

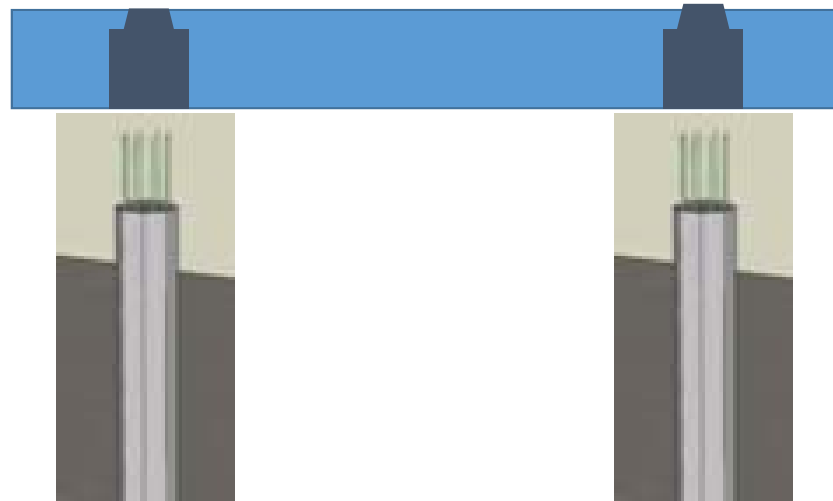
Accelerated Bridge Construction- Seismic Design Module ABC-Seismic 2

Design of Precast Bent Cap Joints in Moderate and High Seismic Zones

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CIP pocket connections

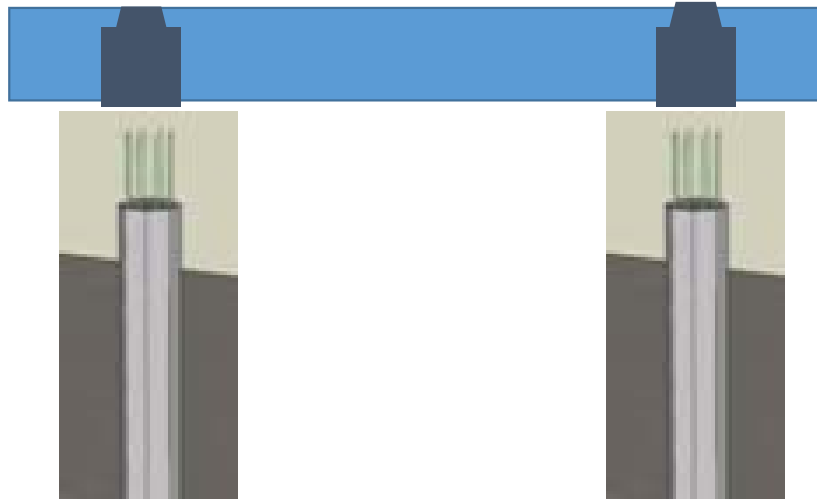


Precast pocket cap beam connections



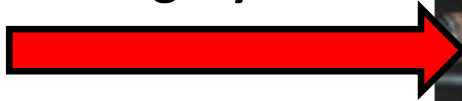
Precast Bent Cap/Precast Column CIP Pocket Connections (Ref. 70 (Restrepo, Et al. 2011)

