ABSTRACT:
This paper presents an overview of the development of a PBES-ABC Precast Intermediate Bent Cap standard based on a recent pilot project featured in a presentation at the 2014 National ABC Conference. A new FDOT Developmental Design Standard for intermediate pile bent caps and multi-column piers provides connection details refined during the pilot project. Details for the Pile Bent Caps also incorporate some of the work from a 1996 preliminary study under FDOT Project No. 510703 improvements based on the first generation TxDOT standards for Prestressed Concrete Piles. Details for the Multi-Column Pier Cap are similar to the SHRP2 Project R04-RR1 (Appendix E) ABC Standard Plans, except the connection design utilizes the recommendations from NCHRP Report 681 with the alternate details for regions of low seismicity. A modified version of the FDOT’s Pile Bent Mathcad program has also been developed as a design tool to assist in completing the necessary Contract Documents for streamlining implementation on Department projects.

INTRODUCTION:
Precast bent caps have been identified by the FDOT as a cost effective means of implementing one practice of Accelerated Bridge Construction (ABC) under the FHWA Everyday Counts initiative using Prefabricated Bridge Elements and Systems (PBES). This type of element has been used in previous FDOT projects and other states with project specific designs and connection details. To ensure consistent design assumptions, leverage economy of scale from standardized components, minimize the perceived risk and develop Contractor expertise, standardized details for Precast Intermediate Bent Caps have been developed for use in Florida.

Details for the Intermediate Pile Bent Caps incorporate some of the work from a 1996 preliminary study under FDOT Project No. 510703 (1), and improvements based on the first generation Texas DOT standards for Precast Concrete Bent Cap Options (2)(3). Development of a Steel Pipe Pile and H-Pile option are also planned for 2016. A grout rheology study (4) is currently underway to assess the potential problems with installation tolerances and grout sensitivity to temperature and flow rate for pile pocket connections. Details for the Multi-Column Pier Caps are similar to the SHRP2 Project R04-RR-1 (5) except the connection design utilizes the recommendations from NCHRP Report 681 (6) with the alternate details for regions of low seismicity. Simple enhancement of the Multi-Column Pier Cap utilizing narrow spaced twin-columns could also provide an economical alternate to cast-in-place Hammerhead piers.

A modified version of the FDOT’s Pile Bent Mathcad program (7) has been developed as a design tool to assist in completing the necessary Contract Documents for streamlining implementation on the Department’s projects, and providing a framework for future enhancements.

BACKGROUND:
FDOT has previous experience with precast substructure components on various projects over the last 30 years. This does not include the extensive use of pretensioned concrete piles, which have been used in Florida since the 1950's (8) and precast concrete piles starting in the 1920's. More ambitious was the incorporation of: Precast post-tensioned hollow column units on Seven Mile, Channel 5 and Sunshine Skyway bridges (9) in the 1980's; Precast I-shape columns and U-shaped caps on the US41 Edison...
Bridge (1992) (10); and precast bent caps on prestressed piles for the I-275 Henry H. Buckman Bridge (1996). Walt Disney World’s Reedy Creek Bridge was another project completed in Florida in 1997 utilizing precast bent caps (11), although not under the jurisdiction of the FDOT.

![Photo 1: Edison Bridge Precast Bents (FDOT 1991)](image1)

![Photo 2: I-275 Henry H. Buckman Bridge Precast Bent Cap (FDOT 1996)](image2)

The State Structures Design Office commissioned an effort to standardize precast bent caps in the mid-1990’s under Project No. 510703 (1). The initial standard drawings developed from this project were never implemented for undisclosed reasons. These efforts were motivated by the successful use of precast substructures on the previously mentioned projects in the 1990’s. Since this time several other FDOT projects have successfully incorporated precast bent cap elements, including: SR 300 St George Island Bridge (2004) (12), and US 90 over Little River Bridge (2014) (13).

