Introduction to Glass Fiber-Reinforced Polymer Concrete Reinforcement

Dr. Aaron Fisher PhD

VP of Business Development

ERNEST MAIER

afisher@emcoblock.com

(202) 510-5545

ernestmaier.com | mstbar.com

EST. 1926 ERNEST MAIER

BLOCK • MASONRY • HARDSCAPING

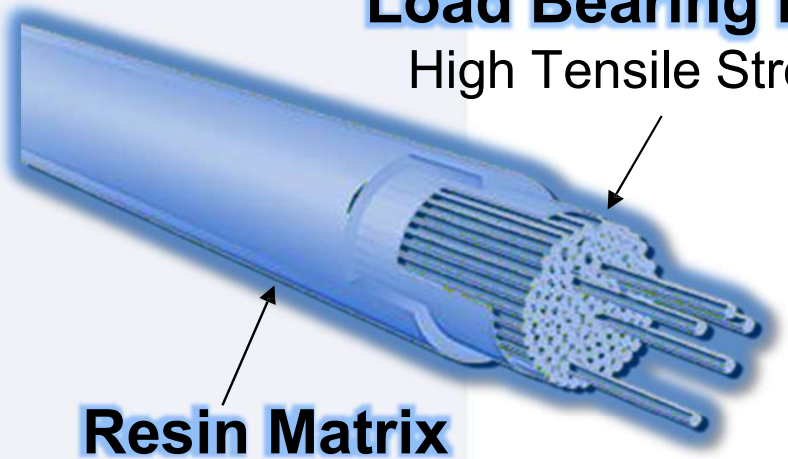
MST BAR

MAXIMUM STRENGTH GFRP

OUR LOCATIONS

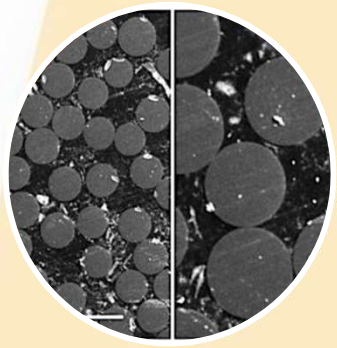
WHAT IS FRP

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



Load Bearing Fibers
High Tensile Strength

Resin Matrix
Durable Binder for Fibers
Provides Shape/Form



- Completely Stable in Acidic and Alkali Environment
- **GFRP DOES NOT REACT WITH CONCRETE**

WHAT IS FRP

RESINS

- Polyester Resin
- Epoxy Resin
- Vinyl Ester Resin

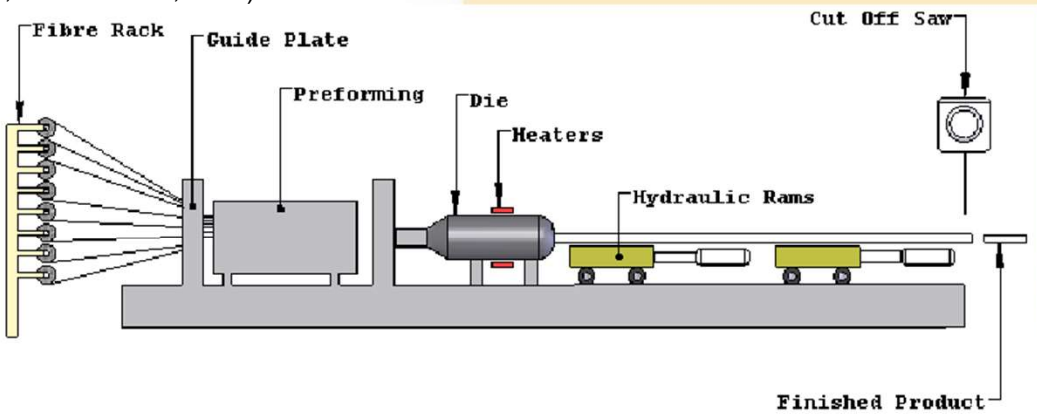
FIBERS

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

KEY CONSIDERATIONS

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

(ASTM D7957, Section 5.2.2, 2017)



