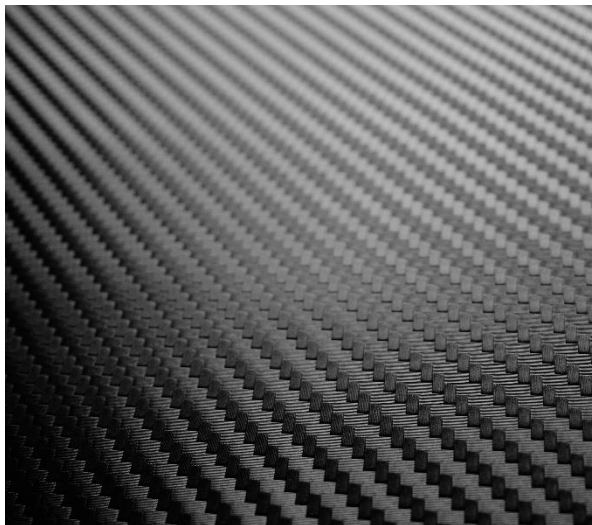
FRP Design Tools, Composite Bridge Beam Implementation & Pedestrian Bridges

TRB 2020 – AFF80 Workshop on FRP Deployment in Transportation Infrastructure
(January 12, 2020)

Presenter: Steven Nolan



FRP for Concrete and Composite Structures

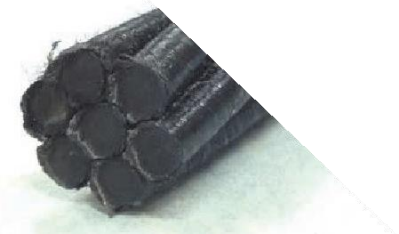
1. **Introduction**
   - Where are we?... Where do we want to go?... How do we get there?

2. **Design Rules & Tools for CFRP-PC and GFRP-RC**
   - Standards
   - Tools
     - Design
     - Justification
     - Delivery

3. **Design Rules & Tools for FRP Members (Composite Bridge Beams and Other Structures)**
   - Standards
   - Tools
   - Bidding Strategies

4. **Composite Pedestrian Bridges**
   - Girder Systems
   - Truss Systems

5. **Needs -** Tools, Research, Certification.



Introduction – Roadmapping Rules and Tools for Transportation Infrastructure

Progression of Implementation:

- Repairs and Strengthening - *1990's* →
- FRP Structural Members (mostly Pultruded and VARTM) - *2008, 2012* →
- CFRP-PC strands & FRP-RC rebar (Glass) - *2017 & 2012/17* → *Basalt?*

Putting it all together:

- Rules, Tools, and Implementation Strategies

"Mainstreaming":

- Codes & Standards
- Certification (Products, Systems, & Producers)
- Training (Designers, Inspectors, & Contractors)

Introduction - Roadmapping FRP for Transportation Infrastructure

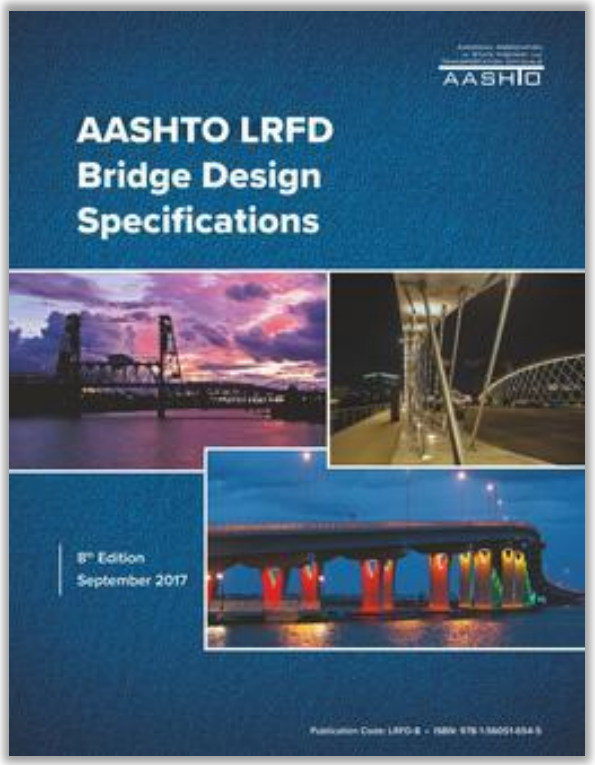
Where Are We?

- Southeast (FL, LA, KY, VA, WV)
- Northeast (ME, NY)
- Mid-west (MI, OH)
- Southwest (TX)
- West (OR)

Introduction - Roadmapping FRP for Transportation Infrastructure

Where do we want to go?

- AASHTO LRFD BDS Integration
- Individual Guide Specs vs Broader Guidelines?
- ASTM vs. AASHTO Materials Specs
- Manufacturer/Producer Certification?



~~***2020 – 9th Ed.***~~
2023 *– 10th Ed.*
2026 *– 11th Ed.*

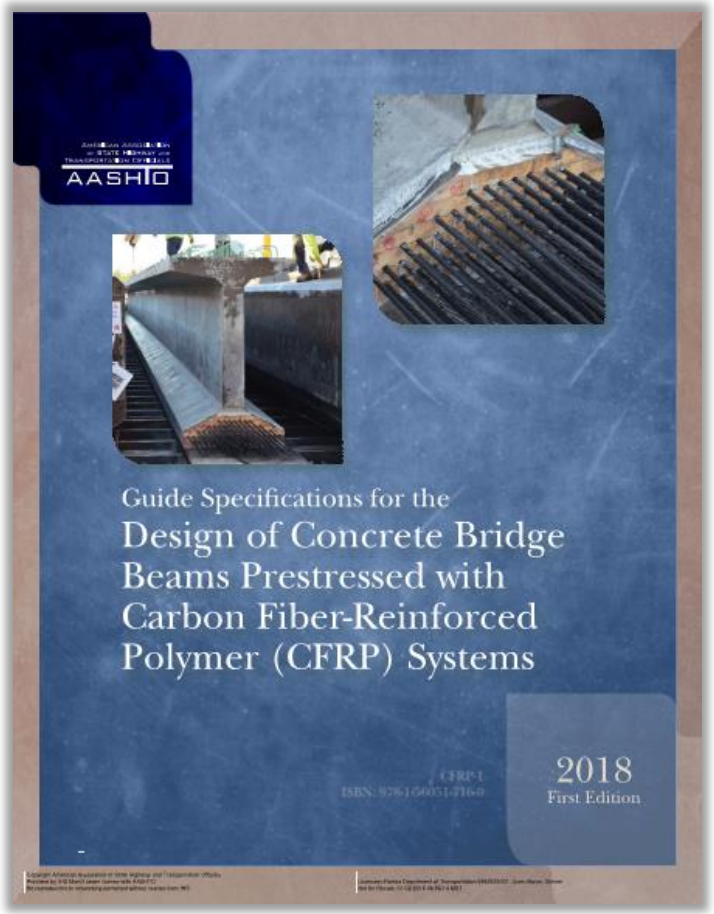
Introduction - Roadmapping FRP for Transportation Infrastructure

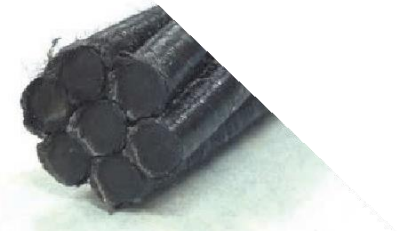
How do we get there?

