Florida Slab Beam (FSB) with Ultra-High Performance Concrete (UHPC) Joint Connections

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Outline

• Background
  • Slab Beams
  • Florida Slab Beam (FSB)
  • Ultra-High Performance Concrete (UHPC)

• Objectives

• Supporting Tasks

• Current Progress
Background

Slab Beams

Slab beams have been used in construction since prestressing began in the US

**Prestressed Rectangular Slab Units (1955)**
- 10” wide closure pour
- No topping
- Forming required

**Prestressed Voided Slab Units – Sonovoids (1959)**
- Transverse tie bars in sleeves
- Grouted shear key
- 4” asphalt topping
- Voids reduce weight

**Prestressed Keyed Slab Units (1958)**
- Transverse tie bars in sleeves
- 4” C.I.P concrete topping
- No forming required

**Prestressed Slab Units – PSU (2008)**
- Grouted shear key
- 6” C.I.P concrete topping
Background

Slab Beams – Performance

There have been some issues observed with previously used slab beams
Background

Slab Beams

Poor performance of previous systems led to development of alternate systems

**Precast Composite Slab Span System – PCSS (2005)**

**Florida Slab Beam – FSB (2015)**

These systems require field placement of large reinforcement
Background

Ultra-High Performance Concrete (UHPC)

<table>
<thead>
<tr>
<th>Property</th>
<th>Range</th>
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</thead>
<tbody>
<tr>
<td>Compressive Strength ( f'_c )</td>
<td>20 to 30 ksi</td>
</tr>
<tr>
<td>Tensile Cracking Strength ( f_r )</td>
<td>0.9 to 1.5 ksi</td>
</tr>
<tr>
<td>Modulus of Elasticity ( E_c )</td>
<td>6,000 to 10,000 ksi</td>
</tr>
</tbody>
</table>

Source: [https://www.fhwa.dot.gov/research/resources/uhpc/](https://www.fhwa.dot.gov/research/resources/uhpc/)
Research Objectives

• Develop cross-section and joint region detail for short- to medium-span bridges for use with accelerated construction

• Assess strength and fatigue performance of cross-section and joint

• Recommend fabrication procedures, on-site construction practices, and erection tolerances
Methodology

Literature Review
Review all available research and field applications for UHPC joints and short-span bridge solutions.
(Tasks 1 and 2)

Analytical Program
Develop and analyze modified sections/joints and their impact on design through numerical analysis and parametric study.
(Tasks 2, 3 and 6)

Refine Numerical Models
Optimize Developed Section

Experimental Program
Evaluate and refine developed sections through small- and full-scale testing.
(Tasks 4 and 5)
Supporting Tasks

1. Literature Review (short-span bridge options, joint details, current practices)
2. Conceptually and Analytically Develop FSB Design Standards and UHPC Joint Details
3. Conceptually and Analytically Develop FSB for 75-ft. Single Span with UHPC Joints
4. Small-Scale Joint Testing
   a) Develop and Evaluate Alternative FSB and UHPC Connection Details and Testing Protocol
   b) Develop Construction Documents for Beam Fabrication
   c) Fabricate Small-Scale Specimens for Strength and Fatigue Testing
   d) Strength Testing of Small-Scale Specimens
   e) Fatigue Testing of Small-Scale Specimens
Supporting Tasks (continued)

5. Full-Scale Specimen Testing
   a) Develop and Evaluate Alternative FSB Details and Testing Protocol
   b) Develop Construction Documents for Beam Fabrication
   c) Fabricate Full-Scale Specimens for Strength and Fatigue Testing
   d) Strength Testing of Full-Scale Specimens
   e) Fatigue Testing of Full-Scale Specimens

6. Conceptually and Analytically Develop FSB Detail as a Continuous Span

7. Draft Final Report and Closeout Teleconference

8. Final Report
Task 1 – Literature Review

Objectives

• Short-span bridge solutions
• Longitudinal and transverse joints (non-UHPC and UHPC)
• Current practice with UHPC joints
• SDCL in prestressed concrete bridges
Task 1 – Literature Review
Longitudinal and Transverse Joints (UHPC)

Full-Depth Deck Connections

Adjacent Box-Beam Connections

(Aeleti and Sritharan, 2014)

(Graybeal FHWA)
Task 2 – Section and Joint Development

Objectives

• Feasible span lengths for beams without CIP deck
• Preliminary joint and section designs

