CFRP & HSSS Strands in Prestressed Concrete Design

Vickie Young and Ge Wan
AGENDA

• PART 1: Corrosion Resistant Materials in Prestressed Concrete

• PART 2: High Strength Stainless Steel (HSSS) Strands

• PART 3: Carbon Fiber Reinforced Polymer (CFRP) Strands
PART 1:
Corrosion Resistant Materials in Prestressed Concrete

AGENDA
1. Introduction
2. Codes & Manuals & References
3. FDOT Current Policy
What are Corrosion Resistant Materials (CRM)?

- Stainless Steel
- Fiber Reinforced Polymers (FRP)
  - Glass (GFRP)
  - Carbon (CFRP)
Introduction

• Focus of this Presentation is limited to Stainless Steel & FRP for:

  1. Reinforcing Bars
  2. Prestressing Strands

• For more information on GFRP & CFRP & Other Innovative Materials

  • Tuesday at 4:20 pm → Structural Advanced Materials for Florida’s Transportation Infrastructure
  • Wednesday at 10:05 am → FRP – Beyond Halls River Bridge
Introduction - Using CRM in Prestressed Concrete Components

• Benefits
  • Lower life cycle costs including reduced Maintenance Costs
  • Reduced concrete cover (FRP)
  • Longer structure life

• Disadvantages
  • Higher Initial Cost (Both HSSS & FRP)
  • Availability & Time (Both HSSS & FRP)
  • Dissimilar metals (CFRP)
  • FRP bars cannot be Field Bent
1. Structures Manual – *Volumes 1 & 4*
2. AASHTO LRFD *Bridge Design Specifications*
3. AASHTO LRFD *Bridge Design Guide Specifications for GFRP-Reinforced Concrete Bridge Decks and Traffic Railings*
4. FDOT *Standard Specifications for Road and Bridge Construction*
Codes & Manuals & References

5. FDOT Materials Manual

6. ACI 440.1 Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars

7. ACI 318 Building Code Requirements for Structural Concrete

8. ACI 440.4 Prestressing Concrete Structures with FRP Tendons
Strand Types:
1. Carbon Steel Strands
2. Stainless Steel Strands
3. Carbon Fiber Reinforced Polymer Strands (CFRP)

Table 3.5.1-1 Concrete Pile Size and Material Requirements

<table>
<thead>
<tr>
<th>Pile Location</th>
<th>Minimum Pile Size (Square inches)</th>
<th>Minimum Cylinder Pile Diameter (Inches)</th>
<th>Material Properties for All Pile Sizes¹</th>
<th>Strand Type</th>
<th>Spiral Type</th>
<th>Reinforcing Bar Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pile Bents</td>
<td>Vehicular Bridges</td>
<td>Pedestrian Bridges &amp; Fishing Piers</td>
<td>New Construction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On land or in environments that are</td>
<td>24²</td>
<td>18²</td>
<td>54²</td>
<td>Carbon steel, Spec 933</td>
<td>Carbon steel, Spec 931</td>
<td>Carbon steel, Spec 931</td>
</tr>
<tr>
<td>Extremely Aggressive due to chlorides</td>
<td></td>
<td></td>
<td></td>
<td>Carbon steel, Spec 933</td>
<td>Carbon steel, Spec 931</td>
<td>Carbon steel, Spec 931</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>14</td>
<td>54</td>
<td>Carbon steel, Spec 933</td>
<td>Carbon steel, Spec 931</td>
<td>Carbon steel, Spec 931</td>
</tr>
<tr>
<td>In water (waterline or mudline) in</td>
<td>24²</td>
<td>18</td>
<td>54</td>
<td>CFRP, Spec 933</td>
<td>CFRP, Spec 932</td>
<td>CFRP, Spec 932</td>
</tr>
<tr>
<td>environments that are Extremely Aggressive</td>
<td></td>
<td></td>
<td></td>
<td>Stainless steel, Spec 933</td>
<td>Stainless steel, Spec 931</td>
<td>Stainless steel, Spec 931</td>
</tr>
<tr>
<td>due to chlorides</td>
<td></td>
<td></td>
<td></td>
<td>Carbon steel, Spec 933</td>
<td>Carbon steel, Spec 931</td>
<td>Carbon steel, Spec 931</td>
</tr>
<tr>
<td>On land or in water in all other</td>
<td>18</td>
<td>14</td>
<td>54</td>
<td>Carbon steel, Spec 933</td>
<td>Carbon steel, Spec 931</td>
<td>Carbon steel, Spec 931</td>
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<tr>
<td>environments</td>
<td></td>
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<td>Carbon steel, Spec 933</td>
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<td>Carbon steel, Spec 931</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>14</td>
<td>54</td>
<td>Carbon steel, Spec 933</td>
<td>Carbon steel, Spec 931</td>
<td>Carbon steel, Spec 931</td>
</tr>
</tbody>
</table>

