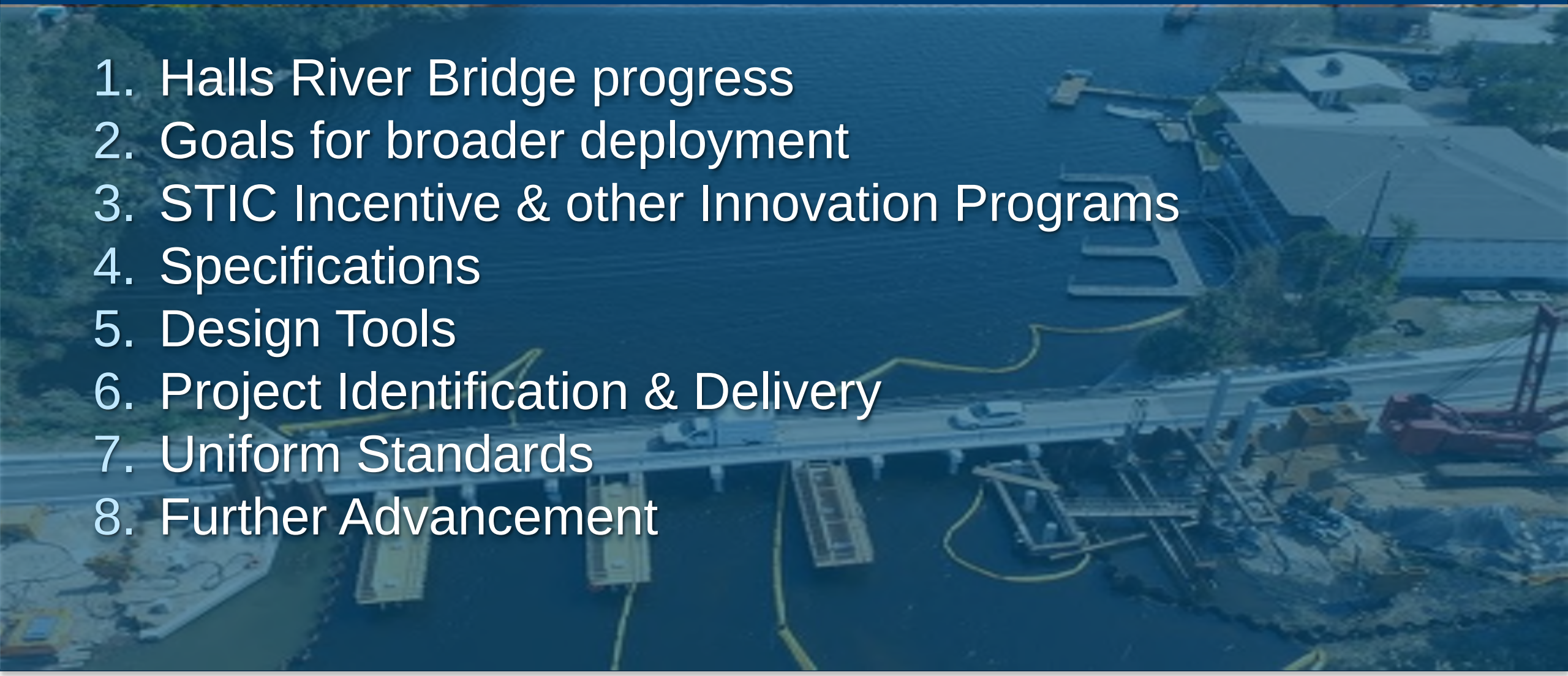
FDOT TRANSPORTATION SYMPOSIUM

FRP Beyond Halls River Bridge

(Invitation to Innovation for Infrastructure)

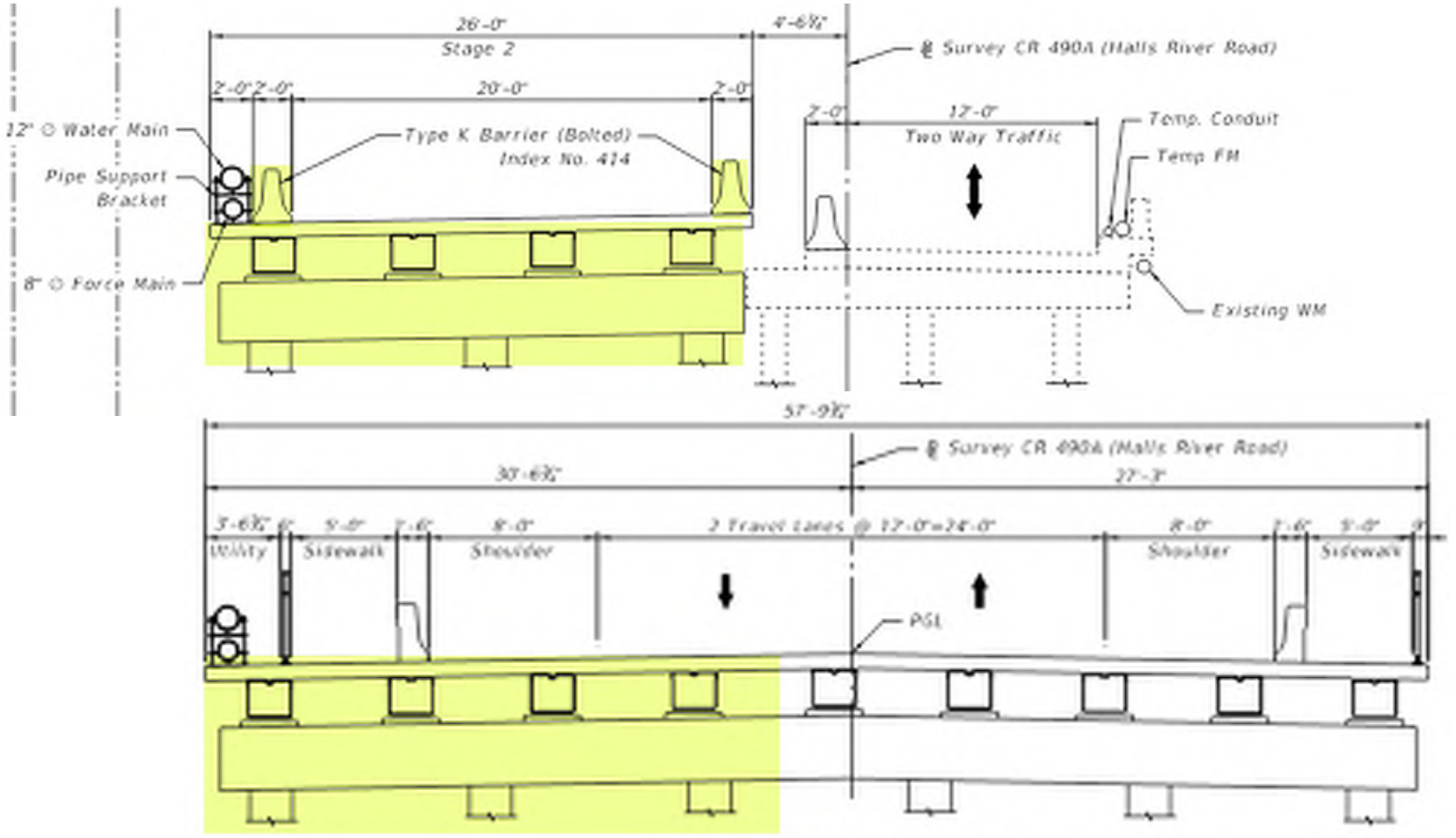
Steve Nolan, P.E. (State Structures Design Office)

Overview



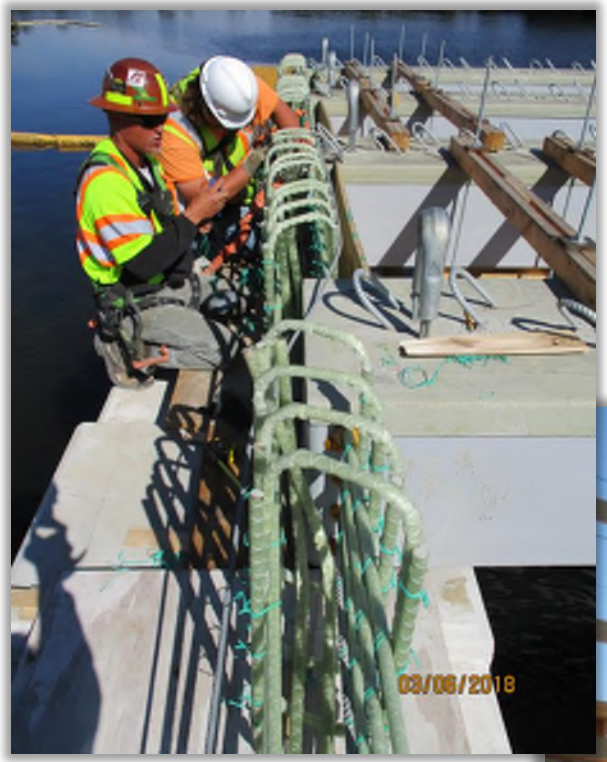
1. Halls River Bridge progress
2. Goals for broader deployment
3. STIC Incentive & other Innovation Programs
4. Specifications
5. Design Tools
6. Project Identification & Delivery
7. Uniform Standards
8. Further Advancement

Halls River Bridge progress



COMPLETED STRUCTURE

Halls River Bridge progress



Halls River Bridge challenges

Looking Beyond Halls River Bridge

FDOT's Fiber-Reinforced Polymer Deployment Train

- ???
- BFRP-RC
- Composite Bridge Girders
- GFRP-RC
- CFRP-PC
- Fender Systems
- External FRP Laminate Repairs

Goals for Broader Deployment

1. Stewardship
2. Confidence
3. Competency
4. Consistency
5. Codification

Goals for Broader Deployment

Top 5 Long-Term Goals

- **S**tewardship
- **C**onfidence
- **C**ompetency
- **C**onsistency
- **C**odification

FDOT

Participants/Collaborators

ACMA, pultron, TUF-BAR, MIAMI, UNF, UF

2018 FDOT-FRP Industry 2nd Winter Workshop

Safe Deployment of FRP-RC/PC for Structural Reinforcement

- Next Generation Infrastructure

(eliminating the threat of steel corrosion)

Strategic Workplan items

1. **Endurance Limits**
2. **Endurance Characteristic Curves and Testing**
3. **Establishing Consistency**
4. **Increasing Material Property Qualification Thresholds and Design Limits**
5. **Cost Estimating**
   a. OC initiative for ACMA FRP-RMC
   b. FDOT SDG Chapter 9 update
6. **Bar Bends**
   a. Complex Shapes
   b. FDOT Index D21310
7. **Minimum Bar Sizes for Design Elements**
8. **Life-Cycle Cost Guidance**
9. **Minimum Concrete Class**

http://www.fdot.gov/structures/Innovation/FDOT%202018%20Winter%20FRP-RC%20Workshop/Default.shtm

Goals for Broader Deployment

1. Stewardship

- Use FRP where it makes sense;
- Maximize material efficiency;
- Identify resources for exploitation.

