



THE INTERNATIONAL
BRIDGE CONFERENCE



MIAMI



UNIVERSITY OF
SOUTH CAROLINA



Bridge Design Guide Specifications for GFRP-RC

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

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



ENGINEERS' SOCIETY
of
WESTERN PENNSYLVANIA

- **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

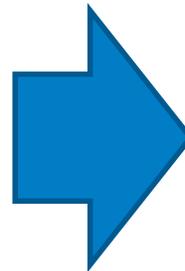
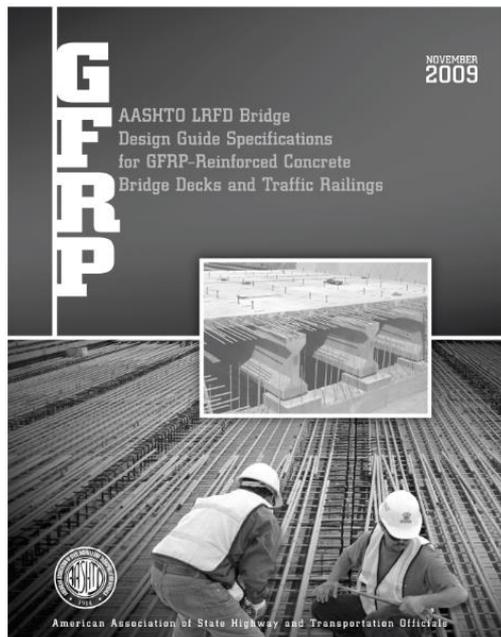
Approach and Relevance

- **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

- 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.



AASHTO LRFD **2018**
BRIDGE DESIGN GUIDE SPECIFICATIONS
FOR GFRP REINFORCED CONCRETE – 2ND
EDITION

TABLE OF CONTENTS

Section 1	INTRODUCTION	9
1.1	SCOPE	9
1.2	DEFINITIONS	9
1.3	LIMITATIONS	10
1.4	DESIGN PHILOSOPHY	10
1.5	REFERENCES	10
Section 2	CONCRETE STRUCTURES	13
2.1	SCOPE	13
2.2	DEFINITIONS	13
2.3	NOTATION	15
2.4	MATERIAL PROPERTIES	17
2.4.1	General	17
2.4.2	GFRP Reinforcing Bars	17
2.4.2.1	Tensile Strength and Strain	17
2.4.2.2	Modulus of Elasticity	18
2.5	LIMIT STATES AND DESIGN METHODOLOGIES	18
2.5.1	General	18
2.5.1.1	Limit-State Applicability	18
2.5.1.2	Design Methodologies	18
2.5.1.2.1	General	18
2.5.1.2.2	B-Regions	19
2.5.1.2.3	D-Regions	19
2.5.2	Service Limit State	19
2.5.3	Creep Rupture Limit State	19
2.5.4	Fatigue Limit State	20

Contents Comparison

Chapter/Section (AASHTO 2 nd)	AASHTO 2 nd 2018	AASHTO 1 st 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

Capacity provisions

$$f_{fd} = C_E f_{fu}^*$$

GFRP (long-term) Design Strength

$$M_r = \begin{cases} \Phi_C A_f f_f \left(d - \frac{0.8 x}{2} \right) & \varepsilon_c = \varepsilon_{cu} \\ \Phi_T A_f f_{fd} \left(d - \frac{0.8 x}{2} \right) & \varepsilon_c = \varepsilon_{fd} \end{cases}$$

Flexural Resistance

$$V_r = \Phi_S (V_c + V_f)$$

Shear Resistance

Serviceability provisions

$$f_{f,c} = C_c C_E f_{fu}$$

GFRP Creep Rupture Strength

$$f_{f,f} = C_f C_E f_{fu}$$

GFRP Fatigue Strength

$$s \leq 1.15 C_b \frac{E_f w}{f_f} - 2.5 C_c$$

Spacing for Crack Control

Comparison of **Critical** Design Parameters

	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	<i>Environmental reduction</i>
C_C	0.25 0.30 ⁽³⁾	0.20	0.20	0.25	<i>Creep rupture reduction</i>
C_f	0.25	0.20	0.20	0.25	<i>Fatigue reduction</i>
C_b	0.80	0.70	0.70	1.0	<i>Bond reduction</i>
w	0.28	0.20/0.28	0.28 to 0.20	0.2?	Crack width limit [in.]
$C_{C, stirrups}$	1.5	1.50	2.0 ⁽¹⁾	40	Clear cover [in.]
$C_{C, slab}$	1.0	0.75 to 2.0	0.75 to 2.0 ⁽¹⁾	40	Clear cover [in.]