Bottom beam bars





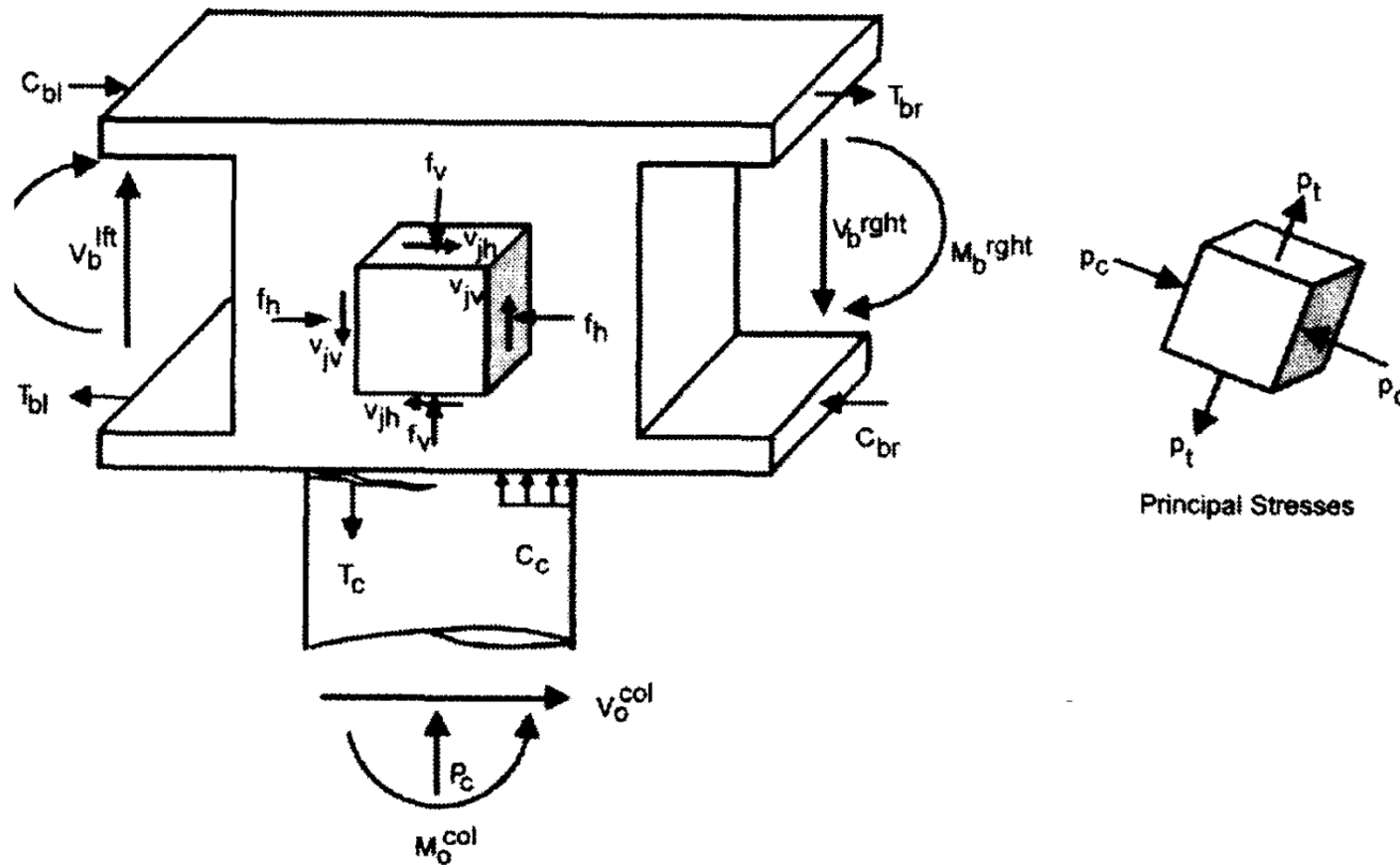
Bedding layer



Precast column



Cap Beam Joint Stresses (CIP or Precast)



Moment-resisting joints shall be proportioned so that the principal stresses satisfy the requirements of Eq. 8.13.2-1 and Eq. 8.13.2-2. (Unit= ksi)

- For principal compression, p_c :

$$p_c \leq 0.25 f'_c \quad (8.13.2-1)$$

- For principal tension, p_t :

$$p_t \leq 0.38 \sqrt{f'_c} \quad (8.13.2-2)$$

in which:

$$p_t = \left(\frac{f_h + f_v}{2} \right) - \sqrt{\left(\frac{f_h - f_v}{2} \right)^2 + v_{jv}^2} \quad (8.13.2-3)$$

$$p_c = \left(\frac{f_h + f_v}{2} \right) + \sqrt{\left(\frac{f_h - f_v}{2} \right)^2 + v_{jv}^2} \quad (8.13.2-4)$$

f_h : average normal stress in the horizontal direction within a moment resisting joint (ksi)

f_v : average normal stress in the vertical direction within a moment resisting joint (ksi)

f_{jv} nominal vertical shear stress in a moment resisting joint (ksi)

$$f_h = \frac{P_b}{B_{cap} D_s} \quad (8.13.2-5)$$

where:

P_b = beam axial force at the center of the joint including the effects of prestressing (kip)

B_{cap} = bent cap width (in.)

D_s = depth of superstructure at the bent cap for integral joints or depth of cap beam for nonintegral bent caps (in.)

The average vertical stress, f_v , shall be taken as:

$$f_v = \frac{P_c}{(D_c + D_s) B_{cap}} \quad (8.13.2-6)$$

where:

P_c = column axial force including the effects of overturning (kips)

D_c = diameter or depth of column in direction of loading (in.)

The average joint stress, v_{jv} , shall be taken as:

$$v_{jv} = \frac{T_c}{\ell_{ac} B_{eff}} \quad (8.13.2-7)$$

where:

T_c = column tensile force associated with the column overstrength plastic hinging moment, M_{po} (kips)

ℓ_{ac} = length of column reinforcement embedded into the bent cap (in.)

B_{eff} = effective width of the bent cap joint (in.)

The column tensile force resultant, T_c , should be obtained directly from the moment-curvature analysis of the column section framing into the joint. In lieu of

T_c may be assumed to be

$$T_c = 0.7 A_{st} f_{ye} \quad (8.13.2-8)$$

where:

A_{st} = total area of column reinforcement anchored in the joint (in.²)

f_{ye} = expected yield stress of column reinforcement anchored in the joint (ksi)

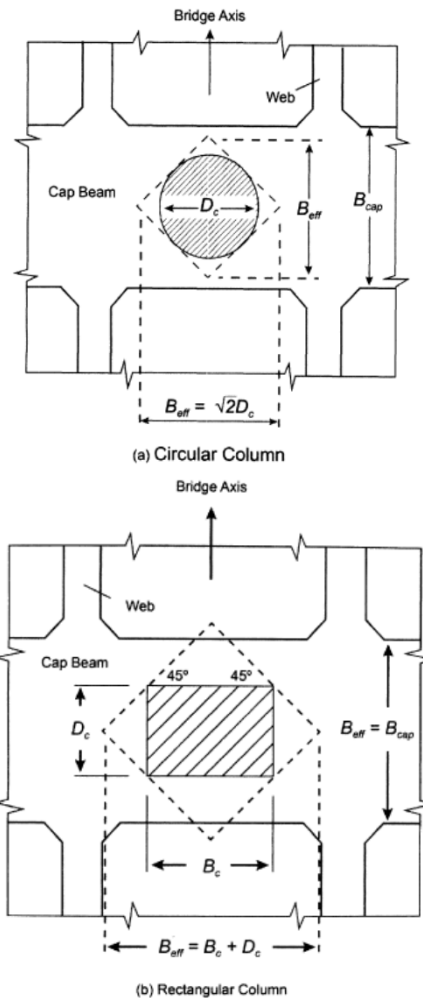


Figure 8.13.2-1—Effective Width of Bent Cap Joint, B_{eff}

The effective width of the bent cap joint, B_{eff} , shall consider the shape of the column framing into the joint as shown in Figure 8.13.2-1 and shall be determined as:

- For circular column sections:

$$B_{eff} = \sqrt{2}D_c \quad (8.13.2-9)$$

- For rectangular column sections:

$$B_{eff} = B_c + D_c \quad (8.13.2-10)$$

where:

B_c = diameter or width of column measured normal to the direction of loading (in.)

Under the transverse loading condition, the effective width of the bent cap joint, B_{eff} , shall not be taken greater than the width of the bent cap beam, B_{cap} .

