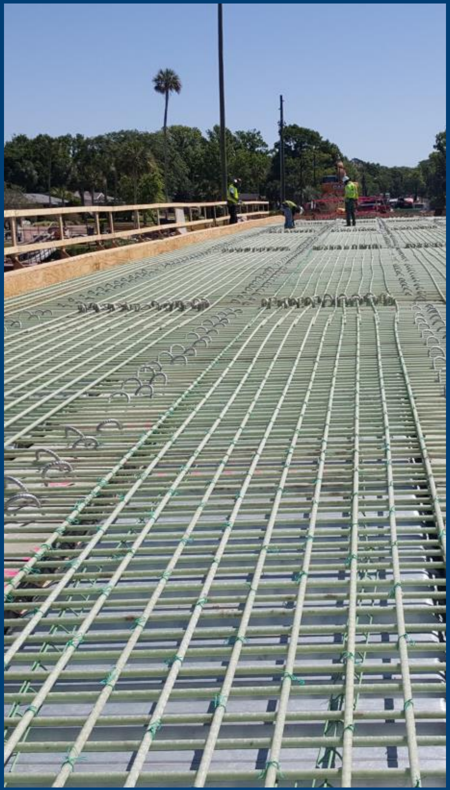

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MIAMI

UNIVERSITY OF SOUTH CAROLINA

FDOT

Bridge Design Guide Specifications for GFRP-RC

AASHTO-BDGS-GFRP 2nd Edition (under consideration)

Antonio Nanni, Marco Rossini, Fabio Matta, William Potter, **Steven Nolan**

ESWP 1880 ENGINEERS' SOCIETY of WESTERN PENNSYLVANIA

Overview

- **Key features of *2nd Edition* update:**
  - Approach & relevance
  - Deliverable
  - Comparisons & key equations
- **Harmonize**
  - ASTM, AASHTO-BDS, ACI & CSA
- **Update**
  - Creep-rupture & fatigue
  - Flexure
  - Compression
- **Expand**
  - Case studies: footing, bent cap, girder & pile
  - Challenge

Approach and Relevance

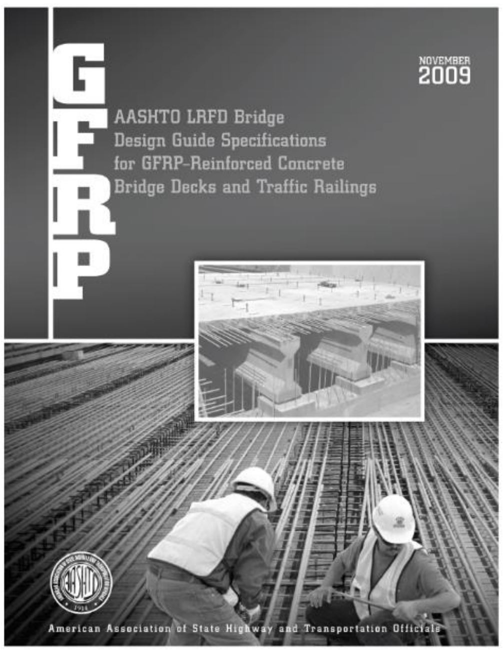
- **Harmonize** with national (***ACI***, ***ASTM*** and ***AASHTO-BDS***) and international (***CSA***) specifications.
  - Ease design/deployment
  - Ease certification
  - Enlarge market
- **Update** existing provisions to reflect better materials and manufacturing, and new research findings.
  - Make design more efficient
  - Creep-rupture & fatigue
  - Flexure
  - Compression

Approach and Relevance

- **Expand** provisions to include all members of a bridge.
  - Allow the design of a bridge entirely GFRP-RC
  - Case studies: footing, bent cap, girder & pile
  - Challenge

Deliverable

- From ***1st Edition*** on decks and railings to complete ***Bridge Design Guide Specifications*** *(**BDGS-**GFRP)* ***2nd Edition***.
- To be voted (06/26/2018) by AASHTO Committee T6 for adoption.



2018

AASHTO LRFD
BRIDGE DESIGN GUIDE SPECIFICATIONS
FOR GFRP REINFORCED CONCRETE – 2ND EDITION

TABLE OF CONTENTS

Contents **Comparison**

Chapter/Section (*AASHTO 2nd*)	***AASHTO 2nd* 2018**	***AASHTO 1st* 2009**	***ACI 440.1R* 2015**	***CSA* 2014**
2. Concrete Structures				
• Flexural elements	x	x	x	x
• **Compression**	**X**			
• Shear	x	x	x	x
• **Torsion**	**X**			
3. Decks	x	x		x
4. Substructures	**X**			
5. Railings	x	x		x
6. Material & Construction	x	x	x	x

Critical Design Provisions

Capacity provisions

$$f_{fd} = \boldsymbol{C_E}\, f_{fu}^{*}$$

GFRP (long-term) Design Strength

$$M_r = \begin{cases} \Phi_{\boldsymbol{C}}\, A_f f_f \left(d - \dfrac{0.8\,x}{2}\right) & \varepsilon_c = \varepsilon_{cu} \\ \Phi_{\boldsymbol{T}}\, A_f \boldsymbol{f_{fd}} \left(d - \dfrac{0.8\,x}{2}\right) & \varepsilon_c = \varepsilon_{fd} \end{cases}$$

