

FRP- Updates & The MD-5 Bridge Deck Case Study

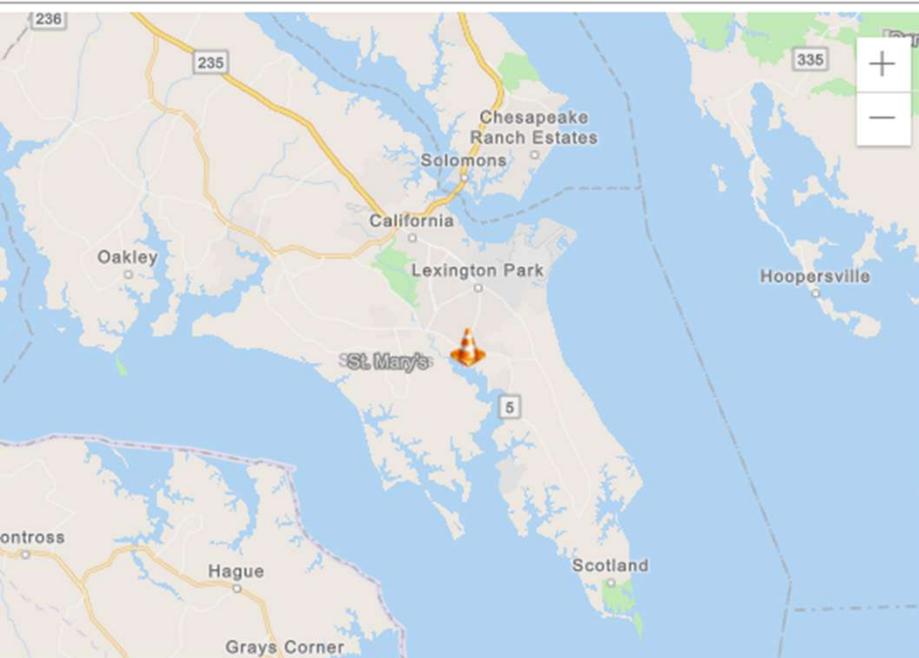
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MD 5 Deck Replacement

Design: Completed April 2024
Construction: Now Through Fall 2025



MD 5 Replacement

- The Maryland Department of Transportation's State Highway Administration (SHA) has initiated the MD 5 (Point Lookout Road) bridge replacement project at the Hilton Run crossing (SM1675180).
- The purpose of the project is to replace the existing bridge as it is nearing the end of its useful service life. This bridge deck will be the first in Maryland (MDOT) to use glass fiber reinforced polymer (GFRP aka fiberglass rebar).

<https://mdot-sha-md5-brg-over-hilton-run-sm1675180-maryland.hub.arcgis.com/>

Why GFRP

- Corrosion is draining the economy silently
- Governments & Taxpayers can no longer afford to pay concurrently for replacing, maintenance and expansion of infrastructure
- Safety of infrastructures should always be of paramount concern
- Steel is an old material, it's great but often does not fit some applications

