MD-5 Case Study: The First GFRP (Fiberglass Rebar) Bridge Deck in Maryland

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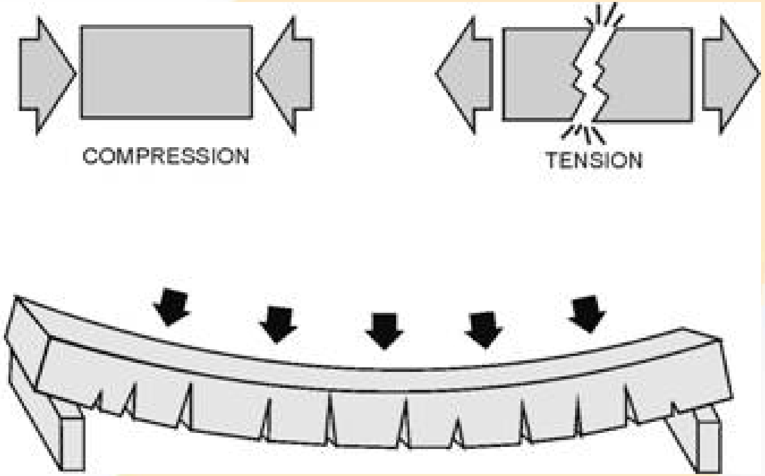
OUR LOCATIONS

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



Steel Corrodes

Why GFRP

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

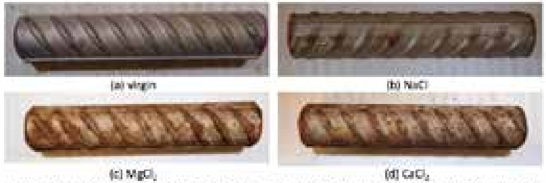


Figure 4-35: 304L specimen (a) prior to testing and exposed to 50 cycles of (b) NaCl, (c) $MgCl_2$ and (d) $CaCl_2$

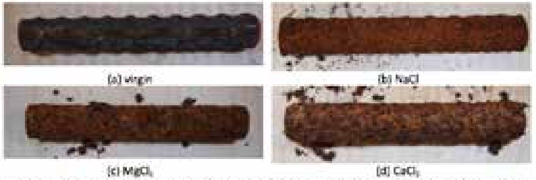
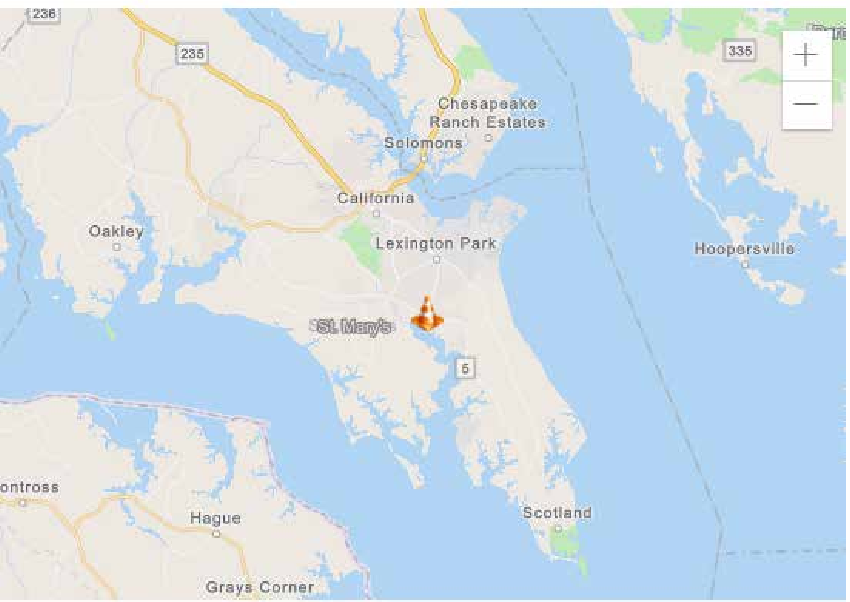


Figure 4-59: MMFX specimen (a) prior to testing and exposed to 50 cycles of (b) NaCl, (c) $MgCl_2$ and (d) $CaCl_2$

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

MD 5 Deck Replacement

Design: Completed April 2024
Construction: April 2025-September 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).

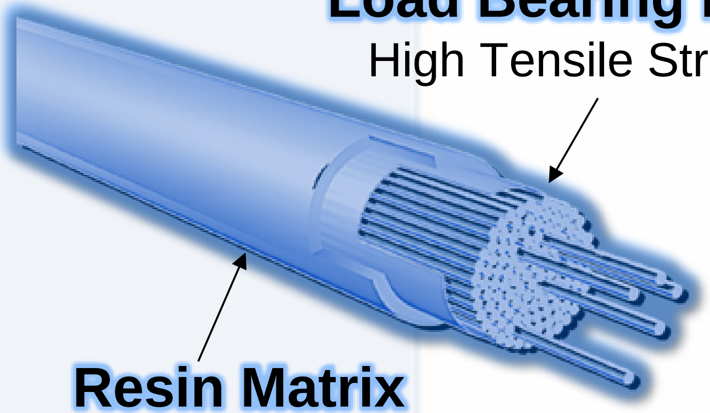
- The purpose of the project is to replace the existing bridge as it is nearing the end of its useful service life. This bridge deck is the first in Maryland (MDOT) to use glass fiber reinforced polymer (GFRP aka fiberglass rebar).

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

WHAT IS FRP

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

Load Bearing Fibers
High Tensile Strength



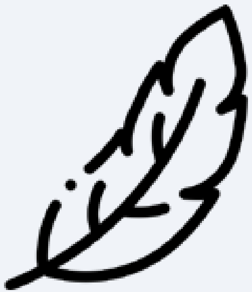
Resin Matrix
Durable Binder for Fibers
Provides Shape/Form

Inert Product

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

Benefits of Glass Fiber Reinforced Polymer (GFRP)

80% lighter

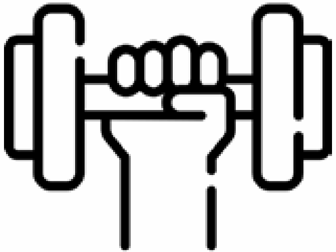


shipping and handling

labor savings

reduced weight

2x-3x tensile strength



1.5x higher bond strength

20x better fatigue strength

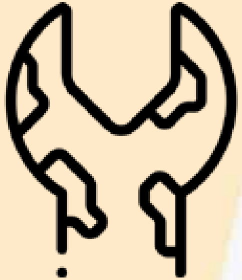
40% less CO_2

thermally insulating

non-conductive

inert in low carbon concrete

no corrosion



longer lasting

less maintenance

Labor Savings

Same Guy
1 steel bar OR 4 GFRP bars

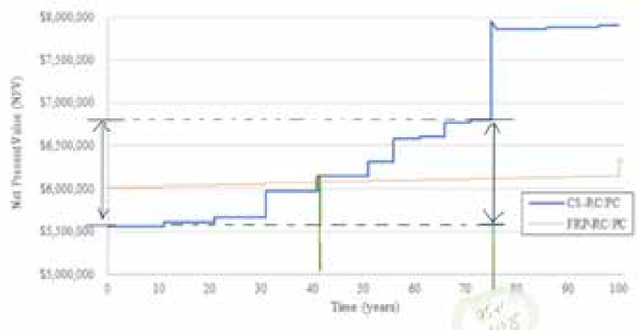
ExxonMobil: 30% - 50% Labor Savings on a slab using GFRP

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



2018 from FDOT

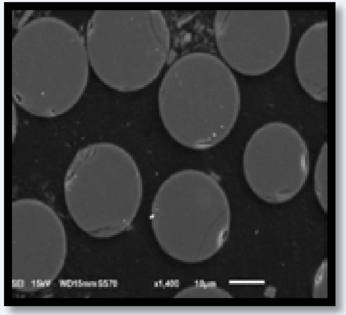
VIRGINIA		
PROJECT	**CITY**	**YEAR**
Gills Creek Bridge	Franklin County	2003

PROJECT DETAILS

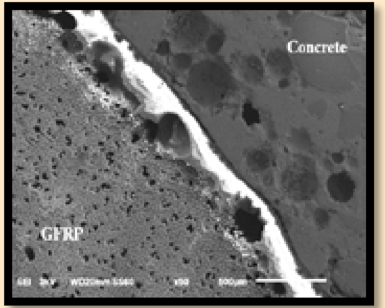
- Three-span bridge with top mat reinforcing with fiberglass rebar
- Total deck area 30 feet by 170 feet, fiberglass rebar reinforced 30 feet by 45 feet
- Bridge located over Gills Creek on Route 668 in Franklin County, VA
- Bridge Owner: Virginia DOT
- Contractor: A.R. Coffey & Sons of Buchanan, VA
- Constructed: Summer 2003
- Core samples were extracted and evaluated as part of ACI SDC durability study, 2019

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 service



Sample	Full-size Strength, psi	Coupon Strength, psi	Coupon to Full-size
Pristine	119,318	96,997	18.71%
Extracted Bars	113,840ᵃ	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

Code Adoption

- **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 (15+ years), Maine, Massachusetts, Michigan, North Carolina (5+ Years), Ohio (10+ Years), South Carolina, Texas

- Delmarva-approved
    - Delaware: Material Standard + Standard Specs + Full Use
    - Maryland: Special Provision + Full Use
    - Virginia: Material Standard + Full Use

- **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/IRC 2024
    - Equivalency to IBC/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)

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.