- AASHTO LRFD BDS Integration
- Individual Guide Specs. vs Broader Class Guidelines?
- ASTM vs. AASHTO Materials Specs
- Manufacturer/Producer Certification?

Design Rules & Tools for CFRP-Prestressed Members

- Standards
- Design tools
- Cost Guidance





Design Rules & Tools for CFRP-Prestressed Members

- Standards
  - ***AASHTO*** Guide Specification for Beams Prestressed with CFRP Systems (2018)
  - ***ACI*** 440.4R-04
  - ***FDOT*** Spec 933; ***Michigan DOT*** Special Provisions for CFCC;
  - ***NCDOT*** Demo (Harkers Island Bridge Replacement);
  - ***VDOT*** FHWA/VTRC 19-R1 (Nimmo Parkway/West Neck Ck) & I-64 High Rise Bridge;
  - FDOT Standard Prestressed Piles (Index 455-100 & -440 series)
- Design tools
- Cost Guidance

Design Rules & Tools for CFRP-Prestressed Members

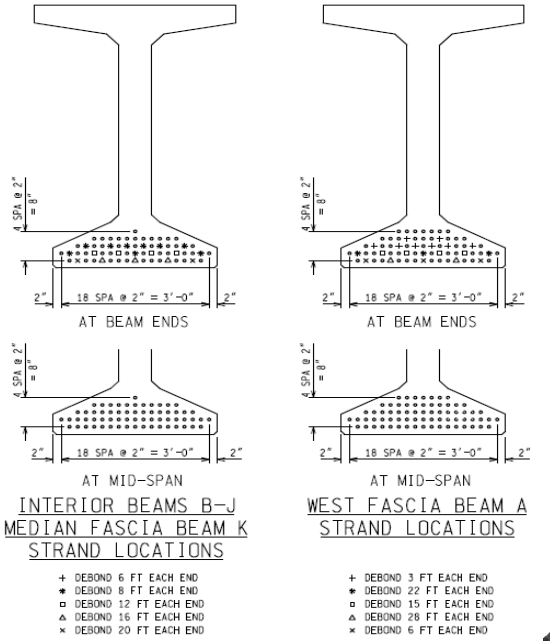
- Standards
- Design tools
  - FDOT Prestressed Beam Program *(Mathcad)*
  - Michigan DOT/LT CFRP Design Guidelines & Program- select "Modeling Bridge"
  - FB MultiPier (piles) - *pending material libraries*

TRB Webinar: Advanced Structural Materials for Concrete Bridges *(December 3, 2019)*

MDOT Lawrence Tech

LRFD Design Example for:

CFCC Prestressed Precast Concrete Bulb T-Beam with Cast-In-Place Concrete Slab



Design Rules & Tools for CFRP-Prestressed Members

- Standards
- Design tools
- Cost Guidance
  - ***FDOT SDG 9.2*** (piles)
  - ~$3 premium/ft. strand

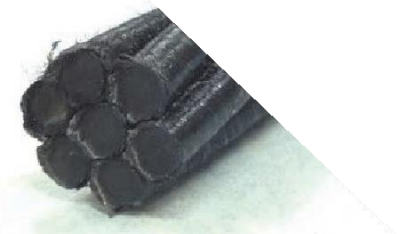
9.2.1 Substructure (Rev. 01/20)

A. Prestressed Concrete Piling; cost per linear foot (furnished and installed)

Size of Piling	Driven Plumb or 1" Batter[1]	Driven Battered[1]
18-inch w/ carbon steel strand[2]	$90	$125
24-inch w/ carbon steel strand[2]	$100	$140
30-inch w/ carbon steel strand[2]	$150	$210
18-inch w/ CFRP or Stainless Steel Strand	$135	$160
24-inch w/ CFRP or Stainless Steel Strand	$150	$210
30-inch w/ CFRP or Stainless Steel Strand	$225	$280

1 When highly reactive pozzolans are used, add $6 per LF to the piling cost.

2 When heavy mild steel reinforcing is used in the pile head, add $250.



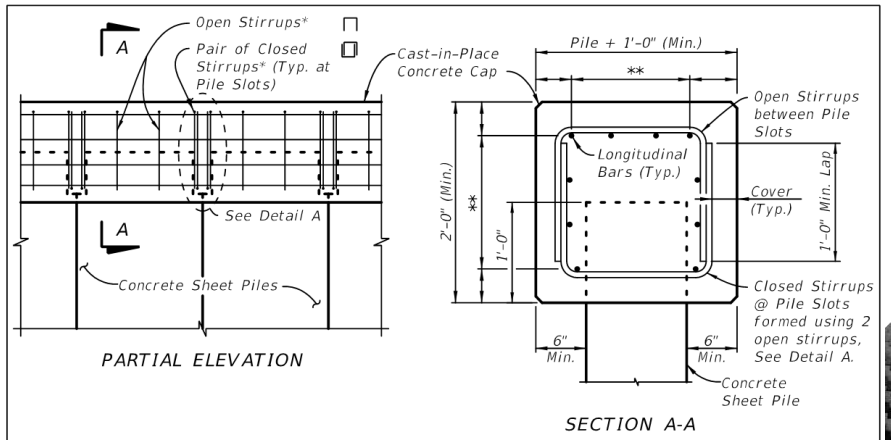
Design Rules & Tools for FRP-Reinforced Concrete Structures

