New Standards for Corrosion-Resistant Prestressed Piling & Precast Bent Cap

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CRPP & PIBC: Outline

Part 1
Corrosion-Resistant Prestressed Piling (Index 22600 series)

- Research
- Demonstration Project
- Standardization
- FDOT Specs
- What’s Next

Part 2
Precast Intermediate Bent Cap Standard (Index 20700 series) – (pending)

- Research
- Development
- Example Project
- Implementation & Training
- Resources
Part 1: Corrosion-Resistant Prestressed Piling Standards (Index 22600 series)
Overview

Invitation to Innovation
• New technology implementation

Research
• FSU, USF & Georgia Tech.

Standardization
• Developmental D20600 series (CFRP prestressed only) – Halls River Bridge Replacement
• Design Standard Index 20600 series (SS or CFRP strand)

FDOT Specifications:
• Developmental Specifications
• Standard Specifications

What’s Next:
• Other Standards
• Questions
FDOT’s Invitation to Innovation

http://www.dot.state.fl.us/structures/innovation/FRP.shtm

Structures Design

Structures Design / Transportation Innovation
Fiber Reinforced Polymer Reinforcing

Overview

Usage Restrictions / Parameters

Design Criteria
Specifications
Standards
Producer Quality Control Program
Technology Transfer (T²)
Contact

Overview

The deterioration of reinforcing and prestressing steel within concrete is one of the prime causes of failure of concrete structures. In addition to being exposed to weather, concrete transportation structures in Florida are also commonly located in aggressive environments such as marine locations and inland water crossings where the water is acidic. Cracks in concrete create paths for the agents of the aggressive environments to reach the reinforcing and/or prestressing steel and begin the corrosive oxidation process. An innovative approach to combat this major issue is to replace traditional steel bar and strand reinforcement with Fiber Reinforced Polymer (FRP) reinforcing bars and strands. FRP reinforcing bars and strands are made from filaments or fibers held in a polymeric resin matrix binder. FRP reinforcing can be made from various types of fibers such as glass (GFRP) or carbon (CFRP). A surface treatment is typically provided that facilitates a bond between the reinforcing
Research

CFRP Prestressed Pile Research:


![Load and elongation diagram (Source: Tokyo Rope)](image1)

![Figure 5.4: EDC installation](image2)
Research

CFRP Prestressed Pile Research:

Research

Stainless Steel Prestressed Pile Research:

  http://g92018.eos-intl.net/eLibSQL14_G92018_Documents/11-34.pdf

Figure 5.4 Driving of pile HSSS #2

![Graph showing stress-strain relationship for Duplex 2205, Duplex 2304, and AISI 1090]
FDOT FRP Demonstration Project

HALLS RIVER BRIDGE REPLACEMENT

Contract Letting: 15th June, 2015
FDOT FRP Demonstration Project

CORROSION COSTS

- District 7 (FY 02/03 to Present)

54 Total Bridge Projects
- 20 Steel
- 34 Concrete

Source: FDOT D7 District Structures Maintenance Office (DSMO) & T.Y. Lin
FDOT FRP Demonstration Project

CORROSION COSTS

• Prevention Methods:
  ✓ Adequate Cover
  ✓ Concrete Quality
  ✓ Corrosion Inhibiting Admixtures
  • Alternative Reinforcements

• Corrosion Protection of Bridge members
  • New Construction
  ✓ Existing Bridge
    ▪ Pile Jacket
    ▪ FRP Wrap
    ▪ Cathodic Protection

Halls River Bridge

• Glass Fiber Reinforced Polymer (GFRP)
• Carbon Fiber Reinforced Polymer (CFRP)
• Hybrid Composite Beam (HCB)
Standardization – Developmental Design Standards
- Prestressed Concrete Piles (with CFRP only)

- Indexes D22600, D20601, D22614, 22618 & 22624
  - New corrosion resistant piling for intermediate bridge pile bents in Extremely Aggressive Environments (splash zone);
  - Used for Halls River Demonstration Project.