A. Prestressed Concrete Piling; cost per linear foot (furnished and installed)

<table>
<thead>
<tr>
<th>Size of Piling</th>
<th>Driven Plumb or 1” Batter¹</th>
<th>Driven Battered¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-inch w/ carbon steel strand²</td>
<td>$90</td>
<td>$125</td>
</tr>
<tr>
<td>24-inch w/ carbon steel strand²</td>
<td>$100</td>
<td>$140</td>
</tr>
<tr>
<td>30-inch w/ carbon steel strand²</td>
<td>$150</td>
<td>$210</td>
</tr>
<tr>
<td>18-inch w/ CFRP or Stainless Steel Strand</td>
<td>$135</td>
<td>$160</td>
</tr>
<tr>
<td>24-inch w/ CFRP or Stainless Steel Strand</td>
<td>$150</td>
<td>$210</td>
</tr>
<tr>
<td>30-inch w/ CFRP or Stainless Steel Strand</td>
<td>$225</td>
<td>$280</td>
</tr>
</tbody>
</table>

¹ When silica fume, metakaolin or ultrafine fly ash is used, add $6 per LF to the piling cost.
² When heavy mild steel reinforcing is used in the pile head, add $250.
HSSS

- Bars
  - Use following steel reinforcing for concrete design with prior approval from the SDO:
    - ASTM A955 Grade 60 or 75, or ASTM A276, UNS S31603 or S31803 deformed stainless steel bar

- Strands
  - The stainless steel strands for prestressing concrete members shall be a high strength stainless steel (HSSS) conforming to the chemical requirements of ASTM A276, UNS S31803 or S32205 (Type 2205) and the mechanical and dimensional requirements of ASTM A416, except the minimum ultimate tensile strength shall be 240 ksi.

CFRP

- Bars
  - GFRP and CFRP reinforcing bars may be used in the following concrete components when approved by the SSDE:
    - Approach Slabs, & Bridge Decks and Overlays
    - Cast-in-Place Flat Slab Superstructures
    - Pile Bent Caps not in direct contact with water
    - Pier Columns and Caps not indirect contact with water
    - Retaining Walls, Noise Walls, Perimeter Walls
    - Traffic Railings & Pedestrian/Bicycle Railings
    - Bulkheads and Bulkhead Copings
    - MSE Wall Panels & Copings
    - Drainage Structures

- Strands
  - Obtain CFRP prestressing strands from producers currently on the Department’s Production Facility Listing. Producers seeking inclusion on the list shall meet the requirements of Section 105.
Standard Plans

• 455-101 Square CFRP and SS Prestressed Concrete Piles Series
• 455-440 Precast Concrete Sheet Pile Wall (CFRP/GFRP & HSSS/GFRP)

