Structural Advanced Materials Implementation in Florida’s Concrete Bridges

Presenter: Steven Nolan, P.E. (FDOT State Structures Design Office)

Jan. 12 10:00 AM - 1:00 PM EST
Structural Advanced Materials Implementation in Florida’s Concrete Bridges

1. Introduction of current needs in bridge durability & structural advancement
2. UHPC: CIP Connections, Precast/Prestressed members
3. HSSS-PC: Prestressed Beams & Piles in EAE
4. CFRP-PC: Prestressed Beams & Piles in EAE
5. FRP-RC: CIP & Precast Elements, Auxiliary Reinforcing
6. Managing Implementation Challenges and LCC strategies
Introduction of current needs in bridge durability & structural advancement.

• **Durability** needs – low-maintenance, extended service-life, cost-effective solutions.

• **Structural** needs – Inspectable, repairable, robust, extended span lengths (light-weighting and/or high-strength & high-endurance)
  - UHPC
  - HSSS-Prestressed Concrete
  - CFRP-Prestressed Concrete
  - FRP-Reinforced Concrete (*using Glass & Basalt rebar*)
  - Light-weight Concrete & Fiber-Reinforced (*not discussed today*)
UHPC Design guidance & standards documents

Design Guidance, Specs, and Design tools

• Mid-2021 implementation
• Interim Guidance webpage for **Design Innovation**

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**Structures Design Office**

- Curved Precast Spliced U-Girder Bridges
- Fiber Reinforced Polymer Reinforcing
- FRP Members and Structures
- Geosynthetic Reinforced Soil Integrated Bridge System
- Geosynthetic Reinforced Soil Wall
- Prefabricated Bridge Elements and Systems
- Segmental Block Walls

**Ultra-High Performance Concrete (UHPC)**

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**Ultra-High Performance Concrete**

Overview
Usage Restrictions / Parameters
Design Criteria
Specifications
Approved Products
Projects
FDOT Research
Technology Transfer (T)
Contact

https://www.fdot.gov/structures/innovation/uhpc.shtm

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**TRBAM 2021 - Structural Advanced Materials Implementation in Florida**
UHPC Design guidance & standards documents

- Interim Guidance webpage for **Design Innovation** Projects:

  Fast-Facts sheets for selected projects are listed below:

  - I-10 over CR268A Approach Slab Replacement
  - I-10 over Flat Creek Approach Slab Replacement
  - I-95 over CR5A - Precast Deck Panel Replacement
  - I-95/JT Butler Interchange Bridge U-Beam Repair
  - SR 714/Danforth Creek - Sonovoid Rehab
  - US1 over Little Duck Key Channel
  - US441 over Taylor Creek - Span 12 Replacement
  - US41 over Sunset Waterway Link-Slab

[https://www.fdot.gov/structures/innovation/uhpc.shtm](https://www.fdot.gov/structures/innovation/uhpc.shtm)
UHPC Design guidance & standards documents

• Developmental Materials & Construction Specifications

STRUCTURES

Ultra-High-Performance Concrete

Prepackaged Ultra-High-Performance Concrete Provide the material requirements for ultra-high-performance concrete.

NOTE: Use with Dev 349UHPC

Jose Armenteros

Dev349UHPC Project List

Dev927UHPC Project List

https://www.fdot.gov/programmanagement/otherfdotlinks/developmental/default.shtm
UHPC Design guidance & standards documents

• Research Activities

Completed Research:
• **BDV31 977-94**: Requirements for Use of Field-Cast, Proprietary UHPC in Florida Structural Applications – *Final Report* 7/8/19

Ongoing Research Activities:
• **In-house SRC**: Spliced Columns with larger bars #8 to #11 (Freeman), Final report early 2021
• **BDV29 977-28**: FSB Bridge with UHPC Joint Connections (FIU) – 1st round testing completed; 6 new beams cast (2 tests) with only bottom reinforcement in joint; Cyclic SDLC testing
• **BDV31-977-105**: Requirements for nonproprietary “UHPC Use in Florida Structural Applications”
• **BDV31-977-101**: Hybrid Prestressed Concrete Bridge Girders using UHPC (Potter) – Final report submitted
UHPC Design guidance & standards documents

**Research Activities**

**Precaster 1:**
- First UHPC octagonal pile tested at SRC in April 2018 another one waiting
- Hollow-Box Beam from SCP. Testing 2~ 47’ beams in flexure completed
- 3x20’ lengths of Waffle Deck & 60’ AASHTO Type II Beam, cast on 06/17/20 tested in Oct 2020 at SRC for resistance of all 3 interface shear connection systems.