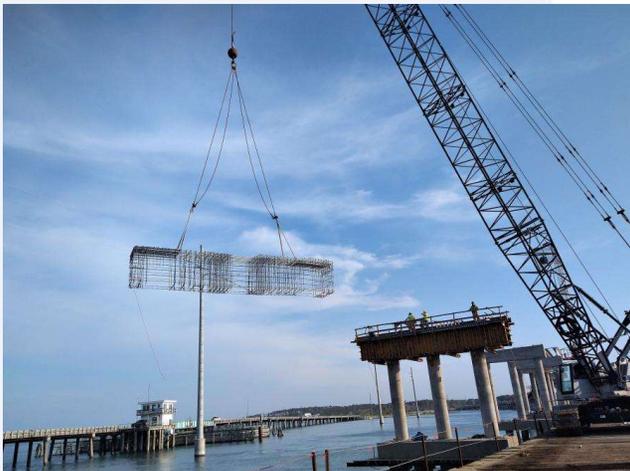


Steel Corrodes

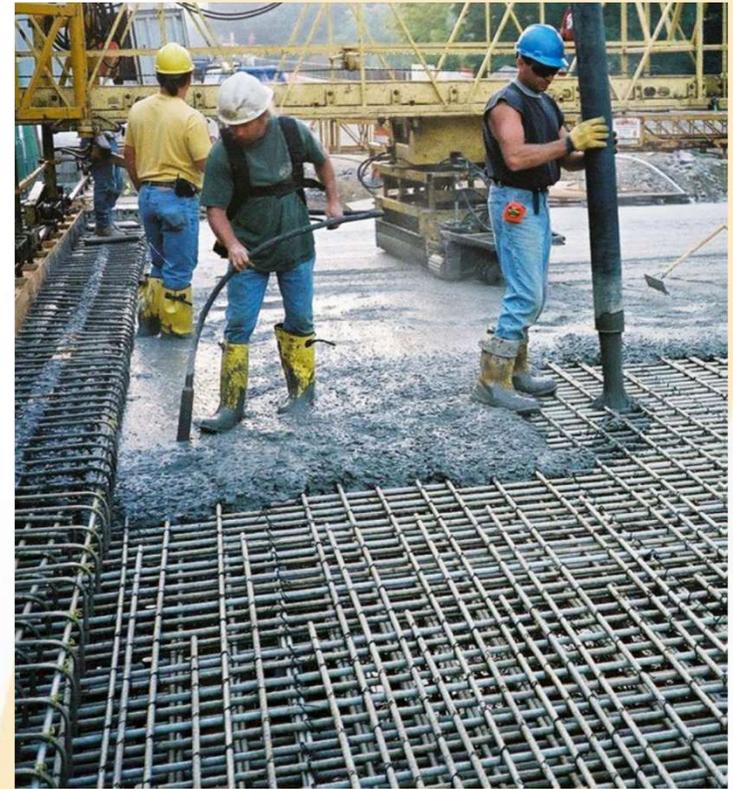


NCDOT: Harkers Island

- 3,200 foot span featuring glass and carbon FRP
- Opened 1 year ahead schedule
- Replaced structure built in 1969
- Will last 100+ years



GFRP in Action



The Codes

- **ACI 440.11 (2022)** Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary
 - ACI 440 Fiber-Reinforced Polymer Reinforcement has been publishing reports, specifications, and design guides since early 2000's
 - Code by reference in IBC 2024
- **ACI 318 Building Code Requirements for Structural Concrete** references ACI 440
- **ACI 332 Residential Code Requirements for Structural Concrete** references ACI 440
 - Equivalency to IRC 2018 and later codes
- **ASTM D7957-17** “Standard Specification for Solid Round Glass FRP Bars for Concrete Reinforcement”- includes bent bars
- **ASTM D8505-23** “Standard Specification for Basalt and Glass FRP Bars for Concrete Reinforcement”- includes high modulus of elasticity bars (60 GPa/8700 ksi)
- **AASHTO GFRP-1 (2019)** ” AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete Bridge Decks and Traffic Railings”, American Association of State Highway and Transportation Officials
 - 13+ States with DOT Approval: Florida, Maine, Massachusetts, Michigan, North Carolina, Ohio, South Carolina, Texas, Virginia, ...
- **TMS 402/602 (2022)** Appendix D “Glass Fiber Reinforced Polymer Reinforced Masonry” The Masonry Society

WHAT IS GFRP

- 80% Fibers (reinforcement)
- 20% Resins (polymers)

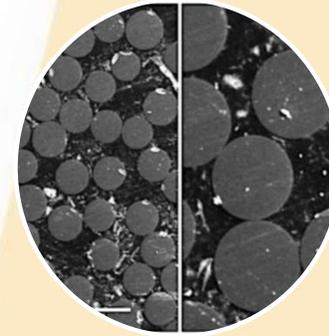
Load Bearing Fibers

High Tensile Strength



Resin Matrix

Durable Binder for Fibers
Provides Shape/Form



Inert Product

Does Not React with Concrete
+ completely stable in Acidic and Alkali environments



WHAT IS FRP



RESINS

- Polyester Resin
- Epoxy Resin
- Vinyl Ester Resin

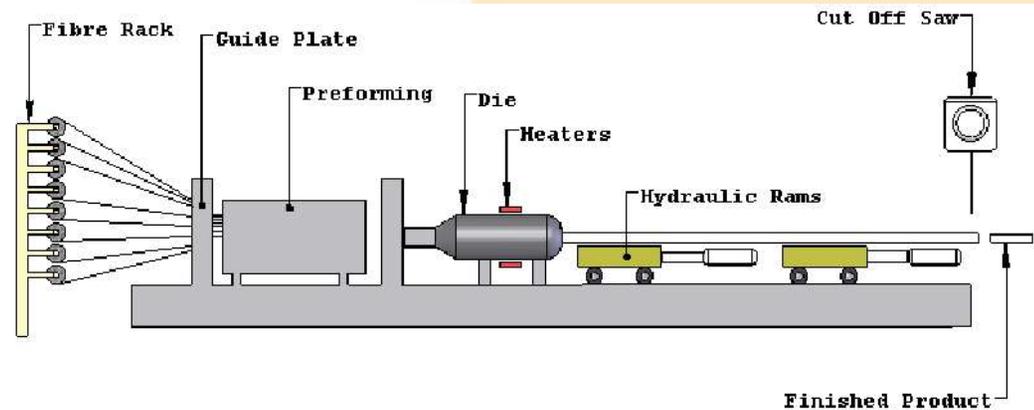
KEY CONSIDERATIONS

Polyester resin is not permitted by ASTM. This affects how you Design & Specify.

(ASTM D7957, Section 5.2.2, 2017)

FIBERS

- Basalt Fiber (BFRP)
- Carbon Fiber (CFRP)
- Aramid Fiber (Kevlar)
- Glass Fiber (GFRP)



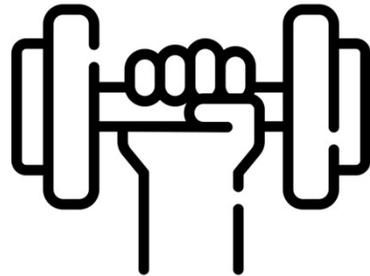
Benefits of Glass Fiber Reinforced Polymer (GFRP)

80% lighter



shipping and handling
labor savings
reduced weight

2x-3x tensile strength



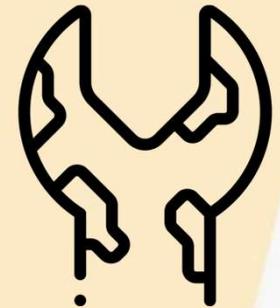
1.5x higher bond strength
20x better fatigue strength