Flexural Resistance

$$V_r = \Phi_{\boldsymbol{S}}\,(V_c + V_f)$$

Shear Resistance

Critical Design Provisions

Serviceability provisions

$f_{f,c} = \boldsymbol{C_c}\, \boldsymbol{C_E}\, f_{fu}$ — GFRP Creep Rupture Strength

$f_{f,f} = \boldsymbol{C_f}\, \boldsymbol{C_E}\, f_{fu}$ — GFRP Fatigue Strength

$s \le 1.15\, \boldsymbol{C_b} \frac{E_f \boldsymbol{w}}{f_f} - 2.5\, \boldsymbol{c_c}$ — Spacing for Crack Control

Comparison of Critical Design Parameters

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	AASHTO 2nd 2018	AASHTO 1st 2009	ACI 440.1R 2015	CSA 2014	
f_{fu}^*	99.73	99.73	99.73	**95.0** (2)	Strength percentile
Φ_C	**0.75**	**0.65**	0.65	0.75	Res. Fact. concr. failure
Φ_T	0.55	0.55	0.55	0.55	Res. Fact. FRP failure
Φ_S	0.75	0.75	0.75	0.75	Res. Fact. shear failure
C_E	0.70	0.70	0.70	**1.0**	*Environmental reduction*
C_C	~~0.25~~ **0.30** *(3)*	**0.20**	0.20	0.25	*Creep rupture reduction*
C_f	**0.25**	**0.20**	0.20	0.25	*Fatigue reduction*
C_b	**0.80**	**0.70**	0.70	**1.0**	*Bond reduction*
w	**0.028**	**0.020/0.28**	0.028 to 0.020	0.02?	Crack width limit [in.]
$c_{c,stirrups}$	1.5	1.50	2.0 (1)	(40 mm)	Clear cover [in.]
$c_{c,slab}$	1.0	0.75 to 2.0	0.75 to 2.0 (1)	(40 mm)	Clear cover [in.]

(1) ACI 440.5-08 Table 3.1; (2) Characteristic Strength *(3) Changed 6/28/18*

In-Depth Look at Key Features

- **Key features**
  - Approach, Relevance, Deliverable
  - Comparisons & key equations
- **Harmonize**
  - ASTM, AASHTO-BDS, ACI & CSA
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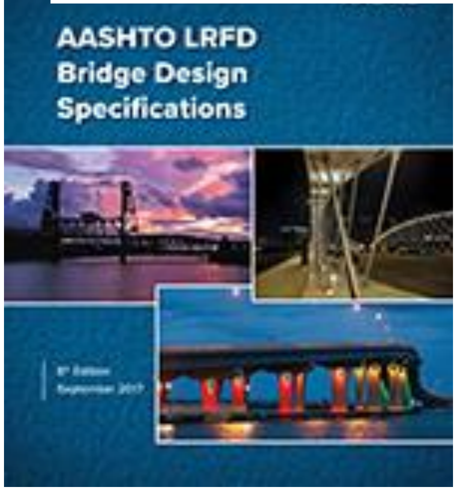
Harmonization: ASTM & AASHTO-BDS

- ***2nd Edition*** Refers to ***ASTM D7957-17*** for material specifications
  - Only vinyl ester GFRP / epoxy GFRP round bars allowed
  - Role separation and eased certification

- Design of GFRP-RC bridge elements follows structure of Bridge Design Specifications for steel-RC/PC (***AASHTO-BDS-17, 8th Ed.***).
  - Same language and integration
  - Familiar environment for the practitioner



Harmonization: ACI & CSA-CHBDC

- **Inputs** from existing guidelines/codes:
  - ***ACI 440.1R-15*** *"Guide for the Design and Construction of Structural Concrete Reinforced with Fiber Reinforced Polymer Bars"*
  - ***CSA S6-14*** **Section 16** *"Canadian Highway Bridge Design Code: Fibre-Reinforced Structures"*
- **Coordination** with next-edition (where possible)
  - ***ACI 440-19*** *"Building Code Requirements for Structural Concrete Reinforced with GFRP Bars"* (under dev.)
  - ***CSA S6-19*** **Section 16** *"Canadian Highway Bridge Design Code: Fibre Reinforced Structures"* (under dev.)

