Precast Bent Cap Systems for Seismic Regions (NCHRP 12-74)

Emulative Nonintegral Connections—Design Example and Specifications

Caltrans-PCMAC Workshop
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1. Design of emulative nonintegral precast bent cap systems using grouted duct and cap pocket connections in CA follows a process similar to existing Caltrans SDC for CIP.

2. However, successful implementation must acknowledge important differences in design, detailing, & construction.

3. It is recommended that proposed design and construction specifications in AASHTO LRFD Seismic Guide Spec format be considered on project-specific basis until formal review by AASHTO Committees. Flow charts, design examples and connection details are available.
Overview

• Background
  • Specimen Fabrication/Assembly/Testing
  • Emulative Response

• Design Example
  • Design Specifications
  • Flow Chart
  • Example for GD and CPFD
  • Example Connection Details

• Construction Specifications
Precast Bent Cap Systems: Non-Integral

Nonintegral connection also required for integral system
Project Objectives

Develop design methodologies, connection details, and design and construction specifications for precast bent cap systems in all seismic regions.

- Systems and methodologies for entire U.S.
- Practical, cost-effective connection details
- Design examples
- Design and construction specifications with commentary in AASHTO LRFD format
- Implementation Plan
## Nonintegral Component Test Matrix

<table>
<thead>
<tr>
<th>Emulative Test Unit</th>
<th>Location (Date)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast-in-place <em>(CIP)</em> Full ductility</td>
<td>CSUS (8/07)</td>
</tr>
<tr>
<td>Grouted Duct <em>(GD)</em> Full ductility</td>
<td>CSUS (7/07)</td>
</tr>
<tr>
<td>Cap Pocket <em>(CPFD)</em> Full ductility</td>
<td>CSUS (8/07)</td>
</tr>
<tr>
<td>Cap Pocket <em>(CPLD)</em> Limited ductility</td>
<td>CSUS (12/08)</td>
</tr>
</tbody>
</table>
Grouted Duct Joint

$A_s^{jvo}$

Outside Joint Stirrups
Grouted Duct Joint

As

Inside Joint Stirrups

"Construction"
Joint Shear Reinforcement (Section)

- $\rho_s$ Joint Hoops
- Bent Cap Long
- $A_{s,jvo}$
- J-bars
## Comparison of Joints

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Joint Design</th>
<th>Grouted Duct</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grouted Duct (GD)</strong></td>
<td>1.75 in diameter steel corrugated ducts (full height) for column bars; 22 gage (0.03 in); Hoops placed around ducts</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Cap Pocket Full Ductility (CPFD)</strong></td>
<td>18 in diameter, 16 gage (0.06 in) steel corrugated helical pipe with lock seam; Added hoop at each end resist potential unraveling.</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Fabricated Column
Fabricated Bent Cap (GD)
Grouted Duct—Assembly

During Cap Placement

After Cap Placement (PGD)

Grouting Connection

Grouted Connection
Cap Pocket Joint

Sonotube Dam at Cap Top

Sand in Sonotube Dam At Cap Top
Cap Pocket—Assembly

Bent Cap Placement

Cap Pocket Assembled

Casting and Vibrating Concrete

Finishing Concrete
Test Setup and Cyclic Loading
Hysteretic Response—Full Ductility Specimens

[Graphs and images showing lateral force and drift ratio graphs for different conditions.]
<table>
<thead>
<tr>
<th>Category</th>
<th>Label</th>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Specification</td>
<td>DS1</td>
<td>Proposed Article 8.13—Joint Design for SDC A (AASHTO LRFD SGS [17])</td>
<td>New Article for SDC A precast bent cap connection design</td>
</tr>
<tr>
<td>Design Specification</td>
<td>DS2</td>
<td>Proposed Article 8.14—Joint Design for SDC B (AASHTO LRFD SGS [17])</td>
<td>New Article for SDC B precast bent cap connection design</td>
</tr>
<tr>
<td>Design Specification</td>
<td>DS3</td>
<td>Revised Article 8.15—Joint Design for SDCs C and D (AASHTO LRFD SGS [17])</td>
<td>Revision of current Article 8.13 for SDCs C and D to Article 8.15 for precast bent cap connection design</td>
</tr>
<tr>
<td>Design Specification</td>
<td>DS4</td>
<td>Proposed Article 8.8.14—Lateral Reinforcement Requirement for Columns Connecting to a Precast Bent Cap (AASHTO LRFD SGS [17])</td>
<td>New Article to ensure spacing between the hoop at top of column and the bedding layer hoop does not compromise system ductility</td>
</tr>
<tr>
<td>Design Specification</td>
<td>DS5</td>
<td>Revised Article 5.10.11.4.3—Column Connections (AASHTO LRFD BDS [25])</td>
<td>Revised Article to ensure AASHTO LRFD SGS is used for emulative precast bent cap-to-column connection design</td>
</tr>
<tr>
<td>Design Specification</td>
<td>DS6</td>
<td>Revised Article 5.11.1.2.4—Moment Resisting Joints (AASHTO LRFD BDS [25])</td>
<td>Revised Article to ensure AASHTO LRFD SGS is used for emulative precast bent cap-to-column connection design</td>
</tr>
</tbody>
</table>
8.15.5.2.2—Grouted Duct Connection