Goals for Broader Deployment

1. Stewardship
2. **Confidence**
   - Build Stakeholder confidence;
   - Supply Chain security.

Goals for Broader Deployment

1. Stewardship
2. Confidence
3. **Competency**
   - Designer qualifications/training;
   - Design Tools
   - Contractor & Inspector guidance

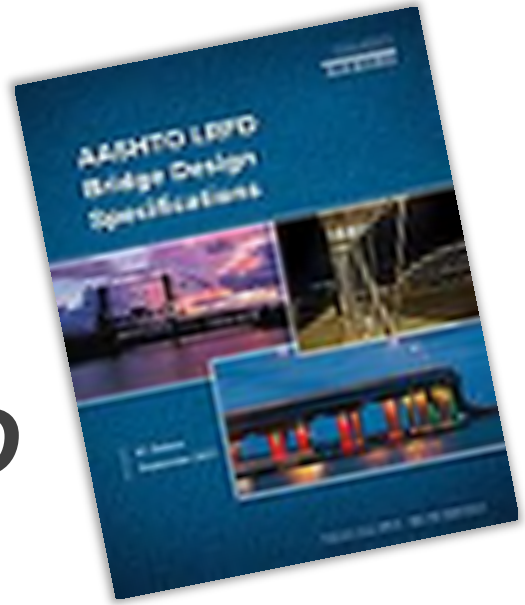
Goals for Broader Deployment

4. Consistency

- Material reliability;
- Encourage improved QC;
- Simplified verification testing;
- Bent Bar improvement and capabilities

Goals for Broader Deployment

4. Consistency
5. **Codification**
   - Establish "**Roadmap**" for ***AASHTO*** adoption;
   - Coordination with ***ACI 440***;
   - Coordination with international authoritative committees.



STIC Incentive Program
(Excellence Award Forward)

"America's highway community faces significant challenges: an aging infrastructure, growing traffic volumes and limited staffing and funding resources. Widespread use of innovation and enhanced business processes is essential to meeting customer needs and increasing the efficiency of project delivery.

Initiatives such as ***Every Day Counts***, the second ***Strategic Highway Research Program (SHRP2)*** Implementation Assistance Program, the ***AASHTO Innovation Initiative***, and others are designed to promote innovations and support the highway community in putting them into practice. Whether through training, workshops, demonstrations, technical assistance or incentive funding, the result of these initiatives is rapid technology transfer and accelerated deployment of innovation across the nation…"

https://www.fhwa.dot.gov/innovation/stic/2018_stic_excellence_award.pdf

STIC Incentive Program

What are these other initiatives ?

Every Day Counts (EDC):

FHWA: PBES → ABC, UHPC, *FRP-RC (proposed EDC-5)*

Strategic Highway Research Program (SHRP2):

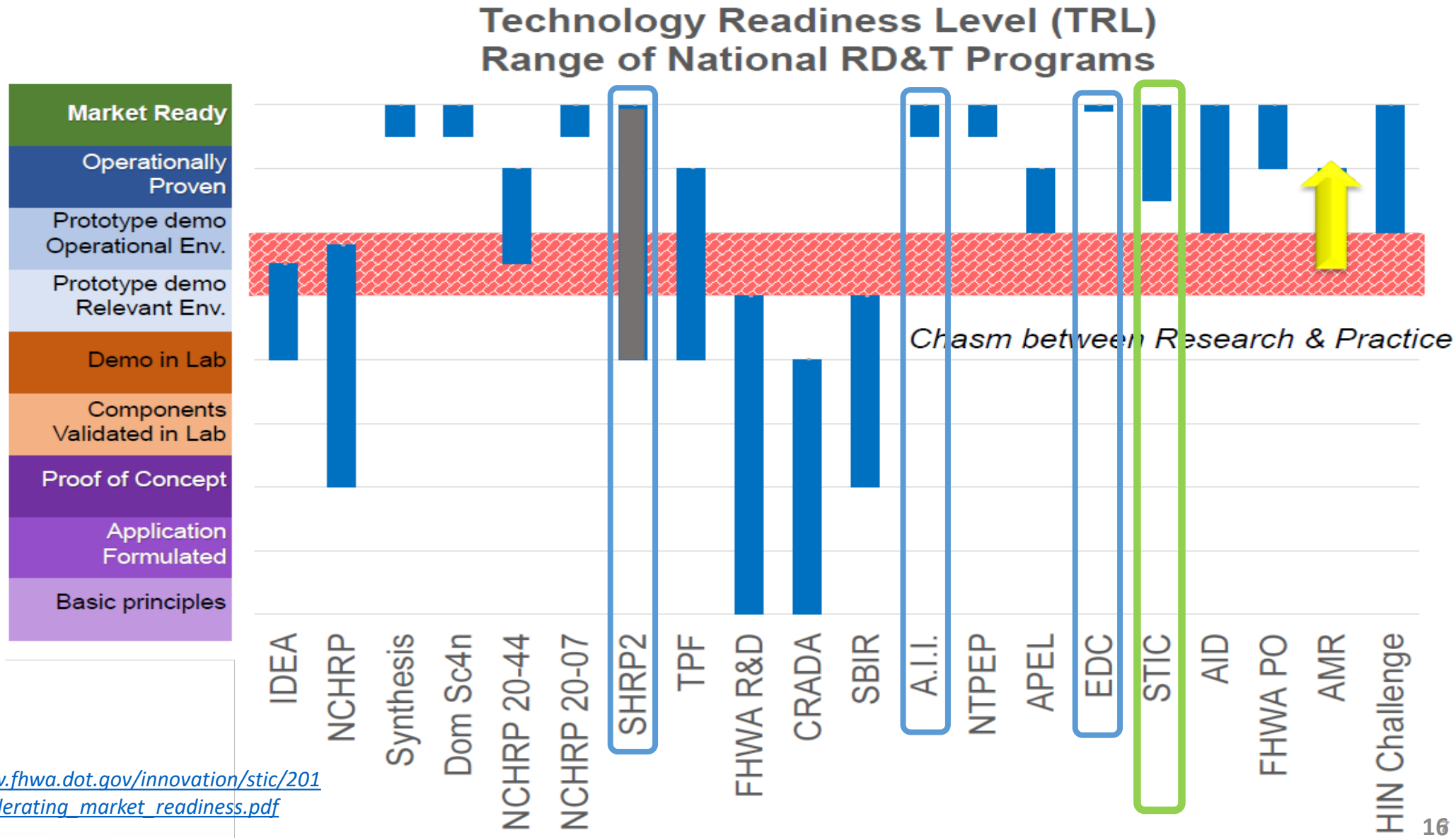
TRB, ***AASHTO*** & ***FHWA:*** Precast Substructures (R04 Toolkit)

Service Life Design for Bridges (R19A)

AASHTO Innovation Initiative (A.I.I):

AASHTO: Carbon Fiber-Reinforced Polymer Strands

STIC Incentive Program



Source:
https://www.fhwa.dot.gov/innovation/stic/20171019_accelerating_market_readiness.pdf

What's in these other Programs for FRP?

STIC Incentive Program

FHWA: Basalt FRP for Reinforced Concrete Standardization

Ideas Deserving of Exploratory Analysis (IDEA):

NCHRP (TRB & ***AASHTO):*** Glass FRP Prestressing Strand (MILDGLASS)

Innovative Bridge Research and Construction (IBRC):

FHWA (1998-2004): FRP Bridges are to be revisited and update report on status issued;

Innovative Bridge Research and Deployment (IBRD):

FHWA (2006-2017): US90 Quincy PBES Bent Caps (used SHRP2 Toolkit for guidence).

What's else is there…

FDOT Invitation to Innovation

FRP Reinforcing & Prestressing: Basalt, Carbon & Glass FRP Rebar; Carbon FRP Prestressing

FDOT Research:

Structures Research Program;

Materials Research Program

FDOT Collaboration Projects):

SEACON (2016-2018): Seawater Concrete and Chloride Contaminated Aggregate

Arthur Drive Bridge in Lynn Haven (2017): US90 Quincy PBES Bent Caps (used SHRP2 Toolkit for guidance)

What's else is there (cont.)…

FDOT Participation in national programs

AASHTO Committee on Bridge and Structures – T6 FRP

TRB AFF80 (Structural Reinforced Fiber Polymers)

FDOT Technical Advisory Groups:

Structures TAG;

Structures Advanced Materials TAG

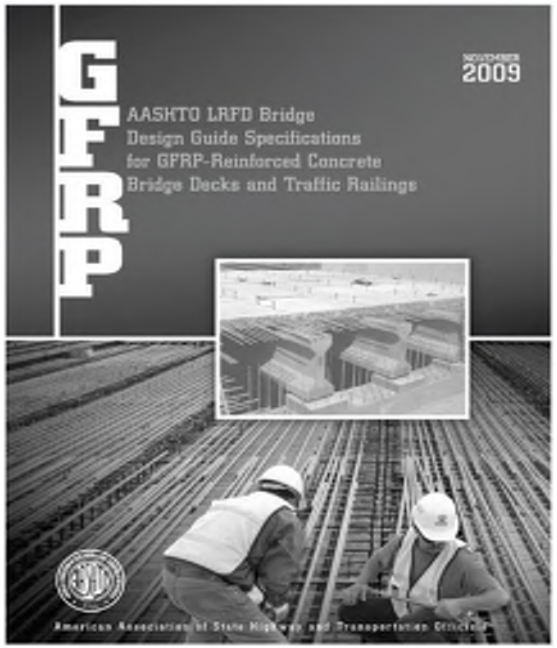
FDOT Projects, Standards & Specifications:

See FRP Design Innovation website:
http://www.fdot.gov/structures/innovation/FRP.shtm

Specifications - GFRP

Support update of *1st Edition* on decks and railings to complete *Bridge Design Guide Spec. (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

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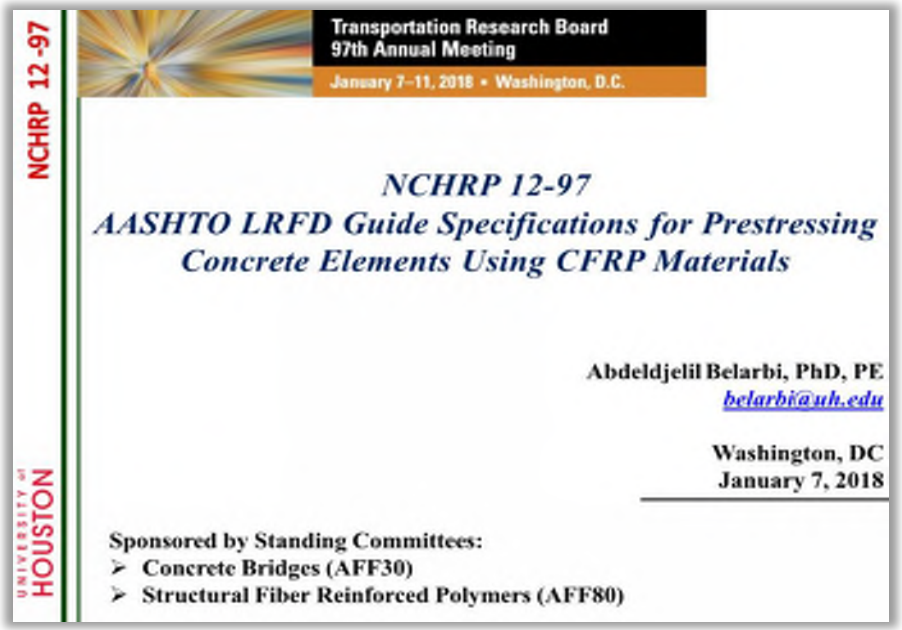
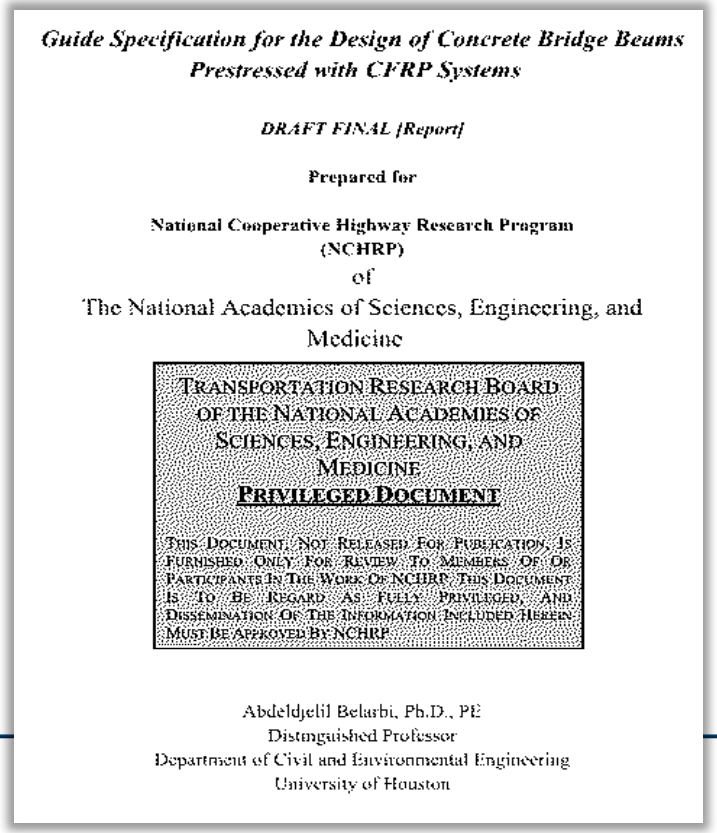
FDOT TRANSPORTATION SYMPOSIUM

Specifications - CFRP

***1st Edition* for pretressed concrete with FRP strands *Bridge Design Guide Specifications (BDGS-CFRP-PC)*.**

- **To be voted (06/26/2018) by AASHTO Committee T6 for adoption.**





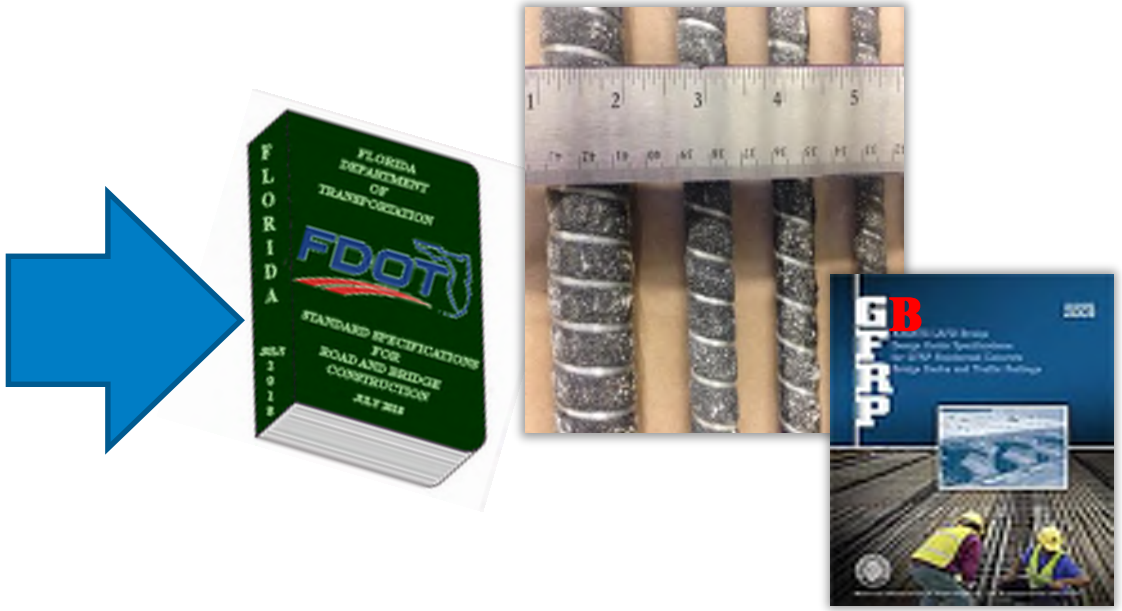
Specifications – BFRP

STIC Incentive Project – BFRP-RC Standardization

Fed. Project: STIC-004-A, (April 2018 - Dec 2019)

FDOT #443377-1; Research Project BDV30 986-01

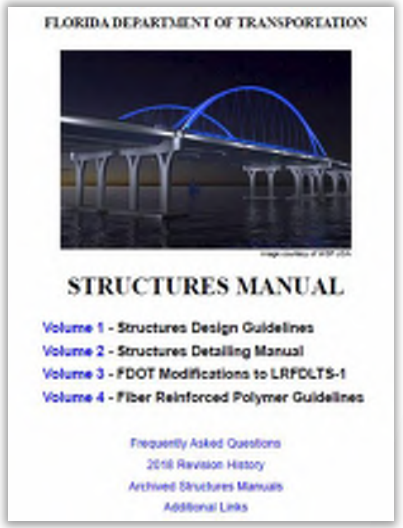
- Develop standard specifications for basalt fiber-reinforced polymer (BFRP) bars for the internal reinforcement of structural concrete.

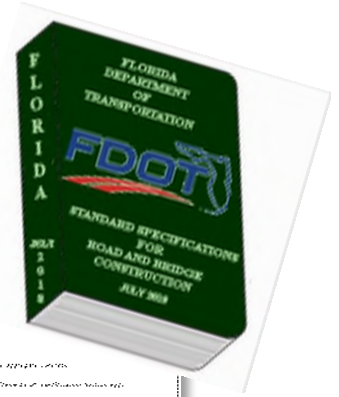


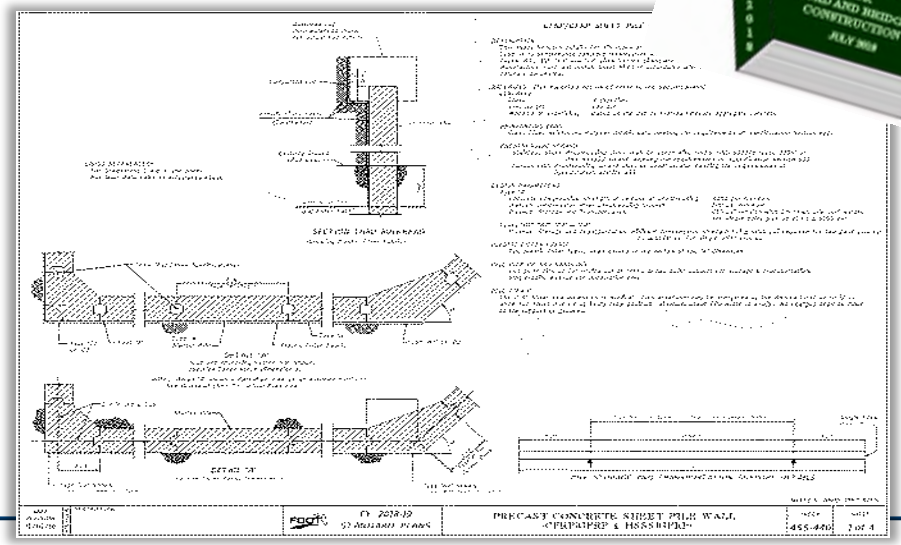
https://www.fhwa.dot.gov/innovation/stic/state_innovation.cfm