In-Depth Look at Key Features *(cont.)*

- **Key features**
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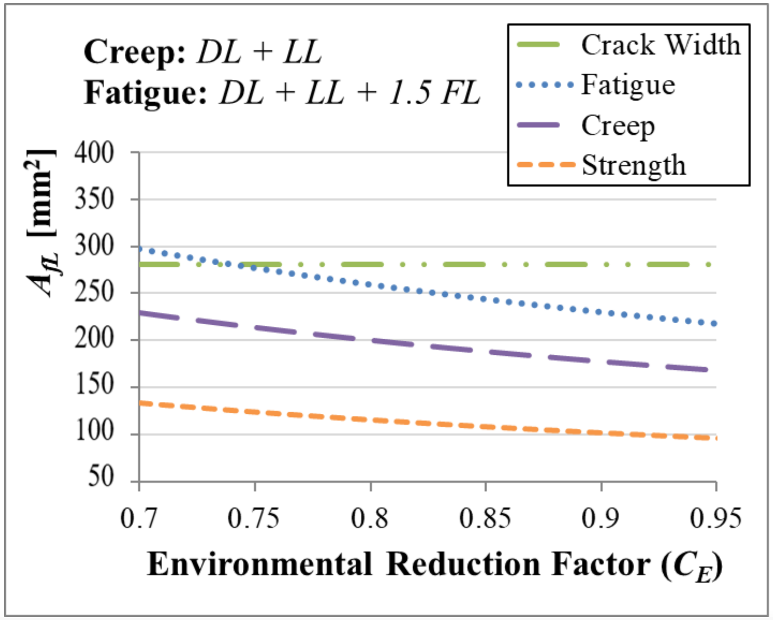
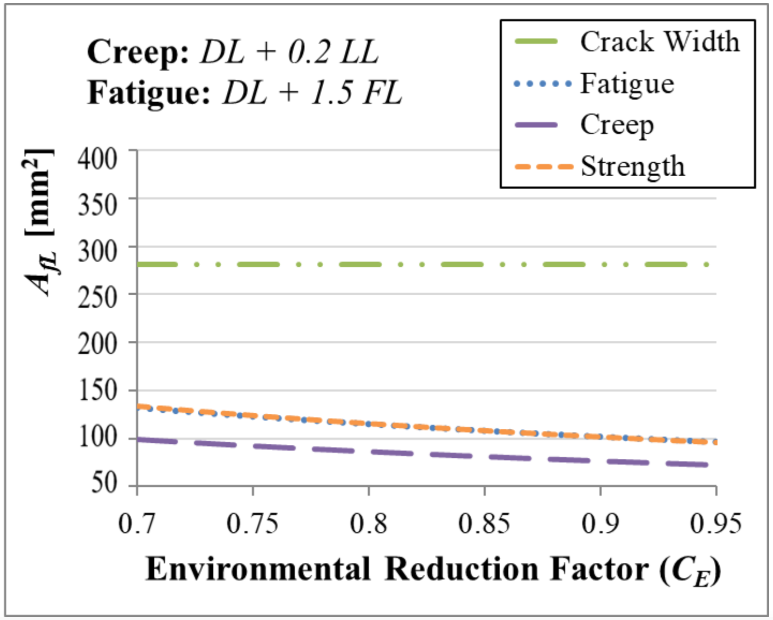
Update: Creep Rupture & Fatigue (Demand)

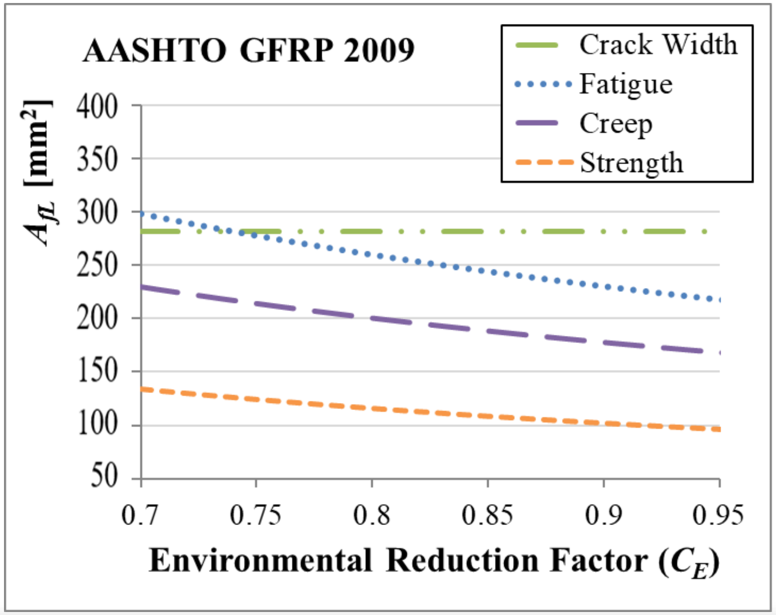
- Rationally defined creep rupture and fatigue load demands
- Only a portion of the **live load** considered **sustained load for creep rupture** calculations
- **Dead load** added to **fatigue load for cyclic fatigue** calculations. Accounts for static/cyclic fatigue coupling

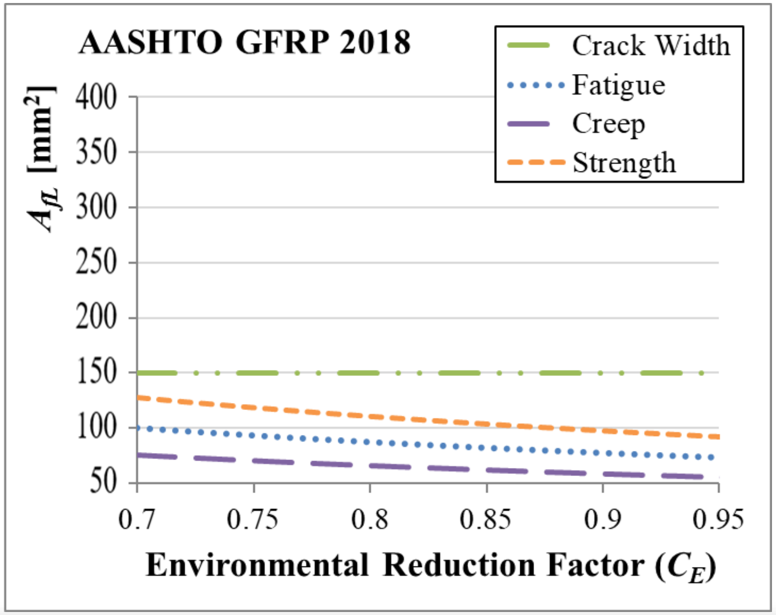




Update: Flexural Parameters (Resistance)

