Presentation Outline

- Prestressing basics
- Background on end region reinforcement
- FIB54 Test Program – Service and Ultimate
- FIB63 Test Program – Service
- Findings
Effect of Prestressing
Prestressing-Hoyer Effect

Flame-cut strand

Unstressed strand expands back to original diameter

Concrete restrains expansion of strand
Result: tension stress

Prestressing-Transfer Length

Girder FBD
Bond Stress

Tendon FBD
Tendon Force
Effective prestress force in tendon
Transfer Length (60d,c)
Prestressing-Transfer Length

Girder FBD

Bond Stress

Effective prestress force in tendon

Distance from end of girder (in.)

Tendon FBD

Bond Stress

Effective prestress force in tendon

th (60d₀)

Prestressing Effect-Splitting

ε_z

Refined Mesh

Tension
5.10.10.1 Factored Bursting Resistance

The bursting resistance of pretensioned anchorage zones provided by vertical reinforcement in the ends of pretensioned beams at the service limit state shall be taken as:

\[ P_e = f_s A_s \]  \hspace{1cm} (5.10.10.1-1)

where:

- \( f_s \) = stress in steel not exceeding 20 ksi
- \( A_s \) = total area of vertical reinforcement located within the distance \( h/4 \) from the end of the beam (in.²)
- \( h \) = overall depth of precast member (in.)

The resistance shall not be less than 4 percent of the prestressing force at transfer.

The end vertical reinforcement shall be as close to the end of the beam as practicable.
5.11.4.3 Partially Debonded Strands

Excerpt:
The number of partially debonded strands should not exceed 25 percent of the total number of strands.
The number of debonded strands in any horizontal row shall not exceed 40 percent of the strands in that row.
Ultimate strength-Strut and Tie

Considerations
- Factored Load
- Flange Geometry
- Bearing
- Geometry
- Strand Locations

\[ R_z = G_z + 2E_z \]

Lateral-Splitting Failure

Isometric
End region & lateral-splitting crack

Section A-A
Without confinement reinforcement

Section A-A
With confinement reinforcement
LRFD "Confinement"

5.10.10.2 Confinement Reinforcement

For the distance of 1.5d from the end of the beams other than box beams, reinforcement shall be placed to confine the prestressing steel in the bottom flange. The reinforcement shall not be less than No. 3 deformed bars, with spacing not exceeding 6.0 in. and shaped to enclose the strands.

For box beams, transverse reinforcement shall be provided and anchored by extending the leg of stirrup into the web of the girder.
Research Approach

FIB54: Flange Cracks & Ultimate Capacity
FIB63: Web Cracks
Finite Element Analysis

FIB54
- 10 Specimens (5 beams)
- Fabrication
  - Strain data
  - Crack data
- Load tests
  - Behavior
  - Capacity
<table>
<thead>
<tr>
<th>Girder H</th>
<th>Girder V</th>
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<tbody>
<tr>
<td>HC</td>
<td>VC</td>
</tr>
<tr>
<td>HU</td>
<td>VU</td>
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<table>
<thead>
<tr>
<th>Girder W</th>
<th>Girder F</th>
<th>Girder D</th>
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<tbody>
<tr>
<td>WN</td>
<td>FN</td>
<td>DC</td>
</tr>
<tr>
<td>WB</td>
<td>FB</td>
<td>DM</td>
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</table>
FDOT Confinement

Modified Confinement

No Confinement

(2)

Bearing Plate

No Bearing Plate
**FIB54 Debonding**

- Fully Bonded
- Shielded entire length
- Shielded 10 ft
- Shielded 5 ft

**Design Pattern**

- 13% debonded

**Flange Pattern**

- 45% debonded

**Web Pattern**

**FIB54 Results**

Flange Splitting Cracks
**Length of flange-splitting cracks**

<table>
<thead>
<tr>
<th>Total length (in.)</th>
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</thead>
<tbody>
<tr>
<td>219.5</td>
</tr>
<tr>
<td>134.0</td>
</tr>
<tr>
<td>107.0</td>
</tr>
<tr>
<td>104.0</td>
</tr>
<tr>
<td>41.5</td>
</tr>
<tr>
<td>44.0</td>
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</tbody>
</table>

**Analytical Program**

- **Half symmetry FIB-54 cross-section**
- **Solid elements**
  - 10 ft. - 0 in.
- **Beam elements**
  - 39 ft. - 6 in.
- **Rigid link**
- **X & Z translation fixed at far support**

**Symbols**

- $F_y$: Prestress force
- $T_r$: Prestress transfer length
- $Z_o$: Z coordinate of girder centroid
- $Z_p$: Z coordinate of prestress centroid

Self-weight (not shown) applied using "mass-proportional" feature in ADINA.

X translation fixed at Y-Z plane of symmetry.

Z translation fixed at nodes along bottom edge at near support.

Embedded bearing plate modeled with shell elements.
**FEA + Experimental-Transfer Length**

Stage 1 – outer strands released  
Stage 2 – all strands released

**FEA + Experimental-Web Stresses**

Location of vertical (ε_v)  
FEA strain data  
X = 0 in., Z = 36 in.