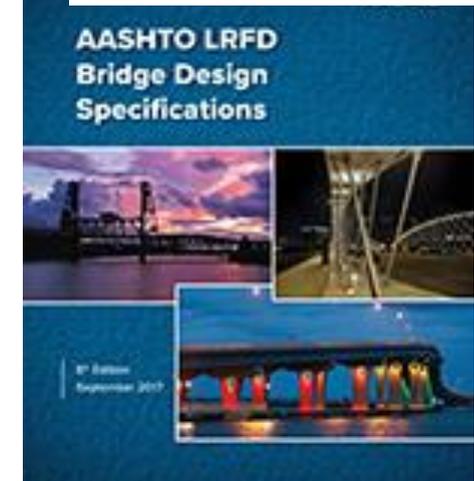
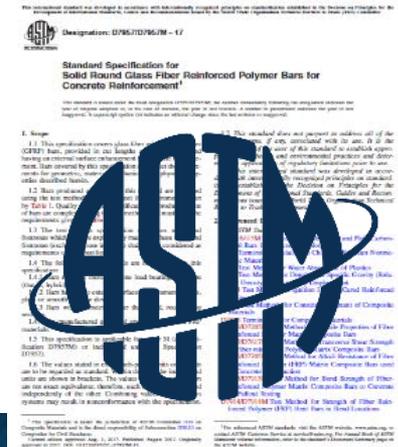
In-Depth Look at Key Features

- **Key features**
 - 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



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.)

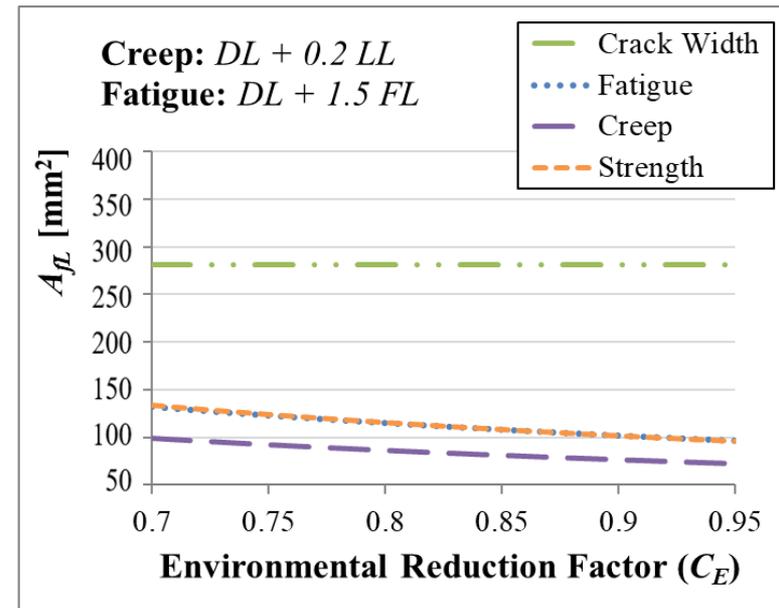
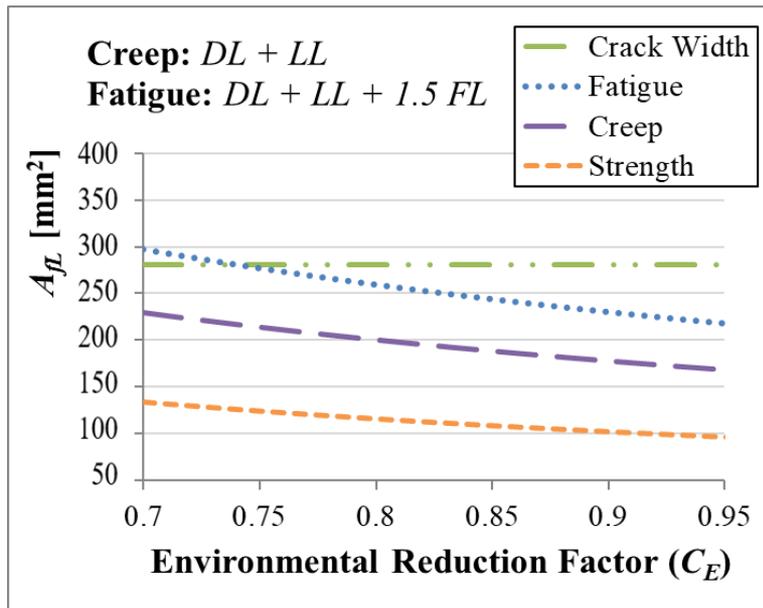


