improving the state-of-the-practice and cost efficiency.

- 2014 FDOT (Invitation to Innovation)





Fiber Reinforced Polymer Reinforcing

Structures Design - Transportation Innovation
Fiber Reinforced Polymer (FRP)
Reinforcing Bars and Strands

- Overview
- Usage Restrictions / Parameters
- Design Criteria
- Specifications
- Standards
- Producer Quality Control Program
- Projects
- Technology Transfer (T^2)
- FDOT Research
- Contact

CFRP Prestressing Strand & more… at FDOT

8/1/1992	Feasibility of Fiberglass Pretensioned Piles in a Marine Environment	Sen, Rajan (USF)
8/1/1995	Durability of CFRP Pretensioned Piles in Marine Environment Volume II	Sen, Rajan (USF)
11/30/1998	Studies on Carbon FRP (CFRP) Prestressed Concrete Bridge Columns and Piles in Marine Environment	Arockiasamy, M. (FAU)

Design: Practices and Standards for FRP-RC/PC

2017 Design Training Expo

VS.

FRP Reinforced Concrete Design

Presented in 2017 by: Rick Vallier, P.E.

Updates in 2024 by: Steven Nolan, P.E.

2017 vs. 2024 FRP Reinforced Concrete Outline

A. FRP Reinforcing Bars
B. Research
C. Structures Manual
~~D. Design Standards~~
~~E. Developmental Design Standards~~
~~E. Standard Specifications~~
~~F. Challenges~~

A. Reinforcing Bars

Spec. 932-~~3~~4.2 Bar Sizes and Loads

Table 932-8
Sizes and Tensile Loads of FRP Reinforcing Bars

Bar Size Designation	Nominal Bar Diameter (in)	Nominal Cross Sectional Area (in^2)	Measured Cross-Sectional Area (in^2)		Minimum Guaranteed Tensile Load (kips)			
			Minimum	Maximum	BFRP & GFRP Bars (Type 0)	BFRP & GFRP Bars (Type III)	CFRP (Type II) Single & 7-Wire Strands	CFRP (Type I) Bars
2.1-CFRP	0.21	0.028	0.026	0.042	-	-	7.1	-
2	0.250	0.049	0.046	0.085	6.1	7.4	-	10.3
2.8-CFRP	0.280	0.051	0.048	0.085	-	-	13.1	-
3	0.375	0.11	0.104	0.161	13.2	16.0	-	20.9
3.8-CFRP	0.380	0.09	0.087	0.134	-	-	23.7	-
4	0.500	0.20	0.185	0.263	21.6	27.9	-	33.3
5	0.625	0.31	0.288	0.388	29.1	40.8	-	49.1
6	0.750	0.44	0.415	0.539	40.9	57.3	-	70.7
6.3-CFRP	0.630	0.19	0.184	0.242	-	-	49.8	-
7	0.875	0.60	0.565	0.713	54.1	75.8	-	-
7.7-CFRP	0.770	0.29	0.274	0.355	-	-	74.8	-
8	1.000	0.79	0.738	0.913	66.8	94.9	-	-
9	1.128	1.00	0.934	1.159	82.0	115.0	-	-
10	1.270	1.27	1.154	1.473	98.2	138.7	-	-
11	1.410	1.56	1.500	1.700	105.8	160.0	-	-

A. Reinforcing Bars

Characteristics of FRP Reinforcement:

- Polymer resin matrix relatively weak:
  - Bond force is transferred through resin to fibers.
  - Shear resistance is considered relatively weak *(~60%).*
- Low compressive strength of FRP:
  - Design contribution of FRP reinforcement to resist compression is ~~not recommended~~ ignored.
- Modulus of elasticity is low:
  - Due to lower stiffness (*6.5 msi & 8.7 msi*), serviceability often controls the design.
- Creep-rupture threshold is low (~~*25%*~~ *30%* f_u):
  - Sustained high tension can cause fibers to fail after a period of time
  - GFRP is considered more susceptible than CFRP (*70%* f_u).

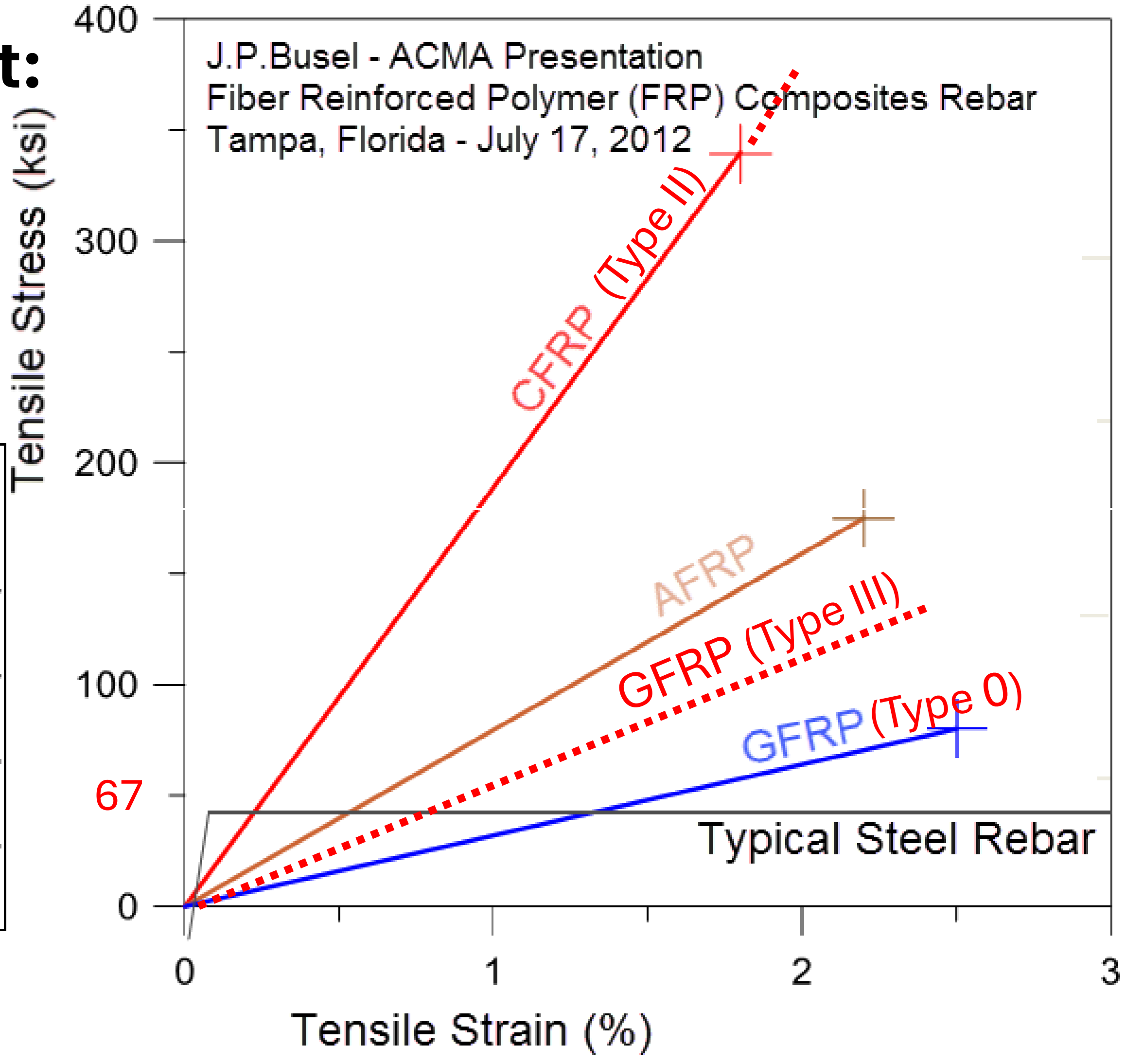
A. Reinforcing Bars

Characteristics of FRP Reinforcement:

- Linear Elastic to Failure
- No Yielding (but higher strain at 60 ksi)
- Higher Ultimate Strength
- Lower Strain at Failure

Bar type	Yield strength f_y or tensile strength f_{fu}, ksi	Modulus of elasticity, ksi
Steel	60	29,000
GFRP	(Type 0) 80 to 120	~~6000~~ 6,500
~~AFRP~~	(Type III) ~~170~~ 105 to 150	~~12,000~~ 8,700
CFRP	(Type II) ~~300~~	~~22,000~~ 22,480

From ~~ACI 440.1R-15~~ FDOT Spec 932-4, ASTM D7957 & D8505



A. Reinforcing Bars

FRP Bar Mechanical Characteristics Influenced By:

Pre-Construction

- Manufacturing Process *(FDOT MM Chapter 12.1)*
- Rate of Curing
- Quality and Quantity of Constituents

Construction and Post-Construction

- Moisture *(current limitation on BFRP in submerged marine environments. See* ***FRPG*** *2.1)*
- Ultraviolet Exposure *(Spec. 416 limits on exposure)*
- Elevated Temperature *(Fire < T_g)*
- Alkaline, Acidic, Saline Solutions *(C_E = 0.70)*

A. Reinforcing Bars

Characteristics of FRP Reinforcement:

- Endurance time in fire or elevated temperature less than for steel for anchorage zones *(**ACI 440-H** is working on criteria):*
  - Reinforcement type, aggregate type, and concrete cover will influence fire performance
  - Tensile, compressive, and shear properties of the resin material diminish as temperature approaches the glass transition temp. (***Tg***)

Property	Test Method	Requirement
Glass Transition Temperature (Tg)	ASTM E1640 (DMA) or ASTM E1356 (DSC)	≥230°F ≥212°F

Specification 932-4
https://www.fdot.gov/programmanagement/specs.shtm

A. Reinforcing Bars

Characteristics of FRP Reinforcement:

- Life cycle costs ~~likely~~ lower where steel corrosion is a concern *(see HRB).*
- SCMs (HRPs) for corrosion protection are ~~may~~ not ~~be~~ needed:
  - Silica Fume
  - Metakaolin
  - Ultrafine Fly Ash
  - ~~Calcium Nitrite~~
- Transportation costs are lower and handling easier for FRP due to light weight *(~25%).*
- Concrete cover reduction is allowed *(see **FRPG** Table 2.2).*

A. Reinforcing Bars

Bent Bars Characteristics:

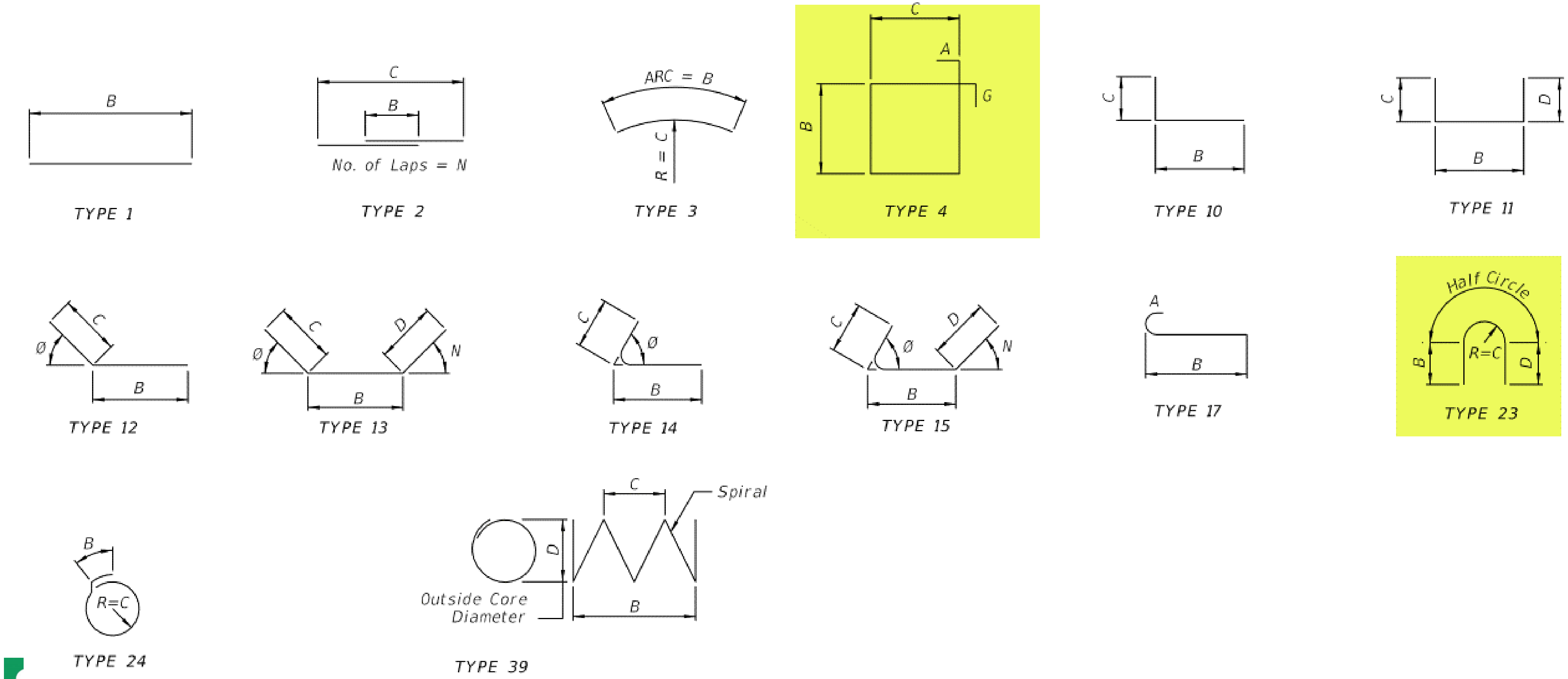
- FRP is pultruded from thermoset resin *(viable thermoplastic resins are emerging)*
- FRP is fabricated with bends *(thermoplastic and olefin resin will allow controlled thermal bending – **NCHRP IDEA-207** validated this):*
  - Sharp bends can be manufactured, but avoided due to potential low stress failure.
  - Bend Radius / Bar Diameter ≥ 3.
  - Tail Length = 12 x Bar Diameter.
  - Field bending not permitted.

- ~~Developmental Design~~ ***Standard Plan Index 415-010*** ~~D21310~~ Bar Bending Details

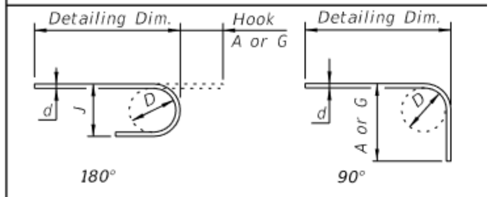
A. Reinforcing Bars

From ~~Developmental Design~~ Standard Plans Index ~~D21310~~ 415-010:

(renumbering to match steel bar bending Index)



HOOK DETAILS

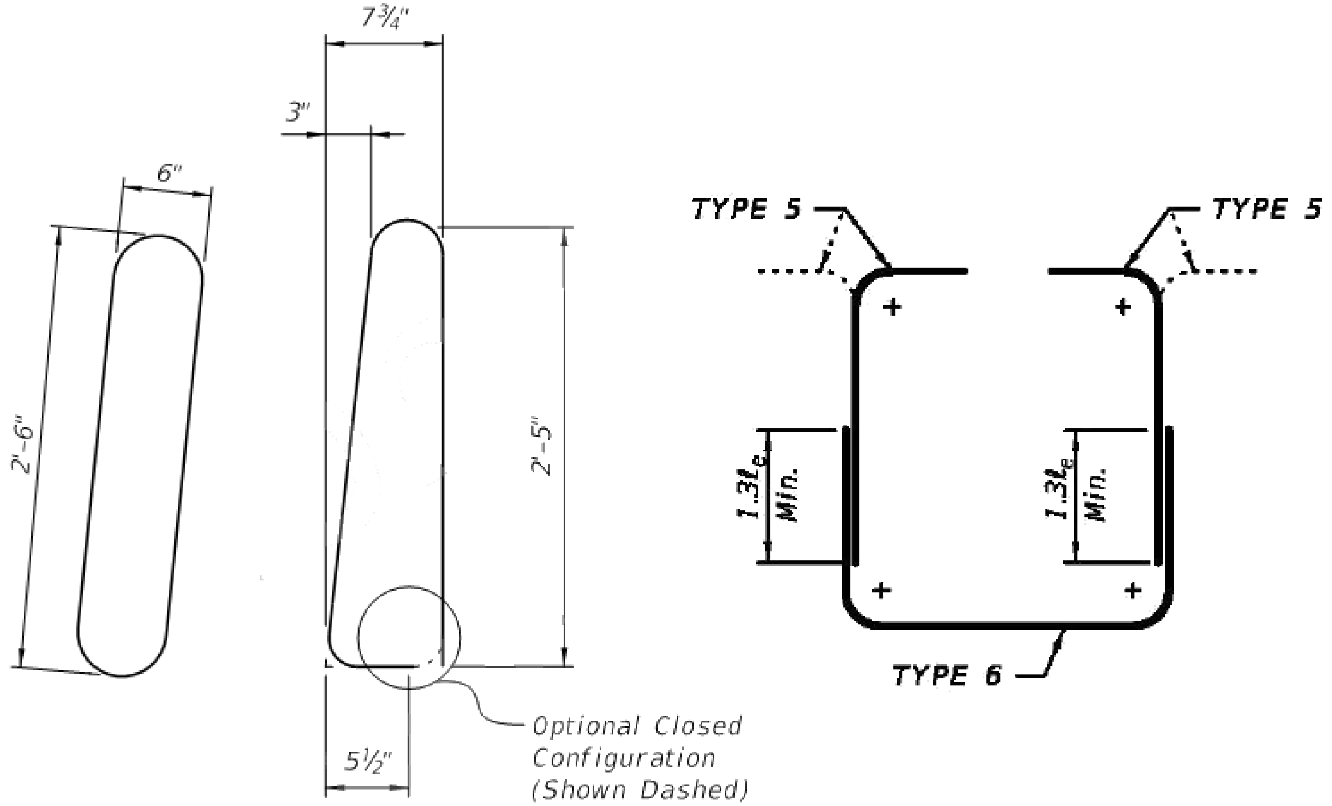


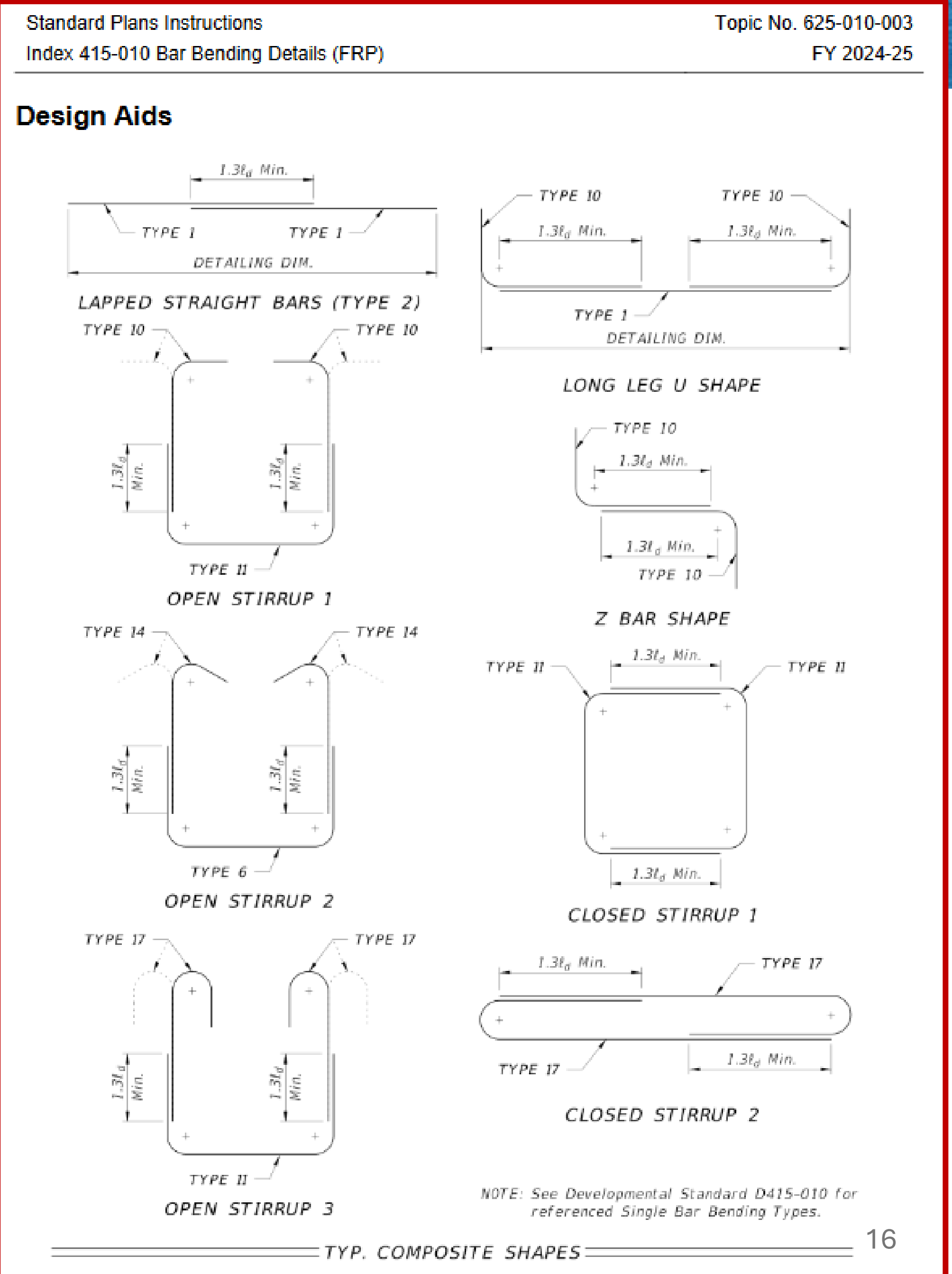
BAR SIZE	D	180° HOOKS A OR G	180° HOOKS J	90° HOOKS A OR G
#3	2¼"	5"	3"	6"
#4	3"	6"	4"	8"
#5	3¾"	7"	5"	10"
#6	4½"	8"	6"	1'-0"
#7	5¼"	10"	7"	1'-2"
#8	6"	11"	8"	1'-4"
STYLE		1		3

CRSNG MIAMI

A. Reinforcing Bars

Complex Shapes:





A. Reinforcing Bars

Cost Comparison (Installed Price)

Bar Size	Nominal Diameter	Average Unit Costs HRB (3-bids) / **		FDOT Structures Manual for BDR Cost Estimating / **	
		GFRP Bars 2016	GFRP Bars 2023	Grade 60 Steel	Stainless-Steel
#4	0.500"	$1.18 / LF	$1.90 / LF	$~~0.60~~ 1.11 / LF	$~~2.72~~ 5.25 / LF
#5	0.625"	$1.37 / LF	$2.29/ LF	$~~0.94~~ 1.74 / LF	$~~4.19~~ 8.09 / LF
#6	0.750"	$1.55 / LF	$2.71/ LF	$~~1.35~~ 2.51 / LF	$~~5.98~~ 11.54 / LF
#8	1.000"	$2.54 / LF	$4.04/ LF	$~~2.40~~ 4.45 / LF	$~~10.74~~ 20.73 / LF

Note: There is not 1:1 substitution of FRP for steel bars.
Black steel bar based on $1.67** ~~$0.90~~ / lb for all bar sizes.
Stainless steel bar based on $7.72** ~~$4.00~~ / lb for all bar sizes.

** 2023 FDOT Bid Avg.

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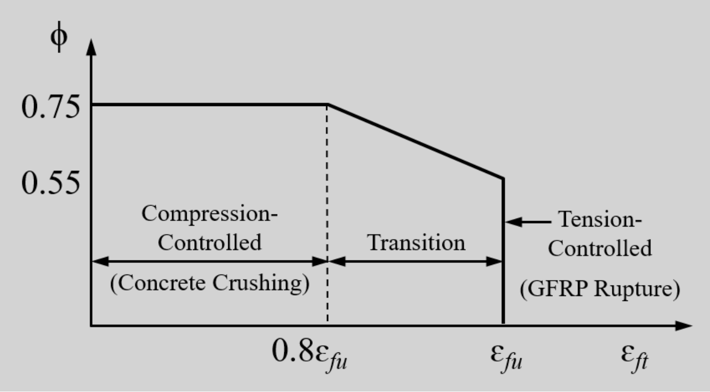
A. Reinforcing Bars

Flexural Strength Design Philosophy

Steel Reinforced Concrete Design

- Tension-Controlled Behavior
- Yielding of Steel Prior to Concrete Crushing Provides Ductility and Warning of Distress through extensive cracking and deformation



FRP Reinforced Concrete Design

- Tension-Controlled Behavior
  - FRP Rupture *(phi = 0.55)*
- Compression-Controlled Behavior
  - Concrete Crushing prior to FRP Rupture *(phi = ~~0.65~~ 0.75)*
- Margin of Safety is Higher than for Steel Reinforced Design

A. Reinforcing Bars

Design Assumptions

- Plane sections remain plane
- Flexural strength using equivalent rectangular concrete stress distribution
- Compressive strain in concrete assumed to be 0.003
- Tensile strength of concrete is ignored
- Perfect bond exists between concrete and FRP reinforcement
- Tensile behavior of FRP reinforcement is linear elastic until failure
- Compressive strength of FRP reinforcement is ignored

B. FDOT Research

Research and field implementation of FRP materials is ongoing and design recommendations continue to evolve and improved.

Complete d	Title	Researcher	Institution	Research No.
Nov. 2018	**Performance Evaluation** of GFRP Reinforcing Bars Embedded in Concrete Under Aggressive Environments	R. Kampmann	FAMU-FSU	BDV30 977-18
April 2019	**Degradation Mechanisms** and **Service Life Estimation** of FRP Concrete Reinforcements	A. El Safty	UNF	BDV34 977-05
6/30/2019	Performance Evaluation of Basalt Fiber Reinforced Polymer (BFRP) Reinforcing Bars Embedded in Concrete	R. Kampmann	FAMU-FSU	BVD30 986-01
April 2022	Epoxy Dowel Pile Splice Evaluation with FRP Bars	A. Mehrabi	FIU	BDV29 977-52
Dec. 2020	"Stainless Steel Strands and Lightweight Concrete for Pretensioned Concrete Girders" (w/ GFRP shear stirrups)	M. Roddenberry	FAMU-FSU	BDV30 977-27 (Report A)
07/30/2022	Improving Testing Protocol and Material Specifications for Basalt Fiber Reinforced Polymer Bars	R. Kampmann	FAMU-FSU	BE694

B. FDOT Research - Completed and In-progress

Research and field implementation of FRP materials is ongoing and expanding…

Completion Date	Title	Researcher	Institution	Research No.
08/29/2022	Development of GFRP Reinforced Single Slope Bridge Rail	G. Consolazio	UF	BDV31 977-110
12/31/2023	Evaluation of Glass Fiber Reinforced Polymers (GFRP) Spirals in Corrosion Resistant Concrete Piles	S. Jung	FAMU-FSU	BDV30 977-27
Feb. 2025	FSBs With Stainless Steel Strands and GFRP Shear Reinforcement	M. Roddenberry	FAMU-FSU	BED30 977-09
April 2025	*Waterline Pile Cap Footings for Bridges using Large Diameter FRP Reinforcing – Material Characterization and Design*	A. Nanni	UM	BEE76 977-01
May 2025	*HRB Extraction and Physio-Mechanical Testing of FRP Reinforcing Bars from 5-year-old Seawater Concrete Test Blocks on Halls River Bridge Bulkhead*	F. De Caso	UM	BEE76 977-02

C. FDOT Structures Manual

FDOT Design Criteria for FRP:

Vol. 1 – SDG

- Bearing Piles – 3.5
- Fender Systems – 3.14
- Structural FRC– 3.17
- BDR Cost Estimating – 9.2
  - Bearing Piles
  - Sheet Pile

Vol. 2 – SDM

- Fender Systems – 24

Vol. 4 – FRPG

- Reinforcing Bars – 2
- Strands – 3
- Strengthening – 4
- Pultruded Shapes – 5
- VIP Shapes – 6
- Thermoplastic Shapes – 7

C. FDOT Structures Manual

FDOT Design Criteria for using FRP Composites:

The Structures Manual implements ***basic design guidelines*** for FRP composites in specific applications.

As is the case with all structural materials, the engineer must practice the ***appropriate standard of care*** when designing components using FRP composites.

C. FDOT Structures Manual

Volume 4 - Fiber Reinforced Polymer Guidelines *(FRPG)*

Unless otherwise stated within the ***FRPG***, the **use of FRP composites requires approval** of the State Structures Design Office.

Obtain concept approval before proceeding with any design effort.

After concept is approved, submit the design to the State Structures Design Office for review.

FDM 121.3.2: *"Any component designed using Fiber Reinforced Polymer (FRP) composite materials except components in the Standard Plans"* is designated as **Category 2 Structure.**

C. FDOT Structures Manual

Volume 4 - Fiber Reinforced Polymer Guidelines *(FRPG)* –

Section 2: Permitted use ~~when approved by the SSDE:~~

- Approach Slabs
- Bridge Decks & Bridge Overlays
- Cast-in-Place Flat Slab Superstructure
- Pile Bent Caps ~~not in direct contact with water~~
- Pile Jackets
- Pier Columns and Caps ~~not in direct contact with water~~
- Retaining Walls, Noise Walls, Perimeter Walls
- ~~Traffic Railings~~
- Pedestrian/Bicycle Railings
- Bulkheads and Bulkhead Copings
- MSE Wall Panels and Copings
- Drainage Structures
- Dowel Bars for Exp. Joints

Note: Other locations will be considered on a case-by-case basis.

C. FDOT Structures Manual

FDOT Structures Manual – Vol. 4 FRPG 2.3

Concrete Cover Requirements in Extremely Aggressive Environments

Component	FRP Cover Requirements	Steel Cover Requirements
External Surface Cast Against Earth	3 in.	4.5 in.
Box Culverts	~~2.5~~ 2 in.	3 in.
C.I.P. Cantilever Retaining Walls	~~2.5~~ 2 in.	3 in.
MSE Walls	~~2~~ 1.5 in.	3 in.
Bulkheads and Sheet Pile Caps	~~3~~ 2 in.	4 in.

See ***FDOT Structures Manual*** for cover requirements for other components.

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http://www.fdot.gov/structures

C. FDOT Structures Manual

GFRP/CFRP Reinforcing Bars – Section 2 – Design Criteria

Design **concrete members** with FRP reinforcement according to:

- *AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete ~~ACI 440.1 Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars.~~*

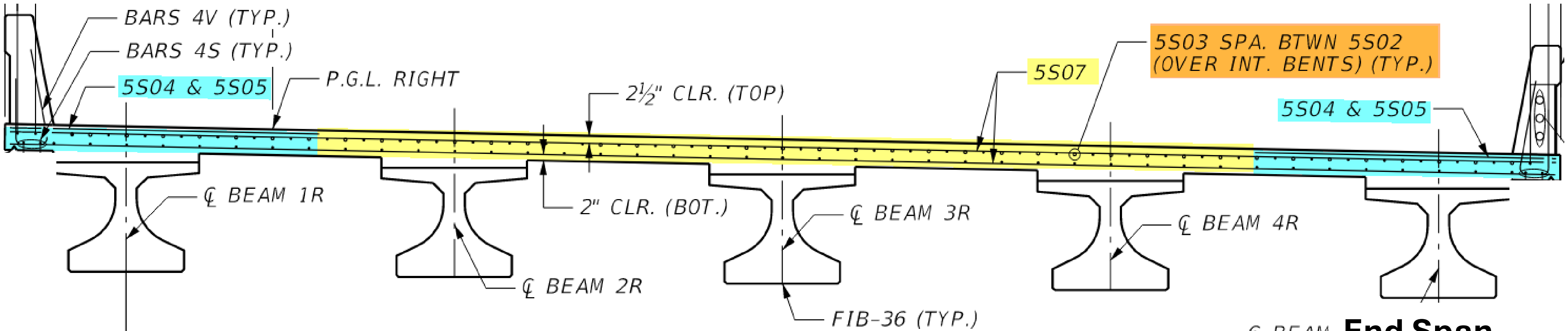
- *AASHTO Guide Specification for the Design of Concrete Bridge Beams Prestressed with CFRP Systems. ~~ACI 440.4 Prestressing Concrete Structures with FRP Tendons~~*

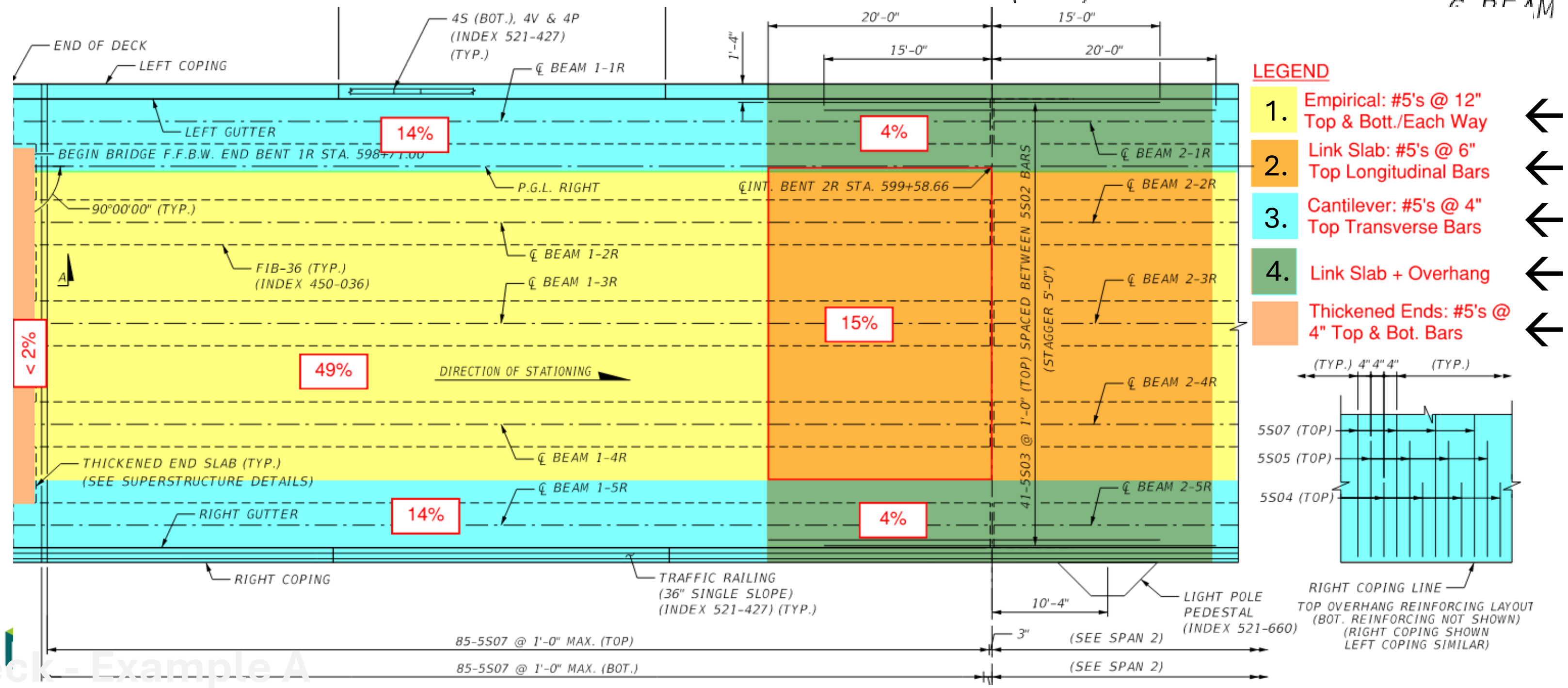
Design **Bridge Decks** according to:

- *AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete ~~Bridge Decks and Traffic Railings~~ (2nd Edition)*

*Use FRP **Mechanical Properties** per FDOT Section 932-4.*

Comparison of Rebar Qty. – Bridge Deck Example A





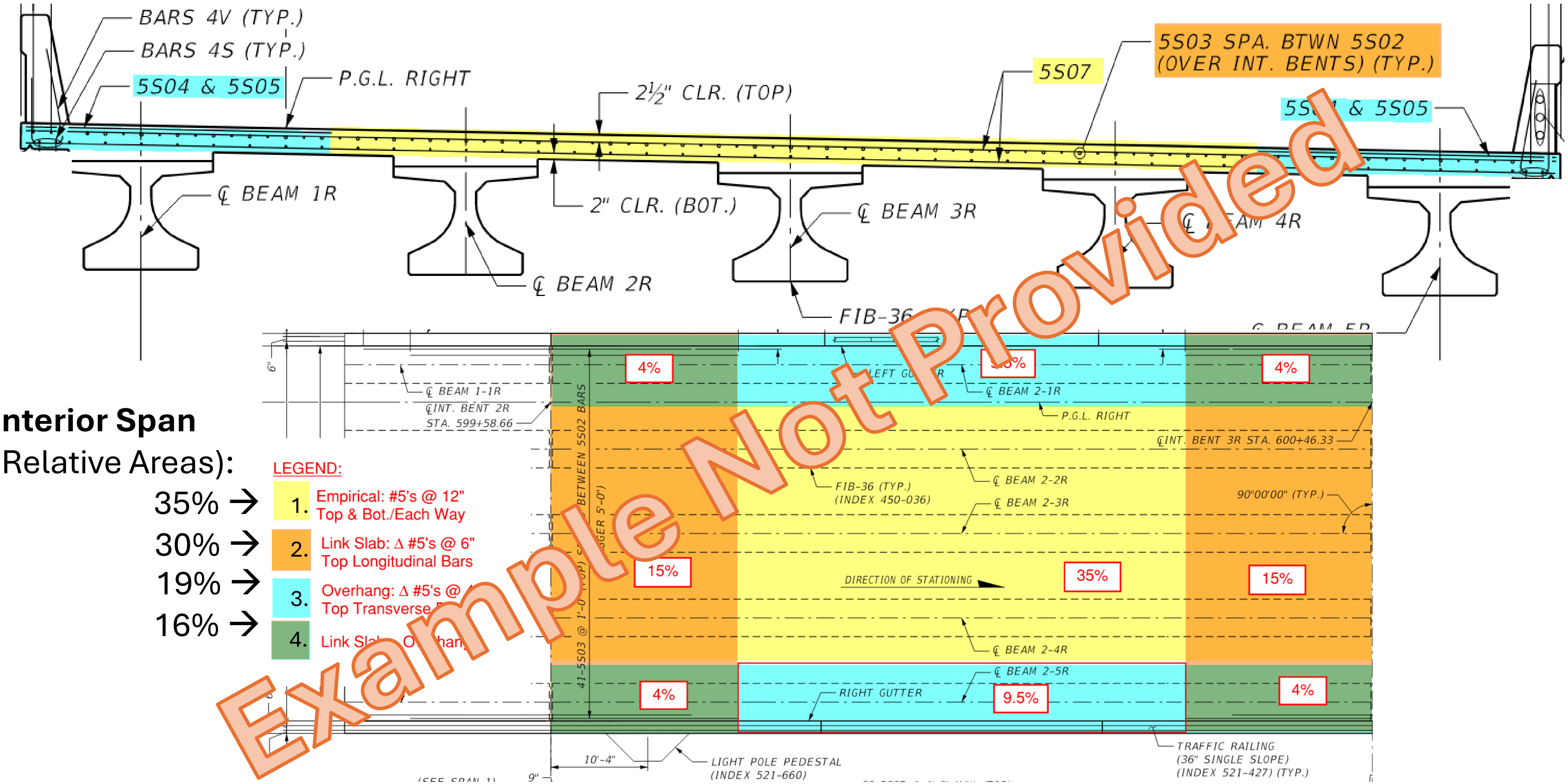
End Span (Relative Areas):

← 49%
← 15%
← 28%
← 8%
← Ignore <2%

Comparison of Rebar Qty. – Bridge Deck Example A

Interior Span
(Relative Areas):

35% →
30% →
19% →
16% →



Interior Span Example

Comparison of Rebar Qty. – Bridge Deck Example A

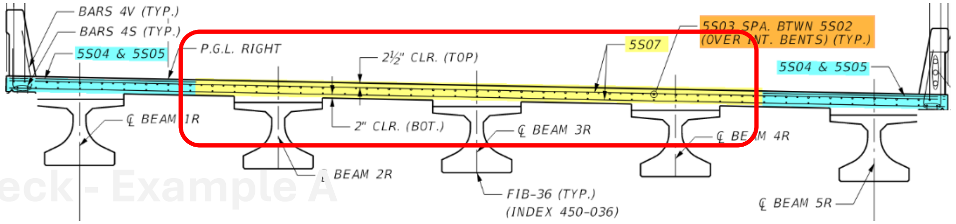
<u>Convention CS-RC</u> *(ASTM A615):*

- Thickness = *8"*
- Concrete Cover = *2"*
- Flexural Depth (#5's) $d = 5.7"$
- Empirical ***(AASHTO-BDS)***: Bottom layers = #5's @ *13.8"* *(0.27 in²/ft)*; Top layers = #4's @ *13.3"* *(0.18 in²/ft)*
- Empirical ***(FDOT)***: *#5's @ 12"* **
- Total Rebar ***(AASHTO)***: $A_s = 0.90\ in^2/ft^2$;
  (FDOT): $A_s = 1.24\ in^2/ft^2$

<u>GFRP-RC</u> *(ASTM D8505-23):*

- Thickness = *7"* → $\Delta_{vol.} = -12\%$; $\Delta_{weight} = -15\%$
- Concrete Cover = *1"*
- Flexural Depth (#5's) $d = 5.7"$
- Empirical ***(AASHTO-GSG)***: ** Bottom transverse layer = *#5's @ 6.5"* *(0.83%)* Other 3-layers = *#5's @ 12"* *(0.35%)*
- Total Rebar: $A_f = 1.50\ in^2/ft^2$ *deck)*

→ Δ_{volume} ***(AASHTO)*** = +67%; $\Delta_{weight} = -58\%$
→ Δ_{volume} ***(FDOT)*** = +21%; $\Delta_{weight} = -70\%$



End Span Bridge Deck - Example A

Interior Section

** *Minimum bar size and spacing governs*

Comparison of Rebar Qty. – Bridge Deck Example A

<u>Convention CS-RC</u> *(ASTM A615):*

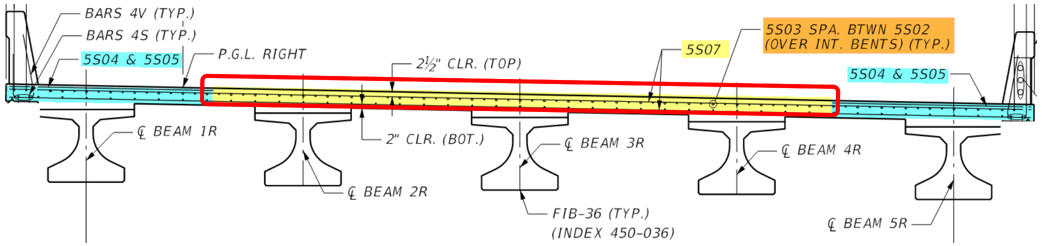
- Thickness = *8"*
- Concrete Cover = *2"*
- Flexural Depth (#5's) *d = 5.7"*
- Empirical: ***(AASHTO)***: Bottom layers = #5's @ *13.8" (0.27 in²/ft)*; Top transverse = #4's @ 13.3" *(0.18 in²/ft)*; + Top long. = *#5's @ 6" (0.62 in²/ft)*
- Empirical: ***(FDOT)***: *3-layers @ #5's @ 12"* ** *(0.31 in²/ft)*;
- Total Rebar ***(AASHTO)***: $A_s = 1.34\ in^2/\ ft^2$
  (FDOT): $A_s = 1.55\ in^2/\ ft^2$

<u>GFRP-RC</u> *(ASTM D8505-23):*

- Thickness = *7"* → $D_{vol.} = -12\%;\ D_{weight} = -15\%$
- Concrete Cover = *1"*
- Flexural Depth (#5's) *d = 5.7"*
- Empirical ***(FDOT/AASHTO-GSG)***: ** Bottom transverse = *#5's @ 6.5" (0.83% = 0.57 in²)*; Other 2-layers = *#5's @ 12" (0.35% = 0.31 in²)*; + Top long. = *#5's @ 6" (0.62 in²/ft)*
- Total Rebar: $A_f = 1.81\ in^2/ft^2$

→ $\Delta_{vol.}$ **(AASHTO)** $= +35\%;\ \Delta_{weight} = -66\ \%$
→ $\Delta_{vol.}$ **(FDOT)** $= +17\%;\ \Delta_{weight} = -71\ \%$

Link-Slab Section



** Minimum bar size and spacing governs

Comparison of Rebar Qty. – Bridge Deck Example A

Convention CS-RC *(ASTM A615):*

- Thickness = *8”*
- Concrete Cover = *2”*
- Flexural Depth (#5’s) *d = 5.7”*
- Empirical ***(AASHTO-BDS)***: 2~Bot. layers = #5’s @ *13.8”* *(0.27 in²/ft)*; Top long. = #4’s @ 13.3” *(0.18 in²/ft)*; Top transv. = #4’s + #5’s @ 4” *(0.82 in²/ft)*.
- Empirical ***(FDOT)***: 3-layers #5’s @ 12” ** *(0.31 in²/ft)*; Top Tranv. = #5’s @ 4” *(0.93 in²/ft)*.
- Total Rebar ***(AASHTO)***: $A_s = 1.54\ in^2/ft^2$;
  (FDOT): $A_s = 1.86\ in^2/ft^2$.