The grouted duct connection uses corrugated ducts embedded in the precast bent cap to anchor individual column longitudinal bars. The ducts and bedding layer between the cap and column or pile are grouted with high strength, non-shrink cementitious grout to complete the precast connection. Ducts are sized to provide adequate tolerance for bent cap fabrication and placement and should be accounted for in sizing the bent cap to minimize potential congestion.

Where the principal tension stress in the joint, $p_p$, is greater than or equal to $0.11\sqrt{f'_c}$, joint shear reinforcement requirements are essentially the same as those for cast-in-place connections. However, where the principal tension stress in the joint, $p_p$, is less than $0.11\sqrt{f'_c}$, minimum vertical stirrups are required in the joint per Article 8.14.5.2.2a. See Article 8.15.3.2.1.
Example Design Specification—Joint Design For SDCs C and D

- Vertical Stirrups Outside the Joint, $A_{s}^{vo}$
- Transverse Joint Reinforcement, $\rho_s$
- Horizontal J-Bars, $A_{s}^{jh}$
- Vertical Stirrups Inside the Joint, $A_{s}^{vi}$
- Additional Long Bent Cap Reinforcement
- Corrugated Metal Duct
- Side Face Reinforcement
- Bedding Layer Hoop
- Transverse Column Reinforcement
- Bedding Layer Column
- Precast Bent Cap
- Longitudinal Column Reinforcement, $A_{st}$
<table>
<thead>
<tr>
<th>Design Flow Chart</th>
<th>DF1</th>
<th>SDC A Design Flow Chart</th>
<th>Flow chart for design of precast bent cap connections in SDC A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Example</td>
<td>DE1</td>
<td>SDC A Design Example—Grouted Duct Connection</td>
<td>Design example for grouted duct connection in SDC A (minimum joint reinforcement)</td>
</tr>
<tr>
<td>Design Example</td>
<td>DE2</td>
<td>SDC A Design Example—Cap Pocket Connection</td>
<td>Design example for cap pocket connection in SDC A (minimum joint reinforcement)</td>
</tr>
<tr>
<td>Design Flow Chart</td>
<td>DF2</td>
<td>SDCs B, C, and D Design Flow Chart</td>
<td>Flow chart for design of precast bent cap connections in SDCs B, C, and D</td>
</tr>
<tr>
<td>Design Example</td>
<td>DE3</td>
<td>SDC B Design Example—Grouted Duct Connection</td>
<td>Design example for grouted duct connection in SDC B (minimum joint reinforcement)</td>
</tr>
<tr>
<td>Design Example</td>
<td>DE4</td>
<td>SDC B Design Example—Cap Pocket Connection</td>
<td>Design example for cap pocket connection in SDC B (minimum joint reinforcement)</td>
</tr>
<tr>
<td>Design Example</td>
<td>DE5</td>
<td>SDCs C and D Design Example—Grouted Duct Connection</td>
<td>Design example for grouted duct connection in SDCs C and D (additional joint reinforcement)</td>
</tr>
<tr>
<td>Design Example</td>
<td>DE6</td>
<td>SDCs C and D Design Example—Cap Pocket Connection</td>
<td>Design example for cap pocket connection in SDCs C and D (additional joint reinforcement)</td>
</tr>
</tbody>
</table>
Joint Design Flow Chart

DESIGN FLOW CHART FOR CAST-IN-PLACE AND PRECAST BENT CAP JOINT DESIGN PER PROPOSED ARTICLE 8.15 (SDCs C AND D) AND ARTICLE 8.14 (SDC B)*

Joint performance shall satisfy Article 8.15.1; 8.14.1*. Evaluate principal tension and compression stresses in joint per Article 8.15.2.1 and concurrently satisfy Article 8.15.2.2.