Feasible span lengths

Modified section and joint
Task 2 – Section and Joint Development

Feasible Span Lengths

Current Design

- $h_{topped} = 24''$
- $t_{slab} = 6''$

Modified for ABC

- $h_{untopped} = 18''$
- $t_{slab} = 0''$

$L_{max, topped} = 61'$

$L_{max, untopped} = 55'$

Using FDOT Design MathCAD Program
Task 2 – Section and Joint Development

Development of Joint Details

Option 1 – Box Beam Joint Integration

Joint 1 – Integrated Box Beam Joint:
Task 2 – Section and Joint Development

Development of Joint Details

Options 2 and 3 – FDOT Joints

Original FSB Section:

FDOT 1

FDOT 2

Joint 2 – No Shear Key
(4” lip)

Joint 3 – No Shear Key
(2” lip)
Task 2 – Section and Joint Development
Development of Joint Details

Options 4 – Modified Box Beam Joint

Joint 1 – Integrated Box Beam Joint

Joint 4 – Modified Box Beam Joint

(Note this joint was developed after some testing in Task 4)
Task 2 – Section and Joint Development

Development of Joint Details

Joint 1 – Integrated Box Beam Joint:

Joint 2 – No Shear Key (4” lip):

Joint 3 – No Shear Key (2” lip):

Joint 4 – Modified Box Beam Joint:
Task 2 – Section and Joint Development
Numerical Modeling of Joint Details

**Experimental Setup**

- 84"
- 12"
- 53"
- 53"

wheel path (20”x10”)

**Numerical Model**
Task 3 – FSB for 75-ft. Span

Objectives

Determine options for 75-ft. span
• No CIP deck
• Adaptable for ABC projects (UHPC Joint)
• High notoriety
Task 3 – FSB for 75-ft. Span

Section Options

- **Box Beam**
  - Height: 28”
  - Strands: 18

- **Inverted-T Beam**
  - Height: 28”
  - Strands: 20

- **NEXT D Beam**
  - Height: 36”
  - Strands: 40

- **Pre-Topped Florida**
  - Height: 28”
  - Strands: 20

- **Modified Florida Slab Beam**
  - Height: 27”
  - Strands: 39
### Task 3 – FSB

**Section Options**

<table>
<thead>
<tr>
<th>Section Type:</th>
<th>Texas 4B28</th>
<th>NEXT D 96</th>
<th>Pre-Topped FIT</th>
<th>FSB 27x53</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>depth [in]</strong></td>
<td>28</td>
<td>36</td>
<td>28</td>
<td>27</td>
</tr>
<tr>
<td><strong>width [in]</strong></td>
<td>48</td>
<td>96</td>
<td>48</td>
<td>53</td>
</tr>
<tr>
<td><strong>0.6” diameter strands for 75’ length</strong></td>
<td>18</td>
<td>40</td>
<td>20 (4*)</td>
<td>39 (3**)</td>
</tr>
<tr>
<td><strong>A [in²]</strong></td>
<td>678.8</td>
<td>1,562</td>
<td>635.4</td>
<td>1,176</td>
</tr>
<tr>
<td><strong>Iₓₓ [in⁴]</strong></td>
<td>68,745</td>
<td>176,674</td>
<td>77,574</td>
<td>74,098</td>
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<tr>
<td><strong>yₜ [in]</strong></td>
<td>14.38</td>
<td>12.97</td>
<td>11.02</td>
<td>13.99</td>
</tr>
<tr>
<td><strong>yₚ [in]</strong></td>
<td>13.62</td>
<td>23.03</td>
<td>16.98</td>
<td>13.01</td>
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<tr>
<td><strong>weight [k/ft]</strong></td>
<td>0.707</td>
<td>1.627</td>
<td>0.661</td>
<td>1.225</td>
</tr>
<tr>
<td><strong>ρ (efficiency)</strong></td>
<td>0.517</td>
<td>0.379</td>
<td>0.652</td>
<td>0.351</td>
</tr>
</tbody>
</table>

Box Beam and Pre-Topped Florida Inverted-T are the most efficient sections.

$$\rho = \frac{I}{Ay_byss} = \frac{r^2}{ybyss}$$
Task 4 – Joint Testing Program

Preliminary Test Specimens

Slab Beam w/CIP Deck:

Joint 1 – Integrated Box Beam Joint:

Joint 2 – No Shear Key (4’ Lip):

Joint 3 – No Shear Key (2’ Lip):

Joint 4 – Modified Box Beam Joint:
Task 4 – Joint Testing Program

Preliminary Test Specimens – Naming Convention

FSB:

A1:

F1:

F2:

A2:

18F1

Note: 2 tests were performed on each specimen
Task 4 – Joint Testing Program

Test Setup

- Support (5” width)
- Wheel path (20” x 10”)
- 104”
- 56”
- 60”
- 60”
Task 4 – Joint Testing Program

Instrumentation Schedule

Legend
- Concrete surface gauge
- Rebar strain gauge
- Crack opening gauge
- Laser displacement transducer
Task 4 – Joint Testing Program
Numerical Modeling
Task 4 – Joint Testing Program
Specimen Fabrication

Specimen Reinforcement
Concrete Pour
Finished Cast
Surface Raked Finish
Task 4 – Joint Testing Program

Specimen Fabrication

Delivered Specimens

Beam w/CIP Deck Cast

UHPC Mixing

UHPC Joint Cast
Task 4 – Joint Testing Program

Specimen in Test Setup

Side View

Bottom View

Top View
Task 4 – Joint Testing Program

Experimental Results

![Bar chart showing ultimate capacity (kips) for different samples (18FSB, 18A1, 18F1, 18F2, 12A1, 12F1, 12F2, 12A2) under Tests 1, 2, 2 (After cyclic), and Software.](chart.jpg)
Task 4 – Joint Testing Program

Experimental Results

Ultimate Capacity (kips)

18-inch deep specimens

- FSB
- 18F1
- 18F2
- 18A1

Test 1  Test 2  Test 2 (After cyclic)  Software
Task 4 – Joint Testing Program

Experimental Results

![Bar chart showing Ultimate Capacity (kips) for different specimens: 18FSB, 18A1, 18F1, 18F2. The chart compares Test 1, Test 2, Test 2 (After cyclic), and Software.]

- **18-inch deep specimens**
- **FSB**
- **UHPC Joints**
Task 4 – Joint Testing Program

Experimental Testing – 18” Specimens
Task 4 – Joint Testing Program

Experimental Results

18-inch deep specimens

- Current FSB joint failed much lower than expected

Ultimate Capacity (kips)

- 18FSB
- 18A1
- 18F1
- 18F2

Test 1
Test 2
Test 2 (After cyclic)
Software
Task 4 – Joint Testing Program

Experimental Results

18-inch deep specimens

- Current FSB joint failed much lower than expected
- Modified UHPC joints had similar ultimate capacities to current FSB
Task 4 – Joint Testing Program

Experimental Results

18-inch deep specimens

- Current FSB joint failed much lower than expected
- Modified UHPC joints had similar ultimate capacities to current FSB
- Joint 18A1 had the largest ductility among all the joints
Task 4 – Joint Testing Program

Experimental Results

- Load (kips) vs. Deflection (in.)
- Lines representing different control and software configurations:
  - FSB Control-1
  - FSB Control-2
  - FSB Control-Software
  - 18F1-1
  - 18F1-2
  - 18F2-1
  - 18F2-2
  - 18A1-1
  - 18A1-2
Task 4 – Joint Testing Program

Experimental Results

18-inch deep specimens

- Current FSB joint failed much lower than expected
- Modified UHPC joints had similar ultimate capacities to current FSB
- Joint 18A1 had the largest ductility among all the joints
- Sandblasted joint finish was not sufficient for achieving desired bond
Task 4 – Joint Testing Program

Experimental Results

18-inch deep specimens

- Current FSB joint failed much lower than expected
- Modified UHPC joints had similar ultimate capacities to current FSB
- Joint 18A1 had the largest ductility among all the joints
- Sandblasted joint finish was not sufficient for achieving desired bond

Best Performance 18A1
Task 4 – Joint Testing Program

Experimental Results

12-inch deep specimens

Ultimate Capacity (kips)

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 2 (After cyclic)</th>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>12F1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12F2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12A1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12A2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Task 4 – Joint Testing Program

Experimental Results

12-inch deep specimens

Failure mechanism 1

Failure mechanism 2

Ultimate Capacity (kips)

