Pultruded Fiberglass Rebar for Infrastructure Applications

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Owens Corning

Pultruded Fiberglass Rebar

- **Fiberglass Rebars are finding increased adoption in Concrete structures due to efficiency, light-weight, and long term durability.**
- Faster adoption of higher performance pultruded rebar meeting ASTM D7957 and CSA S807 GFRP rebar material specification.
- Enabling more effective bridge design with improved material endurance limits in ACI 440 and AASHTO LRFD BDGS design standards
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Fiberglass Rebar Application



Fiberglass “FRP or GFRP rebar” bring a **high-level benefit** to concrete structures that:

- Are susceptible to corrosion from seawater or de-icing salts
    - Bridge decks, superstructure and substructure
    - Seawalls and retaining walls
- Need to mitigate electro-magnetic interference
    - Electrified rail plinths
    - Toll-way sensors
    - Automated Guided Vehicles in ports/warehouses
- Are bored through during construction
    - Tunnel Soft-Eye
    - Mining applications

Key Benefits of Fiberglass Rebar

- Installed cost advantage compared to coated steel rebar
- Corrosion-free: 100 year+ service life of structures[1,2]
- Improved life-cycle cost
  - Longer service life and reduced periodic maintenance
- **Increased construction productivity**
  - **Lightweight - 4x lighter than steel**
- **Safer work environment**
  - **Longer worker productivity, less injuries and fatigue**
- Exceptional strength
  - Ultimate tensile strength of fiberglass rebar 2x yield strength of steel
  - GFRP exhibits linear-elastic behavior up to ultimate tensile strength
- Allows concrete to be used cured with saltwater
  - Reduce impact on freshwater sources

[1] Loaria,J, Nolan S., Diggs II, A., Hartman D. *US 41 over North Creek; FRP Reinforced Concrete Two-Span Flat Slab Bridge and CFRP-Prestressed Concrete/GFRP Reinforced Substructure and Bulkhead Wall System,* August 2020

[2] Gremel, D, Koch R, Nagarajan M, Yee N, Hartman D. I*mproved GFPR Rebar for Reinforced Concrete Structural Application*. 8th International Conference on Advanced Composite Materials in Bridges and Structures.

Lightweight - Safe to Handle with less Fatigue

Long Term Durability

- ACI SDC 2019 study evaluated core samples 11 bridges, example of Miles Road Bridge Cuyahoga County, Ohio
- Negligible evidence of fiberglass rebar negatively affected by concrete environment in 20 years service
- Today's industry products are better than 10 years ago and perform better in accelerated aging protocols
  - ASTM D7957 material characterization accelerated testing per ASTM D7705 for 90 days in a high pH durability bath to simulate 100 year service life. Retention of greater than 80% of tensile properties.
- Demonstrates confidence in long term durability and justified **less conservative limits in design guides**