**Precaster 2:**
- 14” sq. solid UHPC piles (Freeman) – Flexure test 4/2/19 @ SRC 4-point bending on 30’ pile; driving demonstration of 100’ pile 4/4/19 @ Leware.
- 30” x 30’ H-Pile COR-TUF UHPC: H-Pile tested at SRC 10/2/19
- 30” x 140’ H-Pile COR-TUF UHPC: One pile driven at CR 339 on Feb 13, 2020 - PDA report available)

**UHPC Material Producers: Lafarge, CorTuf USA, Argos USA: Developing proprietary mix**
UHPC Design guidance & standards documents

• Projects in Design:
  1. Precast Voided Slab - #-span continuous

  2. 250’ Single Span?
HSSS-PC Design guidance & standards documents

Interim Guidance webpage for **Design Innovation** *(pending)*

**Structures Design Office**

- Curved Precast Spliced U-Girder Bridges
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- Geosynthetic Reinforced Soil Wall
- Prefabricated Bridge Elements and Systems
- Segmental Block Walls
- Ultra-High Performance Concrete (UHPC)

**Stainless-Steel Pretensioned Concrete** *(pending)*
HSSS-PC Design guidance & standards documents
designation, Specs, and Design tools:

• NCHRP Project → 12-120 (SS Strands for PC Beams) ...
• FDOT Research Project BDK84 977-07 (2014)
• FDOT Research Project BDV30 977-22 (2020)

TRBAM 2021 - Structural Advanced Materials Implementation in Florida
3. HSSS-PC Design guidance & standards documents

Design Guidance, Spec, and Design tools

• BDV30 977-22

Mechanical properties

**HSSS strand Grade 240**
- ASTM A1114
- Low-relaxation
- Ultimate stress = 240 ksi
- Ultimate strain = 1.4%
- Elastic modulus = 24,000 ksi
- Keep increasing after yielding up to failure

**Carbon steel strand Grade 270**
- ASTM A416
- Low-relaxation
- Ultimate stress = 270 ksi
- Ultimate strain = 3.5%
- Elastic modulus = 28,500 ksi
- Reach plateau after yielding

Projects used HSSS strands in US
- After successful research projects by Georgia, Florida, and Virginia DOTs, HSSS strands have been deployed in many projects

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HSSS-PC Design guidance & standards documents

Design Guidance, Specs, and Design tools

- **BDV30 977-22**

### Girders design

- **Material properties**
  - Concrete strength
    - Beam = 8.5 ksi
    - Deck slab = 4.5 ksi
  - Prestress reinforcement \( \rightarrow \) HSSS strand (ASTM A1114)
    - Area = 0.231 in\(^2\)
    - Ultimate stress = 240 ksi
    - Ultimate strain = 0.014 in./in.
    - Elastic modulus = 24,000 ksi

- **Initial jacking stress**
  - 65% of ultimate stress

- **Design method:**
  - Force equilibrium and strain compatibility

- **Design objective:**
  - Determine optimum number of 0.6-in.-dia. HSSS strands

![Girders design](image)

### Girders design

- **Design limits:**
  1. Tensile stress at release (AASHTO 5.9.2.3.1);
  2. Tensile stress at service (AASHTO 5.9.2.3.2);
  3. Minimum reinforcement (AASHTO 5.6.3.3);
  4. Strength (AASHTO 5.5.4).

- **Failure mode**
  - Rupture of strand
  - Resistance factor = 0.75 \( \rightarrow \) brittle failure

- **Results**
  - 11 0.6-in. HSSS strands
HSSS-PC Design guidance & standards documents

Design Guidance, Specs, and Design tools

• **BDV30 977-22**

### Prestress losses

- Initial jacking stress → 156.5 ksi (65% of guaranteed ultimate stress)

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Elastic shortening losses increased with increasing number of strand

AASHTO approximate method conservatively estimated the prestress losses of 0.6-in. HSSS strands

Maximum measured total prestress losses of 0.6-in. HSSS strand was 12.1%
HSSS-PC Design guidance & standards documents