Test 1  Test 2  Test 2 (After cyclic)  Software

12A1  12F1  12F2  12A2

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FDOT
Task 4 – Joint Testing Program

Experimental Testing – 12” Specimens

12F1-1
$P_{\text{max}} = 70.0 \text{ kips}$
(8x speed)

12F2-1
$P_{\text{max}} = 98.1 \text{ kips}$
(8x speed)

12A1-1
$P_{\text{max}} = 61.0 \text{ kips}$
(10x speed)

12A2-1
$P_{\text{max}} = 98 \text{ kips}$
(12x speed)
Task 4 – Joint Testing Program

**Experimental Results**

**12-inch deep specimens**

- Reinforcement lever arm has greater impact on strength (12F2 had highest strength)

![Bar chart showing ultimate capacity in kips for 12-inch deep specimens.]

- Test 1
- Test 2
- Test 2 (After cyclic)
- Software

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12A1 12F1 12F2 12A2
Task 4 – Joint Testing Program

**Experimental Results**

12-inch deep specimens

- Reinforcement lever arm has greater impact on strength (12F2 had highest strength)
- Ledge was too shallow in 12F2

![Chart showing ultimate capacity (kips) for different tests and specimens.](image-url)
Task 4 – Joint Testing Program

Experimental Results

12-inch deep specimens

- Reinforcement lever arm has greater impact on strength (12F2 had highest strength)
- Ledge was too shallow in 12F2
- Joint 12A2 had largest ductility
Task 4 – Joint Testing Program

Experimental Results

![Graph showing experimental results with load vs. deflection for different materials and specimens.](image)
Task 4 – Joint Testing Program

Experimental Results

12-inch deep specimens

- Reinforcement lever arm has greater impact on strength (12F2 had highest strength)
- Ledge was too shallow in 12F2
- Joint 12A2 had largest ductility
- Better finish with paste retarder

Sandblasting

Paste Retarder
**Task 4 – Joint Testing Program**

**Experimental Results**

**12-inch deep specimens**

- Reinforcement lever arm has greater impact on strength (12F2 had highest strength)
- Ledge was too shallow in 12F2
- Joint 12A2 had largest ductility
- Better finish with paste retarder

**Best Performance**

- **12A2**
## Task 4 – Joint Testing Program

### Fatigue Testing

<table>
<thead>
<tr>
<th>Loading type</th>
<th>Load Range Steps</th>
<th>Lower Limit Load</th>
<th>Upper Limit Load</th>
<th>Frequency</th>
<th># Cycles</th>
<th>Testing Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatigue</td>
<td>1 - Calibration</td>
<td>2 kip</td>
<td>12.64 kip</td>
<td>1 Hz</td>
<td>200,000</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2 – Under Cracking Performance</td>
<td>2 kip</td>
<td>12.64 kip</td>
<td>1 Hz</td>
<td>900,000</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>3 – After Cracking Performance</td>
<td>19 kip</td>
<td>31 kip</td>
<td>1 Hz</td>
<td>900,000</td>
<td>11</td>
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<tr>
<td>Strength</td>
<td>4 – Overload Performance</td>
<td>0 kip</td>
<td>100% Failure Load</td>
<td>N/A</td>
<td>N/A</td>
<td>1</td>
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</tbody>
</table>
**Task 4 – Joint Testing Program**

**Fatigue Testing**

![Graph showing normalized stiffness vs. millions of cycles before and after cracking, with load vs. deflection curves for two samples labeled 12F1-1 and 12F1-2.](image)

- **Normalized Stiffness**
  - Before Cracking
  - After Cracking

- **Load (kips)** vs. **Deflection (in.)**
  - 66.9 k
  - 70.0 k
  - 12F1-1

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**Cal.**
Task 4 – Joint Testing Program

Experimental Results

12-inch deep specimens

- Reinforcement lever arm has greater impact on strength (12F2 had highest strength)
- Ledge was too shallow in 12F2
- Joint 12A2 had largest ductility
- Better finish with paste retarder
- Fatigue loading did not impact the strength of the joint
Future Work

- **Task 5** - Full-Scale Beam Testing
- **Task 6** - Conceptually and Analytically Develop FSB Detail as a Continuous Span
- **Task 7** - Draft Final Report and Closeout Teleconference
- **Task 8** - Final Report
Thank You

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