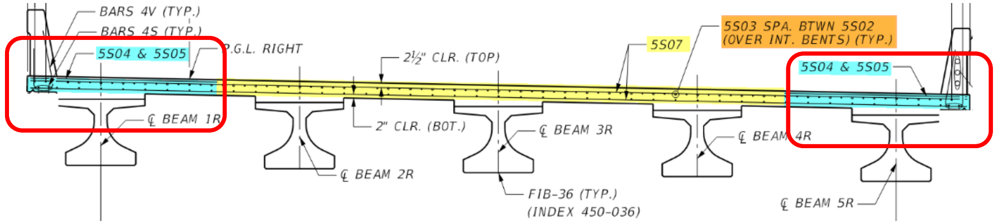
GFRP-RC *(ASTM D8505-23):*

- Thickness = *7”* → $\Delta_{vol.} = 88\%$; $\Delta_{weight} = 85\%$
- Concrete Cover = *1”*
- Flexural Depth (#5’s) *d = 5.7”*
- Empirical ***(AASHTO-GSG)***: Bot. ** transv. = *#5’s @ 6.5”* *(≥0.83% = 0.57 in²)*; 2~long. layers = *#5’s @ 12”* *(≥0.35% = 0.31 in²)*; Top transv. = *#5’s @ 4”* *(0.93 in²/ft)*.
- Total Rebar: $A_f = 2.12\ in^2/ft^2$ *deck)*

→ Δ_{volume} ***(AASHTO)*** = +38%; Δ_{weight} = -66 %

→ Δ_{volume} ***(FDOT)*** = +14%; Δ_{weight} = -72 %

Overhangs (midspan)



End Span Bridge Deck - Example A

** Minimum bar size and spacing governs

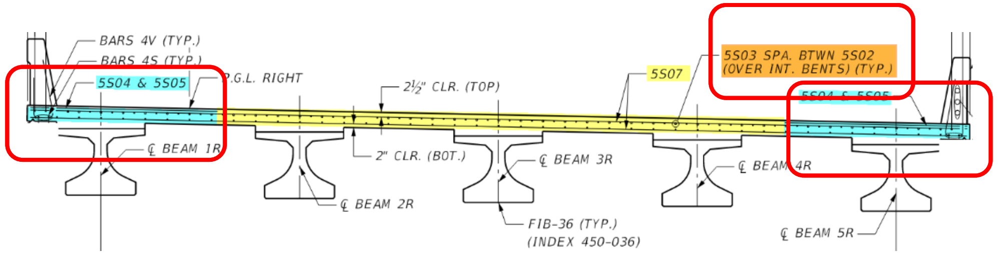
Comparison of Rebar Qty. – Bridge Deck Example A

Convention CS-RC *(ASTM A615):*

- Thickness = *8”*
- Concrete Cover = *2”*
- Flexural Depth (#5’s) *d = 5.7”*
- Empirical Overhang + Link-Slab ***(AASHTO-BDS)***: 2~Bot. layers = *#5’s @ 13.8” (0.27 in²/ft)*; Top long. = *#4’s & #5’s @ 6.7” (0.46 in²/ft)*; Top transv. = #4’s + #5’s @ 4” *(0.82 in²/ft)*.
- Empirical-Link ***(FDOT):*** 2~Bot. layers #5’s @ 12” ** *(0.31 in²/ft)*; Top Tranv. = #5’s @ 4”*(0.93 in²/ft)*. Top. long. = #5’s @ 6”*(0.62 in²/ft)*.
- Total Rebar ***(AASHTO):*** $A_s = 1.82\ in^2/ft^2$; ***(FDOT):*** $A_s = 2.17\ in^2/\ ft^2$.

GFRP-RC *(ASTM D8505-23):*

- Thickness = *7”* → $\Delta_{vol.} = -12\%$; $\Delta_{weight} = -15\%$
- Concrete Cover = *1”*
- Flexural Depth (#5’s) *d = 5.7”*
- Empirical Overhang + Link-Slab ***(AASHTO-GSG)***: Bot. ** transv. = *#5’s @ 6.5” (≥0.83% = 0.57 in²)*; Bot. long. = *#5’s @ 12” (≥ 0.35% = 0.31 in²)*; Top transv. = *#5’s @ 4” (0.93 in²/ft)*. Top long. = *#5’s @ 6” (0.62 in²)*
- Total Rebar: $A_f = 2.69\ in^2/ft^2$ *deck)*
  - → Δ_{volume} ***(AASHTO)*** = +48%; Δ_{weight} = -67 %
  - → Δ_{volume} ***(FDOT)*** = +24%; Δ_{weight} = -69 %



Overhangs @ Link-Slab

End Span Bridge Deck – Example A

** Minimum bar size and spacing governs

Comparison of Rebar Qty. – Bridge Deck Example A

Convention CS-RC *(ASTM A615):*

- **Example A** (End Span Rebar)
  - Empirical (AASHTO): As= 0.49*0.90 + 0.15*1.34 + 0.28*1.54 + 0.08*1.82 = **1.22 in^2/ft^2**
  - Empirical (FDOT): A_s = 0.49*1.24 + 0.15*1.55 + 0.28*1.86 + 0.08*2.17 = **1.53 in^2/ft^2**

GFRP-RC *(ASTM D8505-23):*

- **Example A** (End Span Rebar)
  - Empirical (both): As= 0.49*1.50 + 0.15*1.81 + 0.28*2.12 + 0.08*2.69 = **1.82 in^2/ft^2**

*Concrete → $\Delta_{vol.}$ **(AASHTO)** = -12%; Δ_{weight} = -15% for GFRP-RC*

*Rebar → Δ_{volume} **(AASHTO)** = +49%; Δ_{weight} = -63 %.*

*Rebar → Δ_{volume} **(FDOT)** = +19%; Δ_{weight} = -70 %.*

*** Minimum bar size and spacing governs*

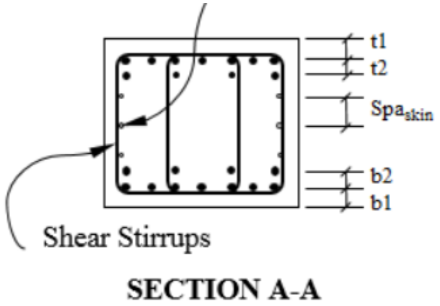
Comparison of Rebar Qty. – Pile Bent Cap Example

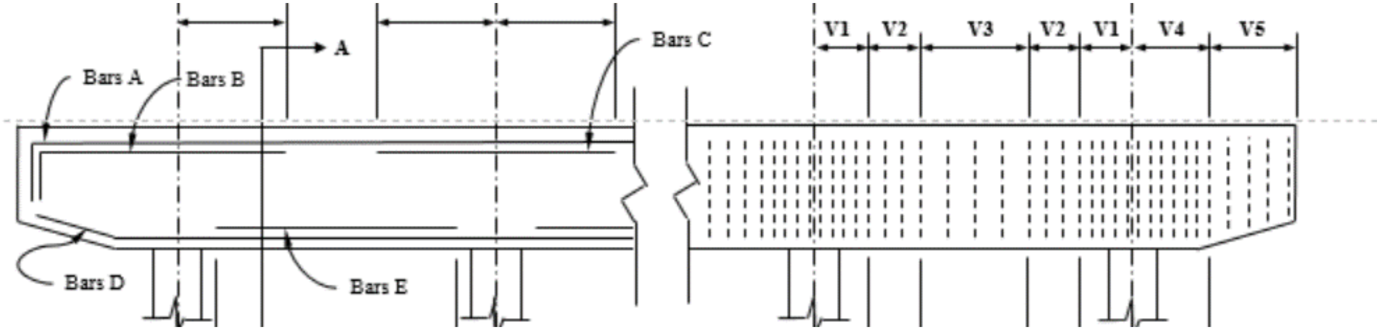
10/20/2022	GFRP Reinforced Concrete Design for Pile Bent Caps	Presentation

Comparison of Rebar Qty. – Pile Bent Cap Summary

- **Comparison of different design alternates for 5-piles @ 9-ft spacing (Example 1) – Higher Modulus GFRP Rebar (Ef = 6,500 psi to 8,700 psi for future enhancements to ASTM D7957)**

Rebar Location	GFRP-RC (Type 0) 3-ft Deep Cap (E_f = 6,500 ksi)	GFRP-RC 3-ft Deep Cap (E_f = 7,250 ksi)	GFRP-RC (Type III) 3-ft Deep Cap (E_f = 8,700 ksi)
Bars A - Flexural Top	**6 ~ #8's** (A_f = 4.7 in^2)	**7 ~ #7's** (A_f = 4.2 in^2)	**6 ~ #7's** (A_f = 3.6 in^2)
Bars D & E - Flexural Bottom	**8 ~ #8's** (A_f = 6.3 in^2)	**7 ~ #8's** (A_f = 5.5 in^2)	**6 ~ #8's** (A_f = 4.7 in^2)
Bars V3 - Shear Stirrups	**4-legs #5 at 11" sp.** (A_f = 1.4 in^2/ft)	**4-legs #5 at 13" sp.** (A_f = 1.1 in^2/ft)	**4-legs #4 at 10" sp.** (A_f = 1.0 in^2/ft)

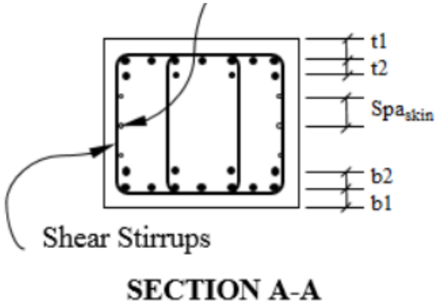


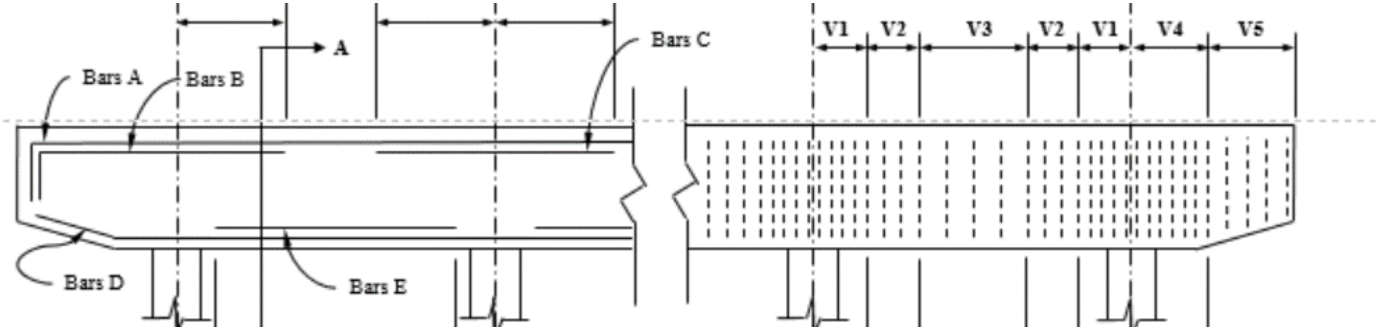


Comparison of Rebar Qty. – Pile Bent Cap Summary

- **Comparison of different design alternates for 5-piles @ 9-ft spacing (Example 1)**

Rebar Location	GFRP-RC (Type 0) 3-ft Deep Cap	Δ_{volume} Type 0 or (Type III)	Steel-RC 3-ft Deep Cap
Bars A - Flexural Top	**6 ~ #8's** (A_f = 4.7 in^2)	*+80% or (+38%)*	**6 ~ #6's** (A_s = 2.6 in^2)
Bars D & E - Flexural Bottom	**8 ~ #8's** (A_f = 6.3 in^2)	*+50% or (+12%)*	**7 ~ #7's** (A_s = 4.2 in^2)
Bars V3 - Shear Stirrups	**4-legs #5 at 11" sp.** (A_f = 1.4 in^2/ft)	*+75% or (+25%)*	**4-legs #4 at 12" sp.** (A_s = 0.8 in^2)





Construction: Example Projects & Lessons Learned

Projects with Fast-Facts Sheet

- 4th St North over Big Island Gap (D7) ***– In-house Design.***
- 40th Ave NE over Placido Bayou (D7)
- Arthur Drive over Lynn Haven Bayou (D3)
- Bakers Haulover Cut Bulkhead Replacement (D6)
- Bimini Dr Bridge on Duck Key (D6)
- Cedar Key Bulkhead Rehab (D2)
- Halls River Bridge (D7) ***– In-house Design.***
- Key West Bight Ferry Terminal Extension (D7)
- NE 23rd Ave over Ibis Waterway (D6)
- PortMiami Tunnel Retaining Walls (D6)
- South Maydell Dr over Palm River (D7)
- SR-A1A Flagler Beach Seawall (Segment 3) (D5)
- SR-A1A over Myrtle Creek and Simpson Creek (D2)
- SR-5 (US-17) over Trout River (D2)
- SR-5 (US 41) over Morning Star and Sunset Waterways (D1)
- SR-30 over St Joe Inlet (D3)
- SR-45 (US 41) over North Creek (D1)
- SR 112/I-195 Over Westshore Waterway (D5)
- SR-312 over Matanzas River (D2)
- SR-520 over Indian River Bulkhead Rehab (D5)
- Sunshine Skyway Seawall Rehabilitation (D7)
- UM Innovation Bridge
- UM Fate Bridge
- UM I-Dock
- US-1 over Cow Key Channel (D6)

Upcoming Bridge and Seawall Projects

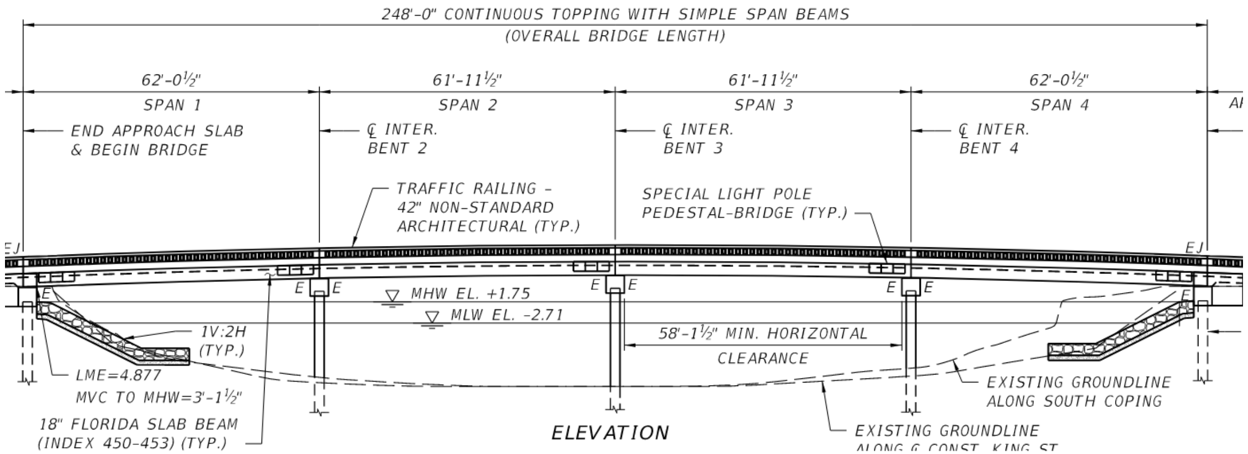
- D2: US1/King St over San Sebastian River (437428-1)
- D2: St. Augustine A1A/Avenida Menendez Seawall replacement (428271-2)
- D2: CR 357 over Shired Creek (437402-1)
- D3: CR30A over Western Lake (443331-1)
- D3: CR30B/Indian Lagoon (441185-2)
- D3: CR 372/Surf Road over Otter Creek Rise (442951-1)
- D4: US 1/Jupiter Federal Observation Platform (428400-2)
- D4: SR-A1A North Causeway Bridge Observation Platform (429936-2)
- D4: 17th St/Indian River, East End-Vero (446106-2)
- D4: SR 5/US 1 Over Earman River (442891-1) ***– In-house Design.***
- D5: SR-A1A Seawalls - Flagler Beach & Nth Volusia Co. (452443-1 & 452444-1)
- D5: Barracuda Blvd New Smyrna (437935-1) ***– In-house Design.***
- D5: 5th Street over Yacht Club Cut (437936-1)
- D5: US1 over Pellicer Ck (447118-1)
- D6: FKOSH Bridge Replacement… (448206-1 & (448207-1)

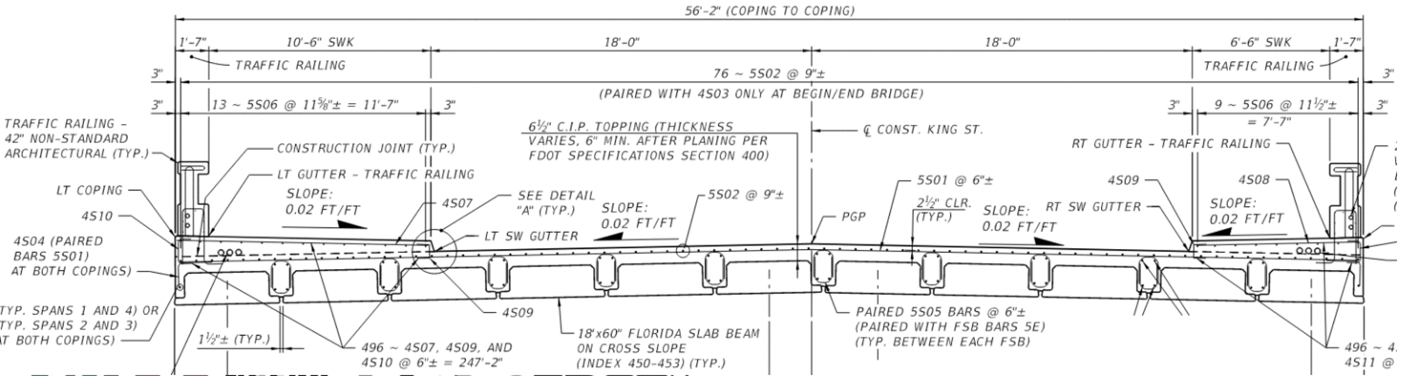
NSERC CRSNG

FDOT

Future Construction: D2 Example Projects

- US1/King St over San Sebastian River (437428-1)
- St. Augustine A1A/Avenida Menendez Seawall Replacement (428271-2)





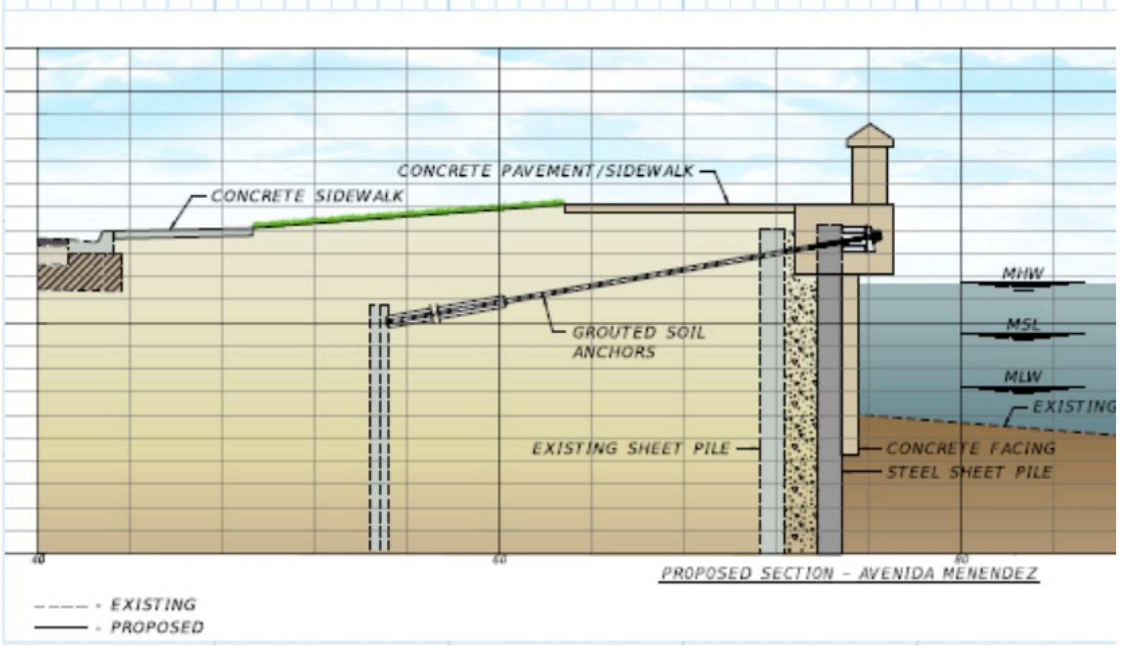
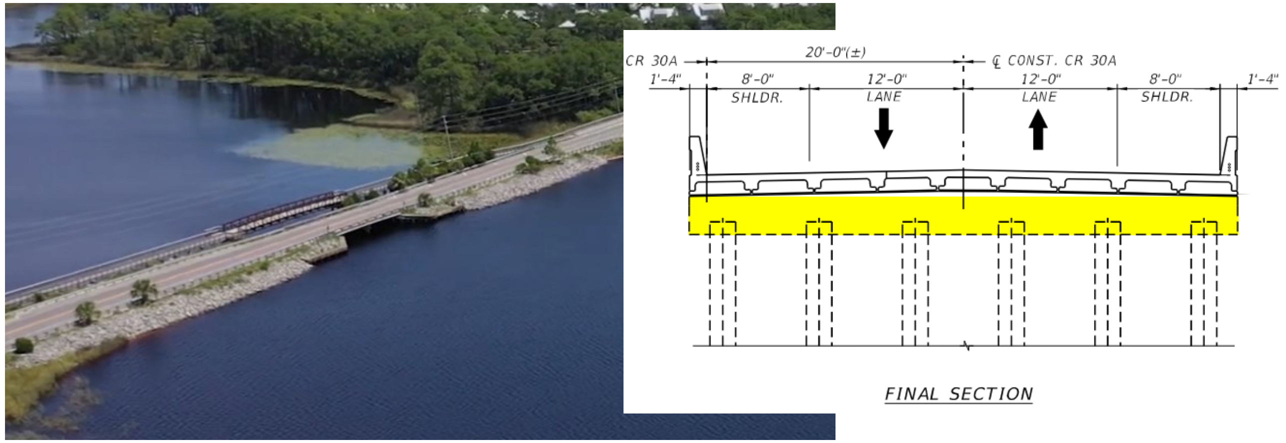
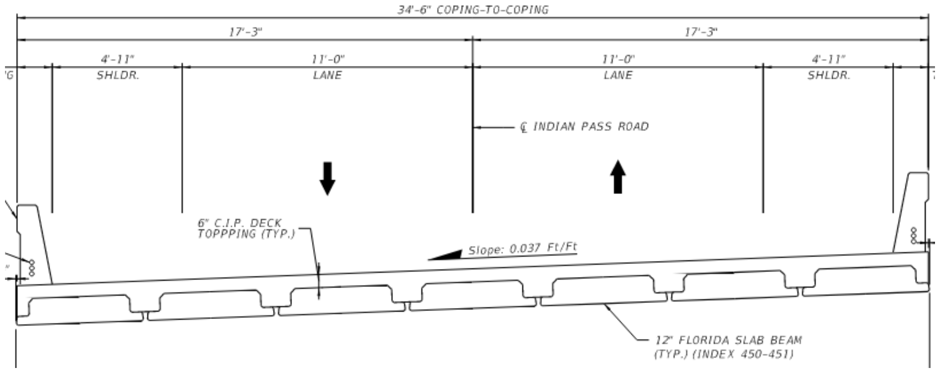


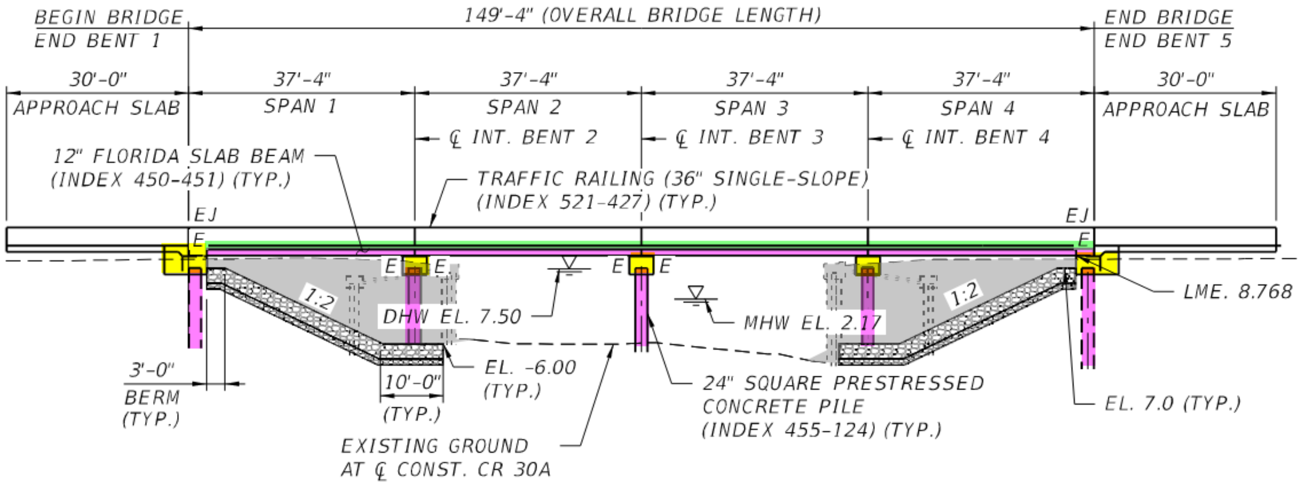
Figure 2 - Proposed Bulkhead Typical Section

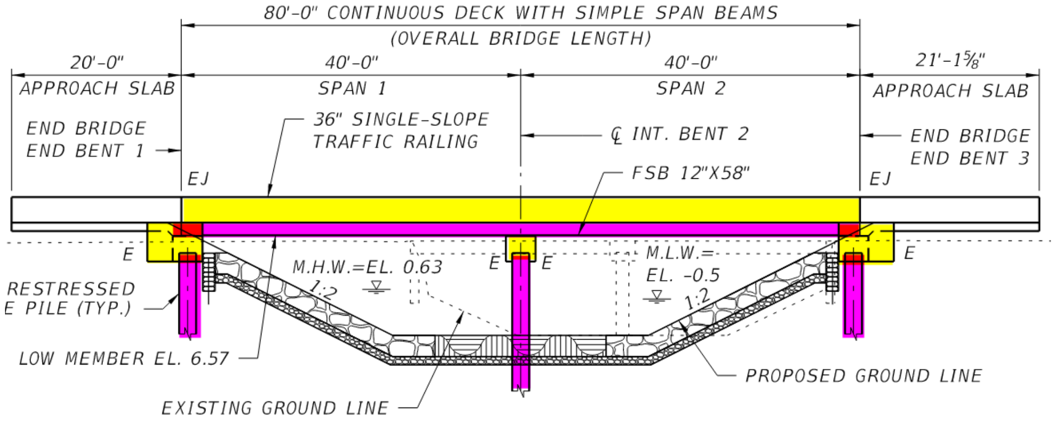
Construction: D3 Example Projects

- CR30A over Western Lake (443331-1)
- CR30B/Indian Lagoon (441185-2)



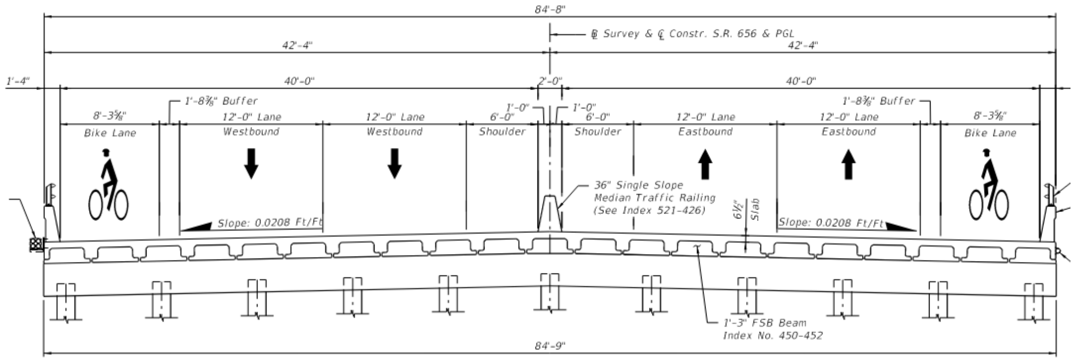


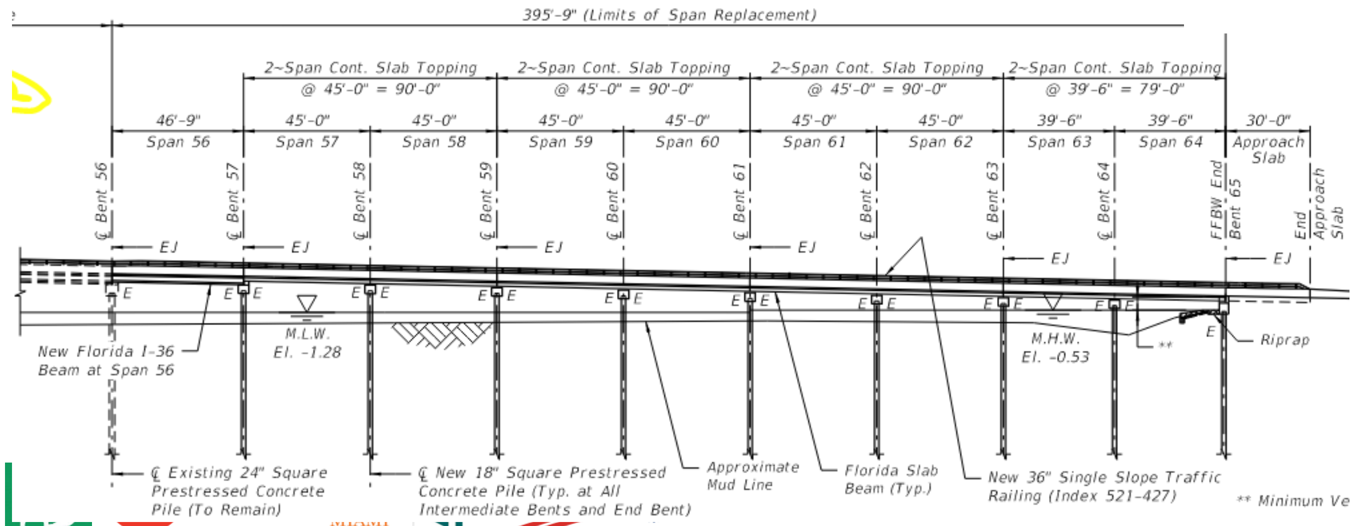




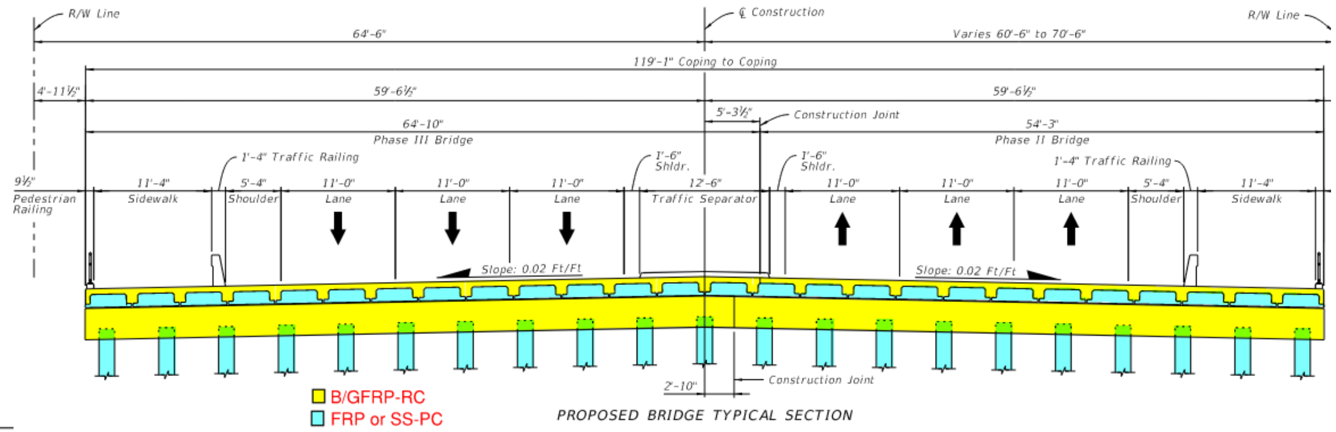
Construction: D4 Example Projects

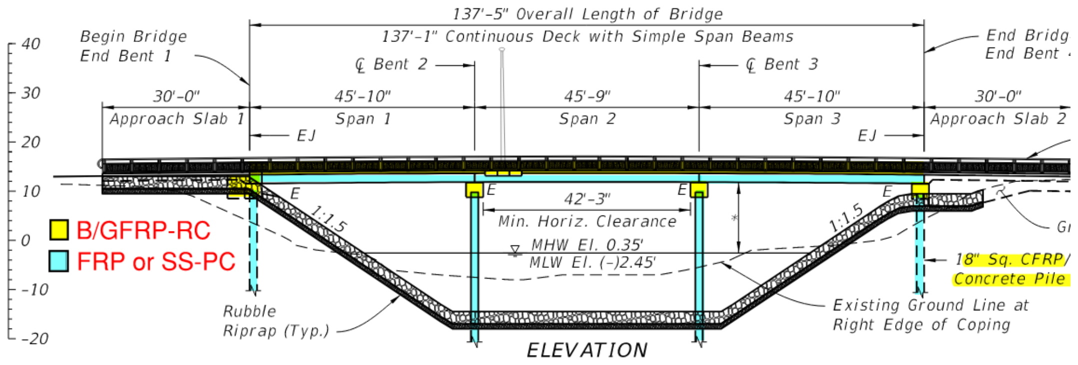
- 17th St/Indian River, East End-Vero (446106-2)





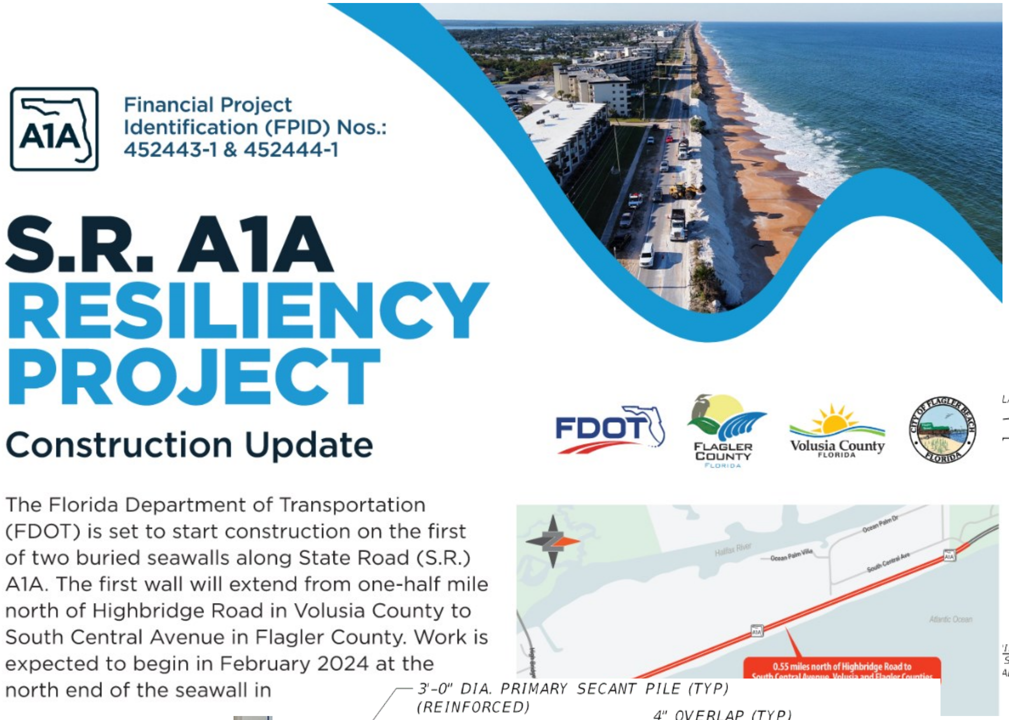
- SR 5/US 1 Over Earman River (442891-1) *In-house Design*

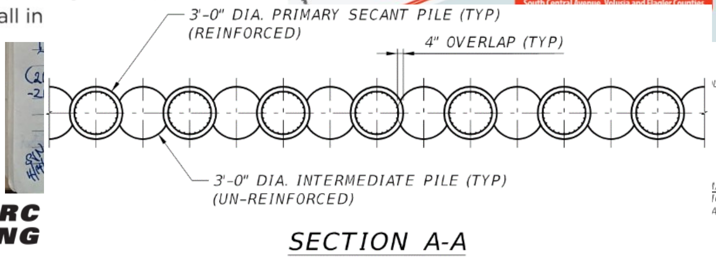


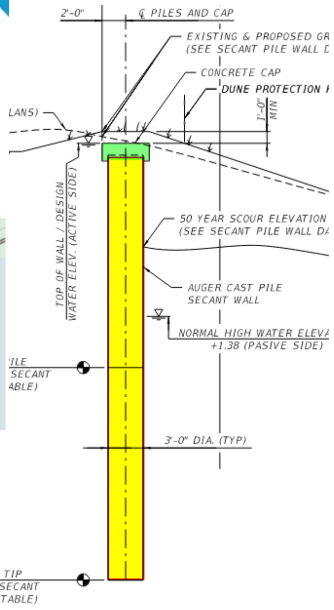


Construction: D5 Example Projects

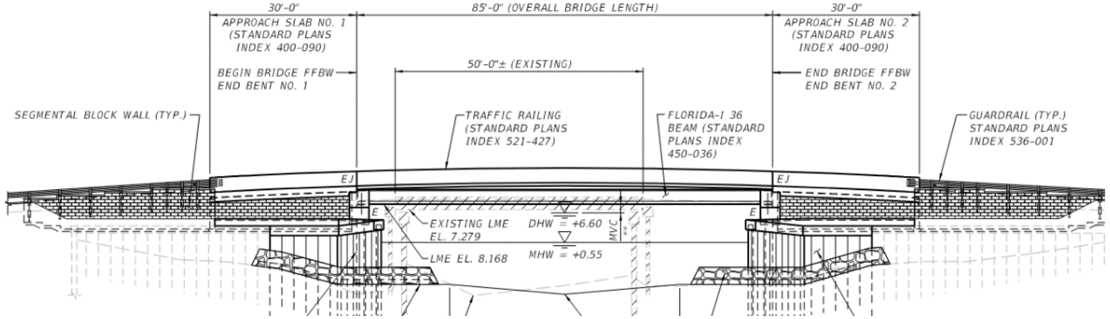
- SR-A1A Seawalls - Flagler Beach & Nth Volusia Co. (452443-1 & 452444-1)