35% less CO₂



thermally insulating
non-conductive
inert in low carbon concrete

no corrosion



longer lasting
less maintenance

Lightweight



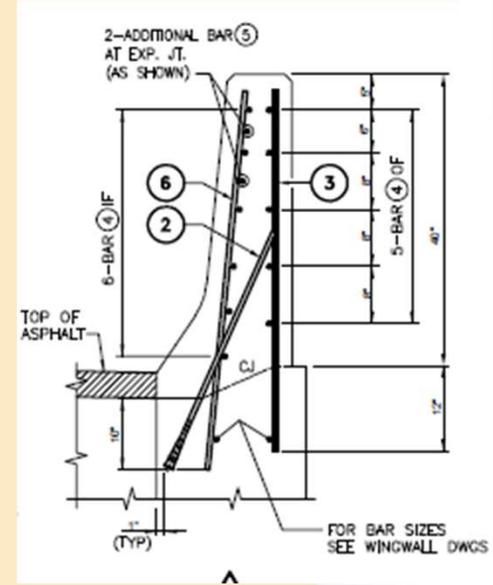
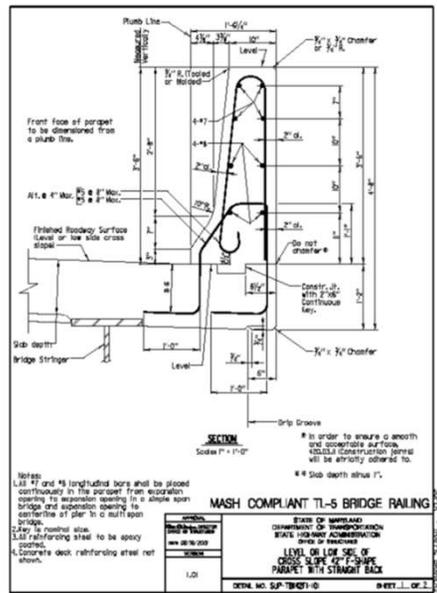
Straight GFRP vs. Steel

	STRAIGHT GFRP*	STEEL
Tensile Strength	185-145 KSI	65 KSI
Bond Strength to Concrete	2900 PSI	>1700 PSI
Elastic Modulus (Concrete ~4350 KSI)	9400 KSI	29,000 KSI
Loss of Tensile Strength at -100°F	0% Drop	Brittle - Premature failure
Ultimate strain %	1.5 - 2%	10%
Transverse Shear Strength	220	240
Oxidation	Never (NO Fe)	YES
Compression Strength	>80 KSI	58 KSI
Density	131 lb/ft ³	487 lb/ft ³
Conductive (Heat, Electricity)	No	Yes

Understand the difference in Mechanical & Physical Properties

*values are for MST Bar

Where To Use: Barrier Walls



Embedded Video slide of Barrier wall Crash Test with Semi Truck

Where To Use: Barrier Walls

Crash Test of PL3 Barrier with GFRP



Fig. 11. General view of the barrier wall after vehicle impact



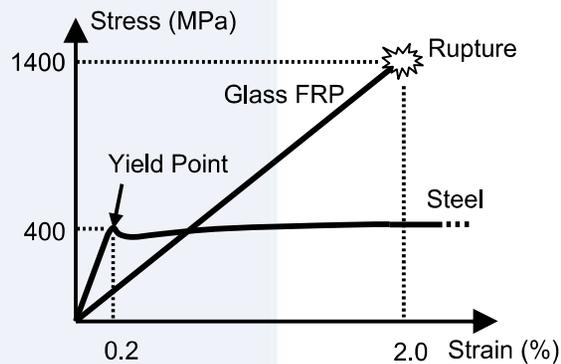
Compression Controlled Failure



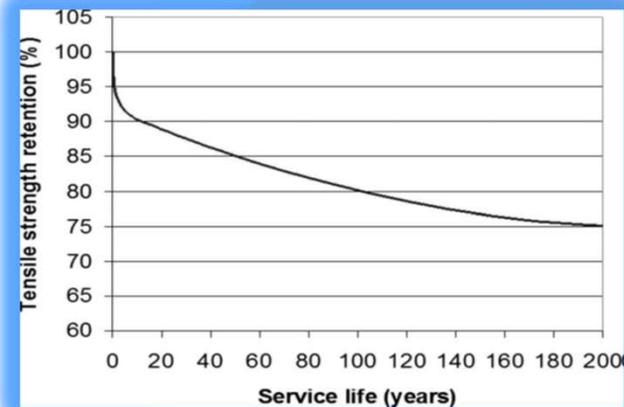
Embedded video of GFRP Beam tested to failure

Key differences between GFRP and Steel Rebar

- GFRP is linear elastic up to rupture, steel is linear elastic up to yield, and plastic up to ultimate failure.
- GFRP strength changes over time. While steel corrodes if exposed to chlorides, its material properties do not change. Lower Φ factor for GFRP design accounts for strength degradation due to environmental exposure.