Design Guidance, Specs, Costs and Design tools

• **BDV30 977-22**

**Flexural test**

- **Results**
  - All girders satisfied AASHTO allowable deflection limit at service load
  - Post-cracking behavior continued to increase up to failure
  - Capacity and deformation increased linearly when increasing reinforcement ratio
  - All girders
    - Exhibited large reserve deflection beyond cracking load
    - Exhibited large reserve capacity beyond cracking load
    - Provided substantial warning through large deflection

*TRBAM 2021 - Structural Advanced Materials Implementation in Florida*
3. HSSS-PC Design guidance & standards documents

Design Guidance, Specs, and Design tools

• **BDV30 977-22**

### Failure modes

What are the feasible failure modes for concrete girders prestressed with HSSS strands?

1. Rupture of strand
2. Balanced (rupture of strand & crushing of concrete)
3. Crushing of concrete

- Failure mode $\rightarrow$ prestressing reinforcement ratio

\[
\frac{\varepsilon_c}{\varepsilon_{pu}} + \varepsilon_{pe} = \frac{0.85 \varepsilon_c}{f_{pu} \varepsilon_{cu} + \varepsilon_{pu}}
\]
HSSS-PC Design guidance & standards documents

Design Guidance, Specs, and Design tools:

- **Standard Drawings & Design Aids**

![Diagram of a square prestressed concrete pile interaction diagram]

<table>
<thead>
<tr>
<th>Document Number</th>
<th>Description</th>
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<td>455-101</td>
<td>Square CFRP and SS Prestressed Concrete Piles - Typical Details and Notes</td>
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<td>455-102</td>
<td>Square CFRP and SS Prestressed Concrete Pile Splices</td>
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<td>12&quot; Square CFRP and SS Prestressed Concrete Pile</td>
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<td>455-154</td>
<td>54&quot; Precast/Post-Tensioned CFRP and SS Concrete Cylinder Pile</td>
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<td>455-160</td>
<td>60&quot; Prestressed CFRP and SS Concrete Cylinder Pile</td>
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<td>455-400</td>
<td>Precast Concrete Sheet Pile (Conventional)</td>
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<td>455-440</td>
<td>Precast Concrete Sheet Pile (CFRP/CFRP and HSSS/GFRP)</td>
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[https://www.fdot.gov/design/standardplans/current/default.shtm](https://www.fdot.gov/design/standardplans/current/default.shtm)

TRBAM 2021 - Structural Advanced Materials Implementation in Florida
HSSS-PC Design guidance & standards documents

Design Guidance, Specs, and Design tools:

- Software:
  - V6.0 coming early 2021
  - Prestressed Beam v5.2 (beta version HSSS-PC)
  - 11/07/2018
  - Exe (Zip) (Mathcad 15)

https://www.fdot.gov/structures/proglib.shtm
CFRP-PC Design guidance & standards documents

Design Guidance, Specs, and Design tools:

• NCHRP Report 907 → 2018 AASHTO Guide Spec – CFRP-1
• NCHRP Project → 12-121 (FRP Auxiliary Reinforcing) ...

Section 931

NCHRP 12-121 [RFP]
Guidelines for the Design of Prestressed Concrete Bridge Girders Using FRP Auxiliary Reinforcement

Posted Date: 11/5/2020

<table>
<thead>
<tr>
<th>Project Data</th>
<th>Value</th>
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<td>Contract Time:</td>
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<td>(includes 1 month for NCHRP review and approval of each interim report and 3 months for NCHRP review and for contractor revision of the final report)</td>
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<td>Authorization to Begin Work:</td>
<td>6/1/2021 – estimated</td>
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<tr>
<td>Staff Responsibility:</td>
<td>Dr. Vaheem Dakehla</td>
</tr>
<tr>
<td>Email:</td>
<td><a href="mailto:vaheemdash@fas.edu">vaheemdash@fas.edu</a></td>
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<td>RFP Close Date:</td>
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<td>Fiscal Year:</td>
<td>2021</td>
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CFRP-PC Design guidance & standards documents

Design Guidance, Specs, and Design tools:

• Software:

  V6.0 coming early 2021 → Prestressed Beam v5.2 11/07/2018 Exe (Zip) (Mathcad 15) (beta version CFRP-PC)

  https://www.fdot.gov/structures/proglib.shtm

Other’s Design Software:

  Adaption of FRP analysis or design enhancements:

  – FB-MultiPier (BSI) CFRP-PC available in Jan. 2021
  – Michigan DOT/LTU CFRP-Beam Design
    Mathcad:
    https://mdotjboss.state.mi.us/SpecProv/trainingmaterials.htm (also see TRB Webinar Dec 3, 2019)
CFRP-PC Design guidance & standards documents

Design Guidance, Specs, and Design tools:

- Standard Drawings & Design Aids:

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See Alternate Strand Patterns

https://www.fdot.gov/design/standardplans/current/default.shtm

TRBAM 2021 - Structural Advanced Materials Implementation in Florida
FRP-RC Design guidance & standards documents

Design Guidance, Specs, and Design tools

https://www.fdot.gov/structures/innovation/FRP.shtm
FRP-RC Design guidance & standards documents

Design Guidance, Specs, and Design tools
FRP-RC Design guidance & standards documents

### Design Guidance, Specs, and Design tools

- **Ongoing FDOT Research**

<table>
<thead>
<tr>
<th>Year</th>
<th>Project Title</th>
<th>Author(s)</th>
<th>Institution</th>
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<tbody>
<tr>
<td>2018</td>
<td>Bridge Girder Alternatives for Extremely Aggressive Environments</td>
<td>Brown, J.</td>
<td>ERAU</td>
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<td>2018</td>
<td>Performance Evaluation of GFRP Reinforcing Bars Embedded in Concrete Under Aggressive Environments</td>
<td>Kampmann, R.</td>
<td>FAMU/FSU</td>
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<td>2019</td>
<td>Performance Evaluation, Material and Specifications for Basalt FRP Reinforcing Bars Embedded in Concrete</td>
<td>Kampmann, R. Roddenberry, M.</td>
<td>FAMU/FSU</td>
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<td>2020</td>
<td>Basalt FRP-FRC Link-Slab Demonstration Project Monitoring (STIC-Phase 1)</td>
<td>El-Safty, A.</td>
<td>UNF</td>
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<td>2020</td>
<td>Inspection and Monitoring of Fabrication and Construction for the Halls River Bridge Replacement</td>
<td>Roddenberry, M.</td>
<td>FAMU/FSU</td>
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<td>2020</td>
<td>HSSS Strands and Lightweight Concrete for Pretensioned Concrete Girders (w/ Shear &amp; Confinement Rebar)</td>
<td>Roddenberry, M.</td>
<td>FAMU/FSU</td>
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<td>2021</td>
<td>Evaluation of GFRP Spirals in Corrosion Resistant Concrete Piles</td>
<td>Jung, S.</td>
<td>FAMU/FSU</td>
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<td>2021</td>
<td>Development of GFRP Reinforced Single-Slope Railing</td>
<td>Consolazio, G.</td>
<td>UF</td>
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<tr>
<td>2021</td>
<td>Epoxy Dowelled Pile Splice Evaluation &amp; Testing</td>
<td>Mehrabi, A.</td>
<td>FIU</td>
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</tbody>
</table>

[https://www.fdot.gov/structures/structuresresearchcenter/activeresearch.shtm](https://www.fdot.gov/structures/structuresresearchcenter/activeresearch.shtm)
FRP-RC Evaluation of Durability: Selected Bridges

- **Eleven bridges** located across the United States in 2017-18
- Each bridge contains GFRP bars in deck or other location and has been in service for **at least 15 years**

- Gills Creek Bridge (VA)
- O’Fallon Park Bridge (CO)
- Salem Ave Bridge (OH)
- Bettendorf Bridge (IA)
- Cuyahoga County Bridge (OH)
- McKinleyville Bridge (WV)
- Thayer Road Bridge (IN)
- Roger’s Creek Bridge (KY)
- Sierrita de la Cruz Creek Bridge (TX)
- Walker Box Culvert Bridge (MO)
- Southview Bridge (MO)
- Pearl Harbor Dry Dock #4 (HI)

[Full Report link](https://www.acifoundation.org/Portals/12/Files/PDFs/GFRP-Bars-Full-Report-with-Addendum.pdf)
FRP-RC Design guidance & standards documents

Design Guidance, Specs, and Design tools:

• Standard Drawings & Design Aids:

Office of Design
Developmental Standard Plans

Developmental Standard Plans are to be released by the appropriate section within the Office of Design to implement new technologies in a limited trial fashion on an as-needed or an as-available basis. As a DDS is released, Bulletin will be issued to announce its availability. Designers wishing to use a DDS must follow the Development Standards Usage Process which is posted in the link provided below. Plans reviewers must verify each DDS, incl. DDDB, is permitted for the use by confirming the project’s FDID number which is listed with the appropriate DDS below.