- Updates reflect performances of ***ASTM***-certified materials.
- **Flexural resistance Φ_C** aligned to ***AASHTO BDS-17*** (0.65 to **0.75**)
- **Creep C_c and fatigue C_f** separated and aligned to ***CSA-14*** (0.20 to **0.30**(3) & **0.25**)
- **Crack width *w*** limit aligned to ***ACI 440-19*** (0.5 to **0.7 mm**)





(3) *Changed 6/28/18 based on approved ballot version*

Update: Compression, Shear and Torsion

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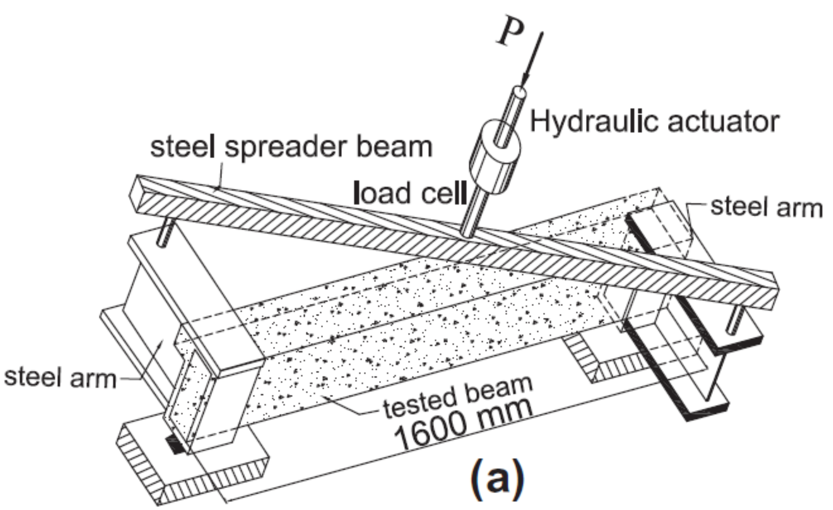
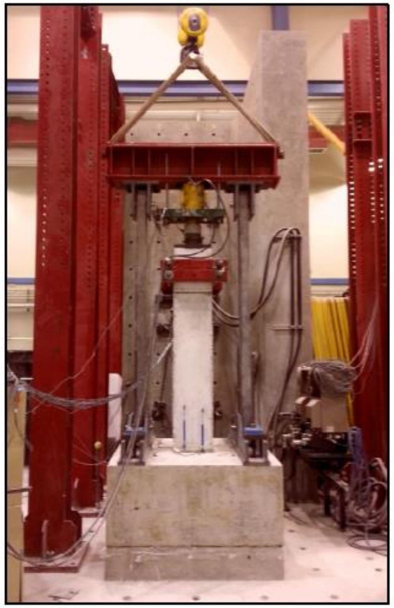
- Include **compression** and **torsion** for GFRP-RC.
- Design procedures **aligned to *BDS-17 (8th)* new format.** Variations limited to material properties and related parameters.
- Include all superstructure and substructure elements
- Harmonized with *ACI 440-**19*** Building Code under development





from Deifalla et al. (2013), Tobbi et al. (2012), Naqvi et al. (2017)