**ALTERNATE STRAND PATTERNS**
12 ~ 0.6" Ø, CFRP Strand, at 34 kips
12 ~ ½" Ø, CFRP Strand, at 33 kips
Standardization – Design Standards
- Prestressed Concrete Piles (with CFRP or SS)

• **Indexes 22600, 20601, 22612, 22614, 22618, 22624, & 20630**
  - New corrosion resistant piling for intermediate bridge pile bents in Extremely Aggressive Environments (marine)
    - see *Structures Design Bulletin 15-10* for more information and
    - SDG Table 3.5.1-1 for application.
  - Carbon FRP strands (single or 7-strand) & spiral reinforcing or Stainless Steel strand (7-wire) and spiral reinforcing (at contractor’s/producer’s option)

Will be reduced to 0.2” diameter
Standardization – Design Standards
- Prestressed Concrete Cylinder Piles (with CFRP or SS)

- **Indexes 22654, & 20660**
  - Carbon FRP strands (single or 7-strand) & spiral reinforcing or Stainless Steel strand (7-wire) and spiral reinforcing (at contractor’s/producer’s option)
Standardization – **Design Standards**
- Prestressed Concrete Piles (with CFRP or SS)

• **Instructions – IDS-22600, 22654, & 20660**
  - Slight differences in Strength Limit States due to reduced resistance factors for CFRP prestressing. Refer to the *Design Aid* M-N Charts
Standardization – Design Standards
- Prestressed Concrete Piles (with CFRP or SS)

- **SDG Table 3.5.1-1**
  - Piles in the “splash zone” (= Intermediate Pile Bents in marine environments), preferred use of Carbon FRP strands & spiral reinforcing or Stainless Steel strand and spiral reinforcing.

<table>
<thead>
<tr>
<th>Pile Location</th>
<th>Minimum Square Pile Size (inches)</th>
<th>Minimum Cylinder Pile Diameter (inches)</th>
<th>Material Properties for All Pile Sizes¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pile Bents</td>
<td>Vehicular Bridges Pedestrian Bridges &amp; Fishing Piers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On land or in water in all other environments</td>
<td>18</td>
<td>14</td>
<td>54</td>
</tr>
<tr>
<td>New bridges and fishing piers³</td>
<td>24²</td>
<td>18</td>
<td>54</td>
</tr>
<tr>
<td>Widenings</td>
<td>24²</td>
<td>18</td>
<td>54</td>
</tr>
<tr>
<td>Footings</td>
<td>In water (waterline or mudline) in environments that are Extremely Aggressive due to chlorides</td>
<td>18</td>
<td>14</td>
</tr>
<tr>
<td>On land or in water (waterline or mudline) in all other environments</td>
<td>18²</td>
<td>14²</td>
<td>54²</td>
</tr>
</tbody>
</table>

³ The use of FRP or stainless steel strand and reinforcing is preferred for use in splash zones.

*Exhibit: FDOT Structures Manual*
FDOT Specifications

a) Standard Specifications (effective July 2016):
   • Implemented previous Developmental Specifications for FRP materials;
   • Added Stainless Steel Bar, Wire & Strand;
   • 931 Metal Accessory Materials for Concrete Pavement and Concrete;

b) Previous Developmental Specifications:
   • Dev400FRP Concrete Structures – Fiber Reinforced Polymer Reinforcing;
   • Dev410FRP Precast Concrete Box Culvert;
   • Dev415FRP Reinforcing for Concrete;
   • Dev450FRP Precast Prestressed Concrete Construction – Fiber Reinforced Polymer (FRP);
   • Dev932FRP Nonmetallic Accessory Materials for Concrete Pavement and Concrete Structures;
   • Dev933FRP Prestressing Strand;
FDOT Specifications

Standard Specifications (effective July 2016):

• 931 Metal Accessory Materials for Concrete Pavement and Concrete

  931-1.2.2 Stainless Steel Wire Reinforcement: Plain and deformed stainless steel wire reinforcement shall meet the requirements of ASTM A276, UNS S30400.

• 933 Prestressing Strand and Bar

  933-1 Strands for Prestressing.

  933-1.1 Carbon Steel Strands for Prestressing: The steel strands for prestressing concrete members shall be Grade 270, low-relaxation seven wire strand and shall conform to the requirements of ASTM A416.

  933-1.2 Stainless Steel Strands for Prestressing: 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.

  933-1.3 Carbon Fiber Reinforced Polymer (CFRP) Strands for Prestressing: CFRP strand shall meet the requirements of ACI 440.4, following the test methods from ACI 440.3. The CFRP strand shall meet the additional requirements of this Section following the sampling frequency and number of specimens required by ACI 440.6.
What’s Next?