Developmental Standard Plans

• D21310 FRP Bar Bending Details
• D22420 Traffic Railing (32” F Shape – GFRP Reinforced)
• D22440 Precast Concrete CFRP/GFRP Sheet Pile Wall
• D22900 Approach Slab – GFRP Reinforced
**FDOT POLICY**

**STRAND PATTERN**

- 28 ~ ½" Ø, HSS at 26 kips

**ALTERNATE STRAND PATTERNS**

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

**ALTERNATE STRAND PATTERNS**

- 16 ~ 0.6" Ø, Grade 270 LRS, at 44 kips
- 20 ~ ½" Ø (Special), Grade 270 LRS, at 34 kips
- 24 ~ ½" Ø, Grade 270 LRS, at 31 kips
PART 2:
High Strength Stainless Steel (HSSS) Strands

AGENDA
1. Research
2. Design Considerations
3. Projects
Previous Research

Design and Construction of Precast Piles with Stainless Steel Reinforcing

- Done USF in 2014
- Additional Follow Up Testing done by FDOT SRC 2017 – 2018

Research Project Objective:
- Evaluate 3 Different Stainless Steel Materials to identify a suitable Stainless Steel Strand
- Grade 316 SS, XM-29 & Duplex 2205

Testing & Evaluation Included:
- Structural Capacity
- Long-term Relaxation
- Corrosion Resistance
- Field Fabrication
- Cost Comparison

Final Conclusions & Recommendations:
- Use Duplex 2205

Table (1) Mechanical properties of strands

<table>
<thead>
<tr>
<th>Mechanical properties</th>
<th>Carbon Steel</th>
<th>2205</th>
<th>XM-29</th>
<th>316</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (in)</td>
<td>0.507</td>
<td>0.504</td>
<td>0.515</td>
<td>0.497</td>
</tr>
<tr>
<td>Area (in$^2$)</td>
<td>0.155</td>
<td>0.152</td>
<td>0.158</td>
<td>0.151</td>
</tr>
<tr>
<td>Ultimate Tensile Strength (ksi)</td>
<td>289.65</td>
<td>264.43</td>
<td>238.13</td>
<td>189.75</td>
</tr>
<tr>
<td>Ultimate strain %</td>
<td>7.6</td>
<td>2.3</td>
<td>2.0</td>
<td>2.5</td>
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<tr>
<td>Elastic modulus (ksi)</td>
<td>28,732</td>
<td>25,000</td>
<td>22,546</td>
<td>21,541</td>
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</tbody>
</table>
Ongoing Research

Stainless Steel Strands for Pretensioned Concrete Girders

- Done by FSU with support from:
  - Structures Research Center for Structural Testing
  - Structures Materials Office for Material Testing

- Research Project Objective:
  - Strength
  - Ductility
  - Deformability
  - Evaluate Shear Using CRM Bars

- Material Testing:
  - 0.6” Diameter Low Relaxation Stainless Steel Strands

- Structural Testing:
  - Testing AASHTO Type II Girders with 0.6” Diameter HSSS Strands
  - Stainless Steel Bars for Shear Reinforcement
  - GFRP Bars for Shear Reinforcement

<table>
<thead>
<tr>
<th>Task #</th>
<th>Task Description</th>
<th>Status</th>
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<tr>
<td>n/a</td>
<td>Kickoff Meeting</td>
<td>✔</td>
</tr>
<tr>
<td>1</td>
<td>Design Proposed Girders for Testing</td>
<td>✔</td>
</tr>
<tr>
<td>2</td>
<td>Testing &amp; Instrumentation Plans</td>
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<tr>
<td>3</td>
<td>Fabricated Girders and Field Evaluation</td>
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<tr>
<td>4</td>
<td>Flexural Testing</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Evaluate Test Data &amp; Provide Design &amp; Detailing Guidelines</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Shear Testing</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Evaluate Test Data &amp; Provide Design &amp; Detailing Guidelines</td>
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<tr>
<td>8 - 9</td>
<td>Lightweight Concrete Testing</td>
<td>N/A</td>
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<tr>
<td>10</td>
<td>Draft and Final Reports</td>
<td></td>
</tr>
</tbody>
</table>
Ongoing Research
Stainless Steel Strands for Pretensioned Concrete Girders