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

Why GFRP

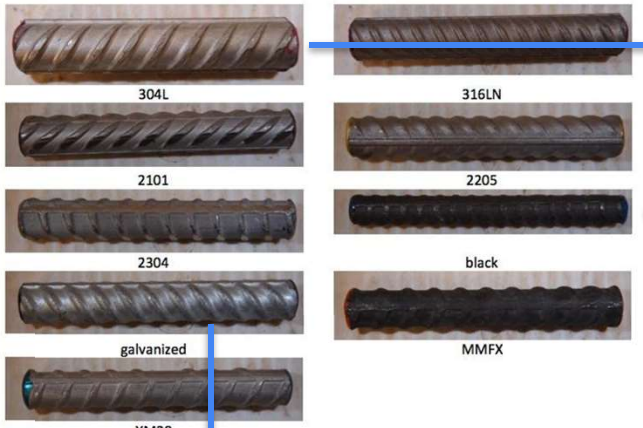


Figure 3-12: Steel rebar specimens prior to testing in the corrosion chamber

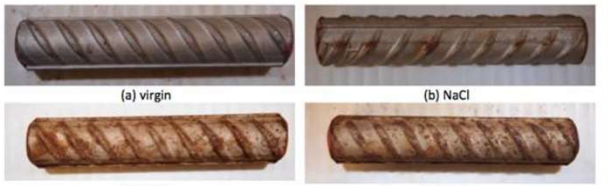


Figure 4-35: 304L specimen (a) prior to testing and exposed to 50 cycles of (b) NaCl, (c) $MgCl_2$ and (d) $CaCl_2$

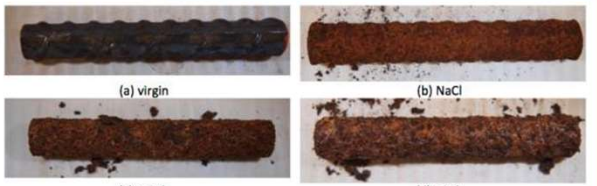


Figure 4-59: MMFX specimen (a) prior to testing and exposed to 50 cycles of (b) NaCl, (c) $MgCl_2$ and (d) $CaCl_2$

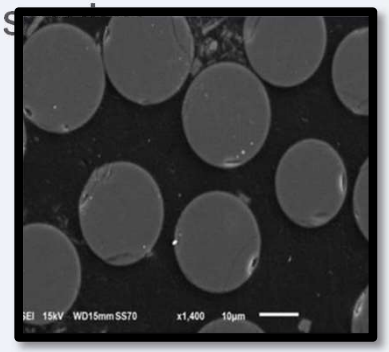
Figure 4-46: XM28 specimen (a) prior to testing and exposed to 50 cycles of (b) NaCl, (c) $MgCl_2$ and (d) $CaCl_2$

Benefits of GFRP

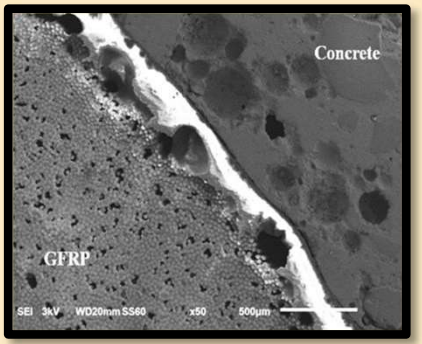
- **STRENGTH** - 2-3 times stronger than steel with tensile strength of 60 KSI
  - **BONDING STRENGTH** - Much greater Bonding Strength to Concrete
  - **FATIGUE STRENGTH** - 20 times higher resistance under cyclic loading
- **WEIGHT** - 4 times lighter than steel
- **FIRE RATED** - Capacity to stand for more than 3 hours in direct fire with minimum concrete cover
- **ECONOMICAL CURING** - Concrete can be cured with sea water instead of purified water; a major economical factor
- **CONDUCTIVITY** - Electromagnetic non-conductive; for MRI Applications & other uses
- **DETECTION BY GPR** - Easily detected by GPR (ground penetration radar)
- **THERMAL EXPANSION** - Very low thermal expansion factor results in added compatibility with concrete

Does GFRP Work?