Minimum Joint shear reinforcement

About 3.5 sq. ft. f'_c (psi)

Where the principal tension stress in the joint, p_t , as specified in Article 8.13.2 is less than $0.11\sqrt{f'_c}$, the transverse reinforcement in the joint, ρ_s , shall satisfy Eq. 8.13.3-1 and no additional reinforcement within the joint is required:

$$\rho_s \geq \frac{0.11\sqrt{f'_c}}{f_{yh}} \quad (8.13.3-1)$$

where:

f_{yh} = nominal yield stress of transverse reinforcing (ksi)

f'_c = nominal concrete compressive strength (ksi)

ρ_s = volumetric reinforcement ratio of transverse reinforcing provided within the cap as defined by Eq. 8.6.2-7

Where the principal tension stress in the joint, p_t , is greater than $0.11\sqrt{f'_c}$, then transverse reinforcement in the joint, ρ_s , shall satisfy Eq. 8.13.3-2 and additional joint reinforcement is required as indicated in Article 8.13.4 for integral bent cap beams or Article 8.13.5 for nonintegral bent cap beams:

$$\rho_s \geq 0.40 \frac{A_{st}}{\ell_{ac}^2} \quad (8.13.3-2)$$

where:

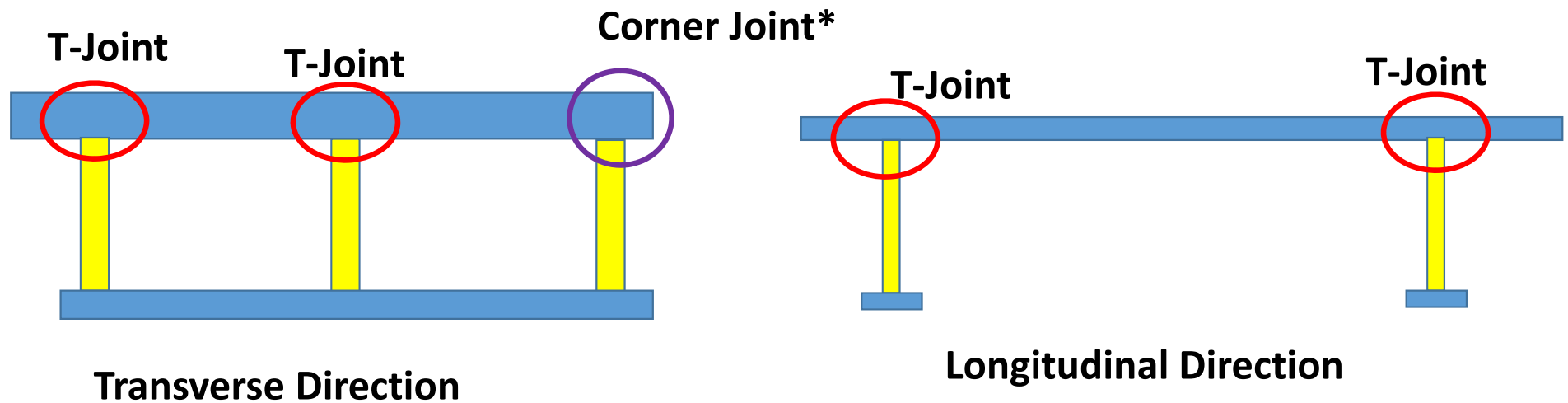
A_{st} = total area of column reinforcement anchored in the joint (in.²)

ℓ_{ac} = length of column reinforcement embedded into the bent cap (in.)

For interlocking cores, ρ_s shall satisfy Eqs. 8.13.3-1 and 8.13.3-2 and be based on the total area of reinforcement of each core.

T-Joint Design

Definition:



* Cantilever too short for cap beam long. bars to develop

T-Joint Reinforcement:

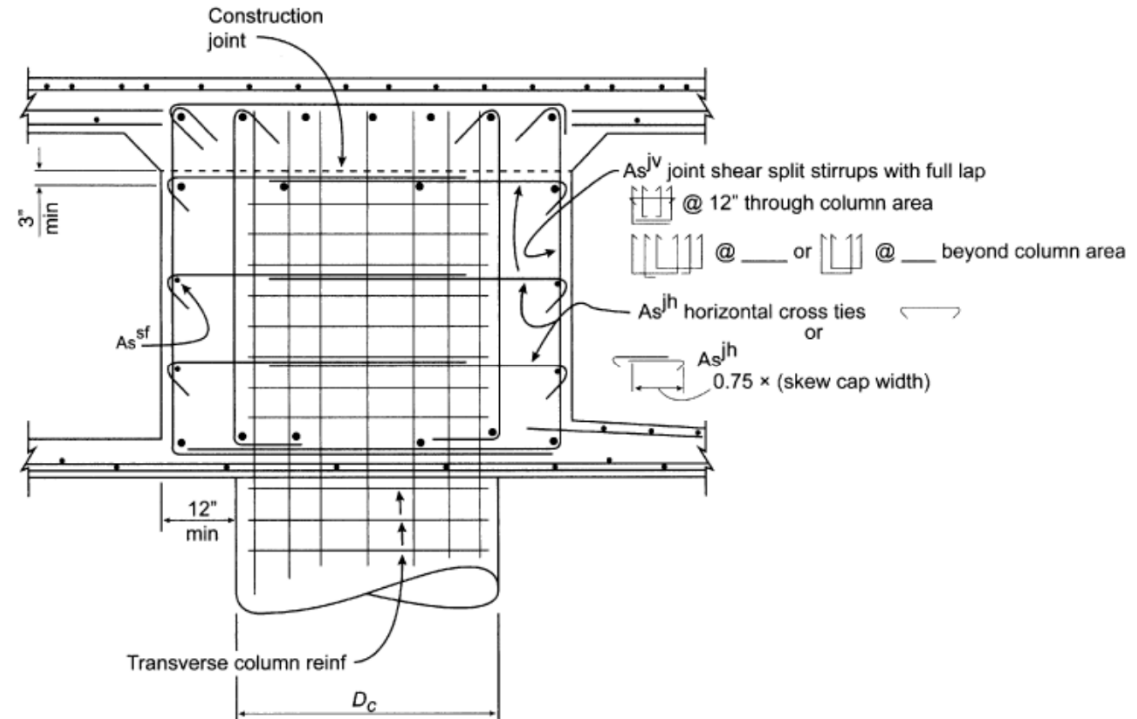
Vertical bars

$$A_s^{jv} \geq 0.20 A_{st} \quad (8.13.4.1.2a-1)$$

where:

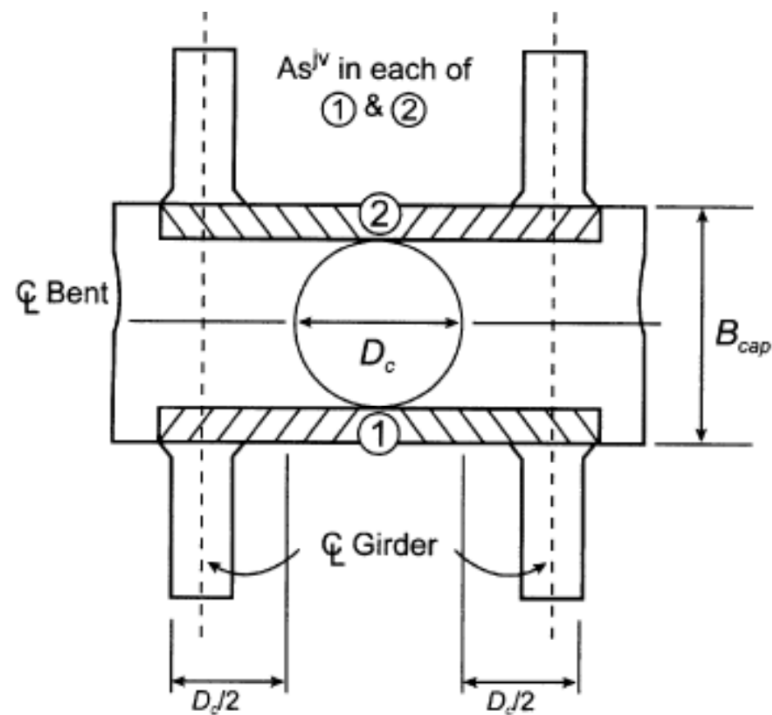
A_{st} = total area of column reinforcement anchored in the joint (in.²)

Vertical stirrups or ties shall be placed transversely within a distance equal to the column diameter, D_c , extending from either side of the column centerline.

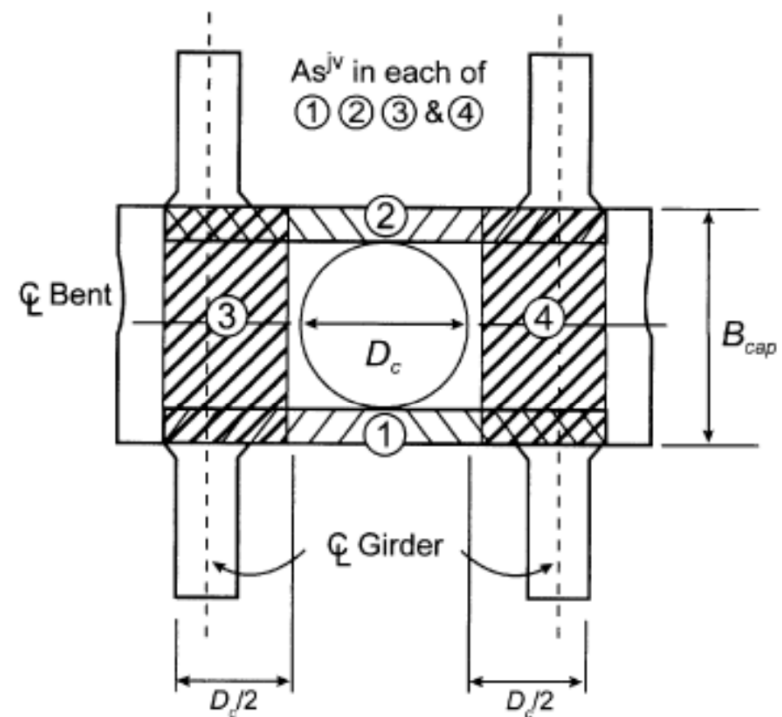


T-Joint Reinforcement:

Location of Vertical bars



Single-Column Bent



Multi-Column Bent

T-Joint Reinforcement:

Horizontal stirrups

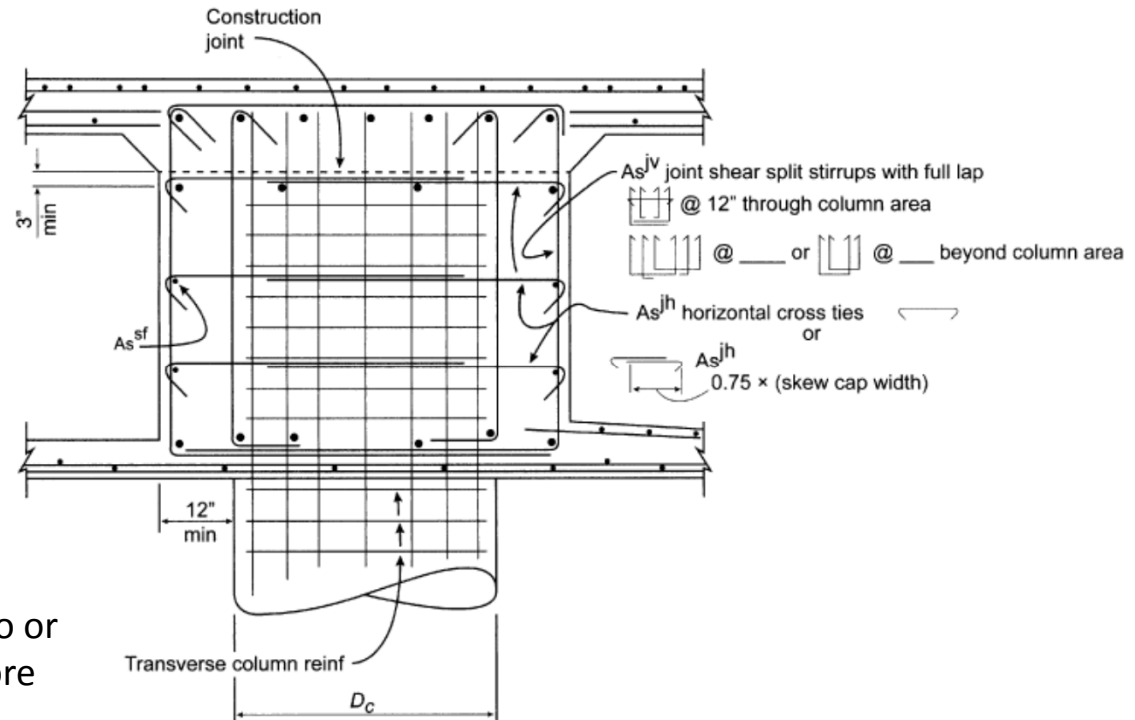
$$A_s^{jh} \geq 0.10 A_{st}$$

8.13.4.1.2b-1

where:

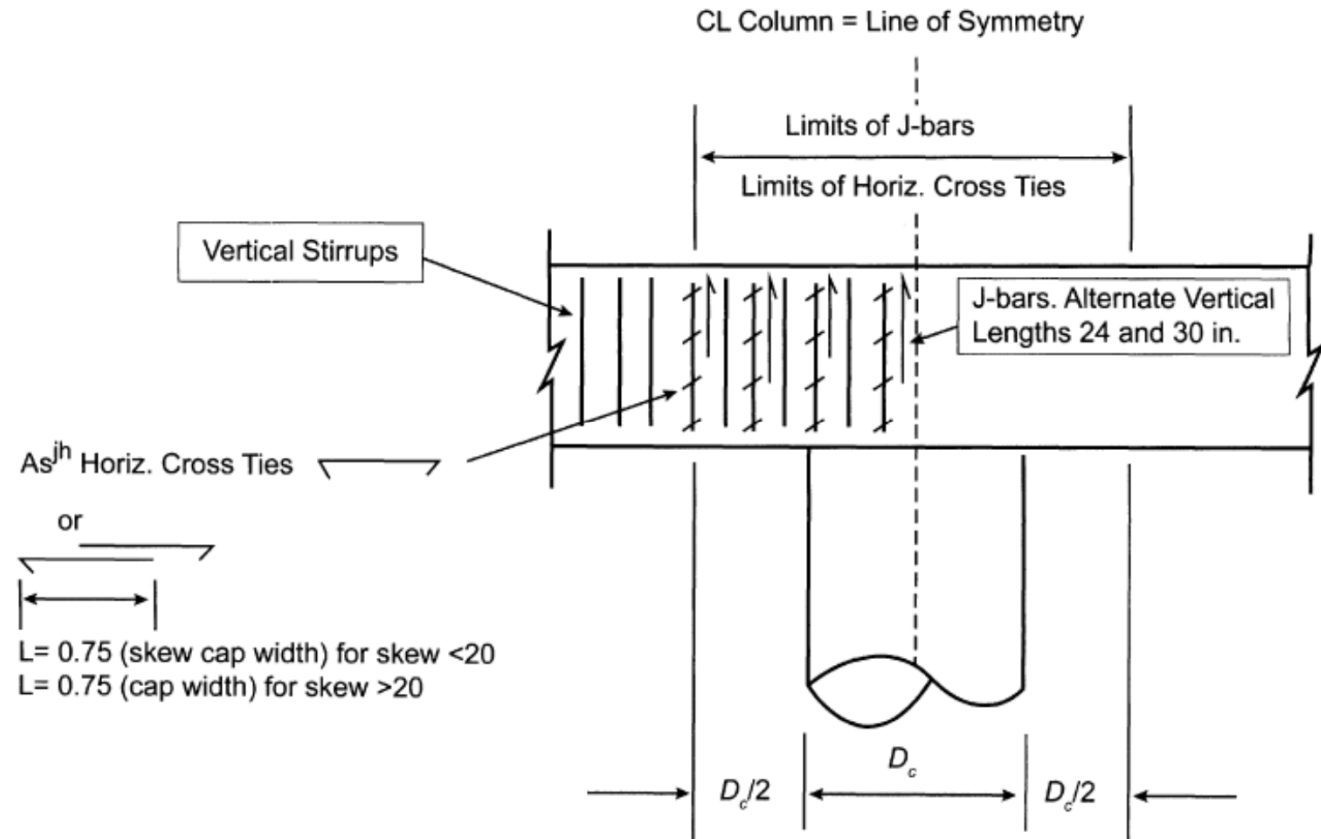
A_{st} = total area of column reinforcement anchored in the joint (in.²)

Horizontal stirrups or ties shall be placed transversely around the vertical stirrups or ties in two or more intermediate layers spaced vertically at not more than 18 in. The horizontal reinforcement shall be placed within a distance D_c from each side of the column Centerline.



T-Joint Reinforcement:

Location of Horizontal stirrups



T-Joint Reinforcement:

Horizontal side reinforcement

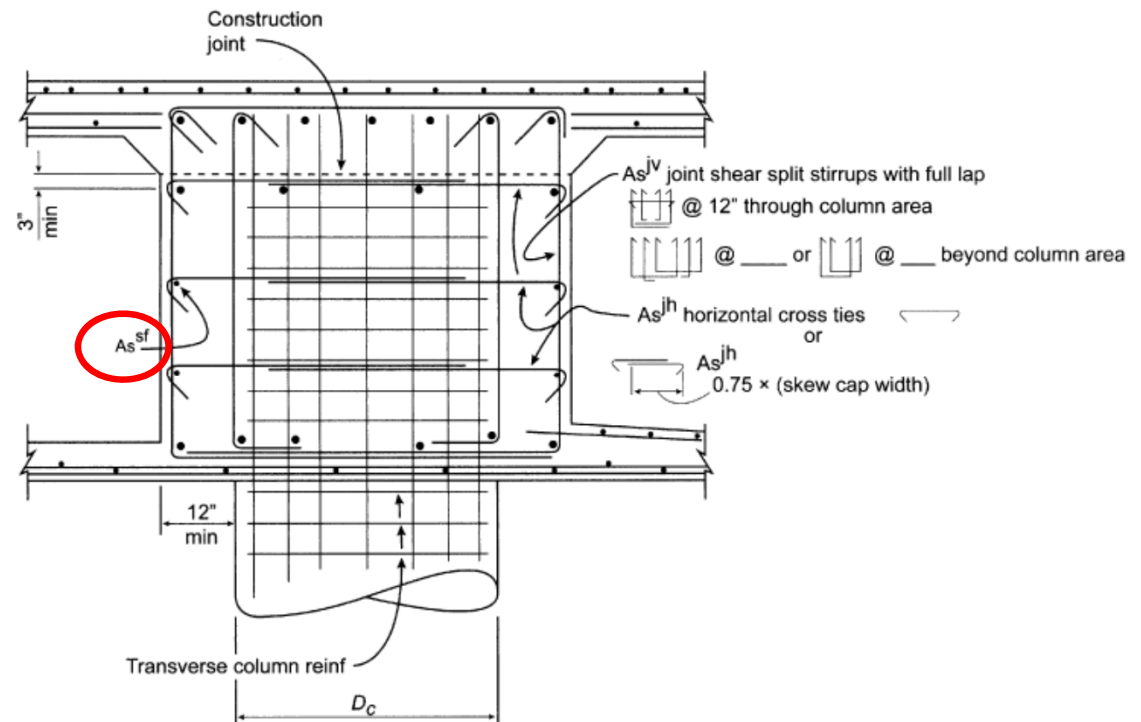
$$A_s^{sf} \geq \max \begin{cases} 0.10 A_{cap}^{top} \\ 0.10 A_{cap}^{bot} \end{cases} \quad (8.13.4.1.2c-1)$$

where:

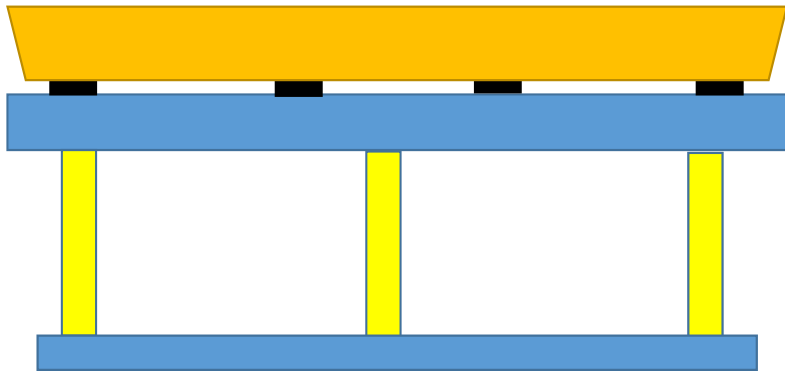
A_s^{sf} = area of longitudinal side reinforcement in the bent cap (in.²)

A_{cap}^{top} = area of bent cap top flexural steel (in.²)

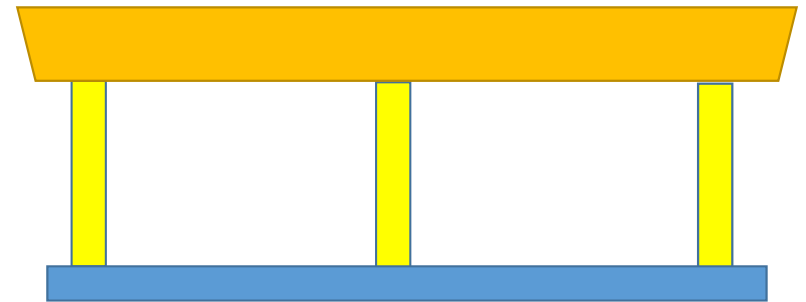
A_{cap}^{bot} = area of bent cap bottom flexural steel (in.²)



Integral vs. Non-integral Bent Caps



Nonintegral Bent Cap



Integral Bent Cap

Reinforcement Requirement for Nonintegral Caps

$$D_c \leq d \leq 1.25D_c \quad (8.13.5-1)$$

where:

D_c = column diameter (in.)

d = total depth of the bent cap beam (in.)

8.13.5.1.1—Vertical Stirrups Outside the Joint Region

Vertical stirrups with a total area, A_s^{jvo} , provided to each side of the column shall satisfy:

$$A_s^{jvo} \geq 0.175 A_{st} \quad (8.13.5.1.1-1)$$

where:

A_{st} = total area of column reinforcement anchored in the joint (in.²)

Vertical stirrups or ties shall be placed transversely within a distance equal to the column diameter, D_c , extending from each face of the column as shown in Figure 8.13.5.1.1-1 and Figure 8.13.5.1.1-2. The area of these stirrups shall not be used to meet other requirements such as shear in the bent cap.