Stress strain curves for GFRP and steel reinforcement (ISIS 2006)



General relation between tensile strength retention and predicted service life at mean annual temperature of 6°C Montreal (Robert et al. 2009)

Cracks and Deflection

- Deflection GFRP > Deflection Steel
 - Possible to control for in design
 - Modified Bischoff Equations
 - Empirical Models, same as for steel
- Cracks, not necessarily a sign of failure
 - Allowed by code to be larger: 0.028"
 - No concern from moisture penetration
- Condition of bar is less of a concern



MD GFRP Material Spec

- Uses ASTM Standards and ACI Specs
- Imitates other states
- Expands upon past pilot efforts

CATEGORY 400 STRUCTURES

SECTION 400 – GLASS FIBER REINFORCED POLYMER (GFRP) REINFORCING BARS

400.01 DESCRIPTION.

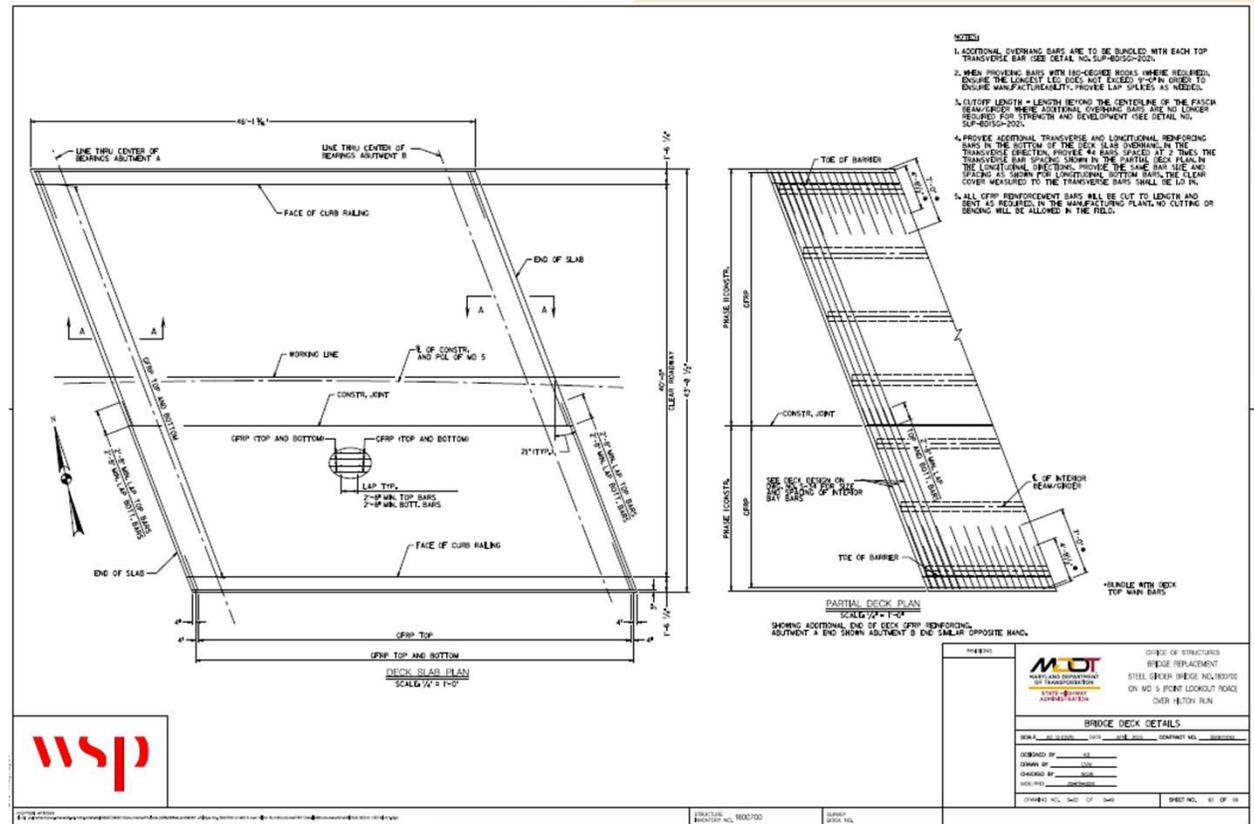
Furnish and place glass fiber reinforced polymer (GFRP) reinforcing bars for the deck and for the bars extending from the deck into the concrete barriers as shown on the Plans. All GFRP bars shall be glass fiber reinforced as specified below.

Testing Requirements for Project Material Acceptance of GFRP Reinforcing Bars				
Property	Test Method	Requirement	Test Required for Straight Bar	Test Required for Bent Bar
Fiber Mass Fraction	ASTM D2584 or ASTM D3171	≥70%	Yes	Yes – bent portion ^b
Short-Term Moisture Absorption	ASTM D570, Procedure 7.1; 24 hours immersion at 122°F	≤0.25%	Yes	Yes – bent portion ^b
Glass Transition Temperature	ASTM D7028 (DMA) or ASTM E1356 (DSC; T_m)/ASTM D3418 (DSC; T_{mg})	≥230°F ≥212°F	Yes	Yes – bent portion ^b
Degree of Cure	ASTM E2160	≥95% of Total polymerization enthalpy	Yes	Yes – Straight portion ^b
Measured Cross-Sectional Area		Within the range listed in the table below		
Guaranteed Tensile Strength ^a	ASTM D7205	#4 bars: 100 ksi #5 bars: 95 ksi #6 bars: 90 ksi	Yes	No
Tensile Elastic Modulus		≥8,500 ksi	Yes	No
Ultimate Tensile Strain		≥1.2%	Yes	No
Shear Strength (Perpendicular to bar fibers)	ASTM D7617	≥29 ksi		
Alkaline Resistance	ASTM D7705		Yes	No
Ultimate Bond Strength (based on 4000 psi concrete pull-out testing)	ASTM D7913	≥2900 ksi	Yes	No