Research Project Objective In Depth, Verify the Following:

- **Initial Stress**
  - Carbon Steel Strand → 270 ksi @ 75%
  - SS Strand → 240 ksi @ 65%

- **Cracking Moment**
  - Carbon Steel Strand → Mcr or 1.33Mu
  - SS Strands → 1.1Mcr or 1.5Mu
  *Adjusted due to lower ductility

- **Elongation**
  - Carbon Steel Strand → 3.5%
  - SS Strand → ~ 1.5%
  *Note: Minimum Acceptable Values to be included in the Specifications*

- **Allowable Tension**
  - Carbon Steel → $0.19\sqrt{f_c}$ or $0.0948\sqrt{f_c}$ ksi
  - SS Strands → $0.0948\sqrt{f_c}$ or 0 ksi
  *To compensate for Lower Elastic Modulus*
## Ongoing Research

**Stainless Steel Strands for Pretensioned Concrete Girders**

### Testing Matrix:

<table>
<thead>
<tr>
<th>Girder Designation</th>
<th>Strand Type</th>
<th>Stainless Steel</th>
<th>Number of Strands</th>
<th>End Zone Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>X</td>
<td>X</td>
<td>11</td>
<td>X</td>
</tr>
<tr>
<td>A2</td>
<td>X</td>
<td>X</td>
<td>11</td>
<td>X</td>
</tr>
<tr>
<td>A3</td>
<td>X</td>
<td>X</td>
<td>11</td>
<td>X</td>
</tr>
<tr>
<td>B2</td>
<td>X</td>
<td>X</td>
<td>11</td>
<td>X</td>
</tr>
<tr>
<td>B3</td>
<td>X</td>
<td>X</td>
<td>11</td>
<td>X</td>
</tr>
<tr>
<td>C1</td>
<td>X</td>
<td>X</td>
<td>13</td>
<td>X</td>
</tr>
<tr>
<td>C2</td>
<td>X</td>
<td>X</td>
<td>13</td>
<td>X</td>
</tr>
<tr>
<td>C3</td>
<td>X</td>
<td>X</td>
<td>13</td>
<td>X</td>
</tr>
</tbody>
</table>

#### Diagrams:

- **Type 1**: 11 Strands
- **Type 2**: 13 Strands

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**FDOT**

**FAMU-FSU College of Engineering**

**Transportation Symposium**
Ongoing Research

Stainless Steel Strands for Pretensioned Concrete Girders

- SRC has 6,000 ft of 0.6” SS Strand
- Material Testing Performed:
  - ASTM A1061 – Tensile Tests for Mechanical Properties
  - ASTM A1061 – Tensile Tests Using Conventional Wedge Grips
  - ASTM A1081 – Tensile Tests to Evaluate Bond
- Results ➔ Stay Tuned...
Aspire Magazine

Spring 2018 Issue, 2 articles were published regarding Stainless Steel Strands:
1. **Structural Design Using Stainless Steel Strands**
2. **Production of Prestressed Concrete Piles Using Stainless Steel Strand**

### Comparison of Material Properties for Types of Strands

<table>
<thead>
<tr>
<th>Strand Material</th>
<th>Minimum Tensile Strength $f_{pu}$, ksi</th>
<th>Elastic Modulus $E$, ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>2205 Stainless Steel Grade 250*</td>
<td>250</td>
<td>25,500</td>
</tr>
<tr>
<td>1080 Carbon Steel Grade 270*</td>
<td>270</td>
<td>28,600</td>
</tr>
</tbody>
</table>

GUTS = guaranteed ultimate tensile strength.
*Nominal value—actual value may vary with manufacturer's production lot.
Current Design Considerations