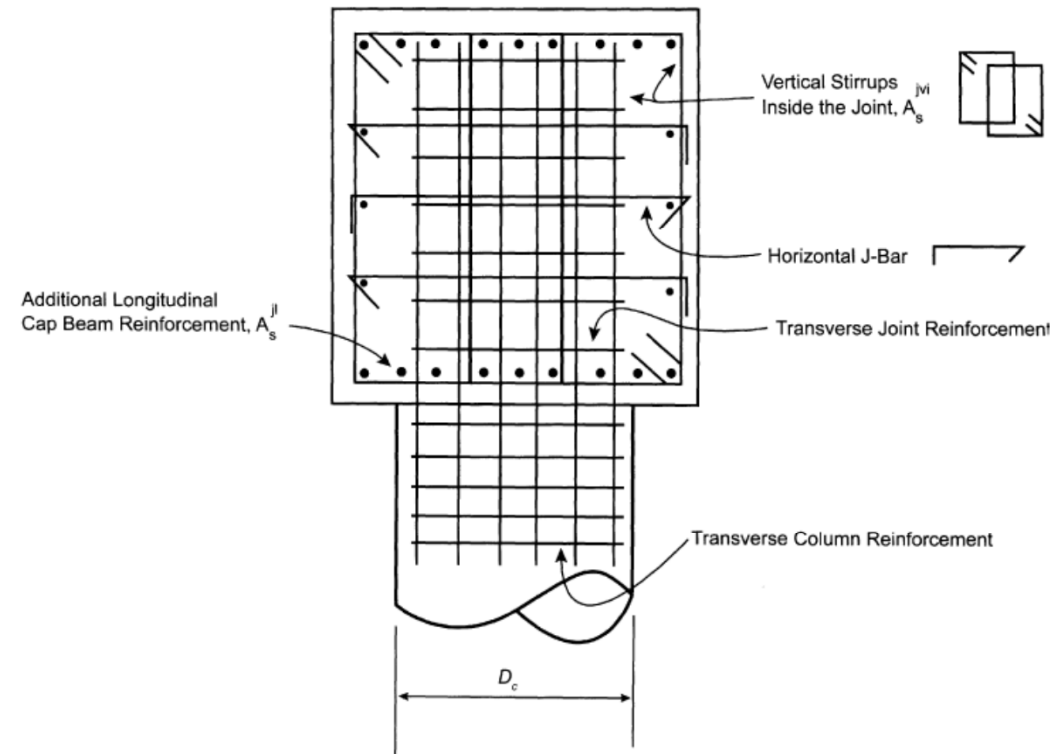


Figure 8.13.5.1.1-1—Joint Shear Reinforcement Details

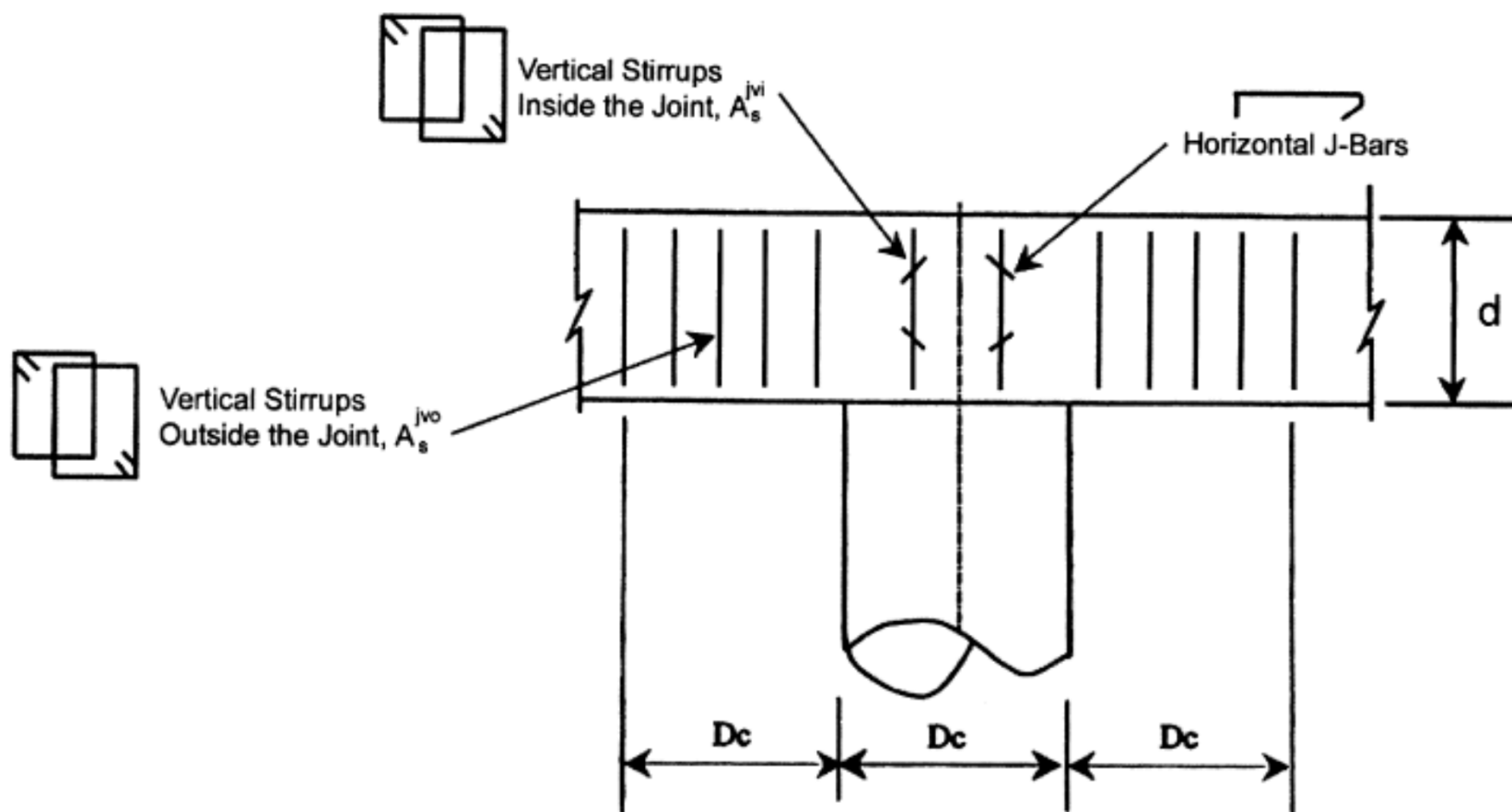


Figure 8.13.5.1.1-2—Location of Vertical Joint Shear Reinforcement

8.13.5.1.2—Vertical Stirrups Inside the Joint Region

Vertical stirrups with a total area, A_s^{jvi} , spaced evenly over the column shall satisfy:

$$A_s^{jvi} \geq 0.135 A_{st} \quad (8.13.5.1.2-1)$$

where:

A_{st} = total area of column reinforcement anchored in the joint (in.²)

★ **ABC Exception:**
Use $0.12 A_{st}$ for precast bent cap; reduced based on test data; Ref. 70 (Restrepo, Et al. 2011)

8.13.5.1.3—Additional Longitudinal Cap Beam Reinforcement

Longitudinal reinforcement, $A_s^{j\ell}$, in both the top and bottom faces of the cap beam shall be provided in addition to that required to resist other loads. The additional area of the longitudinal steel shall satisfy:

$$A_s^{j\ell} \geq 0.245 A_{st} \quad (8.13.5.1.3-1)$$

where:

A_{st} = total area of column reinforcement anchored in the joint (in.²)

The additional longitudinal reinforcement shall extend a sufficient distance to develop its yield strength at a distance of D_c from the column face as shown in Figure 8.13.5.1.3-1.