- A core study of 11 bridges in the US averaging 17 years old with:
  - E glass (FIBER)
  - Polyester Resin
- 1st generation rebar showed real degradation of performance of only 2%
- Worst case extrapolation to 100 years gives 12.5%
- No sign of bond degradation nor loss of contact or mechanical properties after 15 years in



Sample	Full-size Strength, psi	Coupon Strength, psi	Coupon to Full-size
Pristine	119,318	96,997	18.71%
Extracted Bars	113,840[a]	90,110	20.84%
Difference due to degradation %			2.13%



Source: Long-term Durability of GFRP Reinforcement in Concrete: A Case Study after 15 years of service - O. Gooranorimi, E. Daur, J. Myers, A. Nanni

Early Challenges

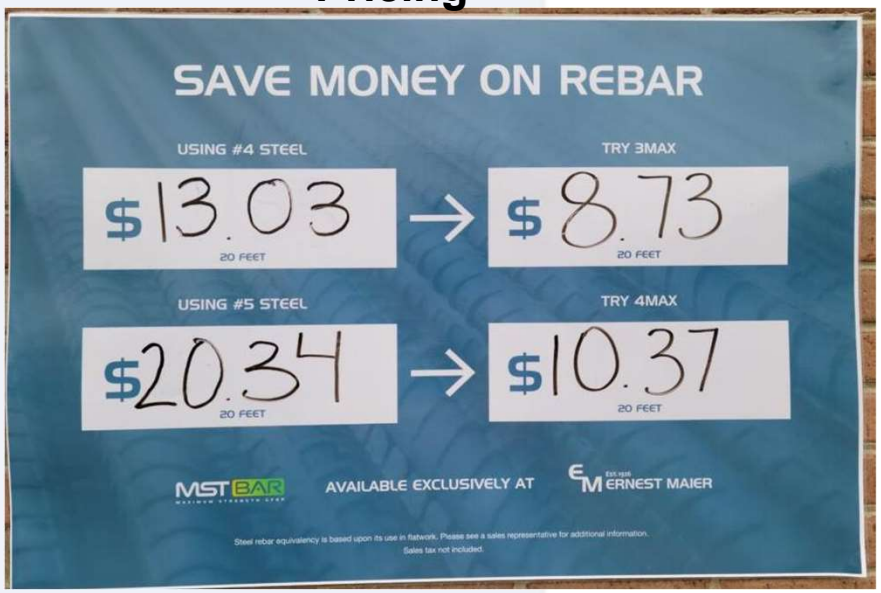
The Codes

- **ASTM D7957-17 "**Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement"
- **American Concrete Institute (ACI) 318 Building Code Requirements for Structural Concrete** references ACI 440
- **ACI 332 Residential Code Requirements for Structural Concrete** references ACI 440
- **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- Additional Documents**
  - **ACI 440.1-06 (2006/2007)** "Reporton Fiber Reinforced Poly. (FRP) Reinforcement for Concrete Structures", ACI Committee 440, *Replaced by 2015 ed.*
  - **ACI 440.5-08 (2008)** "Specification for Constructionwith Fiber-Reinforced Polymer Reinforcing Bar" ACI Committee 440
  - **ACI 440.6-08 (2008/2017/2022)** "Specification for Carbon and Glass Fiber-Reinforced Polymer Bar Materials for Concrete Reinforcement," ACI Committee 440
  - **ACI 440.1-15 (2015)** Guide for the Designand Construction of Structural Concrete Reinforced with Fiber-Reinforced Polymer Bars", ACICommittee 440
- **AASHTO GFRP-1 (2019)** " AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete Bridge Decks and Traffic Railings", American Ass ociation of State Highway and Transportation Officials
  - DOT Approval: Florida, Massachusetts, Michigan, North Carolina, Ohio, Texas, Virginia
- **TMS 402/602 (2022)** Appendix D "Glass Fiber Reinforced Polymer Reinforced Masonry" The Masonry Society

Allowed in reinforced masonry in non-loadbearing applications

WHY GFRP: Pricing

Retail Pricing



Commercial Pricing

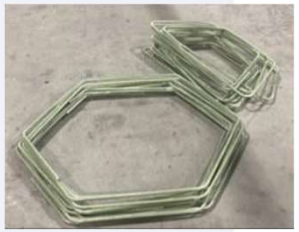
- ±10% material costs for plain rebar
- 20% savings on labor
- 75% reduction in deliveries
- Superior corrosion-free product
- Lower cost concrete mixes

Cutting & Bending

- Field Bending is not possible with GFRP Rebar
- Field forming of large radius curves is possible with GFRP Rebar
- Easily cuts with diamond blade hand power tools
- No limits on diameters and lengths / Bent bars up to #8