Specifications – FDOT stuff

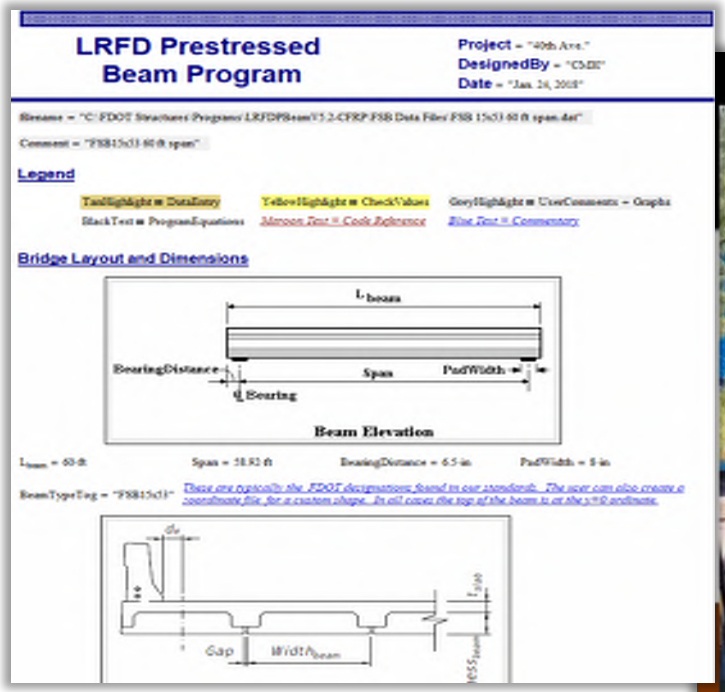
1. Structures Manual – Vol. 4 *(FRPG)*
2. Construction Specs. *(Division II)*
3. Materials Specs. *(Division III)*
4. Production Facility Approvals
5. Standard Plans (SP)
   - SP Instructions (SPI)

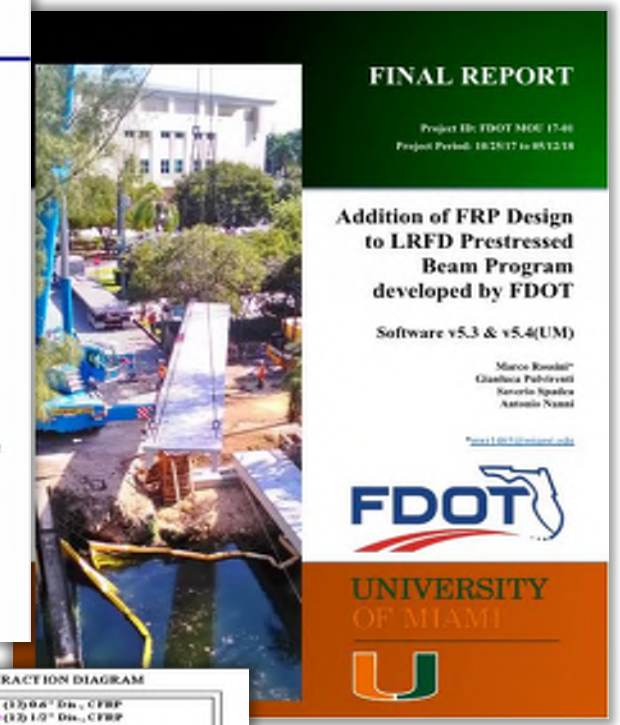


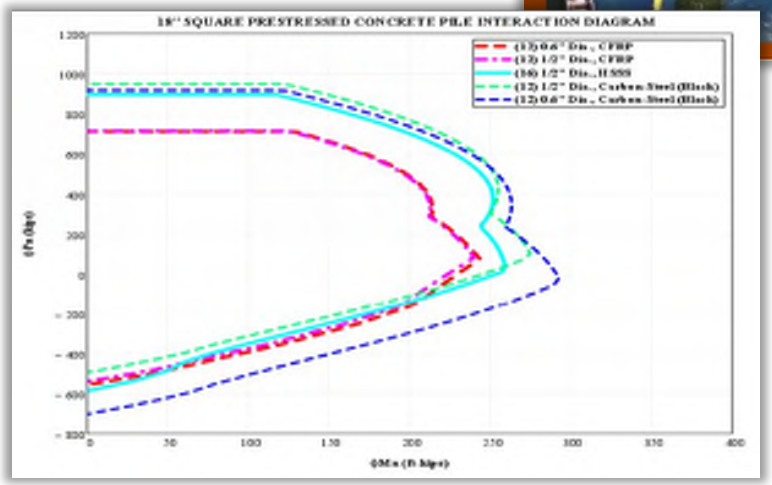




Design Tools - FDOT stuff

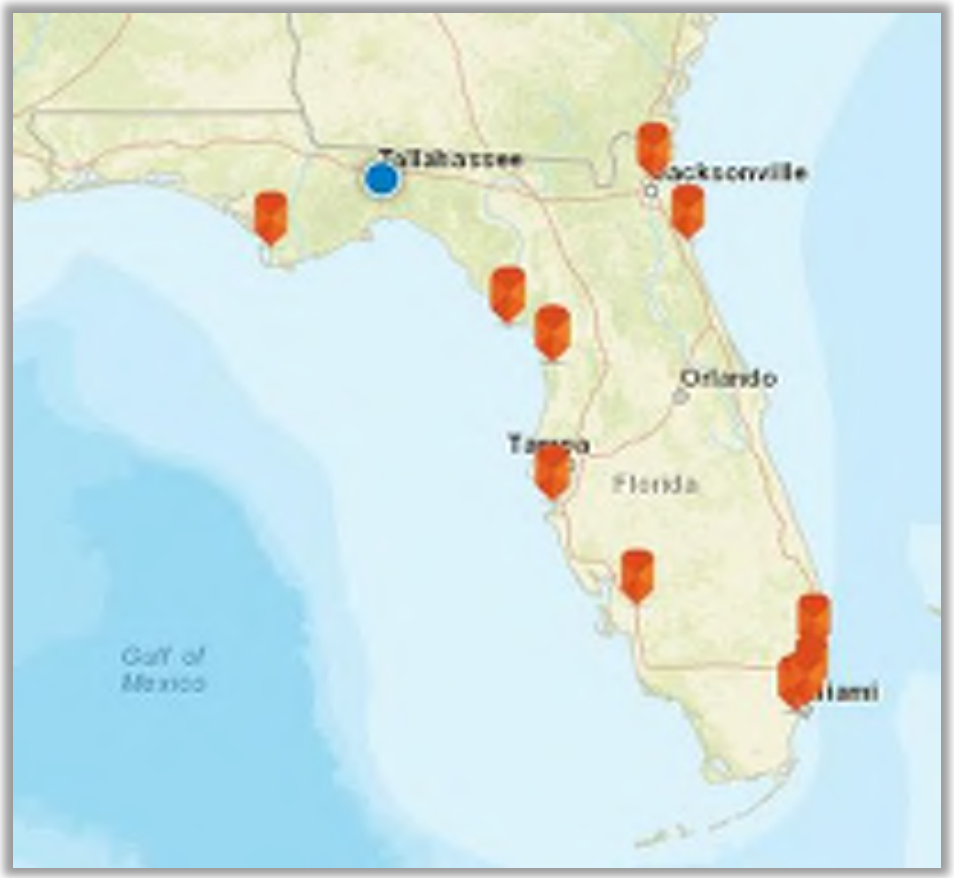






1. **Design Programs**
   - CFRP-PC Beams
   - GFRP-RC Flat-Slab
   - GFRP-RC Bent Cap
   - *Retaining Walls soon!*
2. ***SPI* "Design Aids"**
3. **Project GIS-Map App.**
4. **Under development**
   - LCC Analysis Guidance
   - Cost Estimating Guidance

Design Tools – GIS-Mapping



1. **Currently includes:**
   - Active and Completed FRP-RC/PC projects;
2. **Plans to add:**
   - Bridge beam repair/ strengthening projects (20+ year history of wet-layup repairs)
   - FRP-Fender Systems
   - HSSS projects

https://fldot.sharepoint.com/sites/FDOT-Design/Structures/SpecialProjects/Lists/FRP%20Rebar%20Project/AllItems.aspx

Project Identification & Delivery

1. **Environment Driven**
   - Durability/Magnetic Transparency/LCC
2. **Optional precast alternatives**
   - Encourage stakeholder buy-in
3. **Desire for multiple suppliers**
   - Redundancy & Supply chain security
4. **Simplify design process/workflow**
5. **Minimize change for Contractors**
   - Business as usual…almost

Uniform Standards

- ***BDGS-GFRP 2nd Ed.*** refers to ***ASTM D7957-17*** for material specifications
  - Only vinylester 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

Uniform Standards (cont.)

- **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.)

Uniform Advancement

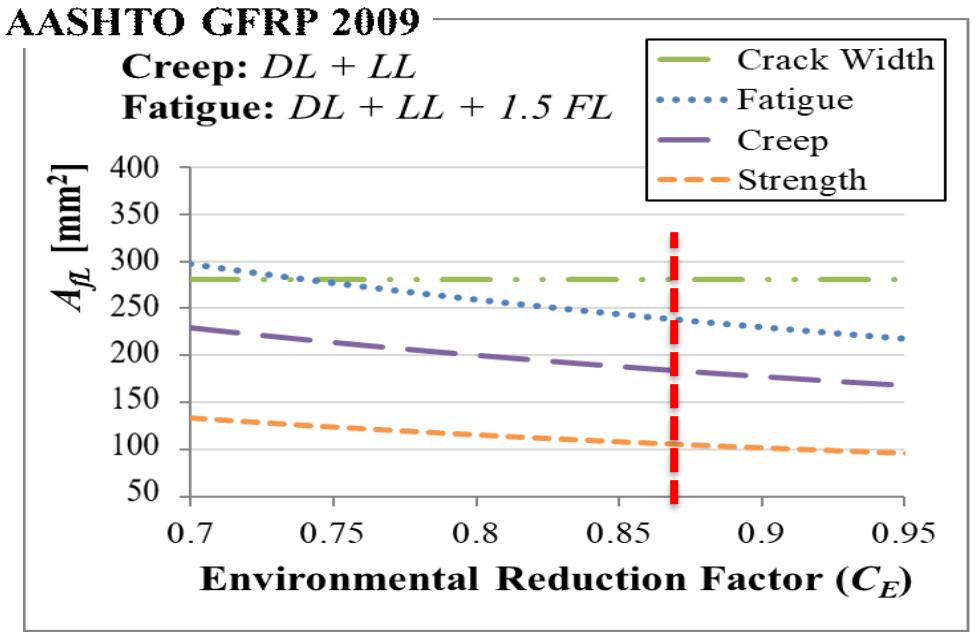
	AASHTO 2nd 2018	AASHTO 1st 2009	ACI 440.1R 2015	CSA 2014	
f_{fu}^*	99.73	99.73	99.73	**95.0** (2)	Strength percentile
Φ_C	**0.75**	**0.65**	0.65	0.75	Res. Fact. concr. failure
Φ_T	0.55	0.55	0.55	0.55	Res. Fact. FRP failure
Φ_S	0.75	0.75	0.75	0.75	Res. Fact. shear failure
C_E	0.70	0.70	0.70	**1.0**	*Environmental reduction*
C_C	**0.25**	**0.20**	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	**0.28**	**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.]

