NCHRP 12-74
Precast Bent Cap Systems for Seismic Regions

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Introduction
NCHRP 12-74 Project Deliverables

- Develop a variety of precast bent cap column connection suitable for all seismic regions in the U.S.
  - Integral and nonintegral bent cap systems
  - Emulative and Hybrid
- Demonstrate, through experimentation, the performance of the connection details proposed
- Develop codified design methodologies in AASHTO LRFD Seismic Guide Specification format
- Develop construction specifications
- Provide design examples on the use of the different bent cap column connections
- All bent caps systems have been proof tested and are ready for implementation
NCHRP 12-74: Bent Cap Classification

- **Non-Integral**
  - No long. moment transfer
  - Simpler field connection
  - Superstructure sits on bearings atop bent cap
  - Column fixity req’d at base
  - Large foundation forces

- **Integral**
  - Full continuity
  - Connection challenge
  - Redundancy
  - Decrease drift
  - Reduce foundation demand
  - Increased vert. clearance

PCI Bridge Manual
NCHRP 12-74: Bent Cap – Column Connection Classification

• **Emulative Connections:**
  - Perform similar to CIP connections
  - “Fat” hysteretic behavior
  - Dissipate energy through system yield
  - Residual displacement

• **Hybrid Connections:**
  - Unbonded PT & bonded bars
  - Large displacement capacity
  - Return to zero displacement state following earthquake
  - Less permanent damage than emulative/CIP connections


Christopolous, Filiatrault and Restrepo
Precast Bent Cap Concepts
NCHRP 12-74: Grouted Duct Connection (Emulative)

- Metallic ducts are left embedded in the cap at the column joint for anchoring the column longitudinal reinforcement
- Requires strict tolerances, use of templates are necessary
- Flowable grout is pumped from below
- Careful sealing of the cap-column joint is required to resist the hydraulic head pressure
- Always be prepared to abort the grouting operation, clean and regROUT
NCHRP 12-74: Grouted Duct Connection (Emulative)
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NCHRP 12-74: Grouted Duct Connection (Emulative)
NCHRP 12-74: Cap Pocket (Emulative)

- Corrugated steel pipes are left embedded in the cap at the column as permanent form and joint reinforcement
- Ample tolerances
- Small aggregate with good workability is placed from the top
NCHRP 12-74: Cap Pocket (Emulative)
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NCHRP 12-74: Cap Pocket (Emulative)
GD Specimen – Assembly

During Cap Placement

After Cap Placement (PGD)

Grouting Connection

Grouted Connection
NCHRP 12-74: Integral Bent Cap
NCHRP 12-74: Integral Bent Cap

- Simple detail, no inverted T-cap is needed.
- No end diaphragms are needed.
- Girders temporarily held with strong backs (strong backs can also be used as shear transfer mechanism is deemed necessary).
- Girders are fabricated up to 4 in. short to give ample tolerances and to allow for skew bridge construction.
- Gap is filled with a fiber-reinforced grout (polypropylene with fibers dosed at 0.2% per volume).
- Splicing of PT ducts.
- 2-stage post-tensioning operation.
Integral Bent Cap
Integral Bent Cap
NCHRP 12-74: Hybrid connection concept

- Bent cap
- Fiber reinforced grout
- Precast column
- Prestressing tendon
- Mild steel reinforcement
NCHRP 12-74: Hybrid connection concept

Force

Loading

Displacement
NCHRP 12-74: Hybrid connection concept
NCHRP 12-74: Hybrid connection concept
Non-Integral, Hybrid: Conventional PT Column

Grouted duct connection
Non-Integral, Hybrid: Steel Shell

Shell acts as longitudinal and transverse reinforcement

Confinement via shell

Grouted duct connection
Non-Integral, Hybrid: Dual Steel Shell

- Both shells act as longitudinal and transverse reinforcement
- Inner shell corrugated steel pipe
- Grouted duct connection
- Confinement via shell
Non-Integral, Hybrid: Steel Shell
Non-Integral, Hybrid: Dual Steel Shell
Design and Construction Specifications
8.15.5.2.2—Grouted Duct Connection

Where the principal tension stress in the joint, $p_b$, is greater than or equal to $0.11 \sqrt{f'_c}$, grouted duct connections shall satisfy the additional joint shear reinforcement required by Article 8.15.5.1. In addition, the vertical stirrups inside the joint shall consist of double leg stirrups or ties of a bar size no smaller than that of the bent cap transverse reinforcement. A minimum of two stirrups or equivalent ties shall be used. Figure 1 through Figure 3 show details of the connection, including ducts, vertical stirrups inside the joint, and bedding layer reinforcement, in addition to the joint transverse reinforcement.

C8.15.5.2.2

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, $p_b$, 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, $p_b$, 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
Introduction

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. Knee joints such as that represented in C8.15.1 are not addressed in the current SGS, 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)
- $f_{c,\text{pocket}}$ (specified compressive strength of pocket fill)
- $f_{c,\text{pocket}} = f_c + 0.5$ ksi = 5.7 ksi (BCS 8.13.8.3.3a)
- $f_{yh}$ (yield stress of equivalent hoop)
- $f_{yh} = 60$ ksi
- $f_{yo}$ (expected yield stress of column bars)
- $f_{yo} = 68$ ksi

Select cap pocket strength to satisfy BCS.

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 applicable Commentary sections in the AASHTO Guide for LRFD Bridge Construction Specifications (BCS) provide additional background.