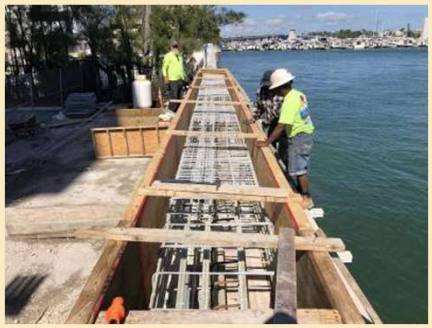





WHEN TO USE GFRP

- As a cost saving alternative to black steel
- As a first cost savings over stainless steel bar, epoxy-coated, or galvanized
- Desirable material properties
  - Corrosion-free
  - Thermal and Electrical Non-Conductivity
  - Tunneling and Mining (bars are easier to shear)
  - Totally linear elastic behavior

Strong Applications



- Exposure to Chemical- road salt, water utilities
- High Fatigue Areas- Bridges
- Water Presence- Pipes, Channels
- Marine Environments- Sea Walls, Pilings
- Non-Magnetic Areas- MRI rooms, automated factories
- Thermal and Electrical Non-Conductivity- Foundations, Electrical, Subway, Balconies

Site Access and Weight

(10) 20 ft bundle

1000 Bars on a ladder truck

Fully Loaded Truck >17,000 bars

<u>Designers</u>

Use unreinforced concrete weight, 150 pcf vs. 155 pcf

145 ksi Tensile Strength in the Field

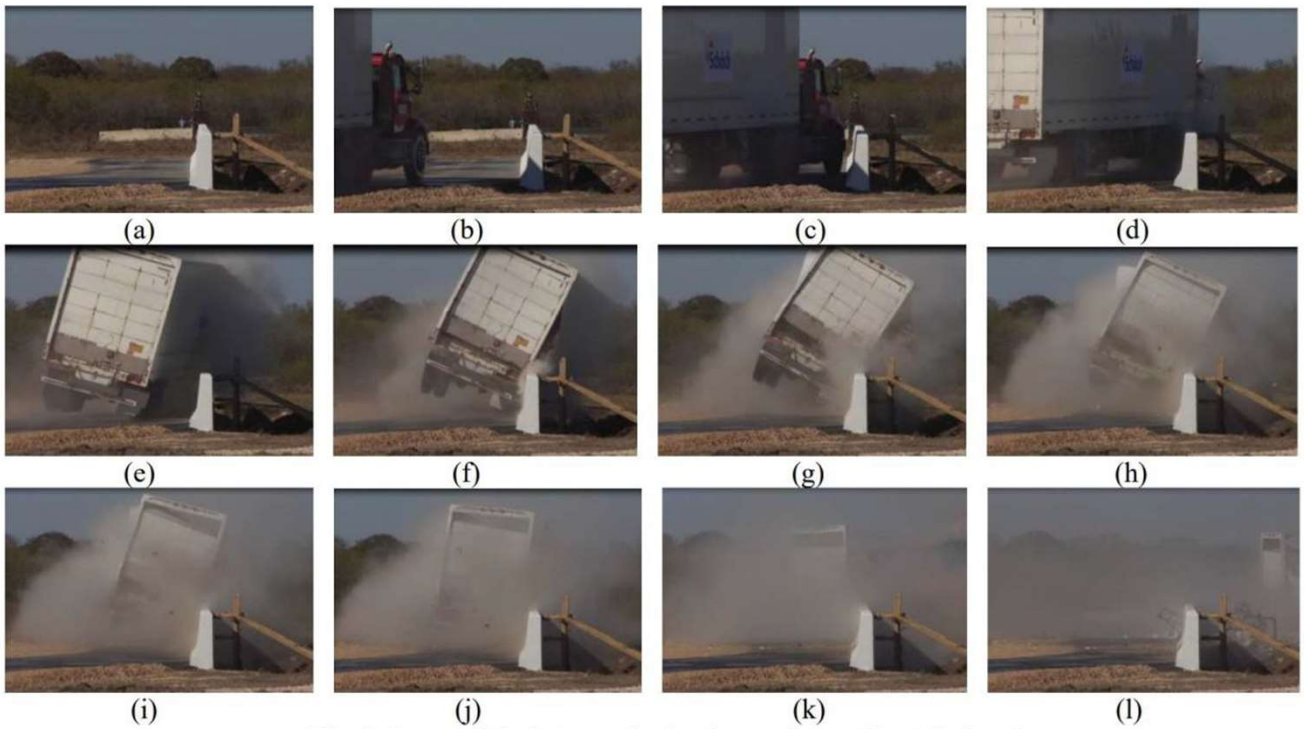


Fig. 9. Sequential photographs for the crash test (frontal views)