In-Depth Look at Key Features *(cont.)*

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Expand: GFRP-RC Footings

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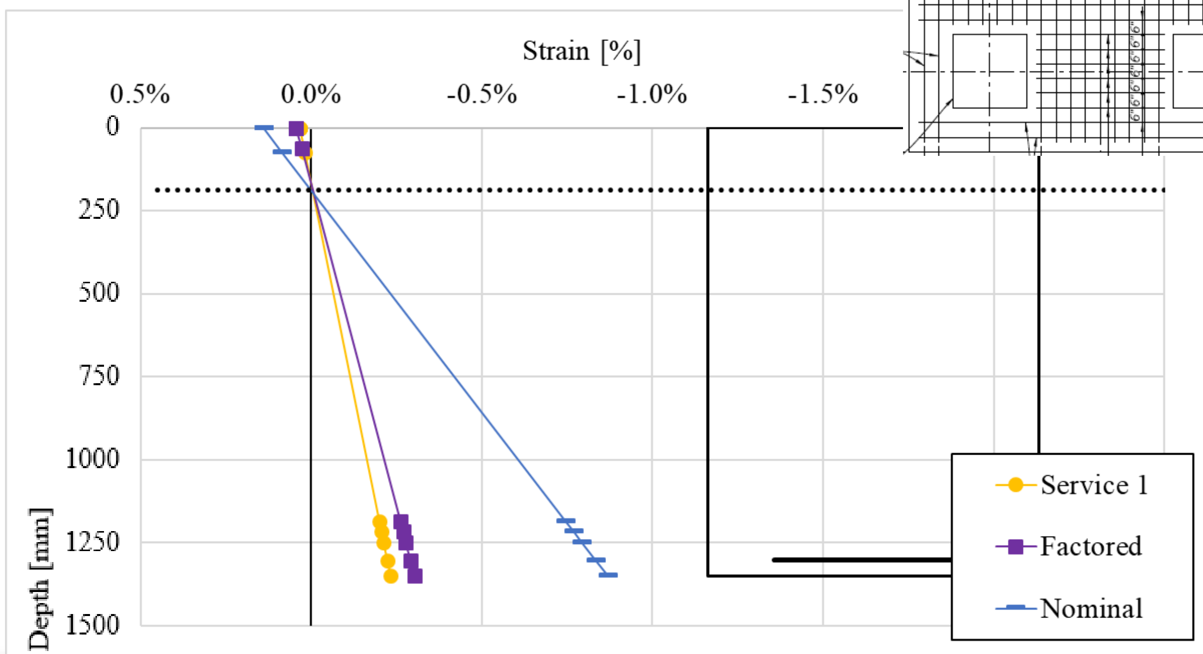
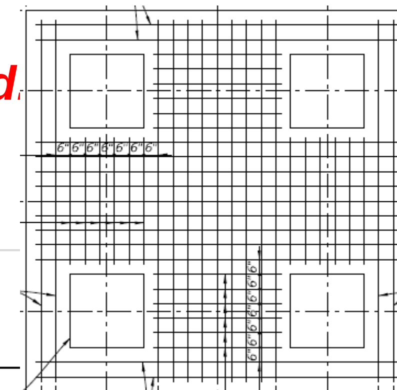
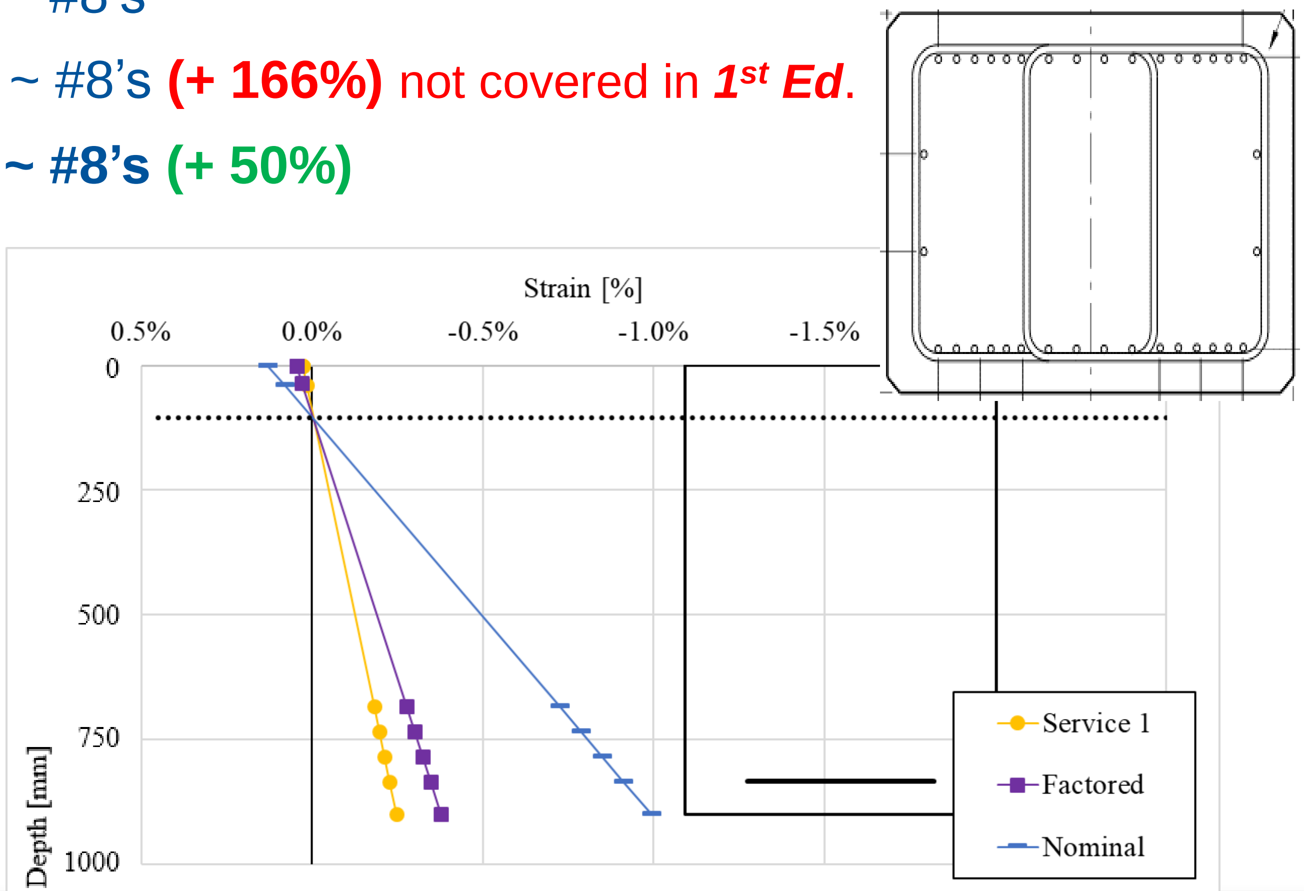
- Reference Project: ***SR 388 over Burnt Mill Creek Bridge***.
- Steel-RC 13 ~ #10's
- GFRP-RC-*1st* 26 ~ #10's **(+ 100%)** not covered in ***1st Ed.***
- **GFRP-RC-2nd 19 ~ #10's (+ 45%)**