Step-by-step Calcs

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

Diagrams
Joint Design Example—Cap Pocket (SDCs C & D)

\[ F_H = 36.1 \text{ kips/ft} \]
\[ H_p = 12.0 \text{ in/ft} \quad \text{(specified unit length)} \]
\[ f_{yp} = 30.0 \text{ ksi} \quad \text{(manufacturer specified)} \]
\[ \theta = 20.0 \text{ deg} \quad \text{(manufacturer specified)} \]

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

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 simplify:

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

\[ t_{pipe} \geq 0.14 \frac{A_{st} D'_{cp} f_{vh}}{l_{ac}^2 f_{yp} \cos \theta} = 0.0982 \text{ in} \quad \text{and} \geq 0.06 \text{ in} \]
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 less than the 0.1068” from the more accurate specification equation. Use of the smaller 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. $D_c = \text{column dia.}$

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

Details
Example of 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.

8.13.8.1.1 These special requirements are intended to ensure precast bent cap connections using grouted ducts or cap pockets are constructible and also provide the expected seismic performance, durability, and economy. Provisions are based primarily on Matsumoto et al. (2001) and Matsumoto (2009).

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 maintain potential connection. The cap pocket connection uses a single, helical, corrugated steel pipe embedded in the precast bent cap to form the cap pocket, which anchors the column longitudinal bars. This pipe, placed between top and bottom bent cap longitudinal reinforcement, serves as both a stay-in-place form and as post-tension reinforcement. Special forming is required above and below the pipe to form the cap pocket void through the full depth of the bent cap. A flowable cast-in-place concrete is used to fill the void and complete the precast connection. The pipe diameter is sized to provide adequate field tolerance for placement of the precast bent cap over column longitudinal bars, and the pipe thickness is sized to satisfy transverse joint reinforcement requirements.

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 precast 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.

8.13.8.3.1 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 8.13.8.3.2a and 8.13.8.3.2b to achieve 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.

Use of lightweight concrete shall be based on applicable research of connection performance, including seismic effects, and approval by the Engineer.

8.13.8.3.2 Grouted Duct Connection

8.13.8.3.2a Hydraulic Cement Grout (Non-Shrink)

Grout used in grouted duct connections shall consist of prepackaged, cementitious, non-shrink grout in accordance with ASTM C 1107 and the additional performance requirements listed in Table 8.13.8.6-1, including the following properties: mechanical, compatibility, constructability, 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 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.

As a minimum, grout compressive strength, and flowability shall be established during trial batches per Article 8.13.8.3.4a. Laboratory testing shall be permitted to establish other properties listed in Table 8.13.8-1.

8.13.8.3.2b Other Types of Grout

The required strength margin between the bent cap and precast connection grout or concrete fill is intended to help ensure the connection does not become a weak link in the system. 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 50 psi. Lightweight concrete can provide significant advantages for a precast bent cap system. However, its use should be based on relevant research including its effect on seismic performance of the connection.

Table 8.13.8-1 includes provisions intended to ensure the grout used in the connection develops mechanical, constructability, compatibility, and durability properties that help ensure the grout is placed efficiently, achieves performance for rapid construction, and does not become a weakness in the structure under the various limit states. For example, Table 8.13.8-1 requires the 28-day grout compressive strength to provide a minimum 500 psi margin over the 28-day expected bent cap concrete compressive strength. This margin accounts for the likelihood that the actual concrete strength will exceed its specified strength as well as the possibility of low grout strength...
Example of Connection Details

**PLAN**

SCALE: 1/4" = 1'-0"

**SECTION**

SCALE: 1/4" = 1'-0"

**ELEVATION**

SCALE: 1/4" = 1'-0"

**Example of Connection Details**

1. The column hoop is spaced from the bedding layer hoop to maintain plastic hinge column hoop spacing within the bedding layer.
2. For clarity, cast-in-place pier diaphragm anchorage is not shown.
3. Detailing shown corresponds to principal tension in the joint equal to 0.11 \( \sqrt{f_{ck}} \) or greater.
4. For clarity, all bent cap reinforcement for limit states other than seismic is not shown.

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**EXAMPLE PRECAST BENT CAP CONNECTION DETAILS**

BY: JHML | CHK | MS/SAW | DATE: 11/24/99 | SCALE: 1/4" = 1'-0" | SHEET: 1 of 1

**SACRAMENTO STATE**

**PLAN**

SCALE: 1/4" = 1'-0"

**SECTION**

SCALE: 1/4" = 1'-0"

**ELEVATION**

SCALE: 1/4" = 1'-0"

**Example of Connection Details**

1. First column hoop to be spaced from bedding layer hoop to maintain plastic hinge column hoop spacing within the bedding layer.
2. For clarity, cast-in-place pier diaphragm and associated dowels anchored into bent cap are not shown.
3. Detailing shown corresponds to principal tension in the joint equal to 0.11 \( \sqrt{f_{ck}} \) or greater.
4. For clarity, all bent cap reinforcement for limit states other than seismic is not shown.

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**EXAMPLE PRECAST BENT CAP CONNECTION DETAILS**

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**SACRAMENTO STATE**
Summary – NCHRP Project 12-74

• 12-74 has been completed. The corresponding report will be published in about 6 months

• The project has a list of comprehensive design and construction specifications, and design examples. All products are ready for implementation
Acknowledgments

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