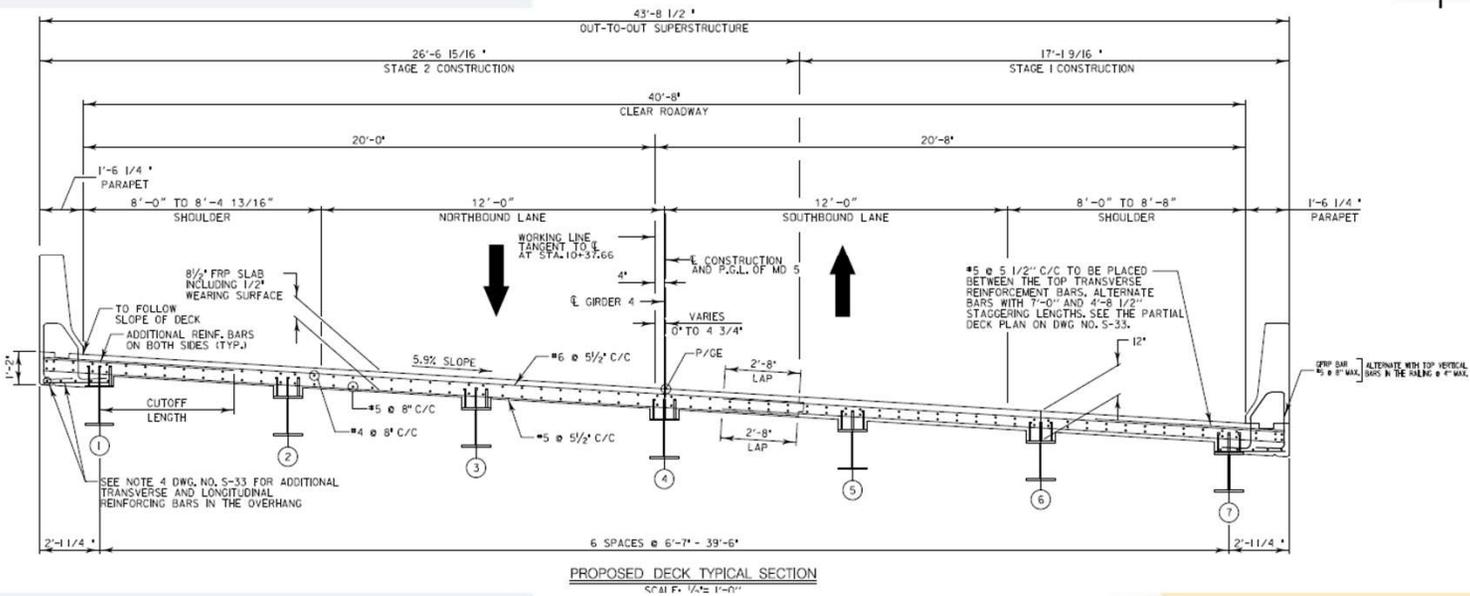
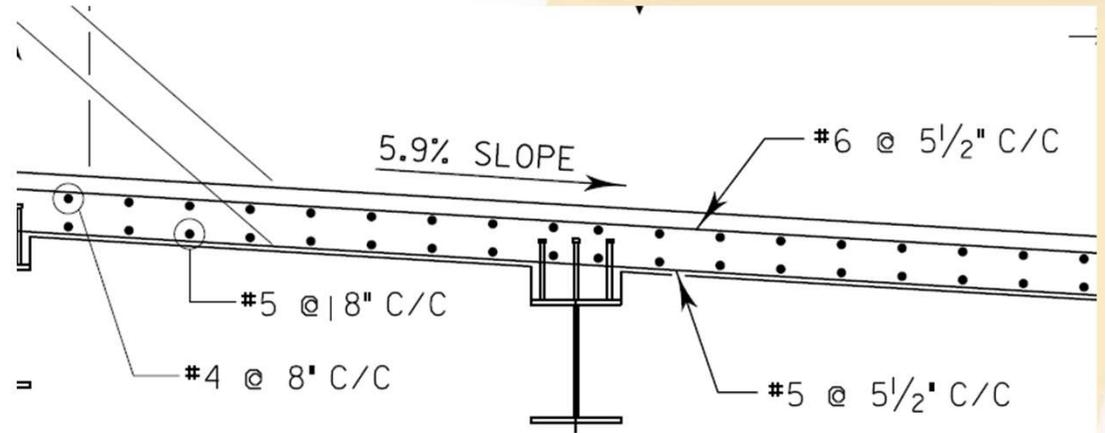
a – Guaranteed tensile strength shall be equal to the average test result from all three LOTs minus three standard deviations.
b – Bent portion specimens shall be extracted from a central location within a 90° bend.

Redesigned by WSP

- Design conversion is simplified by AASHTO Design Guide.
 - Empirical table dictates bar size and spacing, as it does for steel
- Detailing, and installation often mirror that for steel
- Some designs simplified to limit bending where it provides limited value, increases costs, and impacts performance.