SPECIAL PROVISIONS CONTRACT NO. SM1675180
400 — GLASS FIBER REINFORCED POLYMER REINFORCING BARS 2 of 5

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	ASTM D7205	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	ASTM D7205	≥8,500 ksi	Yes	No
Ultimate Tensile Strain	ASTM D7205	≥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.

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

NCDOT: Alligator River

- 2.8 mile span featuring glass and carbon FRP
- Under construction through 2028
- $450MM contract
- Skanska, Coastal Precast, Shelby Erectors

Straight GFRP vs. Steel

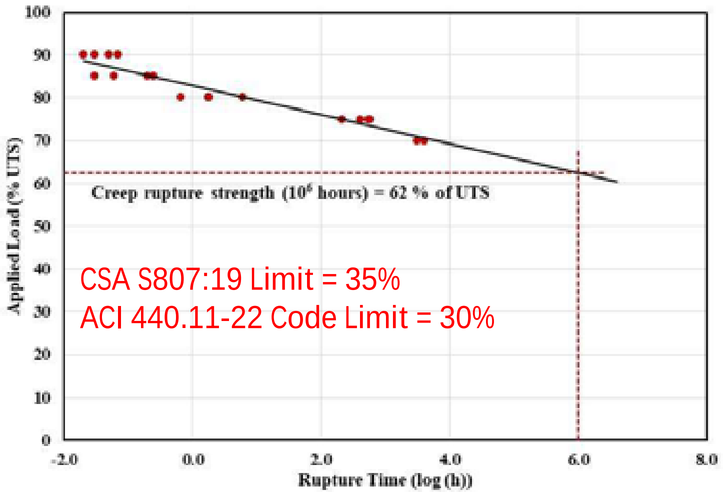
	STRAIGHT GFRP*	STEEL
Tensile Strength	185-145 KSI	65 KSI
Bond Strength to Concrete	2900 PSI	>1700 PSI
Elastic Modulus (Concrete ~4350 KSI)	9400 KSI	29,000 KSI
Loss of Tensile Strength at -100°F	0% Drop	Brittle - Premature failure
Ultimate strain %	1.5 - 2%	10%
Transverse Shear Strength	220	240
Oxidation	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

Creep Testing

The bars were placed under a constant load for a period of ONE full year and the strain in the material was measured in order to determine the maximum load under which the bar might remain unaffected for 114 years.



Fire Testing

- ASTM E119
- 4h
- 1 of 5 slabs failed
- 1.5” Cover, 4,000 psi

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





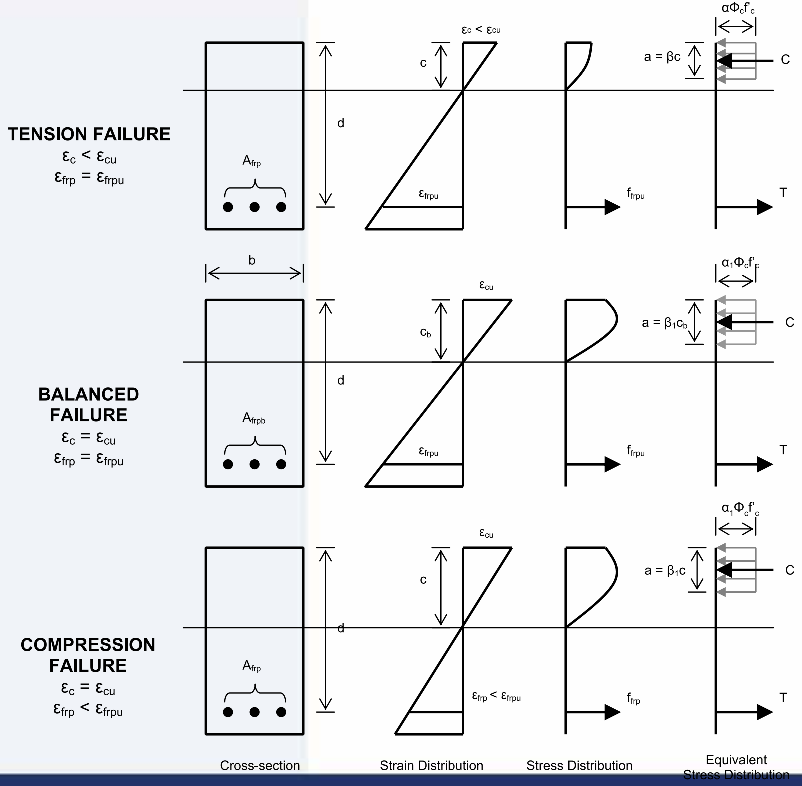




Tying & Installation

- Steel ties and supports are acceptable unless otherwise noted on the plans. FDOT allows plastic ties or epoxy coated steel ties.
- Due to 25% of the weight of steel, floating may occur in high-slump concrete or during concrete vibration. Adequate ties/fasteners in areas of concern.
- Can drive vehicles on– no elastic deformation

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

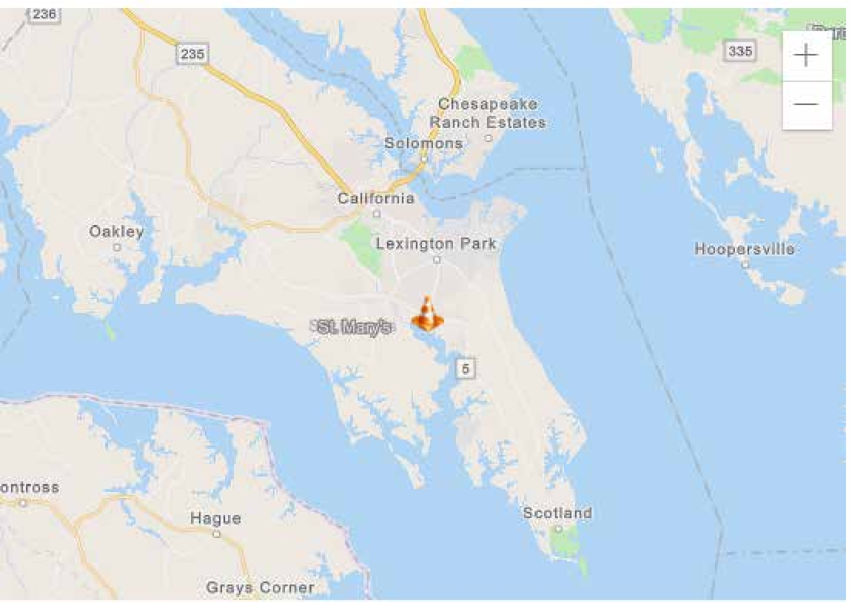
Embedded video of GFRP Beam tested to failure