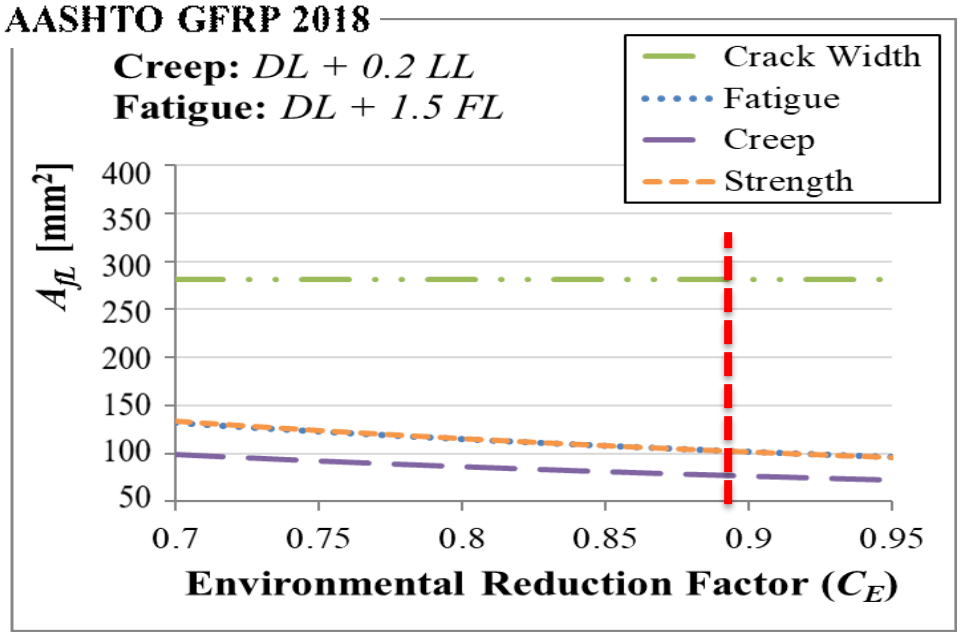
(1) ACI 440.5-08 Table 3.1; (2) Characteristic Strength

Advancement

2nd Ed. updates reflect:

- Rationally defined creep rupture and fatigue load demands
- Separated ***Creep*** C_c and ***Fatigue*** C_f and aligned to *CSA-14* (0.20 to 0.25) – ***Now we need to additional study to improve these still conservative limits!***





Advancement (cont.)

2nd Ed. updates reflect:

- Performances of ***ASTM***-certified materials and increase **Compression-Controlled** Flexural Resistance Φ_C aligned to ***AASHTO BDS-17*** (0.65 to **0.75**);

Now need to:

1. *Rationally increase **Tension-Controlled** Flexural Resistance **Φ_t (0.55 to 0.75 ?)**, and*
2. *Increase **Elastic Modulus…***

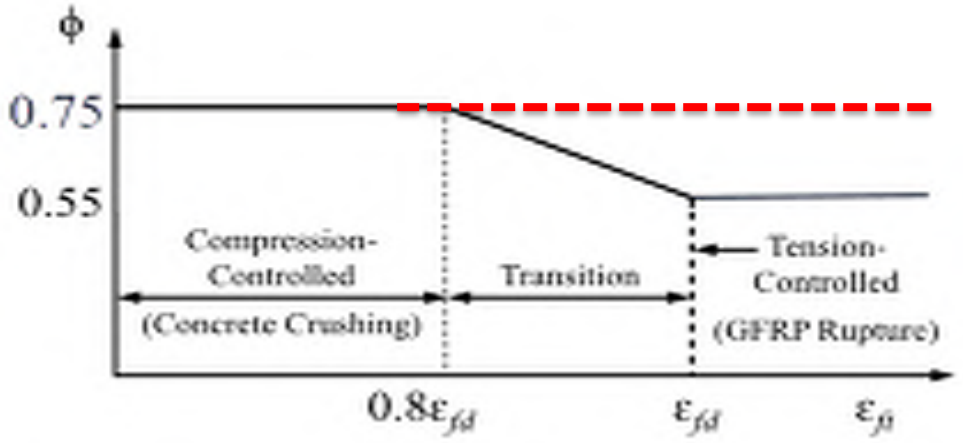
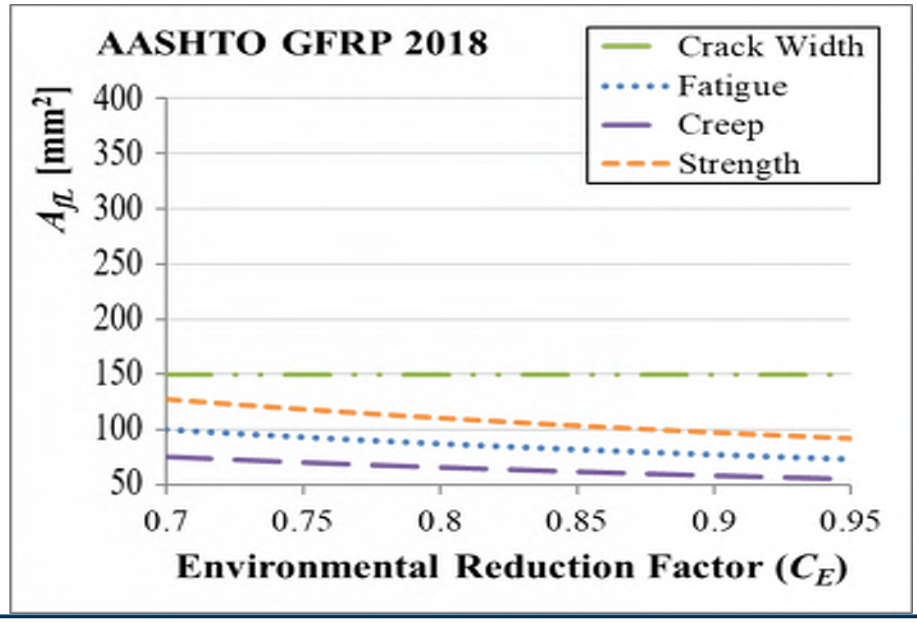
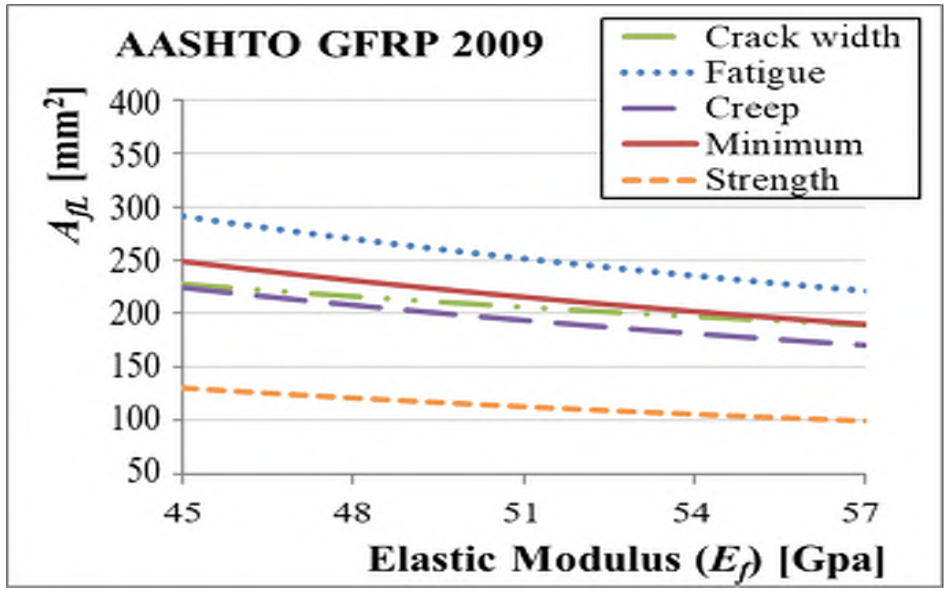


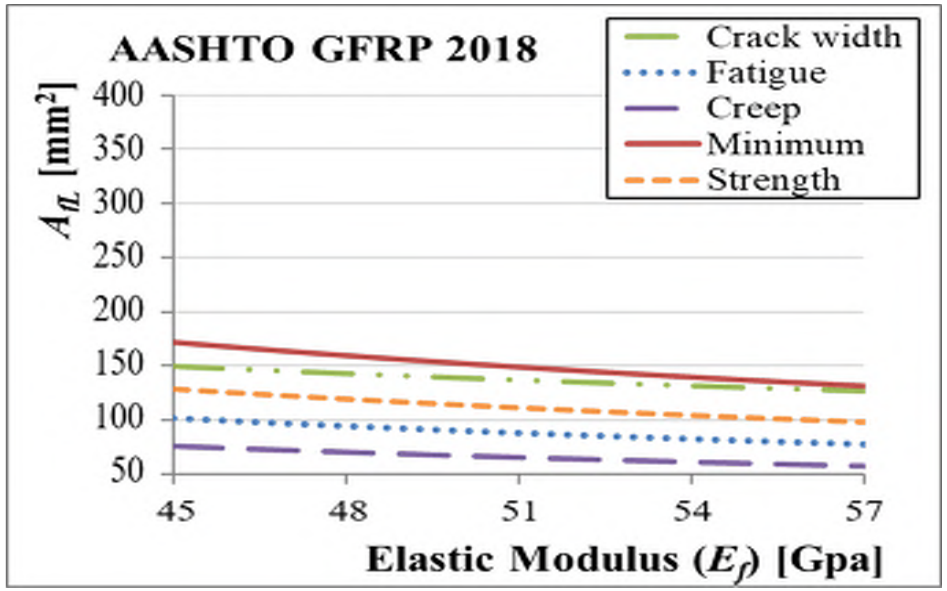
Figure C2.5.5.2-1 – Variation of ϕ with Tensile Strain at Failure, ε_{ft}, in GFRP Reinforcement