- CFRP/GFRP Prestressed Concrete Sheet Piles (Index D22440 → Index 22440 *FY2017-18*);

- New Hybrid - GFRP Reinf./Steel Prestressed Concrete Sheet Piles (Index D22440);

- Pile Bent Caps (with FRP reinforcing) – Halls Bridge Demonstration project: 
  *Index D20700 series* – Precast Intermediate Bent Cap GFRP Option in Mathcad Design Program
What’s Next – Closer Look…

Cantilever Concrete Sheet Pile Walls (with CFRP/GFRP)

A. Components
   i. CFRP/GFRP Prestressed Concrete Sheet Piles (Index D22440)
   ii. GFRP-RC Bulkhead Cap (SM-Vol 4...)

B. Structural System
   i. Cantilevered
   ii. Anchored/Tied-Back Wall

C. Other FDOT projects
   i. Cedar Key SR 24 over Channel 5 bulkhead cap rehab
   ii. Sunshine Skyway South Rest Area seawall rehab

D. Challenges
   i. No AASHTO design specs;
   ii. ACI 440.4R strand jacking forces limits are too conservative;
   iii. FDOT concrete tensile stress limits not optimized for FRP reinforced systems.
What’s Next – Closer Look…
Cantilever Concrete Sheet Pile Walls (with CFRP/GFRP)

Developmental **Index D22440**: (used for Halls River Demonstration Project with reduced number of strands)

### Typical Pile

<table>
<thead>
<tr>
<th>Wall Thickness</th>
<th>CFRP Strand Dia. (in.)</th>
<th>Maximum L **</th>
<th>n</th>
<th>D (in.)</th>
<th>Total # of Strands</th>
<th>Section Modulus (in.)</th>
<th>* Stress (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T=10 in.</td>
<td>0.49 (12.5mm)</td>
<td>26'-0&quot;</td>
<td>4</td>
<td>4</td>
<td>10</td>
<td>500</td>
<td>730</td>
</tr>
<tr>
<td></td>
<td>0.5 (12.7mm)</td>
<td>27'-0&quot;</td>
<td>3</td>
<td>5(\frac{3}{4})</td>
<td>8</td>
<td>500</td>
<td>830</td>
</tr>
<tr>
<td></td>
<td>0.6 (15.2mm)</td>
<td>27'-0&quot;</td>
<td>3</td>
<td>5(\frac{3}{4})</td>
<td>8</td>
<td>500</td>
<td>840</td>
</tr>
<tr>
<td>T=12 in.</td>
<td>0.49 (12.5mm)</td>
<td>31'-0&quot;</td>
<td>5</td>
<td>3(\frac{3}{4})</td>
<td>12</td>
<td>720</td>
<td>730</td>
</tr>
<tr>
<td></td>
<td>0.5 (12.7mm)</td>
<td>31'-0&quot;</td>
<td>3</td>
<td>5(\frac{3}{4})</td>
<td>8</td>
<td>720</td>
<td>700</td>
</tr>
<tr>
<td></td>
<td>0.6 (15.2mm)</td>
<td>31'-0&quot;</td>
<td>3</td>
<td>5(\frac{3}{4})</td>
<td>8</td>
<td>720</td>
<td>710</td>
</tr>
</tbody>
</table>

* Unit Prestress after losses.
** Based on lifting using single point pick-up.

Alternate symmetrical strand patterns:
(1) 4 sp. @ 2" & 1 sp. @ 8"
(2) 2 sp. @ 4" & 1 sp. @ 8"
Part 1 - Questions?

Contact Information:

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Steven.Nolan@dot.state.fl.us
Ph. 850-414-4272
Part 2: Precast Intermediate Bent Cap Standard (Index 20700 series)
Overview

Introduction:
• Past FDOT Projects & 1996 FDOT Precast Substructure Study
• Other States (Iowa DOT, WSDOT, SCDOT & TxDOT)
• FHWA’s Every Day Counts Initiative
• FDOT’s Invitation to Innovation – EDC-PBES

Research
• NCHRP Report 681
• SHRP2 Project R04-RR1

Example FDOT Project
• US 90 Demonstration project (IBRD) – Overview, Specification Modifications & Lessons Learned

Development:
• FDOT Developmental Design Standard – Index D20700
• Aesthetic Levels and Configurations
• Mathcad Design Program

Implementation:
• Schedule & Training
• Information References & Questions

Example Projects:

- **US 41 (Business) Edison Bridge (1993);**
- **I-295 Southbound Buckman Bridge (1997);**
- **Reedy Creek WDW (1997 - Privately Funded);**
- **SR 300 St George Island Bridge (2004).**