No sign of bond degradation or loss of bond contact and mechanical properties

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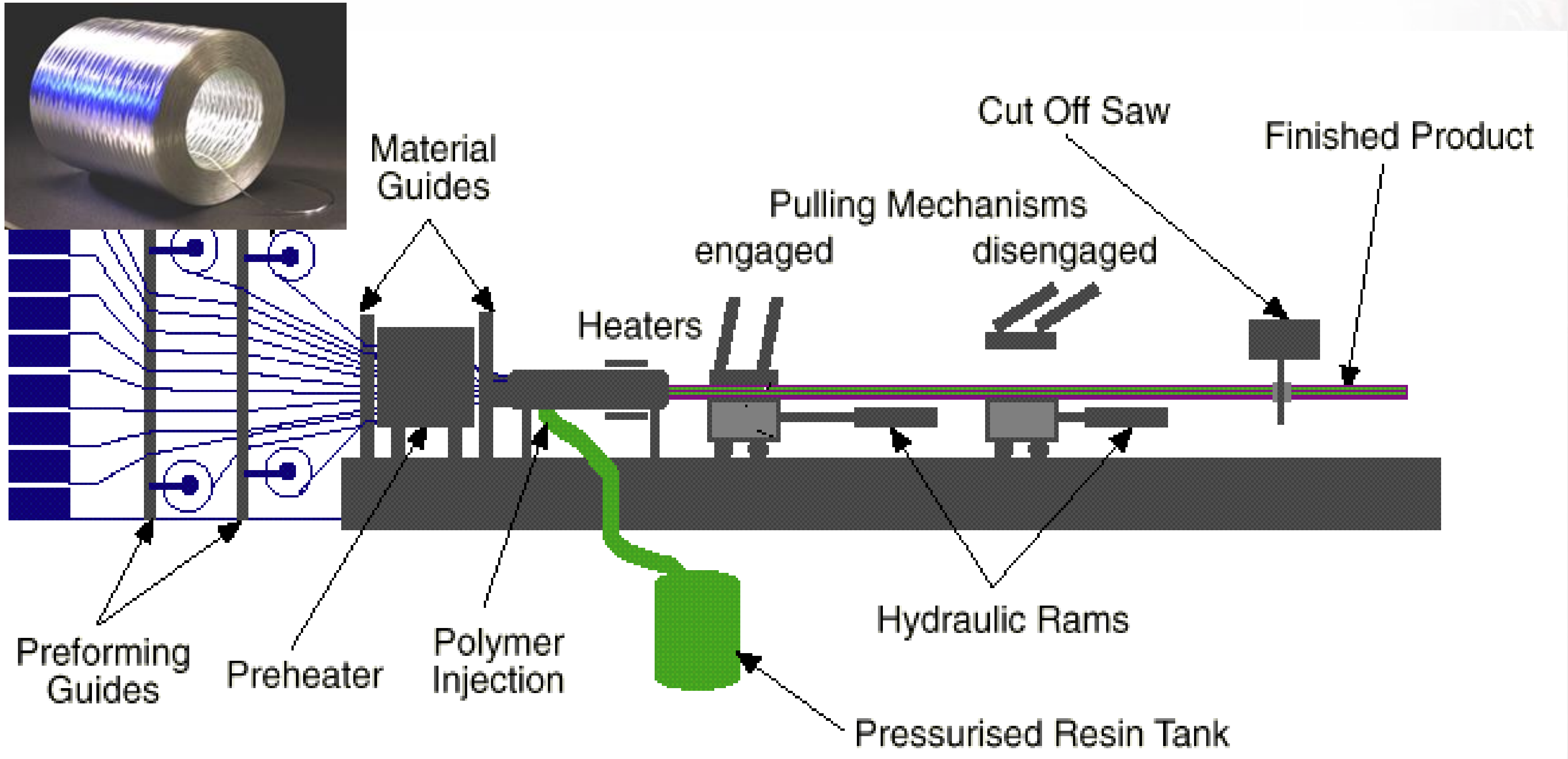
Adoption of Fiberglass Rebar in the Field

- Over 100 fiberglass rebar bridge projects in NA since 1999
  - O’Fallon Park Bridge – Kittredge, Denver County, CDOT
  - Sierrita de la Cruz Creek Bridge – Amarillo, TX, TxDOT
  - Halls River Bridge – Homosassa, FL, FDOT
  - 53rd Ave. Bridge – Bettendorf, IA, IowaDOT
  - Kauai Bridge 7E – Koloa District, Kauai, Hawai’i, HiDOT
  - Henry County Bridge – Henry County, Ohio, ODOT
- **Complete material and design standards available for fiberglass rebar**
  - **ASTM D7957 for material standards**
  - **ACI 440 and AASHTO LRFD BDGS design guidance for fiberglass rebar**
- Non-proprietary, reliable supply
  - Available through multiple manufacturers in North America
  - Competitive bidding happens on most public projects with fiberglass rebar

Need Efficient Pultrusion Process at Scale for Cost Effective Control to Specifications



GFRP Rebar Form Factor

ASTM D7957 Standard for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement

Structural Rebar Qualification

ASTM D7957-17 CERTIFIED QUALIFICATION TEST RESULTS

Reference	Property	Unit	Bar Size & Properties*			
		SI US	M13 (4)	M16 (5)	M19 (6)	M25 (8)
ASTM D2584	Fiber Mass Content	%	83	84	84	84
ASTM E1356	Mean Glass Transition Temperature (DSC)	°C	119	115	119	110
		°F	247	239	245	230
ASTM E2160	Mean Degree of Cure	%	100	100	100	100
ASTM D7205	Mean Measured Cross-Sectional Area	mm²	148[a]	227	325	574[a]
ASTM D792		in²	0.229[a]	0.352	0.504	0.890[a]
ASTM D7205	Guaranteed* Ultimate Tensile Force (25 - 40%)	kN	123	188	255	474
		kip	27.8	42.2	57.3	101.0
	Nominal Ultimate Tensile Strength	MPa	1105	1101	1092	1054
		ksi	160	160	158	153
	Nominal Mean Tensile Modulus of Elasticity (30 - 40%)	GPa	62.5	64.3	63.4	66.1
		Msi	9.1	9.3	9.2	9.6
	Nominal Mean Ultimate Strain	%	1.8	1.7	1.7	1.6
ASTM D7705-A	Alkaline Resistance: Tensile Retention	%	TBD	108[a]	104[a]	TBD
ASTM D7913	Guaranteed* Bond Strength	MPa	11.4	8.6	9.4	TBD
		ksi	1.7	1.2	1.4	TBD
ASTM D7617	Guaranteed* Transverse Shear Strength	MPa	176	167	161	163
		ksi	25.5	24.2	23.3	23.7
ASTM D570	Mean Moisture Absorption at 24 hrs.	%	0.009[a]	0.014	0.048	0.014[a]
	Mean Moisture Absorption at Saturation		0.079[a]	0.108	0.237	0.107[a]

*For the determination of the mean and guaranteed properties, a minimum of 24 samples were tested in groups/specimens of eight or more from three different production lots. Guaranteed property is equal to mean value minus three standard deviations. Refer to Report Section 1.3 for bar identification.
[a]Partial results reported.

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FDOT Roadmap - Industry Working Together to Improve