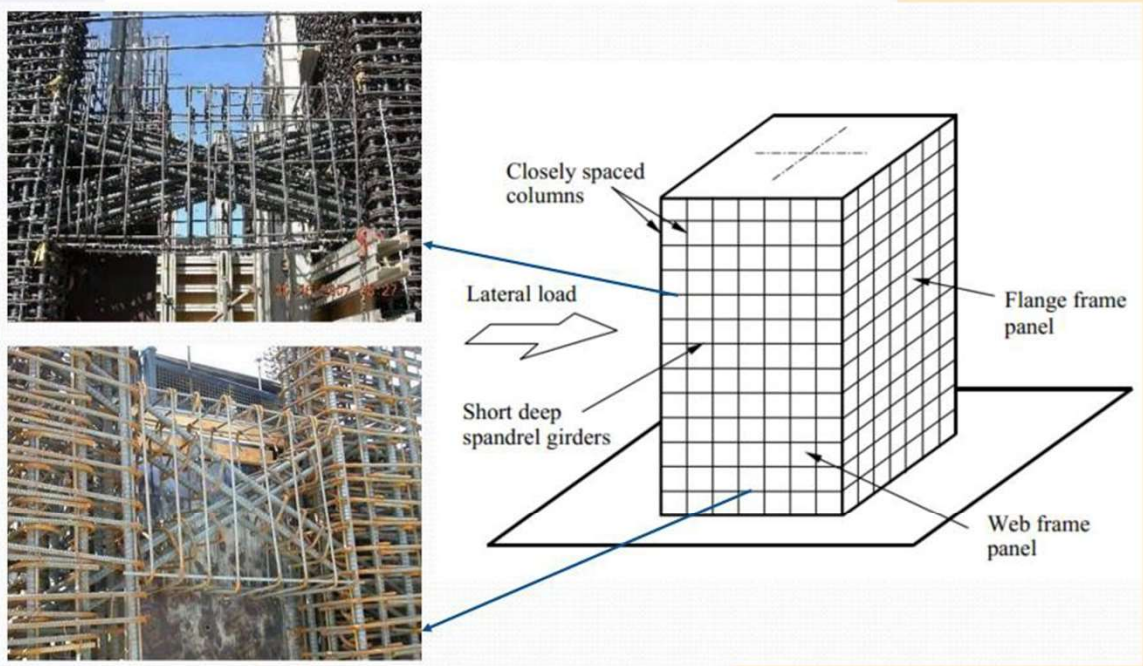
Where To Use: Barrier Walls

Crash Test of PL3 Barrier with GFRP

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

WHERE NOT TO USE GFRP….

- Seismic - Lateral Load Resisting Systems



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)	8,700 KSI	29,000 KSI
Oxidation	Never (NO Fe)	YES
Density	131 lb/ft^3	487 lb/ft^3
Conductive (Heat, Electricity)	No	Yes

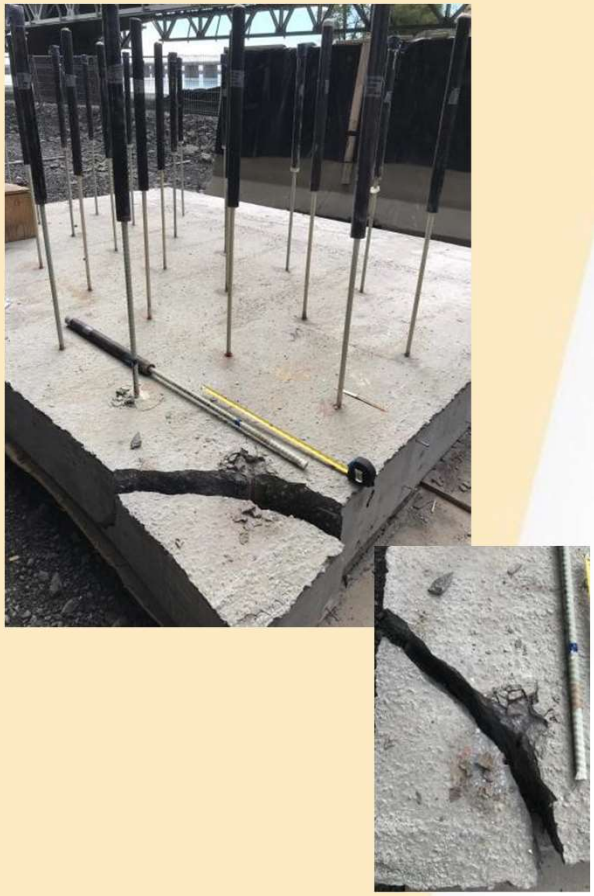
Understand the difference in Mechanical & Physical Properties