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

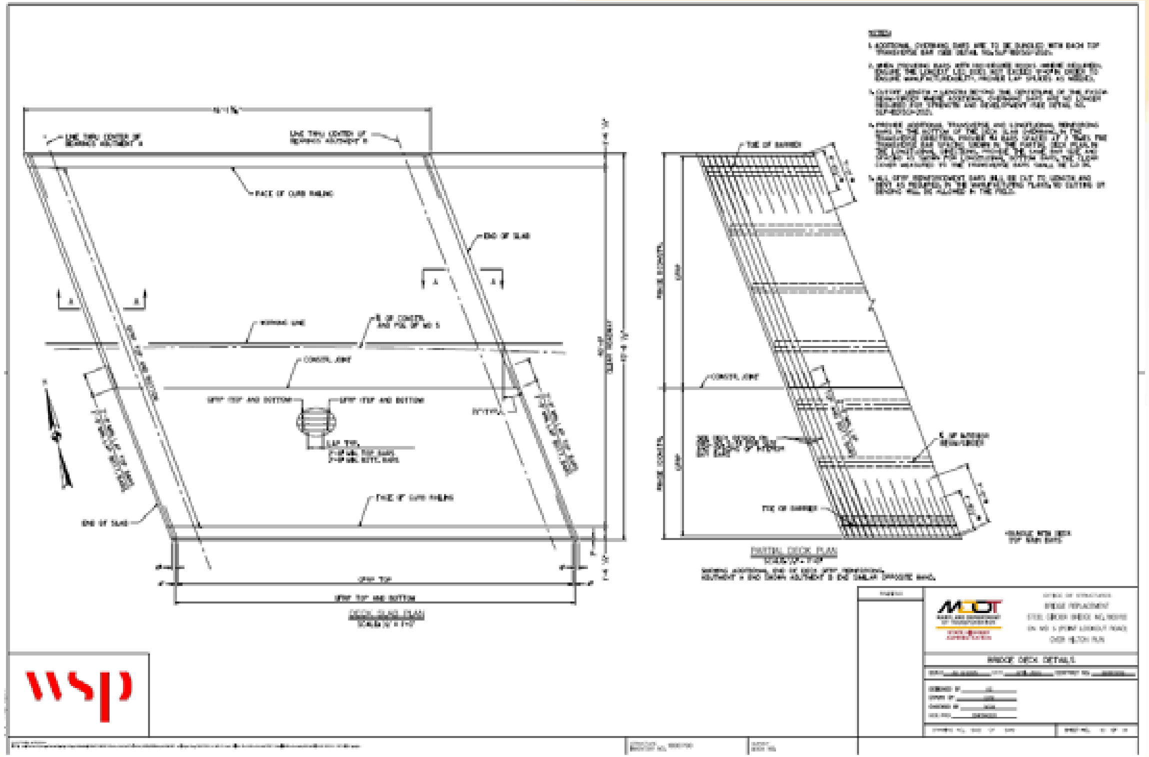
MD 5 Deck Replacement

Design: Completed April 2024
Construction: April 2025-September 2025



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.



Sequencing

Traffic never stopped; Kept one lane open

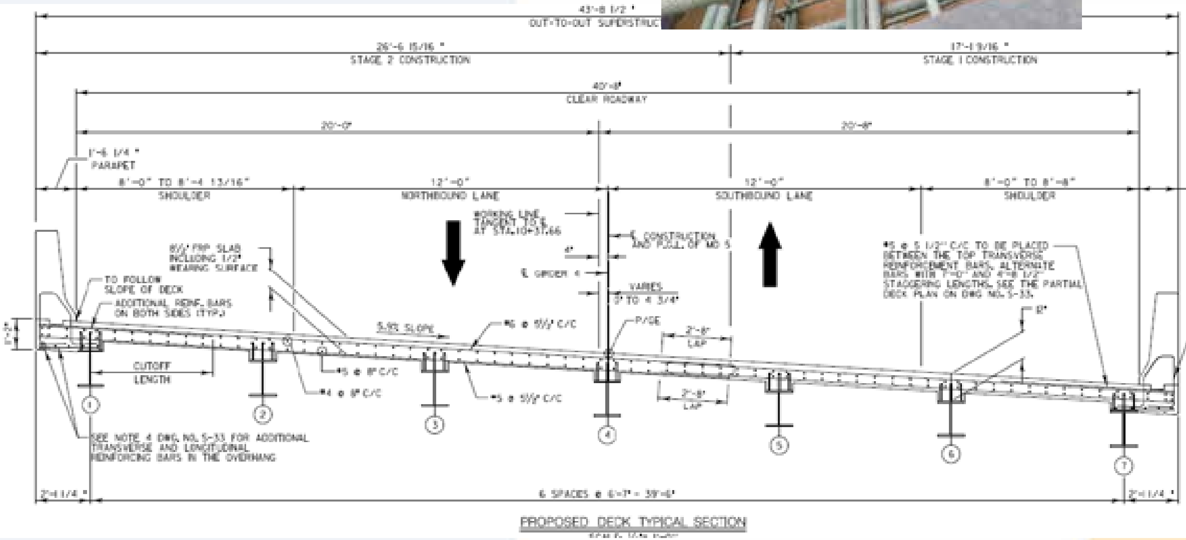
1. Demolish and rebuild Southbound Lane
2. Demolish and rebuild Northbound Lane
3. New bridge to last 100+ years