IF:
Principal compression ≤ 0.25f_c and principal tension ≤ 0.38f_c (Article 8.15.2.1)

IF:
Principal tension ≥ 0.11f_c (Article 8.15.3.1)
Provide transverse confinement to satisfy p_t ≥ 0.11f_c/f_fh and p_d ≥ 0.40f_c/f_fh
(Eq. 8.15.3.1-1) and (Eq. 8.15.3.1-2)

IF:
Principal tension < 0.11f_c (Article 8.15.3.1)
Bent cap is CIP in SDC B

IF:
Principal compression > 0.25f_c or principal tension > 0.38f_c
(Article 8.15.2.1)

Re-proportion joint until the provisions of Article 8.15.2 are satisfied

IF:
Bent connection is a "Knee" joint per Article 8.15; 8.14*

Bent connection is a "T" joint per Article 8.15; 8.14*

TBD by Others

Bent cap is nonintegral

IF:
D > d ≤ 1.25D_c (Eq. 8.15.5-1)
Provide outside vertical joint shear stirrups: A_s ≥ 0.175A_{sh}
(Eq. 8.15.5.1.1-1)
Provide additional longitudinal reinforcement: A_s ≥ 0.245A_{sh}
(Eq. 8.15.5.1.3-1)

IF:
d ≤ D_c or d > 1.25D_c (Eq. 8.15.5-1)
See integral joint shear design flow chart

Use strut & tie provisions of the AASHTO LRFD Bridge Design Specifications and as approved by the Owner to determine joint shear reinforcement.

IF:
Bent cap is integral

IF:
Bent connection is a "Knee" joint per Article 8.15; 8.14*

IF:
Bent cap is nonintegral

Cast-In-Place bent cap

SDCs C or D
Provide inside vertical joint shear stirrups: A_s ≥ 0.125A_{sh}
(Eq. 8.15.5.1.2-1)
Provide supplementary hoops per Article 8.15.5.2.3a
Provide horizontal "J" bars per Article 8.15.5.1.4.

SDC B
TBD by Others

PreCast "Cap pocket" connection

Provide inside vertical joint shear stirrups:
A_s ≥ 0.125A_{sh}
(Eq. 8.15.5.2.3a-1)
Provide horizontal "J" bars per Article 8.15.5.1.4.

PreCast "Grouted duct" connection

Provide inside vertical joint shear stirrups:
A_s ≥ 0.135A_{sh}
(Eq. 8.15.5.2.2-1)
Provide horizontal "J" bars per Article 8.15.5.1.4.

Provide special analysis and detailing of joint.

Provide inside vertical joint shear stirrups:
A_s ≥ 0.10A_{sh}
(Eq. 8.14.5.2.2-1) for grouted duct; A_s ≥ 0.104A_{sh}
(Eq. 8.14.5.2.3a-1) for cap pocket; CIP Provisions TBD by Others.

Provide horizontal "J" bars per Article 8.15.5.1.4.

Bedding layer ≤ 3" (Article 8.15.5.2.1)

Place bedding layer confinement per Article 8.15.5.2.1 and place top column hoop per Article 8.8.14.

Bedding layer > 3" (Article 8.15.5.2.1)

Use Owner established provisions for bedding layer confinement and place top column hoop per Article 8.8.14.

*Articles referenced in flow chart are for SDCs C and D; alternate article references for SDC B are shown italicized following the related SDCs C and D reference as applicable.
Proportion Joint

Principal compression $\leq 0.25f_c$ and principal tension $\leq 0.38\sqrt{f_c}$ (Article 8.15.2.1)

IF: Principal tension $\geq 0.11\sqrt{f_c}/f_{yr}$ (Article 8.15.3.1)

- Provide transverse confinement to satisfy $\rho_s \geq 0.11\sqrt{f_c} / f_{yr}$ and $\rho_s \geq 0.40A_{et} / l_{et}$ (Eq. 8.15.3.1-1) and (Eq. 8.15.3.1-2)

- Bent connection is a “Knee” joint per Article 8.15; 8.14*

- Provide special analysis and detailing of joint.

- Cast-in-Place bent cap
  - SDCs C or D
  - Provide inside vertical joint shear stirrups: $A_{jv}^{\text{hi}} \geq 0.13A_{et}$ (Eq. 8.15.5.1.2-1)
  - Provide horizontal “J” bars per Article 8.15.5.1.4.

- Precast “Cap pocket” connection
  - SDC B
  - Provide inside vertical joint shear stirrups: $A_{jv}^{\text{hi}} \geq 0.12A_{et}$ (Eq. 8.15.5.2.3a-1)
  - Provide supplementary hoops per Article 8.15.5.2.3a

- Precast “Grouted duct” connection
  - Provide inside vertical joint shear stirrups: $A_{jv}^{\text{hi}} \geq 0.13A_{et}$ (Eq. 8.15.5.1.2-1)
  - Provide horizontal “J” bars per Article 8.15.5.1.4.