In-Depth Look at Key Features *(cont.)*

- **Key features**
 - 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

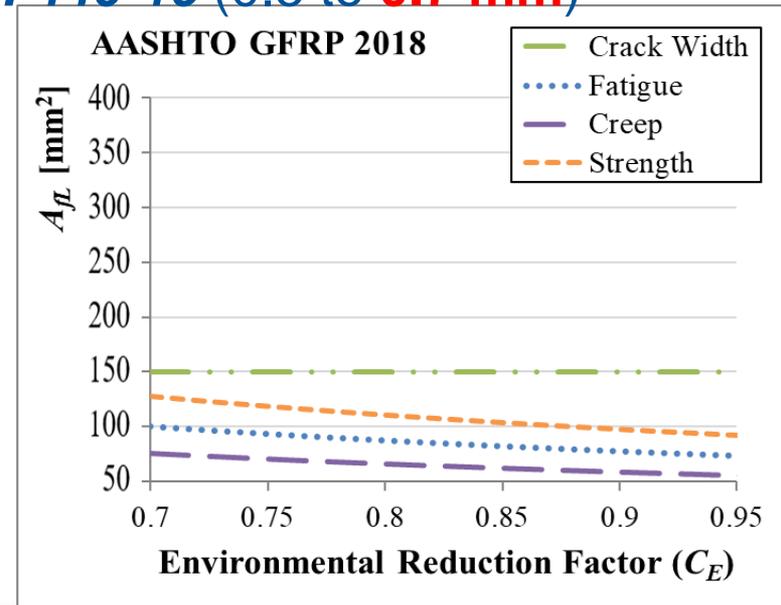
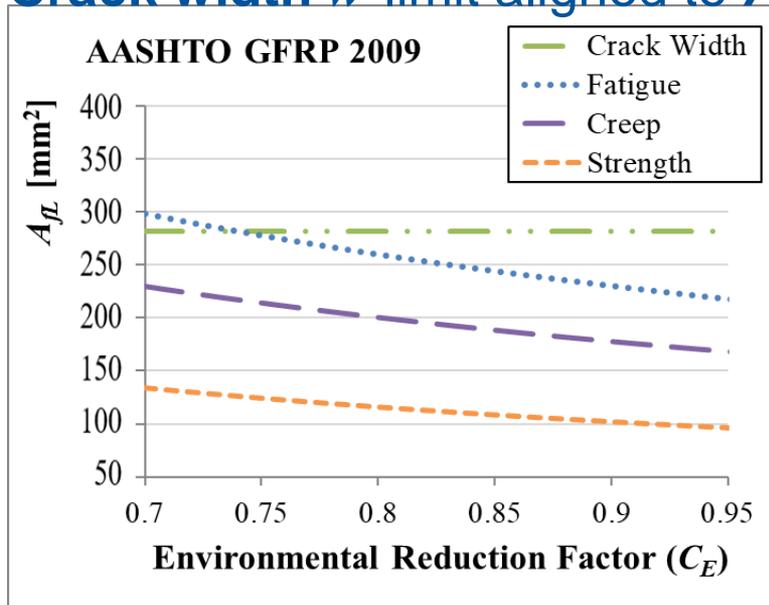
Update: Creep Rupture & Fatigue (**Demand**)