*values are for MST Bar

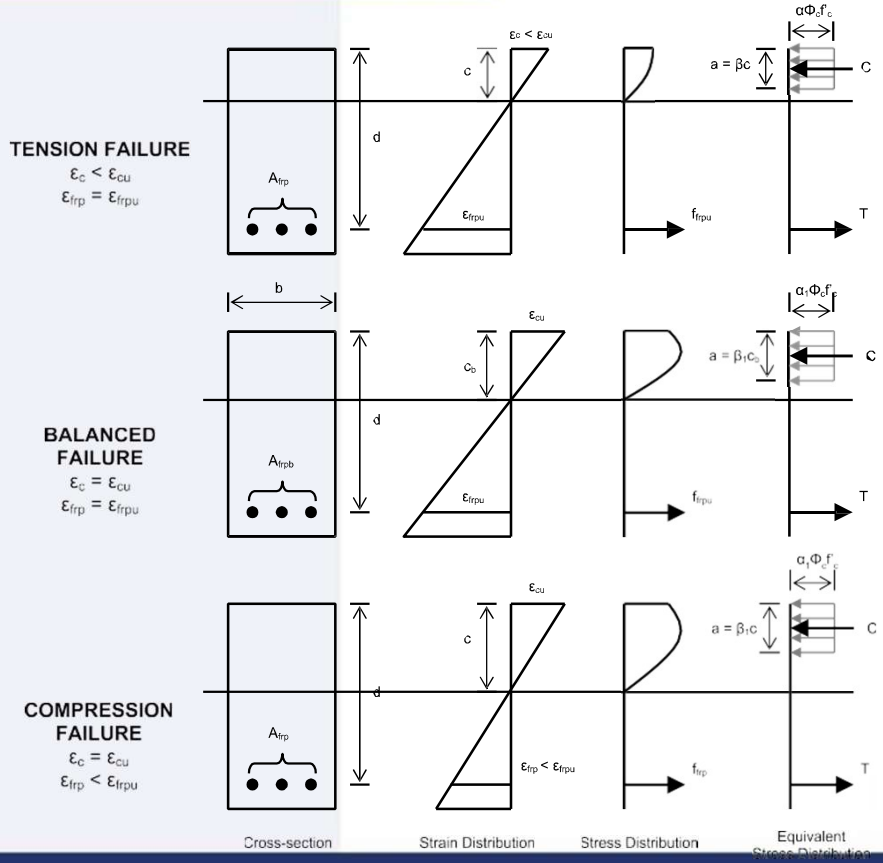
Bond Testing

- Compatible with most of the commercial adhesive in the market.
  - HILTI HIT-RE-500-SD Epoxy Adhesive;
  - Sika AnchorFix-2001; or,
  - Sika AnchorFix-3001.

- Please note that the bar will not provide ductile failure
  critical for design in high seismic areas.