Principal tension $< 0.11\sqrt{f_c}$ (Article 8.15.3.1)

IF: Bent cap is CIP in SDC B

IF: Bent cap is nonintegral

- $D_c \leq d \leq 1.25D_c$ (Eq. 8.15.5-1)

- Provide outside vertical joint shear stirrups: $A_{jv}^{\text{hi}} \geq 0.175A_{et}$ (Eq. 8.15.5.1.1-1)

- Use strut & tie provisions of the AASHTO LRFD Bridge Design Specifications as approved by the Owner to determine joint shear reinforcement.

- See integral joint shear design flowchart

- Bent connection is a “Knee” joint per Article 8.15; 8.14*

- Cast-in-Place bent cap
  - SDCs C or D
  - Provide inside vertical joint shear stirrups: $A_{jv}^{\text{hi}} \geq 0.13A_{et}$ (Eq. 8.15.5.1.2-1)

- Precast “Cap pocket” connection
  - SDC B
  - Provide inside vertical joint shear stirrups: $A_{jv}^{\text{hi}} \geq 0.12A_{et}$ (Eq. 8.15.5.2.3a-1)
  - Provide supplementary hoops per Article 8.15.5.2.3a

- Precast “Grouted duct” connection
  - Provide inside vertical joint shear stirrups: $A_{jv}^{\text{hi}} \geq 0.13A_{et}$ (Eq. 8.15.5.1.2-1)
  - Provide horizontal “J” bars per Article 8.15.5.1.4.

Principal compression $> 0.25f_c$ or principal tension $> 0.38\sqrt{f_c}$ (Article 8.15.2.1)

Re-proportion joint until the provisions of Article 8.15.2 are satisfied.

IF: Bent cap is not CIP in SDC B

- Provide transverse confinement to satisfy $\rho_s \geq 0.11\sqrt{f_c} / f_{yr}$ (Eq. 8.15.3.1-1)

- Bent connection is a “T” joint per Article 8.15; 8.14*

- Provide special analysis and detailing of joint.

- Precast “Grouted duct” connection
  - SDC B
  - Provide inside vertical joint shear stirrups: $A_{jv}^{\text{hi}} \geq 0.10A_{et}$ (Eq. 8.14.5.2.2a-1) for grouted duct; $A_{jv}^{\text{hi}} \geq 0.10A_{et}$ (Eq. 8.14.5.2.3a-1) for cap pocket; CIP Provisions TBD by Others.

Bedding layer $\leq 3$” (Article 8.15.5.2.1)

- Place bedding layer confinement per Article 8.15.5.2.1 and place top column hoop per Article 8.8.14.

Bedding layer $> 3$” (Article 8.15.5.2.1)

- Use Owner established provisions for bedding layer confinement and place top column hoop per Article 8.8.14.
Check Joint Principal Stress (C/D and B)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal tension ≥ 0.11\sqrt{f_t'c} (Article 8.15.3.1)</td>
<td>( \rho_s \geq 0.11\sqrt{f_t'c} / f_{ph} ) and ( \rho_s \geq 0.40A_{st} / A_{st} ) (Eq. 8.15.3.1-1) and (Eq. 8.15.3.1-2)</td>
</tr>
<tr>
<td>Principal tension &lt; 0.11\sqrt{f_t'c} (Article 8.15.3.1)</td>
<td>Bent cap is CIP in SDC B</td>
</tr>
<tr>
<td>Bent connection is a ‘Knee’ joint per Article 8.15; 8.14*</td>
<td>Provide special analysis and detailing of joint.</td>
</tr>
<tr>
<td>Bent connection is a ‘T’ joint per Article 8.15; 8.14*</td>
<td>TBD by Others</td>
</tr>
<tr>
<td>Bent cap is nonintegral</td>
<td>Provide transverse confinement to satisfy ( \rho_s \geq 0.11\sqrt{f_t'c} / f_{ph} ) (Eq. 8.15.3.1-1)</td>
</tr>
<tr>
<td>Bent cap is integral</td>
<td>See integral joint shear design flow chart</td>
</tr>
<tr>
<td>Bent cap is nonintegral</td>
<td>Provide transverse confinement to satisfy ( \rho_s \geq 0.11\sqrt{f_t'c} / f_{ph} ) (Eq. 8.15.3.1-1)</td>
</tr>
</tbody>
</table>

Supplementary Hoops

Bedding Layer Hoop

CP

A_s jvi

Precast “Cap pocket” connection

Provide inside vertical joint shear stirrups: \( A_{jvi}^{h} \geq 0.12A_{st} \) (Eq. 8.15.5.2.3a-1)

J Bars

A_s jvi

Precast “Grouted duct” connection

Provide inside vertical joint shear stirrups: \( A_{jvi}^{h} \geq 0.135A_{st} \) (Eq. 8.15.5.1.2-1)

GD

A_s jvi

Use Owner established provisions for bedding layer confinement and place top column hoop per Article 8.8.14.