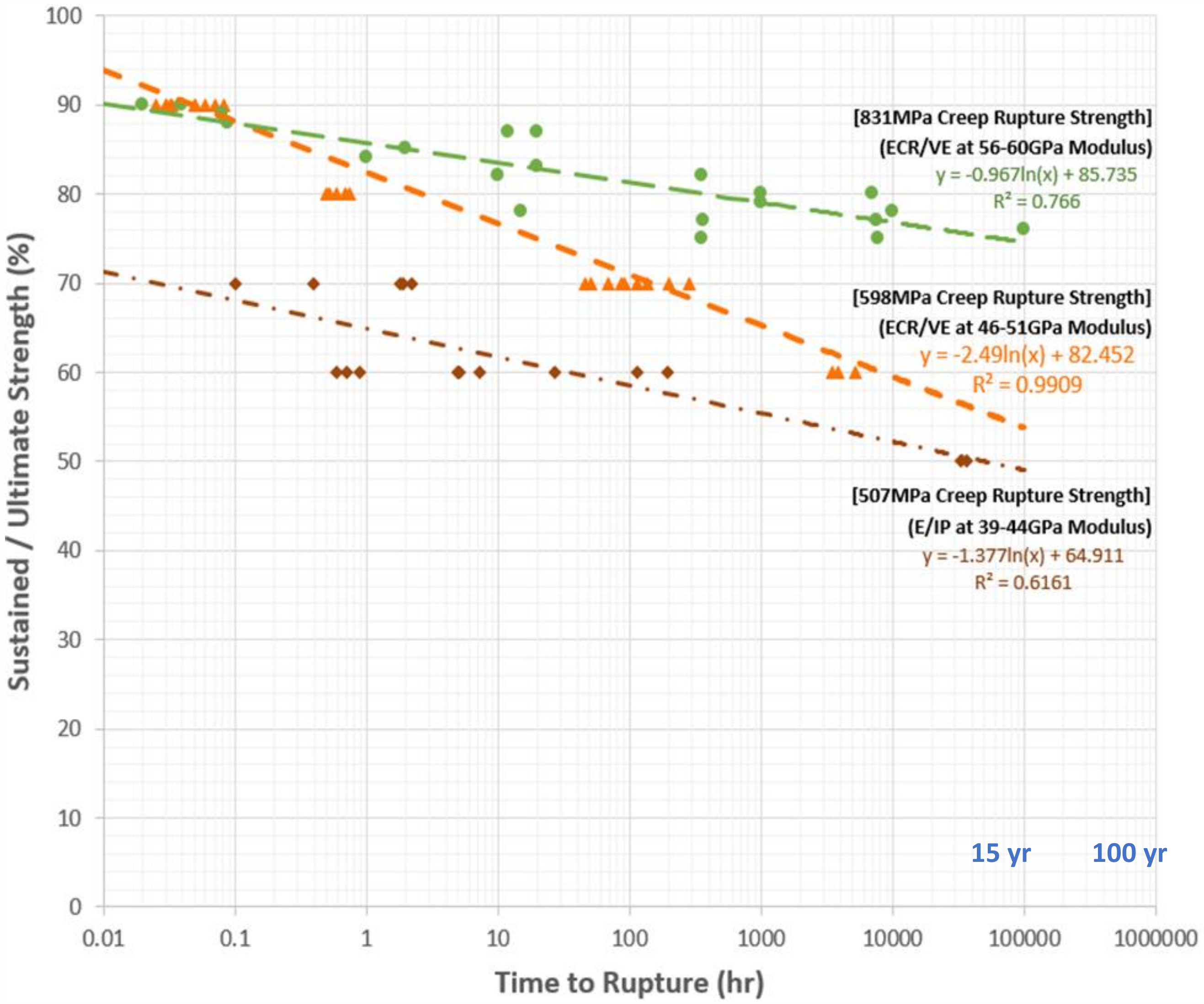
Interim Update - July 19, 2020

FDOT FRP-RC Strategic Workplan Summary

Version 20.0

Priority Item #	Goal #'s (1)	Topic	Responsible Team	Timeline	Justification	Action Item
1	1, 2, 3	**Endurance Characteristic Curves Testing** a. Need time/cycles to rupture curves; b. What is the test method or surrogate measure for supplier product acceptance?	FRP Industry (Dave Hartman-OC) in consultation with SMO (Chase Knight)	ASAP	a. Reliably extending service-life beyond 50-75 years: *new AASHTO Guide Spec for Service Life Design of Highway Bridges will target 75, 100, & 150-years;* b. Simple, timely, low cost verification tests.	Develop Plan with FDOT at 3/28/18 meeting (Hartman, Knight, Nolan) Dave Hartman working with Sandia/MSU database for further improvement. Sam Fallaha still seeking NCHRP support for research funding. *RNS available at https://rns.trb.org/details/dproject.aspx?n=41501*
2	1, 5	**Endurance Limits** - on FRP for design (is 20% the best we can do?)		Awaiting test results from #1	Directly proportional to area of rebar required. Perhaps we should consider a strain-limit approach (Benmokrane)	a) Creep Rupture factor raised to 0.30 for ***AASHTO BDGS-2nd edition.*** b) Fatigue Rupture factor raised to 0.25 to match ***CSA*** *(but C_F is only included for AASHTO-GFRP-2)*
3	1, 4, 5	**Increasing Material Property Qualification Thresholds and Design Limits** - desirably 20-30% above *ASTM D7957-17*. *No increase was implemented, but tacit support during IW-GFRPCS2 1/19/2019. Ef --> targeting 60 MPa similar to CSA S807-19 (Grade III)*	FDOT with industry concurrence & UM GFRP Guide Spec Team	Decision needed by 8/1/~~2018~~*2020* for ***SM*** publication.	>20% reduction in rebar area possible for SLS controlled designs. *CSA S6-19 has Grade III with improved properties preferred by some Provinces. ASTM D7957-17 update in progress (Chair: Doug Gremel)*	UM/FDOT to develop charts with Manufacturers' test results, vs current and proposed limits (Nanni). *Several papers have been presented at conferences to date (See Attachments)*