There have also been several recent national and state PBES substructure initiatives, including: NCHRP Report 681 - Development of a Precast Bent Cap System for Seismic Regions (8); SHRP2 Report S2-R04-RR-1 Standard ABC Plans (14); and Texas DOT standards for Precast Concrete Bent Caps (2)(3)(15). The most recent FDOT experience is from a pilot project involving the design and construction of four replacement highway bridges on US 90 over Little River and Hurricane Creek, which was presented at the 2014 National ABC Conference (13). By utilizing precast components the FDOT gained valuable knowledge about construction techniques, durability concerns, and cost for precast bridges in a low risk application. Positive project results led to advancing Precast Intermediate Bent Caps as the first ABC-PBES element to be fully standardized in Florida.

![Figure 1: Precast Intermediate Bent Cap from US 90 over Little River pilot project](image3)
STANDARD DEVELOPMENT

The new FDOT Developmental Design Standard (D20700 series) will provide connection details refined during the US 90 pilot project, which were primarily based on NCHRP Report 681, while also taking into consideration general details from the ABC Standard Plans developed under the SHRP2 Project R04-RR-1. The reinforcing and cap dimensions will not be predesign as was developed for the ABC Standard Plans, but rather incorporate standardize geometry, details, connections and reinforcing configurations to assist the designer in completing project specific designs. This concept is similar to that used for FDOT’s prestressed beam standards where the designer must complete a table of standard variables which the Contractor’s precaster can directly build from or develop shop drawings if requested.

The strategy was to develop three levels of aesthetics and economy as depicted in Figure 2 and described below:

**Level 1** – Pile Bent Caps, are prismatic members with simple recessed pile pockets, usually designed as pinned or partially restrained connections (see Figure 2a).

**Level 2** – Multi-Column Pier Caps, typically utilize two or three columns (round or square) with dowels in grouted ducts for partial or full-moment connections. The cap geometry is very similar to the SHRP2 R04-RR-1 ABC Standard Plans with tapered ends on rectangular caps (see Figure 2b).

**Level 3** – Hammerhead Cap on Twin-Column Pier, is intended for enhanced aesthetics or improved horizontal clearance above congested roadway alignments. The caps utilize taper rates similar to the Level 2 caps, but with much longer cantilevers and closely spaced twin-columns for either round, elliptical or rectangular cross section (see Figure 2c).

All options can use enhanced aesthetic treatments with simple form inserts to create shadow lines or contextual shapes, and/or textured surface treatments with inexpensive form liners (see Figure 2d).

![Figure 2: Precast Cap Options](image)

The modified version of the FDOT’s Pile Bent Mathcad program is currently under final QC testing and will provide a necessary design tool to assist in completing the design and construction plan data tables. Comparison with two designs recently completed in-house (see Figure 3), a published TxDOT Pile Bent Design Example (June 2010), the SHRP2 R04-RR-1 two-column bent cap design example (see Figure
and analysis with Bentley’s RC Pier software show good correlation of results. Deviations in the results can be explained by the refinements in modeling and loading assumptions for the different designs.

<table>
<thead>
<tr>
<th>US90 Project: 2-Drilled Shaft Cap Design</th>
<th>Str, +M&lt;sub&gt;i&lt;/sub&gt; (kip*ft)</th>
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<th>-M&lt;sub&gt;i&lt;/sub&gt; w/ 20/#11 (kip*ft)</th>
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**Figure 3**: Comparisons of US 90 pilot project designs with new FDOT Mathcad program.