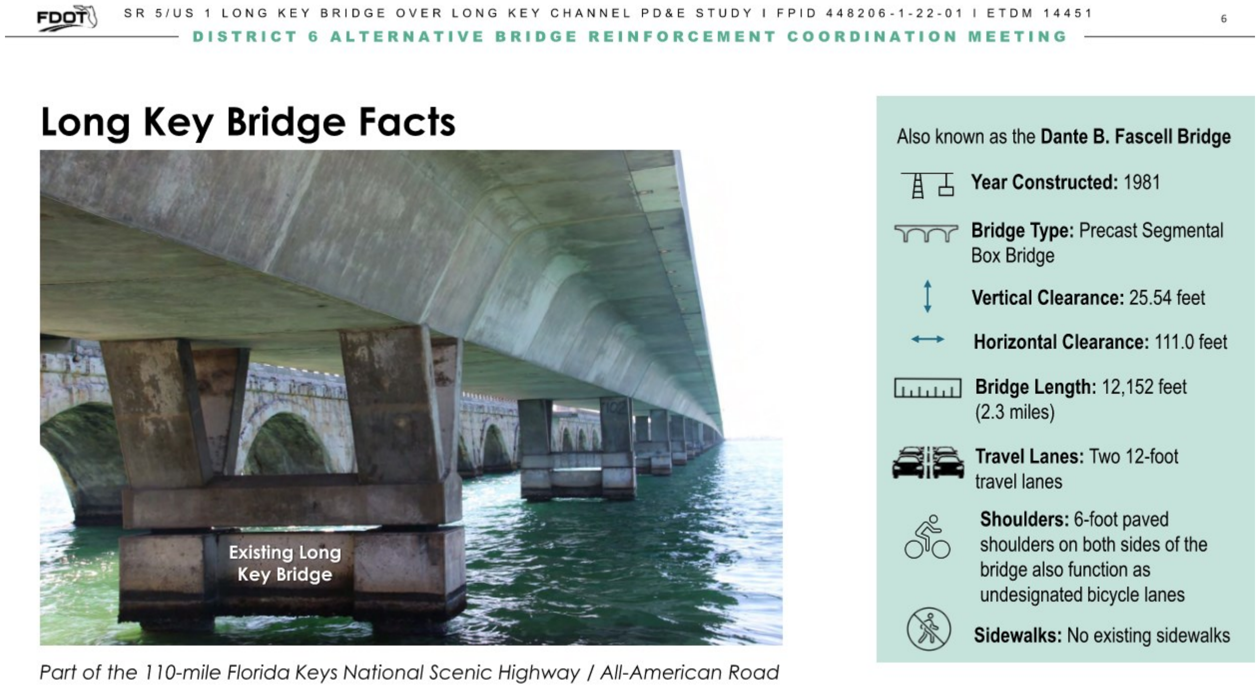
- Barracuda Blvd over Canal Bradano (437935-1) *In-house Design*



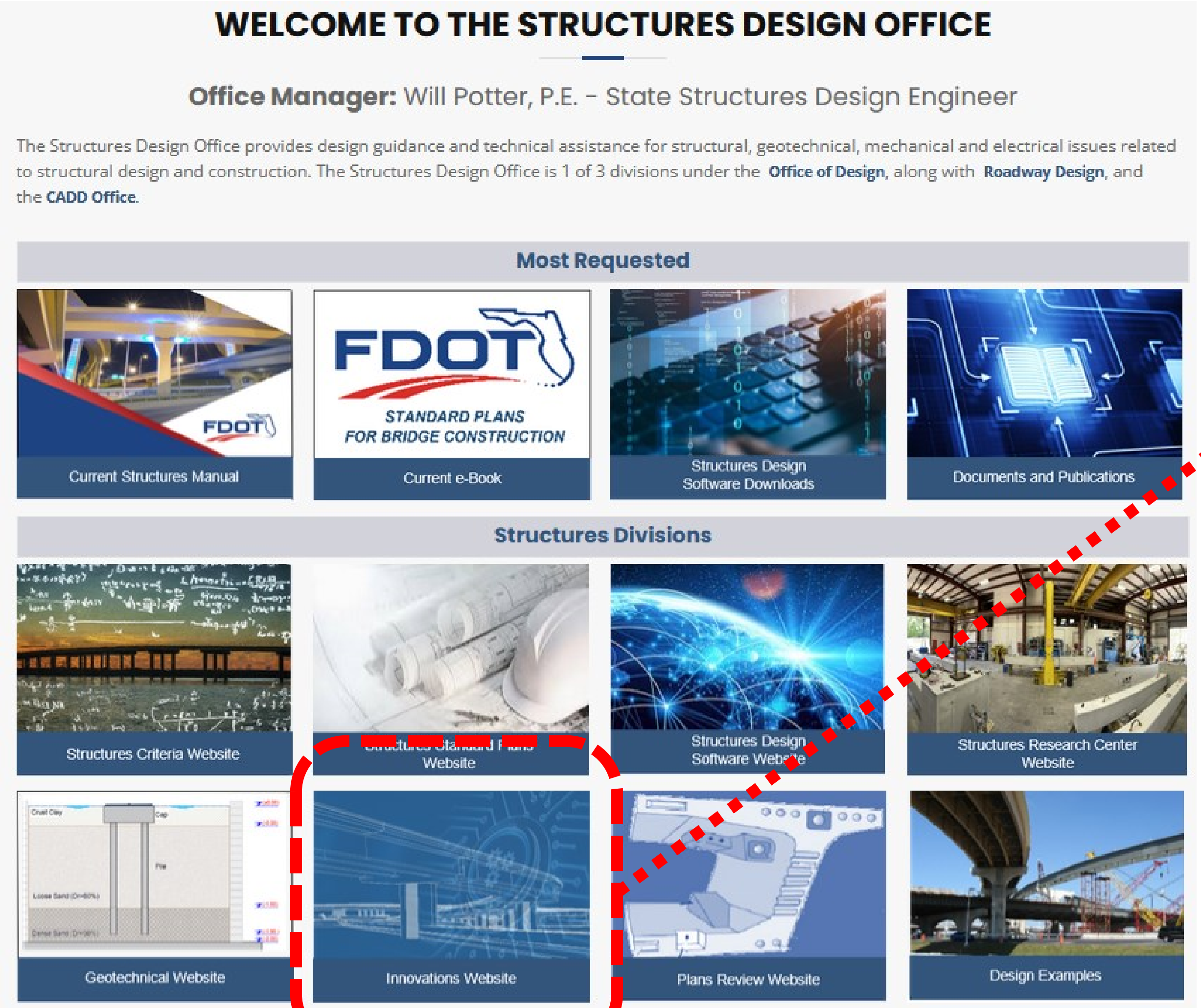
Future Construction: D6 Example Projects

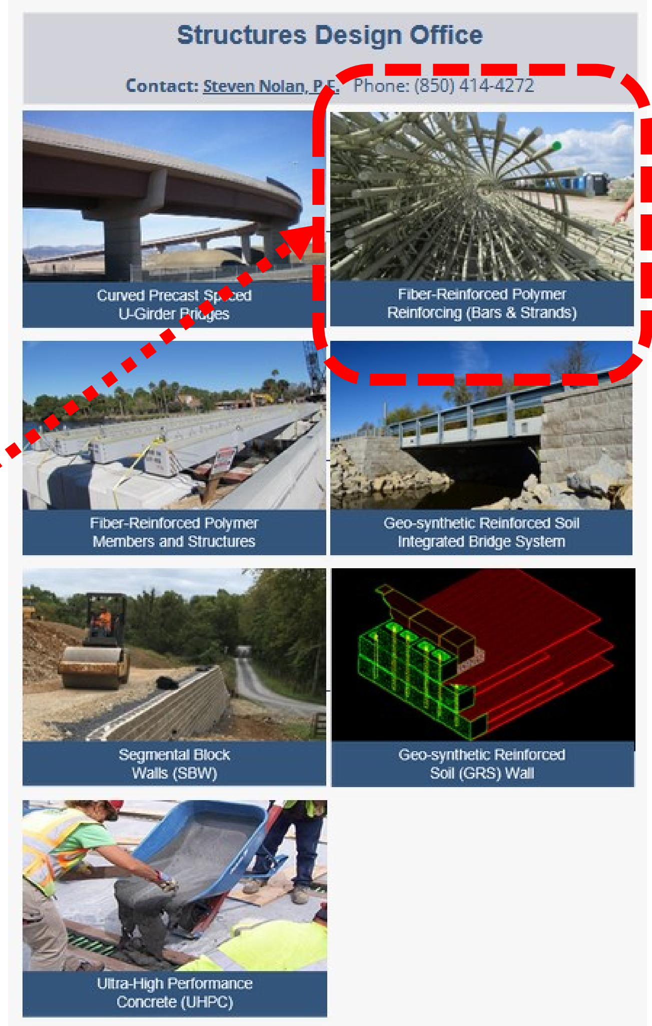
- Long Key Bridge Replacement (448206-1 & (448207-1)

- Seven Mile Bridge Replacement (448207-1)



FRP RC/PC Design Innovation webpage





Fiber Reinforced Polymer Reinforcing

Structures Design - Transportation Innovation
Fiber Reinforced Polymer (FRP)
Reinforcing Bars and Strands

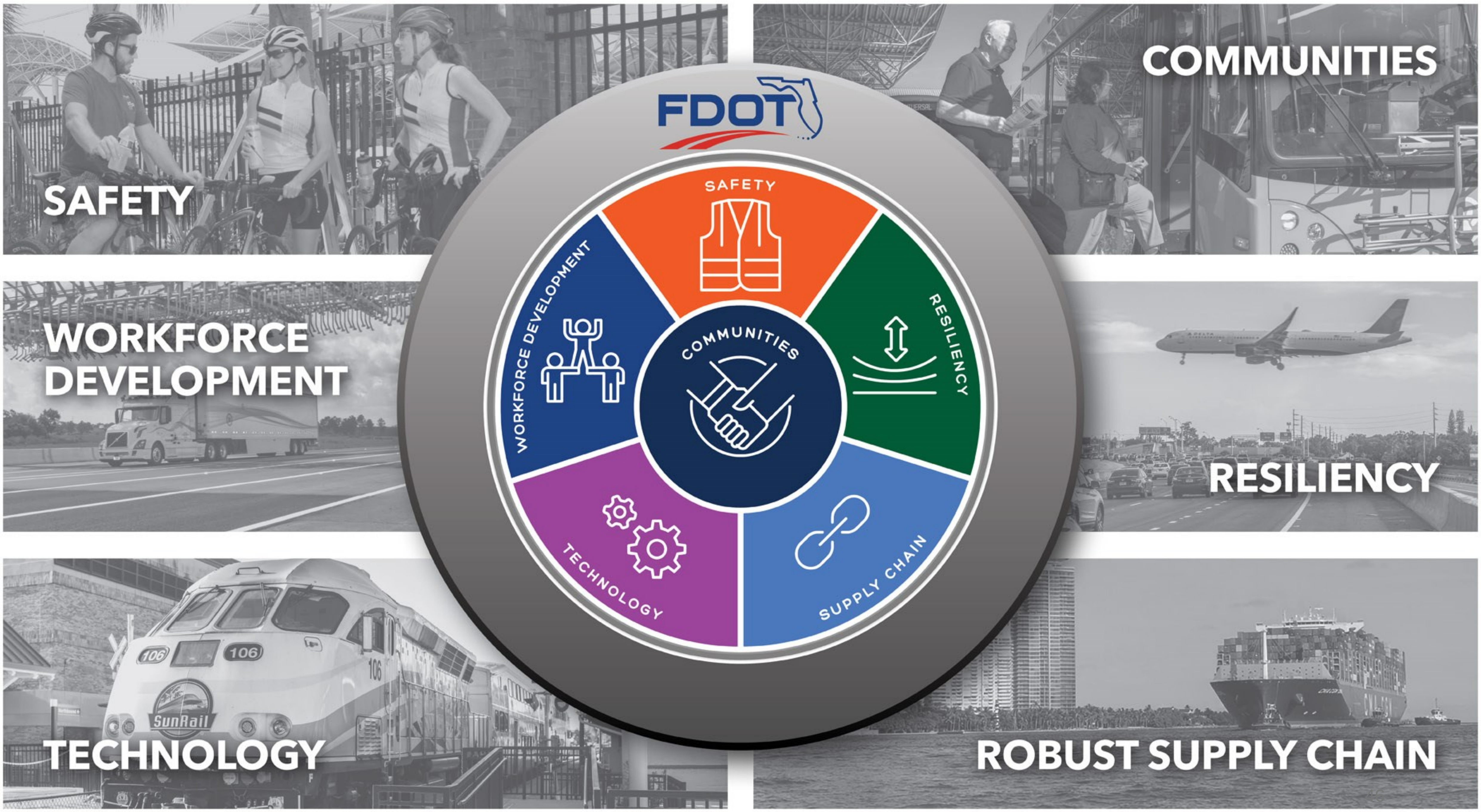
- Overview
- Usage Restrictions / Parameters
- Design Criteria
- Specifications
- Standards
- Producer Quality Control Program
- Projects
- Technology Transfer (T[2])
- FDOT Research
- Contact

NSERC CRSNG MIAMI FDOT

NO text.
NO call.
NOTHING
is worth losing a life over.

PUT IT DOWN
IT'S THE LAW

Steven Nolan, P.E.
State Structures Design Office
Florida Department of Transportation
Email: steven.nolan@dot.state.fl.us
Office #: 850-414-4272
Website: https://www.fdot.gov/design/Innovation/

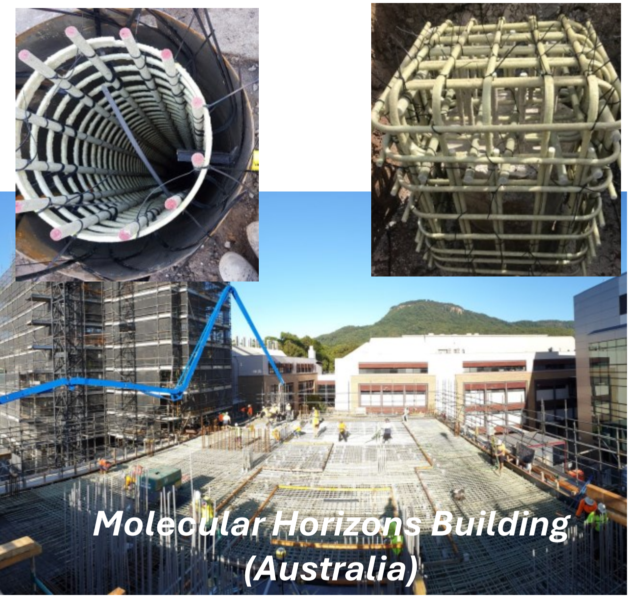


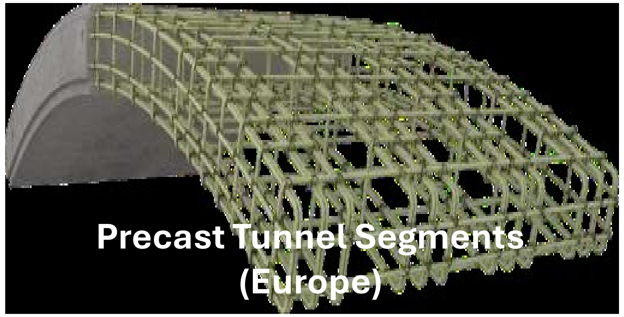
SAFETY
COMMUNITIES
WORKFORCE DEVELOPMENT
RESILIENCY
TECHNOLOGY
ROBUST SUPPLY CHAIN
FDOT
SAFETY
RESILIENCY
SUPPLY CHAIN
TECHNOLOGY
WORKFORCE DEVELOPMENT
COMMUNITIES

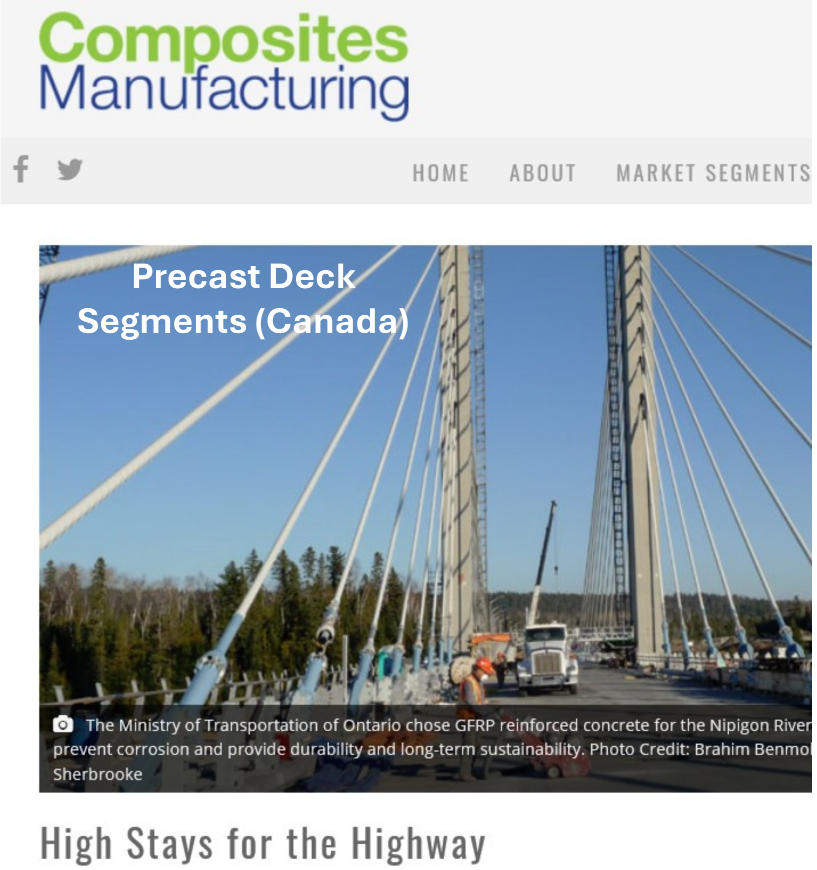
FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

***August 8-9th, 2024.** Toronto, ON.*







Archival webpage:
https://www.fdot.gov/structures/innovation/iwfrpcs4

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

Michigan DOT Implementation of FRP Prestressing

Steven Nolan, PE.

Presented on behalf of Matt Chynoweth, RS&H (former State Bridge Engineer and AASHTO CBS T6 Chair)

SPONSORED BY:

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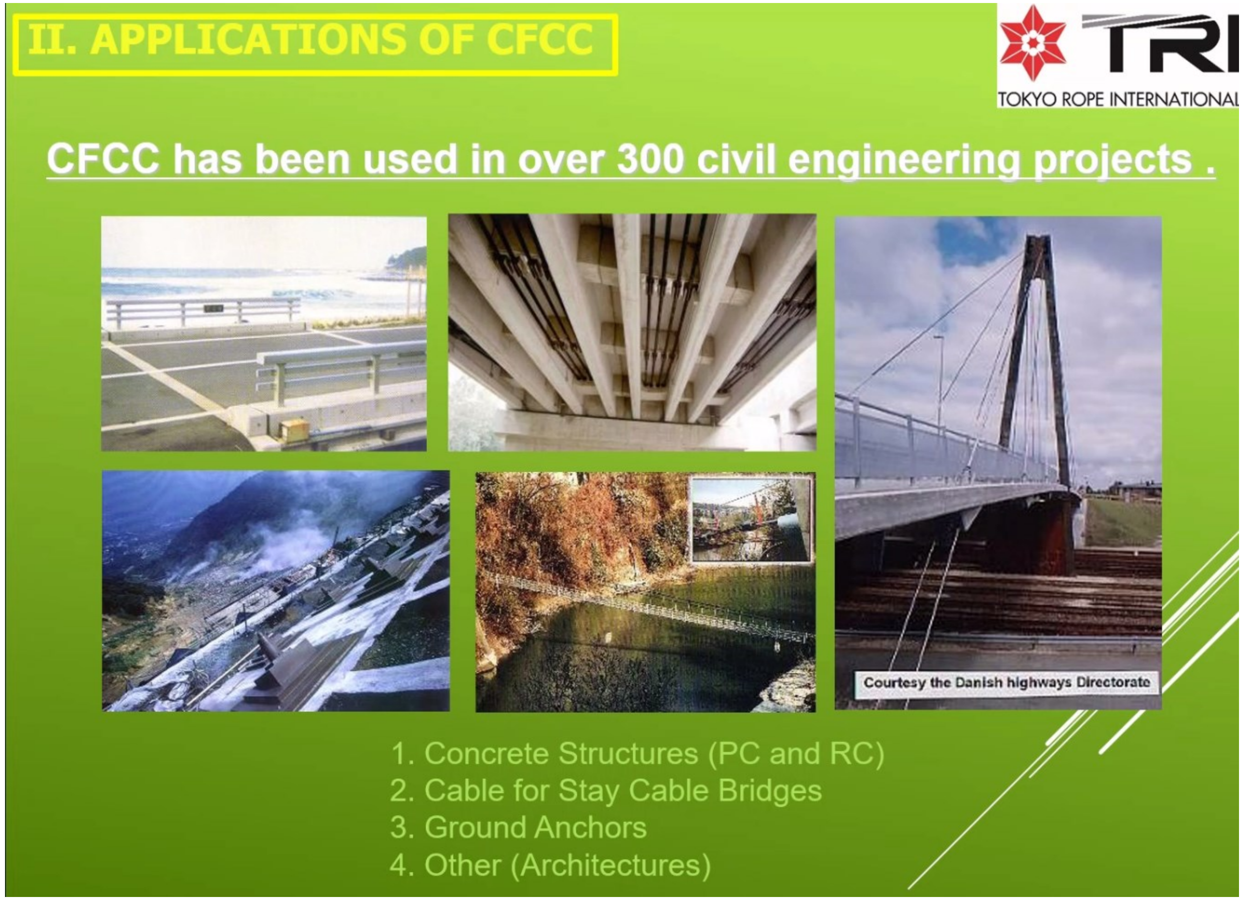
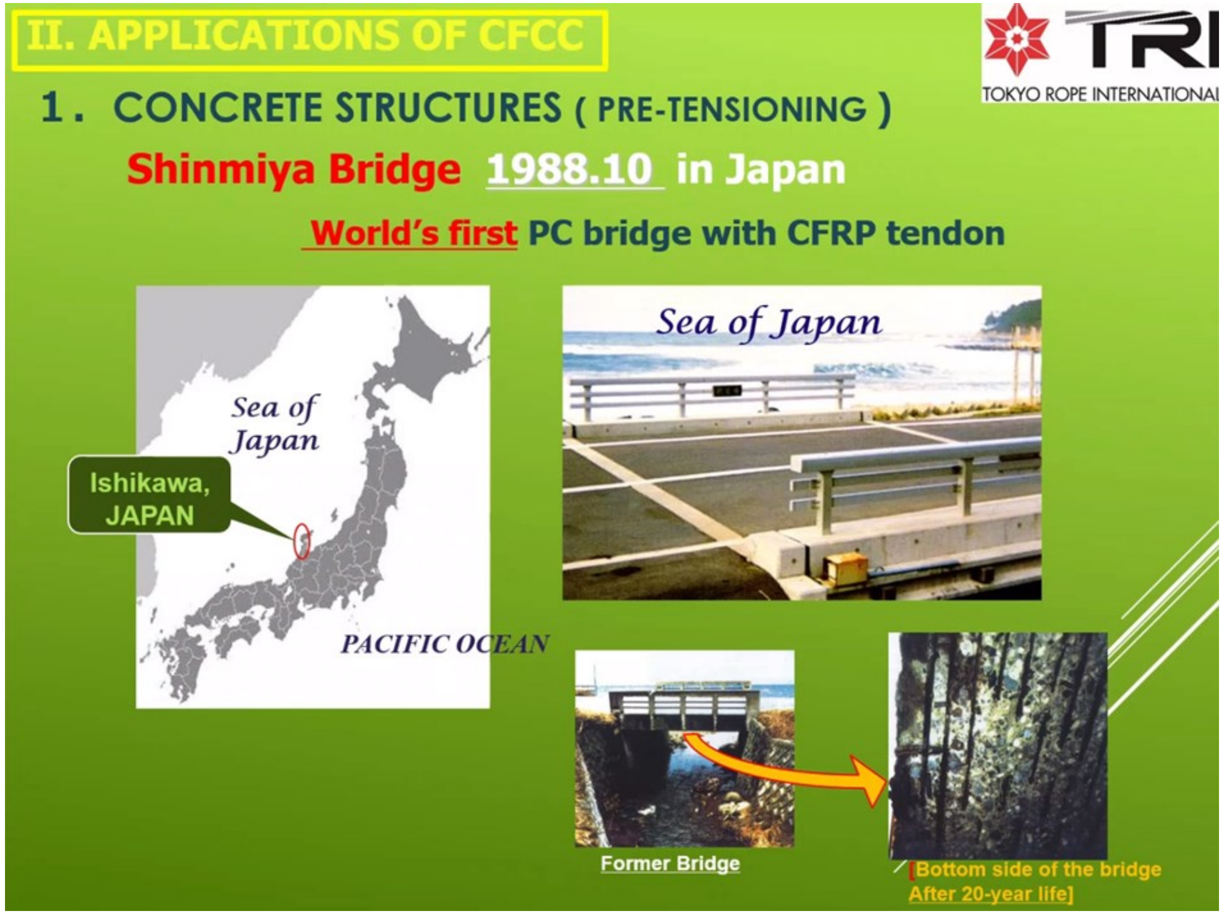
UNIVERSITÉ DE SHERBROOKE NSERC CRSNG UNIVERSITY OF MIAMI Center for Integration of Composites into Infrastructure FDOT

1980's: CFRP Prestressing Strand

- CFCC: Developed in Japan with first prestressed bridge application in 1988





1980's: CFRP Prestressing Strand

- CFCC: Developed in Japan with first prestressed bridge application in 1988

2000's: CFRP Prestressing Strand

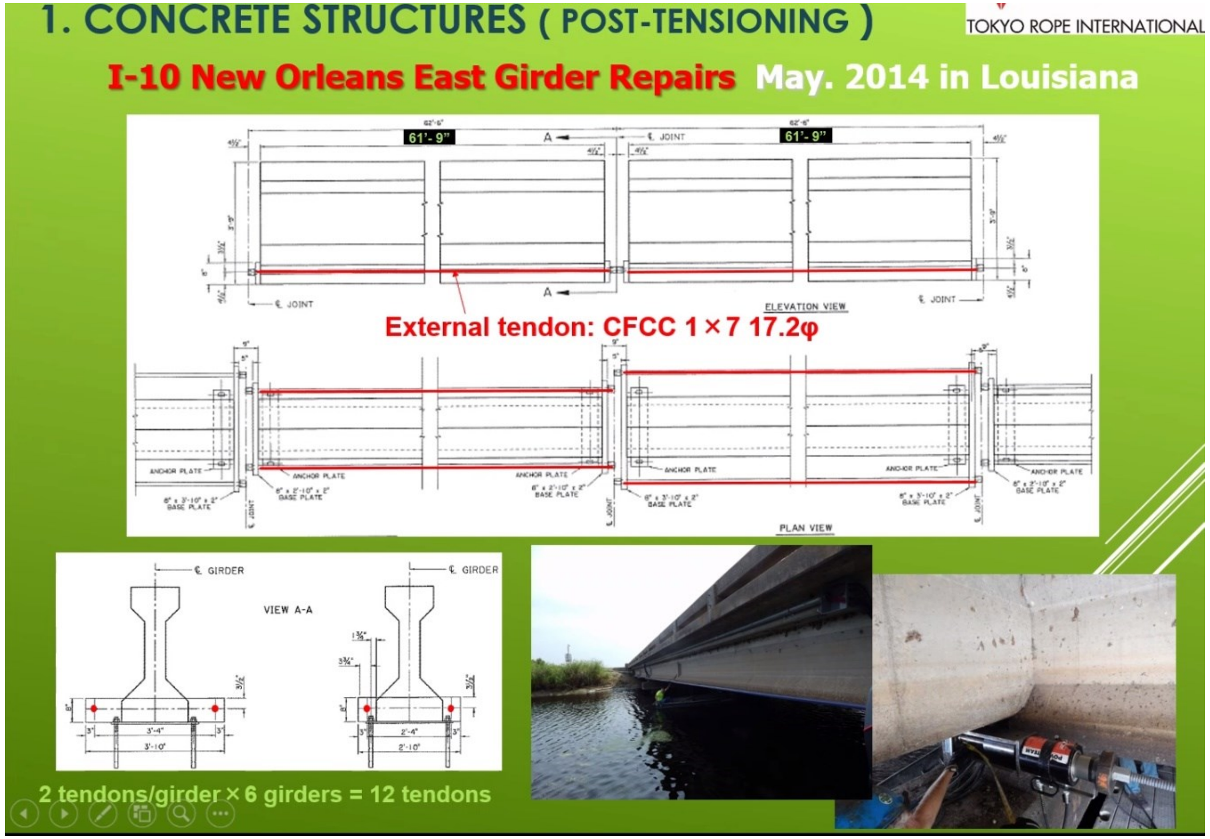
- CFCC: First USA bridge application in Michigan in 2001 – Post-Tensioning

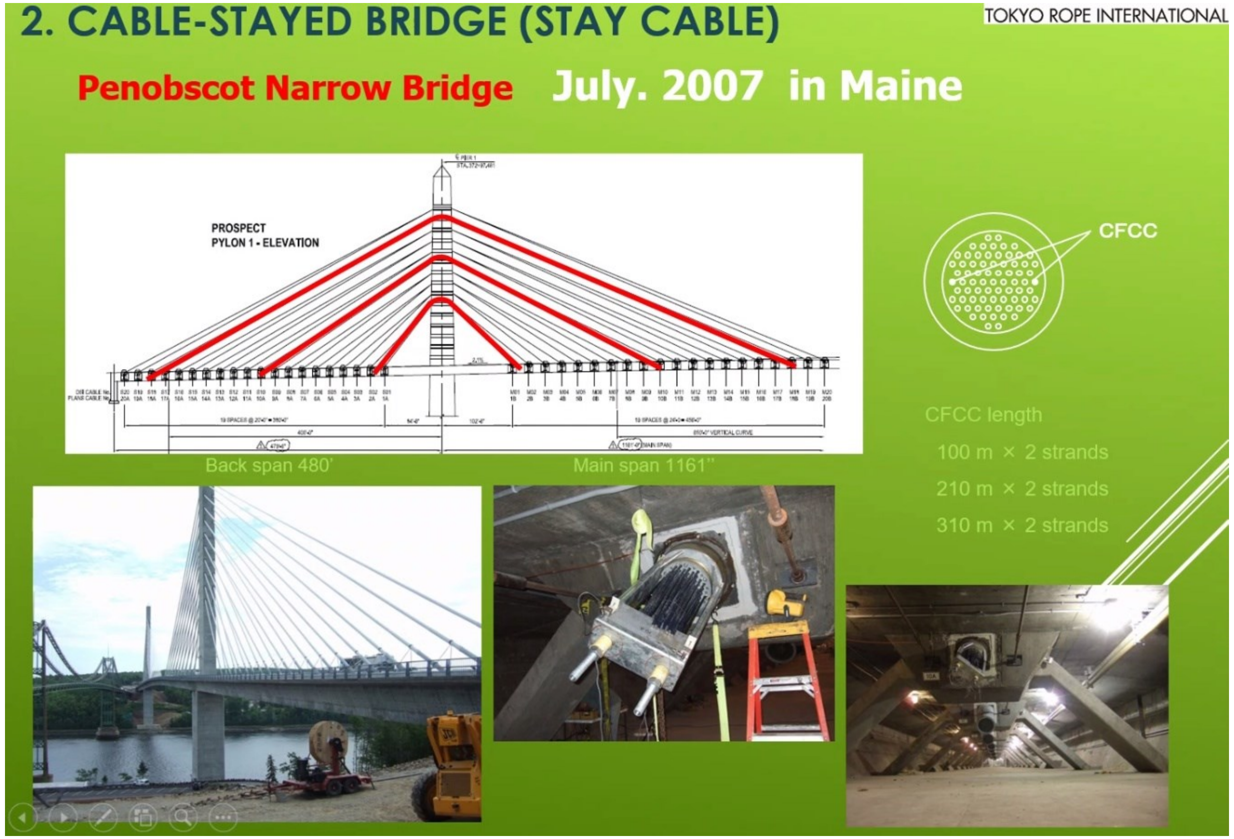
2010's: CFRP Prestressing Strand

- 2012 (Maine) & 2012-13 (Virginia)

2010's: CFRP Prestressing Strand

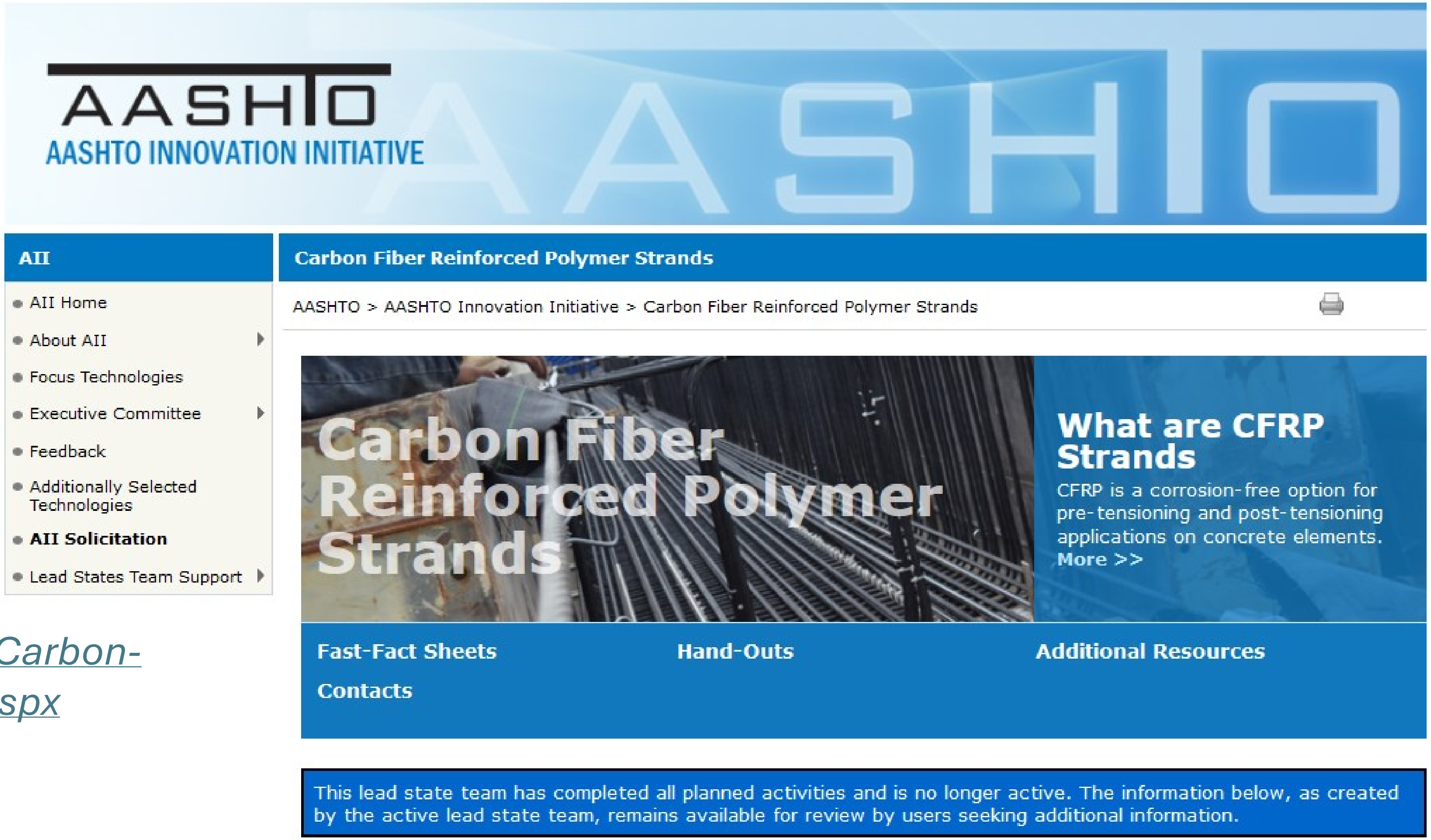
- 2014 (Louisiana) & 2016 (Maine)





2010's: CFRP Prestressing Strand

- AASHTO Innovation Initiatives



https://aii.transportation.org/Pages/Carbon-Fiber-Reinforced-Polymer-Strands.aspx

2010's: CFRP Prestressing Strand & Bars

- MDOT Project Fast Facts

- [MDOT Implementation of Carbon Fiber Technology [PDF]]
2014 MAASTO Annual Meeting
(July 2014)

A.I.I. | AASHTO Innovation Initiative

FAST FACTS:

Carbon Fiber Reinforced Polymer Strands

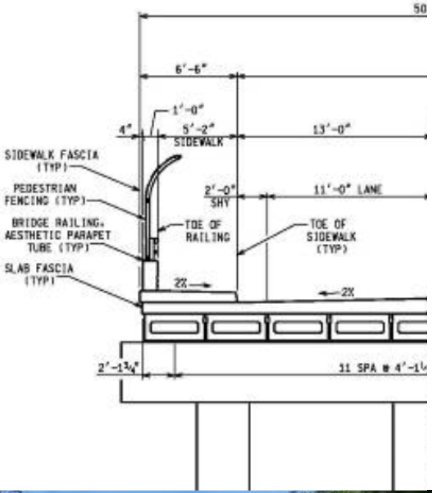
PROJECT LOCATION:	Detroit, Michigan
AGENCY:	Michigan DOT
URL:	aii.transportation.org (select *Carbon Fiber Reinforced Polymer Strands)*
PROJECT NAME:	Pembroke Avenue over M-39 Superstructure Replacement
PROJECT DESCRIPTION:	Replacement of an existing pre-stressed I-beam superstructure with a side-by-side pre-stressed box beam superstructure, transversely post-tensioned with CFRP tendons, and containing CFRP deck reinforcement.
PROJECT PURPOSE AND NEED:	In 2011, the Michigan Department of Transportation reconstructed a three-mile segment of the depressed urban freeway M-39 in the cities of Detroit and Southfield. As part of that project, several local roadway bridges over M-39 were replaced or rehabilitated. Many of the bridges were simple span configurations with open joints and severe steel deterioration due to years of exposure. MDOT chose a bridge connecting two neighborhoods in which to replace the superstructure with durable, non-corrosive CFRP deck reinforcement and CFRP transverse post-tensioning tendons. The deck reinforcement required little concrete cover, and the post-tensioning tendons did not have to be grouted in the duct.

A.I.I. | AASHTO Innovation Initiative

FAST FACTS:

Carbon Fiber Reinforced Polymer Strands

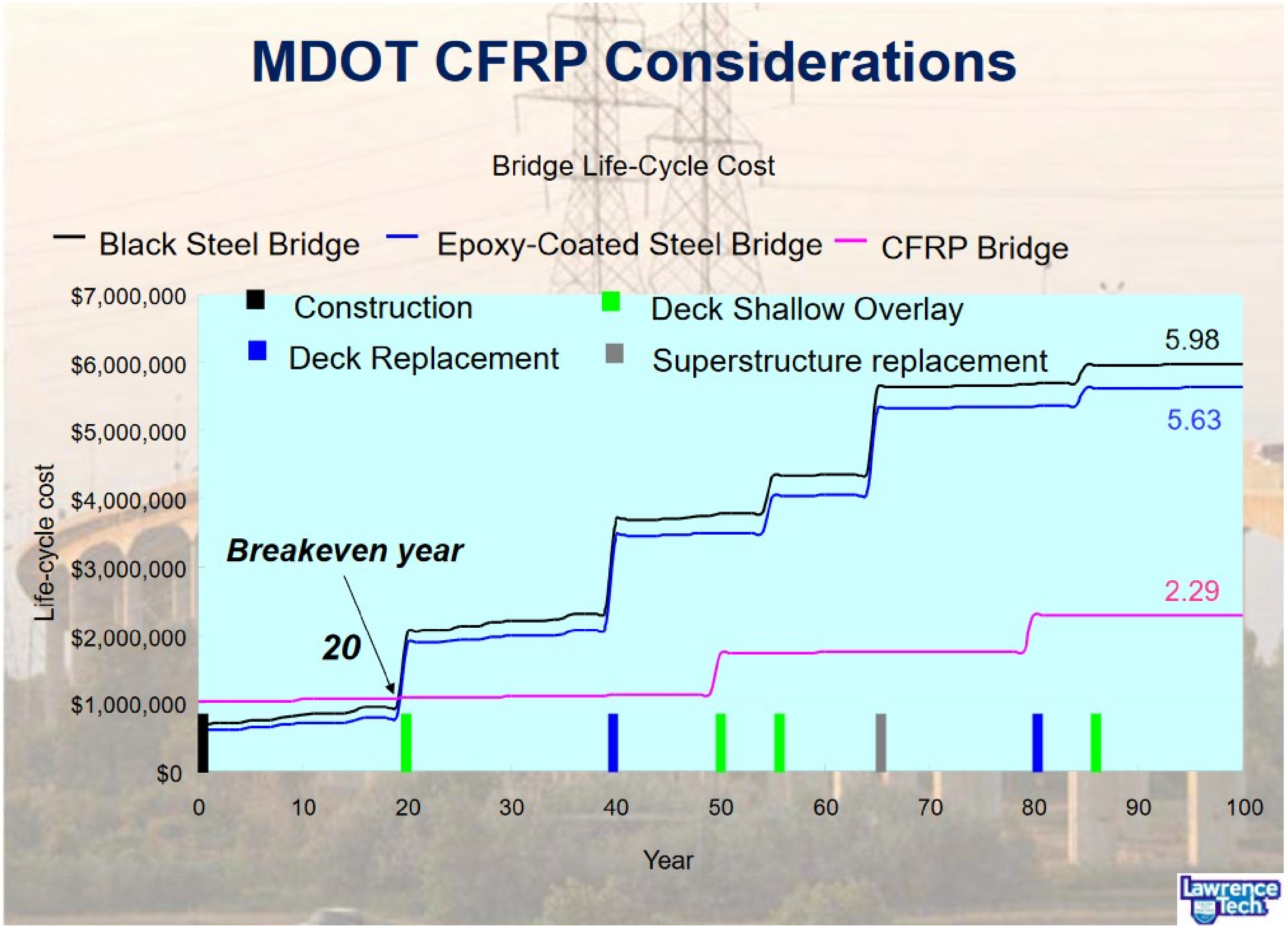
PROJECT LOCATION:	Detroit, Michigan
AGENCY:	Michigan DOT
URL:	aii.transportation.org (select *Carbon Fiber Reinforced Polymer Strands)*
PROJECT NAME:	M-102 over Plum Creek Bridge Replacement
PROJECT DESCRIPTION:	Replacement of an existing earth-filled arch culvert with a pre-stressed spread box beam superstructure, pre-stressed and reinforced with carbon fiber reinforced polymer (CFRP) strands. The beams contain no steel materials.
PROJECT PURPOSE AND NEED:	In 2013, the Michigan Department of Transportation replaced an existing earth-filled arch culvert on M-102 (8 Mile Road) with a CFRP pre-stressed spread box beam structure. M-102 is a major urban route the city of Detroit, with four lanes of traffic in direction. Working on this route presents a m impact to regional mobility, so the decision to durable, non-corrosive materials was deliber made to ensure that life cycle rehabilitation a can be delayed for as long as possible. The box beams are pre-stressed with CFRP stra contain CFRP shear stirrups and mild reinfor The bridge deck is also reinforced with CFRI reinforcement. Each bridge consists of a sing span, with eight 33" deep by 48" wide, pre-st spread box beams.



