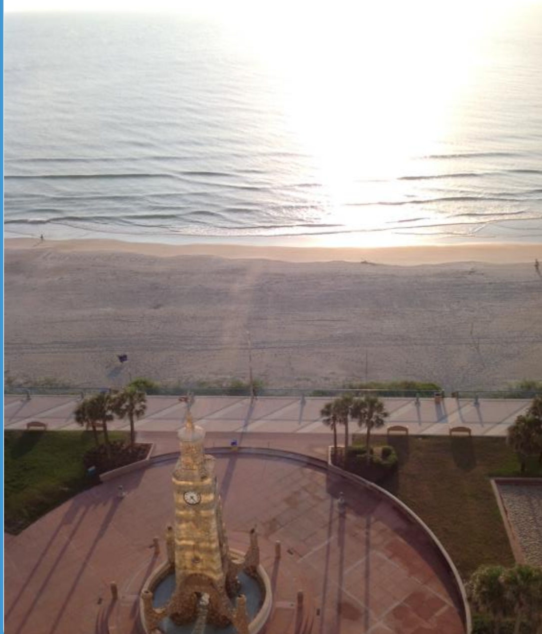
GFRP Rebar Workshop

2016 Design Training Post-Expo



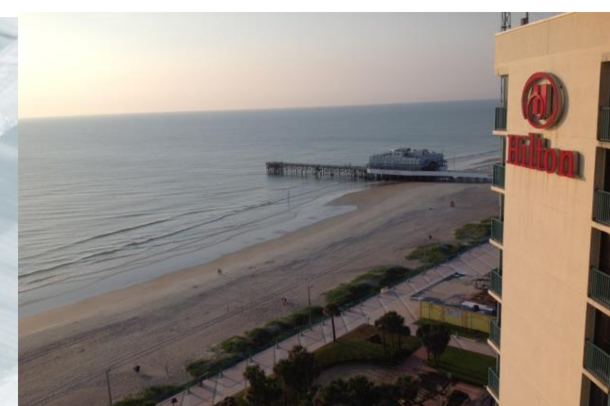
6/15/2016, 1:00pm - 4:00pm

Hilton Daytona Beach Oceanfront Resort

St Johns Room

100 North Atlantic Avenue
Daytona Beach, Florida 32118, USA
Tel: 1-386-254-8200

FDOT



Part 2 - Discussion on Needs

1. Design Criteria
2. Durability Issues
3. Material Specifications & Vendor Approvals
4. Construction Specifications
5. Products in the marketplace (present and future)
6. Research Focus

Roadmap for Safe Deployment of FRP Reinforcement for Concrete Structures

- Barriers to expanded FRP Implementation
- Potential Focus Areas

FDOT's Fiber-Reinforced Polymer Deployment Train

??? → GFRP Reinforcing Bars → CFRP Prestressed Piles → Fender Systems → External FRP Laminate Repairs

Roadmap for Safe Deployment of FRP Reinforcement for Concrete Structures

<u>Barriers to expanded FRP Implementation</u>:

1. **First cost**
   - This topic has to be addressed by industry directly, but volume of material was identified as the main driver. Expanding the number of potential structural element uses in the ***FRPG*** would help to increase the volume.
   - First cost should include benefits of reduced cover, reduction of additives, no need for surface coating, and labor/installation savings due to lightweight.
   - SEACON will generate LCC data that may be helpful.
   - Consider example cost comparison similar to that prepared for SMO on SS/SS clad rebar.

FDOT's Fiber-Reinforced Polymer Deployment Train

Roadmap for Safe Deployment of FRP Reinforcement for Concrete Structures

<u>Barriers to expanded FRP Implementation </u>(cont.):

2. **Lack of confidence in durability for submerged environments (FDOT seeking 75 - 100 year service life)**
   - Accelerated testing could address this issue. OC can volunteer its laboratory for samples subjected to sustained load+saltwater+60^{o}C ? (alkalinity). The outcome could be a new set of creep-rupture curves that account for environmental effects. Initially proposed to look at existing data through a synthesis study.
   - OC to look into their experimental capabilities when using naked #3 bars (Nanni proposal).
   - Look at quality of bends compared to straight bars.
   - Compression testing will eventually have to be addressed.

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???