1

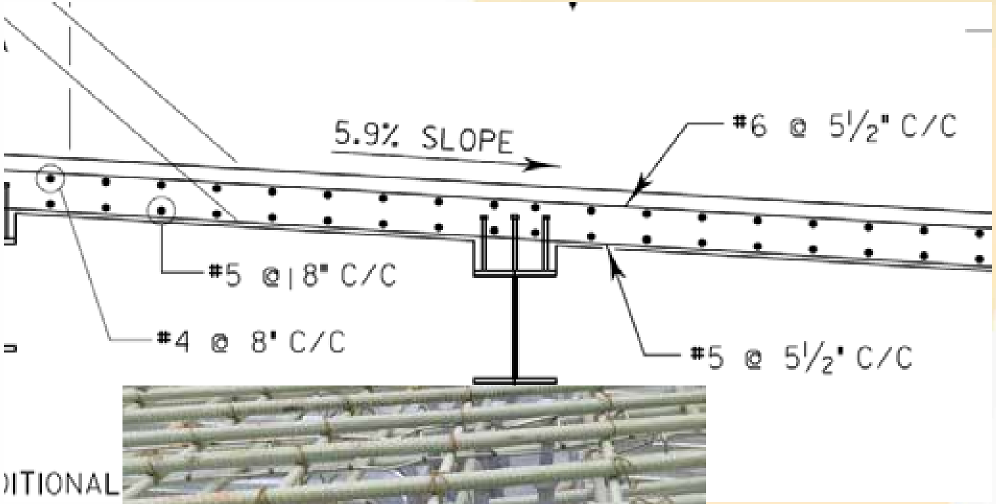
2

3

Bridge Deck

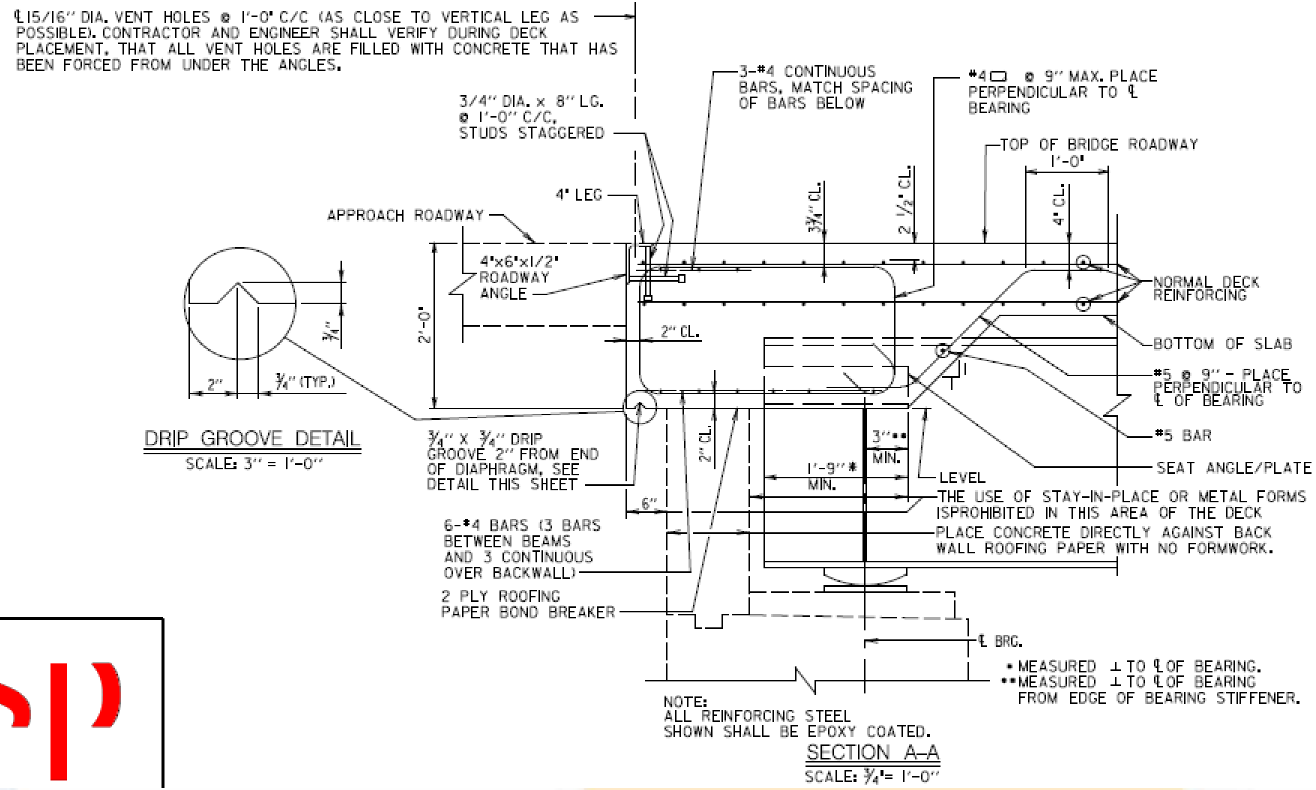

43'-8 1/2"
OUT-TO-OUT SUPERSTRUC
26'-6 15/16"
STAGE 2 CONSTRUCTION
17'-1 9/16"
STAGE 1 CONSTRUCTION
40'-8"
CLEAR ROADWAY
20'-0"
20'-8"
1'-6 1/4"
PARAPET
8'-0" TO 8'-4 13/16"
SHOULDER
12'-0"
NORTHBOUND LANE
12'-0"
SOUTHBOUND LANE
8'-0" TO 8'-8"
SHOULDER
WORKING LINE
TANGENT TO ℄
AT STA.10+37.66
℄ CONSTRUCTION
AND P.G.L. OF MD 5
℄ GIRDER 4
VARIES
3" TO 4 3/4"
8½" FRP SLAB
INCLUDING 1/2"
WEARING SURFACE
TO FOLLOW
SLOPE OF DECK
ADDITIONAL REINF. BARS
ON BOTH SIDES (TYP.)
5.0% SLOPE
#6 @ 5½" C/C
P/GE
2'-8"
LAP
#5 @ 5 1/2" C/C TO BE PLACED
BETWEEN THE TOP TRANSVERSE
REINFORCEMENT BARS. ALTERNATE
BARS WITH 7'-0" AND 4'-8 1/2"
STAGGERING LENGTHS. SEE THE PARTIAL
DECK PLAN ON DWG NO. S-33.
CUTOFF
LENGTH
#5 @ 8" C/C
#4 @ 8" C/C
#5 @ 5½" C/C
SEE NOTE 4 DWG. NO. S-33 FOR ADDITIONAL
TRANSVERSE AND LONGITUDINAL
REINFORCING BARS IN THE OVERHANG
2'-4 1/4"
6 SPACES @ 6'-7" = 39'-6"
2'-4 1/4"
PROPOSED DECK TYPICAL SECTION

Bridge Deck

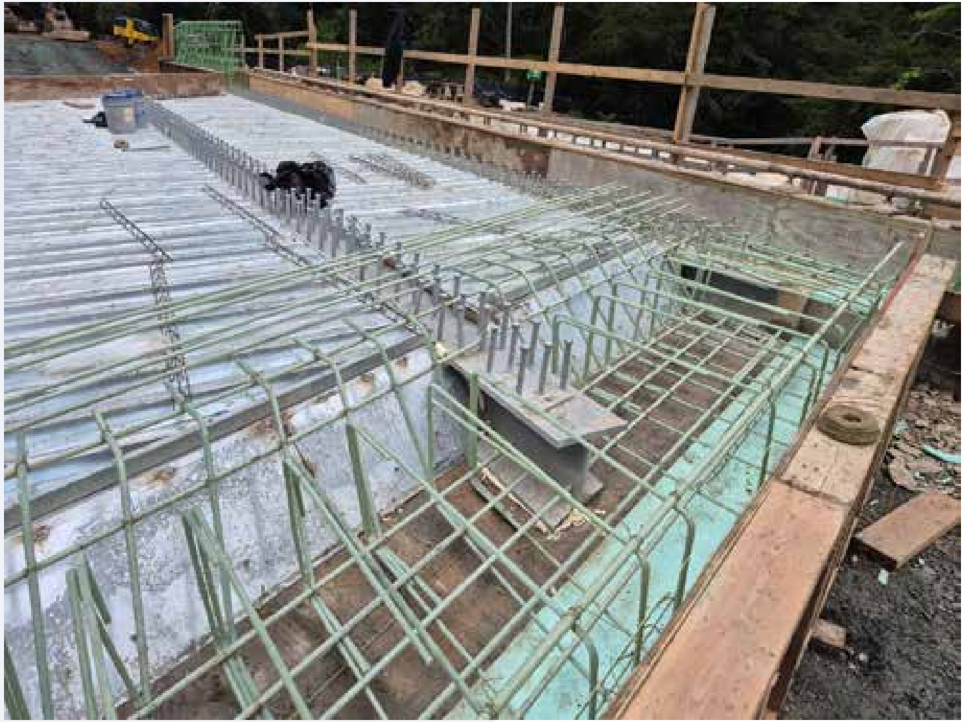


Parapet Walls

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

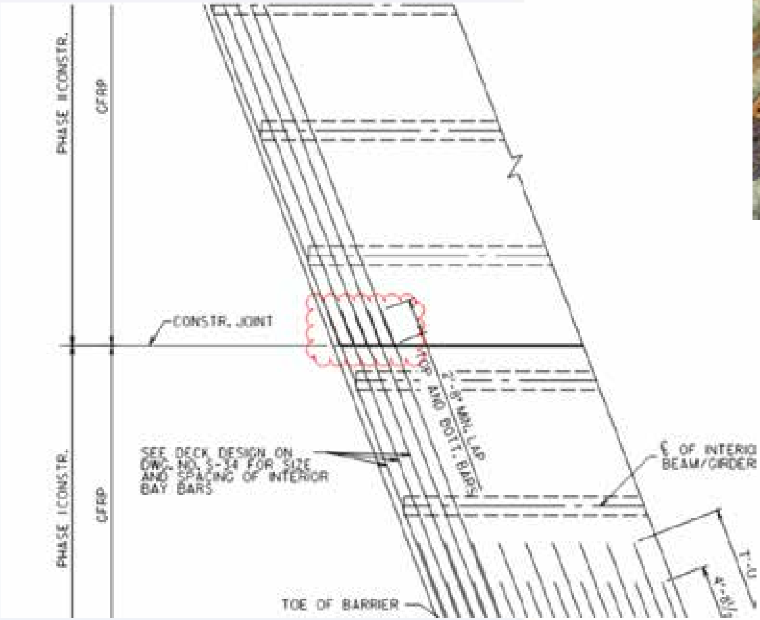


Installed Bent Bar



Construction: Nothing Else Different

Field Damage



Followed ACI Spec 440.05: Drill and dowel in replacement bars adjacent to the existing transverse bars (lap splice). Use commercial adhesive (HILTI HIT-RE 500 V3 adhesive).