• **Strength:**
  • Ultimate Tensile Strength = 240 ksi per Specification Section 933 (250 ksi mill cert)

• **Ductility:**
  • Elongation ≈ 1.5% (1.9% mill cert)

• **Elastic Modulus:**
  • Modulus of Elasticity ≈ 25,000 ksi (24,400 ksi mill cert)

• **Once Research is Complete, Guidance On the Following:**
  • Initial Stress (65% of ultimate)
  • Cracking Moment
  • Allowable Tension

Red Text is the information for the 0.6” dia. strand currently at FDOT SRC
Projects

• Airport Road at Daughtry Bayou, Levy County
  • 24” Sq. PCP with Stainless Steel Strand and Reinforcing

• Gulf Boulevard at Lewis Pass, Levy County
  • 24” Sq. PCP with Stainless Steel Strand and Reinforcing
PART 3:
Carbon Fiber Reinforced Polymer (CFRP) Strands

AGENDA
1. Tensile Behavior of CFRP Strands
2. Beams Prestressed with CFRP Systems
3. Design Guidance
4. Design Considerations
5. Design Example
Why CFRP strands?

- **FDOT Structures Design Innovation**
- Fiber Reinforced Polymer (FRP) Bars and Strands
  - Glass (GFRP)
  - Basalt (BFRP)
  - Carbon (CFRP)
- **AASHTO Innovation Initiative**
- Advantages of CFRP Strands
  - Superior corrosion resistance
  - Light weight and flexible
  - High tensile strength
  - Good creep and fatigue resistance

[Image of CFRP strands]
Tensile Behavior of CFRP Systems

- No plastic behavior before rupture
- The tensile strength and stiffness are dependent on:
  - Fiber content
    - Fiber mass fraction $\geq 70\%$ [FDOT Specs Section 933]
  - Rate of curing
  - Manufacturing process
  - Manufacturing quality control
Tensile Behavior of CFRP Strands

• Typical values for the tensile strength:
  
<table>
<thead>
<tr>
<th>Type</th>
<th>Nominal Diameter (in)</th>
<th>Nominal Cross Sectional Area (in²)</th>
<th>Nominal Ultimate Load (Ps) (kips)</th>
<th>Nominal Ultimate Tensile Stress (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Strand - 5.0mm Ø</td>
<td>0.20</td>
<td>0.030</td>
<td>9</td>
<td>300</td>
</tr>
<tr>
<td>7-strand - 7.5mm Ø</td>
<td>0.30</td>
<td>0.050</td>
<td>17</td>
<td>340</td>
</tr>
<tr>
<td>7-strand - 10.5mm Ø</td>
<td>0.41</td>
<td>0.060</td>
<td>32</td>
<td>355</td>
</tr>
<tr>
<td>Single Strand - 9.5mm Ø</td>
<td>0.38</td>
<td>0.081</td>
<td>35</td>
<td>318</td>
</tr>
<tr>
<td>7-strand - 12.5mm Ø</td>
<td>0.49</td>
<td>0.118</td>
<td>41</td>
<td>347</td>
</tr>
<tr>
<td>Single Strand - 12.7mm Ø</td>
<td>0.50</td>
<td>0.196</td>
<td>59</td>
<td>301</td>
</tr>
<tr>
<td>7-strand - 13.2mm Ø</td>
<td>0.60</td>
<td>0.179</td>
<td>61</td>
<td>341</td>
</tr>
<tr>
<td>19-strand - 20.5mm Ø</td>
<td>0.81</td>
<td>0.320</td>
<td>71</td>
<td>222</td>
</tr>
<tr>
<td>7-strand - 17.2mm Ø</td>
<td>0.68</td>
<td>0.234</td>
<td>79</td>
<td>338</td>
</tr>
<tr>
<td>19-strand - 25.5mm Ø</td>
<td>1.00</td>
<td>0.472</td>
<td>103</td>
<td>222</td>
</tr>
<tr>
<td>19-strand - 28.5mm Ø</td>
<td>1.12</td>
<td>0.521</td>
<td>134</td>
<td>215</td>
</tr>
<tr>
<td>37-strand - 35.5mm Ø</td>
<td>1.40</td>
<td>0.916</td>
<td>189</td>
<td>206</td>
</tr>
<tr>
<td>37-strand - 40.0mm Ø</td>
<td>1.57</td>
<td>1.240</td>
<td>270</td>
<td>218</td>
</tr>
</tbody>
</table>