Photo: Berger/ABAM Engineers Inc.
### 1996 FDOT Precast Substructure Study

<table>
<thead>
<tr>
<th>Component</th>
<th>Configuration</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-Column Pier Cap</td>
<td>Solid Rectangle (IA)</td>
<td>Inverted U (III)</td>
</tr>
<tr>
<td>Multi-Column Pier Column</td>
<td>Hollow Rectangle - Rounded Corners (IIIIB)</td>
<td>I-Shaped (IVA)</td>
</tr>
<tr>
<td>Pile Bent Caps</td>
<td>Solid Rectangle (IV)</td>
<td>Inverted U (I)</td>
</tr>
<tr>
<td>Hammerhead Pier Column</td>
<td>Hollow Rectangle - Rounded Corners (IIIIB)</td>
<td>Double I-Shaped (III)</td>
</tr>
<tr>
<td>Hammerhead Pier Cap</td>
<td>Solid Cantilever (RB)</td>
<td></td>
</tr>
</tbody>
</table>
Other State DOT's - Precast Bent Caps

- Iowa
- South Carolina
- Washington
- Texas ...

**Research:** TxDOT sponsored research projects at CTR related to Precast Bent Cap Systems and Connections:


**Example Projects:**

- Red Fish Bay and Morris-Cummings Cut Bridge (1994)
- Lake Ray Hubbard Bridge (2002)
- Lake Belton Bridge (2004)
Bridge Standards **PBC-P** and **PBC-RC**:

- Initially released in 2011
- Drawings updated January 2015
  [http://www.dot.state.tx.us/insdtdot/orgchart/cmd/cserve/standard/bridge-e.htm](http://www.dot.state.tx.us/insdtdot/orgchart/cmd/cserve/standard/bridge-e.htm)

Square Concrete or Steel H-Piles

Round Columns
FHWA’s Every Day Counts Initiative


Lake Belton Bridge
At the end of 2012, sponsorship of the EDC-1 innovations by the Every Day Counts initiative came to a close, and a new set of innovations, EDC-2, was selected for deployment. Some of these were holdovers from EDC-1, including PBES, while others were new to the Every Day Counts initiative.
FDOT’s Invitation to Innovation – PBES

http://www.dot.state.fl.us/structures/innovation/PBES.shtm

Structures Design - Transportation Innovation

Every Day Counts - Prefabricated Bridge Elements & Systems (EDC-PBES)

Structures Design Office

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

Website Overview - Video (WMV)

Plans Preparation Manual (PPM), Volume 1, Section 26.9.2.9 provides expanded direction for investigating prefabricated bridge alternatives during the Bridge Development Report (BDR) phase of design. The referenced section of the PPM formalizes the process for evaluating whether prefabricated options should be considered based on feasibility questions, then, when warranted, how to develop and select prefabricated options through an assessment matrix. An assessment matrix methodology allows for alternate selection based on less than perfect knowledge. Both direct and indirect costs for prefabricated and conventional options are to be reported in the BDR. See PPM Exhibit 26-F for additional background information.

This website is intended to provide design guidance for developing prefabricated bridge alternatives and gives examples on how to estimate both direct and indirect costs. To date, the FDOT does not have sufficient historical bid data for prefabricated bridge alternatives in order to develop reasonable cost estimates from average unit material costs. To fill this gap, the Structures Design Office has developed several training videos for the purpose of educating designers on factors for consideration related to use of PBES for Accelerated Bridge Construction (ABC). Sample contractor estimates are provided to show how project costs may be developed to compare conventional construction methods versus a prefabricated ABC approach.

INVITATION TO INNOVATION
FDOT's Invitation to Innovation – PBES

The 2015 FDOT Structures Manual has been released. Chapter 25 of the Structures Detailing Manual (SDM) has been added and provides design considerations for detailing PBES for FDOT contract plans. A compilation of PBES concepts with annotated notes to designers that supplement this new chapter of the SDM is provided here (PDF).

Structures Detailing Manual
25 - Prefabricated Bridge Elements and Systems
25.1 DESIGN CONSIDERATIONS - GENERAL

Figure 25.4.3.1-1 Precast Pier Assembly

A. This Chapter contains PBES:
1. Applicability
2. Connections
3. Components
Research - NCHRP Report 681 (Project 12-74)

Research - SHRP2 Project R04-RR-1

Source: NCHRP 12-74 (Restrepo et al., 2011).

**Figure 3.33. Grouted duct connection.**

Source: NCHRP 12-74 (Restrepo et al., 2011).

**Figure 3.34. Cap pocket connection.**

Source: NCHRP 12-74 (Restrepo et al., 2011).