Storage

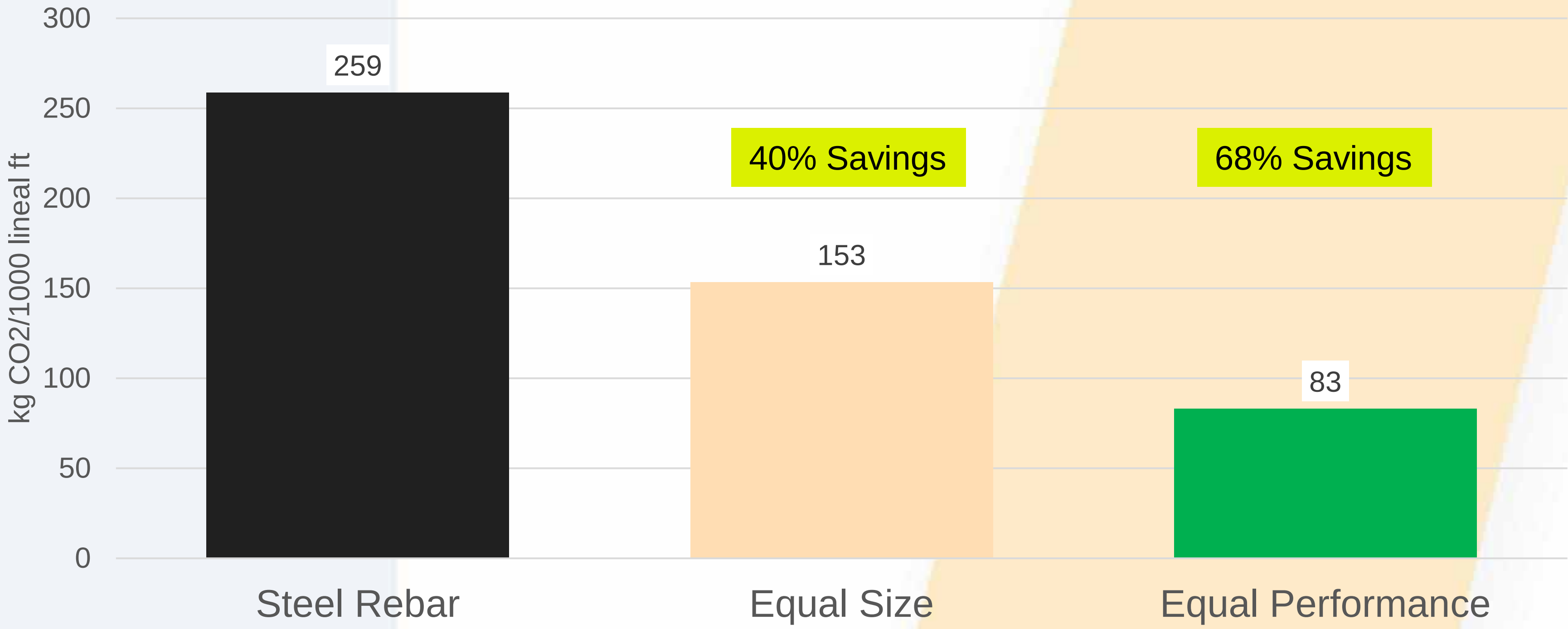
Epoxy-coated and GFRP stored the same way.

GFRP is okay; steel is not okay with moisture and ground contact

Finished Deck

Just A Bridge

GWP: Embodied Carbon



Embodied Carbon of Bridge Deck

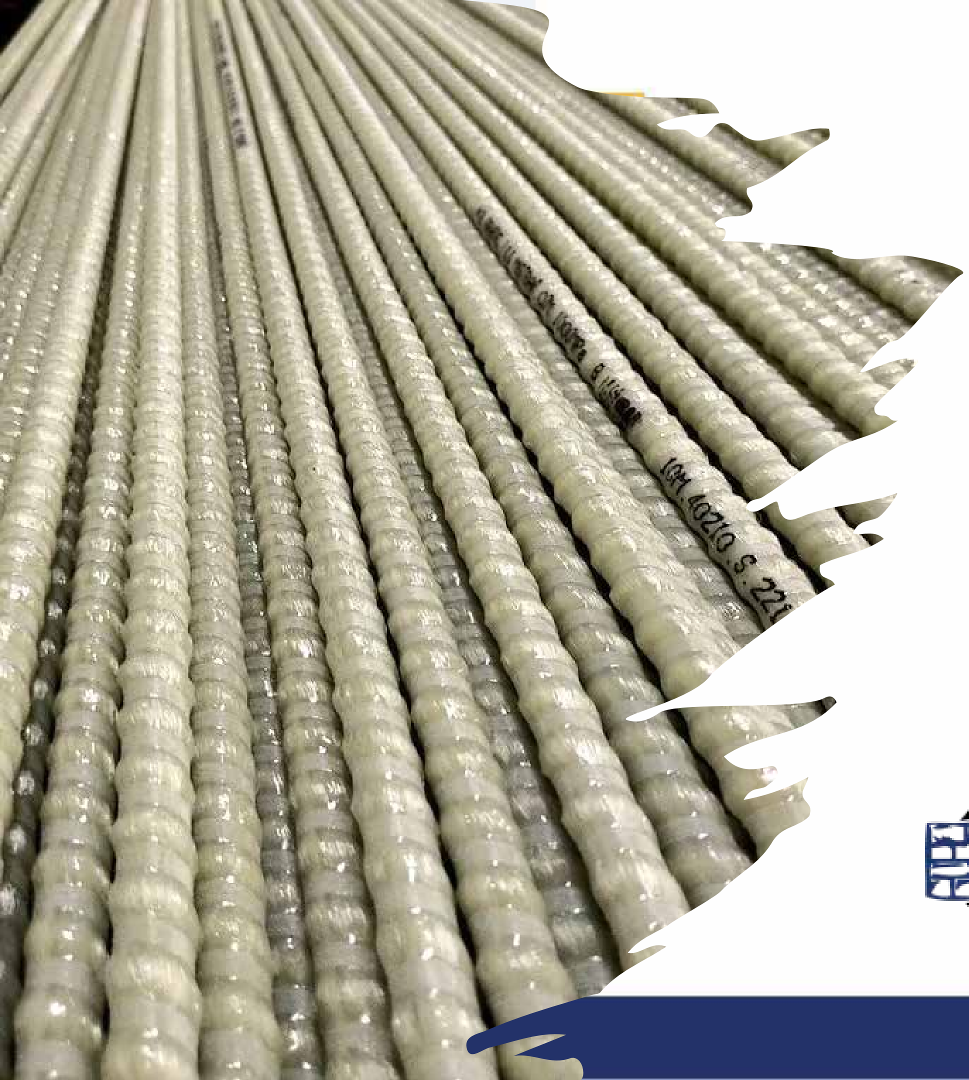
	Total weight (kg)	GWP ($kgCO_2e/kg$)	Total GWP ($kgCO_2e$)
GFRP, Rt. 5 bridge	3,570	1.41	5,040
Steel*, Type XXXII bridge	10,500	1.31	13,740

* Grade 60 Epoxy-coated

Calculations by Rod Meyers

Great Investment

- It’s an unremarkable new bridge
- Corrosion-free = 100+ year lifespan of bridge deck
  - No maintenance
  - Abutments and wing walls will fail before the deck
- Lower initial cost over steel rebar
- Reduced installation costs
  - “A guy can carry a bar by himself; normally it would need a few guys.” Jose Ortiz, foreman Martins Construction



Thank You

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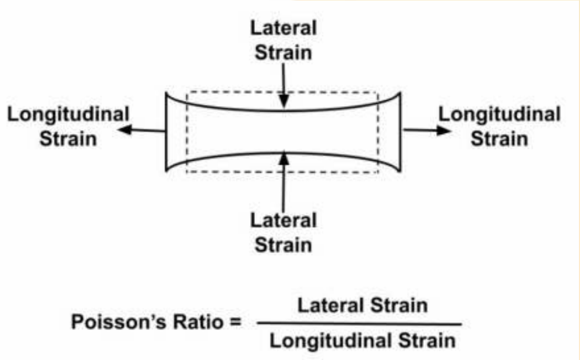
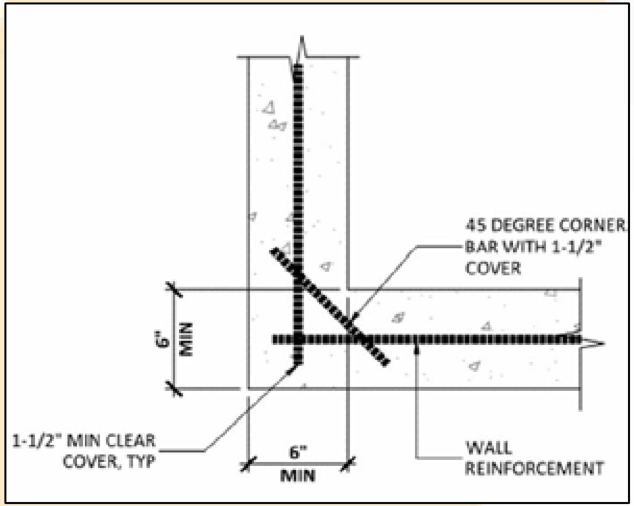
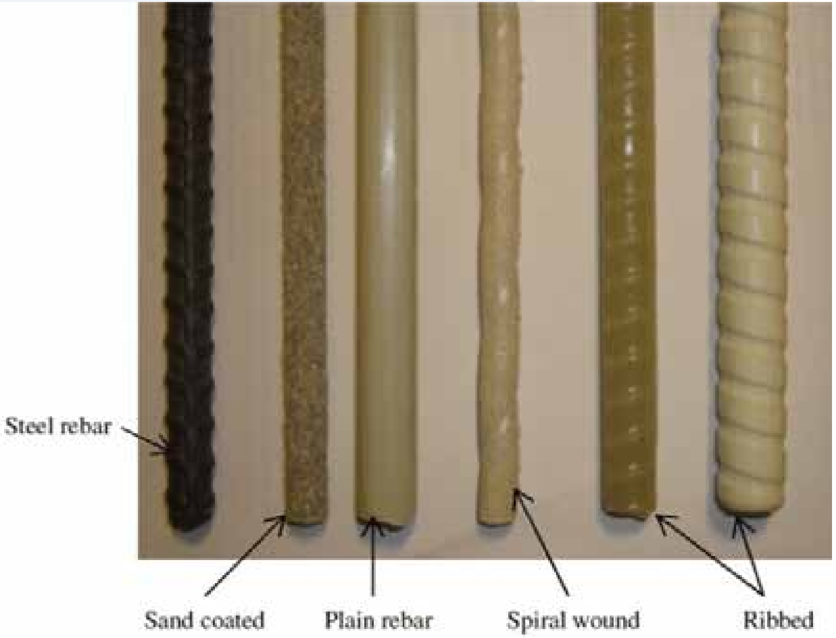
Corners and Bends