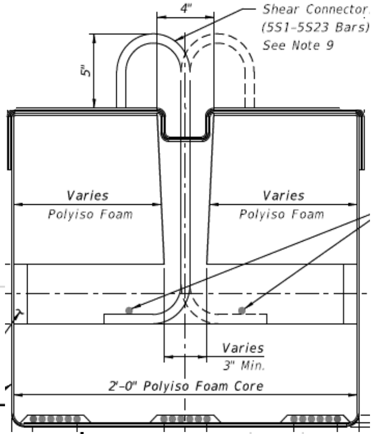
Expand: GFRP-RC Bent Cap

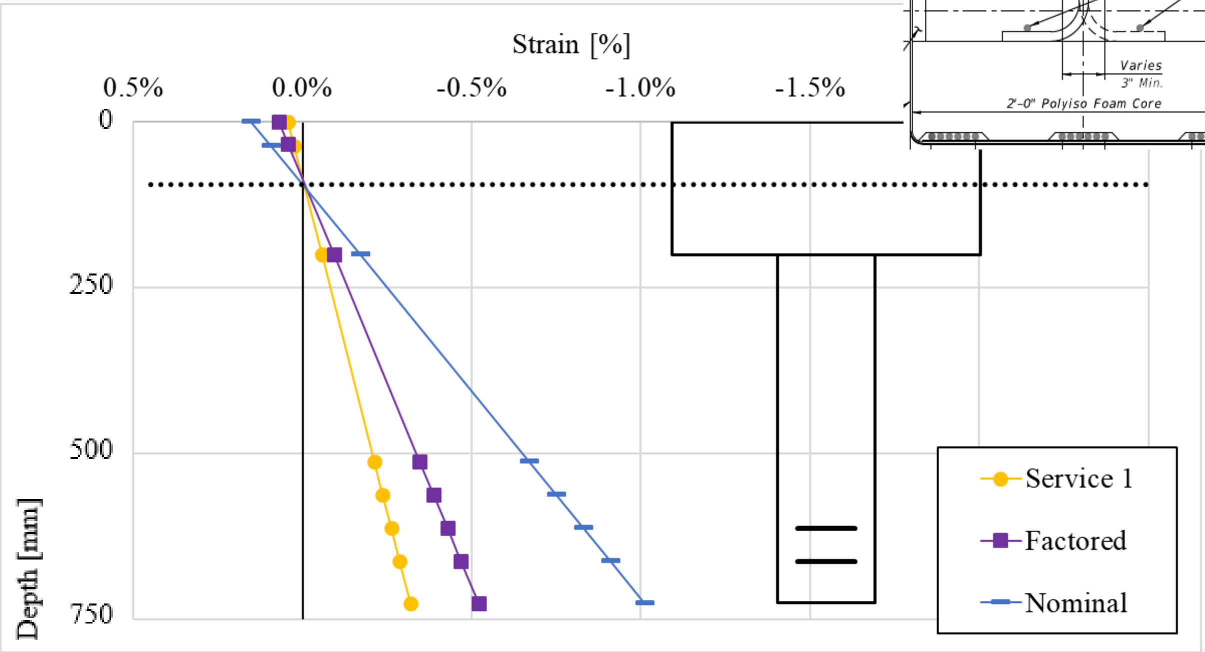
- Reference Project: ***Halls River Bridge Replacement***.
- Steel-RC 6 ~ #8's
- GFRP-RC-*1st* 16 ~ #8's **(+ 166%)** not covered in ***1st Ed***.
- **GFRP-RC-*2nd* 9 ~ #8's (+ 50%)**



Expand: GFRP-RC **Girders**

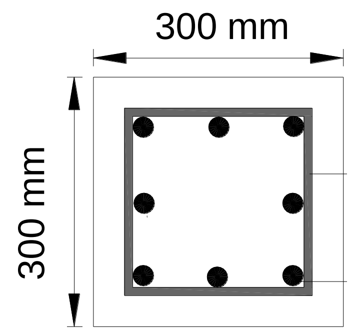
- Reference Project: ***Halls River Bridge Replacement***.
- Steel-RC 12 ~ #8's
- GFRP-RC-1st 32 ~ #8's **(+ 166%)** not covered in ***1st Ed.***
- **GFRP-RC-2nd 18 ~ #8's(+ 50%)**