**Figure 3.35. Cap pocket connection close-up.**

![Table 3.5. Connection Types for U.S. Seismic Regions](attachment:Table_3.5.pdf)

A, B, C, D

Table 3.5. Connection Types for U.S. Seismic Regions

<table>
<thead>
<tr>
<th>Column-to-Cap Connection Type</th>
<th>Seismic Design Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grouted splice sleeve(^a)</td>
<td>A, B, C</td>
</tr>
<tr>
<td>Grouted duct</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>Cap pocket(^b)</td>
<td>A, B, C, D</td>
</tr>
</tbody>
</table>

\(^a\) NCHRP 12-74 has recommended use for limited-ductility applications only.

\(^b\) NCHRP 12-74 tested both a limited-ductility and a full-ductility cap pocket connection.
Research - SHRP2 Project R04-RR-1 & 2

http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R04-RR-2.pdf (June 2013)
US 90/Little River PBES Demonstration
- Example Project -

<table>
<thead>
<tr>
<th></th>
<th># of Spans</th>
<th>Span Length</th>
<th>Intermediate Bent Caps</th>
<th>Precast Deck Panels</th>
<th>Reinforced</th>
<th>Prestressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little River EB</td>
<td>4</td>
<td>3 @ 110’, 1 @ 106’</td>
<td>Precast (Reinforced)</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Little River WB</td>
<td>4</td>
<td>3 @ 110’, 1 @ 106’</td>
<td>Precast (Reinforced)</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Hurricane Creek EB</td>
<td>1</td>
<td>110’</td>
<td>n/a</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Hurricane Creek WB</td>
<td>1</td>
<td>110’</td>
<td>n/a</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

All bridges have cast-in-place abutments, drilled shafts, and precast/prestressed FIBs

Little River EB & WB

Hurricane Creek EB & WB
Expanded Polystyrene used to create a void for reduced weight
Grout holes & Fill joint

US 90/Little River PBES Demonstration - Example Project -

2” Moth for scale

Grout holes & Fill joint

SECTION B-B
INTERMEDIATE BENTS NO. 2, 3 & 4

6” Dowel Bars 9D
4 CSL Tubes

Precast Intermediate Bent Cap
US 90/Little River PBES Demonstration - Specification Modifications -

**Required submittals of:**
- Precast Placement Plan
- ABC-PBES Erection Stability
- Grouting Plan
  - Material
  - Equipment
- Grout Demo/ Mock-Up

**Specified:**
- Materials (MSP 934)
- Tolerances (MSP 455)
- Minimum Ages & Strength (Dev404 & MSP450)
- Installation (Dev404)
- Grouting (Dev404)
1. Pre-approved grouts expedite construction;
2. Need grouts with greater tolerance to ambient temperature change (less temperature sensitivity);
3. Pre-construction mock-up was valuable;
4. C-I-P Beam seats provided versatility;
5. Lifting from precast bed is critical for controlling cracks in slender non-prestressed elements;
6. ABC cost increase mostly due to deck panels. Precast bent caps are cost competitive with C-I-P construction.
FDOT Developmental Design Standard
- Index D20700 series -

http://fdotsharepoint.dot.state.fl.us/sites/Officeofdesign/DSD/Lists/DSDR/Attachments/19/DSDR-20700-PhaseIall.pdf
FDOT Developmental Design Standard
- Index D20700 series -

**Level 1:**
Pile Bents
(20710 series)

**Level 2:**
Multi-Column Pier
(20720 series)

**Level 3:**
Twin-Column Hammerhead Pier
(20730 series)

**Enhanced Level 3:**
Project Specific

Levels of Aesthetics and Precast Bent/Pier Cap Configurations
FDOT Developmental Design Standard
- Index D20710 series -

Pile Bent with Pile Pocket Connections
– Prestressed Concrete and Steel Pipe Piles (Level 1)

Source: Draft Developmental Design Standard Index D20710
Source: SHRP2 Report S2-R04-RR-1 & 2 (ABC Toolkit)

Pile Bent with Open Cap Pocket Connections – Steel H-Piles (Level 1)
### FDOT Developmental Design Standard