- 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





Bar Surfaces



Molded

Grooved/
Etched

Solid
Hollow

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.

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)

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  - 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

GFRP in Action

Fiberglass Rebar

Local Contractor

Fiberglass Rebar

HOW TO USE GFRP….

DETERMINE THE FLEXURAL FAILURE MODE:

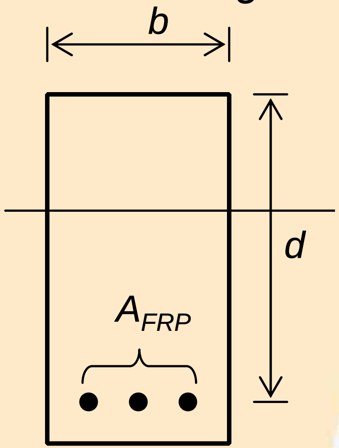
- Calculate balance failure reinforcement ratio:

  $\rho_{FRPb} = \alpha_1\, \beta_1\, \varphi_c/\varphi_{FRP}\, f'_c/f_{FRPu}\, \varepsilon_{cu}\,/(\varepsilon_{cu} + \varepsilon_{FRPu})$

  This is not exactly correct since φ_{FRP} has not been included in the strain diagram, but close enough as a first step.

- Calculate reinforcement ratio for FRP-reinforced beam:

  $\rho_{FRP} = A_{FRP}\,/(d\, b)$



- $\rho_{FRP} < \rho_{FRPb} \rightarrow$ Tension Failure
- $\boldsymbol{\rho_{FRP} > \rho_{FRPb}} \rightarrow$ **Compression Failure**

WHO PROVIDES GFRP….

Bar diameter	Specimens	Failure load (KN)	Bond Strength (MPa)
#6 (20 mm)	1	101	20.1
	2	146	29.1
	3	121	24.0
	4	133	26.5
	5	106	21.2
	6	125	24.9
	7	108	21.5
	8	114.28	22.7
	Average value	**119**	**23.8**
	Standard deviation	15.2	3.0
	C.O.V (%)	12.7	12.7

Bar diameter	Specimens	Failure load (KN)	Bond Strength (MPa)
#6 (20 mm)	1	105	20.9
	2	104	20.8
	3	106	21.1
	4	89	17.7
	5	108	21.4
	6	166	33.1
	7	155	30.9
	8	132	26.3
	Average value	**121**	**24.0**
	Standard deviation	27.5	5.4
	C.O.V (%)	22.7	22.7

Bar diameter	Specimens	Failure load (KN)	Bond Strength (MPa)
#6 (20 mm)	1	165	32.8
	2	155	30.9
	3	150	29.9
	4	134	26.6
	5	141	28.1
	6	139	27.7
	7	145	28.9
	8	135	26.9
	Average value	**145.6**	**29**
	Standard deviation	10.7	2.1
	C.O.V (%)	7.4	7.4

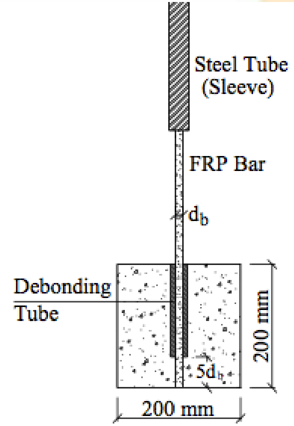


Figure 1: Details of the pullout specimens

MTO & CSA Requirements
are only 8MPa

ALL MST-BAR BOND STRENGTHS WERE FOUND
TO BE
BEYOND 20MPa

OHIO DOT FIBERGLASS REBAR SPECIFICATIONS

- Construction and Material Specifications (C&MS) Section 705.28
  - Section 705.28 material specification standard follows requirements of ASTM D7957 with three additions:
  - Mean Tensile Modulus of Elasticity limit (ASTM D7957 Table 1 and 2) shall meet or exceed 8,700 ksi (60GPa)
  - Mean Ultimate Tensile Strain limit (ASTM D7957 Table 1 and 2) shall meet or exceed 1.4%
  - Minimum Guaranteed Ultimate Tensile Force (ASTM D7957 Table 3 comparison) by bar diameter is also provided in the C&MS
- Certification – Supplement 1138
  - Producers/suppliers must submit a written Quality Control Plan (QCP) to the Office of Materials Management (OMM) for approval
  - The QCP includes the procedures and processes for ordering, testing, accepting, verifying, controlling, storing, shipping, documenting, and recording GFRP materials compliance for certification
  - A certified producer/supplier is responsible for all materials shipped under their TE-24 certification document
- ODOT Bridge Design Manual
  - Follows AASHTO LRFD Bridge Design Guide Specifications (BDGS2, 2018) for GFRP Reinforced Concrete
  - GFRP for traffic barriers/railings in Section 309.4 In 2020, ODOT published design drawings SBA 1, SBA 2, SBA 3
  - BDM Deck Design Table for GFRP Reinforcement under Industry Resources with link to similar GFRP tables for comparison to epoxy coated steel BDM Figures 309-3 and 309-4
  - Value Engineering Change proposal is submitted by the contractor per C&MS 105.19 for acceptance by ODOT
- Procurement – Supplement 1138
  - Contractor awarded the project are to purchase a certified bar
  - Producer/suppliers will be furnished sample ID numbers for each GFRP construction material item they are certified to supply (C&MS 705.28 deformed bar, C&MS 705.01 dowel bar, C&MS 509.10 construction items)
  - Provide certified test data according to C&MS 101.03 with each shipment
  - Certified GFRP materials shipments must include a bill of lading
- Quality Assurance (Field Acceptance) – Supplement 1138
  - Random inspections performed by ODOT quality assurance inspectors (QAI)
  - Audit testing procedures, QCP compliance, actual dimensions, and documentation at the certified producer/supplier
  - OMM may obtain random samples from producer/supplier inventory or at the project for testing. OMM determines the cause for non-specification materials

NTPEP Composite Concrete Reinforcements Technical Committee

- States represented on the TC include AK, CA, CT, FL, GA, IL, MA, ME, MI, NC, OH, OR, SC, TN, TX, VA, WI
- TC Work Plan was balloted and passed in spring 2022
- Initial audits will begin in 2023 will only include Glass Fiber Reinforced Polymer (GFRP) Bars
- Anticipate near 100% US and Canadian manufacturer participation from the start
- Basalt Fiber Reinforced Polymer Bars, Carbon Fiber Bars, and Carbon Fiber Strand to be added in near future