Advancement (cont.) - Elastic Modulus

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

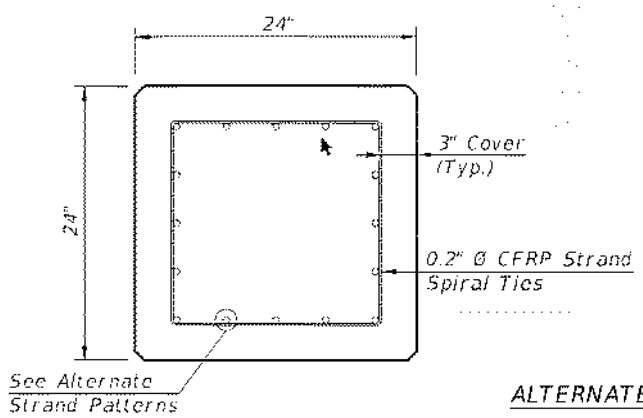




Advancement (cont.) - Piles

Bridge Bearing Pile Standards

455-101		Square CFRP and SS Prestressed Concrete Piles - Typical Details and Notes
455-102		Square CFRP and SS Prestressed Concrete Pile Splices
455-112		12" Square CFRP and SS Prestressed Concrete Pile
455-114		14" Square CFRP and SS Prestressed Concrete Pile
455-118		18" Square CFRP and SS Prestressed Concrete Pile
455-124		24" Square CFRP and SS Prestressed Concrete Pile
455-130		30" Square CFRP and SS Prestressed Concrete Pile
455-154		54" Precast/Post-Tensioned CFRP and SS Concrete Cylinder Pile
455-160		60" Prestressed CFRP and SS Concrete Cylinder Pile



SECTION A-A

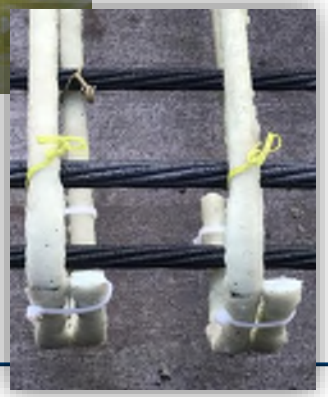
ALTERNATE STRAND PATTERNS

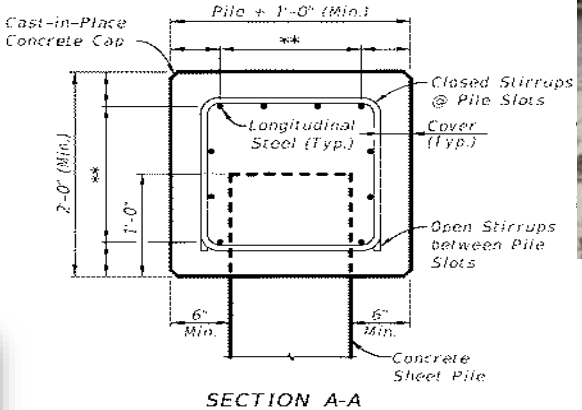
16 ~ 0.6" Ø, CFRP 7-Strand, at 42 kips
16 ~ ½" Ø, CFRP Single-Strand, at 41 kips

Advancement (cont.) - Seawall-Bulkheads

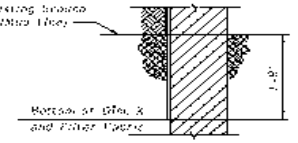
Concrete Sheet Pile Bulkhead Standards

		Structures Foundations - Sheet Pile Wall
455-400		Precast Concrete Sheet Pile Wall (Conventional)
455-440		Precast Concrete Sheet Pile Wall (CFRP/GFRP & HSSS/GFRP)

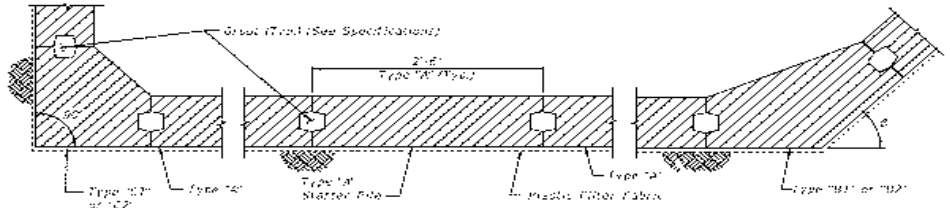




SECTION A-A



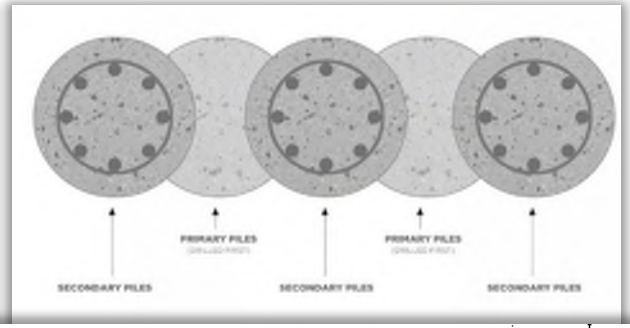
SECTION THRU BULKHEAD

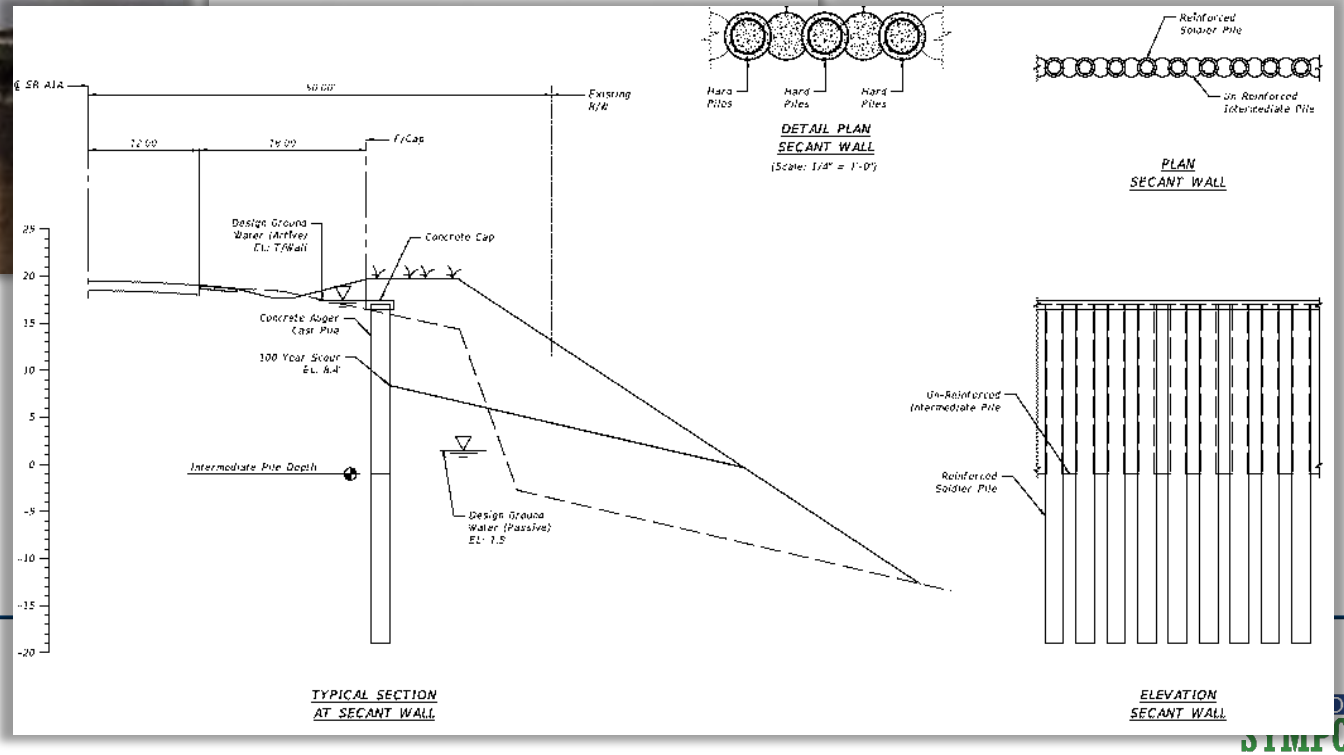


DETAIL "A"