- **Index D20710 series**

#### Data Tables: Pile Bent Cap – Dimensions

- **Prestressed Concrete and Steel Pipe Piles (Level 1)**

#### Structural Component Dimensions

<table>
<thead>
<tr>
<th>BENT NO</th>
<th>CAP END TO @ EXTERIOR BEAM SPACING (ft)</th>
<th>CAP END TO @ INTERIOR BEAM SPACING (ft)</th>
<th>PEDESTAL HEIGHT (ft)</th>
<th>NO. OF PEDESTALS</th>
<th>CAP LENGTH (ft)</th>
<th>CAP WIDTH (ft)</th>
<th>PILE SIZE (Diameter or Width) (in)</th>
<th>OVERHANG (in)</th>
<th>SPACING BETWEEN PILES (in)</th>
<th>DUCT DIAMETER (in)</th>
<th>NO. OF DUCTS</th>
<th>DUCT SPACING</th>
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<tr>
<td>10</td>
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</tbody>
</table>

**Typical Reinforcing for Bent Cap**

**Symmetrical about Q Cap**

(Prestails not shown for clarity)

**Sections**

- **Section A-A**
- **Section B-B**
- **Section C-C**
<table>
<thead>
<tr>
<th>BENT CAP FLEXURAL REINFORCEMENT</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>BAR TYPE</td>
<td>BAR ID</td>
<td>ROW NUMBER</td>
<td>BAR ID</td>
<td>NO. OF BARS</td>
<td>VERTICAL DISTANCE TO C.G. OF ROW (in)</td>
<td>BAR LENGTH (in)</td>
<td>NO. OF BARS</td>
<td>AT SPACING (in)</td>
<td>NO. OF BARS</td>
<td>AT SPACING (in)</td>
<td>MID-ZONE</td>
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</tr>
<tr>
<td>TOP REINFORCING</td>
<td>BAR A (Continuous Longitudinal Bar)</td>
<td>ROW 1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>SIDE FACE REINFORCING</td>
<td>BAR B (Continuous Bars along Side Faces)</td>
<td>ROW 1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>BOTTOM REINFORCING</td>
<td>BAR C (Continuous Longitudinal Bar)</td>
<td>ROW 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>END FACE REINFORCING</td>
<td>BAR D (Supplemental Long. between Int. Piles)</td>
<td>ROW 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BAR E (Horizontal End Face Reinforcing)</td>
<td>ROW 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 1 = Row Number (1, 2, 3, or 4)

** X = Bar Type (A, B, C, D, or E)

---

<table>
<thead>
<tr>
<th>BENT CAP SHEAR REINFORCEMENT</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>BENT NO.</td>
<td>BAR ID</td>
<td>NO. OF SPACES</td>
<td>AT SPACING (in)</td>
<td>BAR ID</td>
<td>NO. OF SPACES</td>
<td>AT SPACING (in)</td>
<td>BAR ID</td>
<td>NO. OF SPACES</td>
<td>AT SPACING (in)</td>
<td>BAR ID</td>
<td>NO. OF SPACES</td>
<td>AT SPACING (in)</td>
</tr>
<tr>
<td>Zone 1</td>
<td>Zone 2</td>
<td>Zone 3</td>
<td>Zone 4</td>
<td>Zone 5</td>
<td>Zone 6</td>
<td>Zone 7</td>
<td>Zone 8</td>
<td>Zone 9</td>
<td>Zone 10</td>
<td>Zone 11</td>
<td>Zone 12</td>
<td>Zone 13</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
</tr>
</tbody>
</table>

---

**Data Tables:** Pile Bent Cap – Reinforcing – Prestressed Concrete and Steel Pipe Piles (Level 1)
Grout Rheology Mockup Testing (Project BDV30 977-16):

- Typical Efflux Time 20-30 seconds;
- Typical Temperature 70-80 degrees;

### Table 1: Test matrix

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Pile Surface</th>
<th>Minimum Gap</th>
<th>Temp. °C Range</th>
<th>Efflux Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>MU1</td>
<td>Concrete</td>
<td>50</td>
<td>21-24</td>
<td>70-75</td>
</tr>
<tr>
<td>MU2</td>
<td>Concrete</td>
<td>2</td>
<td>27-29</td>
<td>80-85</td>
</tr>
<tr>
<td>MU3</td>
<td>Plywood</td>
<td>12.5</td>
<td>29-32</td>
<td>85-90</td>
</tr>
<tr>
<td>MU4</td>
<td>Plywood</td>
<td>0.5</td>
<td>(2 Sides and Top)</td>
<td></td>
</tr>
<tr>
<td>MU5</td>
<td>Plywood</td>
<td>190</td>
<td>(2 Sides)</td>
<td>85-90</td>
</tr>
<tr>
<td>MU6</td>
<td>Plywood</td>
<td>7.5</td>
<td>(2 Sides)</td>
<td></td>
</tr>
<tr>
<td>MU7</td>
<td>Plywood</td>
<td>50</td>
<td>(2 different tapered heads)</td>
<td></td>
</tr>
<tr>
<td>MU8</td>
<td>Plywood</td>
<td>10</td>
<td>(Different tapered heads)</td>
<td></td>
</tr>
<tr>
<td>MU9</td>
<td>Plywood</td>
<td>2</td>
<td>(Different tapered heads)</td>
<td></td>
</tr>
<tr>
<td>MU10</td>
<td>Plywood</td>
<td>8</td>
<td>(Different tapered heads)</td>
<td></td>
</tr>
<tr>
<td>MU11</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