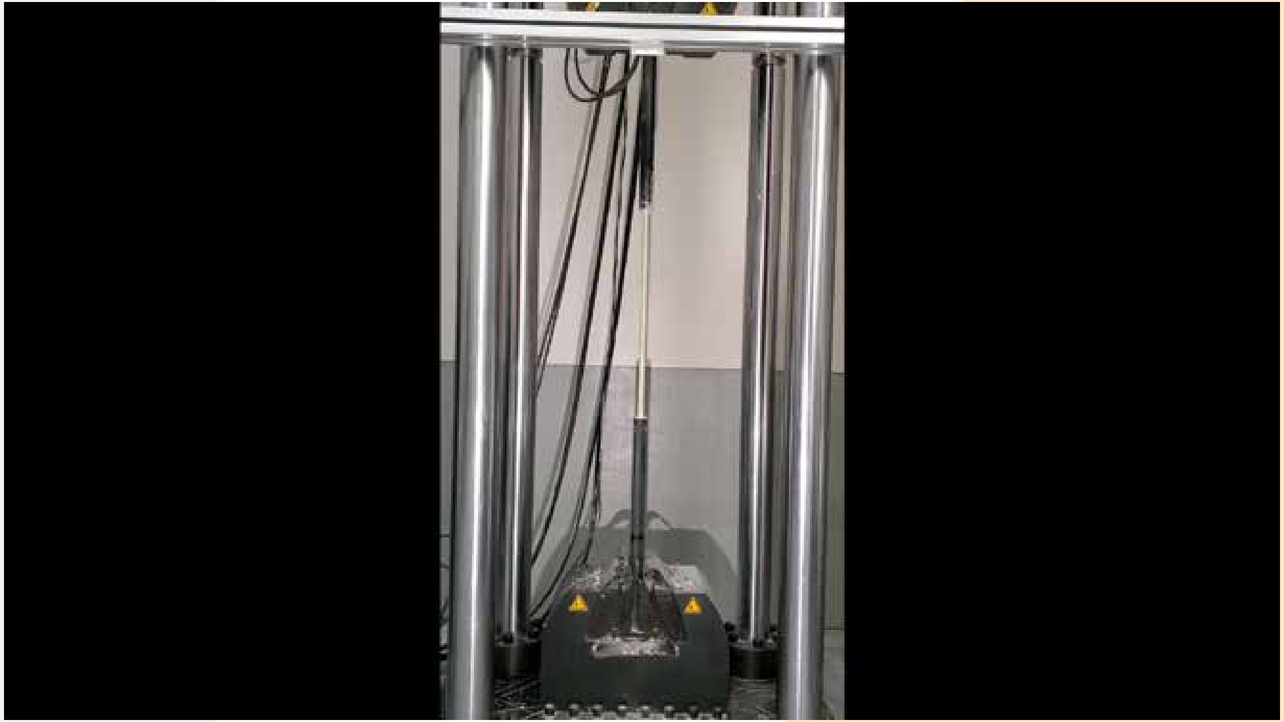
Visit ntpep.transportation.org to access:

- TC Work Plan
- Minutes from TC calls and NTPEP Annual Meeting

Any questions on this program, please contact :

Matthew Bluman, NTPEP Program Manager
mbluman@aashto.org – 202-624-5862

Tensile Failure



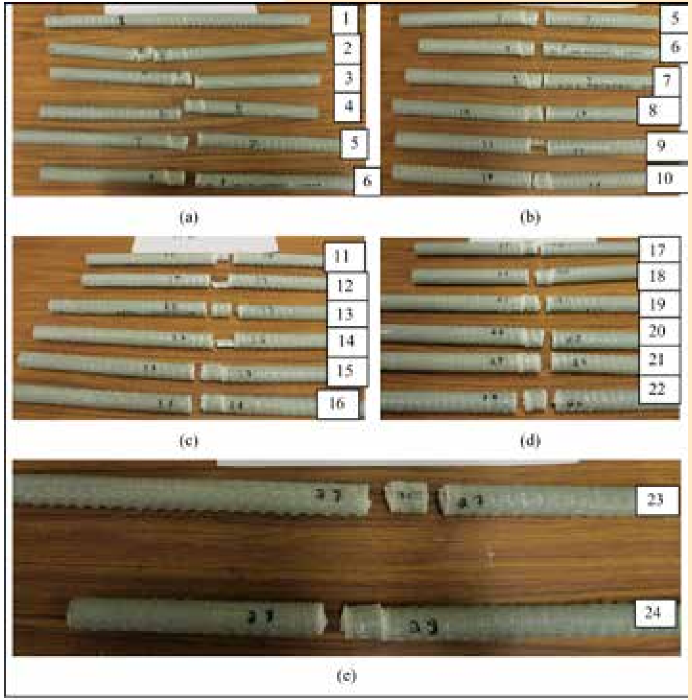
Embedded video of FRP rebar in Tensile failure

Cold Test

Test Setup in -40C°, Failure of bar beyond the 1000MPa
NO REDUCTION IN STRENGTH

Shear Test

Shear Test Setup
TRANSVERSE SHEAR STRENGTH
BEYOND 220MPa IS MAINTAINED.



Durability Testing

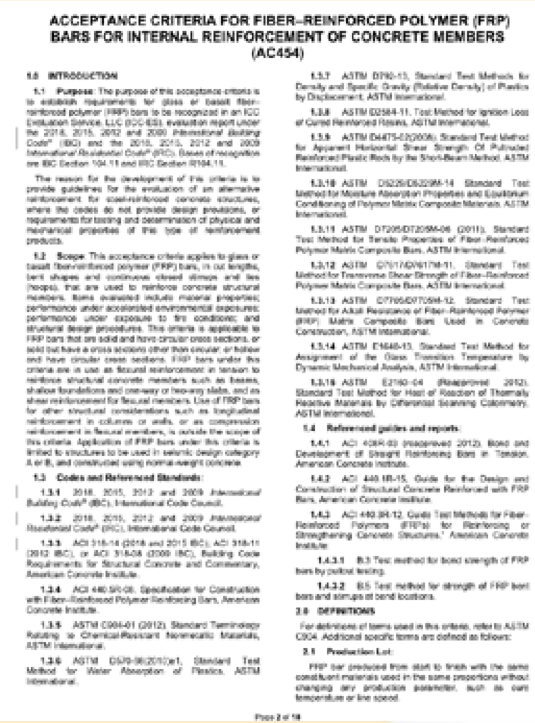
- The test was carried out in an environmental chamber with a 60C temperature.
- The white tubes are filled with a high alkali mixture with a pH level of 13 , under 3000 micro strains load for 90 days.

Material Certification

- ICC Report Ensures the GFRP has been properly tested
- ICC-ES AC 454: Comprehensive Testing for GFRP Rebar
- FRP Institute for DOT projects

Include:

- Bar Physical Properties such as size and materials
- mechanical properties of straight FRP bars
  - Ultimate tensile load
  - Elastic modulus
  - Ultimate shear strength
  - Ultimate tensile strain
  - Bond strength
  - Durability (moisture absorption, resistance to alkali attack, void content)


ACCEPTANCE CRITERIA FOR FIBER-REINFORCED POLYMER (FRP) BARS FOR INTERNAL REINFORCEMENT OF CONCRETE MEMBERS (AC454)

Manufacturers

ICC-ESR

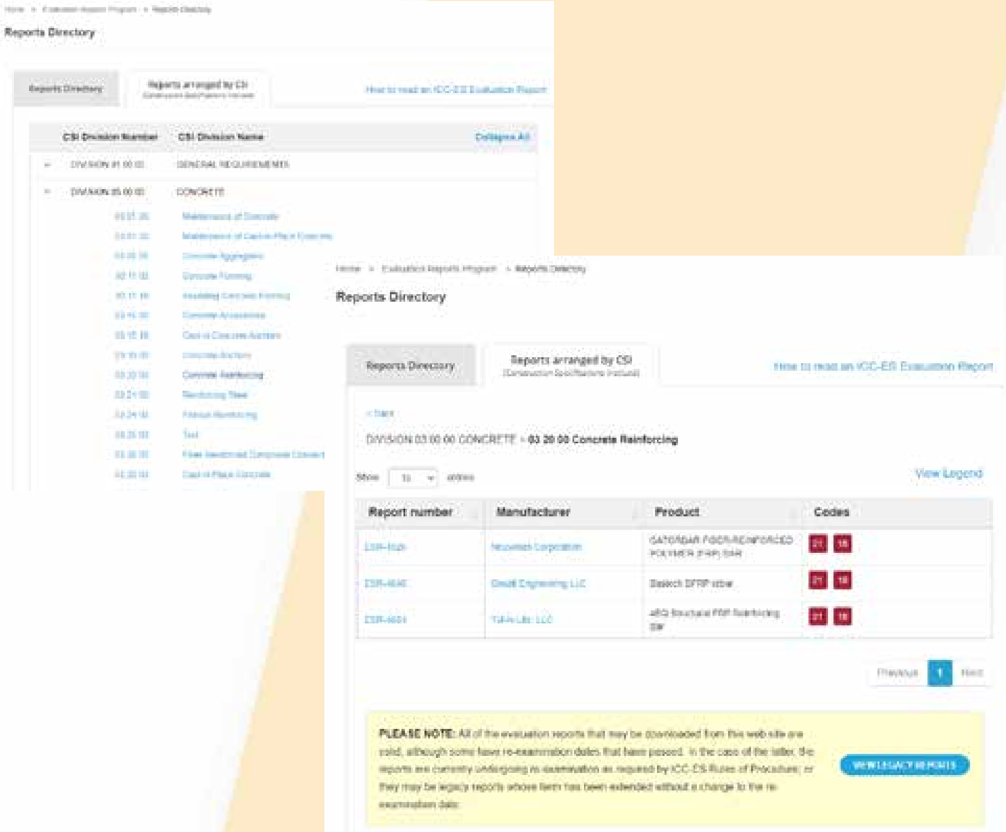
- Basalt Engineering (Bastech)
- Dextra (Durabar)
- Lite-Form (Lite Bar)
- MateenBar (GreenBarX2/PinkBar+)*
- MST Bar (4EQ)*
- Neuvokas (Gator Bar)
- Pultrall (V-ROD)*