Improved Material Endurance Limits



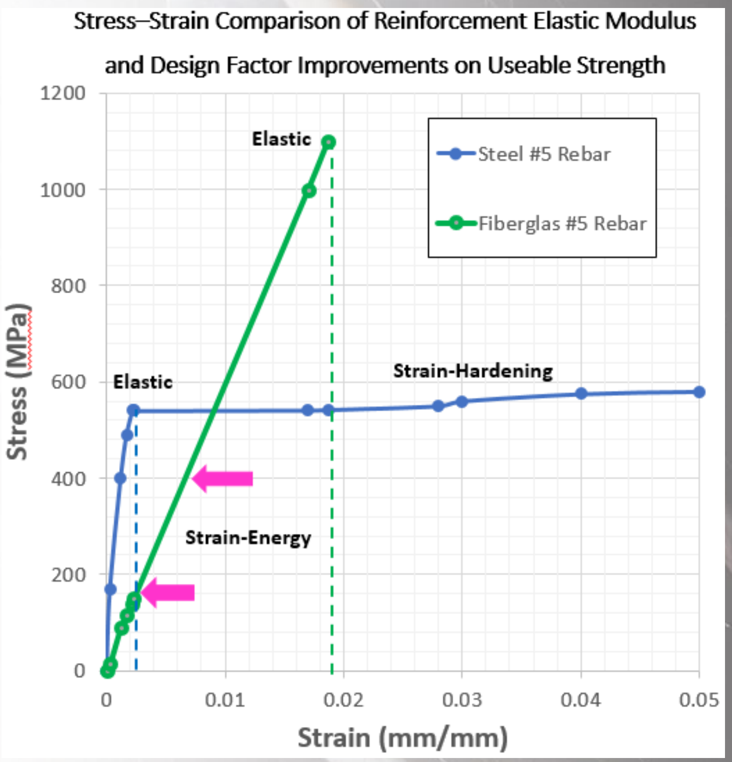
- ACI 440.1R limited allowable sustained load for traditional GFRP rebar (E/IP) based on the ACI 440.3R B.8 GFRP Creep Rupture Limit Test for 75-100 year life
- Fiberglass rebar of ECR glass fiber in vinylester resin (ECR/VE) with higher elastic modulus shows improved creep rupture limit
- **Creep rupture limit recently improved in AASHTO LRFD BDGS at C_C = 0.2 to 0.3 with ongoing work to improve to 0.4**
- Working to further improve creep and fatigue endurance limits to extend bridge service life to 125-150 years

ACI 440.3R B.8 GFRP Sustained Load Creep Rupture Strength at 10^6 hours by Glass/Resin type and Rebar Elastic Modulus

Sources: Owens Corning and FDOT TRB 2019 Presentation, AASHTO LRFD bridge design guidelines