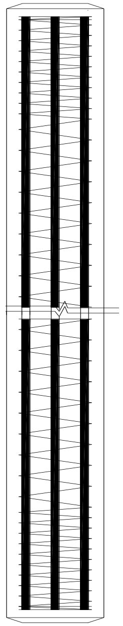


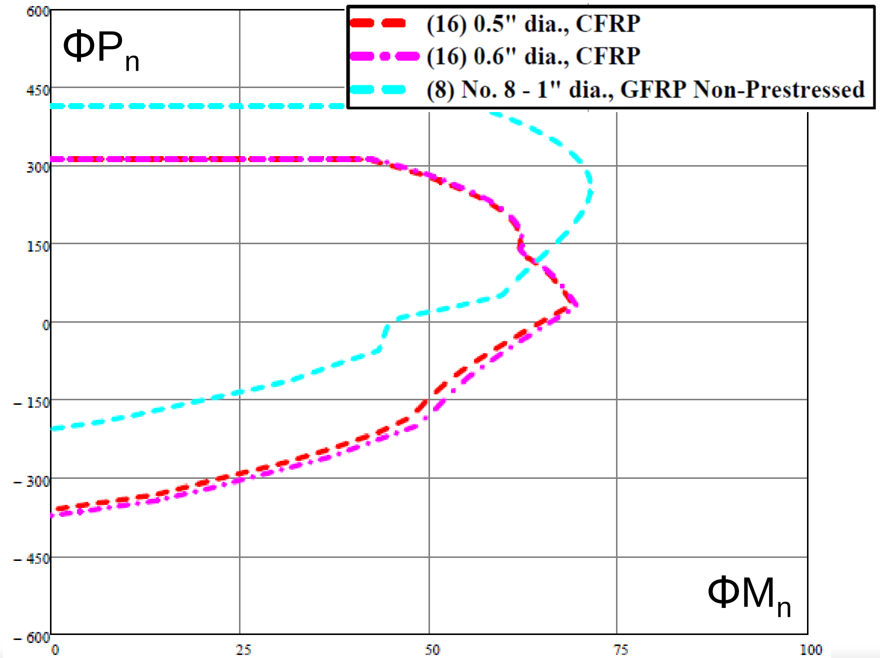


Expand: GFRP-RC Piles

- Reference Project: : ***iDock with Seacrete™***.
- Steel-RC 8 ~ #7's
- GFRP-RC-1st NA **not covered in 1st Ed.**
- **GFRP-RC-2nd 8 ~ #8's (+ 77%)**







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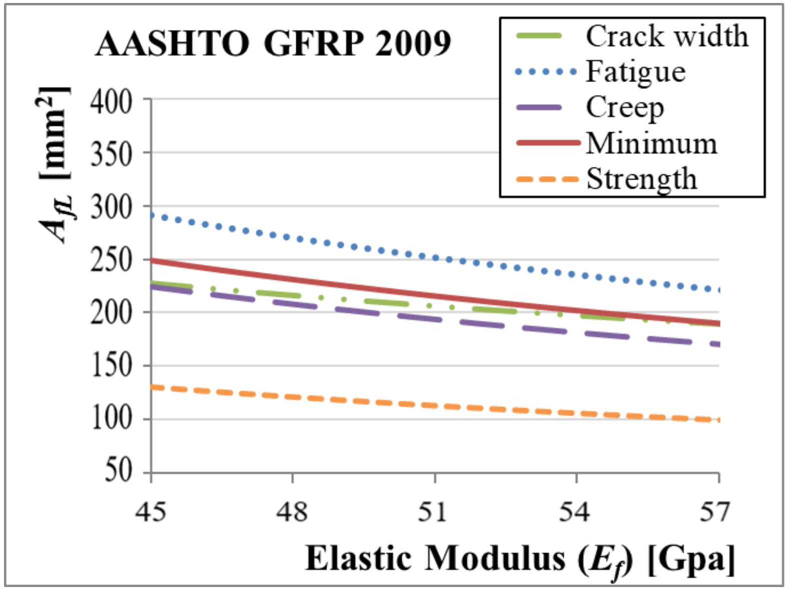
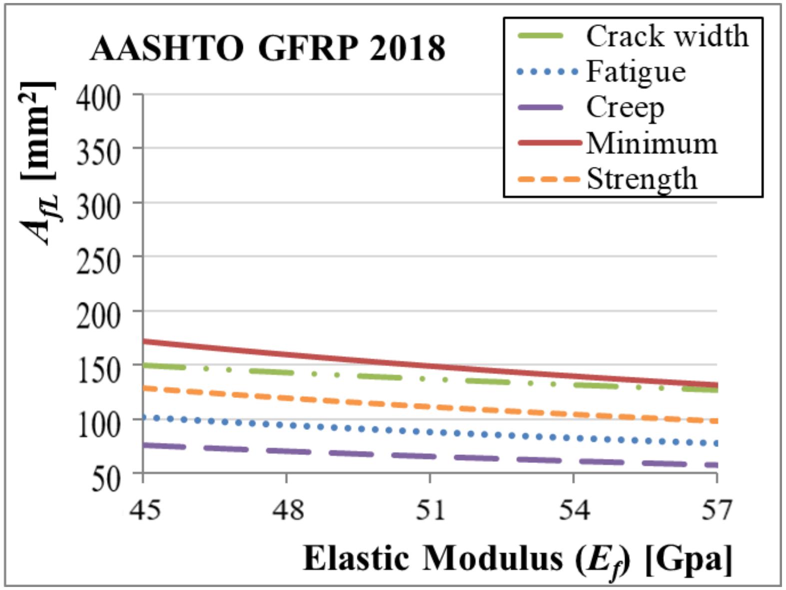
Challenge to Industry: Elastic Modulus

- Elastic modulus is a **game-changer**.
- Increment shall not come from mere sectional area enlargement.
- Need to operate within ***ASTM D7957-17*** boundaries.
- Improve **quality of the manufacturing** process to answer market demand: stiffness, bond performances, durability.