ICC-EER

- MateenBar (GreenBarX2/PinkBar+)
- MST Bar (4EQ) *pending*

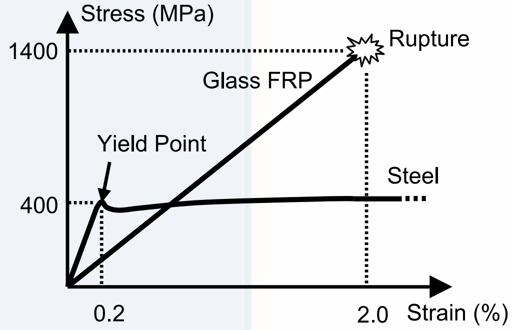
GFRP BFRP *-FRP Institute

Others not ICC-ES certified as of 7/1/2025



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.

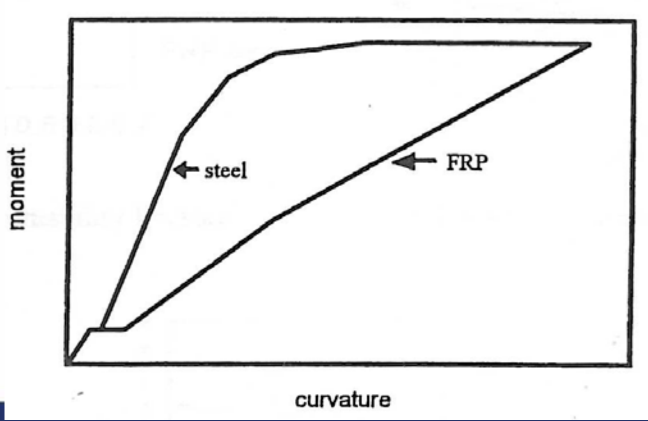


Stress strain curves for GFRP and steel reinforcement (ISIS 2006)

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

How to Design with GFRP

- Deformability takes into account absorbed energy based on deformability, to ensure members reinforced with FRP can sustain **adequate deformation** prior to failure.
- It is desirable that a FRP reinforced section would have comparable deformability as expected of a steel reinforced section. However, since **GFRP does not yield**, deformability is expressed in terms of the total **strain energy at failure** over the **strain energy at service load**.



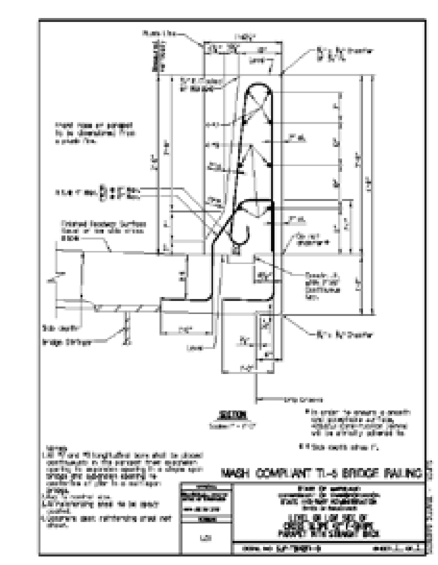
(Jaeger et al. 1997)

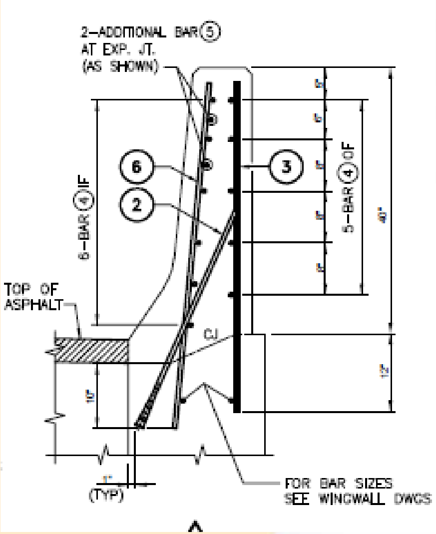
Designing with GFRP: Shear

- The design of GFRP-reinforced concrete is similar to that of steel-reinforced concrete members. The different mechanical properties of FRP bars, however, affect shear strength and should be considered.
- Several issues should be considered for the shear design of FRP-reinforced members.
    1. A relatively low modulus of elasticity;
    2. A low transverse shear resistance;
    3. A high tensile strength and no yield point.

- Also, the tensile strength of the bent portion of an FRP bar is significantly lower than that of the straight portion.

Where To Use: Barrier Walls





Embedded Video slide of Barrier wall Crash Test with Semi Truck

145 ksi Tensile Strength in the Field

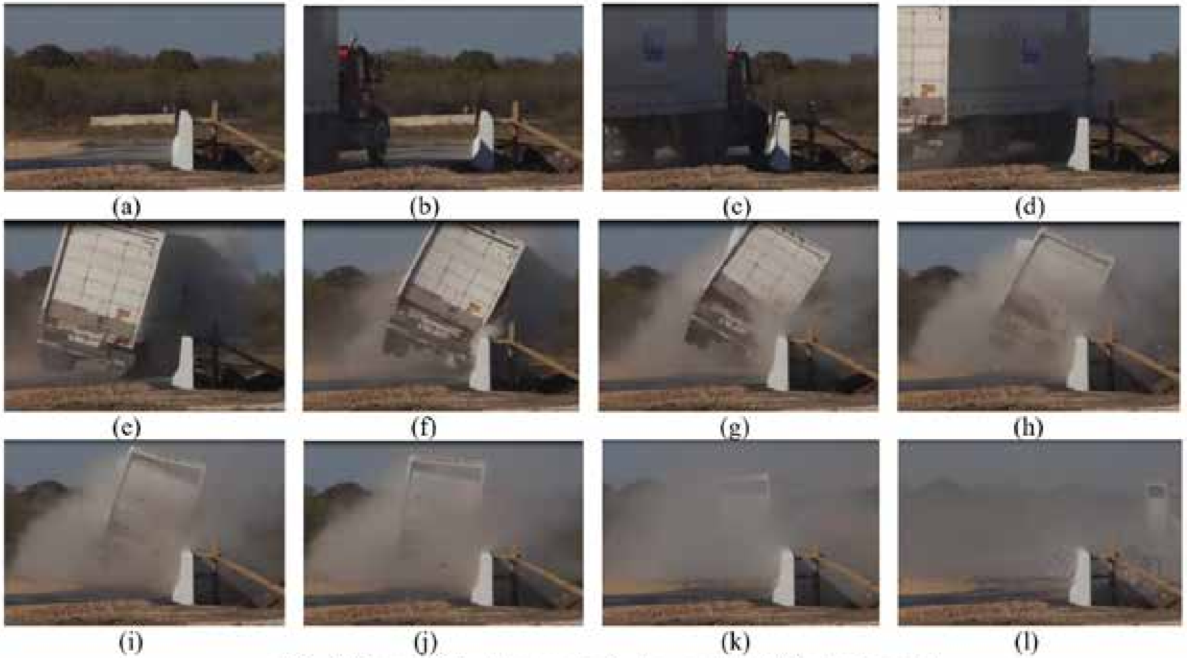


Fig. 9. Sequential photographs for the crash test (frontal views)

Where To Use: Barrier Walls

Crash Test of PL3 Barrier with GFRP

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