GFRP Reinforcing Bars

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Barriers to expanded FRP Implementation (cont.):

3. **Limitations on the strength due to degradation of properties over time (currently C_E factor = 0.7 for GFRP exterior environments)** ***[goes with item #2]***
   - Use tests on field-retrieved bars and correlate to accelerate-conditioning tests to develop knockdown factors for 100 years of service life. Initially proposed to look at existing data through a synthesis study (see Item 2).
   - Existing stress limit is 0.20 of guaranteed times C_E to account for creep-rupture and fatigue under service loads. *Is the creep rupture limit actually affected by long-term environmental exposure?*
   - Current FDOT Materials research project: *BDV34 977-05* Degradation Mechanism and Service Life Estimation of FRP Concrete Reinforcements. SSDO expressed desire to implement waterline applications of GFRP based on partial positive results at some low risk locations.

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INNOVATIVE EFFICIENT EXCEPTIONAL
OUR ROAD AHEAD

Roadmap for Safe Deployment of FRP Reinforcement for Concrete Structures

Barriers to expanded FRP Implementation (cont.):

4. **Limitations on strength due to low design resistance factors (phi factors) related to lack of ductility and strength variability in the FRP materials (currently 0.55-0.65 for tensioned-control to compression-controlled flexural failure modes)**
   - This is a designer's issue that could be tackled immediately based on reliability.
   - Separate shear from flexure.
   - For flexure, revisit existing data and reconfirm proposal by Jawaheri and Nanni (see Table 9).

Table 9—Recommended strength reduction factors for FRP reinforced beams

Limit state	Strength reduction factor (ϕ)
FRP rupture*	0.70
Concrete crushing*	0.75
Shear†	0.75

*Conservatively: $\phi = 0.70$ for both modes; †Shear reinforcement limit is modified as $V_f \leq 3V_c$.

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4. Limitations on strength… (continued)

Code comparison prepared by SSDO:

Action	Failure Mode	Phi (AASHTO)	Phi (ACI)	Comment
Conventional Steel Reinforcing:				
Shear	Brittle	0.75	0.75	
Plain Concrete	Brittle	N/A	0.60	
Flexure-CC	Brittle	0.75	0.75	
Flexure-TC	Ductile	0.90 (1.00)	0.90	() = prestressed
FRP Reinforcing:		(AASHTO-GS)	(ACI -440)	
Shear	Brittle	0.75	0.75	
Plain Concrete	Brittle	N/A	0.60	
Flexure-CC	Brittle	N/A	0.65	non-prestressed
Flexure-TC	Brittle	N/A	0.55	non-prestressed
Flexure-CC	Brittle	N/A	0.65	CFRP-prestressed
Flexure-TC	Brittle	N/A	0.85	CFRP-prestressed

- Consider changing paradigm by looking at strain in GFRP as per steel (i.e., not allowed below a strain of 0.004, full 0.9 above a strain of 0.005).

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Barriers to expanded FRP Implementation (cont.):

5. **Restrictions in bar bending capabilities, and challenges with field modifications to bar shapes**
   - This may be a perceived barrier. Manufacturers need to propose standardized shape of higher quality revisiting minimum radius of curvature and 60% efficiency.
   - Continuous close stirrups/ties are possible and allow sharp corners, and do not rely on GFRP-concrete bond. *Would test methods differ for these types of stirrups?*
   - FRP Bar Bending Index D21310 could be updated to address different bend radii for different production methods, but this must be tied to specification identification and acceptance criteria.

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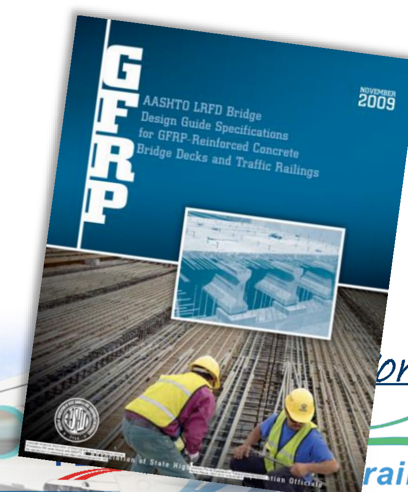
Barriers to expanded FRP Implementation (cont.):

6. **Low Elastic Modulus, resulting in greater deflections and larger crack openings**
   - This is a shortcoming with no immediate solution that industry may or may not consider addressing.
   - Consider combining with FRC to control crack size openings and possibly deflections. Need tools to quantify effect of FRC on crack width and/or deflections.
   - Consider combining GFRP stirrups/ties and carbon steel strand in PC applications
   - Review Canadian codes crack width criteria
   - Review relevance of Kb factor in ACI for GFRP
7. **Update AASHTO Guide Specification**
   - This is a shortcoming for state DOTs