- Standards
- Design tools
- Cost Guidance
- LCC & LCA

Design Rules & Tools for FRP-Reinforced Concrete Structures

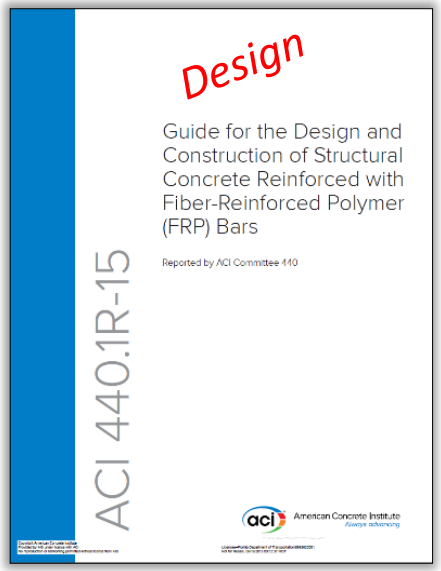
- Standards
  - ***AASHTO*** LRFD Bridge Design Guide Specification for GFRP-Reinforced Concrete (2018)
  - ***ACI 440.1R-15*** *(building code update in process)*
  - Materials - FDOT Spec 932-3; ***ASTM D7957-17***
  - Pre-designed Elements: FDOT Concrete Sheet Piles & Bulkhead Caps (Index 455-440)
- Design tools
- Cost Guidance

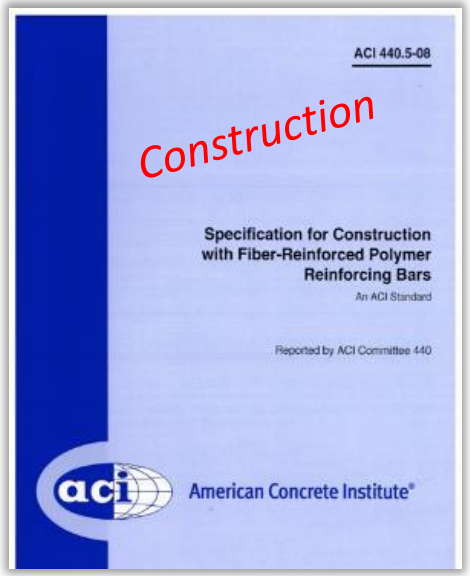
Figure 1 Typical Cap Details



Design Rules & Tools for FRP-Reinforced Concrete Structures

- Standards
- Design tools
- Bidding Strategies





ACI Committee 440:

Plan is to get remaining code chapters balloted at main by Spring 2020 and clean up outstanding issues by Fall 2020

Public comment phase

Document	Doc Ballot by Sub	Doc Ballot by 440 Main	Resolve Negative 440 Main Ballot	Doc to ACI for TAC Review	TAC Review	440 Reply to TAC Comments Ballot	Return to ACI for Layout	In Print
440-H CODE	Complete Fall 2019	Complete Spring 2020	Complete Fall 2020	Spring 2021				
Bar Const. Spec	Done	Done	Done	Done	Done	Spring 2018		

Design Rules & Tools for FRP-Reinforced Concrete Structures

- Standards
- Design tools
  - **FDOT Pile Bent Cap Program *(Mathcad)***
  - FDOT CIP Flat Slab Bridge Program *(Mathcad)*
  - FDOT CIP Retaining Wall Program *(Mathcad)*
  - FDOT CIP Box Culvert Program *(Mathcad)*
  - Commercial interest *(DeepEx, FB-MultiPier, etc.)*
- Cost Guidance

Design Rules & Tools for FRP-Reinforced Concrete Structures

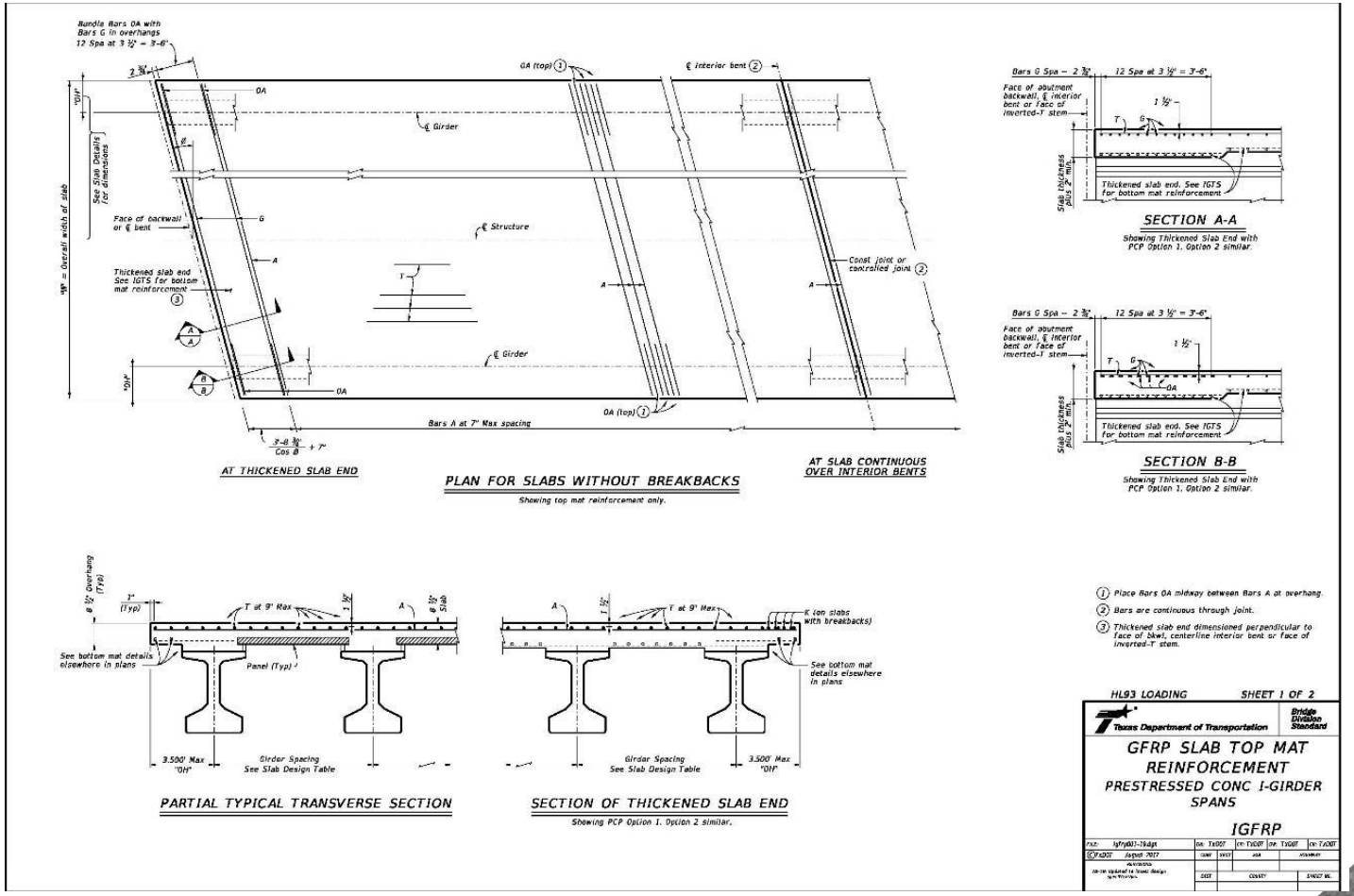
- Standards
- Design tools
  - **FDOT Pile Bent Cap Program (M**
  - Co