Supplementary hoops per Article 8.15.5.2.3a

A_s jvo

Provide horizontal “J” bars per Article 8.15.5.1.4.

A_s jl

Provide transverse confinement to satisfy \( \rho_s \geq 0.11\sqrt{f_t'c} / f_{ph} \) (Eq. 8.15.3.1-1)
# Joint Summary Reinforcement

\[ p_t \geq 0.11 \sqrt{f'_c} \] (SDCs B, C, D)

<table>
<thead>
<tr>
<th>Reinforcement Type</th>
<th>Term (Equation)</th>
<th>2009 SGS</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Hoop</td>
<td>( \rho_s )</td>
<td>Eq. 8.13.3-2</td>
<td>Max (Eq. 1, Eq. 2)</td>
</tr>
<tr>
<td>Inside joint stirrups</td>
<td>( A_{s_{jvi}} / A_{st} )</td>
<td>0.135</td>
<td>0.135</td>
</tr>
<tr>
<td>Outside joint stirrups</td>
<td>( A_{s_{jvi}} / A_{st} )</td>
<td>0.175</td>
<td></td>
</tr>
<tr>
<td>Additional Cap</td>
<td>( A_{s_{jl}} / A_{st} )</td>
<td>0.245</td>
<td></td>
</tr>
<tr>
<td>Horizontal J-bar</td>
<td>-</td>
<td>Every other intersection</td>
<td>Same as CIP</td>
</tr>
<tr>
<td>Anchorage Length</td>
<td>( l_{ac} )</td>
<td>( 0.79 d_{bl} f_{ye} / \sqrt{f'_c} )</td>
<td>( 2d_{bl} f_{ye} / f' )</td>
</tr>
<tr>
<td>Bedding Layer</td>
<td>-</td>
<td>NA</td>
<td>Per Spec</td>
</tr>
<tr>
<td>Supplemental Hoops</td>
<td>-</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

- CIP: CIRP
- GD: GD
- CP: CP
- SGS: SGS
# Joint Summary Reinforcement

\[ p_t < 0.11\sqrt{f'_c} \text{ (SDCs C, D)} \]

<table>
<thead>
<tr>
<th>Reinforcement Type</th>
<th>Term</th>
<th>2009 SGS</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CIP</td>
<td>GD</td>
</tr>
<tr>
<td>Transverse Hoop</td>
<td>( \rho_s )</td>
<td>Eq. 8.13.3-1</td>
<td>Eq. 8.13.3-1</td>
</tr>
<tr>
<td>Inside joint stirrups</td>
<td>( A_s^{jvi} / A_{st} )</td>
<td>NO REQ’T</td>
<td>0.10</td>
</tr>
<tr>
<td>Outside joint stirrups</td>
<td>( A_s^{jvi} / A_{st} )</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Additional Cap</td>
<td>( A_s^{jl} / A_{st} )</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Longitudinal</td>
<td>( I_{ac} )</td>
<td>0.79( d_{bl} f_{ye} / \sqrt{f'_c} )</td>
<td>2( d_{bl} f_{ye} / f_g )</td>
</tr>
<tr>
<td>Horizontal J-bar</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Anchorage Length</td>
<td>-</td>
<td>NA</td>
<td>Per Spec</td>
</tr>
<tr>
<td>Bedding Layer</td>
<td>-</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Supplemental Hoops</td>
<td>-</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
Joint Design Example—
Cap Pocket (SDCs C & D)

Cap Pocket Joint Design Example for SDCs C and D

Cap pocket connection between a column and a precast bent cap in SDCs C and D reinforces the bent cap joint by means of a helical link-slab, corrugated steel pipe, eliminating conventional hoops and y-bars. This SDC C/D design example applies to a T-joint of a rectangular, nonintegral precast bent cap supported by circular columns for which the principal tensile stress in the connection exceeds 0.11 $\sqrt{f_{c}}$. In this case, the connection requires additional joint reinforcement. The applicable commentary sections in the AASHTO Bridge Specifications for LRFD Seismic Bridge Design (SSB) provide additional background.