- 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**)

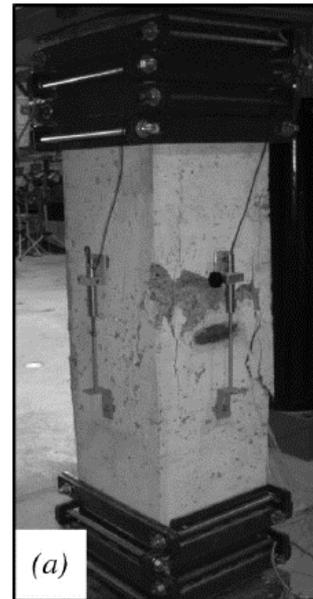
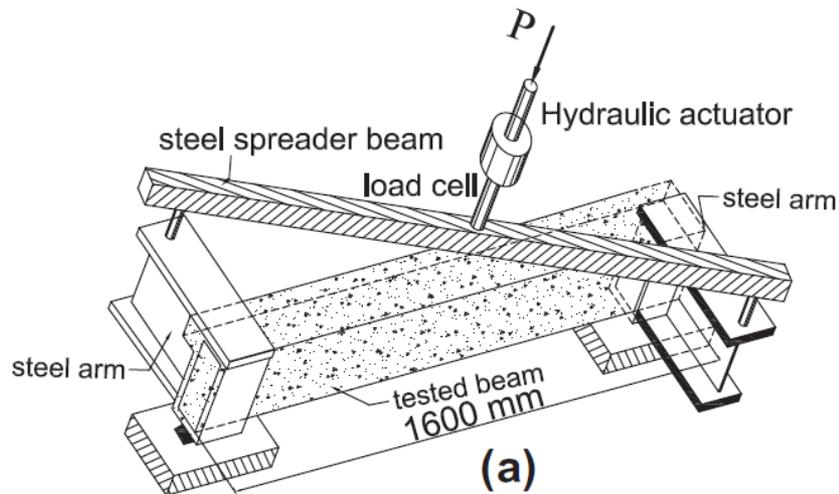
- Updates reflect performances of **ASTM**-certified materials.
- Flexural resistance Φ_c aligned to **AASHTO BDS-17** (0.65 to **0.75**)
- Creep C_c and fatigue C_f separated and aligned to **CSA-14** (0.20 to **0.30⁽³⁾** & **0.25**)
- Crack width w limit aligned to **ACI 440-19** (0.5 to **0.7 mm**)