Box Culvert v4.0 *GFRP-RC in development !*	11/07/2018	Exe (Zip) (Mathcad 15)	Used with **FDOT Standard Plan Index 400-289** (formerly **Index 289**) to design concrete box culverts, wingwalls, headwalls, and cutoff walls in accordance with the AASHTO LRFD Bridge Design Specification.
Prestressed Beam v5.2 *CFRP-PC Beta version ***	11/07/2018	Exe (Zip) (Mathcad 15)	Used with **FDOT Standard Plan Index 450-010 to 450-299** (formerly **Index 20010 to 20299**) to design simple span prestressed beams (Florida-I, AASHTO, Florida Bulb-T, Florida-U, Florida Double-T, Flat Slab, Inverted-T, FSB) in accordance with the AASHTO LRFD Bridge Design Specification.
Bent Cap v1.0 *GFRP-RC included (3b)*	11/07/2018	Exe (Zip) (Mathcad 15)	Analyzes and designs fixed or pinned bent caps, including lateral loads, in accordance with the AASHTO LRFD Bridge Design Specifications.
Retaining Wall v3.3 *GFRP-RC Beta version ***	11/07/2018	Exe (Zip) (Mathcad 15)	Used with **FDOT Standard Plan Index 400-010** (formerly **Index 6010**) to design and analyze cast-in-place retaining walls in accordance with the AASHTO LRFD Bridge Design Specification.

*** Available on request*

Design Rules & Tools for FRP-Reinforced Concrete Structures

- Standards
- Design tools
  - TxDOT IGFRP (Oct, 2019)
- Cost Guidance



Design Rules & Tools for FRP-Reinforced Concrete Structures

- Designer tools/aids
  - Producer/Product approval

https://mac.fdot.gov/smoreports

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Fiber Reinforced Polymer Production Facility Listing

FDOT State Materials Office, 5007 N.E. 39th Avenue, Gainesville, FL 32609 (352) 955-6600

FRP-02 OWENS CORNING (BLYTHEWOOD, SC)

Company: Owens Corning Infrastructure Solutions
Contact: John Amonett
Email: john.amonett@owenscorning.com
Phone: (419) 819-9739
Fax:
Physical Address:
1051 Jenkins Brothers Rd
Blythewood, SC 29016
QC Plan Status: Quality
#04 GFRP BAR
#05 GFRP BAR
#06 GFRP BAR
#07 GFRP BAR
#08 GFRP BAR

FRP-06 PULTRALL

Company: Pultrall Inc
Contact:
Phone:
Physical Ad
700 9eme rue
Thetford Mine
CANADA
QC Plan Stat
#03 (
#04 (
#05 (
#06 (
#08 (

FRP-12 TUF-BAR INC (EDMONTON CANADA)

Company: Tuf-Bar Inc.
Contact: Nathan Sim
Email: nathan@tuf-bar.com
Phone: (780) 448-9338
Fax:
Physical Address:
5715-76 Avenue
CANADA
Mailing Address:
5715-76 Avenue
CANADA

QC Plan Status: Quality Control Plan ACCEPTED 3/19/2019

#03 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #3
#04 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #4
#05 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #5
#06 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #6
#07 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #7
#08 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #8

FRP-07 PULTRON (DUBAI)

Company: Pultron Composites Ltd
Contact: Bogdan Patrascu
Email: bogdan@pultron.com
Phone: (714) 880-9533
Fax:
Physical Address:
S404 Street
Building 10 Jebel Ali Fre
UNITED ARAB EMIRAT
Mailing Address:
QC Plan Status: Qu
#04 GFRP BAR
#05 GFRP BAR
#06 GFRP BAR
#08 GFRP BAR

FRP-08 ATP

Company: ATP
Contact: Aniello Giamundo
Email: a.giamundo@atp.sa.it
Phone: (811) 948-7131
Fax:
Physical Address:
via Campa 34
ITALY
Mailing Address:
via Campa 34
ITALY
QC Plan Stat
#03 (
#04 (
#05 (
#06 (
#08 (

FRP-14 TUF-BAR INC (ONTARIO CANADA)

Company: Tuf-Bar Inc.
Contact: Jay Christopher
Email: jay@tufbarcanada.com
Phone: (519) 833-5050
Fax:
Physical Address:
7 Erin Park Dr
CANADA
Mailing Address:
7 Erin Park Dr
CANADA

QC Plan Status: Quality Control Plan ACCEPTED 12/11/2017

Design Rules & Tools for FRP-Reinforced Concrete Structures

- Standards
- Design tools
- Cost Guidance

D. Reinforcing Bars and Post-tensioning Steel

1. Steel Reinforcing Bars; cost per pound:

Carbon Steel, ASTM A615, Gr. 60 or 75	$1.05
Low-Carbon Chromium Steel, ASTM A1035, Gr. 100	$1.30
Stainless Steel, ASTM A955, Gr. 60 or 75, or ASTM A276, UNS S31653 or S31803	$4.05

2. GFRP Reinforcing Bars, FDOT Standard Specifications 932-3; cost per linear foot. Add $1.00 per hook, or bend for stirrups, and $1.00 per revolution for circular spirals.