**Notes:** 1. The SDC B design example illustrates the procedure to be followed when the 0.11 $\sqrt{f_{c}}$ limit is not exceeded. 2. Core joints such as that represented in Fig. 3.5 are not addressed in the current SSB, and special design provisions should be identified by the designer.

**Geometry and Design Parameters**

- $f_{c} = 4.0$ ksi (specified compressive strength of bent cap)
- $f_{c} = 3.3'$ ksi (specified compressive strength of pocket fill)
- $f_{s}$ (yield strength of equivalent hoop)
- $f_{a}$ (expected yield stress of column bars)
- $f_{p}$ (nominal yield stress of steel pipe)
- $B_{p}$ (butt cap thickness)
- $D_{c}$ (column diameter)
- $A_{s}$ (hoop bar size)
- $A_{c}$ (hoop bar spacing)

**Joint Performance**

- Moment resisting connections are designed to transmit the maximum forces produced when the column reaches its overstrength moment capacity, $M_{u}$.

**Principal Stresses**

Principal stresses in the joint are limited by the following equations:

- Principal compression, $p_{1}$: $p_{1} \leq 0.25 f_{c}$
- Principal tension, $p_{2}$: $p_{2} \leq 0.30 f_{c}$

**Joint Preportioning**

- $R_{u}$ = 84.0 in (7.0 ft x 12"")
- $D_{c}$ = 60.0 in (5.0 ft x 12"")
- $D_{b}$ = 75.0 in (6.25 ft x 12"")
- $L_{c}$ = 72.0 in Note 1
- $P_{r}$ = 620 kips Note 2
- $P_{n}$ = 370 kips Note 3
- $M_{u} = 7164$ kip-ft Note 3

**Notes:**

1) Length of column longitudinal rebar extended into cap. See calculations below.
2) No prestressing in section.
3) Determined from sectional analysis. Tension in column longitudinal rebar may also be derived from sectional analysis.
Cap Pocket Joint Design Example For SDCs C and D

Cap pocket connection between a column and a precast bent cap in SDCs C and D reinforces the bent cap joint by means of a helical lock-seam, corrugated steel pipe, eliminating conventional hoops and j-bars. This SDC C/D design example applies to a T-joint of a rectangular, nonintegral precast bent cap supported by circular columns for which the principal tensile stress in the connection exceeds 0.11\sqrt{f_c}. In this case, the connection requires additional joint reinforcement. The applicable commentary sections in the AASHTO Guide Specifications for LRFD Seismic Bridge Design (SGS) provide additional background.

Notes: 1. The procedure to be followed when the 0.11\sqrt{f_c} limit is not exceeded.

### Geometry and Design Parameters

\[
f_c' = 4.0 \text{ ksi (specified compressive strength of bent cap)}
\]
\[
f_{c, \text{pocket}} (\text{specified compressive strength of pocket fill})
\]
\[
f_{c, \text{pocket}} = f_c' + 0.5 \text{ ksi} = 5.7 \text{ ksi (BCS 8.13.8.3.3a)}
\]
\[
f_y = 60 \text{ ksi (yield stress of equivalent hoop)}
\]

Select cap pocket strength to satisfy BCS.

### Step-by-step Calcs

- Bent cap width = 7.0 ft \( B_{\text{cap}} \)
- Bent cap height = 6.25 ft \( D_s \)
- Stirrup bar size: #6

Requirements for Extreme Load case in cap:

- Top cap rein, \( A_{s, \text{top}}^{\text{cap}} = 16.77 \) in\(^2\)
- Bot cap rein, \( A_{s, \text{bot}}^{\text{cap}} = 11.40 \) in\(^2\)
- Shear rein, \( A_v = 4.12 \) in\(^2/\)ft

Bedding Layer

### Diagrams
F_{ll} = 36.1 \text{ kips/ft}
H_p = 12.0 \text{ in/ft} \quad \text{(specified unit length)}
f_{yp} = 30.0 \text{ ksi} \quad \text{(manufacturer specified)}
\theta = 20.0 \text{ deg} \quad \text{(manufacturer specified)}

\[ t_{pipe} \geq 0.1068 \text{ in} \]

Use a 12 gage corrugated steel pipe, 54" nominal inside diameter. \[ t_{pipe} = 0.1046 \text{ in} \] (2% under, Say OK)