M-50/US-127 BR over NS RR Bridge Replacement →

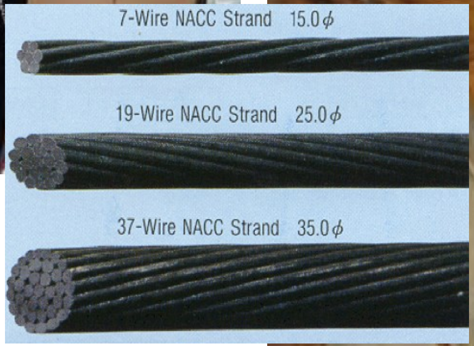
2010's: CFRP Prestressing Strand

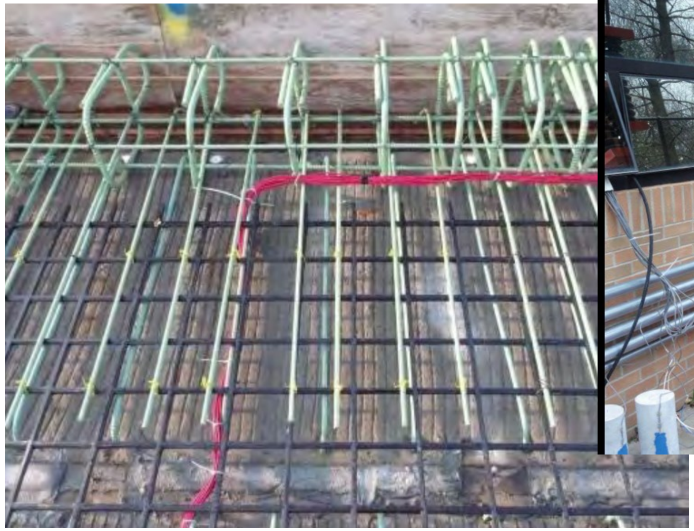
- MDOT Supported Research & Advocacy



2010's: CFRP Prestressing Strand & Bars

- MDOT Projects and Supporting Research





concrete creep testing

2020's: CFRP Prestressing Strand

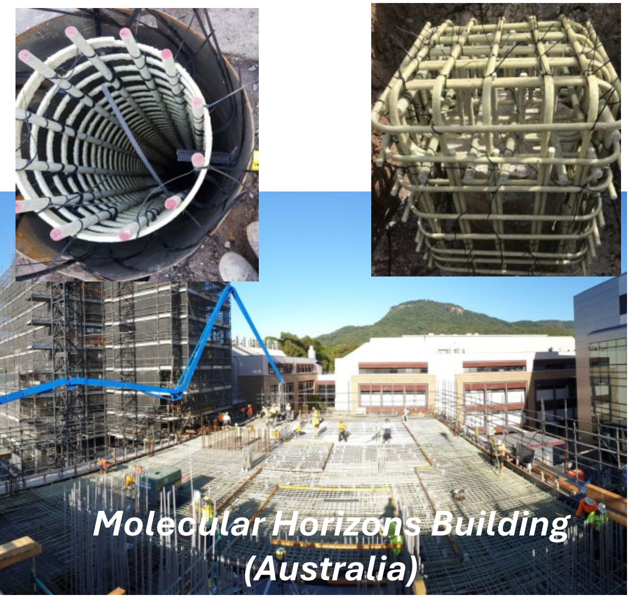
- MDOT Continuing Supporting Research

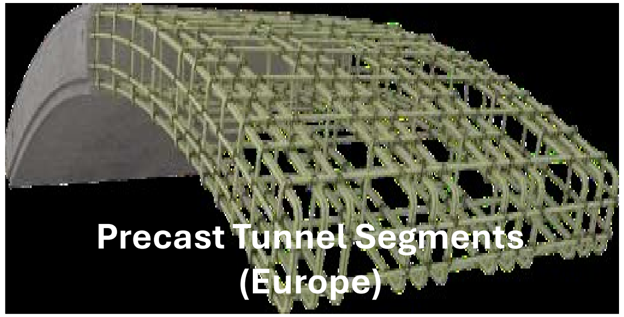
MDOT
Michigan Department of Transportation
BRIDGE FIELD SERVICES

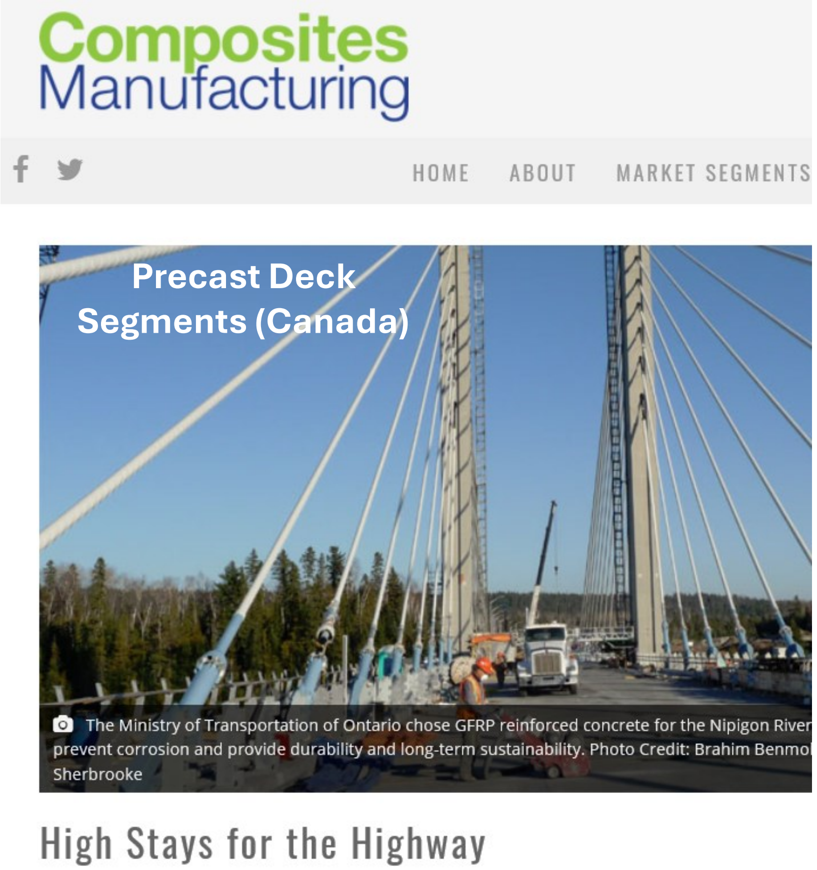
Evaluating Long Term Capacity & Ductility of Carbon Fiber Reinforced Polymer Prestressing & Post Tensioning Strands
Project Number: SPR-1690
Contract Number: 2013-0065 Z2
Status: Complete. Start Date: 10/01/2013, End Date 09/30/2019

Influence of Revising CFCC Guaranteed Strength on Performance of CFCC Prestressed Highway Bridge Beams Subjected to Various Environmental Conditions
Project Number: OR21-018
Project Manager: Steve Kahl
Principal Investigator: Nabil Grace (Lawrence Technical University)

Statewide Overall Carbon Fiber Composite Cable Bridge Monitoring
Research Manager: André Clover
Project Number: OR14-039
Project Manager: Steve Kahl
Principal Investigator: Nabil Grace (Lawrence Technical University)







Archival webpage:
https://www.fdot.gov/structures/innovation/iwfrpcs4

NORTH CAROLINA
Department of Transportation

Fiber Reinforced Polymer Technology – NCDOT History and Vision

W. Cabell Garbee, II, PE
NCDOT Manufactured Products Engineer
August 2024

History in North Carolina

- 2005 – Glass Fiber Reinforced Polymer (GFRP) Bridge Decks
- 2014 – NCDOT/NCSU Research Project 2014-09: *CFRP Strands in Prestressed Cored Slab Units*
- 2017 – Transportation Pooled Fund Research Project – 5(363): *Evaluation of 0.7 inch Carbon Fiber Reinforced Polymer Pretensioning Strands in Prestressed Beams*
- *2021 Harkers Island Replacement Bridge*
    - *3200 ft long, No Structural Steel Reinforcement, Uses GFRP bars and CFRP strands*
- *2023 Brunswick County NC 179B over Calabash River*
    - *FRP Reinforced 20" Square Concrete Piles*
    - *FRP Reinforced End Bents*

In Progress/Proposed in North Carolina

- *2024 Tyrrell/Dare County (Alligator River), ~3 miles long*
  - *FRP Reinforced Square Concrete Piles and Cylinder Concrete Piles*
  - *FRP Reinforced Deck (supplier proposal)*

- *2028 New Hanover County (Wrightsville Beach – 3 Bridges)*
  - *FRP Reinforced Superstructure and Substructure*

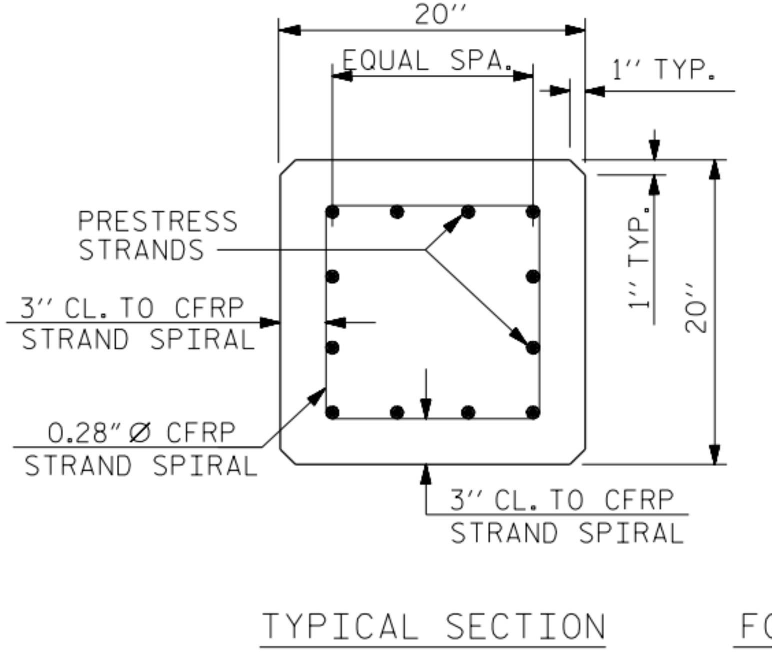
- *TBD New Hanover County (Cape Fear River – Memorial Bridge Replacement)*
  - *FRP Reinforced Substructure*

Brunswick County Bridge Project

Beach Drive SW (NC 179 Business over Calabash River)
Structure: 576 Feet
  Two 12’ lanes with 4’ Shoulder Northbound and 10’ Multi-Use Path Southbound
  Replaces bridge built in 1975
Let May 2023

Piles: 20” Square
  CFRP Spiral
  CFRP Strand

Pile Caps:
  GFRP Bar



Alligator River Bridge Project

Replace Lindsay C. Warren Bridge, US64 over Alligator River in Tyrrell and Dare Counties built in 1960 with Swing Span over Intercoastal Waterway.

Letting: 2024

Proposed:

- Fixed span with 65’ vertical navigation clearance
- Two, 12’ lanes with 8’ shoulders
- Length approximately three miles
- One of Nine FHWA MegaGrant Projects, $110 Million Grant

Piles: 36” Square
- 54” Cylinder
- CFRP Spiral
- CFRP Strand

Pile Caps, Columns, Footings:
- GFRP Bar

GFRP Supplier Proposal to use in Bridge Deck

Cape Fear Memorial Bridge Project

Replace Existing Lift Bridge, 3000FT Long, 408FT Lift Span
Carrying US 17/US 76/US 421 over Cape Fear River
Opened 1969, Deck Rehabilitated in 2024

Letting: TBD
Proposed:
- 135-foot-high fixed span bridge (same as existing lift span clearance)
- FHWA MegaGrant Projects, $242 Million Grant

Wrightsville Beach Bridge Project

Replace 2 Bridges Carrying US 74 & 1 Bridge Carrying US 76 over Banks Channel

US 74 Bridges Built in 1957 & US 76 Bridge Built in 1972

Letting: 2028
Proposed:
- Structure Lengths 100’, 630’, 860’
- Two 12’ lanes with 6’ Shoulder and 12’ Multi-Use Path each bridge

Proposed in North Carolina

Discussion (Future Bridge Projects)
- Deck Reinforcement
  - western counties/areas of heavy salt use
  - coastal areas with seawater exposure
- Substructure Reinforcement
  - coastal areas with seawater exposure

Discussion (Roadway Projects)
- Continuously Reinforced Concrete Pavement
  - (demonstration/research project)
- Barrier
  - slipformed median barrier areas of heavy salt use

Harkers Island Bridge Project Vision

- Cast-in-place Concrete (Superstructure & Substructure)
  - Glass Fiber Reinforced Polymer (GFRP) Bars

- Prestressed Concrete Girders
  - Carbon Fiber Reinforced Polymer (CFRP) Strands
  - GFRP Stirrup Option (utilized)
  - CFRP Stirrup Option

- Prestressed Concrete Piles
  - CFRP Strands
  - CFRP Spiral

- “NO” Steel Reinforcement
  - Steel ONLY in the Railing (MASH compliance)

Harkers Island

Harkers Island, NC

No in-water, seabottom disturbance, work allowed from April 1 through September 30

Prime Contractor:
Balfour Beatty Infrastructure Inc

Prestress Concrete:
Coastal Precast Systems Inc

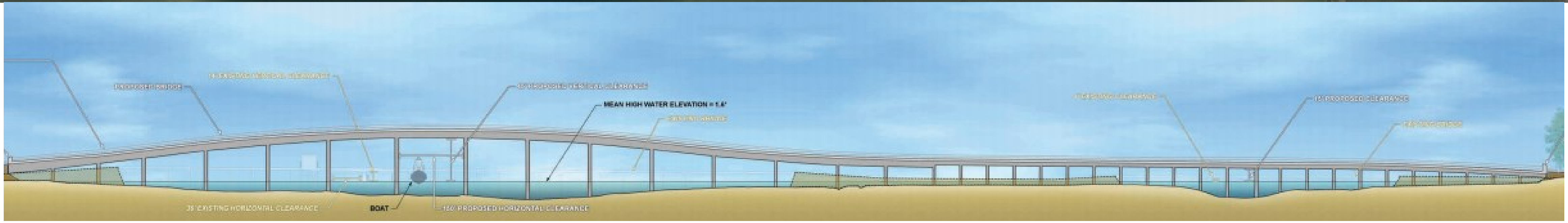
Availability: August 30, 2021
Completion: October 28, 2025

Bridge No. 96

- Built 1970
- Superstructure Replacement 2013
- Functionally Obsolete

Bridge No. 73

- Built 1969
- Posted SV 24, TTST 37
- Structurally Deficient

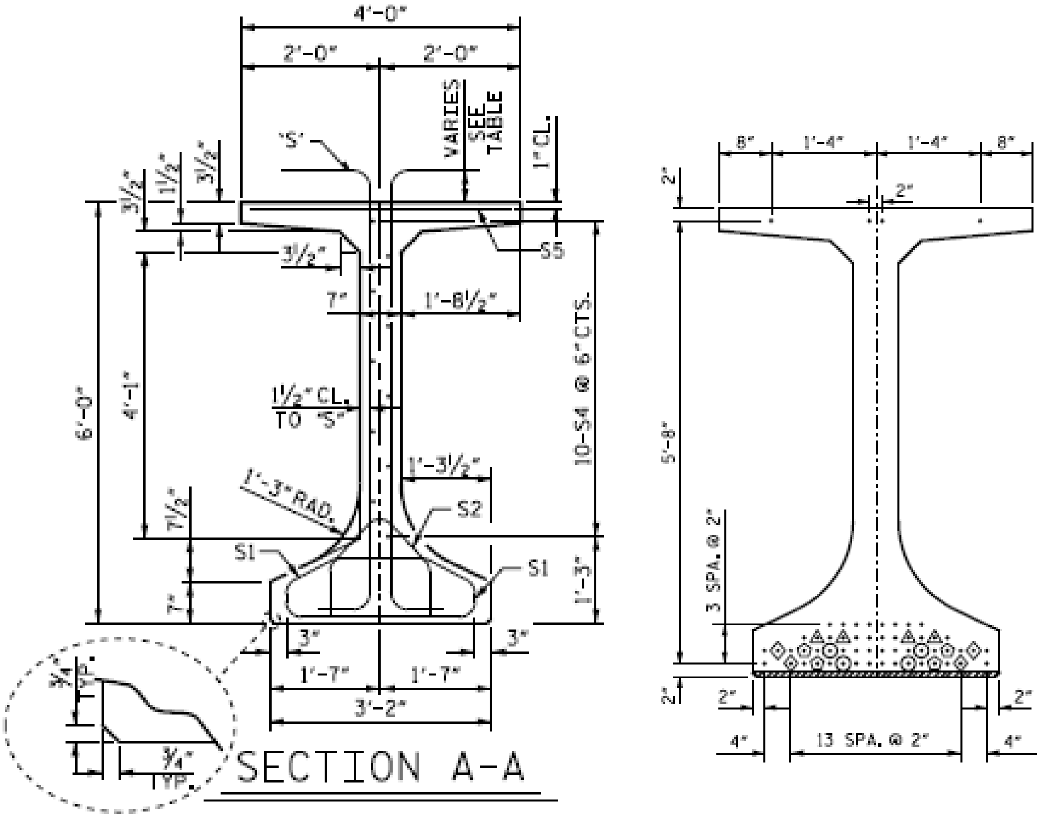


Proposed Structure: 3,200’-0”
28 Spans

Harkers Island Bridge Project Quantities

- CFRP Prestressing Strand:
  - Girders: 650,000 Linear Feet
  - Piles: 325,000 Linear Feet

- GFRP Reinforcement:
  - Superstructure: 715,000 Linear Feet
  - Substructure: 200,000 Linear Feet



Harkers Island Project Material Approvals:

1. NCDOT Product Evaluation (Approved Product List)
2. *NCDOT Vendor Approval (Tokyo Rope, Owens Corning-Mateenbar)*
   Producer Facility Audit (FRP Institute for Civil Infrastructure)

3. Project Acceptance Testing (NCSU)

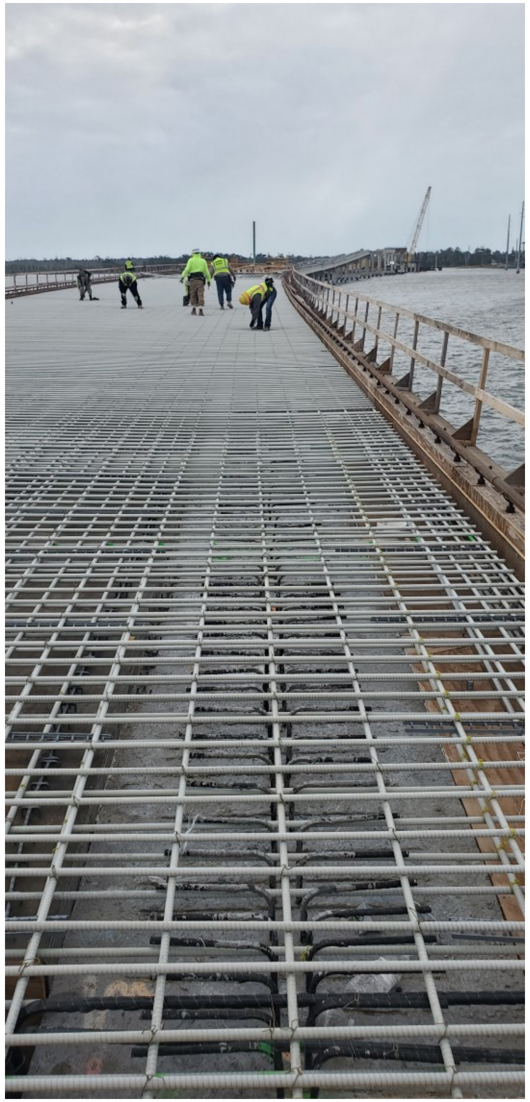
FRP INSTITUTE for CIVIL INFRASTRUCTURE
FRP
2022

NC STATE UNIVERSITY

Pile production and shipment at Coastal Precast Systems Chesapeake, VA

Production of 54” FIB at Coastal Precast Systems Wilmington, NC

March 31, 2022. Mid-channel. End of phase one piles.



November 9, 2022

Glass Fiber Reinforced Polymer (GFRP) Bars

November 9, 2022
Piles, Caps, Beams…

April 27, 2023

Traffic shift to new structure expected Fall 2023.

November 9, 2022
Piles, Caps, Columns, Beams…

November 2023

Questions?

W. Cabell Garbee, II, PE
NCDOT Manufactured Products Engineer
1801 Blue Ridge Road, Raleigh, NC 27607
cgarbee@ncdot.gov

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

Use of FRP Reinforcing in Bridges in Oregon

Tanarat Potisuk

Oregon Department of Transportation

SPONSORED BY:

PULTRALL V-ROD FIBERGLASS innovations
ALTAIR
MST BAR MAXIMUM STRENGTH GFRP
SFTec
ACMA American Composites Manufacturers Association FRP Rebar Manufacturers Council
UNIVERSITÉ DE SHERBROOKE
NSERC CRSNG
UNIVERSITY OF MIAMI
Center for Integration of Composites into Infrastructure
FDOT

ODOT Bridge Design Manual

- **BDM 1.5.5.16**

Table 1.5.5.16-1 Material Properties for Design of GFRP Reinforced Concrete

Material Property	Material Value
Ultimate tensile strength (ksi)	90 ksi (#4 - #6) 75 ksi (#7 - #10)
Tensile modulus of elasticity (ksi)	6,500
Ultimate tensile strain (inch/inch)	0.011

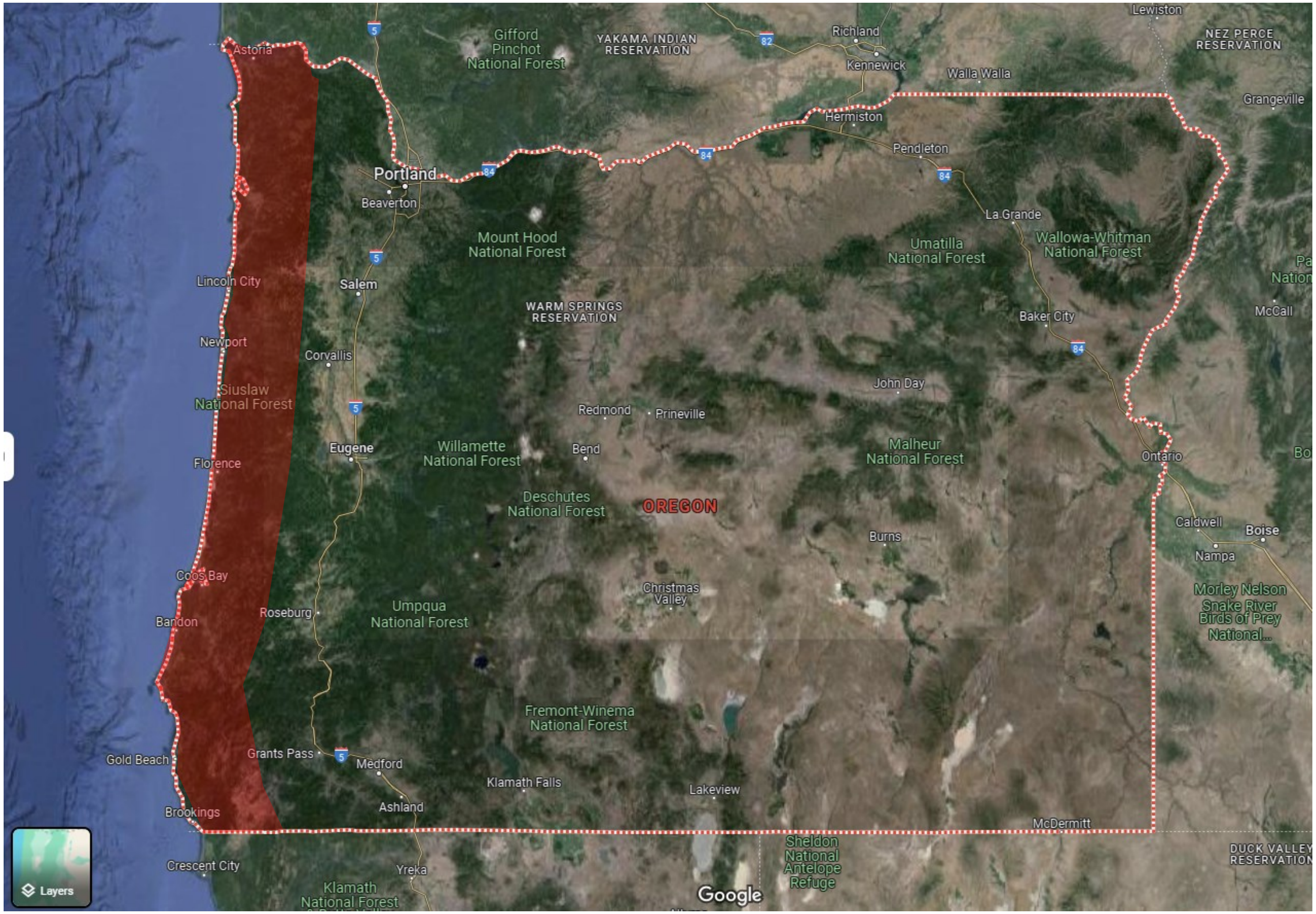
GFRP reinforcement is recommended for structural members that are located in corrosive environment and do not require high ductility. Service limit states often control design over strength limit states. Use GFRP reinforcement only in the following structural members:

- Bridge deck.
- Sound walls.
- Seawalls.
- Bridge Approach Systems.

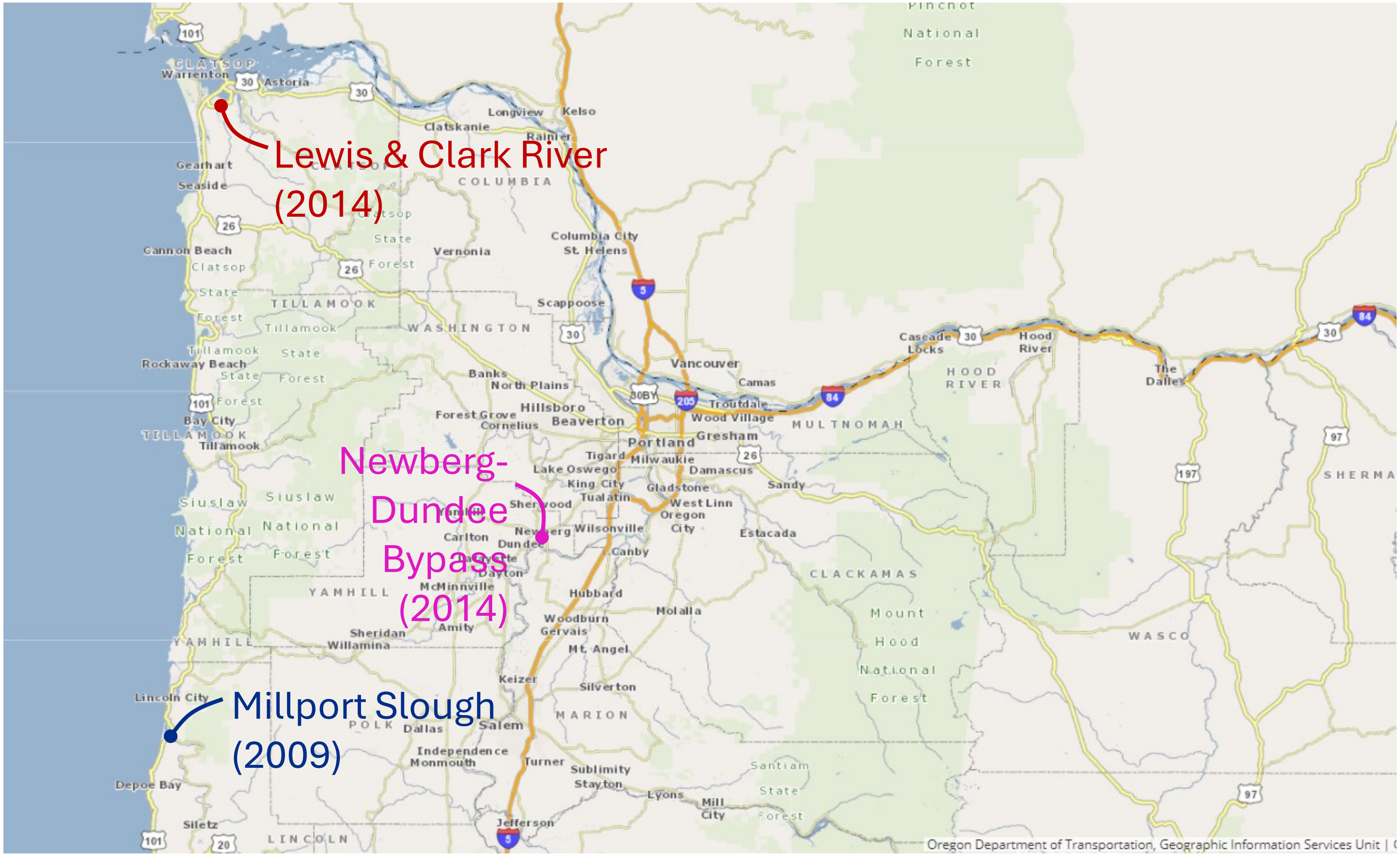
Concerns

- **Ductility for seismic event and vehicular impact (Extreme Event I and II)**
- **Abrasion resistance**

ODOT Bridge Design Manual

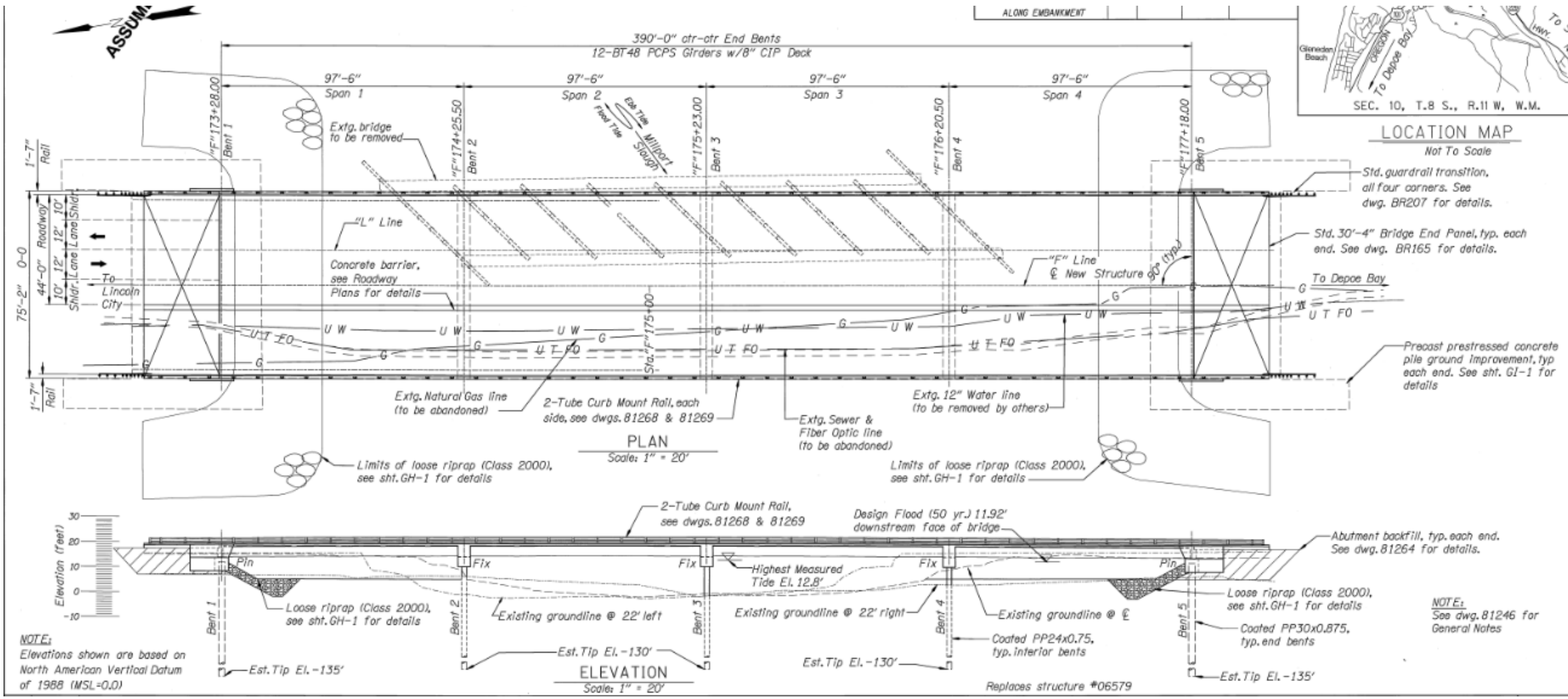


Bridges with GFRP Bars



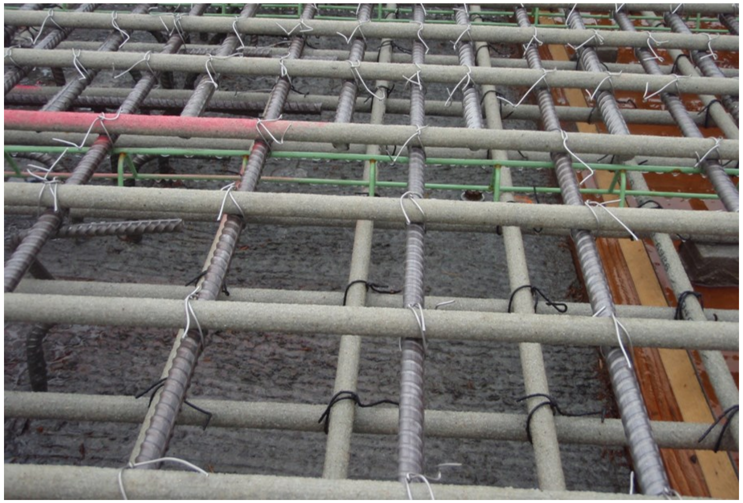
Bridges with GFRP Bars

- **Millport Slough, Hwy 9 (built 2009)**



Bridges with GFRP Bars

- Millport Slough, Hwy 9 (built 2009)



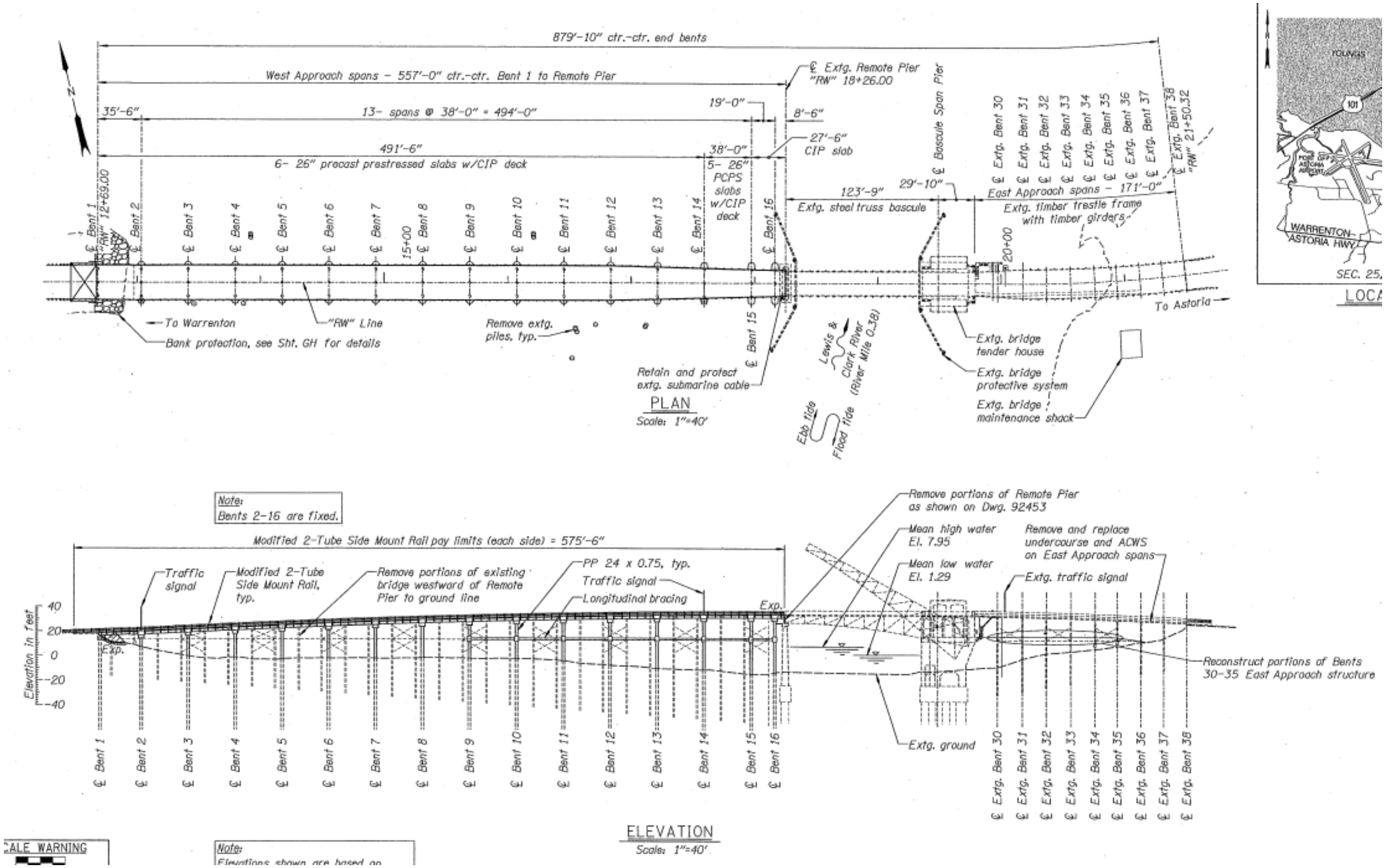
06/07/2023

NBI Category

Category	NBI #	Rating
Deck Condition	58	7 Good
Superstructure	59	8 Very Good
Substructure	60	7 Good
Channel	61	8 Protected
Culvert/Retaining Walls	62	N N/A (NBI)

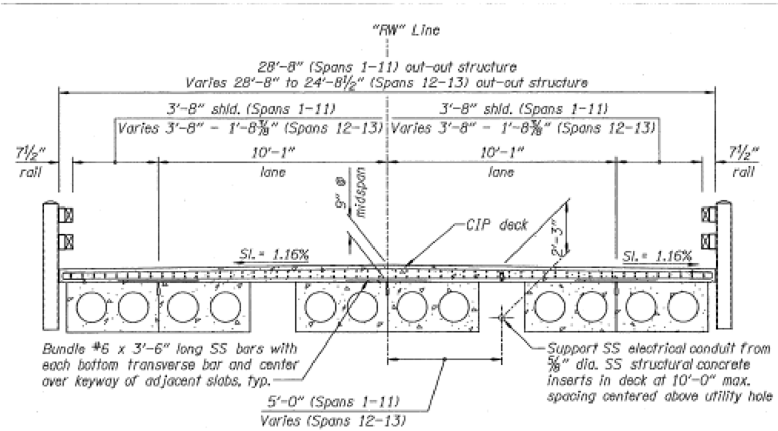
Bridges with GFRP Bars

- **Lewis and Clark River (Rehab in 2014)**

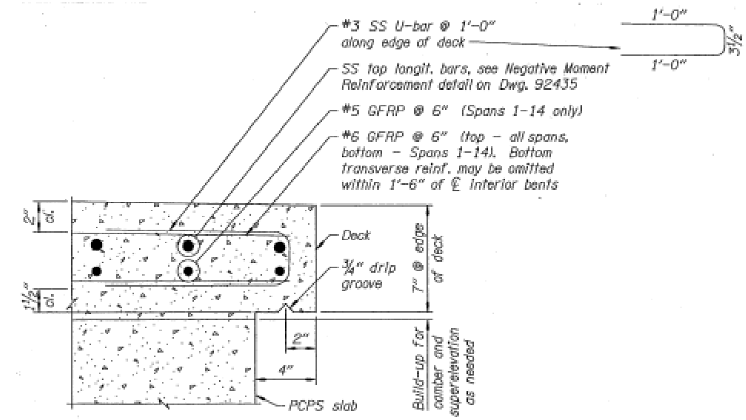


Bridges with GFRP Bars

- **Lewis and Clark River (Rehab in 2014)**



TYPICAL SECTION - SPANS 1-11
(SPANS 12-13 SIMILAR)
Scale: ⅜" = 1'-0"



DECK OVERHANG AND REINFORCEMENT
Scale: 3"=1'-0"