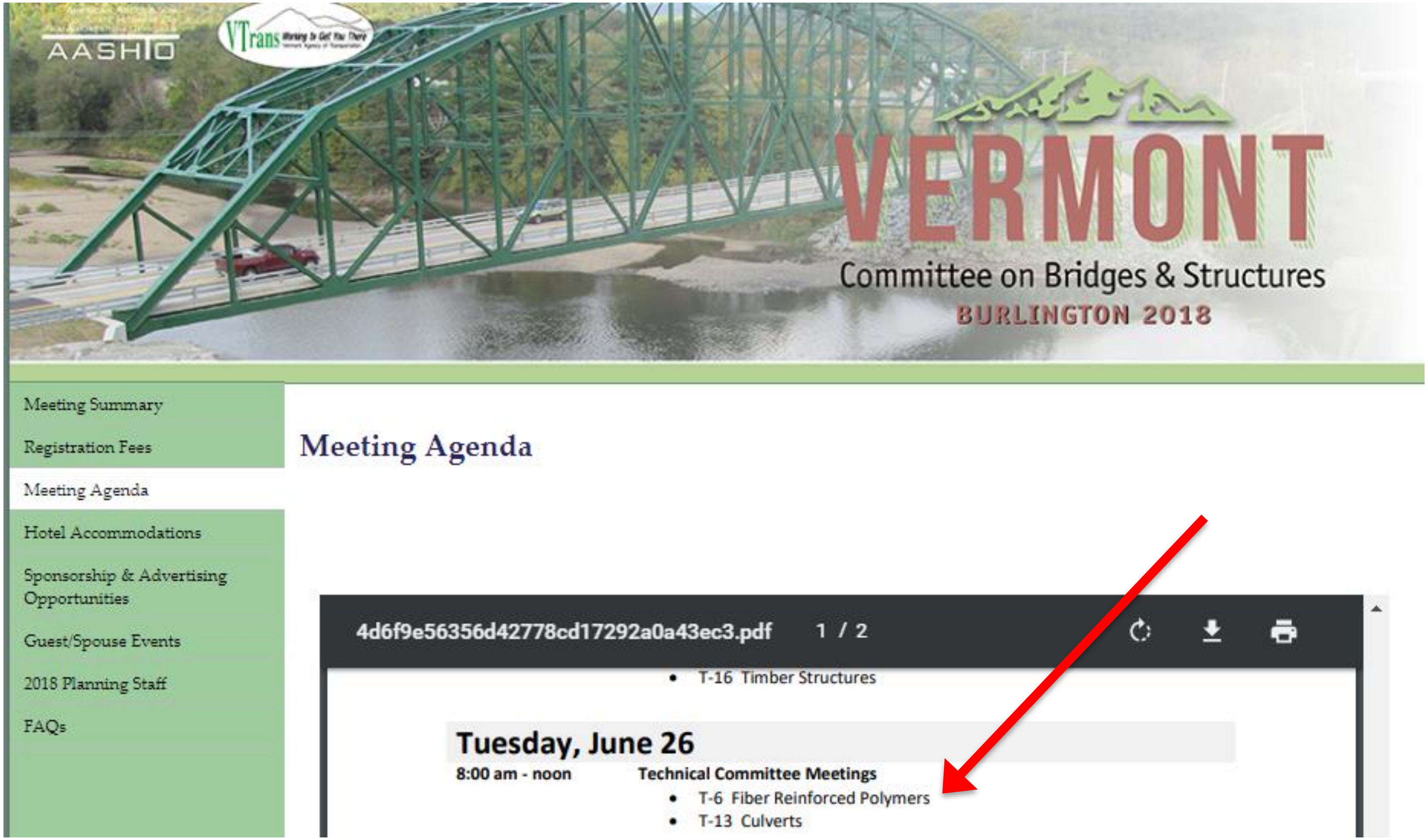
Conclusions

- New generation of FRP spec
- Less reinforcement required
- Fully integrated with BDS
- Covers all RC elements in a bridge

Dreaming is nice, but…

We need adoption
to make it real!!!

Conclusions: Defining moment!



Acknowledgements

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U. Miami (Chair)	**Antonio Nanni**
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U. Miami	**Marco Rossini**
TxDOT	**Tim E. Bradberry**
FHWA	**Jamal Elkaissi**
CalTrans	**Jim Gutierrez**
CT Contr.	**Mark Henderson**
FDOT	**Steven Nolan**
FDOT	**William Potter**

Questions?

Thank U !

FDOT