Designing



Concrete does not crush

Undesirable for design with GFRP

FRP ruptures

Concrete crushes

Undesirable for design with GFRP

FRP ruptures

Concrete crushes

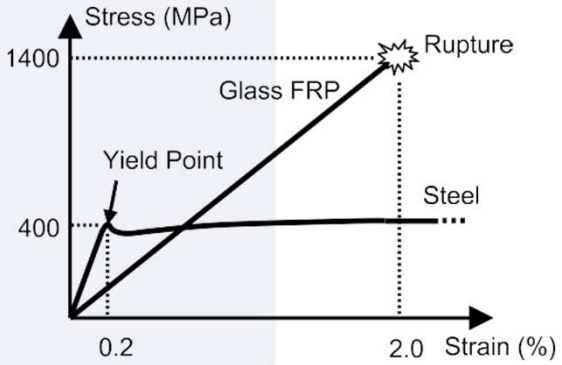
FRP does not rupture

Compression Controlled Failure

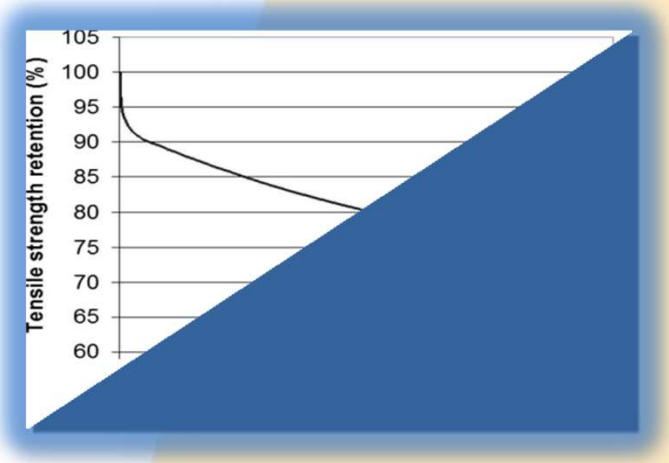
Embedded video of GFRP Beam tested to failure

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.



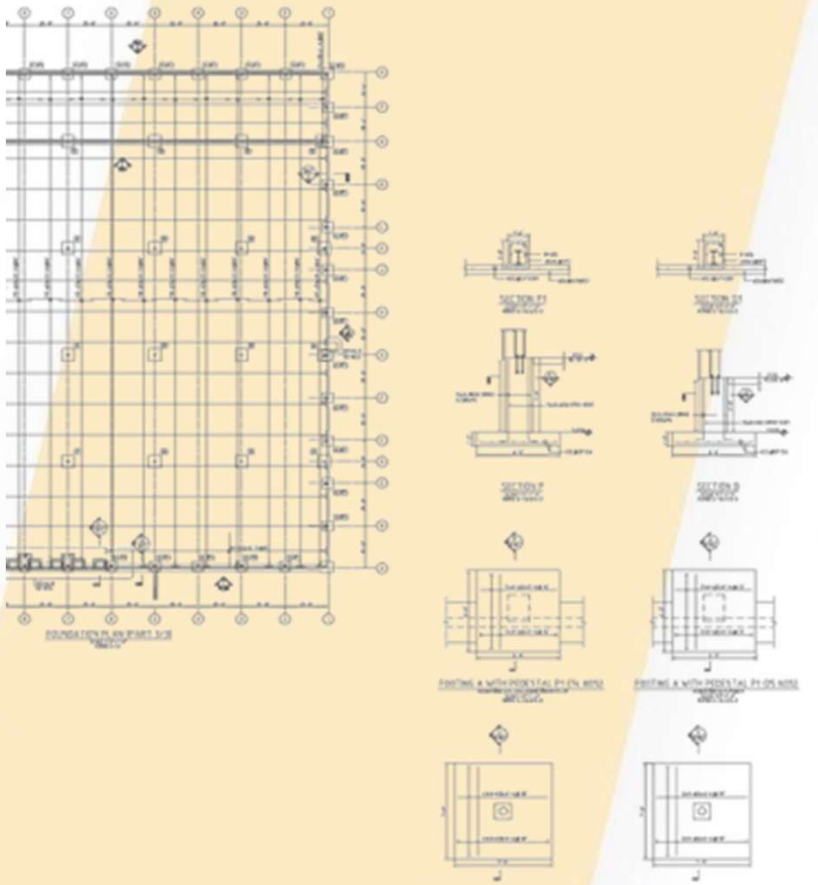
Stress strain curves for GFRP and steel reinforcement (ISIS 2006)



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

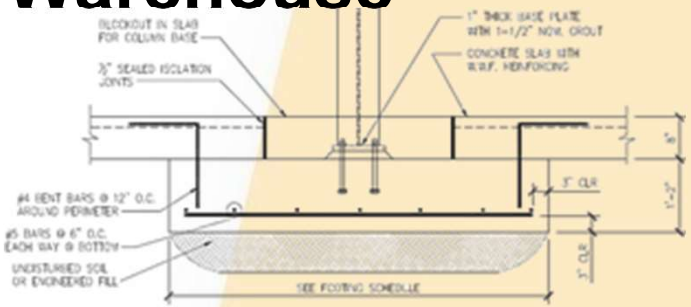
Project Highlight: Commercial Warehouse

- 300,000 sqft Commercial Warehouse.
- Steel-RC design utilized rebar sizes #3, #4, #5, &
  #6.
- Value Engineering was driven by the Contractor, who promoted the idea to the EOR and Owner.
- Lunch & Learn with EOR
- VE provided a High Modulus GFRP-RC design.