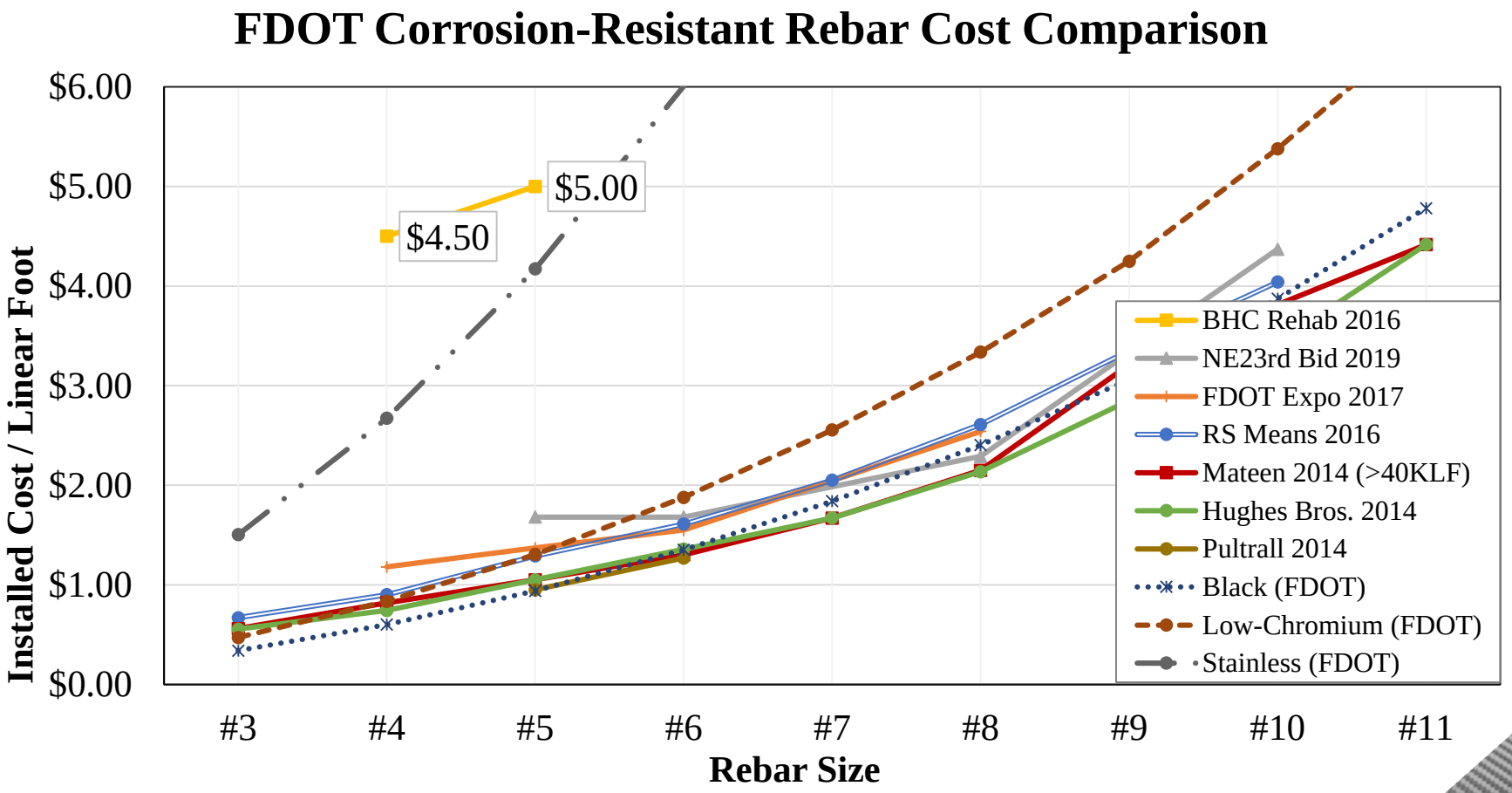
#3	#4	#5	#6	#7	#8
$0.60	$0.95	$1.15	$1.40	$1.80	$2.25

Design Rules & Tools for FRP-Reinforced Concrete Structures

- Standards
- Design tools
- Cost Guidance

Recent FDOT Bid Tabs:

GFRP Bar Size	AIA Seawall Bid 2018	HRB Bid 2016	NE23rd Bid 2019
#3			
#4		$1.00	
#5	$1.45	$1.10	$1.68
#6		$1.40	$1.68
#7			
#8		$1.70	$2.29
#9			
#10			$4.37



Design Rules & Tools for FRP-Reinforced Concrete Structures

- Standards
- Design tools
- Cost Guidance
  - FHWA Presentation 2012 – Industry Meeting

Unit Prices for Rebar

(Materials-only, except as noted; early 12)

	Cost/lb (U.N.O.*)
Black (#4)	.48
Epoxy (#4)	.70
Epoxy II	.50
Galvanized	.68-.73
Purple ECR (includes fabric.)	1.18
Z-bar (includes fabric. & transport.)	1.25-1.50

MMFX-2 (stock length)	.94
Solid SS (#7) (w/surcharge)	2.02-2.95
Basalt FRP (10 mm) ($$/ft)*	0.64 (19.2 kip)
FRP ($$/sq ft)* (#5 and #6)	5 -6.60
($$/lin ft)*	1. -1.44

Cost Comparison of Corrosion Resistant Reinforcing Steel

Deployment Considerations

Louis N. Triandafilou, P.E.
FHWA Office of Infrastructure R&D
Team Leader – Bridge & Foundation Engineering Team
(202) 493-3059
lou.triandafilou@dot.gov

Slides presented at ACI Hot Topic Session on 10/20/2019 by:
Richard F. Bertz, PE, PS
CEO/President
The Mannik & Smith Group, Inc.

Cost Comparisons (ODOT bridge decks)

Anthony Wayne Trail over NSRR (link)	Cost Per Square Foot of Deck
Epoxy Coated Reinforcing	$8.052/SF
GFRP Reinforcing (GFRP 1st Edition)	$9.587/SF
GFRP Reinforcing (GFRP 2nd Edition)	$8.736/SF

- Cost information based of Contractor bid prices
- Price of epoxy reinforcing @ $1.00/LB

Industrial Drive over the Maumee River (link)	Cost Per Square Foot of Deck
Epoxy Coated Reinforcing	$11.805/SF
GFRP Reinforcing	$10.609/SF

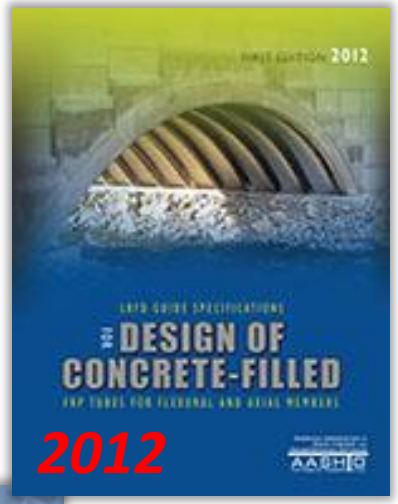
- Cost information is from Engineer's estimate
- Price of epoxy reinforcing @ $1.15/LB
- Recent increase in steel cost (15%-20% Increase)