Advancement (cont.) - Seawall-Bulkheads

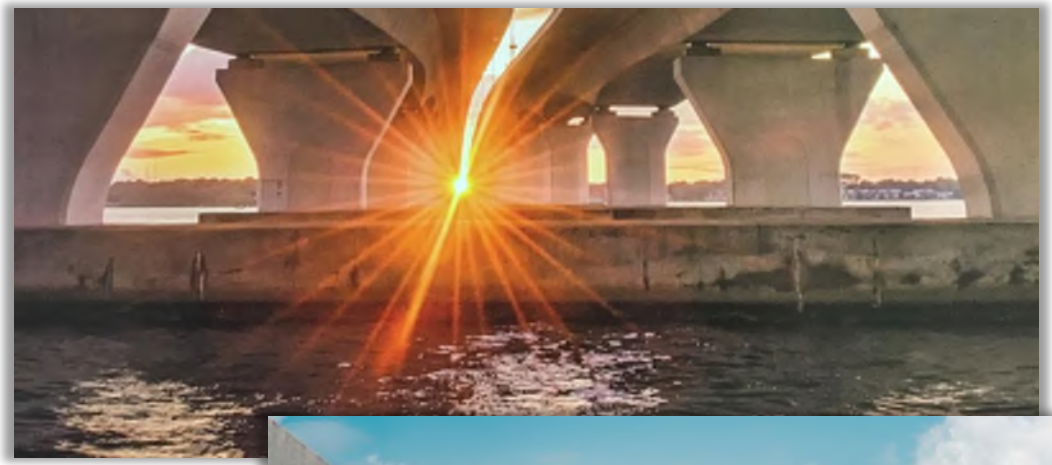
Secant Piles seawall on SR A1A

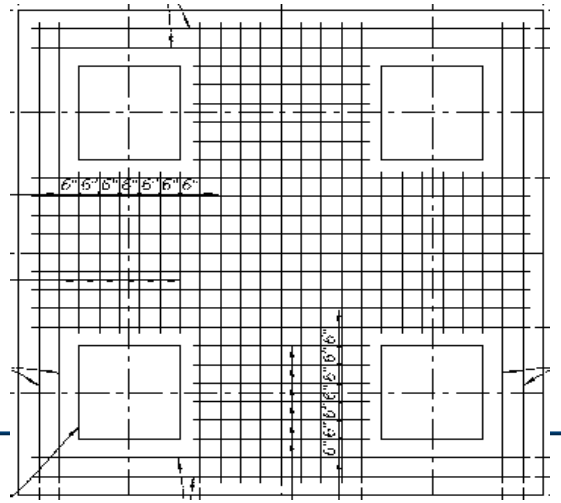




Advancement (cont.) - Footings

Waterline footings in saltwater – *need big bars!*

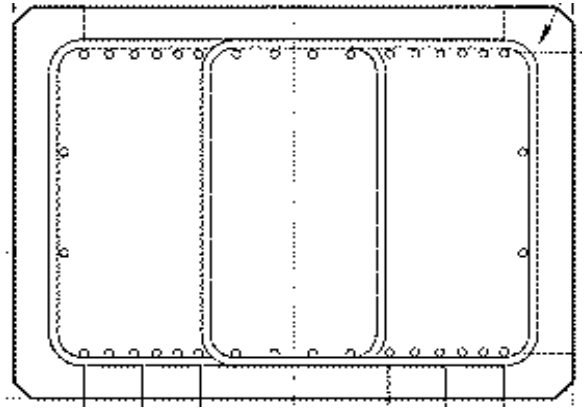




Advancement (cont.) - Bent Cap

Projects:

- Halls River Bridge Replacement (Homosassa)
- NE 23rd Ave/Ibis Waterway (City of Lighthouse Point)
- Barracuda Blvd (New Smyrna)
- Maydell Dr. (Tampa)
- 40th Ave. N (St Petersburg)
- iDock (Miami)



Advancement (cont.) - Girders

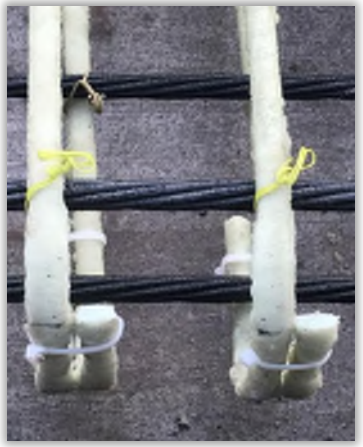
Projects:

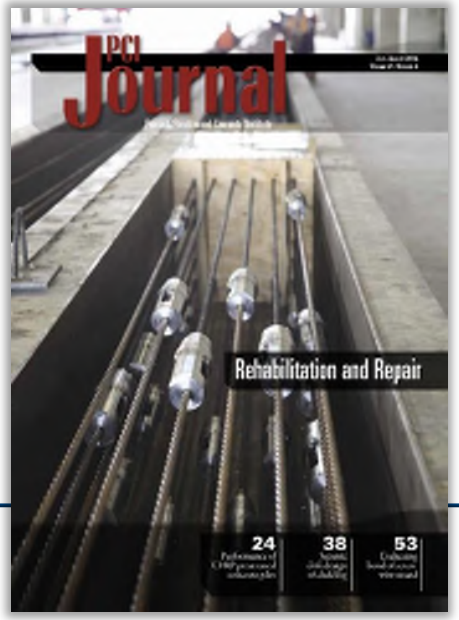

HCB's set on GFRP-RC Pile Caps

- Halls River Bridge = **HCB's** (Homosassa)
- NE 23rd Ave/Ibis Waterway = **Flat-Slab** (City of Lighthouse Point)
- US1 over Cow Key Channel = **FSB hybrid** (Key West)

Maydell Dr. = **FSB's ?** (Tampa)

40th Ave. N = **FSB's** (St Pete.)





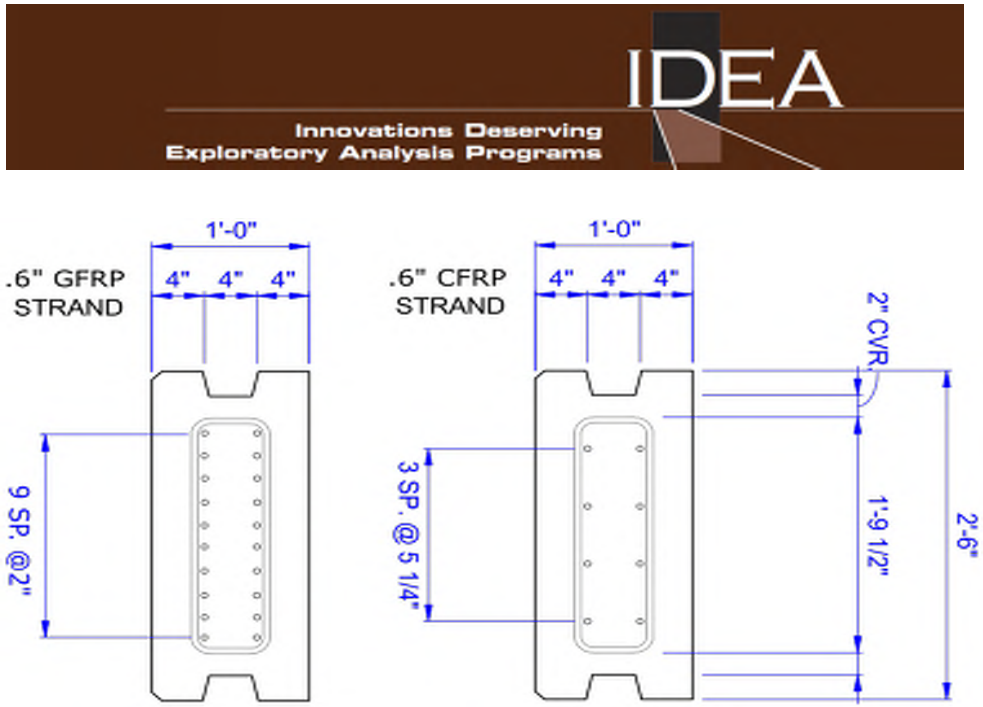
Advancement (cont.) – GFRP-PC

1. *FHWA's* Innovations Deserving of Exploratory Analysis *(IDEA)*

- GFRP Prestressing - MILDGLASS (University of Miami);

(a) & (b) CFRP strand failed during tensioning; (c) cracking following strands release.

(a) GFRP strand prototype cross section; (b) compared to a CFRP alternative.

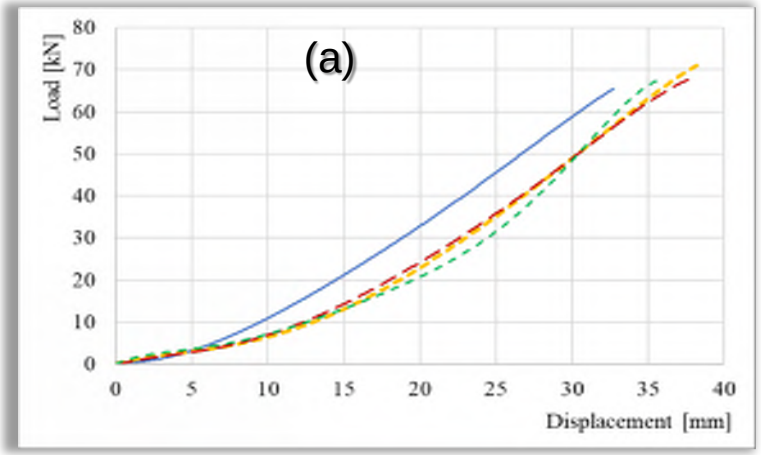


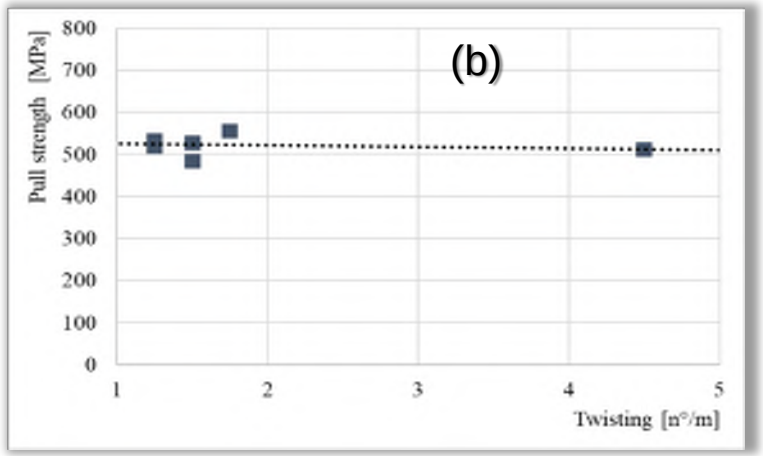
(a) GFRP-PC sheet pile concept (b) CFRP-PC sheet pile design for Halls River Bridge

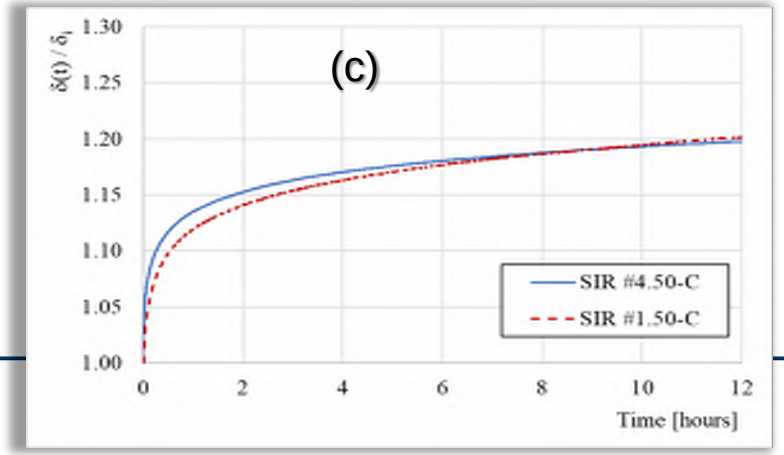
Advancement – GFRP-PC (cont.)