<table>
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<tr>
<th>SHRP2 Example 3b: 2-Column Cap Design</th>
<th>Str, +M&lt;sub&gt;i&lt;/sub&gt; (kip*ft)</th>
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<td>RC Pier vs. Matcad Diff.</td>
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<td>1.1%</td>
<td>-6.8%</td>
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</table>

**Figure 4**: Comparisons of other design examples with new FDOT Mathcad program

The Developmental Design Standard will be refined over the next several years based on the ongoing US 90 pilot project monitoring and several small scale projects, with possible incorporation into the predesigned Off-System Bridge Standards (Index D30000 series) currently under in-house development. Similar to the Buckman and St George Island bridges, several long bridge projects are scheduled to begin design within the next 5 years where this standardized application could provide significant time and cost savings. Some of these potential projects include the new westbound 118th Ave Viaduct East of 40th St (1,600 ft.) (17), Anna Maria Island Bridge replacement (3,500 ft) (18), and Howard Frankland Northbound Bridge replacement (16,000 ft) (19) all located in the Tampa Bay area; and Pensacola Bay Bridge replacement (16,000 ft.) (20) in the Florida panhandle.
Substructure cost savings are expected for short and medium length bridges once contractors become more familiar with PBES techniques and precaster’s can confidently amortized forming costs. Both of these improvements will be facilitated by FDOT’s commitment to this type of ABC practice through standardization. Immediate cost savings are expected for water crossings and long bridges with lower effective labor rates due to reduced working time over water, repetitive construction, and economy of scale with precast components. Estimated construction times could be reduced by 15-30 days for each bent, especially if precast beam pedestals are utilized.

**PBES DETAILS**

The Intermediate Pile Bent Caps incorporate some of the work from a 1996 preliminary study under FDOT Project No. 510703, improvements based on the first generation TxDOT standards for Precast Concrete Bent Cap, and details from the US 90 pilot project 90% Design Plans (Pile Alternate AA2). Future development of a Steel Pipe Pile and H-Pile option, and a Hammerhead Cap with a twin-column pier planned for 2016. The grouted pile pockets with 12-inch embedment are typically assumed to function as pinned connections. When lateral deflections need to be minimized, partial moment connections can be designed using deeper pile head embedment (see Figure 7) with capacities based on Harries and Petrou (16).

![Figure 7: Precast Pile Bent Cap with grouted pockets for partial moment connection (US 90 pilot project).](image)

The Multi-Column Pier Cap connections to the columns were based on dowel bars grouted in corrugated metal ducts described in NCHRP Report 681 (6). Due to Florida’s location in a low-seismicity zone, the simplified grouted duct connections discussed in Chapter 3 and shown in Figures 8 & 9 are utilized. These types of connections provide more construction tolerance than the proprietary grouted bar-splice.
couplers used previously on the Edison Bridge and shown in the ABC Standard Plans. These simplified details are usually sufficient for most designs in Florida, except where design for vessel collision requires a full moment connection to accommodate plastic hinging. Additionally, grouted duct connections do not require exclusive proprietary grouts or pressure injection to secure the dowelled connection, since they can be gravity fed using a number of commercially available fluid (precision) grouts. Based on the experience from the US 90 pilot project, the spiral confinement reinforcing around the grouted ducts may be substituted with #4 hoop bars and designs with more than two legs of vertical shear reinforcing per cross section, will utilize single bars with 135 degree and 90 degree hooks at opposite ends for each leg. Both these modifications will provide maximum flexibility for laying out the longitudinal reinforcing, assembling the complete reinforcing cage and repositioning grout ducts if field adjustments become necessary.

Figure 8: Typical section of precast intermediate bent cap at grouted duct connection (US 90)

Figure 9: Plan view of precast intermediate bent cap at grouted duct connection (US 90)

Figure 10: Precast intermediate bent cap voided section (US 90 pilot project)

Photo 3: EPS voids prior to concrete placement (US 90 pilot project)
To reduce the precast cap weight, the use of optional expanded polystyrene (EPS) voids are permitted. Concrete cover to the reinforcing adjacent to the EPS voids was detailed at 1.5-inches for the US 90 pilot project; however, FDOT recent policy (21) established 3-inches minimum cover for internal surfaces in all environments. Resolution of this issue is important since additional cover greater than the AASHTO-LRFD 1-inch minimum, disproportionately affects the lifting weight with arguably minimal durability benefits. The negative effect on lifting weight is especially significant for multiple cell voids similar to those shown in Figure 10. The use of voided precast units also has the benefit of reducing the concrete volume to surface area ratio mitigating the potential for mass concrete thermal cracking.