Bridges with GFRP Bars

- **Lewis and Clark River (Rehab in 2014)**

Bridges with GFRP Bars

- **Lewis and Clark River (Rehab in 2014)**

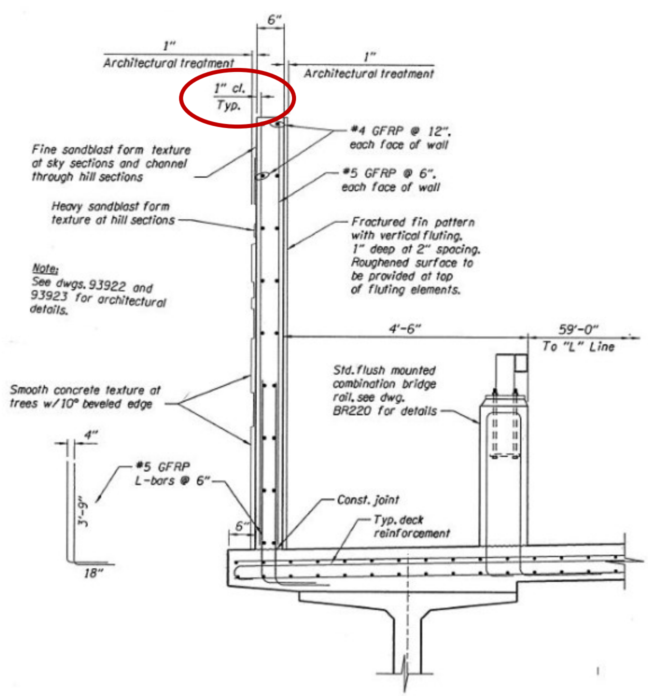
05/07/2024

NBI Category

Category	NBI #	Rating
Deck Condition	58	6 Satisfactory
Superstructure	59	5 Fair
Substructure	60	4 Poor
Channel	61	7 Minor Damage
Culvert/Retaining Walls	62	N N/A (NBI)

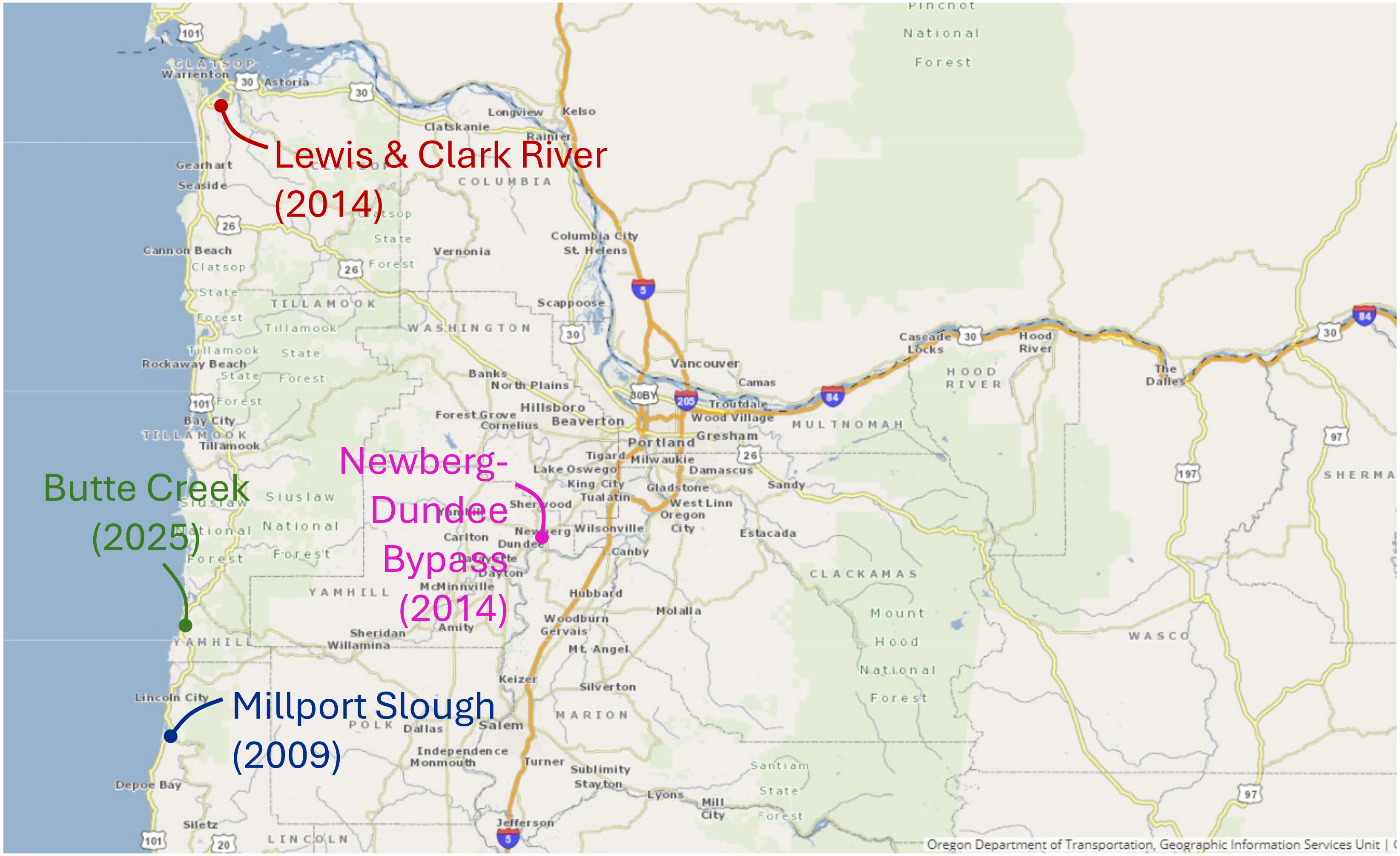
Bridges with GFRP Bars

- **Newberg Dundee Bypass – Sound Wall (2014)**



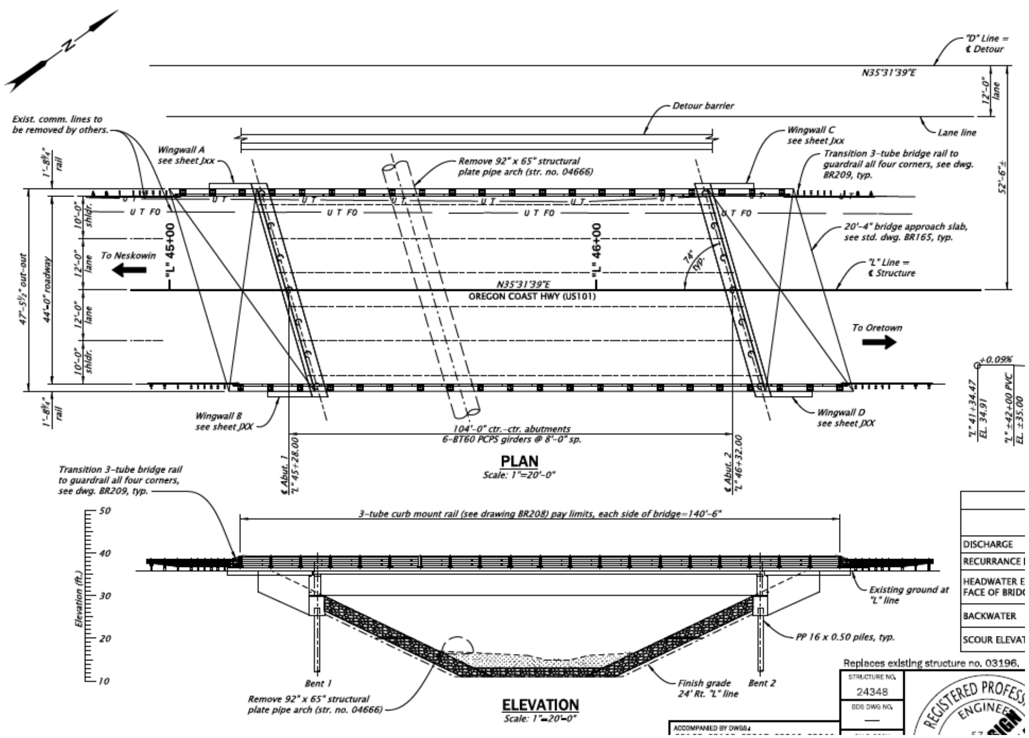
SECTION AT BRIDGE
Scale: ½"=1'-0"

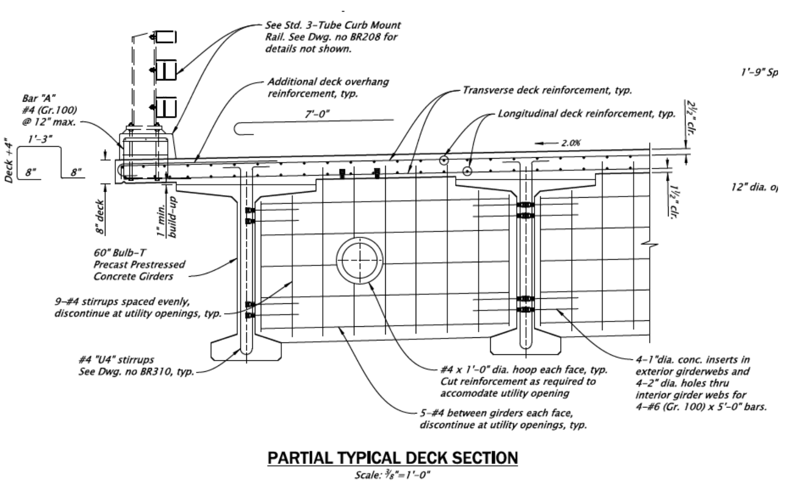
Bridges with GFRP Bars



Bridges with GFRP Bars

- **Butte Creek (bid and construction in 2025)**





Bridges with GFRP Bars

Year	Structure	Bar Size	Quantity
			ft
2009	Millport Slough	#5	53,500
		#6	121,500
2014	Lewis & Clark River	#5	33,135
		#6	57,326
2014	N-D Bypass Sound Wall	#4	40,436
		#5	109,085
2025	Butte Creek	#5	24,200
		#6	18,500

Bridges with GFRP Bars

Year	Structure	Bar Size	GFRP	Black Bar		Stainless steel	
			$/ft	$/lb	$/ft	$/lb	$/ft
2009	Millport Slough	#5	1.12	1.1	1.15	4.37	4.56
		#6	1.48	1.1	1.65	4.37	6.56
2014	Lewis & Clark River	#5	1.36	NA	NA	4.54	4.74
		#6	1.66	NA	NA	4.54	6.82
2014	N-D Bypass Sound Wall	#4	1.76	0.84	0.56	NA	NA
		#5	1.53	0.84	0.88	NA	NA

Project Special Provision

- Performance specifications using ASTM D7957
- Will be made standard construction specifications soon
- Will add ASTM D8505 in ODOT BDM and standard construction specifications

Thank you

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

Use of FRP Reinforcing in Poland

Prof. dr hab. eng. Renata Kotynia

Lodz University of Technology

SPONSORED BY:

PULTRALL V-ROD FIBERGLASS Innovations ALTAIR MST BAR MAXIMUM STRENGTH GFRP SFTec ACMA American Composites Manufacturers Association FRP Rebar Manufacturers Council

UNIVERSITÉ DE SHERBROOKE NSERC CRSNG UNIVERSITY OF MIAMI Center for Integration of Composites into Infrastructure FDOT

Content:

1. FRP Materials

2. Design standards

3. PhD thesis

4. Field applications

To replace traditional steel reinforcement **Fiber Reinforced Polymer (FRP) bars** are made of continuous fibres impregnated with polymeric resins in the pultrusion process in which the fibres are pulled and impregnated before curing in a heated die.

Bond behaviour between FRP bars and concrete depends on:

- a type of bars (GFRP, AFRP, BFRP, CFRP)
- the surface preparation
- bars geometry (shape and diameter)
- mechanical interaction, chemical adhesion and friction
- temperature
- long-term loading
- degradation of concrete

ComRebars sp. z o.o.

FiReP International AG

Schöck ComBAR®

Surface preparation:

- sand covering
- ribbing with fiber braid
- spirally wound ribs
- ribs cutting in the GFRP bar (Schöck ComBAR)

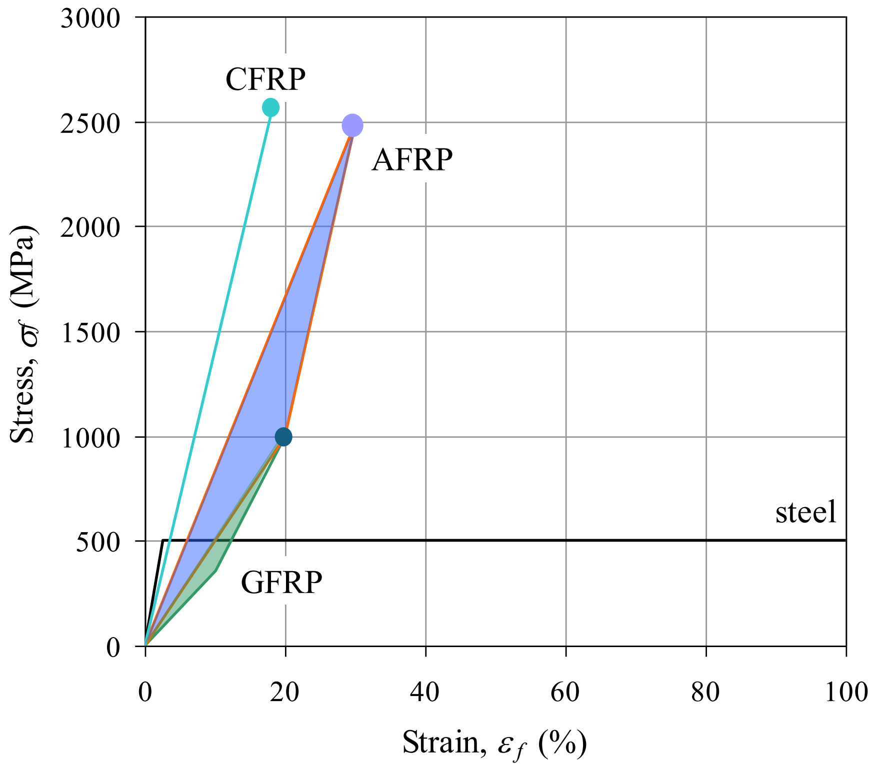
Prefa Composity A.S.

Comparison of FRP and steel reinforcement

$E_s / E_f = 4 – 3$ (GFRP)
$E_s / E_f = 3 – 2$ (AFRP)
$E_s / E_f = 2 – 1$ (CFRP)

$f_f / f_{sy} = 2.0$ (GFRP)
$f_f / f_{sy} = 5.0$ (AFRP)
$f_f / f_{sy} = 6.0$ (CFRP)

$\varepsilon_{su} / \varepsilon_{fu} = 8 - 3$ (GFRP)
$\varepsilon_{su} / \varepsilon_{fu} = 6 - 4$ (AFRP)
$\varepsilon_{su} / \varepsilon_{fu} = 20 - 6$ (CFRP)



Property	Steel	GFRP	CFRP	AFRP
Longitudinal modulus, (GPa)	200	35 to 60	100 to 580	40 to 125
Longitudinal tensile strength, (MPa)	450 to 700	450 to 1600	600 to 3500	1000 to 2500
Longitudinal tensile strain, (%)	5 to 20	1.2 to 3.7	0.5 to 1.7	1.9 to 4.4

Advantages of FRP reinforcement:

Highly resistant to chloride and chemical attack

- Applications:

- structures in marine environments
- in the ground
- in the chemical and industrial plants
- in thin structural concrete elements

- tensile strength is **higher** than that of steel
- weight is **four times lower** than that of steel
- **transparent to magnetic fields and radar frequencies**
- high **cuttability in temporary** applications (recommended to temporary reinforced concrete structures – diaphragm walls, which have to be partially, destroyed by TBM machine)

Disadvantages of FRP reinforcement:

GFRP bars:

- low tensile modulus comparing to steel
- sensitivity to abrasion from handling
- sensitivity alkalise
- relatively low fatigue resistance

CFRP bars:

- high cost
- high brittleness
- electrical conductivity

AFRP bars:

- hygroscopic absorption of moisture up to 10% of fiber at high moisture
- tend to crack internally at pre-existing micro-voids with longitudinal splitting
- low compressive strength
- loss of strength and modulus at elevated temperatures
- difficulty in cutting and machining
- sensitivity to UV lights

Design guidelines:

FprEN 1992-1-1:2023(E) Annex R

Annex R
(informative)

Embedded FRP reinforcement

R.1 Use of this annex

(1) This Informative Annex contains supplementary guidance for the design of new structures reinforced with non-prestressed glass and carbon fibre reinforcement.

NOTE National choice on the application of this Informative Annex is given in the National Annex. If the National Annex contains no information on the application of this Informative Annex, it can be used.

R.2 Scope and field of application

(1) This Informative Annex applies only to profiled or roughened glass and carbon fibre reinforced polymer (FRP) reinforcement bars and mesh. Prestressed FRP is not covered.

(2) This Informative Annex does not apply for use of FRP reinforcement in lightweight concrete and in concrete made with recycled aggregate, i.e. Annexes M and N do not apply.

(3) This Informative Annex applies to members with FRP reinforcement subjected to predominantly static loads, i.e. Clause 10 and Annex E do not apply to members with FRP reinforcement.

R.3 General

(1) The provisions of this Eurocode apply for concrete members with FRP reinforcement unless modified in this Annex R.

NOTE The provisions of this Eurocode apply for concrete members with FRP reinforcement unless modified in this Annex R .

R.4 Verification- Partial factors for FRP reinforcement

(1) The partial factor for material γ_{FRP} shall be used for FRP reinforcement.

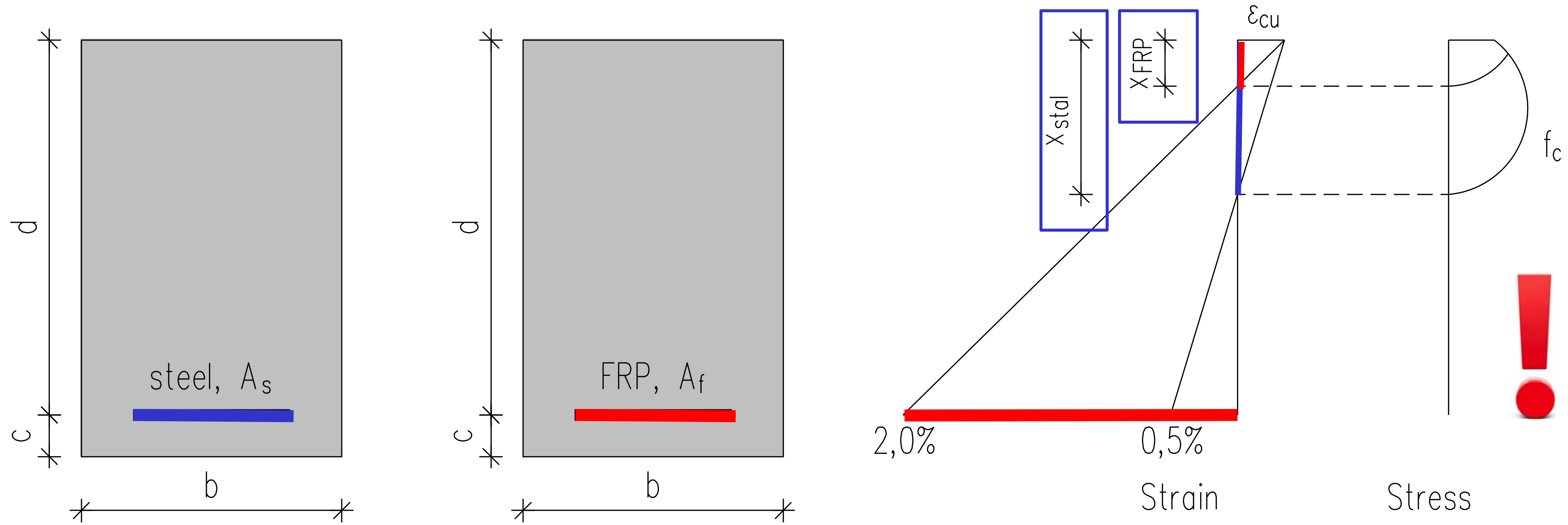
NOTE The values of the partial factors for FRP reinforcement are those in Table R.1 (NDP) unless the National Annex gives different values.

Table R.1 (NDP) — Partial factors for FRP reinforcement

Design Situation	γ_{FRP}
Persistent and transient design situation	1,50
Accidental design situation	1,10
Serviceability limit state	1,00

NSERC CRSNG MIAMI FDOT

Design guidelines - Flexure

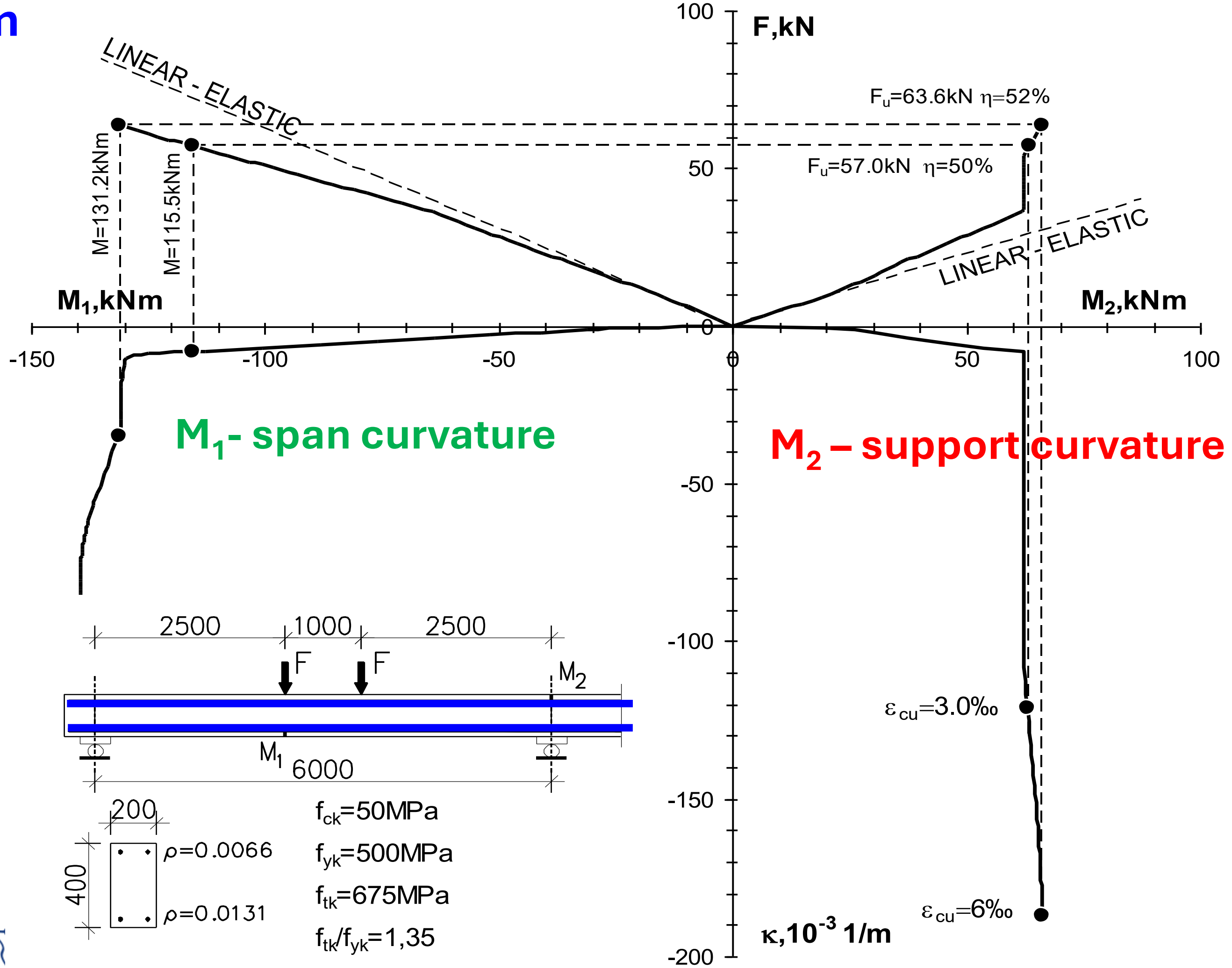


For steel reinforcement, strength to stiffness ratio is similar to normal concrete - neutral axis depth for a balanced rectangular section is around the middle of the overall effective depth.

For FRP reinforcement, the strength-to-stiffness ratio is much greater than that of concrete - the neutral axis depth for the balanced section is very close to the compressive edge.

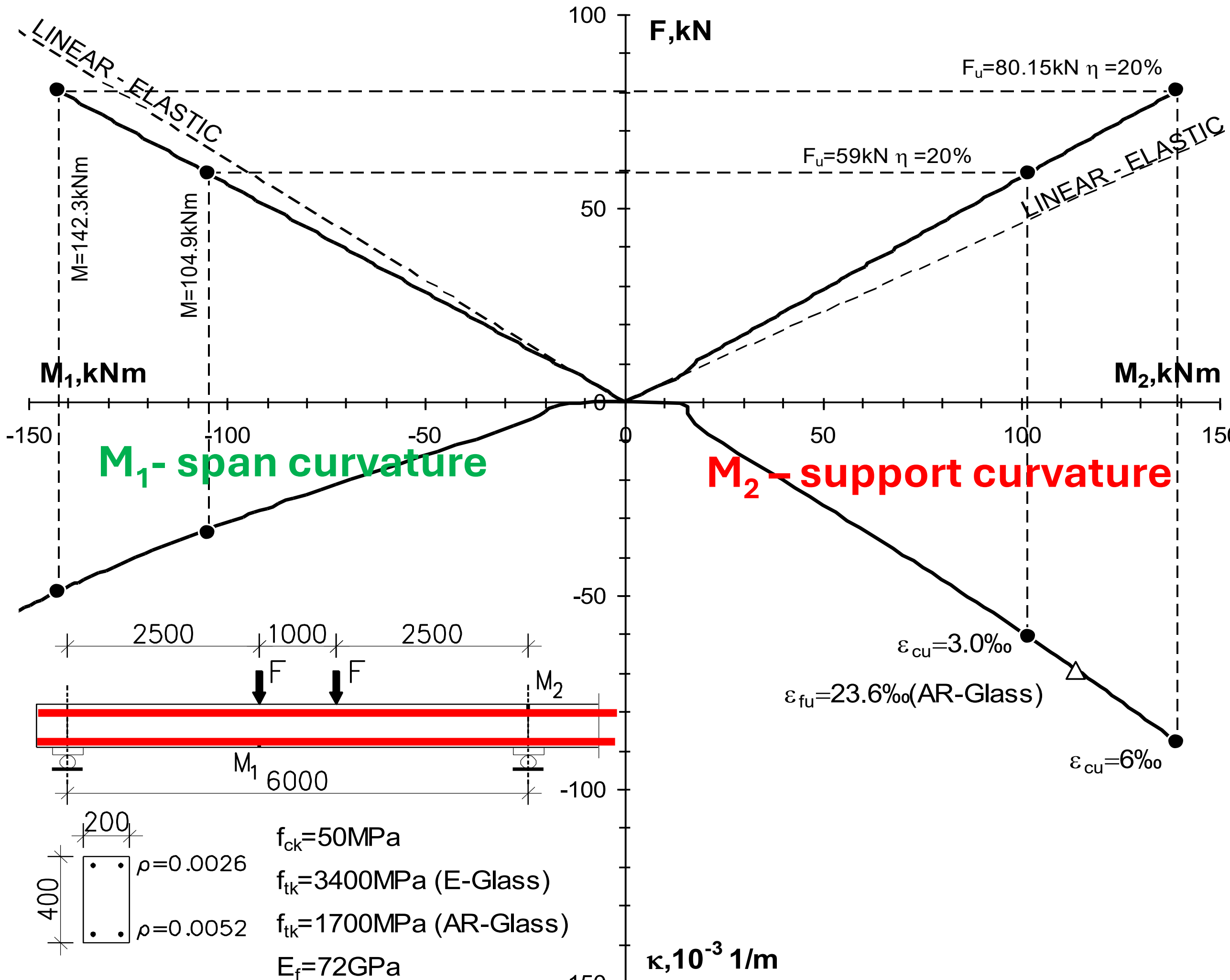
Bending moment redistribution

Steel reinforced beam



Bending moment redistribution

FRP reinforced beam



Annex R - Embedded reinforcement *FprEN 1992-1-1:2022 (E)*

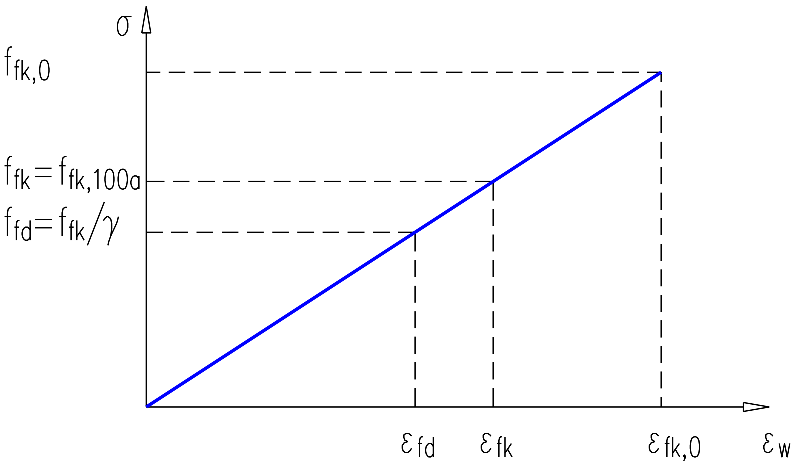
Annex R provides design rules for member reinforced with embedded FRP reinforcement within the following limits of applicability:

- Minimum modulus of elasticity of: $E_{fR} \geq$ **40 GPa**
- Maximum FRP strain: $\varepsilon_{fk} = \dfrac{f_{fk,100a}}{E_{fR}} \geq$ **0.005**
- Characteristic compressive strength of concrete: $f_{ck} \geq$ **20 MPa**
- Maximum degree of reinforcement: $\rho_{lf} \leq$ **0,05**
- γ_{FRP} – FRP factor

Design Situation	γ_{FRP}
Ultimate Limit States (Persistent and transient design situation)	1.50
Accidental Actions	1.10
Serviceability	1.10

Annex R - Embedded reinforcement *FprEN 1992-1-1:2022 (E)*

R.5.3 Design assumptions



$\boldsymbol{f_{fk0}}$ – short term tensile strength
$\boldsymbol{f_{fk.100a}}$ – long term tensile strength
$\boldsymbol{E_{fR}}$ – elasticity modulus of FRP reinforcement
$\boldsymbol{\gamma_{FRP}}$ – FRP factor

$$f_{fd} = \frac{f_{fk,100a}}{\gamma_f}$$

$$f_{fk,100a} = C_t\, C_c\, C_e\, f_{fk,0}$$

C_t - factor considering temperature effects. The following values may be used for
C_t = 1.0 for indoor and underground environments
C_t = 0.8 for outdoor members if heating through solar radiation cannot be excluded

C_c - coefficient between the strength under sustained load and the strength under short-term load equal 0.35 for GFRP and 0.8 for CFRP.

C_e - coefficient of outdoor; **C_e** = 0.7

LODZ UNIVERSITY OF TECHNOLOGY
Faculty of Civil Engineering, Architecture and Environmental Engineering
PHD THESIS

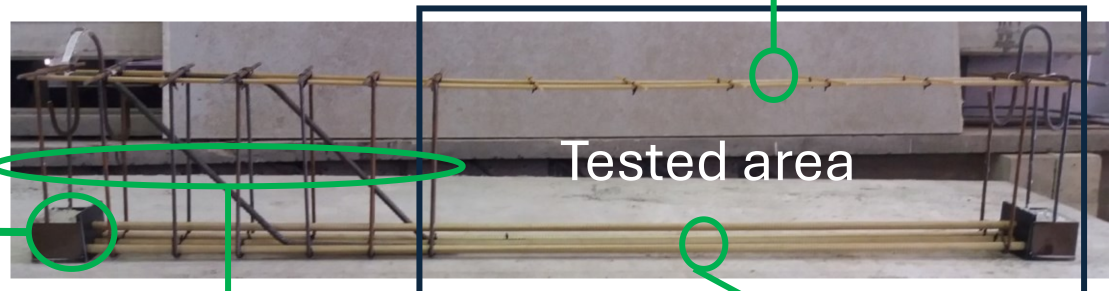
ANALYSIS OF THE EFFECT OF PRIMARY REINFORCEMENT ON THE SHEAR RESISTANCE OF CONCRETE BEAMS WITHOUT TRANSVERSE REINFORCEMENT

Monika Kaszubska, M.Sc.D. Eng.

Renata Kotynia, Prof. of PŁ - Promoter
Prof. Joaquim António Oliveira de Barros
Łódź, 2018

Shear in FRP / steel reinforced beams without stirrups

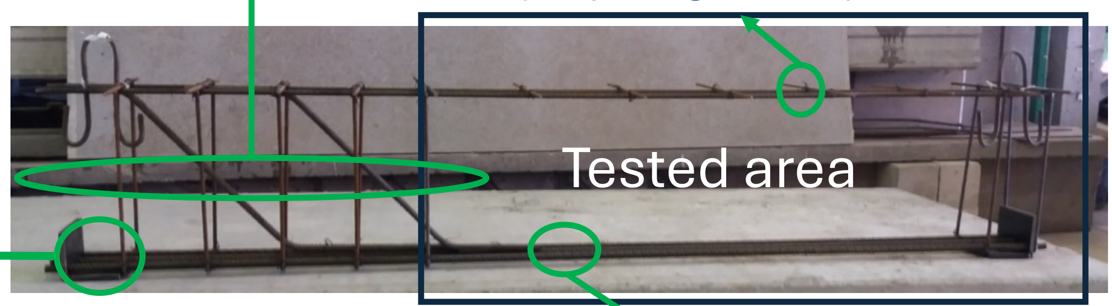
Top reinforcement- GFRP bars #10 and #6 (at spacing 210mm)



Shear reinforcement: steel stirrups #8 (at 130/150mm spacing) and steel bent bars #14

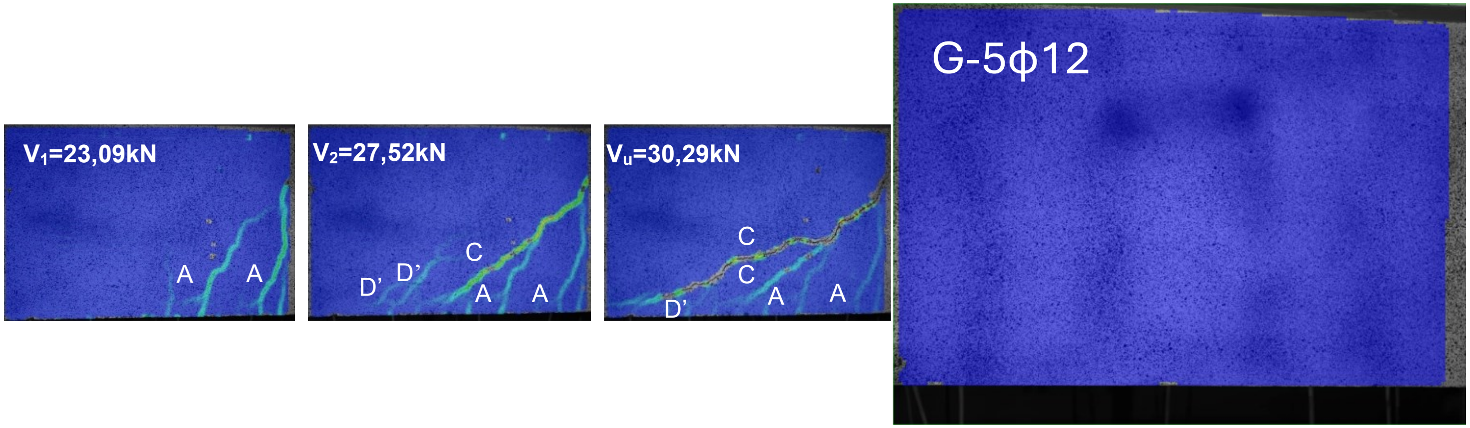
Bottom GFRP reinforcement of 12/16/18 mm diameter

Top reinforcement- GFRP bars #10 and #6 (at spacing 210mm)

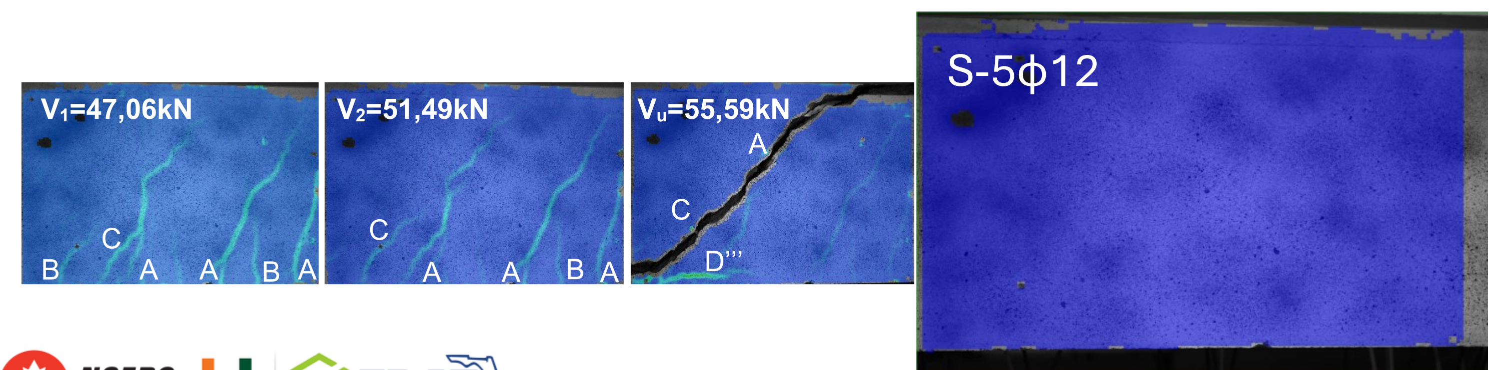


Bottom steel reinforcement of 12/16/18 mm diameter

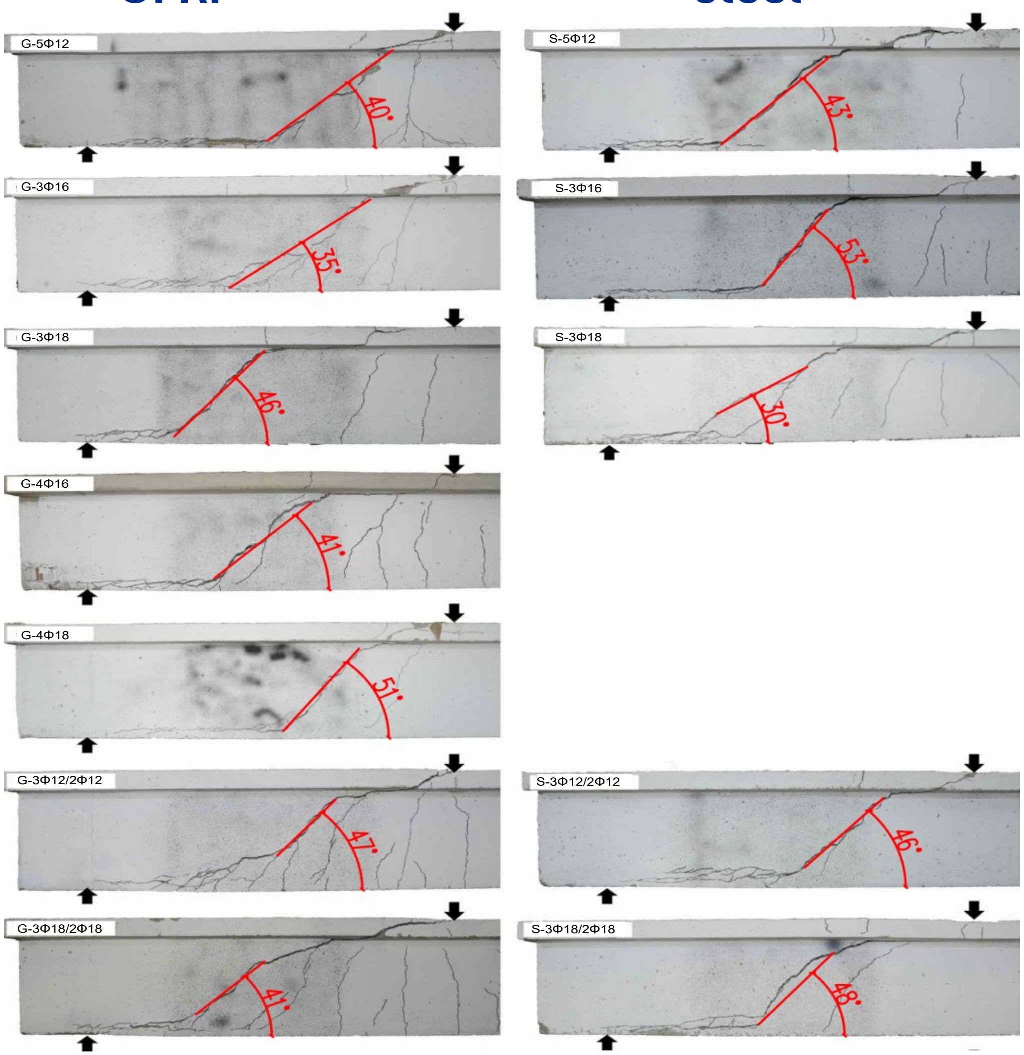
Shear in FRP / steel reinforced beams without stirrups



The GFRP reinforced beams indicated gradual and slow diagonal cracking development, while failure of the steel reinforced beams was sudden and brittle.



GFRP | steel



one reinforcement layer

two reinforcement layers

Example of failure mode

Shear tension

Flexular cracks through the full depth of beam

Small cracks – bond loss of bottom reinforcement

Flexural cracks for two reinforcement layers in GFRP reinforced beams and reverse situation for steel reinforced beams

LODZ UNIVERSITY OF TECHNOLOGY
Faculty of Civil Engineering, Architecture and Environmental Engineering
PHD THESIS

ANALYSIS OF THE TYPE REINFORCEMENT INFLUENCE ON THE SHEAR CAPACITY OF CONCRETE BEAMS WITH TRANSVERSE REINFORCEMENT

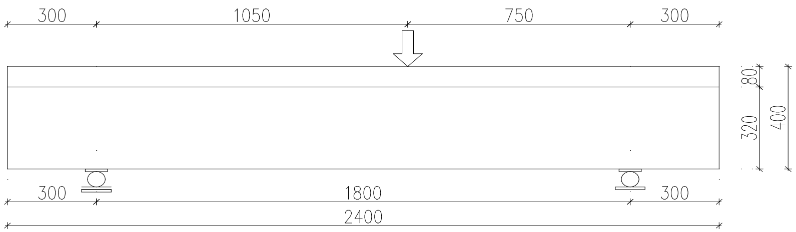
Damian Szczech, M.Sc.D. Eng.