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Roadmap for Safe Deployment of FRP Reinforcement for Concrete Structures

Potential Focus Areas:

1. **Rationalization of Resistance Factors (phi factors)** used to address lack of ductility and variability in material strength properties;
2. **Refinement of Environmental Reduction factors (C_E);**
3. **Resolution of durability question in submerged environments;**
4. **Advancement in bent bar fabrication;**
5. **Mitigation of lower elastic modulus effects** as related to member deflections and concrete crack widths;
6. **Investigate hybrid designs –** using FRC and/or Carbon-steel strand with GFRP rebar:
   - Concrete Sheet Piles;
7. **Improved FRP Industry coordination** especially between ACMA-TSC and AASHTO SCOBS-T6 (FRP) & T10 (Concrete);

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Potential Focus Areas (cont.):

8. Continued Standardization through:

i. Design Specifications
- AASHTO Guide Spec update (T6) –> LRFD Chapter 5 inclusion (T10);
- ACI 318-GFRP design companion document/address column design;

ii. Material Specifications
- FDOT Specification Sections 932 & 933;
- ACI 440-K/ASTM D30.10: new Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement, WK43339;

iii. Pre-Fabrication
- Cages (ACP, Sheet Piles, Traffic Railings, Precast Caps)
  - ✓ Bespoke (wound stirrups & confinement);
- 2D-Grids/Mats (e.g. Decks and Noise Wall Panels);
- Bends/Stirrups/Hoops;
- Headed Anchors;

iv. Pre-designed of Structural Elements (such as **FDOT** ***Design Standards*** Indexes);
- Possible Pendulum Testing of GFRP reinforced Traffic Barriers.

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Potential Focus Areas (cont.):

9. **Accommodation of potential customization and optimization of FRP reinforcing and other products**

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Potential Focus Areas (cont.):

10. Guidance on the use of Life Cycle Cost Analysis for FRP justification:

i. Coordinate with SEACON-WP6;

ii. Utilize FHWA/& NCHRP Report 483;

iii. Consider Leveraging Sustainability angle:

- From **2016 National Bridge Conference**: Jianwei Huang and Chris Strazar, "Sustainability of GFRP RC Bridge Deck: Materials Cost", Southern Illinois University Edwardsville: *This research clarifies the concern of the high initial cost for GFRP RC bridge deck as compared to conventional steel RC deck;*
- **USDOT to require emissions-reduction goals for funding recipients** The US Department of Transportation is working on plans to require highway and transportation funding recipients to set and track carbon dioxide emissions-reduction goals as a condition of receiving money;
- **FHWA proposal: Emissions could gauge success of transportation projects** The amount of emissions, along with congestion, traffic reliability and freight movement, could be used to evaluate the success of a transportation project under new rules proposed by the Federal Highway Administration. The agency has started a 90-day comment period in the proposal.

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Potential Focus Areas (cont.):

11. Project Monitoring

i. SMO monitoring Cedar Key Bulkhead rehab – Test Beams under cap (3 surface coatings of GFRP);

ii. FSU-UM monitoring Halls River bulkheads, piles, bent caps and deck – Test beams under bulkhead (GFRP, CFRP, BFRP & SS);

iii. Coordinate with FHWA for monitoring FRP under ***Fixing America's Surface Transportation (FAST) Act***.

12. Outreach and Technology Transfer:

i. FDOT Invitation to Innovation-FRP website;

ii. FDOT Design Expo;

iii. Project Case-Studies & Workshops.

INVITATION TO INNOVATION

13. Repair Methods

14. Bridge Inspection

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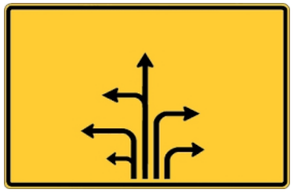
Part 3 - Action Items & Next Step

1. **Immediate Action Items:**
   - Meet 2 or 3 times per year to meet initial deployment challenges;
   - Review current durability data to address GFRP in the splash zone or submerged conditions, and refinement of 0.7 C_E factor;
   - Address Anchorages and Mechanical Splices for GFRP;
   - Update FDOT FRP Bar Bend Index D21310 with input from industry partners;
   - Review 60% Bar Bend Capacity criteria;
   - ACMA-RBMC to propose updates to AASHTO Guide Spec.

2. **Next Steps**
   - Organize next meeting for December/January in South Florida;
   - Continue development of FRP Rebar Roadmap;
   - Explore funding and time requirements for C_E factor review.



Adjourn - Thanks for Coming !!