Grouting specifications for these standards were developed using the NCHRP Report 681 Attachment CS with additional modifications recommended by the FDOT State Materials Office. The standard pre-approved non-shrink grouts on the FDOT Approved Products List (APL) do not meet the minimum desired specification requirements, which will initially necessitate the implementation of a Modified Special Provision (MSP 934) (22). Project specific approval of a non-APL grout may lead to significant delays, therefore pre-approving grouts is preferred to expedite construction especially on more time sensitive installations. Mock-up grouting tests are recommended to familiarize the Contractor with the grouting process prior to beginning construction of the connections.

Templates will be required in the top of the cast-in-place columns to ensure the connection dowel bars are positioned within the construction tolerances. On the US 90 pilot project the contractor’s initial template was not sufficient to secure the dowels during the column concrete placement on the first intermediate bent. The template design was modified to provide a more rigid system for the remaining bents. Fortunately not all the precast bent caps had been cast, so the corrugated metal ducts were easily repositioned to accommodate the as-built location of the column dowel bars. This highlights the advantage of using uniform cap geometry and not precasting beam seat pedestals with the caps.

Fabrication tolerances are specified and clarified on a separate detail sheet (see Figure 11), similar to the ABC Standard Plans.

![Figure 11: Standard Fabrication Tolerances (Multi-column Pier Cap)](image)

Longitudinal flexural reinforcing is usually significantly heavier for FDOT bent cap designs compared with other states. This is primarily due to the FDOT mandated Service III design check limiting the reinforcing tensile stress to 24 ksi (23) which usually controls the design (see Figure 12). The Service III requirement is intended to minimize in-service cracking and enhance durability but has been found by the author to provide inconsistent results for elements with different depths and concrete cover (24). It is proposed that the Service III criteria be modified in accordance with the commentary in AASHTO-BDS LRFD 5.7.3.4 by using a lower exposure factor to control crack size rather than a prescriptive stress limit on reinforcing.
The precast bent caps are detailed levelled on the top and bottom with stepped height beam seat pedestals to accommodate cross slopes (typically 2%) and variable beam grades as shown in *Figures 1 & 7*. Designing bent caps level simplifies the column or pile connection details, which reduces another potential source of error during construction. While it is possible to precast the beam pedestals with the rest of the cap, the recommendation is to require these be cast-in-place after installation because adjustment to some beam seat elevations are inevitably required. C-I-P beam seat pedestals also have the advantage of reducing the cap lifting weight, mitigating conflicts with duct grouting, facilitating greater cap placement tolerances, accommodating deviations from the predicted beam cambers, and providing a more robust seal over the tops of the grouted duct connections and lifting points.

The standard designs for the precast bent caps deliberately do not require any pre-tensioning or post-tensioning. This will simplify on-site or near-site fabrication when desired by the contractor. Industry certification and FDOT approval of a temporary precast facility is much more feasible and less expensive than for a temporary prestressing facility.

There will be no specific restriction on precasting end bents, but typically contractors do not pursued this type of contract change when cast-in-place details are shown in the Plans, possibly due to unfamiliarity with PBES-ABC techniques and/or concern for potential schedule delays waiting on design approvals. On future PBES projects, the FDOT may include both precast and C-I-P alternatives for the end bents to better identify the lowest cost solution. In the author’s opinion, the end bents should match the intermediate bent geometric configuration as much as practicable to maximize the potential for reuse of the precaster’s forms and provide the most economic benefit. C-I-P backwalls and wingwalls may be the optimal solution when construction of the end bents is not scheduled on the critical path.