Location of longitudinal (ε_l)  
FEA strain data  
X = 19 in., Z = 6 in.

Experimental gages at  
Y = 18 in., 5 in.
FEA + Experimental-Transverse Tension

Location of lateral ($l_e$)
FEA strain data
$X = 0$ in., $Z = 8$ in.

Experimental gages at
$Y = 2$ in., 24 in., & 48 in.

Lateral ($l_e$) microstrain (in. $	imes$ 10$^6$)

Y Coordinate (in.)

FIB54-Topping

UF

UF
**FIB54-Test Setup**

- Shear-span = 10 ft
- a/d ~ 2
- FIB54 w/ 8 in. deck
- 50 ft long
- 44 ft span
- 62 in.
- 0.6in. Dia. strands

**FIB54-Test Procedures**

Images showing test procedures.
FIB54-Test Procedures

FIB54-Results
Ultimate Capacity
Failure Modes

**Bond-Shear**
(2) specimens

**Web-Shear**
(4) specimens

**Lateral-Splitting**
(4) specimens

Ultimate Capacity

- Bond-shear
  - $V_n = 528k$ [AASHTO]
  - $V_n = 454k$ [ACI]

- Lateral-splitting
Ultimate Capacity-Transverse Strain
Ultimate Capacity-Transverse Strain

Stress in confinement reinforcement vs. average stress (ksi)

- WN: 14.0, 29.8
- WB: 4.4
- FN: 10.0, 35.8
- FB: 12.8

Includes stress from loading & prestressing.

V = 375 kip

Ultimate Capacity-Transverse Strain

Ultimate Capacity-Transverse Strain

Ultimate Capacity-Transverse Strain

\[ F_{\text{con}} = F_{\text{con}} + F_{\text{pre}} \]
**Ultimate Capacity-Transverse Strain**

- **V=375**
- **Ultimate**

<table>
<thead>
<tr>
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<th>HC</th>
<th>VC</th>
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<th>FB</th>
<th>DC</th>
<th>DM</th>
<th>Avg.</th>
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<tr>
<td>% of transverse (x-x) force carried by bearing plate</td>
<td>75.9</td>
<td>73.0</td>
<td>78.8</td>
<td>70.1</td>
<td>63.9</td>
<td>44.2</td>
<td>37.0</td>
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**FIB63**

- 4 specimens (2 beams)
- Monitor cracks after release
- Load test
**FIB63 Reinforcement and Prestressing Scheme**

- **PT** Post-Tensioned
- **LB** 1in. φ Bars
- **CT** Control
- **SL** 45% Shielding

**Shielding Legend**
- • No shielding
- φ Shielded 5'-0" from end

**FIB63 Test Specimens**

- **SL**
- **CN**
- **LB**
- **PT**
Release Stresses

Calculated Allowable

FIB63 Test Specimens
Web Splitting Cracks

**Total Web Crack Length**

<table>
<thead>
<tr>
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<th>PT</th>
<th>LB</th>
<th>CT</th>
<th>SL</th>
<th>Average</th>
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</thead>
<tbody>
<tr>
<td>Length (in.)</td>
<td>186</td>
<td>336</td>
<td>369</td>
<td>261</td>
<td>288</td>
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</tbody>
</table>

**Total Web Crack Area**

<table>
<thead>
<tr>
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<th>LB</th>
<th>CT</th>
<th>SL</th>
<th>Average</th>
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</thead>
<tbody>
<tr>
<td>Area (in²)</td>
<td>1.10</td>
<td>1.00</td>
<td>1.71</td>
<td>0.69</td>
<td>1.12</td>
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</tbody>
</table>

**Average Crack Width**

<table>
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<th>SL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width (in)</td>
<td>0.0059</td>
<td>0.0030</td>
<td>0.0046</td>
<td>0.0026</td>
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</table>

**Maximum Crack Width**

<table>
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<th>LB</th>
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<th>SL</th>
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</thead>
<tbody>
<tr>
<td>Width (in)</td>
<td>0.012</td>
<td>0.008</td>
<td>0.008</td>
<td>0.006</td>
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</tbody>
</table>
Conclusions-Ultimate Strength

- Horizontal reinforcement - Negligible
- Bearing plate - 9% to 21% improvement
- FDOT confinement reinforcement - 13% increase over no reinforcement
- Bonded Strand - 43% increase for strands placed under web

Conclusions-Flange Splitting

- Tension stress
  - Outer strands
  - Hoyer effect
- Strategies
  - Bonded strand arrangement
  - Confinement reinforcement
  - Bearing plate
  - Partial debonding
Conclusions–Web Splitting

- Post-tensioning (PT)
  - Promising
  - Additional research

- Large diameter bars (LB)
  - Reduce crack width
  - No effect on crack length

- 45% strand shielding (SL)
  - Shorter, smaller cracks
  - Affects strength
Thank You

- Experimental work conducted at M. H. Ansley Structures Research Center
- Many thanks to Sam Fallaha and the Center’s staff!
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- Paul Tighe
- David Wagner
- Chris Weigly
- Steven Nolan, P.E., FDOT Structures Design Office

Wish List

- Flange Strands
- Web Strands
- Flange Strands
- Bottom Flange