† Flowability is measured by the cone discharge time of a 0.456-gallon (1.725-L) sample of fresh grout through a 0.5-in. (12.7-mm) tube orifice at the bottom of the cone.
‡ All specimens in Task 2 will have differently pigmented grout layers, will be filled through a smaller (2-in.) duct to simulate heavily reinforced bent caps, and the pocket in the bent cap will be tapered (towards the center) to promote ventilation and to reduce air entrapment.

Source: BASF Masterflow® 928
Multi-Column Pier Cap with Grouted Duct Connections
– Concrete Columns & Drilled Shafts (Level 2)

Source:
US90/Little River (Contract Plans)
Data Tables: Multi-Column Pier Cap – Dimensions
– Concrete Columns & Drilled Shafts (Level 2)
## FDOT Developmental Design Standard
- Index D20720 series -

### PIER CAP FLEXURAL REINFORCEMENT

<table>
<thead>
<tr>
<th>BAR TYPE</th>
<th>BAR ID</th>
<th>NO. OF BARS</th>
<th>VERTICAL DISTANCE TO C.G. OF ROW (in)</th>
<th>BAR LENGTH (in)</th>
<th>EDGE ZONE</th>
<th>M.D. ZONE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAR A (Continuous Longitudinal Bars)</td>
<td>ROW 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ROW 2</td>
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<tr>
<td></td>
<td>ROW 3</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>ROW 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAR B (Supplemental longitudinal over Ext. Columns)</td>
<td>ROW 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ROW 2</td>
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<tr>
<td></td>
<td>ROW 3</td>
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</tr>
<tr>
<td></td>
<td>ROW 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAR C (Supplemental longitudinal over Int. Columns)</td>
<td>ROW 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ROW 2</td>
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<td>ROW 3</td>
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<tr>
<td></td>
<td>ROW 4</td>
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</tbody>
</table>

**Notes:**
- * = Row Number (1, 2, 3, or 4)
- ** = Bar Type (A, B, C, D, E, or F)

### PIER CAP SHEAR REINFORCEMENT

<table>
<thead>
<tr>
<th>PIER NO.</th>
<th>BAR ID</th>
<th>NO. OF SPACES</th>
<th>AT SPACING (in)</th>
<th>BAR ID</th>
<th>NO. OF SPACES</th>
<th>AT SPACING (in)</th>
<th>BAR ID</th>
<th>NO. OF SPACES</th>
<th>AT SPACING (in)</th>
<th>BAR ID</th>
<th>NO. OF SPACES</th>
<th>AT SPACING (in)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>S1</td>
<td>V1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>S2</td>
<td>V2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>S3</td>
<td>V3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>S4</td>
<td>V4</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>S5</td>
<td>V5</td>
<td></td>
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</tbody>
</table>

**Data Tables:** Multi-Column Pier Cap - Reinforcing
- Concrete Columns & Drilled Shafts (Level 2)
Mathcad Design Program

Intermediate Bent-Cap Analysis & Design

PART 1: LOAD GENERATOR

PART 2: FRAME ANALYSIS

PART 3: DESIGN & AASHTO BDS CHECKS

PART 4: CONNECTION DESIGN

For a list of assumptions/limitations of the current program, click on...... Program Assumptions
For a list of recent changes to the program, click on...... Program Changes
Comparisons of US 90 Demonstration project designs with new FDOT Mathcad program.

Comparison with two designs recently completed in-house, a published TxDOT Pile Bent Design Example (June 2010), the SHRP2 R04-RR-1 two-column bent cap design example, and analysis with Bentley’s RC Pier software showed good correlation of results. Deviations in the results can be explained by the refinements in modeling and loading assumptions for the different designs.