New Less Conservative Limits in Design Guides

Design Factor	AASHTO, (2018a)	AASHTO (2009)	ACI 440.1R-15	CSA (2014)	Critical Design Parameter Description
f_{fu}^{*}	99.9	99.9	99.9	95.0	Strength percentile
Φ_C	0.75	0.65	0.65	0.75	Resistance factor concrete failure
Φ_T	0.55	0.55	0.55	0.55	Resistance factor FRP failure
Φ_S	0.75	0.75	0.75	0.75	Resistance factor shear failure
C_E	0.70	0.70	0.70	1.0	Environmental reduction
C_C	0.30	0.20	0.20	0.25*	Creep rupture reduction (* C_E not applied)
C_f	0.25	0.20	0.20	0.25*	Fatigue reduction (* C_E not applied)
C_b	0.83	0.70	0.70	1.0	Bond reduction
w	0.028 (0.7)	0.02 (0.5)	0.028 -0.020 (0.7-0.5)	0.5	Crack width limit inch (mm)
$c_{c,\ stirrup}$	1.5 (40)	1.5 (40)	2.0 (50)	1.5 (40)	Clear cover inch (mm)
$c_{c,\ slab}$	1.0 (25)	0.79 (20) – 2.0 (50)	0.79 (20) – 2.0 (50)	1.5 (40)	Clear cover inch (mm)



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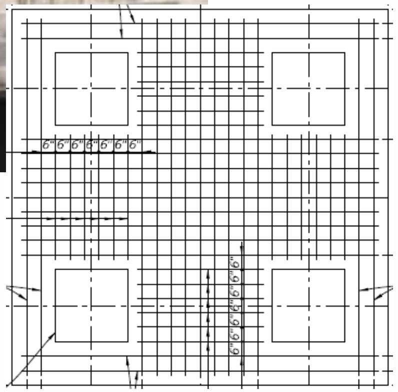
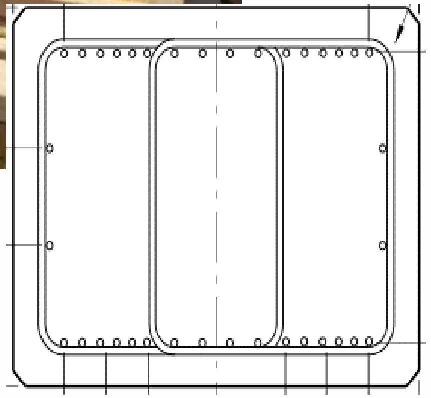
Expanding the DOT use of GFRP Structural Rebar Requires Provisions for all Members of a Bridge

- Need Larger Diameter Rebar, Bent Complex Shapes, Spirals…

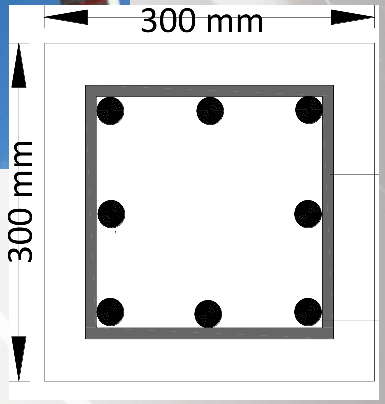
FOOTINGS



BENT CAP



PILES



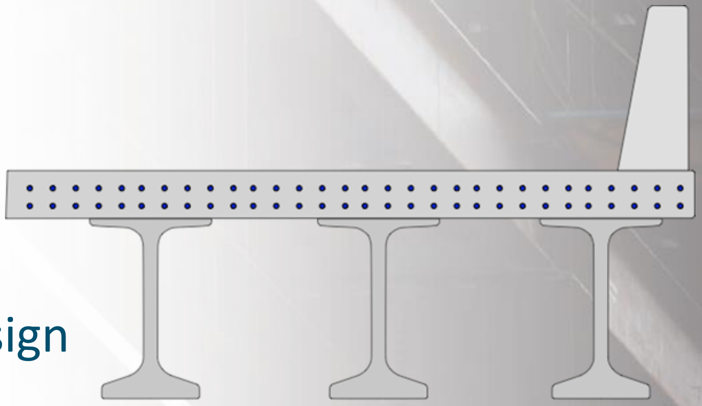
Working with DOT Specifications

Example of ODOT GFRP Specifications – January 2020 ODOT/GFRP Industry Meeting

- C&MS 509 Construction specifications based on ACI 440.5-08
- C&MS 705.28 Material specifications based on ASTM D7957 with the elastic modulus >8700 ksi (60 GPa), tensile strain >1.4%, guaranteed ultimate tensile force ASTM D7957 Table 3 +25%
- Supplement SS-1138 “GFRP Certification Program” for suppliers, as an alternative to Reinforcing Steel, GFRP reinforcement is also certified