As a check, compare minimum \( t_{pipe} \) from Eq. 8.15.3.2.2-1 to simplified equations:

\[ t_{pipe} \geq 0.04 \frac{D'_c p f'_c}{f_{yp} \cos \theta} = 0.1554 \text{ in} \quad \text{and} \geq 0.06 \text{ in} \quad \text{(Note: } f'_c \text{ refers to bent cap concrete)} \quad \text{Eq. C8.15.3.2.2-1} \]

\[ t_{pipe} \geq 0.14 \frac{A_{st} D'_{cp} f_{yh}}{f_{yp} \cos \theta} = 0.0982 \text{ in} \quad \text{and} \geq 0.06 \text{ in} \quad \text{Eq. C8.15.3.2.2-2} \]

If the refined equation (Eq. 8.15.3.2.2-1) is not used, the maximum of these two simplified equations may be used because they provide a more conservative value. Note that the controlling thickness of 0.1554" from commentary equations is considerably larger than the calculated 0.1068" from the more accurate specification equation. Use of the simplified equation should be used for pipe thickness, especially for larger diameter pipes.
Joint Design Example—Cap Pocket (SDCs C & D)

$D_c$ is the distance over which $A_{s}^{jvo}$ is spread in addition to stirrups required in the same region for other forces. $D_c =$ column dia.

Placement of a full $A_{s}^{jvo}$ is required on each side of the column.

Details
Clear Application of Specs for Hoop at Col Top and Bedding Layer
Example Connection Details

NCHRP PROJECT 12-74

EXAMPLE PRECAST BENT CAP CONNECTION DETAILS

BY: JWML  CHK: MSJAW  DATE: 11/24/09  SCALE: 1/4" = 1'-0"  SHEET: 1 of 1
Example Connection Details

NCHRP PROJECT 12-74
EXAMPLE PRECAST BENT CAP CONNECTION DETAILS

BY: JNWL
CHK: MS/AW
DATE: 11/24/09
SCALE: 1/4" = 1'-0"
SHEET: 1 of 1
Construction Specification
Proposed Article 8.13.8

8.13.8—Special Requirements for Nonintegral Precast Bent Caps

8.13.8.1—General

This Article describes special requirements for nonintegral precast bent cap connections using the grouted ducts or cap pockets. The grouted duct connection uses corrugated ducts embedded in the precast bent cap to anchor individual column longitudinal bars. These special requirements are intended to ensure that the bent cap concrete is placed efficiently, achieves performance for rapid construction, and does not become a weak link in the system under various load states.

8.13.8.1 Portland Cement Concrete for Precast Bent Cap

Portland cement concrete for the precast bent cap shall conform to the provisions of Article 8.2.2 for normal-weight concrete. The concrete mix design for the precast bent cap shall conform to the requirements of Articles 8.13.8.2.a and 8.13.8.2.a. The required 500 psi strength margin between the expected bent cap compressive strength and the specified compressive strength of the connection grout or cap pocket concrete fill is required to exceed the expected bent cap concrete compressive strength by at least 500 psi.

Lightweight concrete provides significant advantages for a precast bent cap system. However, it must be placed efficiently, and a weak link in the system under various load states. The specified compressive strength of the connection grout or concrete fill is required to exceed the expected bent cap concrete compressive strength by at least 500 psi.

8.13.8.3 Grouted Duct Connection

8.13.8.3.2 Hydraulic Cement Grout (Non-Shrink)

Grout used in grouted duct connections shall consist of prepackaged, non-shrink grout in accordance with ASTM C 1107 and the additional performance requirements listed in Table 8.13.8.1, including the following properties: mechanical compressive strength, and durability. Table 8.13.8.1 requirements shall govern over ASTM C 1107 requirements.

Grout shall contain no aluminum powder or gas generating system that produces hydrogen, carbon dioxide, or oxygen. Grout using metallic formulations shall not be permitted. Grout shall be free of chlorides. No additives or admixtures, including retarders, shall be added to prepackaged grout. Extension of grout shall only be permitted when recommended by the manufacturer and approved by the Engineer.

At a minimum, bent cap compressive strength and flowability shall be established during precast bent cap column longitudinal bars and the pipe thickness is sized to satisfy transverse joint reinforcement requirements.

Table 8.13.8.1 includes provisions intended to ensure the strength required by the connection develops mechanical compatibility, constructability, and durability. The specified compressive strength of the connection grout or concrete fill is required to exceed the expected bent cap concrete compressive strength by at least 500 psi.

8.13.8.8.3.2a

Table 8.13.8.1 requires the 28-day bent cap compressive strength to provide a minimum 500 psi margin over the 28-day expected bent cap concrete compressive strength. The margin accounts for the likelihood that the actual concrete strength will exceed its specified strength as well as the possibility of low grout strength. The 1.25 factor applied to $f_{c,m}$ in Table 8.13.8.1 accounts for the higher 28-day grout cube compressive strength compared to standard concrete cylinder compressive strength.