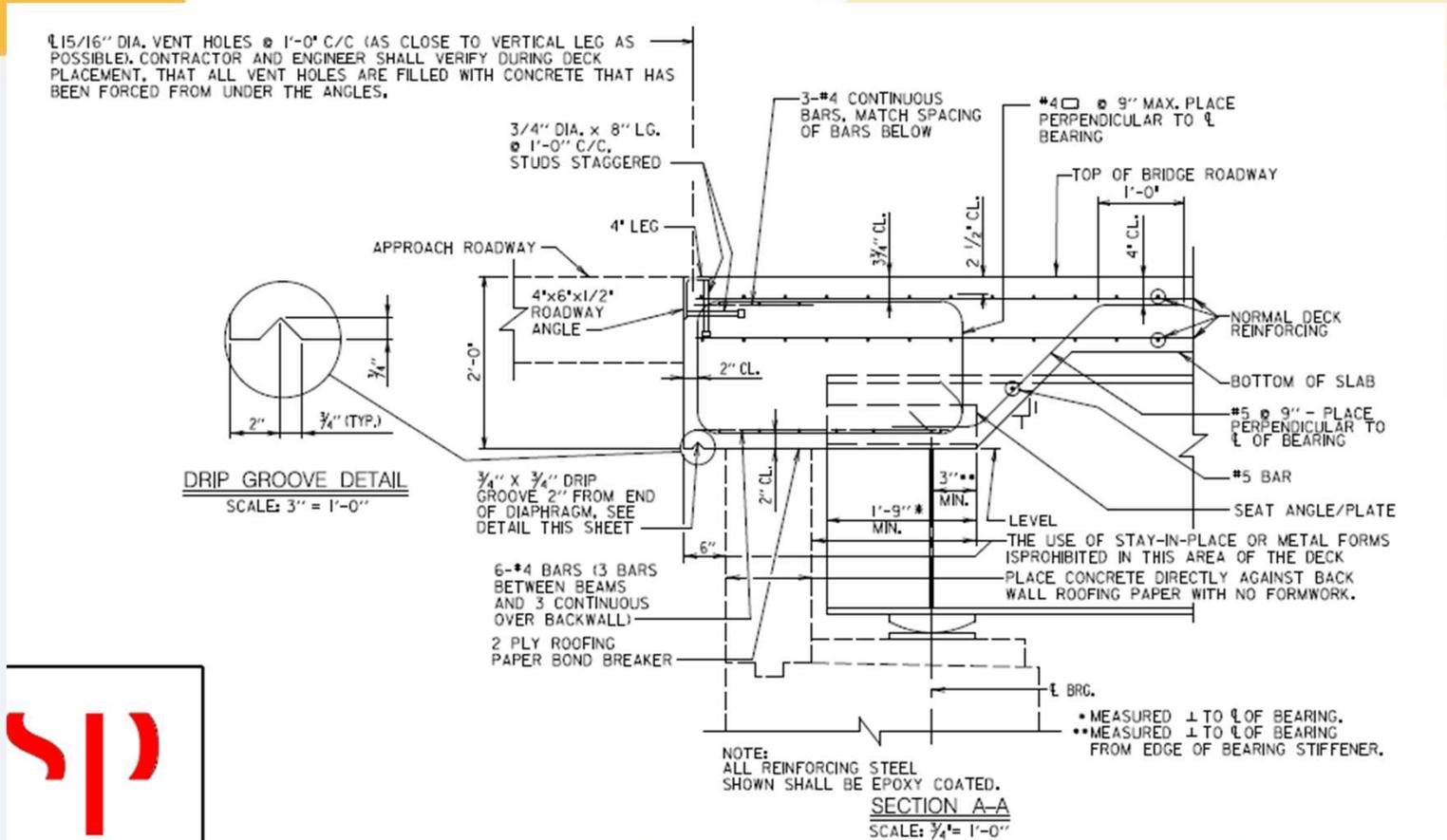


Bridge Deck



Parapet Walls

- So much like steel that this detail even says use epoxy coated reinforcing steel...



Embodied Carbon of Bridge Deck

	Total weight (kg)	GWP (kgCO2e/kg)	Total GWP (kgCO2e)
GFRP, Rt. 5 bridge	3,570	1.41	5,040
Steel*, Type XXXII bridge	10,500	1.31	13,740