**Figure 12: Minimum longitudinal flexural reinforcing required to satisfy different limit states**

<table>
<thead>
<tr>
<th>Design Example: 70' Hammerhead Cap with Twin-Column Pier</th>
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<td>STRENGTH I</td>
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<td>SERVICE III (FDOT-SDG 3.10)</td>
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</tr>
<tr>
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<td>MINIMUM No. OF BARS REQUIRED</td>
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<td>Str 1-Md</td>
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<tr>
<td>(in.)</td>
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<td>Check</td>
</tr>
<tr>
<td>STRENGTH I</td>
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<td>19</td>
<td>19</td>
</tr>
<tr>
<td>SERVICE III (Limit 24 ksi)</td>
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<td>31</td>
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<tr>
<td>SERVICE I (Exposure factor = 1.00)</td>
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<tr>
<td>SERVICE I (Exposure factor = 0.60)</td>
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* Estimated crack width based on Frosch Equation: w = \(2(f_{c}/E_{s})^{0.5} \times \sqrt{C} \times (d_{c})^{0.5} + s/2)\)

*This value is 11.8 in. when the Exposure factor = 1.00.*
DEVELOPMENTAL STANDARDS FAMILY:

Index D20700 series is broken into sub-groupings to facilitate future development and expansion of substructure PBES standards with different supporting components and connections. The proposed numbering and grouping is show below:

**Level 1:**
- D20710 – Precast Intermediate Bent Cap Notes and Fabrication Tolerances
- D20712 – Precast Intermediate Bent Cap Connection Details
- D20713 – Precast Intermediate Bent Cap Details – Square Prestressed Concrete Piles
- D20714 – Precast Intermediate Bent Cap Details – Prestressed Concrete Cylinder Piles
- D20715 – Precast Intermediate Bent Cap Details – Steel Pipe Piles
- D20716 – Precast Intermediate Bent Cap Details – Steel H-Piles

**Level 2:**
- D20720 – Precast Multi-Column Pier Cap Notes and Fabrication Tolerances
- D20722 – Precast Multi-Column Pier Cap Connection Details
- D20723 – Precast Multi-Column Pier Cap Details – C.I.P Columns or Drilled Shafts
- D20724 – Precast Multi-Column Pier Cap Details – Prestressed Cylinder Concrete Piles
- D20725 – Precast Multi-Column Pier Cap Details – Precast Rectangular Columns

**Level 3:**
- D20730 – Precast Hammerhead Pier Cap Notes and Fabrication Tolerances
- D20732 – Precast Hammerhead Pier Cap Connection Details
- D20733 – Precast Hammerhead Pier Cap Details – Precast Rectangular Columns

**CONCLUSIONS**

Construction is 100% completed on the US 90 pilot project substructures with positive feedback from the Contractor and Construction & Engineering Inspectors. The grouted duct connections are very promising based on the grouting mock-up tests and the six as-built precast intermediate bent caps. This type of detail appears to be very forgiving and relatively easy to fabricate with the only downside being the difficulty in producing grout with an optimal flow rate during hot weather. The FDOT is pursuing further research into the grout rheology, with full deployment of the precast intermediate bent cap standards under the D20700 series scheduled for 2016.

**ACKNOWLEDGEMENTS:**

The standard development team consists of Cheryl Hudson, Ge Wan, Tharu Koshy, James Frederick and Steven Nolan. The US 90 pilot project design team consisted of Dennis Golabek, Steven Nolan, Christina Freeman, Vickie Abalo, Jerry Hocking, Cheryl Hudson and James Frederick. Gevin McDaniel championed the developed of construction specifications for the precast products and grout materials. Dr. Rafael Kampmann and Dr. Michelle Roddenberry from the FAMU-FSU College of Engineering lead the grout rheology testing and US 90 monitoring team respectively, and provided additional construction photographs and project information. Will Potter and David Wagner at FDOT’s Marcus H. Ansley Structures Research Center are currently assisting in the grout rheology study.

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