Renata Kotynia, Prof. of PŁ - Promoter
Łódź, 2024

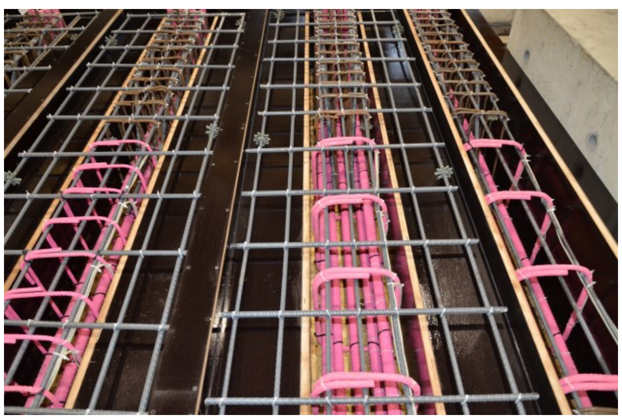
Shear in GFRP / steel reinforced beams with stirrups

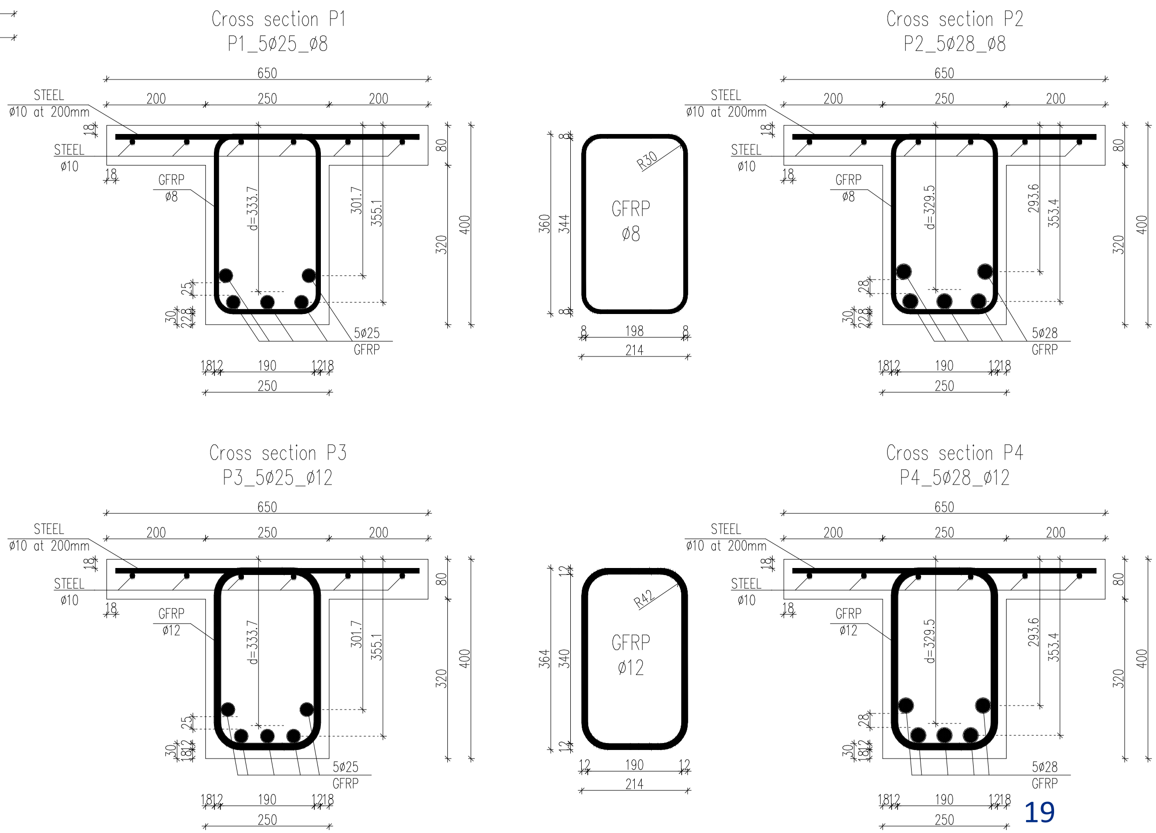
VARIABLE PARAMETERS										
	No.	Element	Cross section	Type of reinf.	Flexural reinf.	Rein. ratio ρ_l [%]	Stirrup diameter	Stirrups spacing	ρ_w [%]	f_{ck} [MPa]
SERIES I	1.	T-G-525-8/250-30	T	GFRP	5 # 25	2,91	8	250 mm	0,16	30
	2.	T-G-525-8/200-30	T		5 # 25	2,91	8	200 mm	0,20	30
	3.	T-G-525-8/120-30	T		5 # 25	2,91	8	120 mm	0,33	30
	4.	T-G-525-12/270-30	T		5 # 25	2,91	12	270 mm	0,33	30
	5.	T-G-525-N-30	T		5 # 25	2,91	NO STIRRUPS			30
	6.	T-G-528-8/250-30	T		5 # 28	3,69	8	250 mm	0,16	30
	7.	T-G-528-8/200-30	T		5 # 28	3,69	8	200 mm	0,20	30
	8.	T-G-528-8/120-30	T		5 # 28	3,69	8	120 mm	0,33	30
	9.	T-G-528-12/270-30	T		5 # 28	3,69	12	270 mm	0,33	30
	10.	T-G-528-N-30	T		5 # 28	3,69	NO STIRRUPS			30
	11.	T-S-525-8/260-30	T	STEEL	5 # 25	2,91	8	260 mm	0,15	30
	12.	T-S-525-8/200-30	T		5 # 25	2,91	8	200 mm	0,20	30
	13.	T-S-525-8/110-30	T		5 # 25	2,91	8	110 mm	0,37	30
	14.	T-S-525-N-30	T		5 # 25	2,91	NO STIRRUPS			30
	15.	T-S-528-8/260-30	T		5 # 28	3,69	8	260 mm	0,15	30
	16.	T-S-528-8/200-30	T		5 # 28	3,69	8	200 mm	0,20	30
	17.	T-S-528-8/110-30	T		5 # 28	3,69	8	110 mm	0,37	30
	18.	T-S-528-N-30	T		5 # 28	3,69	NO STIRRUPS			30

Shear in GFRP / steel reinforced beams with stirrups

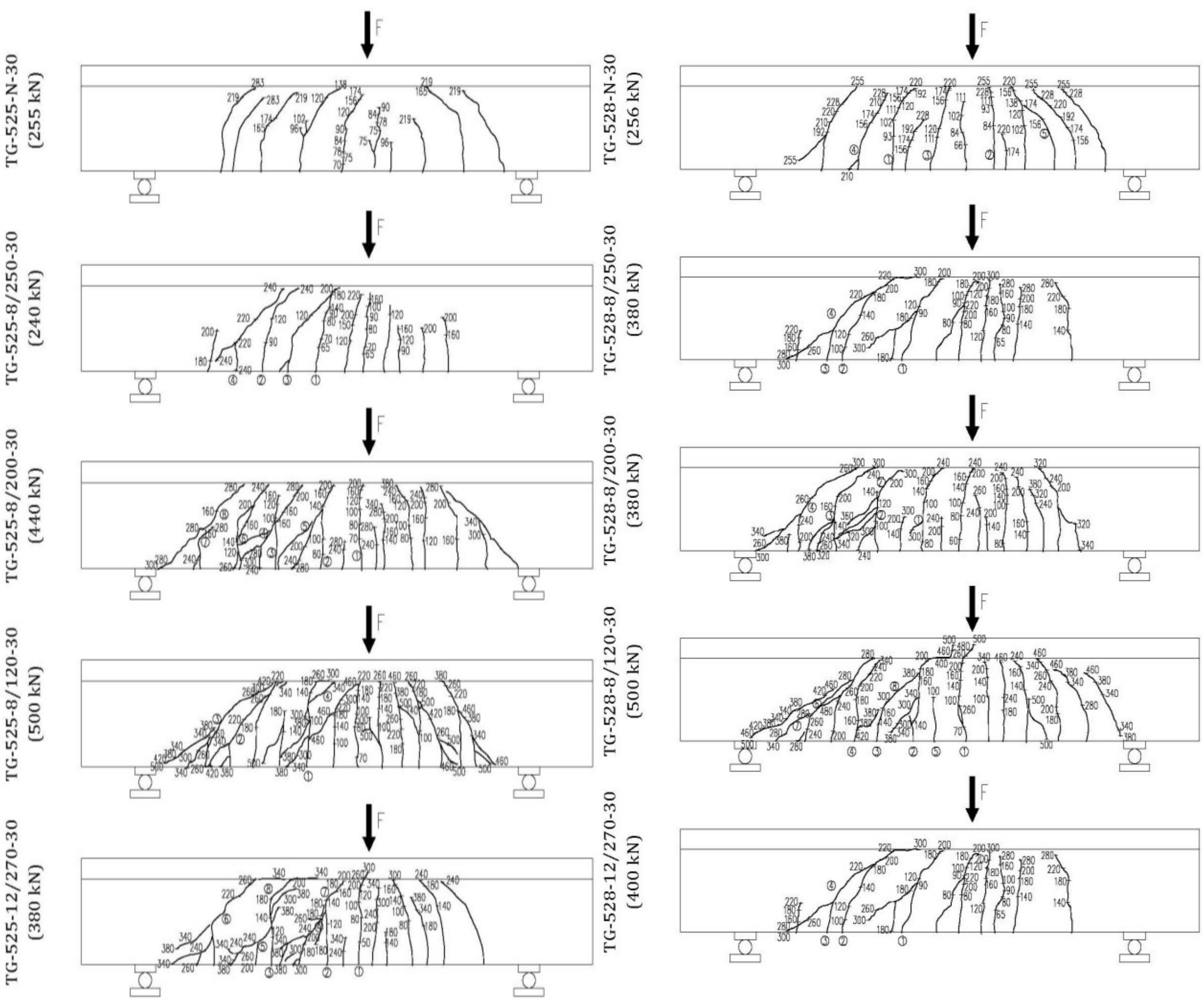


FiReP International AG

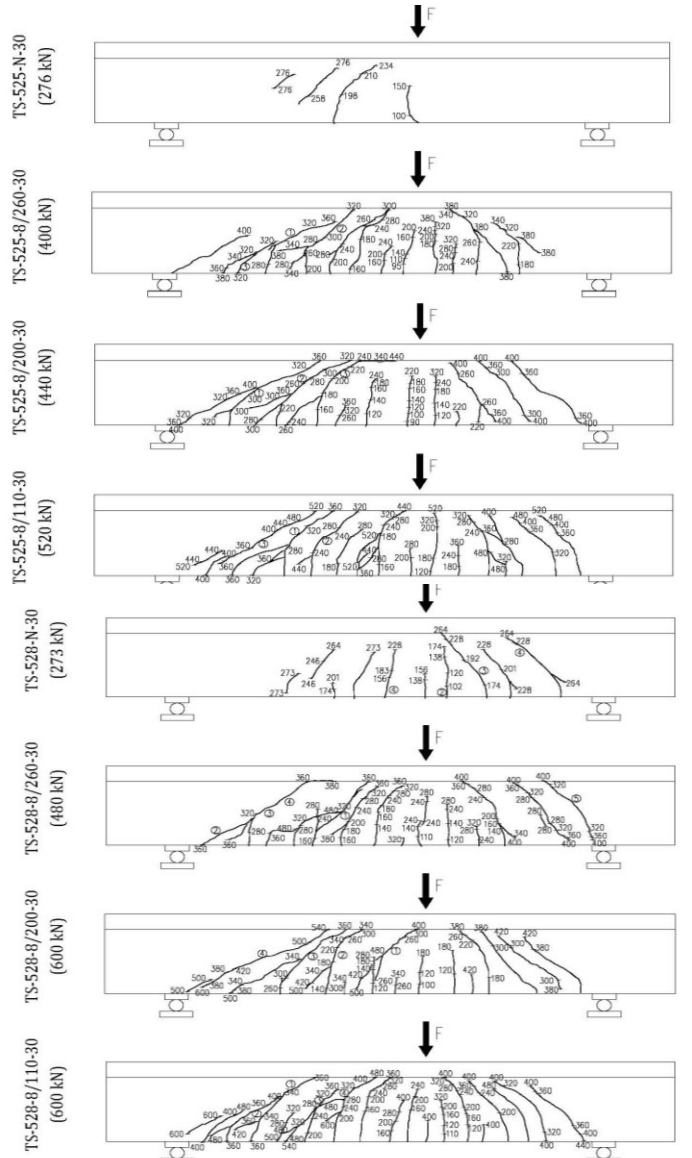




GFRP reinforced beams



Steel reinforced beams



Field Applications - Poland

Contractors: **Mostostal Warszawa S.A., Promost Consulting T. Siwowski S.J., Rzeszow University of Technology**

Location: **„Com-bridge – innovative road bridge FRP" in Błażowa**

FRP Producer: **ComRebars Sp. z o. o.**

GFRP reinforced bridge decks over the Ryjak River – road no. 1411R in Błażowa

Field Applications - Poland

Contractors: **Mostostal Warszawa S.A. , Budmost Rafał Jędrzejek, SHM Kraków**

Location: **Pedestrian and bicycle bridge across the Kamienica River in Nowy Sącz**

FRP Producer: **ComRebars Sp. z o.**

Epsilon GFRP bars with optical sensors for structural monitoring

Field Applications - Poland

Contractors: **Mostostal Warszawa S.A.,**

Location: **Fountain Park in Warsaw**

BFRP reinforced concrete fountain foundation slab

Field Applications - Poland

Contractors: **Mostostal Warszawa S.A.**

Location: **Provincial Hospital for Nervous and Mentally Ill in Drewnica (2014)**

FRP Producer: **Mostostal Warszawa S.A.**

GFRP rod reinforcement under the tank for storage of 809 m^3 of water (seasonal thermal energy storage from a solar installation).

Field Applications - Poland

Contractors: **Skanska S.A.**

Location: **Institute of Aviation, Warsaw**

FRP Producer: **ComRebars Sp. z o.**

Application of GFRP rods for reinforcement of an industrial floor in a complex of technical buildings

Field Applications - Poland

Contractors: **Skanska S.A.**

Location: **Reconstruction of the cross street in Lublin**

FRP Producer: **ComRebars Sp. z o.**

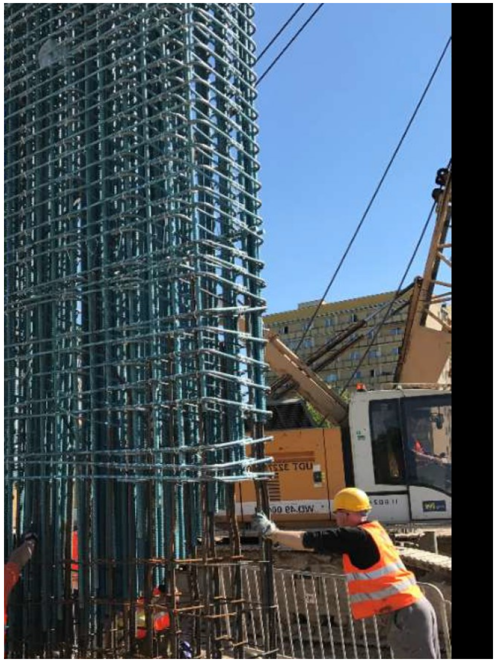
Field Applications - Poland

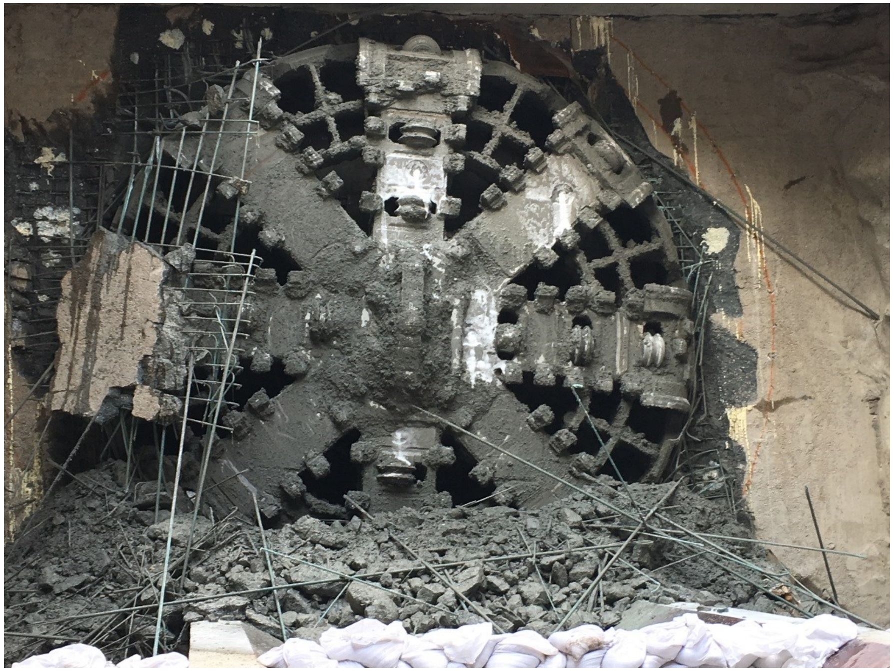
Contractors: **Budimex S.A.**

Location: **Metro in Warsaw**

FRP Producer: **FiReP, Switzerland**

GÜLERMAK ASTALDI





FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

Thank you for support!

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ALTAIR

MST BAR MAXIMUM STRENGTH GFRP

SFTec

ACMA American Composites Manufacturers Association FRP Rebar Manufacturers Council

UNIVERSITÉ DE SHERBROOKE

NSERC CRSNG

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Center for Integration of Composites into Infrastructure

FDOT

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

“Advances in concrete reinforcement”

August 8-9, 2024 - Toronto, Ontario

Use of FRP Reinforcing in Saudi Arabia

Ehab Ahmed and Ali Alibrahim

Alternative Rebar Plant (ARP)

Dammam; Kingdom of Saudi Arabia

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UNIVERSITÉ DE SHERBROOKE NSERC CRSNG UNIVERSITY OF MIAMI Center for Integration of Composites into Infrastructure FDOT

Outline

The key points in this presentation include:

- Saudi Market for FRP – An Overview
- Current Specs and Codes
- GFRP-RC Projects – Lessons Learned and Impact
- Local Manufacturing and Supply
- Alternative Rebar Plant (ARP)
  - Most Recent GFRP Manufacturing Facility Inaugurated by Aramco in November 2023

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Saudi Market for FRP – An Overview

FRP market in Saudi Arabia has been growing through the last decade. This is attributed to:

- **Support for composites industry from Aramco.**
- **Design of infrastructure projects for 75-100 years.**
- **Service / Exposure conditions.**
- **Saudi Industrial Development Fund (SIDF).**
- **Kingdom's 2030 Vision.**

The economic transformation under Vision 2030 is propelling Saudi Arabia towards a future of diversity and prosperity. Through strategic investments, the fostering of new industries, and the nurturing of exceptional leadership, the Kingdom is accelerating growth and building a resilient economy that stands at the forefront of global innovation and development.

Saudi Market for FRP – An Overview

FRP market in Saudi Arabia has been growing through the last decade. This is attributed to:

- Experience gained from mega projects designed with GFRP such as the Jizan flood mitigation channel.
- Life cycle cost analysis of the projects designed with GFRP against that designed with epoxy coated steel (ECS) supported the use of GFRP.
- Availability of FRP manufactures and suppliers.
- ACI Saudi Arabian Chapter – Eastern Province (KFUPM).

Saudi Market for FRP – An Overview

FRP market in Saudi Arabia has been growing through the last decade. This is attributed to:

- **Availability of FRP Specs and Codes (Aramco, SASO, ACI 440.1R, and AASHTO GFRP 2008)**

أرامكو السعودية
saudi aramco

Materials System Specification

12-SAMSS-027 10 December 2017
Fiber-Reinforced Polymer Bar Materials for Concrete Reinforcement

Document Responsibility: Non-metallic Standards Committee

Note: ACI 440.6-08
E = 5700 ksi (39.3 GPa)

المملكة العربية السعودية
KINGDOM OF SAUDIA ARABIA
الهيئة السعودية للمواصفات والمقاييس والجودة
Saudi Standards, Metrology and Quality Org.(SASO)

Standard Specification		مواصفة قياسية
Standard No.	SASO-GSO-2488	رقم المواصفة
Reference No.	GSO-2488	مرجع المواصفة
Issue Year	2017	سنة الاصدار
Adoption Year	2017	سنة الاعتماد
Numeric Coding	950-2488	الترميز الرقمي

مواصفة الأسياخ من البوليمر المقوى بالألياف الزجاجية لتسليح الخرسانة

Specification for fiber-reinforced polymers (FRP): FRP (Bars, Grids and sheet)

Note: CSA S807-10
E = 40, 50, 60 GPa

SASO
المواصفات القياسية السعودية
Saudi Standards

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Current Specs and Standards

Updated Specs and Design Codes:

- ARAMCO Material Specification (2021) – Based on ASTM D7957

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saudi aramco

Materials System Specification 24 February 2021

12-SAMSS-027
Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement

Document Responsibility: Nonmetallic Standards Committee

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

ASTM INTERNATIONAL

Designation: D7957/D7957M – 22

Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement[1]

This standard is issued under the fixed designation D7957/D7957M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers glass fiber reinforced polymer (GFRP) bars, provided in cut lengths and bent shapes and having an external surface enhancement for concrete reinforcement. Bars covered by this specification shall meet the requirements for geometric, material, mechanical, and physical properties described herein.

1.2 Bars produced according to this standard are qualified using the test methods and must meet the requirements given by Table 1. Quality control and certification of production lots of bars are completed using the test methods and must meet the requirements given in Table 2.

system shall be used independently of the other, and values from the two systems shall not be combined.

1.7 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.

1.8 This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

ASTM D7957 "45 GPa" – Straight and Bent Bars

NSERC CRSNG MIAMI FDOT

Current Specs and Standards

Updated Specs and Design Codes:

- GSO Material Specification (2017) – Based on CSA S807-10


هيئة التقييس لدول مجلس التعاون لدول الخليج العربية
GCC STANDARDIZATION ORGANIZATION (GSO)
GSO 2488/2015 (E)
مواصفة الأسياخ من البوليمر المقوى بالألياف الزجاجية لتسليح الخرسانة
Specification for fiber-reinforced polymers (FRP):
FRP (Bars, Grids and sheet)


S807-10
CANADIAN STANDARDS ASSOCIATION
Specification for fibre-reinforced polymers
Committee Member's Copy Only. Distribution Prohibited.

CSA S807 "40, 50, and 60 GPa" – Straight and Bent Bars

Current Specs and Standards

Updated Specs and Design Codes:

- Saudi Codes are being updated.

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GFRP-RC Projects – Lessons Learned and Impact

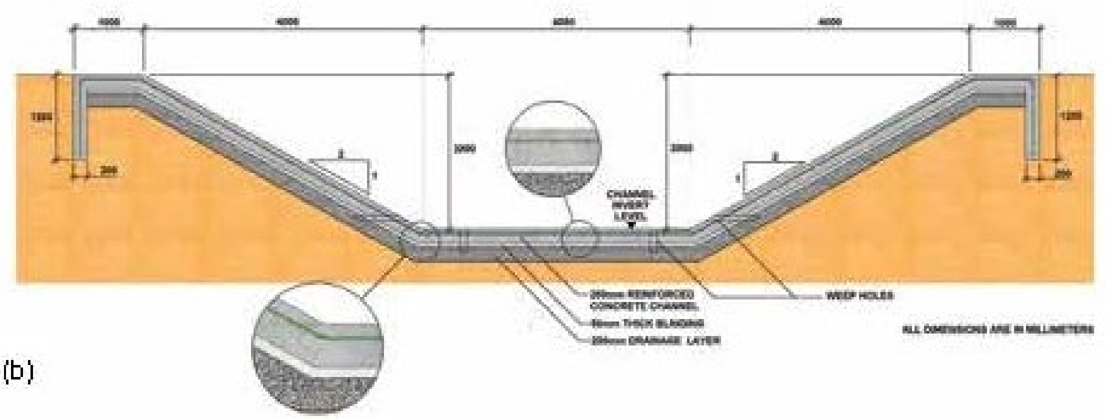
- **Experience from projects designed with GFRP:**
  - **Jizan flood mitigation channel** (Salan et al., 2021)
  - **SPARK Bridge** (Bader et al., 2023)

- Salan et al. 2021 "A Monumental Flood Mitigation Channel in Saudi Arabia - The 21 km long lining is the world's largest concrete structure reinforced with GFRP bars" ACI Concrete International.
- Bader et al., 2023 "The Heart of Innovation in SPARK, Saudi Arabia The first bridge deck reinforced with GFRP bars in the GCC" ACI Concrete International.

Jizan Flood Mitigation Channel

- Original design was made with ECS for a 50-year service life, during which minor maintenance would be needed.

- In line with Aramco strategic decision to use nonmetallic reinforcement in concrete structures in company facilities, the design was changed to GFRP with expected maintenance-free service life of a 100 years.



(b)

Jizan Flood Mitigation Channel

Jizan Flood Mitigation Channel

- **Cost analysis**

Table 3:
Cost comparison for ECS and GFRP options based on a 30 x 30 x 0.2 m slab panel

Expenditure item	ECS bars, $	GFRP bars, $	GFRP cost / ECS cost, %
Reinforcing bars	9235	8222	89
Concrete	17 514	15 810	90

ECS and GFRP had the same price per linear meter. However, <u>additional</u> 17% was required for customs and value-added taxes for the GFRP bars, as they were imported from Dubai, China, and Russia. These taxes raised the average price of GFRP bars.

SPARK Bridge Deck

- The first bridge deck reinforced with GFRP bars in the GCC.

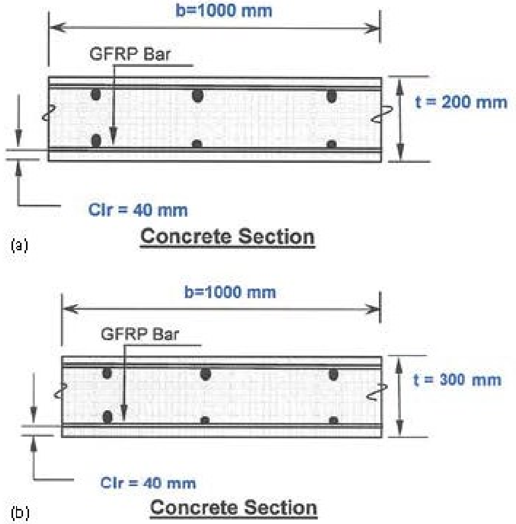


Fig. 3: Cross sections: (a) bridge deck; and (b) approach slab (from Reference 10)

- Life cycle cost analysis showed savings of just over 314,462 USD are anticipated with the GFRP option in the 100-year period.

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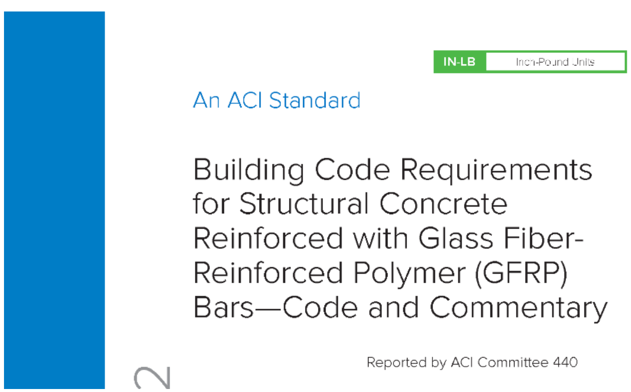
Local Manufacturing and Supply

Now, there are local manufacturing and supply in Saudi Arabi and more projects are expected due to:

- **The support and the vision for durable and sustainable design of infrastructure projects with extended service life.**
- **Availability of local raw materials.**
- **Updated specs and design codes (ASTM D7957; ASTM D8505; CSA S806; ACI 440.11; AASHTO GFRP 2nd Ed.; CSA S6).**



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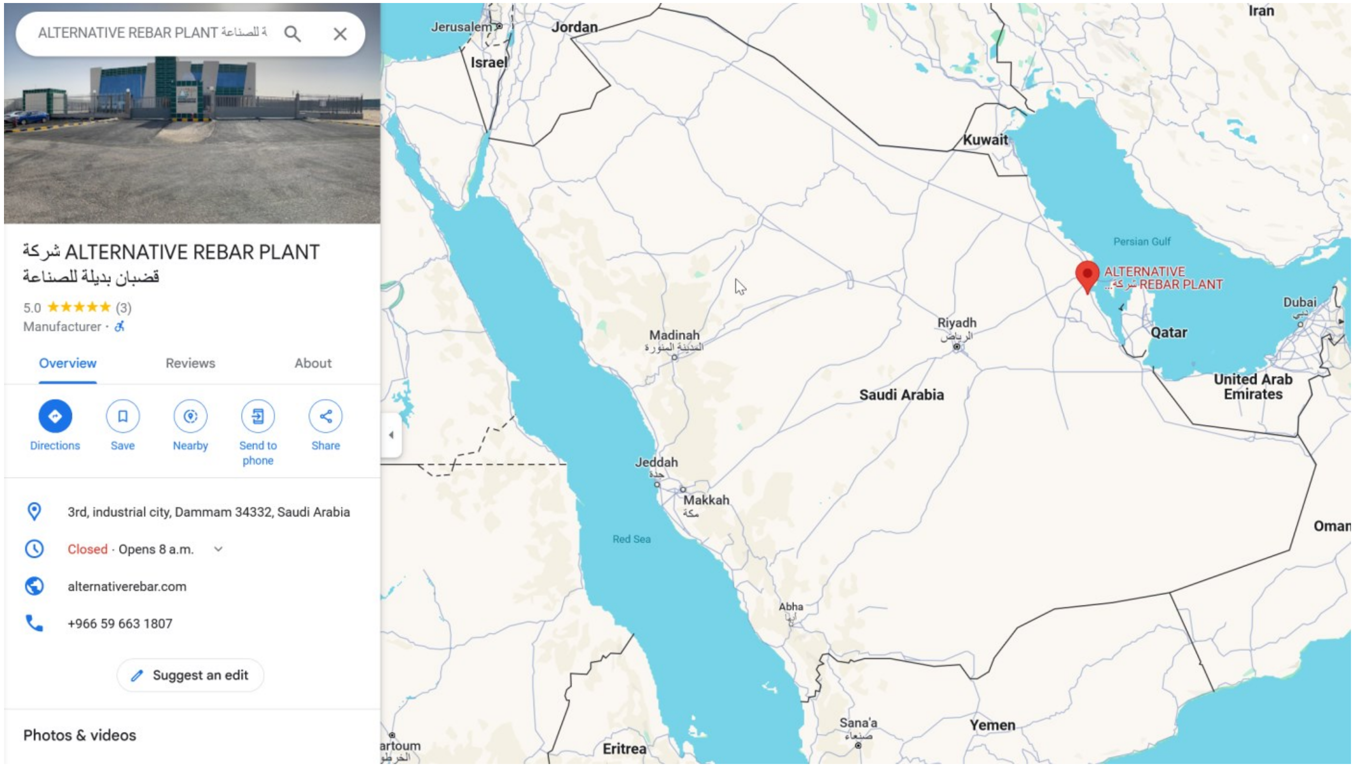
Local Manufacturing and Supply

- Alternative Rebar Plant (ARP) started production in 2023. **It is a 100% Saudi Made GFRP manufacturing facility.**

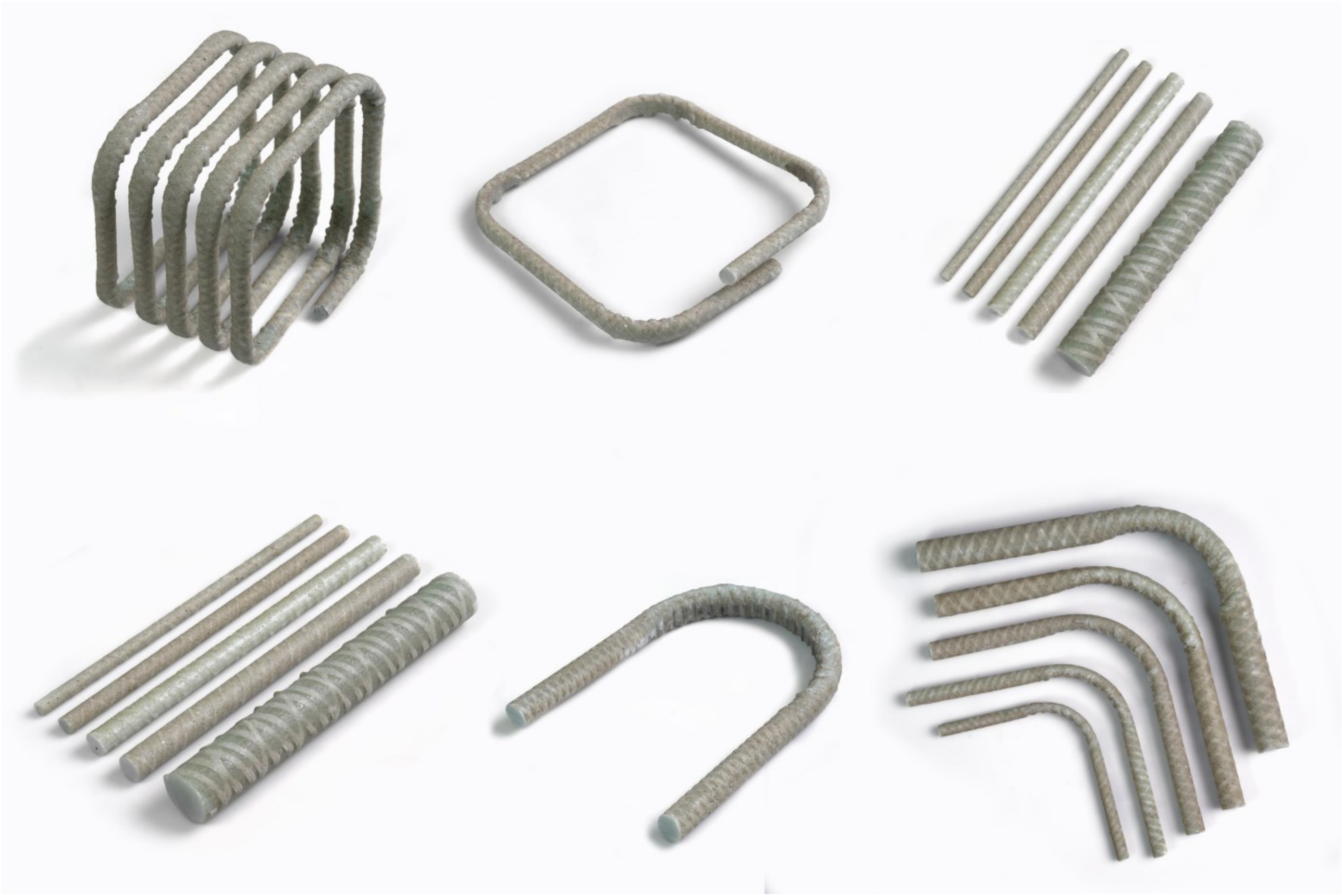


Local Manufacturing and Supply

- ARP established under an agreement with a Canadian Technology Supplier - Tuf-Bar Inc. - to keep up the Kingdom's 2030 localization vision.
- ARP has the capacity to run GFRP bars of sizes from #2 (6 mm) to #12 (38.1 mm).

Local Manufacturing and Supply

- **ARP products meet the ASTM D7957; ASTM D8505; CSA S807.**



Local Manufacturing and Supply

- ARP is ISO Certified and runs full in-house quality control. ARP was inaugurated by Aramco in November 2023.

Local Manufacturing and Supply

- Recently, ARP joined the NSERC Industrial Research Chair (Dr. Brahim Benmokrane) at the University of Sherbrooke.

Thank You!