* Grade 60 Epoxy-coated

Calculations by Rod Meyers



Thank You

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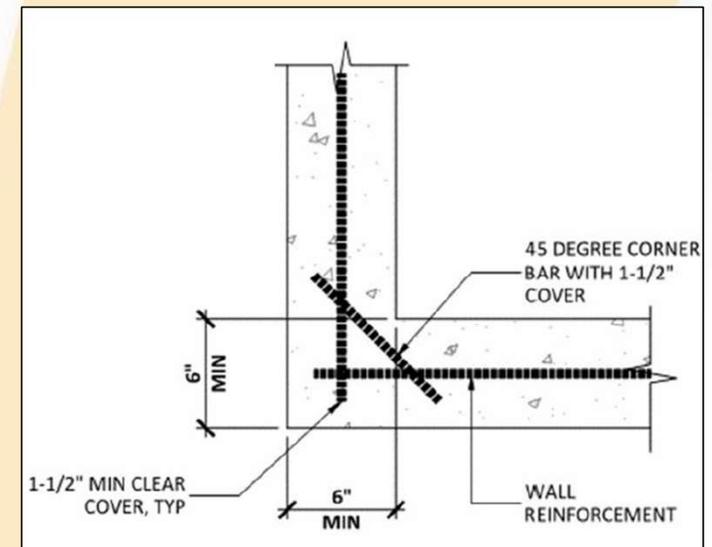
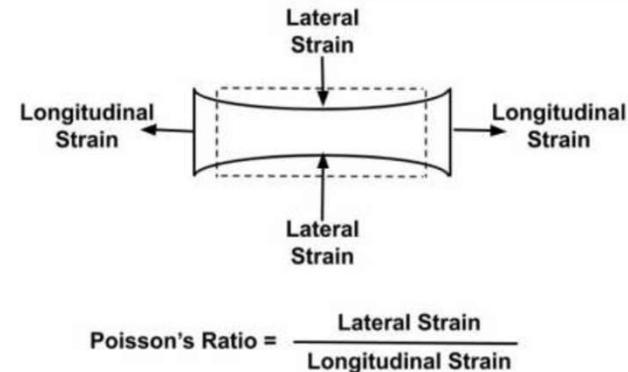
www.ernestmaier.com

www.mstrebar.com



Corners and Bends

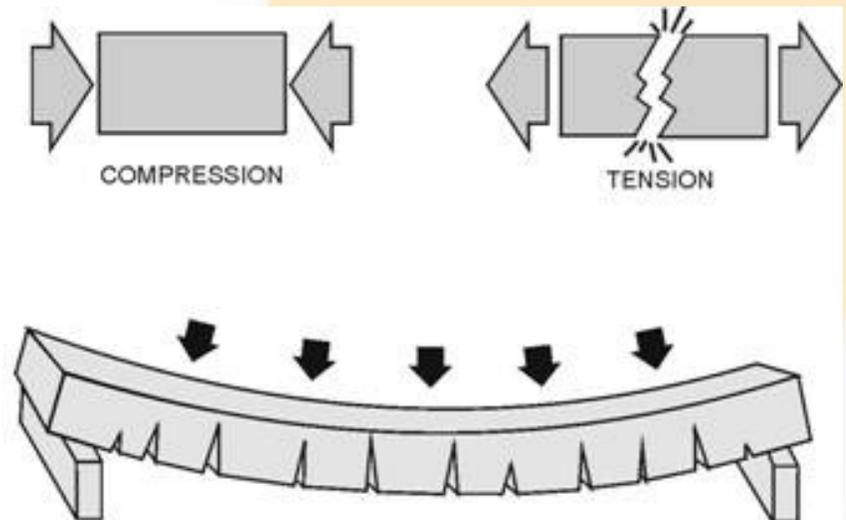
- Bent bars are required with steel
 1. Poisson's Ratio- Thins as stretched
 2. Development length, without compromising embedment
- Bent GFRP bars are often avoided
 - Bent GFRP bars are de-rated
 - Weak point is the bend
- Innovations in GFRP
 - Embedding with straight bar
 - 45° Lap Splice



Concrete 101

- Great compressive strength
- About 1/10 as strong under tension
- Steel has a high tensile strength

Reinforcing concrete with steel yields a single building material good under both tension and compression



Relevant Standards

ASTM

- **ASTM D7957-17** “Standard Specification for Solid Round Glass FRP Bars for Concrete Reinforcement”- includes bent bars (45 Gpa/6500 ksi)
- **ASTM D8505-23** “Standard Specification for Basalt and Glass FRP Bars for Concrete Reinforcement”- includes high modulus of elasticity bars (60 GPa/8700 ksi)

ACI SPEC 440.5-22: Analog to ACI 301 Section 3, for GFRP Bars

State DOT (Ohio being the template)

Submittals

- Test Reports
 - ASTM D7957
 - ASTM D8505
 - ICC Evaluation Reports
- Approved Manufacturer
 - Quality Control Plan
 - FRP Institute
- Placement drawings showing size, spacing, splice locations and lengths, bends
- Description of supports and ties to be used

Properties	
<ul style="list-style-type: none">• Fiber Content• <u>Guaranteed Ultimate Tensile Strength</u><ul style="list-style-type: none">• Straight• Fabricated• <u>Modulus of Elasticity</u>• Shear Strength• Ultimate Tensile Strain• <u>Bond Stress</u>• <u>Degree of Cure</u>	<ul style="list-style-type: none">• Glass Transition Temperature• Alkaline Resistance• Moisture Absorption• Cross Sectional Area

Quality Control Documentation

Production Information

- i. Supplier;
- ii. Lot number of bars;
- iii. Batch number of resin;
- iv. The start and end date of production for each production lot of material; and
- v. The total linear feet produced in each lot for straight bars or the total number of bars in each lot for bent bars and anchor headed bars.

Summary of all material test results listed in order as identified in preceding table with the following information for each property:

- i. The actual number of samples tested for each lot;
- ii. The result of every test as specified in the Quality Control;
- iii. The average and standard deviation of test results;
- iv. The minimum result for tensile strength, tensile elongation, transverse shear strength and bend strength obtained from testing of the required samples.