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

Update: **Compression**, Shear and Torsion

- 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

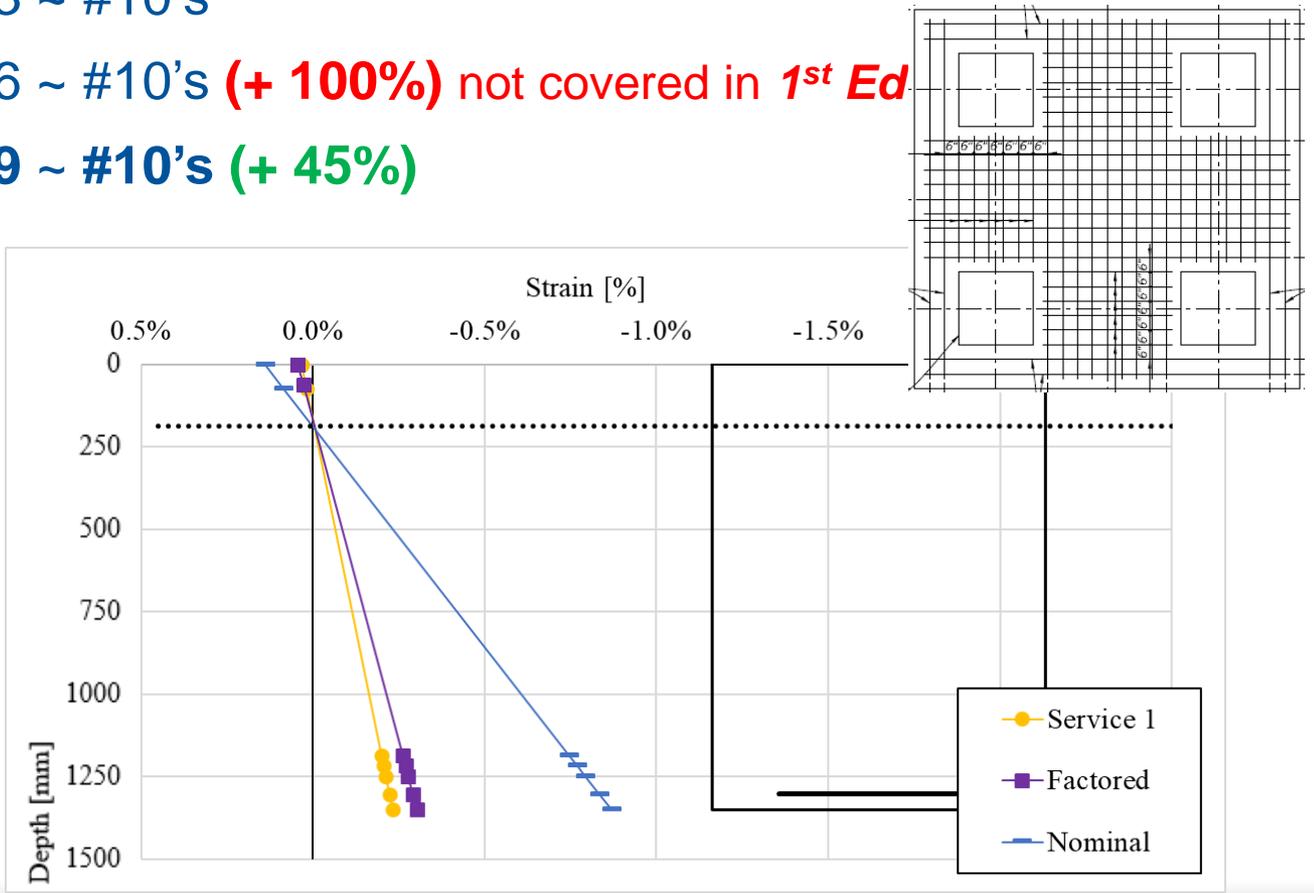


In-Depth Look at Key Features *(cont.)*

- **Key features**