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

FRP-SEAWATER SEA-SAND CONCRETE STRUCTURES

Tao Yu

The Hong Kong Polytechnic University

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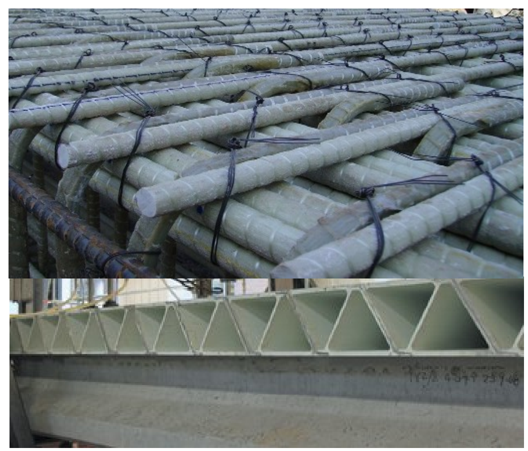
Seawater sea-sand concrete (SSC) + FRP

Steel	→	FRP
River sand	→	Sea sand
Fresh water	→	Seawater

Seawater and sea sand

+



FRP products

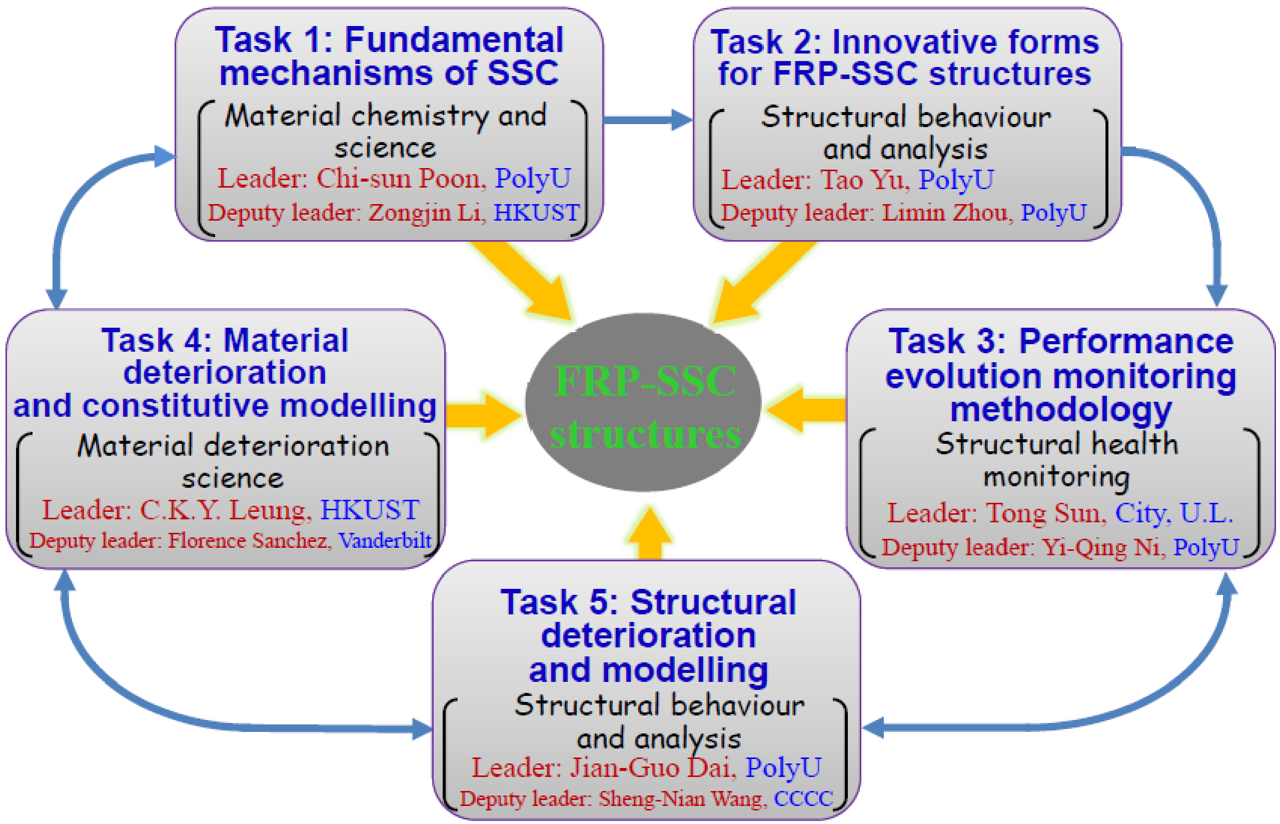
=

- Corrosion resistance
- Use of local materials

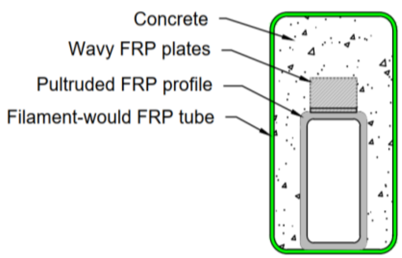
Teng Jin-Guang, Yu Tao, Dai Jian-Guo, Chen Guang-Ming, 2011

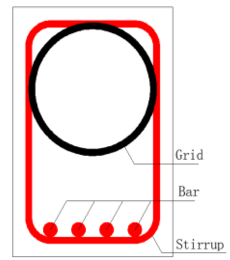
A Major Research Project

Theme-based Research Project "Sustainable Marine Infrastructure Enabled by the Innovative Use of Seawater Sea-Sand Concrete and Fibre-Reinforced Polymer Composites" (Grant value: around HK$52.4 million; Project coordinator: Prof. YU Tao)

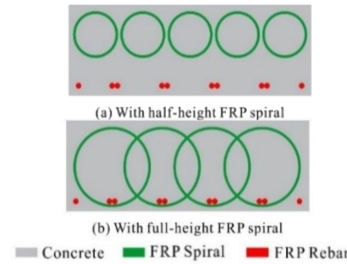


Innovative Forms for FRP-SSC Structures





FRP-SSC beams

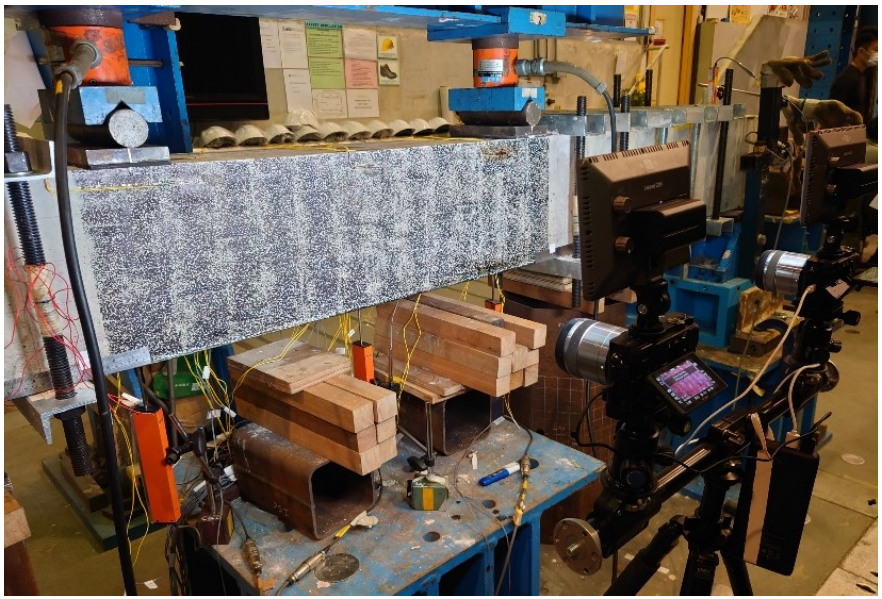


FRP-SSC Slabs

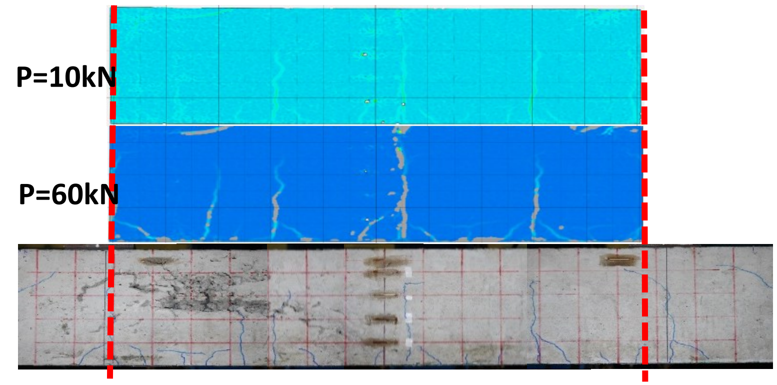
Tests of innovative beams

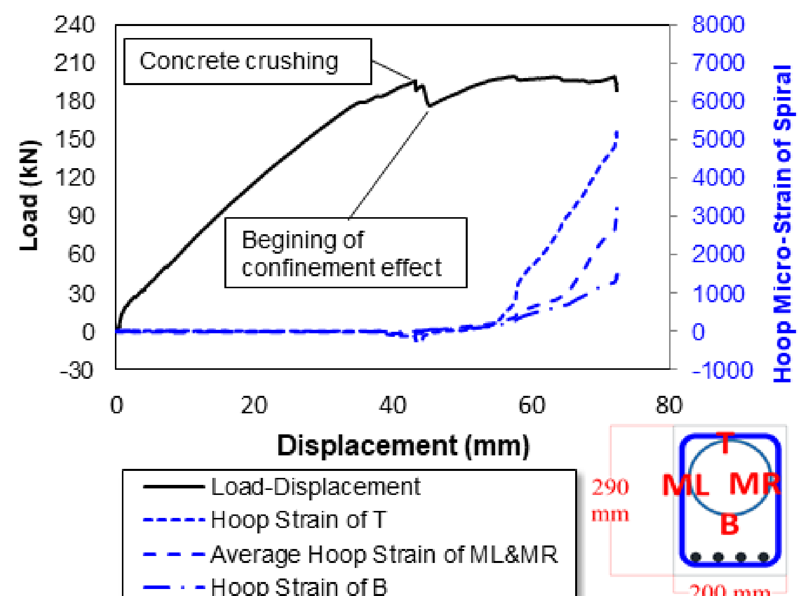
Innovative Forms for FRP-SSC Structures

Innovative FRP-SSC beams

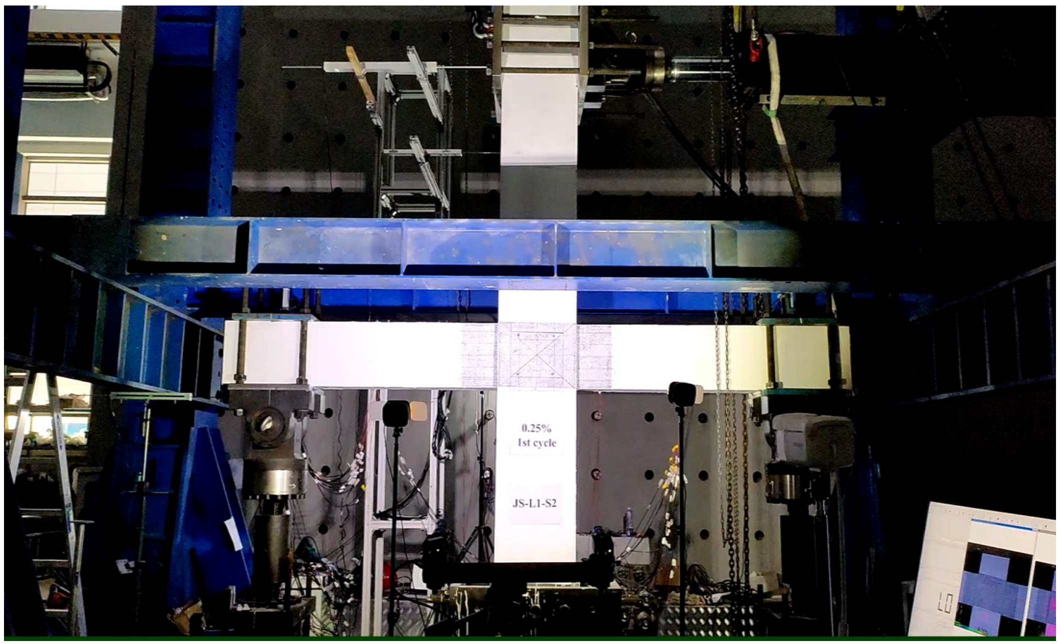


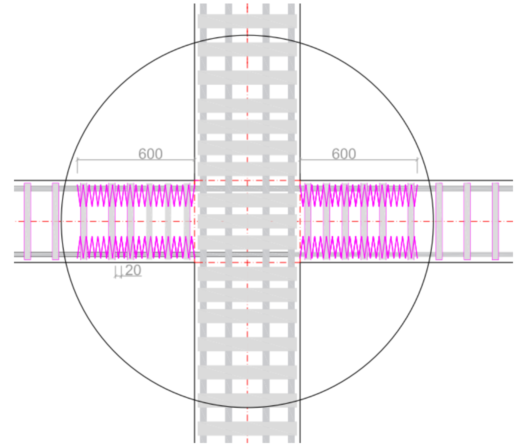
Test set-up

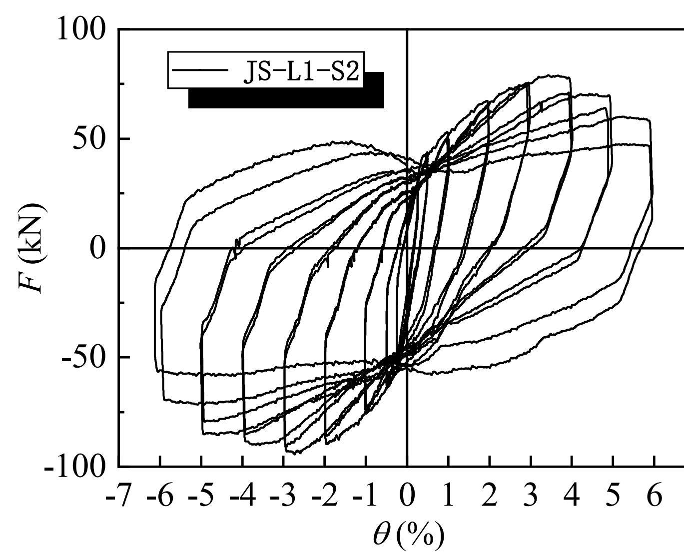




Innovative Forms for FRP-SSC Structures







Beam-column connections

Innovative Forms for FRP-SSC Structures

Innovative FRP elements

Hybrid bars

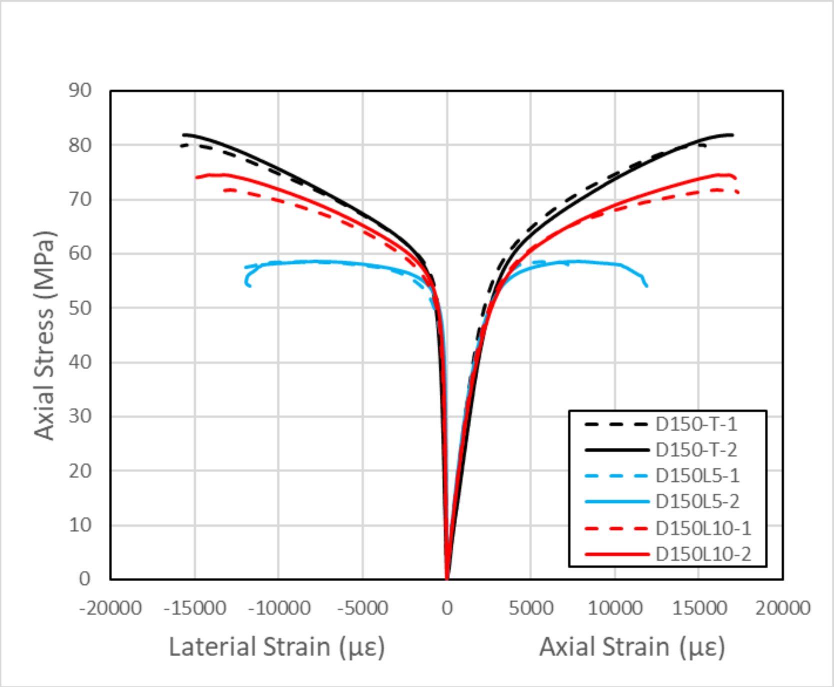
FRP grid tubes

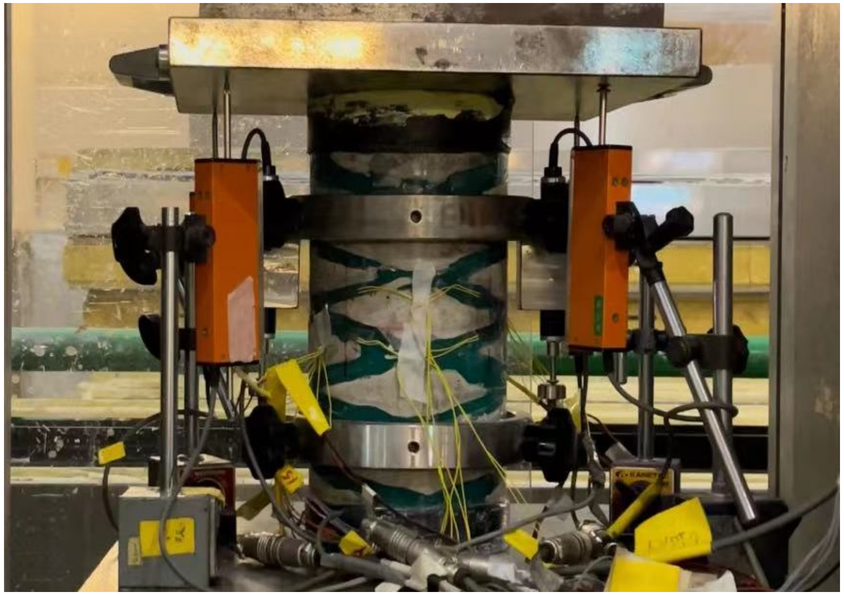
FRP stirrups

FRP Connectors

Innovative Forms for FRP-SSC Structures

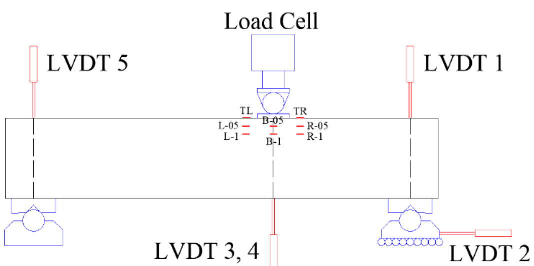
FRP grid tube as a confining device

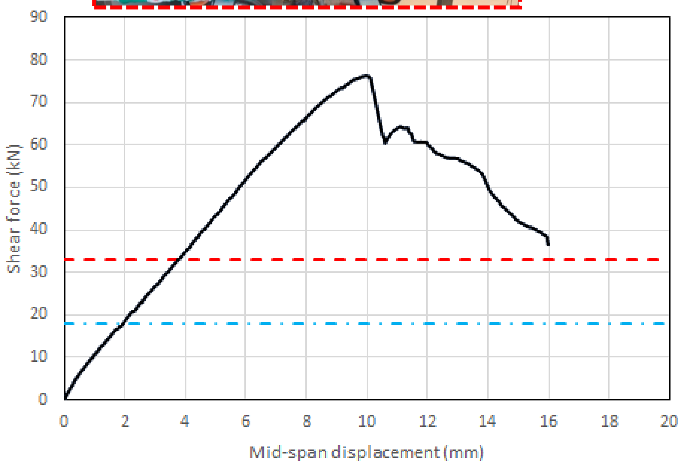


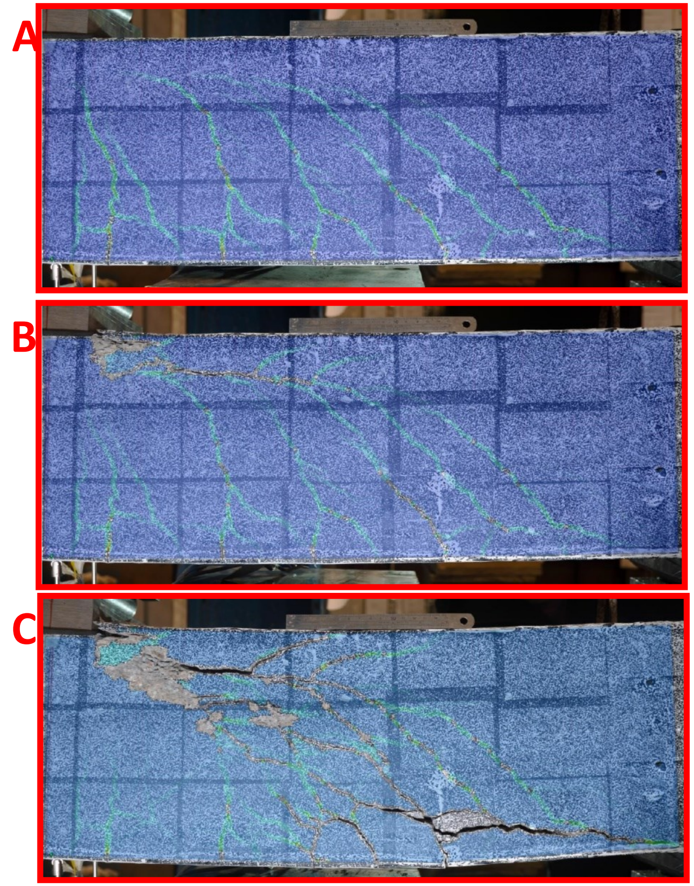


Innovative Forms for FRP-SSC Structures

FRP grid tube as shear reinforcement



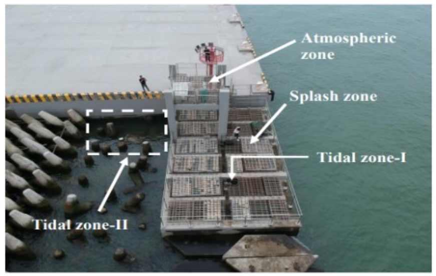


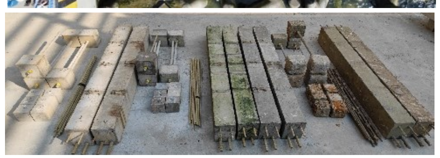


Field Exposure Tests

➢ **Station I: HZM Bridge Exposure Station**

The West Artificial Island of Hong Kong-Zhuhai-Macau Bridge

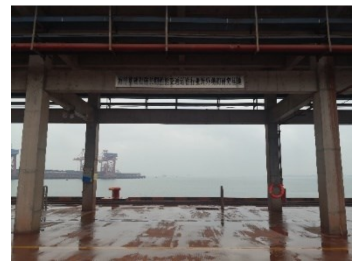


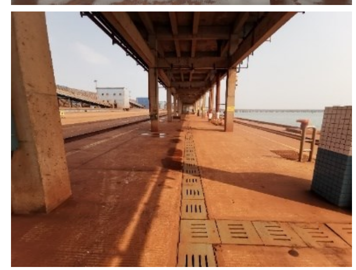


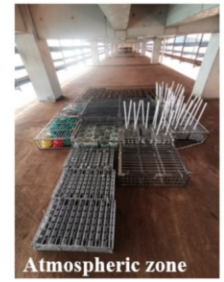
- **Commencement:** 2020, 2021
- **Exposure duration**: 8, 12, 24, 37, 48 months

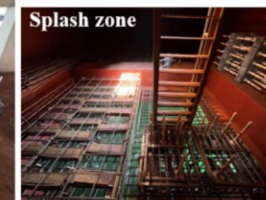
➢ **Station II: Zhanjiang Exposure Station**

The Port of Zhanjiang, China





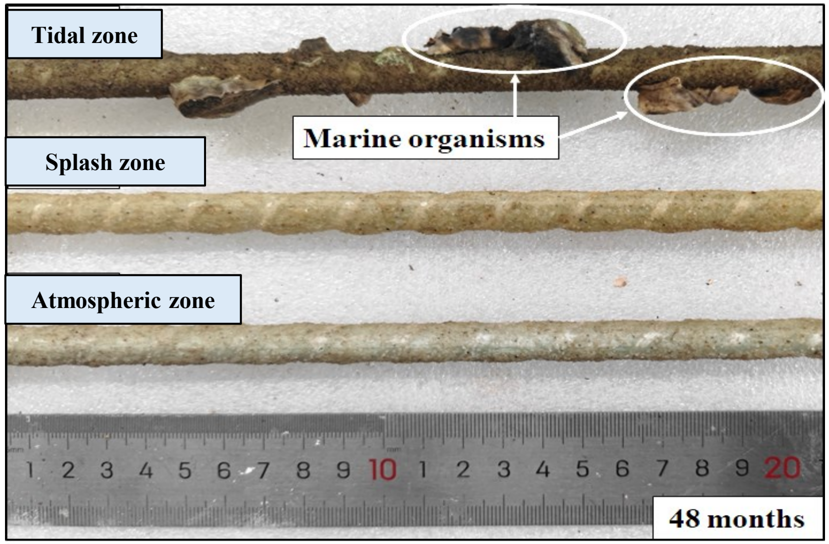


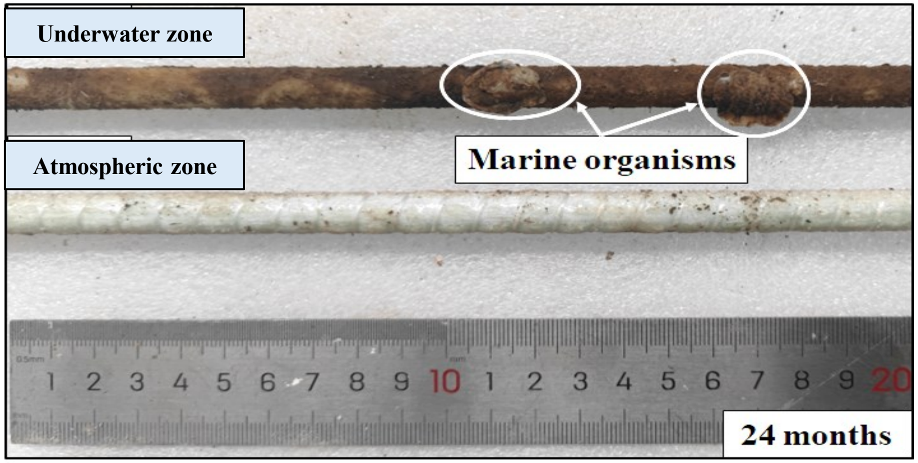


- **Commencement:** 2022, 2023
- **Exposure duration**: 13, 24 months

➢ Four series of specimens including FRP, SSC, novel structural elements, FRP-SSC beams and sensors.

Field Exposure Tests

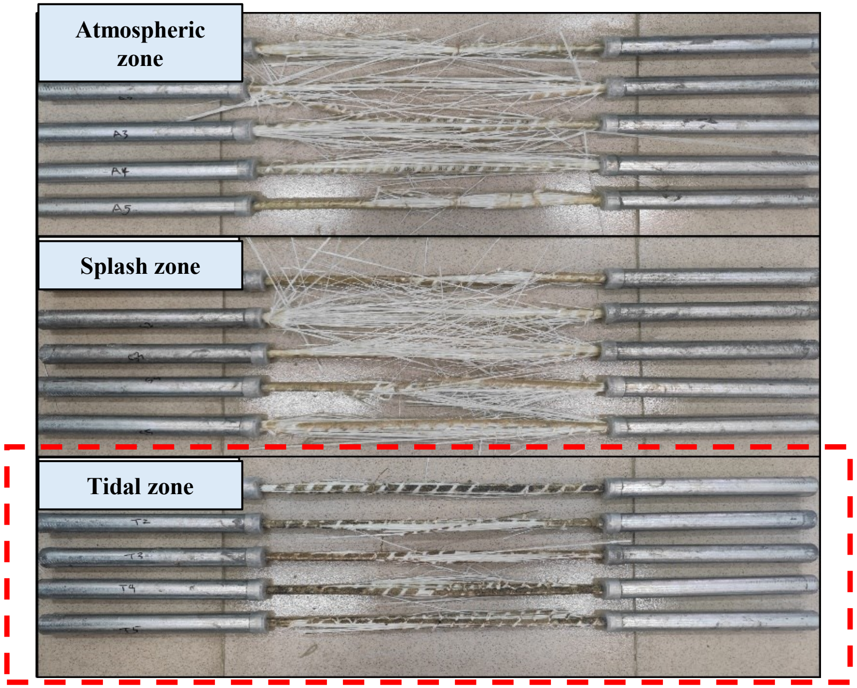




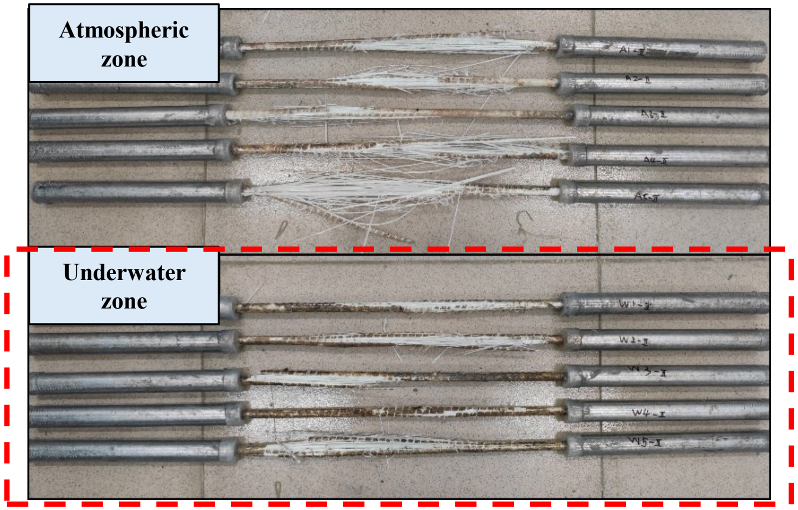
10-mm GFRP Bars (after field exposure for 48 months)

10-mm GFRP Bars (after field exposure for 24 months)

Field Exposure Tests

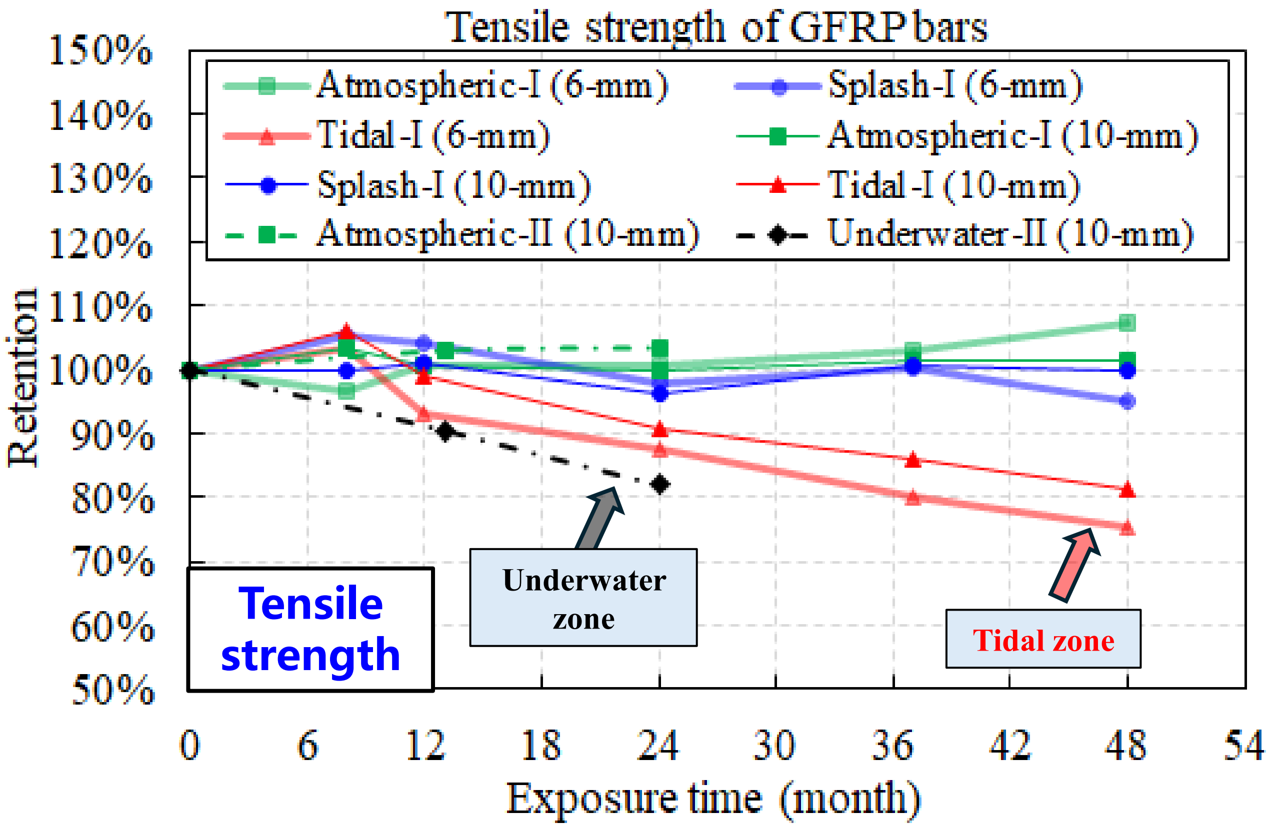


10-mm GFRP Bars (after exposure for 48 months)

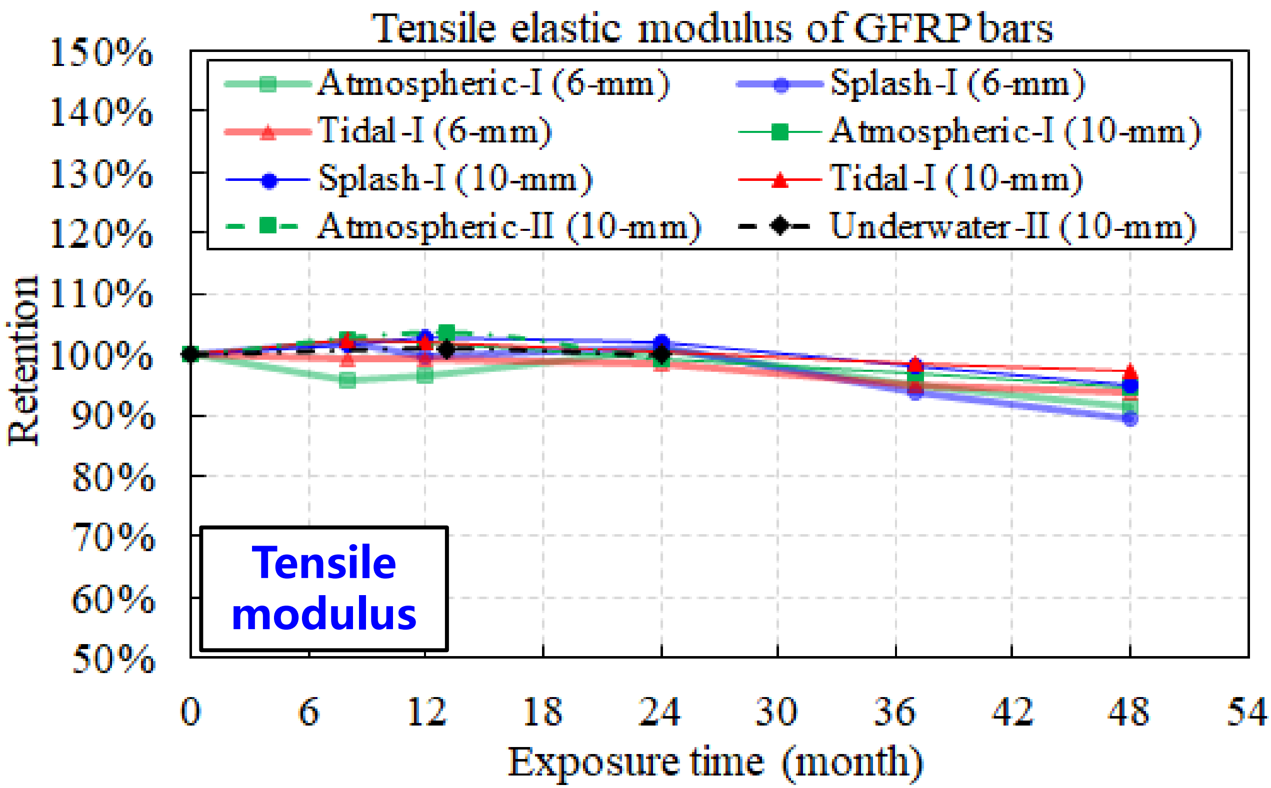


10-mm GFRP Bars (after exposure for 24 months)