  [FDOT Specs Section 933 ]

• Typical values for the modulus of elasticity: 17,000 to 25,000 ksi.
  • 18,000 ksi minimum  [FDOT Specs Section 933 ]
Beams Prestressed with CFRP Strands

- Lower modulus of elasticity
- Lack of traditional ductility
- Acceptable deformability can be achieved

[ACI 440.4R-04 Fig. 3.1]
Design Guidance

NCHRP 12-97
Proposed AASHTO LRFD Bridge Design Guide Specifications and Material Specifications for Concrete Bridge Beams Prestressed with Carbon Fiber-Reinforced Polymer Systems

Abdeldjelil Belarbi, PhD, PE
belarbi@uh.edu

T-6 (FRP Composites)
Design Considerations - Prestressing

• Stress Limitations for Prestressing CFRP
  • Immediately prior to transfer \( (f_{pbt}) : 0.70 f_{pu} \)
  • At service limit state after all losses \( (f_{pe}) : 0.65 f_{pu} \)

• Prestress Losses

\[
\Delta f_{pt} = \Delta f_{pES} + \Delta f_{pLT} + \Delta f_{pTH}
\]

• Elastic shortening \( (\Delta f_{pES}) \)

\[
\Delta f_{pES} = \frac{E_f}{E_{ct}} f_{cgp}
\]

• Long-term shrinkage and creep of concrete, and relaxation of CFRP \( (\Delta f_{pLT}) \)

\[
\Delta f_{pRT} = \left( 0.019 \left( \frac{f_{pt}}{f_{pu}} \right) - 0.0066 \right) \log(24t) \times f_{pu}
\]

• Temperature change \( (\Delta f_{pTH}) \)

\[
\Delta f_{pTH} = \Delta T (\alpha_{f,T} - \alpha_c) E_f \geq 0
\]
Design Considerations - Prestressing

• Development of Prestressing CFRP
  • Transfer length
    \[ \ell_t = \frac{f_{pbt}d_b}{\alpha_t f_{ci}^{0.67}} \]
  • Flexural bond length
    \[ \ell_b = \frac{(f_{pu} - f_{pe})d_b}{\alpha_d f_c^{0.67}} \]
  • Development length
    \[ l_d = \ell_t + \ell_b \]
Design Considerations - Service

• Concrete Stresses

• Article 5.9.2.3 of the AASHTO LRFD Bridge Design Specifications

<table>
<thead>
<tr>
<th>Allowable stress at transfer of prestress (before losses)</th>
<th>(ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Extreme fiber stress in compression</td>
<td>$0.65 f'_{ci}$</td>
</tr>
<tr>
<td>(b) Extreme fiber stress in tension except (c)</td>
<td>$0.0948 \sqrt{f'_{ci}}$</td>
</tr>
<tr>
<td>(c) Extreme fiber stress in tension at ends</td>
<td>$0.24 \sqrt{f'_{ci}}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Allowable stress under service load (after losses)</th>
<th>(ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Extreme fiber stress in compression due to prestress plus sustained loads</td>
<td>$0.45 f'_{c}$</td>
</tr>
<tr>
<td>(b) Extreme fiber stress in compression due to prestress plus total loads</td>
<td>$0.60 f'_{c}$</td>
</tr>
<tr>
<td>(c) Extreme fiber stress in precompressed tensile zone – moderate corrosion</td>
<td>$0.19 \sqrt{f'_{c}}$</td>
</tr>
<tr>
<td>– severe corrosion</td>
<td>$0.0948 \sqrt{f'_{c}}$</td>
</tr>
</tbody>
</table>

[FDOT SM Vol.4]
Design Considerations - Strength

• General Procedure
  • The design principles are based upon equilibrium and strain compatibility.