What is a Lot

Lot means GFRP made from the same batch of resin from the resin supplier. In addition:

- a) straight bars, bent bars and anchor headed bars shall be divided into separate lots;
- b) for straight bars, bent bars and anchor headed bars, a lot shall consist of bars of the same grade and diameter;
- c) bent bars of congruent shape may be considered as the same lot for establishing the number of samples for QC and QA testing;
- d) bars manufactured by different machines for multiple lines of production shall be considered as separate lots;
- e) bars shall be considered as a separate lot if there is an interruption in production or change in batch of raw material;

Ship GFRP bars in standard bundles; each tagged and marked with a corresponding lot number with the lot numbers affixed to each bundle by means of a durable tag. Keep bundles intact, undamaged, and properly identified until ready for use. Identification markings are often printed on the bars

Delivery



(10) 20 ft bundle



1000 Bars on a ladder truck



Fully Loaded Truck >17,000 bars

Lifting

- GFRP bars are less than 1/3 the weight of steel bars
 - A 30-ft long, #5 GFRP bar weighs 9-lbs.
 - A 30-ft long, #5 steel bar weighs 30-lbs.
- Lift bars up to 40-ft long with 2 pick points (3 pick points for bars over 40-ft long)
- Avoid dragging, dropping, or excessive bending



Storage and Handling

- Store off the ground
- Protect from dirt, oils, and other contaminants
- Direct sunlight will eventually start to affect the resin
 - Cover if being exposed over 4 months
 - *Manufacturers have been able to show 12+ months in Florida sun*
- Prevent exposure to temperatures exceeding 120°F
- Standard equipment, including gloves



Damaged Bars

- If bars are damaged, ACI 440.5 allows them to be used if the damage is less than 2% of the surface area of the length of bar and that the depth of the damage is less than around 1/32 in.
- Bars with damage beyond these limits should not be used.
- Alternatively, splices of new bars over damaged sections can be done. Splices need to be appropriately designed and detailed per ACI 440.11 requirements.
- Brittle Breakage/Fracture are binary conditions; unlike with steel



Cutting

- Bars can be easily cut using rotary saws with a silica carbide blade, reciprocating saws with a fine-tooth blade (suitable for cutting metal) or manually using a hack saw
- Do not cut by shearing action (bolt cutters)
- Do not cut with torches
- Do not cut by bending



Placement

- Tie the Same as Steel
 - Can also use Nylon Zip Ties and Plastic Bar Clips
- Bar Supports
 - Chairs are required to maintain bar position.
 - Chairs may need to be spaced tighter than equivalent steel bar supports (2/3 spacing),
 - Weights may be needed to prevent bars from floating in fresh concrete
- Non-metallic or corrosion-free options can be used



Cover Requirements (ACI 440.5)

Concrete Exposure	Member	Reinforcement	Specified Cover (in)
Cast against and permanently in contact with the ground	All	All	3
Exposed to Weather	All	#6-#10	2
		#5 and smaller	1-1/2
<ul style="list-style-type: none"> • Cover is NOT dictated by durability, only constructability, bond, and fire-related performance issues • Weather or Cast Against Ground 	Slabs, joists, and walls	All	3/4
	Beam, columns, pedestals, and	All	1-1/2

Bends

- **NO FIELD BENDING**
- All bends, hooks, and transitions are fabricated by the bar manufacturer
 - Bond strength can overcome need for hook, and save money
- Bend diameters are larger than steel hooks, minimums in ASTM D7957
 - Usually aim for bend radius/bar diameter >4

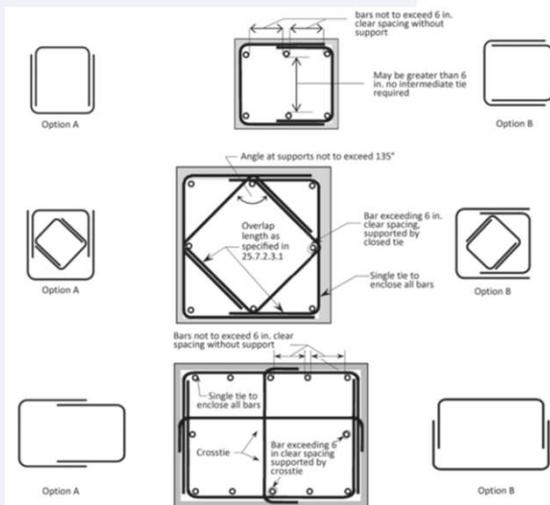


TABLE 4 Minimum Inside Bend Diameter of Bent Bars^A

Bar Designation, mm [U.S. Standard]	Minimum Bend Diameter mm [in.]
M6 [2]	38 [1.50]
M10 [3]	58 [2.25]
M13 [4]	76 [3.00]
M16 [5]	96 [3.75]
M19 [6]	114 [4.50]
M22 [7]	134 [5.25]
M25 [8]	152 [6.00]

Shaping

- Manufacturers have different shape options and capabilities, be specific when corresponding
 - Fully closed loop versus overlapping “C” or “U” shape
- 135° bends are not common



Coupling

- No mechanical coupling
- Compatible with most of the commercial adhesive in the market.
 - HILTI HIT-RE-500-SD Epoxy Adhesive;
 - Sika AnchorFix-2001; or,
 - Sika AnchorFix-3001.