Use of Developmental Standard Plans requires approval by the FDOT Central Office monitor listed below. See the FDOT Design Manual (FDM), Chapter 115, for additional information.

https://www.fdot.gov/design/standardplans/dev.shtm
FRP-RC Design guidance & standards documents

Design Guidance, Specs, and Design tools:  **Software**

https://www.fdot.gov/structures/proglib.shtm

- **Box Culvert v4.0**  
  11/07/2018  
  GFRP-RC included

- **FB-MultiPier**  
  See UF-BSI Website  
  CFRP-PC coming soon!

- **Live Load Generator-LRFD v3.0**  
  02/18/2011  
  Exe (Zip) (Mathcad 15)

- **Prestressed Beam v5.2**  
  11/07/2018  
  CFRP-PC (w/ GFRP-RC Shear) Beta version **

- **Bent Cap v1.0**  
  11/07/2018  
  GFRP-RC included

- **Retaining Wall v4.0**  
  06/01/2020  
  GFRP-RC included

**Available on request**

- Exe
  - (Zip) (Mathcad 15)

- Zip
  - (Mathcad 15)

- Exe (Zip)
  - (Mathcad 15)

- Exe (Zip)
  - (Mathcad 15)

- Exe (Zip)
  - (Mathcad 15)

- Exe (Zip)
  - (Mathcad 15)

Used with FDOT Standard Plan Index 400-289 (formerly Index 289) to design concrete box culverts, wingwalls, headwalls, and cutoff walls in accordance with the AASHTO LRFD Bridge Design Specification.

FB-MultiPier is a nonlinear finite element analysis program for analyzing bridge pier structures and is supported and available from the University of Florida Bridge Software Institute.

Calculates live loads for truck, truck train, lane, partial lane, and permit loads in accordance with the AASHTO LRFD Bridge Design Specification.

Used with FDOT Standard Plan Index 450-010 to 450-299 (formerly Index 20010 to 20299) to design simple span prestressed beams (Florida-I, AASHTO, Florida Bulb-T, Florida-U, Florida Double-T, Flat Slab, Inverted-T, FSB) in accordance with the AASHTO LRFD Bridge Design Specification.

**Available on request**

Analyzes and designs fixed or pinned bent caps, including lateral loads, in accordance with the AASHTO LRFD Bridge Design Specifications.

Used with FDOT Standard Plan Index 400-010 (formerly Index 6010) to design and analyze cast-in-place retaining walls in accordance with the AASHTO LRFD Bridge Design Specification.
Managing SAM Implementation Challenges, LCC, and Technology Transfer

• Change is hard work and often thankless task...
• Provide early and accessible information...
• Economics is in the eye of the beholder!
6. Life-Cycle Cost analysis strategies

- Comparisons and synergies
  - Economics is (sometimes) in the eye of the beholder
  - Save now, and $$$ later
  - Use realistic discount rates:
    (i) recognizing long-term investment using government bonding rates – highway/bridge construction inflation rates (NHCCI) = < 1%

Idiom: “Penny wise and pound foolish”
6. Life-Cycle Cost analysis strategies

- Comparisons and synergies
- Conventional-RC with periodic Repair & Rehabilitation & CP
- or Durable SAM’s

6. Life-Cycle Cost analysis strategies

- Future enhancements or needs
  - Highly Corrosion-resistant solutions
  - Improvement of Probabilistic techniques

Cadenazzi at al. (2021), “Evaluation of Probabilistic and Deterministic Life-Cycle Cost Analyses for Concrete Bridges Exposed to Chlorides”. *Journal of Cleaner Production* (pending)
Conclusions

• The is a definite place for **Structural Advance Materials**
• Balance **cost** and **needs** => **Value**
• Finding & showing the correct balance is **Our Challenge.**
Questions ???

Contact Information:
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Florida Department of Transportation
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Website: https://www.fdot.gov/design/Innovation/