• Resistance Factors
  • 0.75 for tension controlled (CFRP rupture)
  • 0.75 for compression controlled (concrete crushing)
Design Example

- FIB 72 @ 10’ spacing, 155’ span, moderately aggressive
- See Standard Plans Instructions of Index 450-072 for full list of design assumptions
<table>
<thead>
<tr>
<th></th>
<th>Low Relaxation Steel</th>
<th>CFRP</th>
<th>CFRP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diameter,(d_b)</strong></td>
<td>0.6 inch</td>
<td>0.6 inch</td>
<td></td>
</tr>
<tr>
<td><strong>Area,(A_{ps})</strong></td>
<td>0.217 sq. inch</td>
<td>0.179 sq. inch</td>
<td></td>
</tr>
<tr>
<td><strong>Modulus of elasticity,(E_p)</strong></td>
<td>28,500 ksi</td>
<td>22,400 ksi</td>
<td></td>
</tr>
<tr>
<td><strong>Ultimate tensile stress,(f_{pu})</strong></td>
<td>270 ksi</td>
<td>341 ksi</td>
<td></td>
</tr>
<tr>
<td><strong>Yield strength,(f_{py})</strong></td>
<td>243 ksi (90%(f_{pu}))</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td><strong>Jacking stress,(f_{pj})</strong></td>
<td>202.5 ksi (75%(f_{pu}))</td>
<td>238.7 ksi (70%(f_{pu}))</td>
<td></td>
</tr>
<tr>
<td><strong>Effective stress after losses,(f_{pe})</strong></td>
<td>171.3 ksi (15%(f_{pu}))</td>
<td>203.5 ksi (14.7%(f_{pu}))</td>
<td></td>
</tr>
<tr>
<td><strong>Effective prestressing force per strand</strong></td>
<td>37.2 kips</td>
<td>36.4 kips</td>
<td></td>
</tr>
<tr>
<td><strong>Total number of strands</strong></td>
<td>59</td>
<td>59</td>
<td>62</td>
</tr>
<tr>
<td><strong>Service stress checks</strong></td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td><strong>Strength I flexural demand,(M_u)</strong></td>
<td>16239 kip*ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nominal flexural capacity,(M_n)</strong></td>
<td>19280 kip*ft</td>
<td>20972 kip*ft</td>
<td>21880 kip*ft</td>
</tr>
<tr>
<td><strong>Factored flexural capacity,(\phi M_n)</strong></td>
<td>19280 kip*ft ((\phi =1.00))</td>
<td>15729 kip*ft ((\phi =0.75))</td>
<td>16410 kip*ft ((\phi =0.75))</td>
</tr>
</tbody>
</table>
Summary

- Why CFRP and HSSS strands?
  - Corrosion resistance
  - Lower life cycle costs, including reduced maintenance and rehabilitation work
  - Comparable performance to steel in the finished product in terms of load carrying capacity, constructability, and other factors

- FDOT has implemented Specifications, Design Criteria and Guidelines

- Standard Plans to use both CFRP and HSSS strands in Prestressed Concrete Piles and Sheet Piles were released in 2016
Summary

• What’s coming:
  • Implementation of CFRP and HSSS Strands for PS Concrete Girders
  • Once implemented, the Beam Program will be modified to select one of the following strand types:
Thank You!

SPECIAL THANKS TO:

WILL POTTER
STEVE NOLAN
STATE MATERIALS OFFICE