 - 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

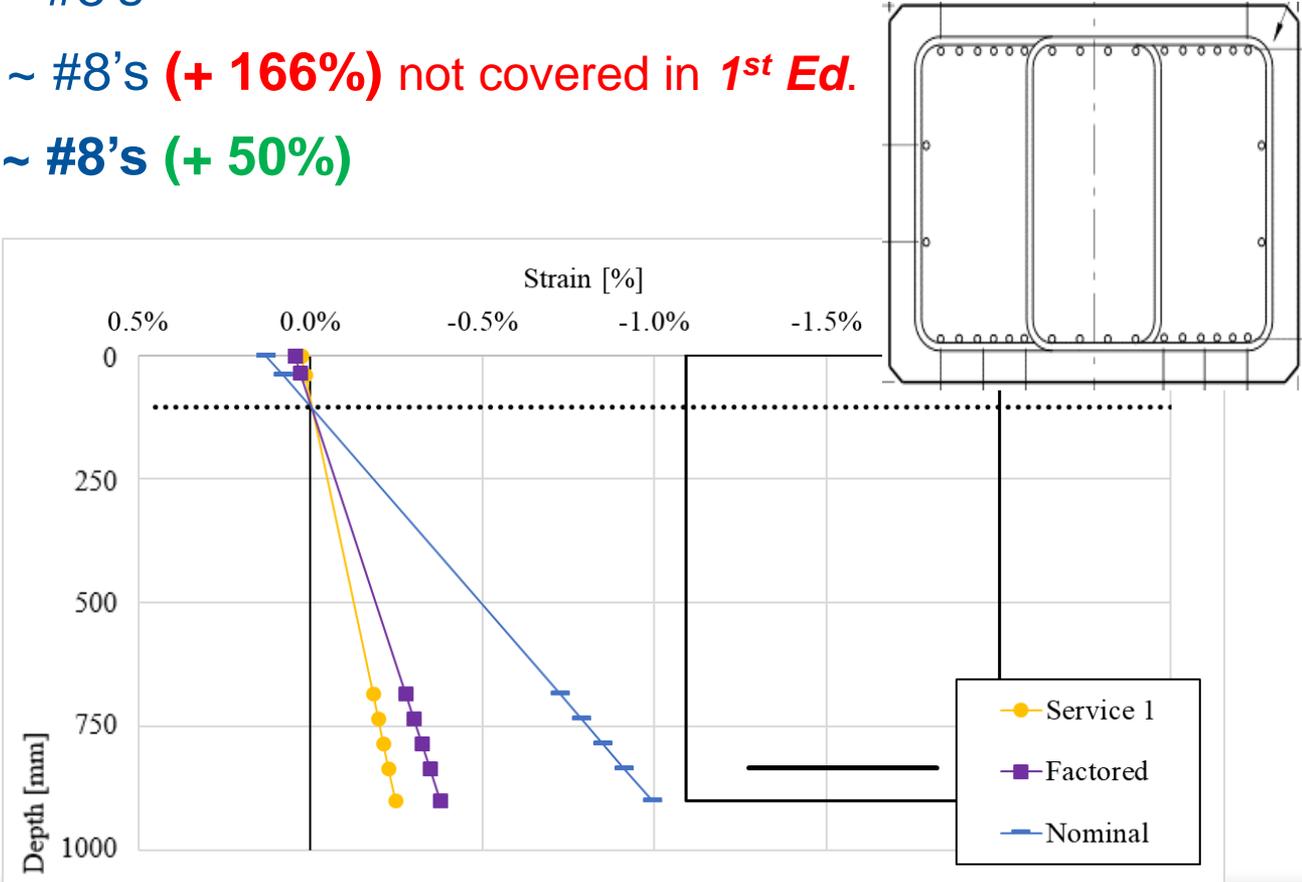
Expand: GFRP-RC Footings

- 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%)



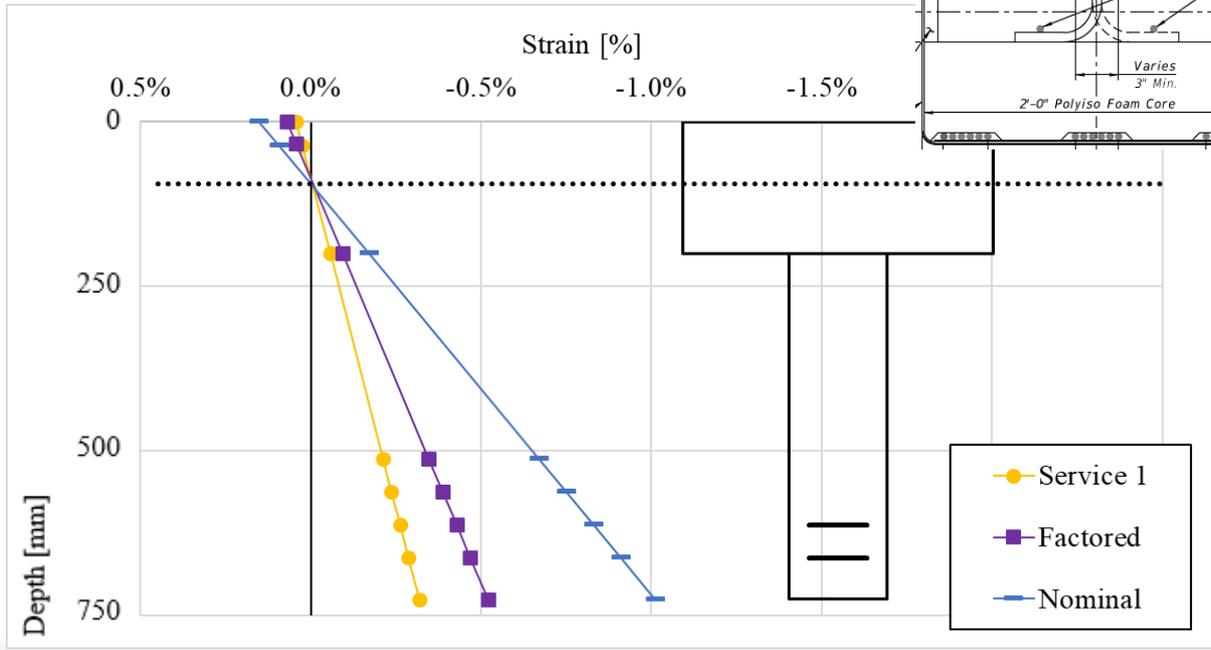
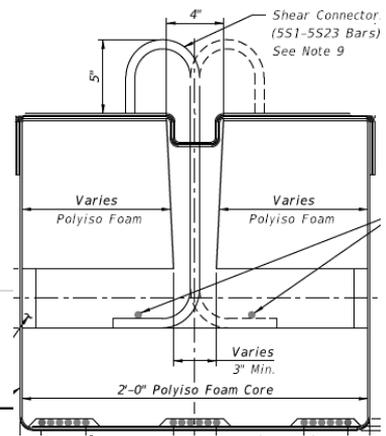
Expand: GFRP-RC Bent Cap