Project Highlight: Commercial Warehouse

- All steel rebar was replaced by a single sized AC454-approved bar (ESR-4664) meeting High Modulus criteria.
- **11,127 lbs** of GFRP rebar (pickup truck & trailer) replaced **79,194 lbs** of steel rebar (two truckloads).
- Contractor saved **19%** compared to steel package.



Thank You

Aaron Fisher
VP of Business Development
Ernest Maier
afisher@emcoblock.com
www.ernestmaier.com
www.mstrebar.com

ERNEST MAIER

MST BAR
MAXIMUM STRENGTH GFRP

Value Engineering Process

Critical for maximizing the cost savings on a project

COMMUNICATION & PLANNING

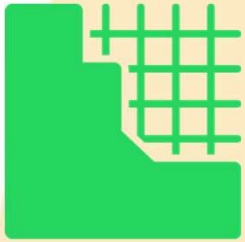
- Know Contractor's timeline.
- Know the project's submittal/approval process.

STRUCTURAL DRAWINGS

- Acquire structural drawings, project plans, loading info, any additional data.

RED LINE MARKS & ESTIMATION

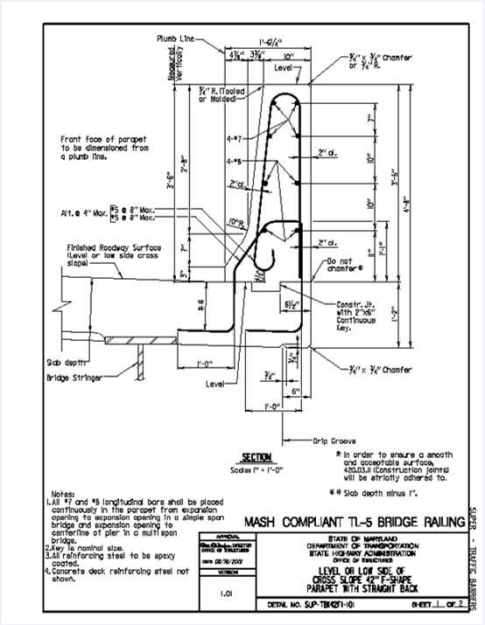
- Other deliverables could include Stamps, Placing Docs, Updated CAD Drawings, Estimation.

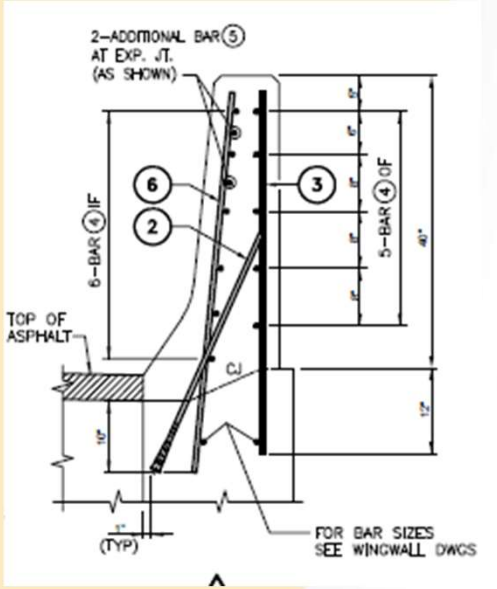


START TO FINISH SUPPORT

- Provide support & education: Contractor, EOR, Local Building Officials, Structure Owners.

Where To Use: Barrier Walls





Embedded Video slide of Barrier wall Crash Test with Semi Truck

Tensile Failure

Embedded video of FRP rebar in Tensile failure

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

Contractor Perspective: Skyway Bridges Tampa Bay, FL


MST BAR
MAXIMUM STRENGTH GFRP