Part 1b - Discussion – Review Roadmap

Roadmap Review Discussion

Roadmap to the safe deployment of FRP reinforcement for concrete structures

- Challenges to expanded FRP Implementation
- Potential Focus Areas

Roadmap Review Discussion

Challenges to expanded FRP Implementation:

1. **First cost**
   - This topic has to be addressed by industry directly.
   - 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/LCA data that may be helpful.
   - Consider developing example cost comparison

Roadmap Review Discussion

Challenges to expanded FRP Implementation (cont.):

2. **Lack of confidence in durability for submerged environments (FDOT seeking 75 - 100 year service life)**
    - Accelerated testing could address this issue. OC could volunteer its laboratory for samples subjected to sustained load+saltwater+60°C (alkalinity). The outcome could be a new set of creep-rupture curves that account for environmental effects.
        - *FDOT doing some accelerated testing investigation under BDV30-977-15 Performance evaluation of glass fiber reinforced polymer (GFRP) reinforcing bars embedded in concrete under aggressive environments (FSU-UM)*
    - OC to look into their experimental capabilities when using naked #3 bars.
    - OC will look at quality of bends compared to straight bars.
        - *FDOT proposed SMO research not advanced last year*
    - Compression testing will eventually have to be addressed.

Roadmap Review Discussion

Challenges to expanded FRP Implementation:

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.
   - 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 research project: *BDV34 977-05* Degradation Mechanism and Service Life Estimation of FRP Concrete Reinforcements

Roadmap Review Discussion

Challenges to expanded FRP Implementation:

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 $V_f \leq 3V_c$.

Roadmap Review Discussion

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	
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	
Flexure-CC	Brittle	0.65	0.65	non-prestressed
Flexure-TC	Brittle	0.55	0.55	non-prestressed
Flexure-CC	Brittle	N/A	0.65	CFRP-prestressed
Flexure-TC	Brittle	N/A	0.85	CFRP-prestressed

- Prestress resistance factors may actually come down for TC = 0.75 & increase for CC = 0.80 based on new reliability study by Kim & Nickle *(ACISJ Tile 113-S89, Sept-Oct 2016)*
- Consider changing paradigm by looking at strain in GFRP as per high strength steel rebar (i.e., not allowed below a strain of 0.002???, full 0.9 above a strain of 0.008??).

FDOT FRP Deployment Train

Roadmap Review Discussion

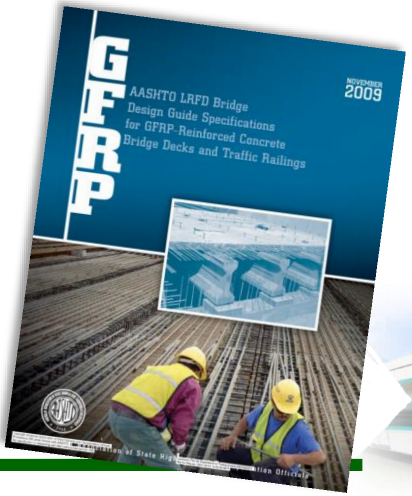
Challenges to expanded FRP Implementation:

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. *How is the 60% reduction applied in design for shear stirrups?*
    - 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?*
        - *What is the maximum leg length before surface bonding would be required?*

Roadmap Review Discussion

Challenges to expanded FRP Implementation:

6. **Low Elastic Modulus, resulting in greater deflections and larger crack openings**
   - This is a shortcoming with no immediate solution that OC 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
7. **Update AASHTO Guide Specification**
   - This work is underway



Roadmap Review Discussion

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 (CE);**
3. **Resolution of durability question especially in submerged environments;**
   - SMO projects. (Do we need others ?)
     1. BDV34 977-05 Degradation Mechanisms and Service Life Estimation of FRP Concrete Reinforcements, A. El-Safty (UNF), due 3/31/2018
     2. BDV30 977-18 Performance Evaluation of GFRP Reinforcing Bars Embedded in Concrete Under Aggressive Environments, R Kampmann (FSU), Due 5/31/2018
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;

Roadmap Review Discussion

Potential Focus Areas (cont. expanded):

7. **Improved FRP Industry coordination** especially between ACMA-TSC and AASHTO SCOBS-T6 (FRP) & T10 (Concrete);
8. **Continued Standardization through:**
   i. Design Specifications
      - AASHTO Guide Spec update (T5) –> 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 in the future (2020).

Roadmap Review Discussion

Potential Focus Areas (cont.):

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

Roadmap Review Discussion

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 if permitted:

- 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.

Roadmap Review Discussion

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 Expos;

iii. Project Case-Studies & Workshops.

INVITATION TO INNOVATION

Roadmap Review Discussion

Potential Focus Areas (cont.):

13. **Repair Methods**
14. **Bridge Inspection**
    i. Test Methods for identifying deterioration (NDT preferable)

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Part 2 - New Items – 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
7. ACMA/FRP-RMC Industry Concerns
    1. Necessary and required testing today versus years of test data compiled from other installations
    2. Identification and selection process of testing laboratories which are ISO qualified
    3. Government agencies and engineers that use products that may be interpreted by some as questionable, un-tested and does not meet the expected standards generated by ASTM, ACI, others
    4. First costs versus cost premium impact to overall project cost. How is this handled from the owners stand point. Do life cycle costs play a role as identified in MAP-21?
    5. Durability testing: field versus accelerated testing. Which will the DOT feel gives them the results they need? What is the DOT looking for?

Adjourn - Thanks for Coming !!