ODOT Bridge Deck GFRP Design Tables – September 2020

- BDM will incorporate GFRP design specification when AASHTO approved
- Design focus on serviceability of GFRP-RC
- Traditional unit strip method with 1:1 substitution of steel rebar desired
- Interest in a GFRP database module for AASHTO-Ware used in bridge design and rating with certification to codes and standards



ODOT Fiberglass Rebar Needs

Anthony Wayne Trail Bridge

Bridge Flat Slab - bridge decks, approach slabs, and slab bridges

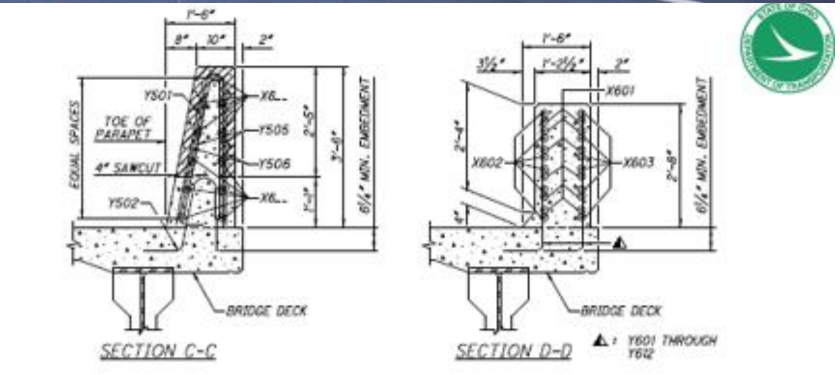
- Anthony Wayne Trail Bridge, I-475 Dorr St, and Hill St Overpass are examples of recent bridge projects in Ohio
- ODOT realized benefits of GFRP utility in flat slabs using VECP engineered solutions, design policy evolving to using an owner decision in Scope of Services agreement.
- “manufactured in USA” GFRP alternative to epoxy steel

I-475 Dorr St Overpass

ODOT Learnings:

- Need mechanical splice coupler for phased construction:
  - ODOT approved list with specification to ASTM A1034 using guaranteed properties of C&MS 705.28
  - Splice sample verification testing at the project level
- Need GFRP detectability with Ground Penetrating Radar
- Need GFRP field repair-ability guidance

ODOT New Application



DESIGN DATA:
CONCRETE - COMPRESSIVE STRENGTH = 4.5 KSI
REINFORCING STEEL - MINIMUM YIELD STRENGTH = 60 KSI
GFRP - C&MS 705.28 (MODULUS = 8700 KSI)
AREA OF STANDARD 42" SBR-1 CROSS SECTION = 588.0 SQ. IN.
VOLUME OF 42" SBR-1 14'-0" TRANSITION SECTION = 1.82 CU. YD.

(Source: ODOT released drawing)

Traffic Barriers

- ODOT previously specified GFRP dowel as a non-structural element at location of deflection joint saw-cuts. The new GFRP CM&S permitted use of GFRP rebar for longitudinal reinforcement in concrete barriers.
- In January 2020 ODOT released new drawing SBR-1 for traffic barrier standards requiring use of high modulus 60 GPa (8700 ksi) GFRP Rebar as the horizontal and stiffening reinforcement in 42” bridge railing or parapets meeting MASH TL-4 or TL-5.
- In July 2020 ODOT released SBR-2 drawing standards for use of GFRP horizontal and stiffening reinforcement in 57” tall median traffic barriers, single slope MASH TL-3 and double slope meeting MASH TL-5.
- In July 2020 ODOT released SBR-3 drawing standards for use of GFRP in 36” tall single slope bridge railing concrete barriers used off system.