Grout should be selected with a compressive strength based on water required for fluid consistency using the ASTM C 959 Flow Cone Test. Grouts mixed to a flowable or plastic consistency according to ASTM C 730 are appropriate. The 28-day expected bent cap concrete compressive strength should be greater than the specified compressive strength required for the connection.

8.13.8.2 Description

This item shall govern for connection of precast concrete bent caps to cast-in-place columns, precast concrete columns, or prestressed concrete piles.

8.13.8.3 Materials

The materials and manufacturing processes used for precast concrete bent caps shall conform to the requirements of Article 8.13.3 except as those requirements are modified or supplemented by the provisions that follow.

8.13.8.9 "Column bar" refers to column bars, column dowels, and pile dowels.

8.13.8.10 Laboratory testing shall be permitted to establish other properties listed in Table 8.13.8.1.
Proposed Article 8.13.8 – Continued

1—General
2—Description
3—Materials

3.1 Portland Cement Concrete for Precast Bent Cap
3.2 Grouted Duct Connection
   3.2a Hydraulic Cement Grout (Non-Shrink)
   3.2b Corrugated Metal Duct
3.3 Cap Pocket Connection
   3.3a Portland Cement Conc. for Cap Pocket Fill
   3.3b Steel Pipe
3.4 Connection Hardware

4—Contractor Submittal
4.1 General
4.2 Precast Bent Cap Placement Plan
4.3 Design Calculations for Construction Procedures
4.4 Shop Drawings
Proposed Article 8.13.8 – Continued

5—Construction Methods

5.1 General

5.2 Handling

5.3 Placement

5.4 Grouting of Grouted Duct Connection
   5.4a Trial Batch
   5.4b Grout Placement
   5.4c Grout Testing

5.5 Concreting of Cap Pocket Connection
   5.5a Trial Batch
   5.5b Concrete Placement
   5.5c Testing of Cap Pocket Fill Concrete

5.6 Beam Placement

6—Measurement and Payment
### Grout Specification (TxDOT 1748)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mechanical</strong></td>
<td></td>
</tr>
<tr>
<td>Compressive strength (ASTM C 109, 2” cubes)</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>Compressive strength (psi)</td>
</tr>
<tr>
<td>1 day</td>
<td>2,500</td>
</tr>
<tr>
<td>3 days</td>
<td>4,000</td>
</tr>
<tr>
<td>7 days</td>
<td>5,000</td>
</tr>
<tr>
<td>28 days</td>
<td>Maximum [6000, 1.25 ($f_{ce_cap}$ + 500)]</td>
</tr>
<tr>
<td><strong>Compatibility</strong></td>
<td></td>
</tr>
<tr>
<td>Expansion requirements (ASTM C 827 &amp; ASTM C 1090)</td>
<td>Grade B or C—expansion per ASTM C 1107</td>
</tr>
<tr>
<td>Modulus of elasticity (ASTM C 469)</td>
<td>2.8-5.0x10^6 psi</td>
</tr>
<tr>
<td>Coefficient of thermal expansion (ASTM C 531)</td>
<td>3.0-10.0x10^-6/deg F</td>
</tr>
<tr>
<td><strong>Constructability</strong></td>
<td></td>
</tr>
<tr>
<td>Flowability (ASTM C 939 Flow Cone)</td>
<td>fluid consistency efflux time: 20-30 sec</td>
</tr>
<tr>
<td>Set Time (ASTM C 191)</td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>2.5-5.0 hrs</td>
</tr>
<tr>
<td>Final</td>
<td>4.0-8.0 hrs</td>
</tr>
<tr>
<td><strong>Durability</strong></td>
<td></td>
</tr>
<tr>
<td>Freeze Thaw (ASTM C 666)</td>
<td>300 cycles, RDF 90%</td>
</tr>
<tr>
<td>Sulfate Resistance (ASTM C 1012)</td>
<td>expansion at 26 weeks &lt; 0.1%</td>
</tr>
</tbody>
</table>
Final Thoughts

✓ Grouted duct and cap pocket connections can be designed using SDC-type process for joint shear. However, differences in design, detailing, and construction must be carefully followed to achieve emulative response.

✓ Proposed design and construction specifications are recommended for project-specific use until formal review by AASHTO.

✓ Successful implementation is ensured by careful use of specifications with flow charts, design examples, and example details.
Acknowledgements

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