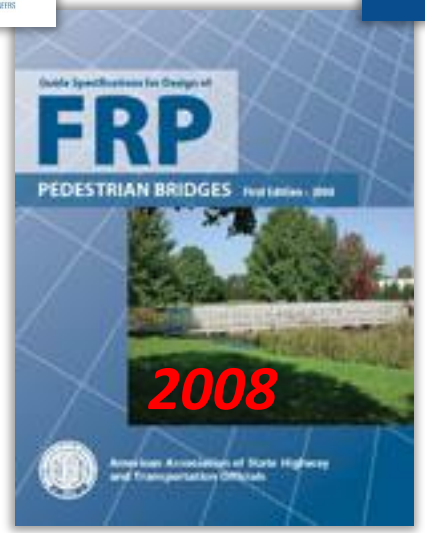
I-475 over Dorr Street & Hill Avenue (link)	Cost Per Square Foot of Deck
Epoxy Coated Reinforcing	$10.104/SF
GFRP Reinforcing (w/ Mech. Conn.)	$10.025/SF
GFRP Reinforcing (w/o Mech. Conn.)	$8.563/SF

- Cost information is from Engineer's estimate
- Price of epoxy reinforcing @ $1.15/LB
- Recent increase in steel cost (15%-20% Increase)
- Mechanical connectors $20/bar (Assumed)

Design Rules & Tools for FRP Members (Composite Bridge Beams & Other Structures)

- Standards
- Design tools
- Bidding Strategies





Design Rules & Tools for FRP Members (Composite Bridge Beams & Other Structures)

- Standards
- Design tools
  - HCB worksheet
  - Vendor software
- Bidding Strategies

FLORIDA DEPARTMENT OF TRANSPORTATION

District 7 Structures Design Office
PROJECT: *Halls River Road Bridge - 100% Submittal*
SUBJECT: *HCB Design - Interior Beam - Intermediate Spans - Final Phase*

FPID: *430021-1-52-01*
PREPARED BY: *ETM*
CHECKED BY: *MMRS*

- **SDG:** Structures Design Guidelines, FDOT Structures Manual volume 1, 2015
- **SDM:** Structures Detailing Manual, FDOT Structures Manual volume 2, 2015
- **AASHTO LRFD:** AASHTO LRFD Bridge Design Specifications, 7th Edition, 2015 with 2015 interim revisions
- **Spec:** FDOT Standard Specificaitons for Road and Bridge Construction, 2016
- **Index:** FDOT Design Standards, 2016
- **FDOT LR Manual:** Bridge Load Rating Manual, FDOT, July 2015.
- **LRFR:** AASHTO Manual for Bridge Evaluation, FDOT, 2014 Interim Revisions to 2010 edition.
- **HCB DM:** AHybrid-Composite Beam (HCB) Design and Maintenance Manual.

$kcf := \frac{kip}{ft^3}$

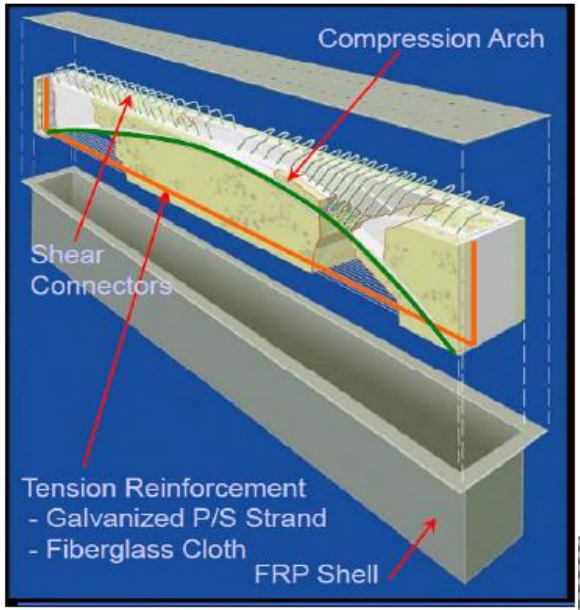
3. INPUT:

3.1 Geometry:

Bridge:

Interior or Exterior	$beam_{type} := "Interior"$
Overall width of bridge (final phase)	$Width_{overall} := 57ft + 9.75in = 57.813\,ft$
Curb to curb width of bridge (final phase)	$Width_{ctc} := 40ft$
Width of Barrier	$Width_{barrier} := 1.5ft$
Skew of bridge	$Skew := 0deg$
Overhang length from CL of exterior beam	$Overhang := 3ft + 2.5in = 3.208\,ft$
Span length	$L_{span} := 37ft + 2in = 37.17\,ft$
Beam overall length	$L_{beam} := 36ft + 2in = 36.17\,ft$
Beam design length	$L_{des} := 35ft + 1.5in = 35.13\,ft$
Beam spacing	$Spcg := 6ft + 7.625in = 6.635\,ft$

430021-1 Halls River - 100% 1 of 85



Design Rules & Tools for FRP Members (Composite Bridge Beams & Other Structures)

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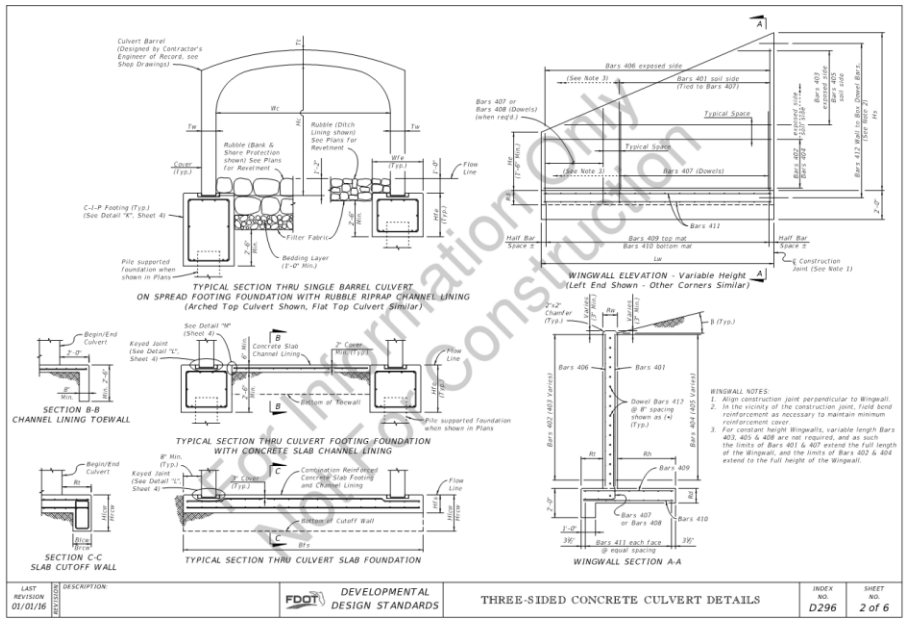