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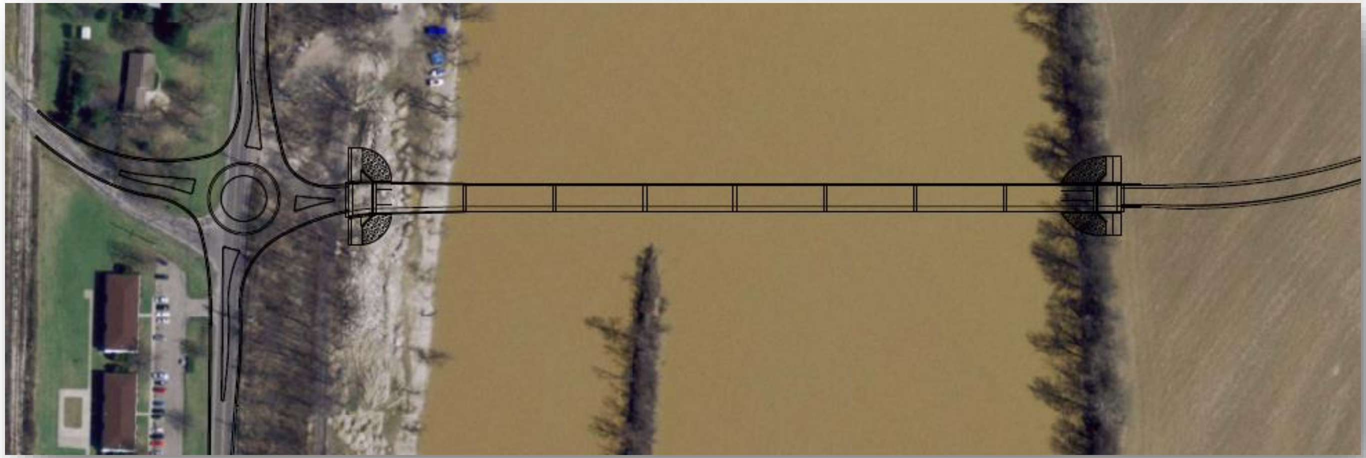
Henry County Bridge, Ohio – Cost Comparison

Initial Construction Costs (Industrial Drive Bridge) (Based on Engineer's Estimate)			
	Quantity	Unit Price	Cost
#4 Bars (GFRP)	61,600 Ft.	$0.68/Ft	$41,888.00
#5 Bars (GFRP)	105,787 Ft.	$0.80/Ft	$84,629.60
#6 Bars (GFRP)	266,809 Ft.	$0.92/Ft	$245,464.28
Total (GFRP)			$371,981.88
Epoxy Steel Reinforcing	359,928 lbs	$1.15/lb	$413,917.20
Total Savings			**$41,935.32**



(Source: Mannik & Smith Group - picture and estimate)

Fiberglas™ Reinforcement Solutions and Segments

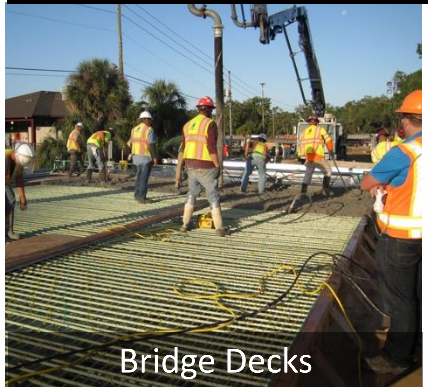
Civil/Heavy Construction

- 20+ Years of Experience
- **MATEENBAR™ Fiberglas™ Rebar**
- Owens Corning Fiberglas™ Dowels
  - Economic solution vs. steel reinforcement
  - Sustainable for structural applications

Residential/Light Commercial

- Product Launched 2019
- PINKBAR® Fiberglas™ Rebar
  - Economic solution for crack mitigation vs. black steel in slab-on-ground applications

Structural Concrete Reinforcement


Bridge Decks


Sea Walls


Jointed Paving

Crack Mitigation for Slab on Ground


Agricultural Pads


Driveways


Industrial Pads

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