Field Exposure Tests

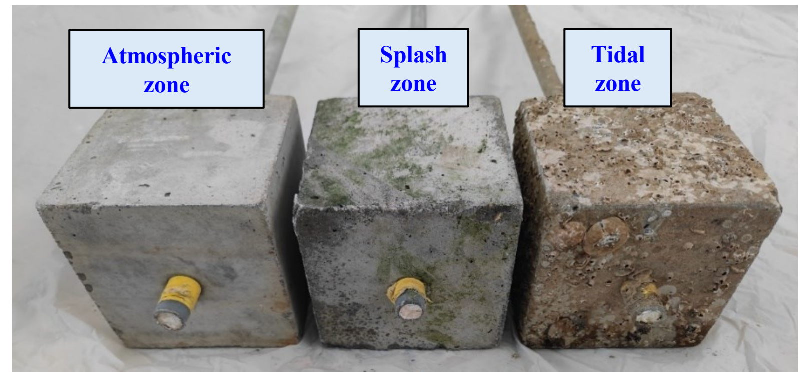


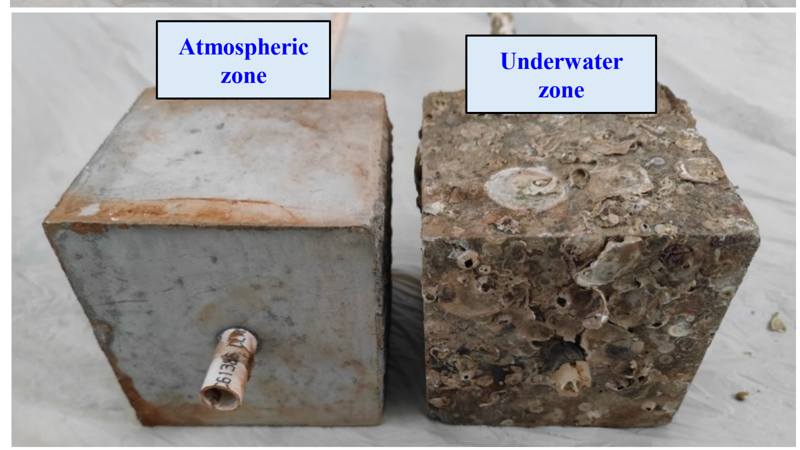
Field Exposure Tests



Field Exposure Tests

❖Bonded joint specimens

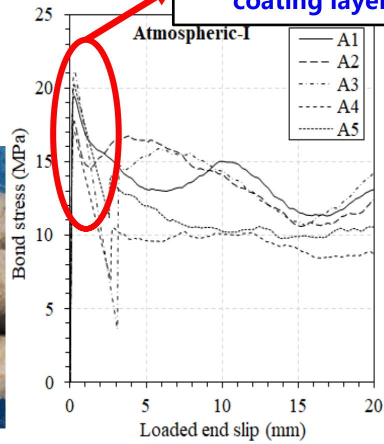


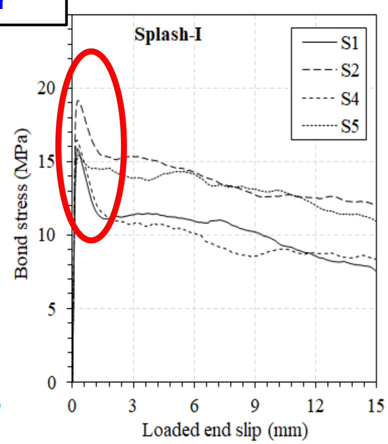


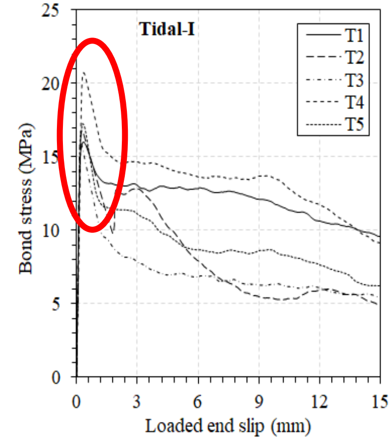
Field Exposure Tests

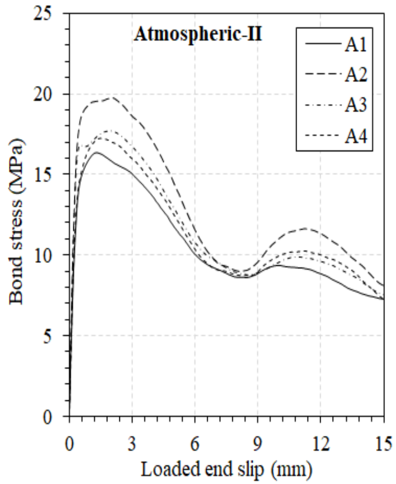
❖Bond-Slip Curves

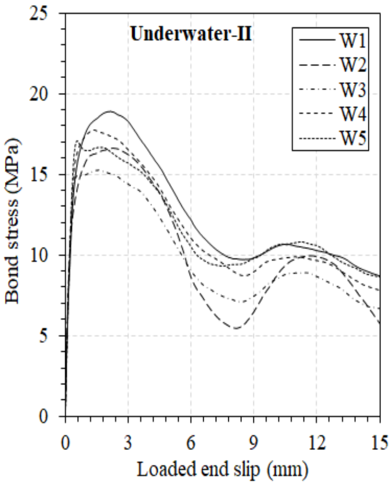
Damage of sand coating layer





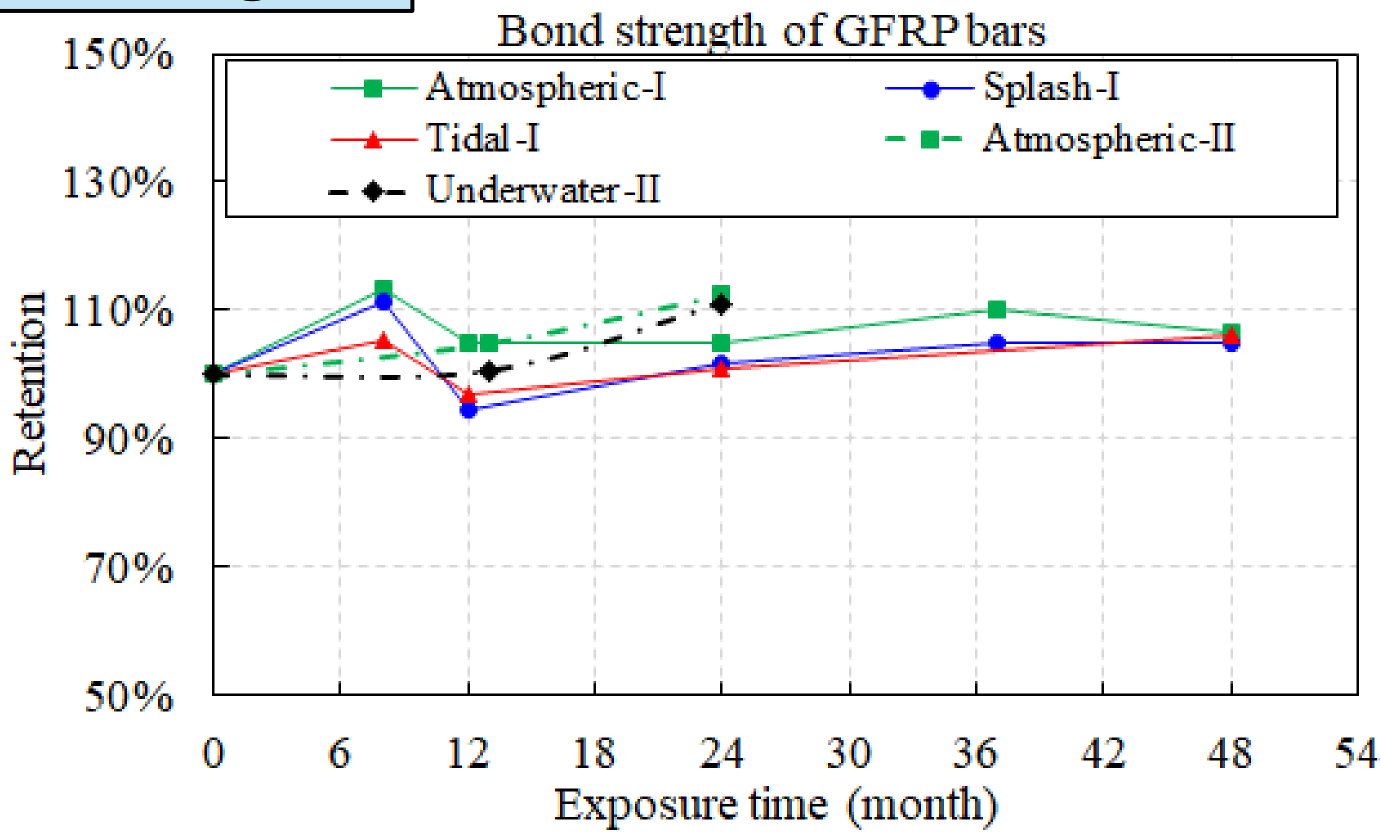






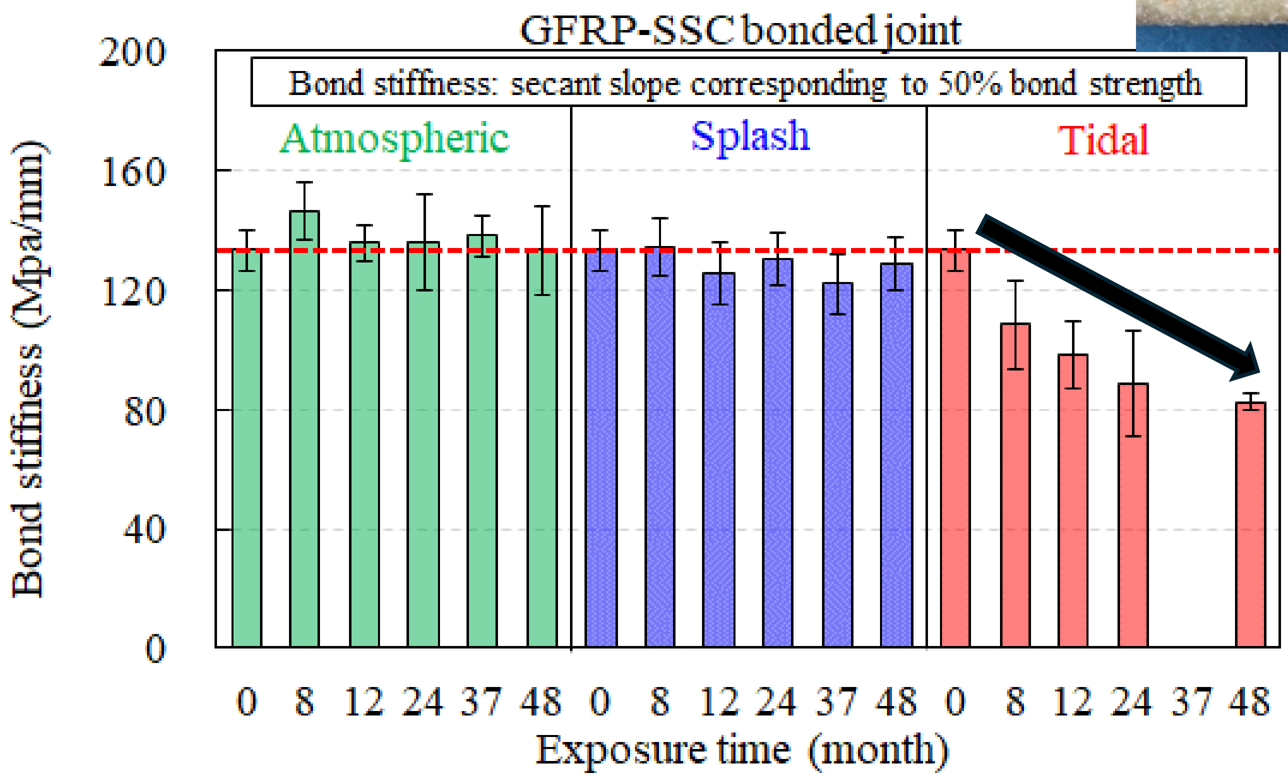
Field Exposure Tests

❖Bond Strength



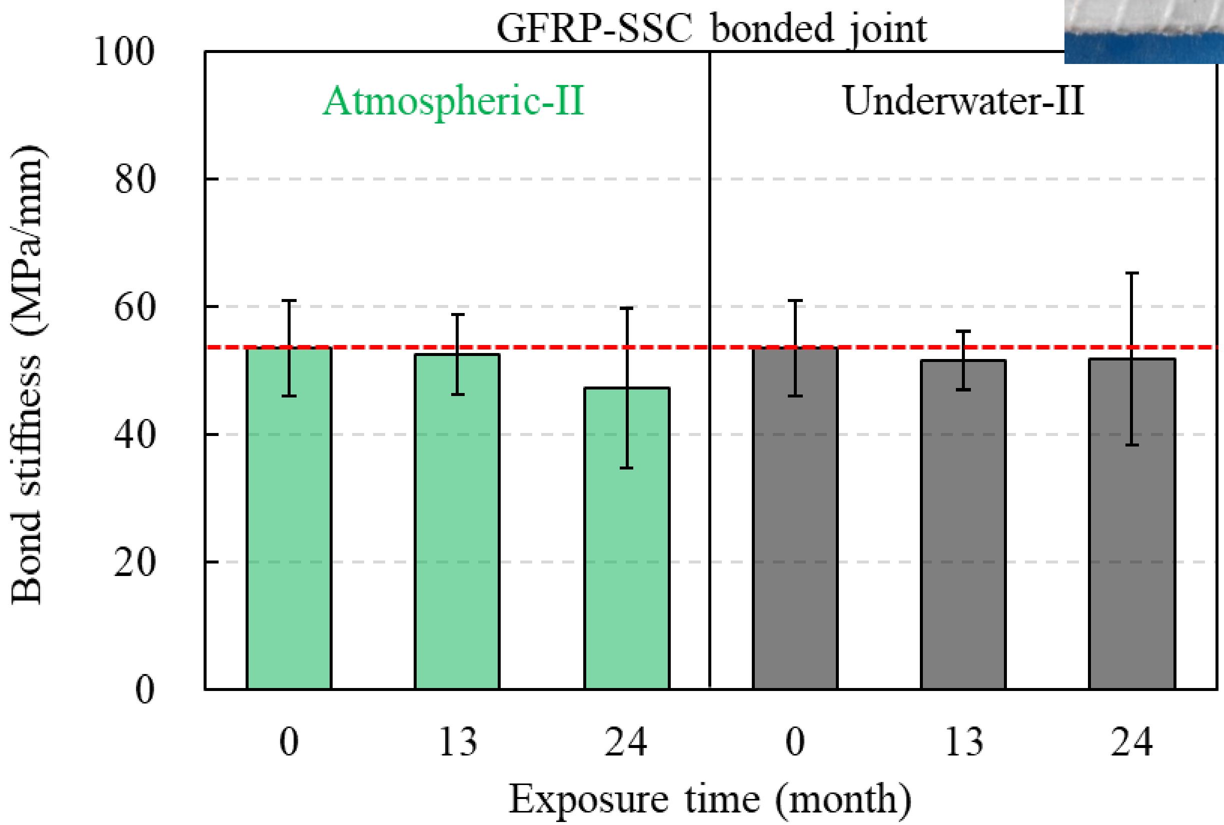
Field Exposure Tests

❖Bond Stiffness



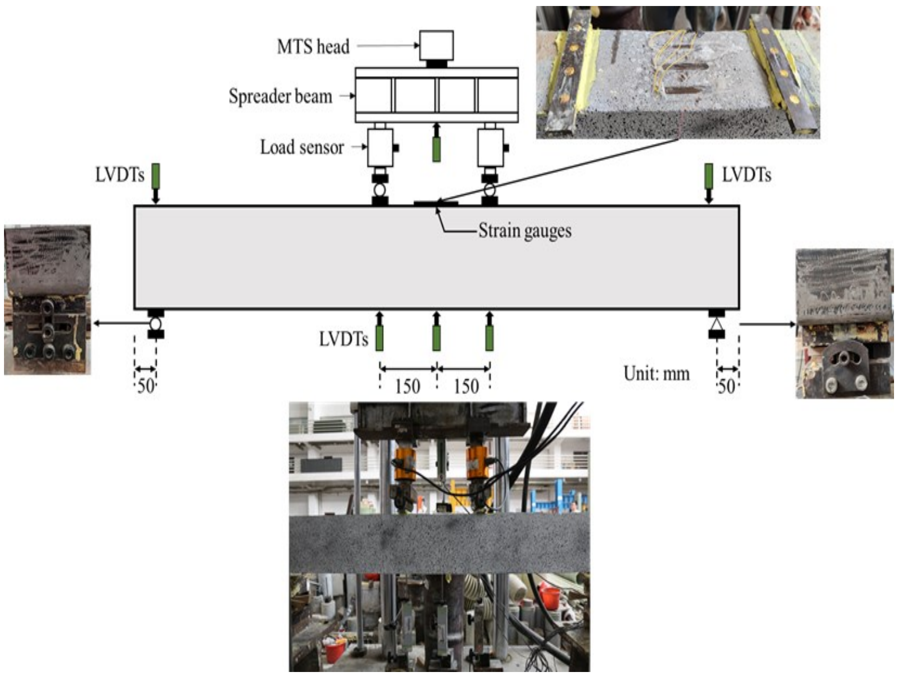
Field Exposure Tests

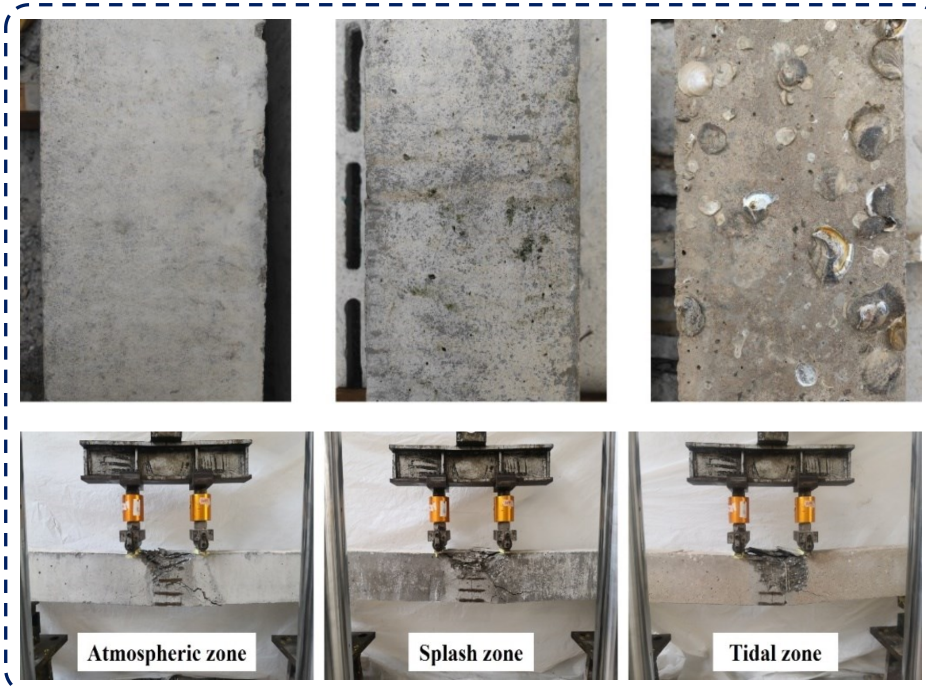
❖Bond Stiffness



Field Exposure Tests

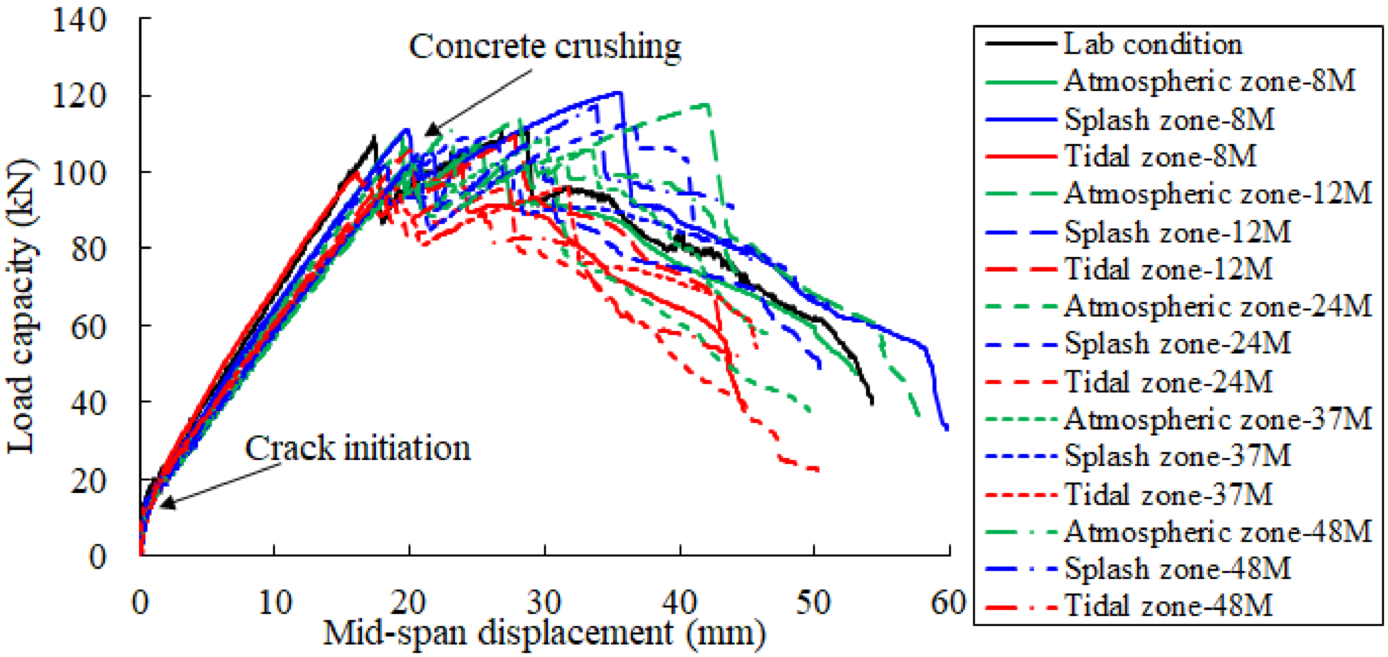
❖Beam Specimens



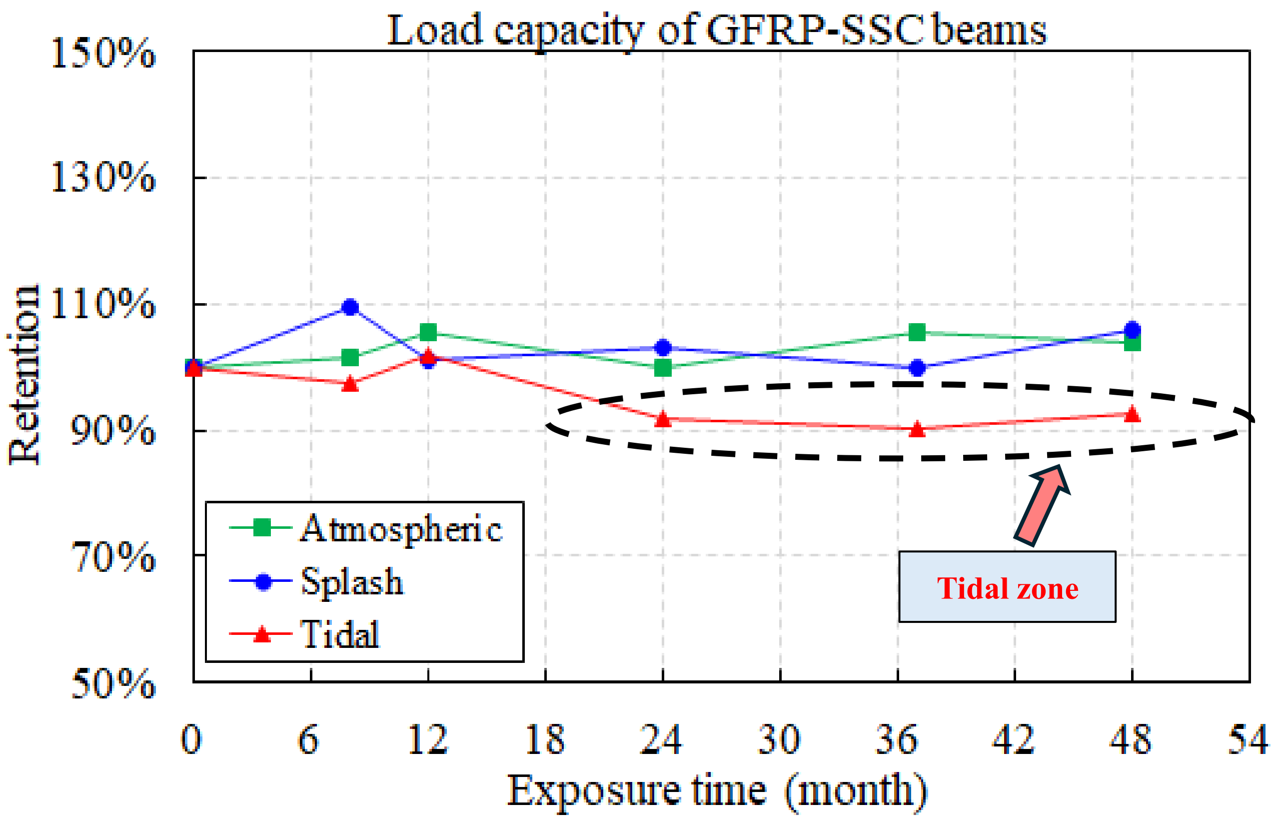


Field Exposure Tests

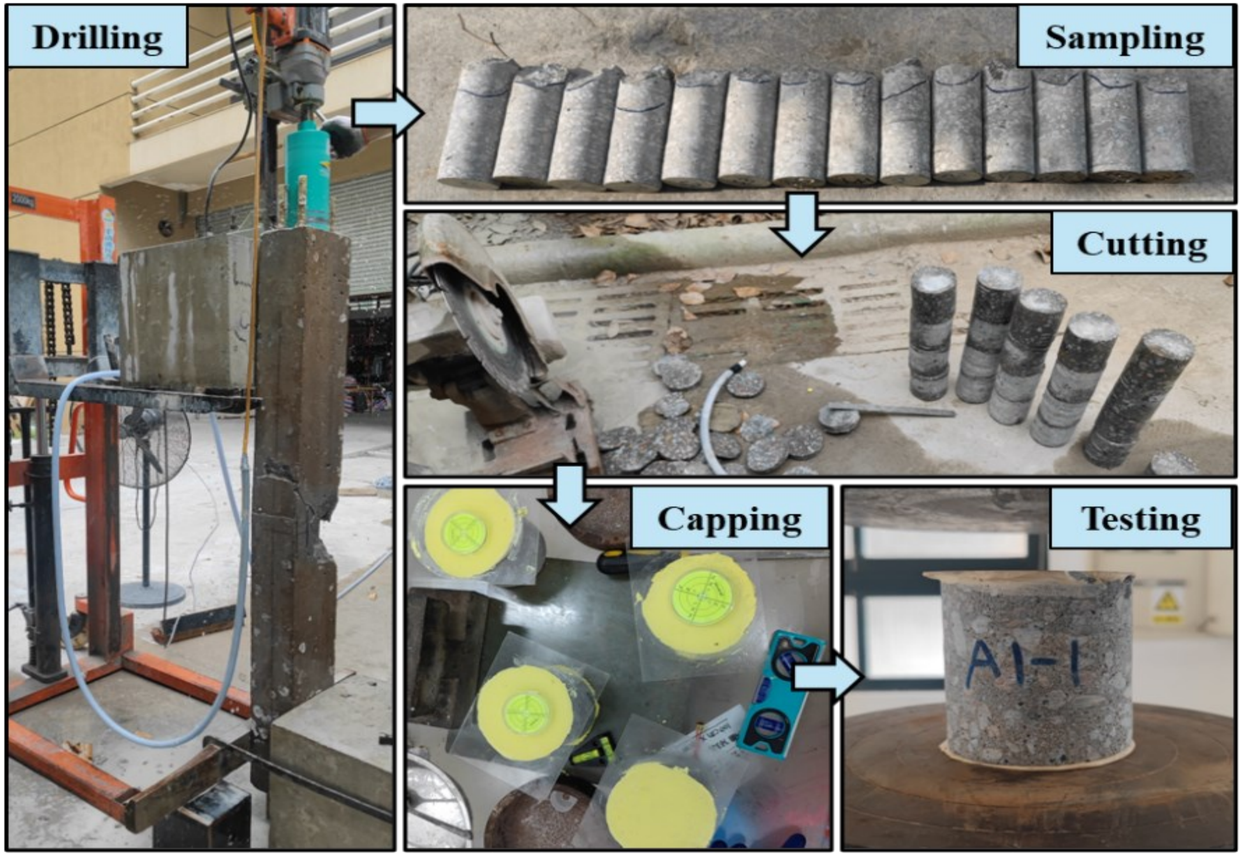
❖Beams without sustained loading



Field Exposure Tests



Field Exposure Tests



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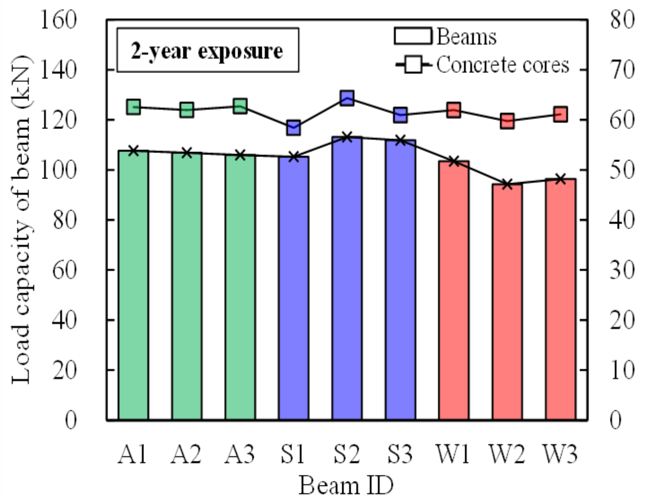
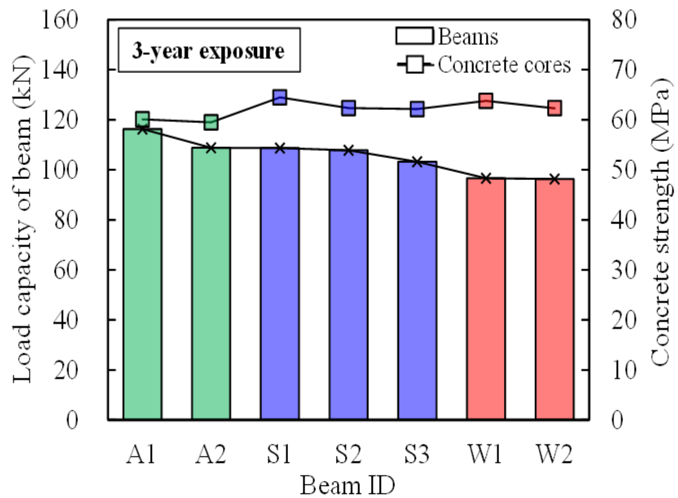
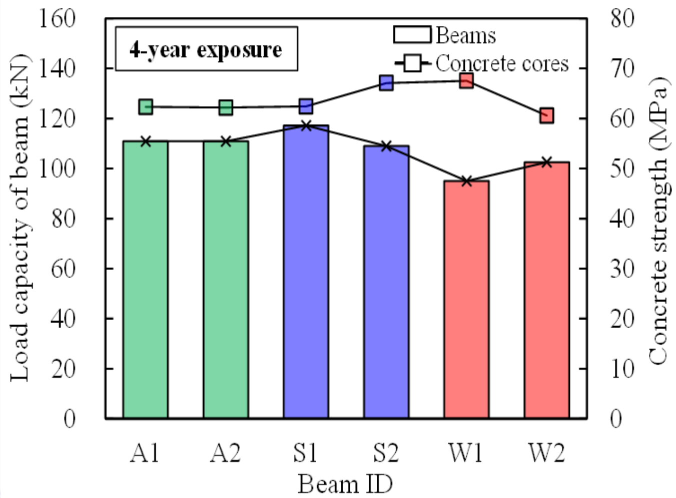
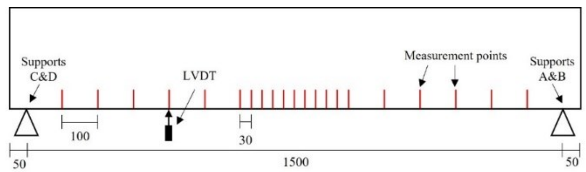


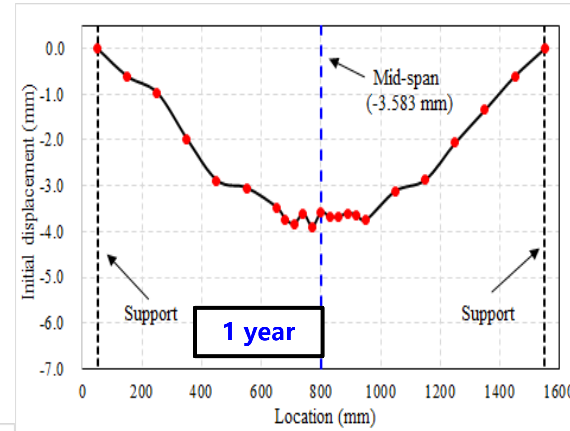


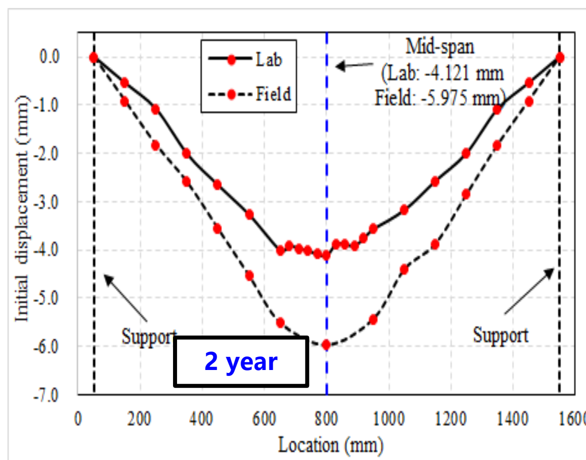


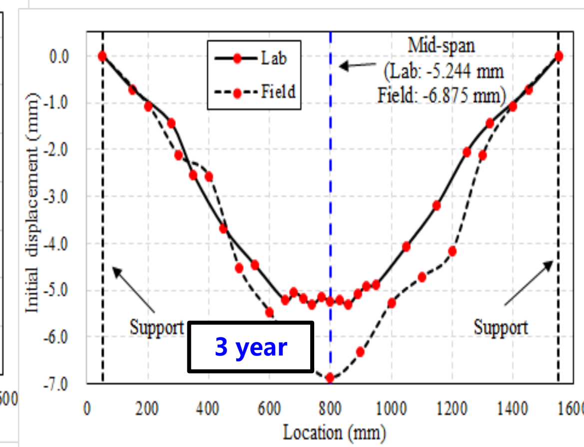
Field Exposure Tests

❖Beams with sustained loading









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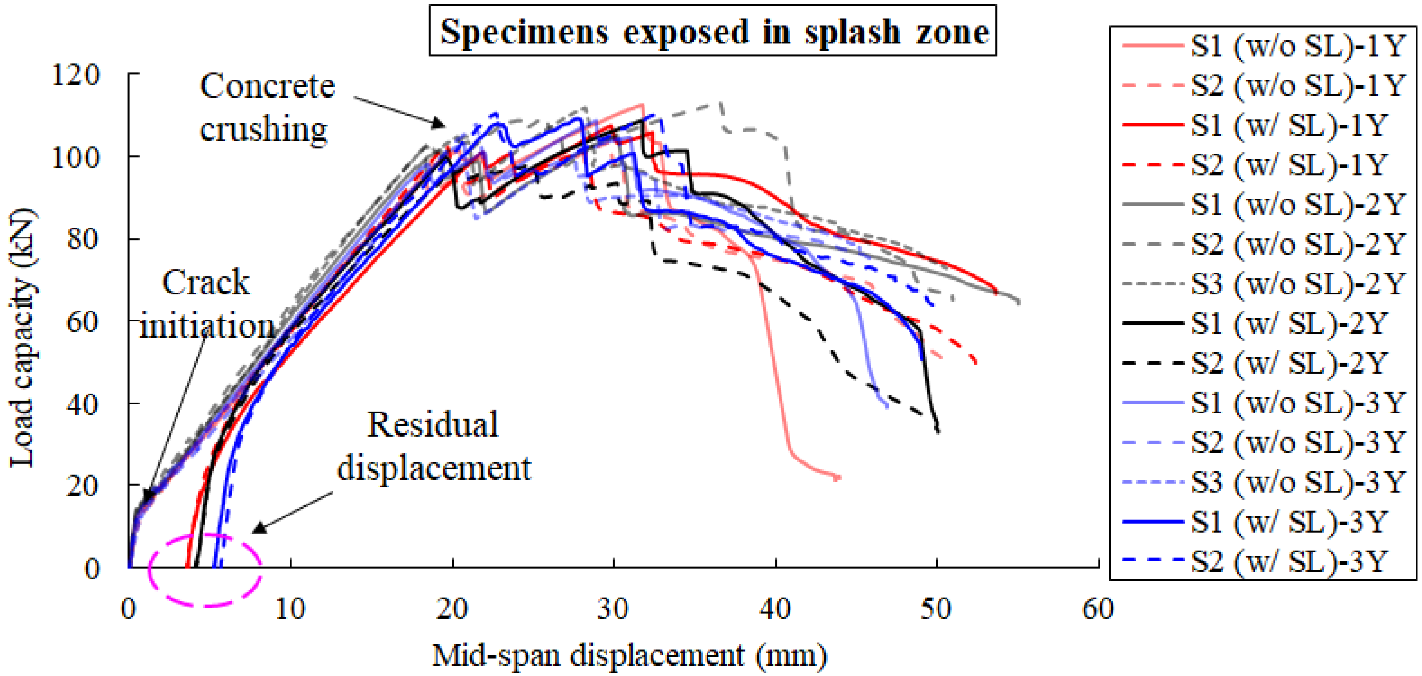
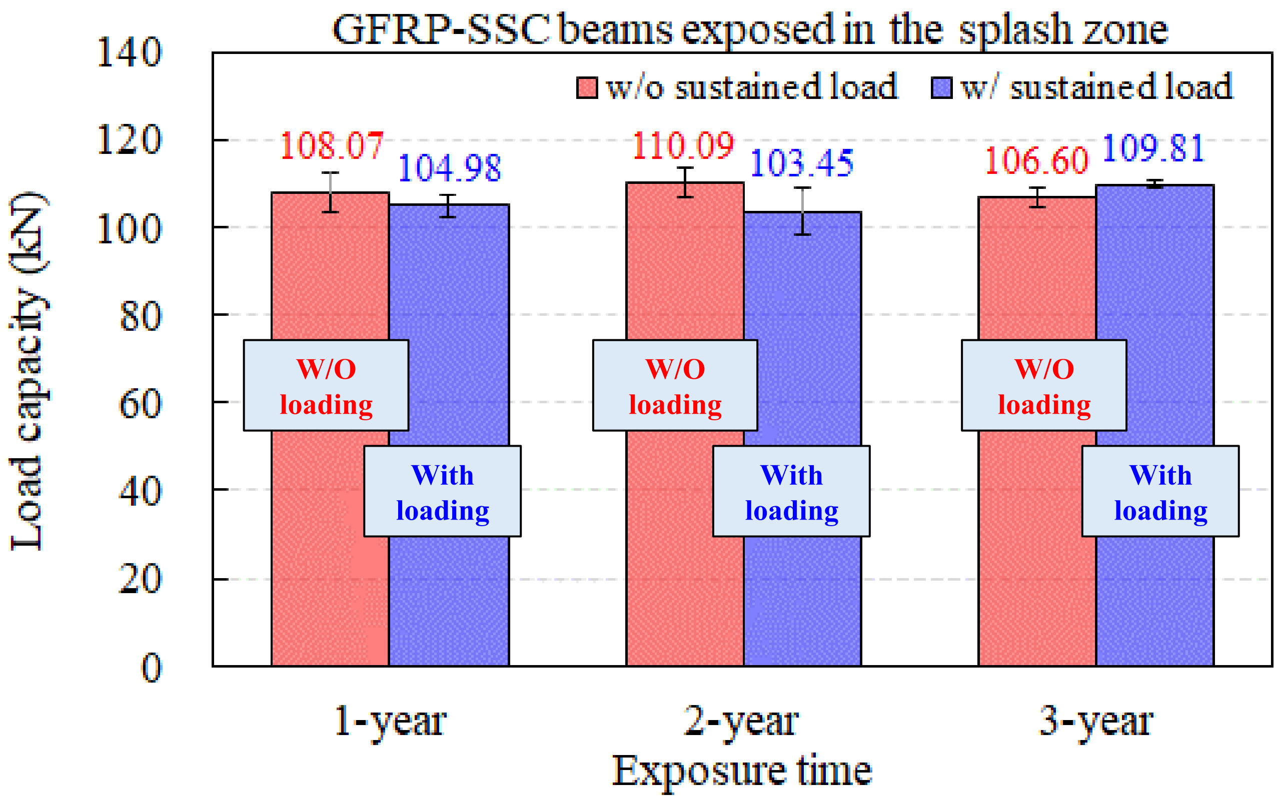


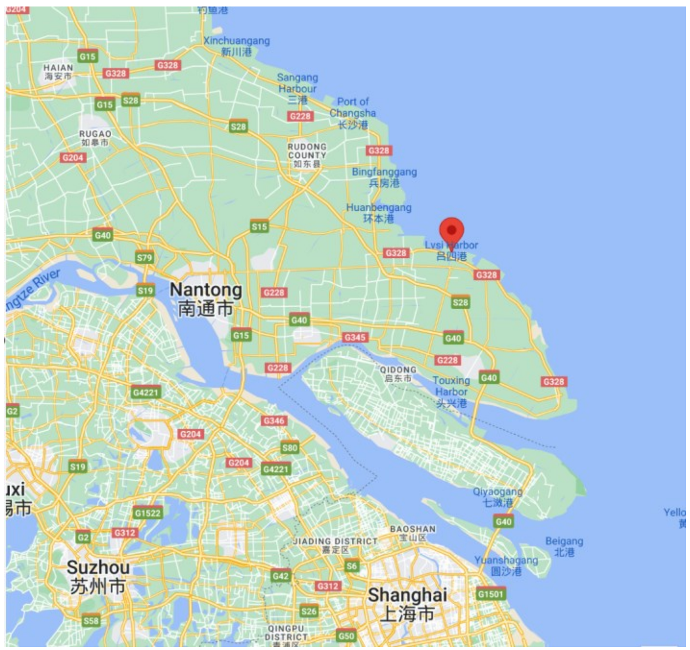
Field Exposure Tests



Exposure Station Construction Project, Lvsi Port, Nantong, China

Demonstration Project

Demonstration: **FRP-Seawater Concrete Slab**



Source: https://www.google.com/maps

The slab

Constructed in Oct 2021

NSERC CRSNG MIAMI FDOT

Sha Tin Sewage Treatment Works
Ma Liu Shui, Sha Tin, Hong Kong
Demonstration: FRP-SSC Paving Slab

Demonstration Project

Joint efforts of Tasks 1, 2 and 3

- Optimized SSC mix
- FRP-SSC structural design
- Optical fibre sensors
- Smart aggregates

Source: zh.wikipedia.org/wiki/沙田污水處理廠

Constructed in Dec 2022

Reconstruction Project

Lai Chi Chong Pier, Hong Kong

Demonstration: **FRP-SSC Slabs**

Demonstration Project

The slab

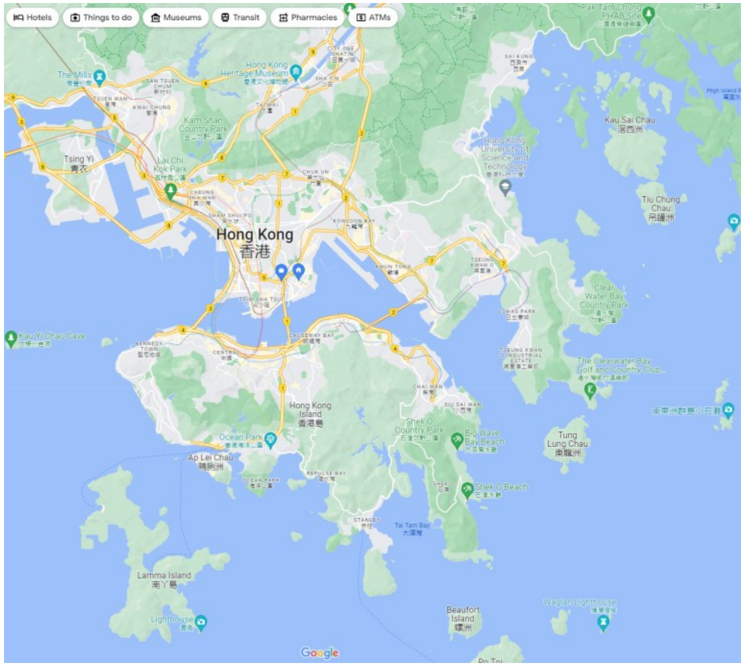
Design completed, expected to be constructed in late 2024

Wave Wall Construction Project

Lei Yue Mun, Hong Kong

Demonstration: FRP-SSC Wave Wall

Demonstration Project

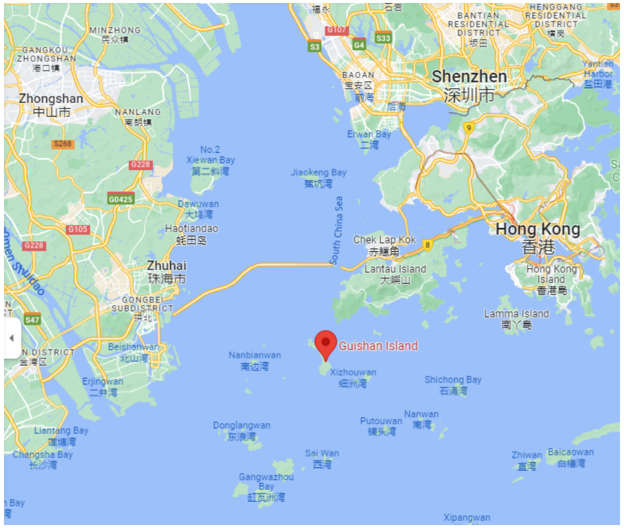


Source: https://www.google.com/maps

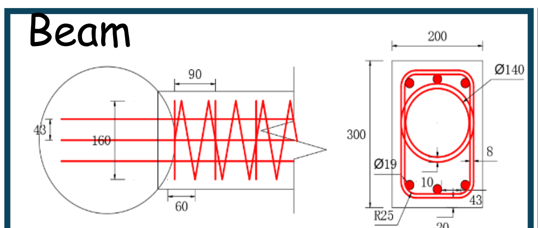
Source: CEDD, Hong Kong

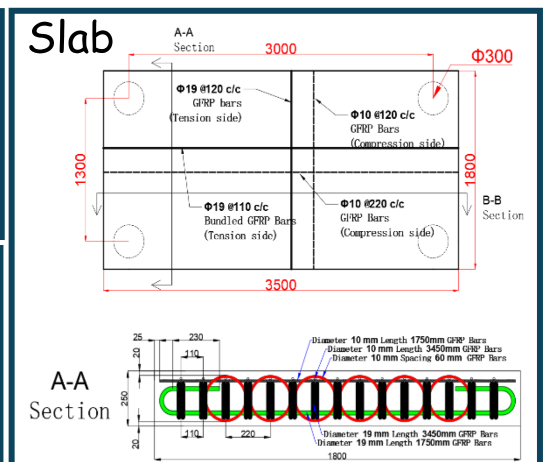
Design completed, expected to be constructed in late 2024

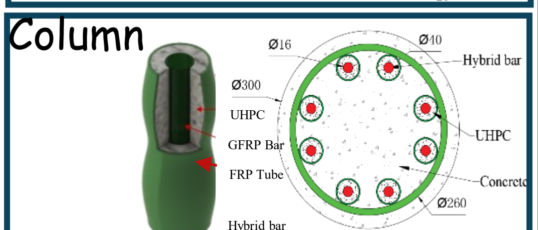
Mock-up Frame

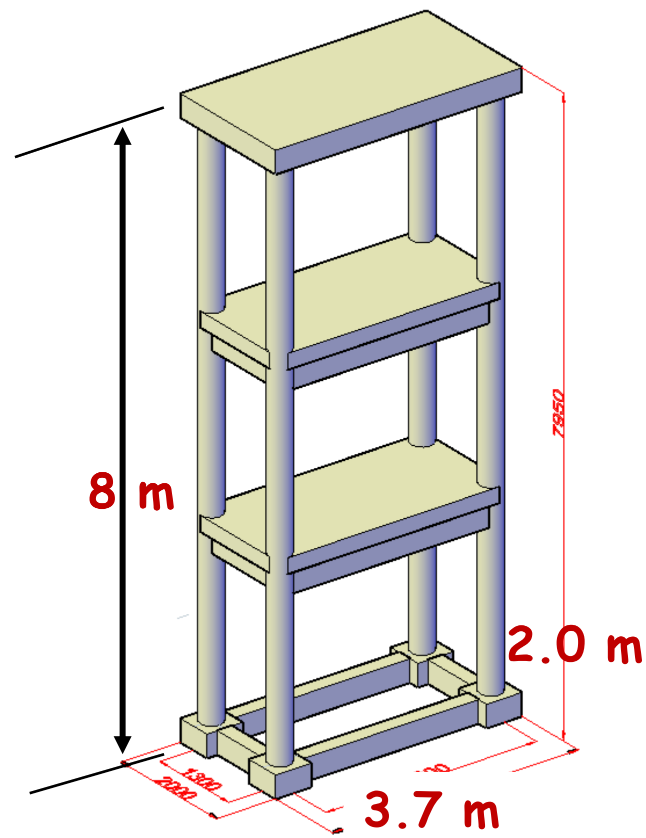


- Full-scale FRP-SSC Mock-up Frame
- Installation & Casting Site: Zhu Hai, China
- Construction completed



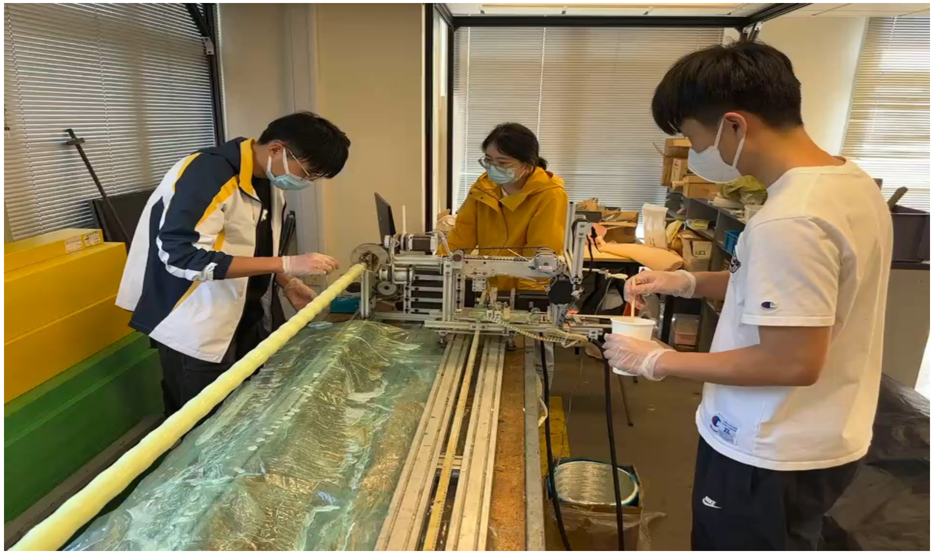






Mock-up Frame

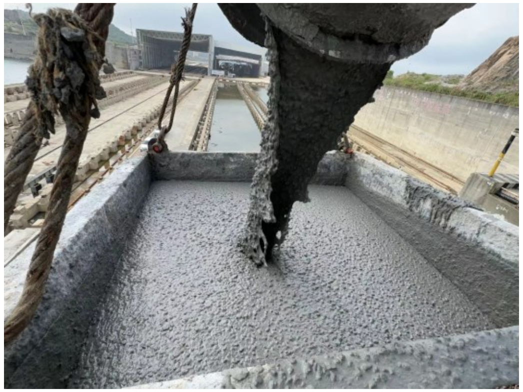
Frames for producing 4-meter-long hybrid rebars



Winding wavy-shaped FRP tubes

Mock-up Frame

Concrete casting
25 May 2023



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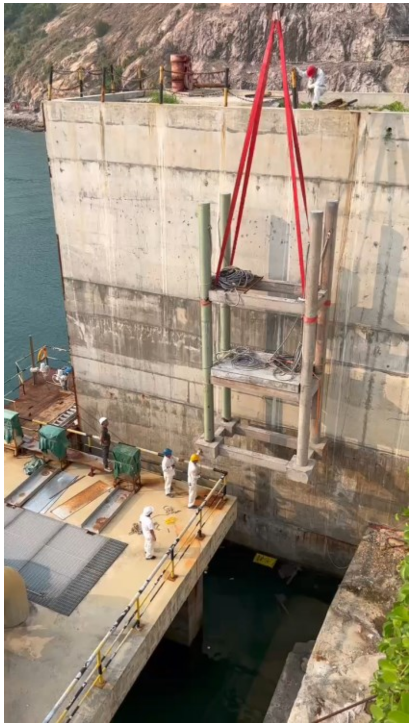
Mock-up Frame

Installation
31 May 2023



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FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

Thank you for your attention!

Tao Yu, Email: tao-cee.yu@polyu.edu.hk

The Hong Kong Polytechnic University

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