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Potential format: FDOT Index D296 **Three sided Concrete Culvert Details** IDDS-D296

Design Rules & Tools for FRP Members (Composite Bridge Beams & Other Structures)

- Standards
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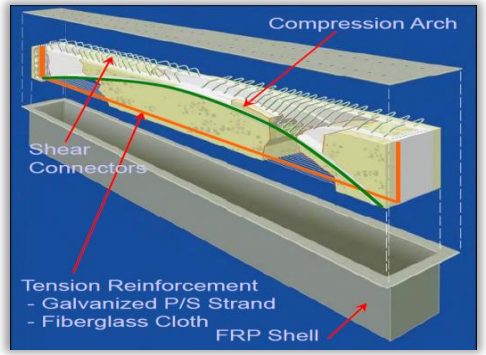
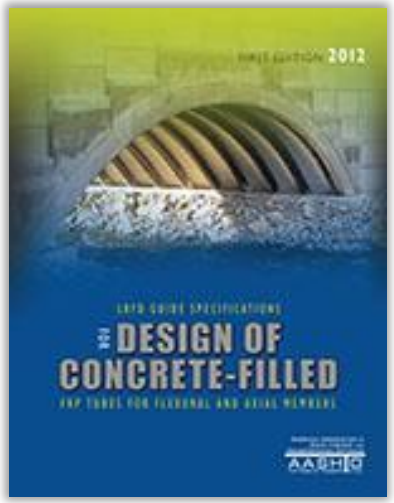




"Detail-Build" option:

MnDOT SP 531 Detail-Build Bridge Structure ***bid book*** describes the process.

- allowing bid options for relatively straight forward bridge projects (or bridge elements)
- requires the contractor to complete the design according to the requirements in SP 531.

For projects with prefabricated elements it allows the contractor select the best option based on cost, product availability and preference; and allows the owner to include proven proprietary products as bid alternates.

Examples:

Industry, Sawyer Bridge – Detail Build buried structure (34' span)
Bid Date: 12/19/2018

North Berwick, Staples Bridge – Detail Build short span bridge (40' span - no FRP option) **Bid Date: 1/8/2020**

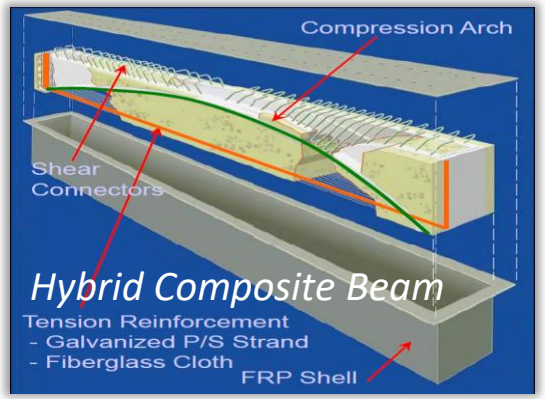
MnDOT used this process for approximately 10 years with good success with a 4 or 5 week bid period. Avoid any projects with complexities that require in-depth design.

Composite Bridge Systems

- Girder Bridges

Photo: Wagners CFT


Photo: AIT bridges



- Pedestrian Truss Systems


95-ft. trail bridge being flown to a remote staging site in Alberta, Canada. *(Photos: Emerald Atlas, courtesy of Dustin Troutman – Creative Pultrusion)*


Photo: Emerald Atlas


Photo: Wagners CFT

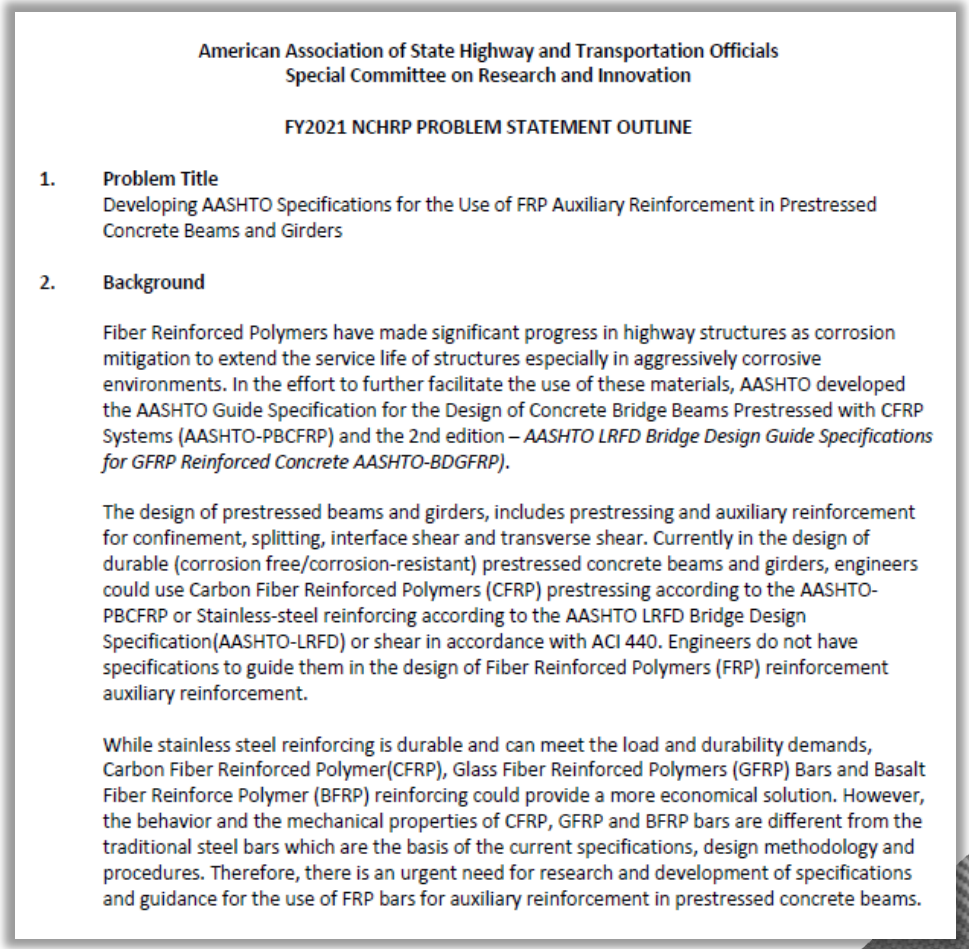
Needs – Design Tools, Research & Other

- What do we need to get in the Bridge Code?
  - AFF80 Research Needs Statements (priorities)
  - NCHRP options (Scan, Synthesis, Research ?)
  - State DOT research programs vs. Pooled Fund

- Is FHWA's ***Every Day Counts (EDC-6)*** important for FRP *(Jan 21, 2020 deadline)*?
- FHWA ***Accelerated Market Readiness (AMR)*** and other programs *(previous BAA Apr 22, 2019, 2020 pending)*?