- 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%)



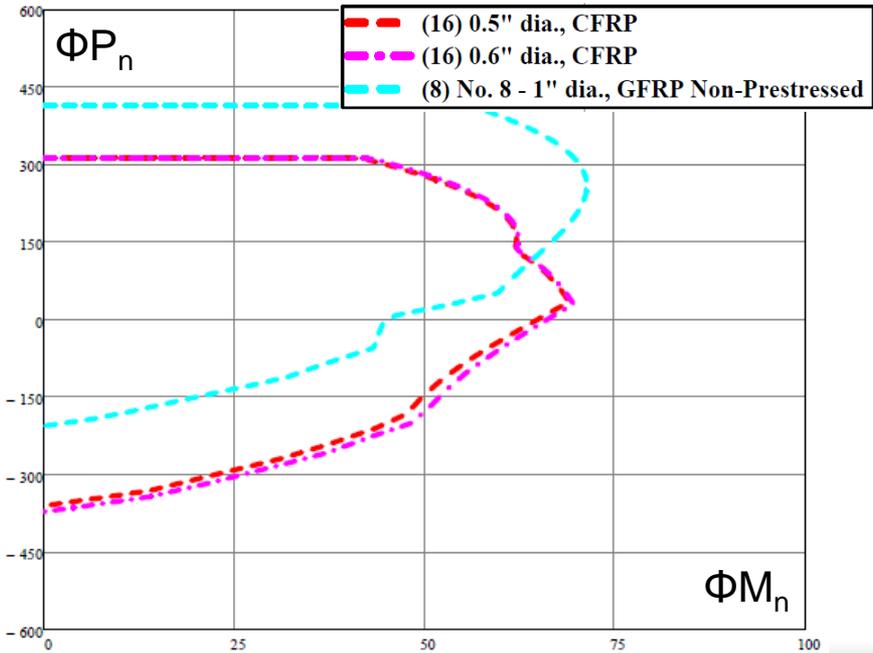
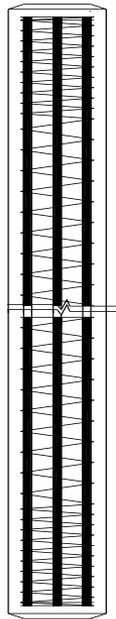
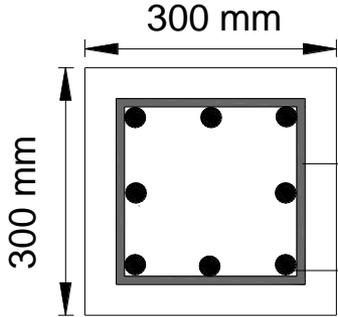
Expand: GFRP-RC Girders

- 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%)