### US90 Project: 2-Drilled Shaft Cap Design

<table>
<thead>
<tr>
<th>EOR’s Design</th>
<th>FDOT Mathcad (conc.)</th>
<th>FDOT Mathcad (distr.)</th>
<th>Difference (distributed)</th>
<th>RC Pier</th>
<th>RC Pier vs. Mathcad Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2988</td>
<td>3196</td>
<td>2947</td>
<td>1.4%</td>
<td>3471</td>
<td>17.8%</td>
</tr>
<tr>
<td>-3255</td>
<td>-3286</td>
<td>-3268</td>
<td>-0.9%</td>
<td>-2874</td>
<td>-12.5%</td>
</tr>
<tr>
<td>588</td>
<td>855</td>
<td>788</td>
<td>-25.1%</td>
<td>773</td>
<td>-3.1%</td>
</tr>
<tr>
<td>4818</td>
<td>4825</td>
<td>5274</td>
<td>-0.1%</td>
<td>4891</td>
<td>1.4%</td>
</tr>
<tr>
<td>5298</td>
<td>5274</td>
<td>687</td>
<td>0.5%</td>
<td>4710</td>
<td>-10.7%</td>
</tr>
<tr>
<td>719</td>
<td>715</td>
<td></td>
<td>4.7%</td>
<td>715</td>
<td>4.1%</td>
</tr>
</tbody>
</table>

### US90 Project: 6 x Pile Bent Cap Design

<table>
<thead>
<tr>
<th>EOR’s Design</th>
<th>FDOT Mathcad (conc.)</th>
<th>FDOT Mathcad (distr.)</th>
<th>Difference (distributed)</th>
<th>RC Pier</th>
<th>RC Pier vs. Mathcad Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1255</td>
<td>981</td>
<td>753</td>
<td>-21.8%</td>
<td>590</td>
<td>-21.6%</td>
</tr>
<tr>
<td>-520</td>
<td>-443</td>
<td>-421</td>
<td>-14.8%</td>
<td>-495</td>
<td>17.5%</td>
</tr>
<tr>
<td>330</td>
<td>467</td>
<td>322</td>
<td>-2.4%</td>
<td>412</td>
<td>28.1%</td>
</tr>
<tr>
<td>1348</td>
<td>1347</td>
<td>924</td>
<td>-0.1%</td>
<td>1160</td>
<td>-13.9%</td>
</tr>
<tr>
<td>921</td>
<td>924</td>
<td>458</td>
<td>0.3%</td>
<td>959</td>
<td>3.8%</td>
</tr>
<tr>
<td>365</td>
<td>458</td>
<td></td>
<td>25.5%</td>
<td>453</td>
<td>-1.0%</td>
</tr>
</tbody>
</table>

### SHRP2 Example 3b: 2-Column Cap Design

<table>
<thead>
<tr>
<th>SHRP2 Example 3b</th>
<th>FDOT Matchcad (dist.)</th>
<th>Difference</th>
<th>RC Pier</th>
<th>RC Pier vs. Mathcad Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1901</td>
<td>2626</td>
<td>38.2%</td>
<td>2504</td>
<td>-4.6%</td>
</tr>
<tr>
<td>-2263</td>
<td>-1799</td>
<td>-20.5%</td>
<td>-1613</td>
<td>-10.3%</td>
</tr>
<tr>
<td>354</td>
<td>351</td>
<td>-0.9%</td>
<td>276</td>
<td>-21.3%</td>
</tr>
<tr>
<td>2823</td>
<td>2823</td>
<td>0.0%</td>
<td>2802</td>
<td>-0.6%</td>
</tr>
<tr>
<td>2396</td>
<td>2396</td>
<td>0.0%</td>
<td>2422</td>
<td>1.1%</td>
</tr>
<tr>
<td>809</td>
<td>711</td>
<td>-12.1%</td>
<td>663</td>
<td>-6.8%</td>
</tr>
</tbody>
</table>

Comparisons of other design examples with new FDOT Mathcad program.
Implementation, Training & Tracking

- Beta Testing of Mathcad Program – Oct-April 2015
- Preliminary Release - November 2016
- Draft D20730 - ?
- Design Update Training - February 2017
- Project Tracking and Monitoring – 2017 & 18
- Full *Design Standard* Implementation - ???

**Research --> Demonstration Project --> DDS --> Design Standard Index**
Developmental Design Standards (DDS) can provide a bridge across the “Trough of Disillusionment” (Valley of Death) for effective implementation!

Source: Gartner Inc. Hype Cycle

Research --> Demonstration Project --> DDS --> Design Standard Index
Information References


Questions?

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*Design Technology – Structures Standards Group*

[Steven.Nolan@dot.state.fl.us](mailto:Steven.Nolan@dot.state.fl.us)

Ph. 850-414-4272