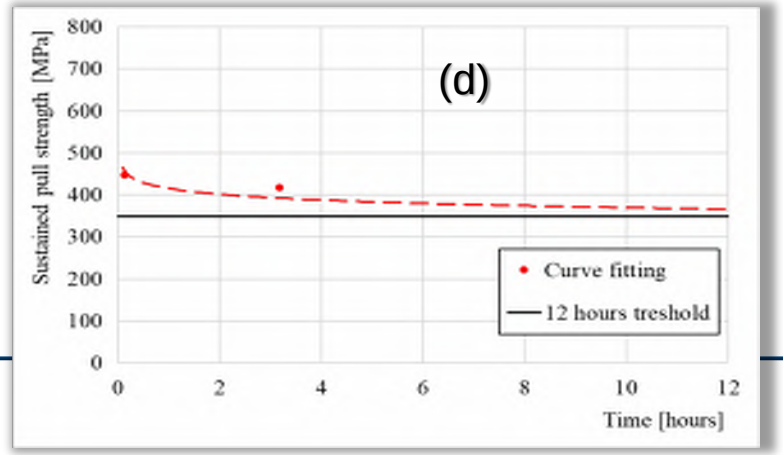
1. *FHWA's* Innovations Deserving of Exploratory Analysis *(IDEA)*

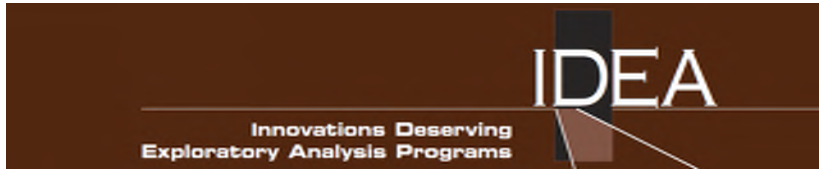
- GFRP Prestressing - MILDGLASS (University of Miami);











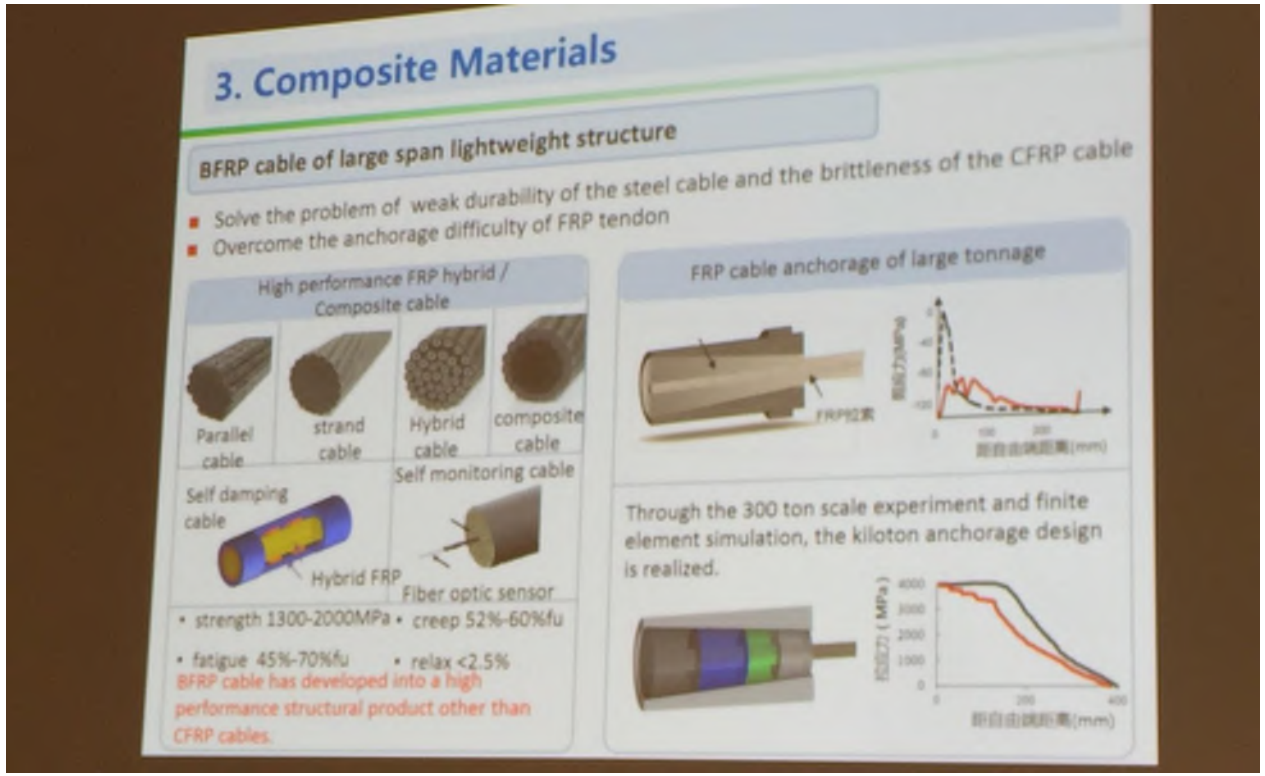
Pull test load:

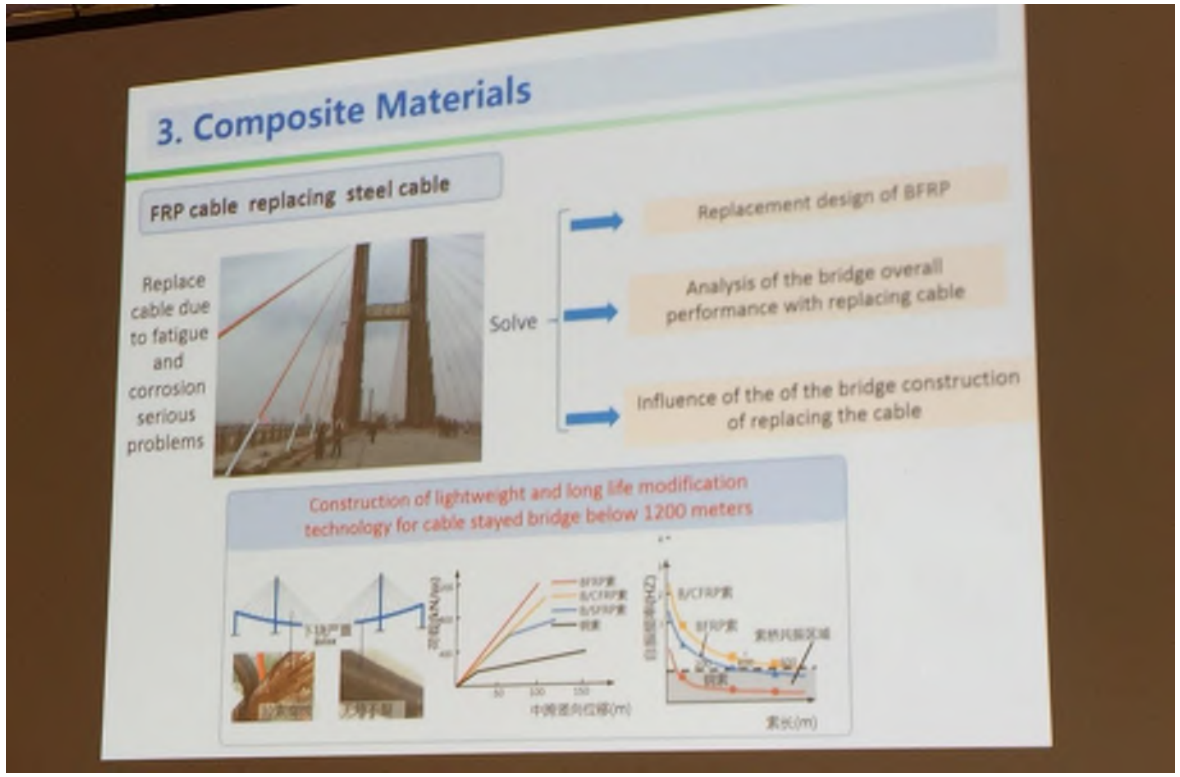
(a) Displacement diagrams;
(b) Pull strength at varying twist per meter;
(c) Creep displacement over initial value;
(d) Creep rupture logarithmic regression

Advancement (cont.) – Next

2. *Next* Innovation Deserving of Exploratory Analysis…

- BFRP Prestressing (perhaps)???





Advancement (cont.) – SAM-TAG

Structural Advance Materials – TAG mission:

- Advance the safe implementation and broad deployment of innovative structural materials through advisement to the Structures Technical Advisory Group (TAG) and coordination with national and international specification development organization representatives…

Members are to support *District Structures Design Engineers* make informed choices:

1 ~ Champion & 1 ~ Backup from each District Structures Office

2 ~ Consultants - structures design community

2 ~ State Materials Office materials experts

2 ~ State SDO facilitators & coordinators

1 ~ Structures Research Center representative

~ Friends of the TAG (Collaborators)

…future Construction and Maintenance representatives?

Questions?


FDOT's Fiber-Reinforced Polymer Deployment Train
???
BFRP
Composite Bridge Girders
GFRP-RC
CFRP-PC
Fender Systems
External FRP Laminate Repairs
2019?
2016
2016
2015
2000's
1990's
FDOT

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District Structures Offices:
SAM-TAG representatives
&
District Structures Design Engineers

FDOT's Fiber-Reinforced Polymer Deployment Train

FDOT TRANSPORTATION SYMPOSIUM