Needs – Design Tools, Research & Other

- What more do we need to get in the Bridge Code?
  - AASHTO RNS (Research)
    - PC Beam Auxiliary FRP Reinforcement submitted
  - Competitive materials: NCHRP 12-120 *"Stainless Steel Strands for Prestressed Bridge Elements"*



American Association of State Highway and Transportation Officials
Special Committee on Research and Innovation

FY2021 NCHRP PROBLEM STATEMENT OUTLINE

1. **Problem Title**
Developing AASHTO Specifications for the Use of FRP Auxiliary Reinforcement in Prestressed Concrete Beams and Girders

2. **Background**

Fiber Reinforced Polymers have made significant progress in highway structures as corrosion mitigation to extend the service life of structures especially in aggressively corrosive environments. In the effort to further facilitate the use of these materials, AASHTO developed the AASHTO Guide Specification for the Design of Concrete Bridge Beams Prestressed with CFRP Systems (AASHTO-PBCFRP) and the 2nd edition – *AASHTO LRFD Bridge Design Guide Specifications for GFRP Reinforced Concrete AASHTO-BDGFRP).*

The design of prestressed beams and girders, includes prestressing and auxiliary reinforcement for confinement, splitting, interface shear and transverse shear. Currently in the design of durable (corrosion free/corrosion-resistant) prestressed concrete beams and girders, engineers could use Carbon Fiber Reinforced Polymers (CFRP) prestressing according to the AASHTO-PBCFRP or Stainless-steel reinforcing according to the AASHTO LRFD Bridge Design Specification(AASHTO-LRFD) or shear in accordance with ACI 440. Engineers do not have specifications to guide them in the design of Fiber Reinforced Polymers (FRP) reinforcement auxiliary reinforcement.

While stainless steel reinforcing is durable and can meet the load and durability demands, Carbon Fiber Reinforced Polymer(CFRP), Glass Fiber Reinforced Polymers (GFRP) Bars and Basalt Fiber Reinforce Polymer (BFRP) reinforcing could provide a more economical solution. However, the behavior and the mechanical properties of CFRP, GFRP and BFRP bars are different from the traditional steel bars which are the basis of the current specifications, design methodology and procedures. Therefore, there is an urgent need for research and development of specifications and guidance for the use of FRP bars for auxiliary reinforcement in prestressed concrete beams.

Needs – Design Tools, Research & Other

- What do we need to improve efficiency for Bridge Code?
  - Elastic Modulus
  - Sustained Stress Limits
  - Fatigue Limits

From: M.Rossini, F.Matta, S.Nolan and A.Nanni, Extended Abstract *"Overview of Proposed AASHTO Design Specifications for GFRP-RC Bridges 2nd Edition using Case-Specific Parametric Analysis"* (2017)

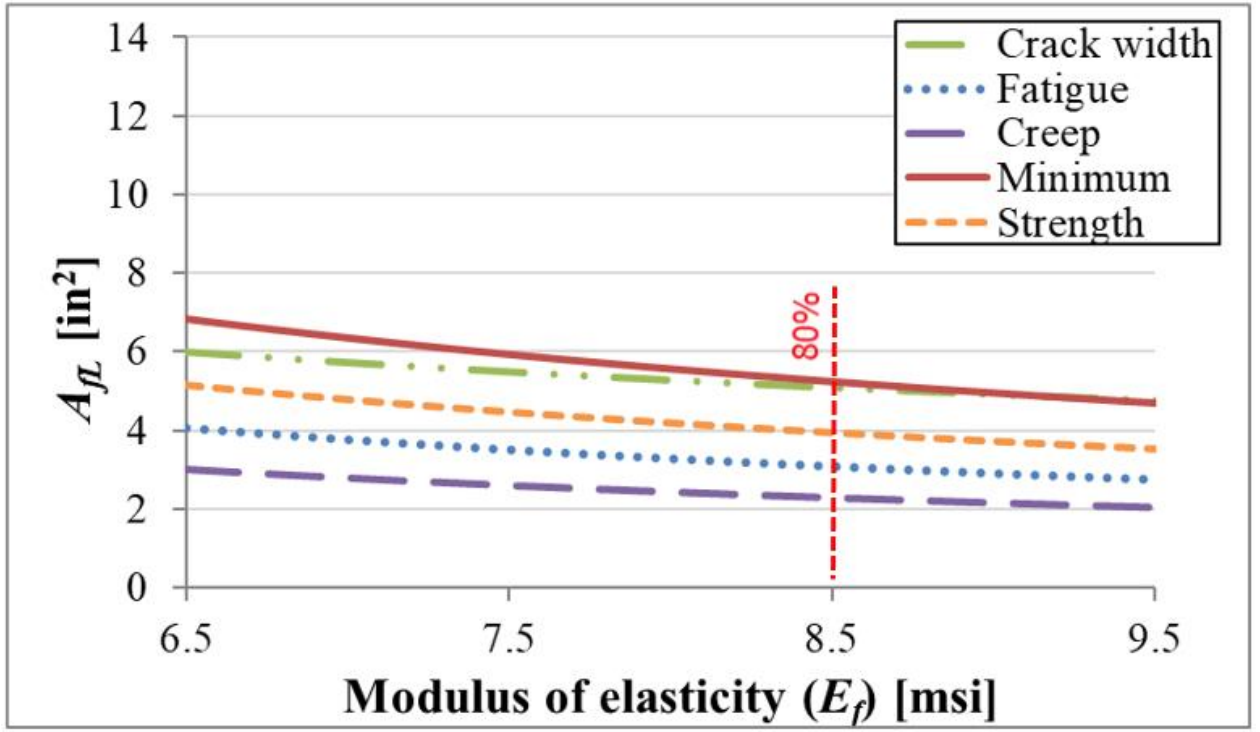


Figure: Parametric analysis of flexural design algorithms per AASHTO GFRP-RC 2nd edition for HRB Bent Cap

Questions?

- What Tools are Still Needs:
  - For Design
  - For Product Acceptance
  - For Contract Delivery
  - For Inspection