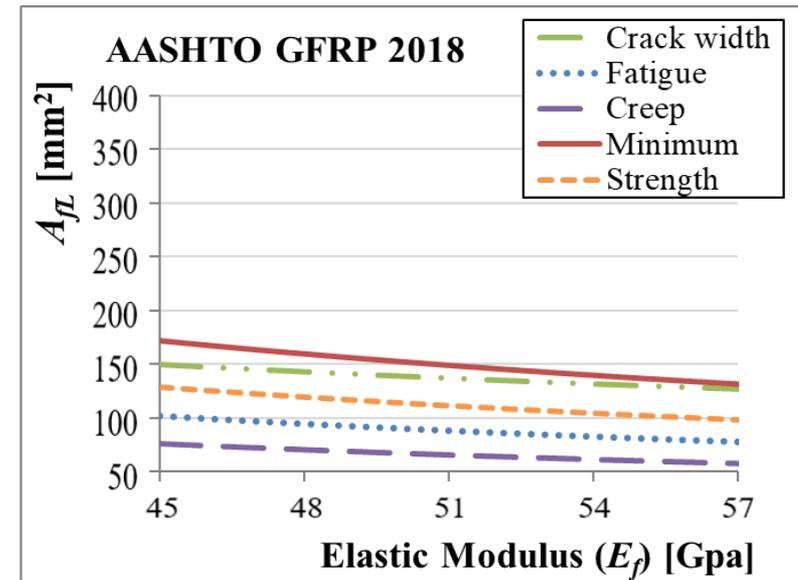
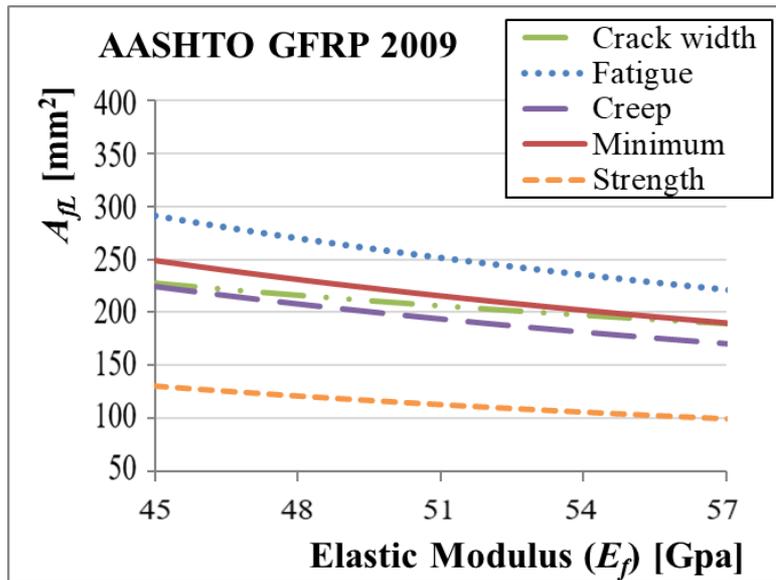
Expand: GFRP-RC Piles

- 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%)**



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!



AASHTO VTtrans Working to Get the Job Done
Vermont Committee on Bridges & Structures
BURLINGTON 2018

- Meeting Summary
- Registration Fees
- Meeting Agenda
- Hotel Accommodations
- Sponsorship & Advertising Opportunities
- Guest/Spouse Events
- 2018 Planning Staff
- FAQs

Meeting Agenda

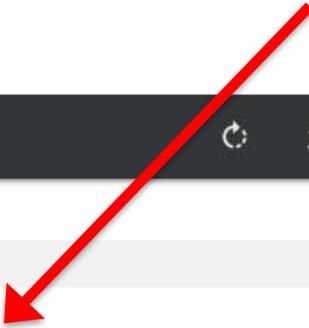
4d6f9e56356d42778cd17292a0a43ec3.pdf 1 / 2

- T-16 Timber Structures

Tuesday, June 26

8:00 am - noon **Technical Committee Meetings**

- T-6 Fiber Reinforced Polymers
- T-13 Culverts



Acknowledgements



BDGS-GFRP 2nd Ed. Taskforce:

U. Miami (Chair)

Antonio Nanni

U. South Carolina

Fabio Matta

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 **UJ**!