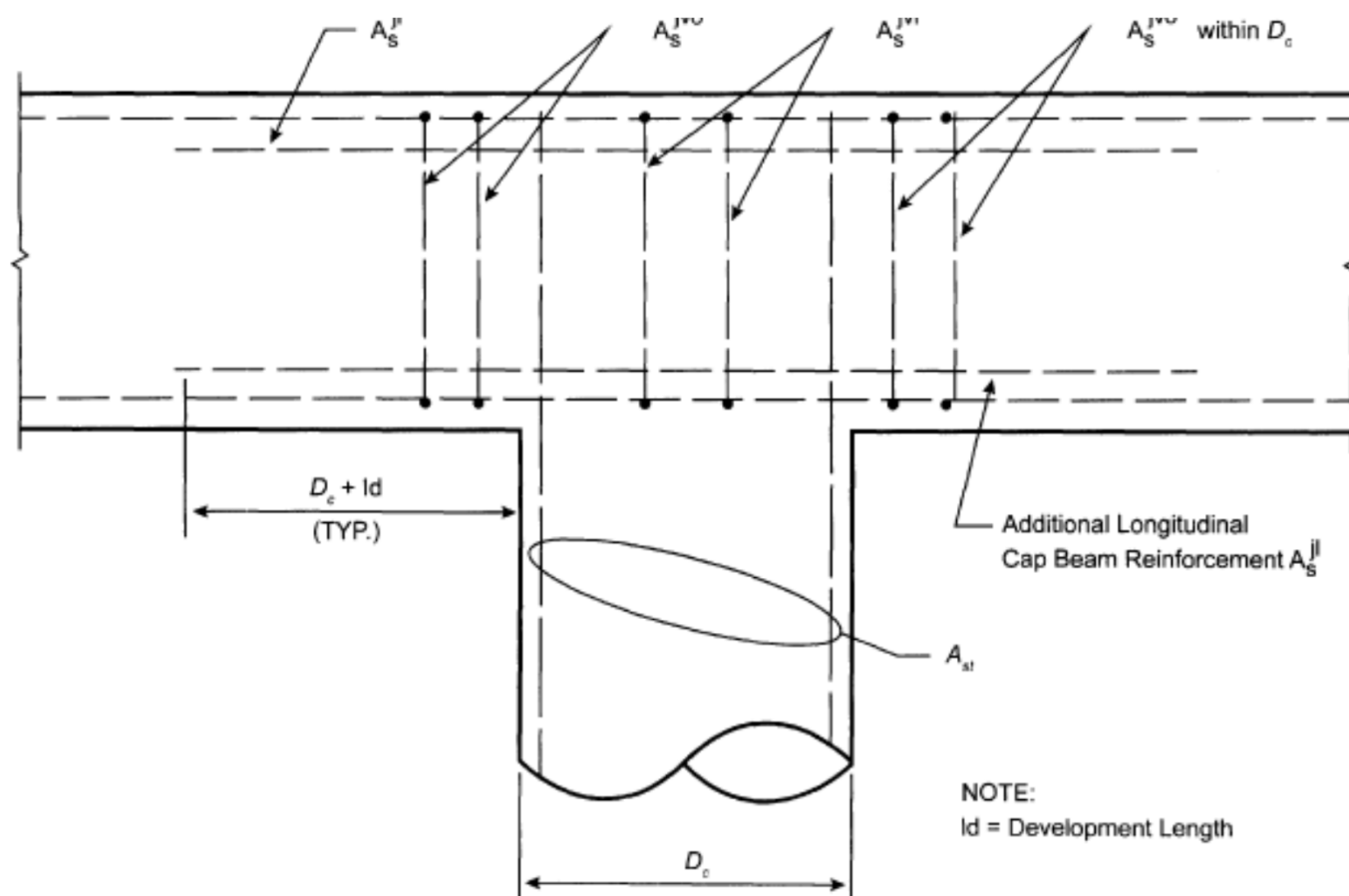
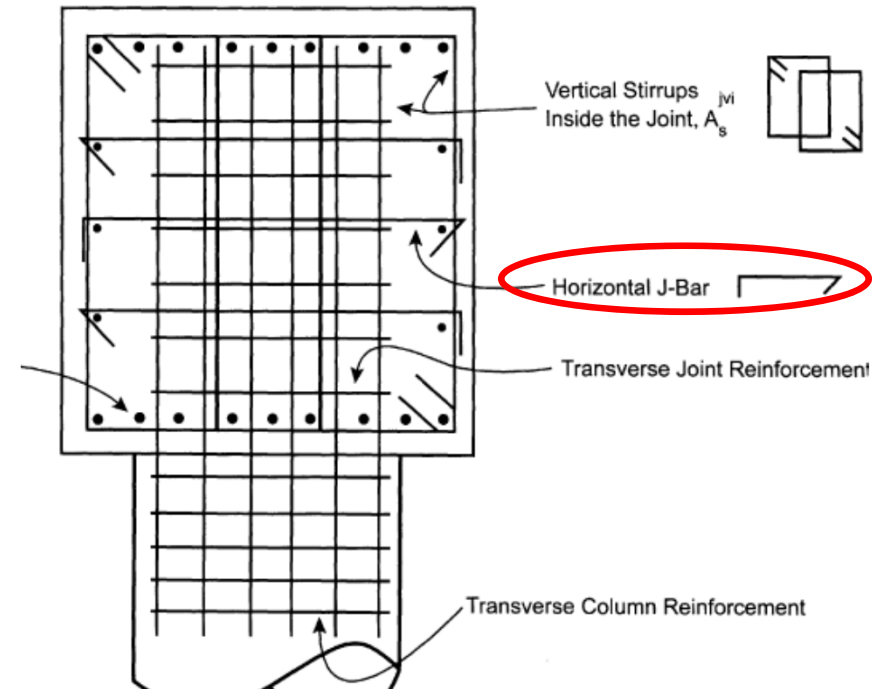


Figure 8.13.5.1.3-1—Additional Longitudinal Cap Beam Reinforcement for Joint Force Transfer

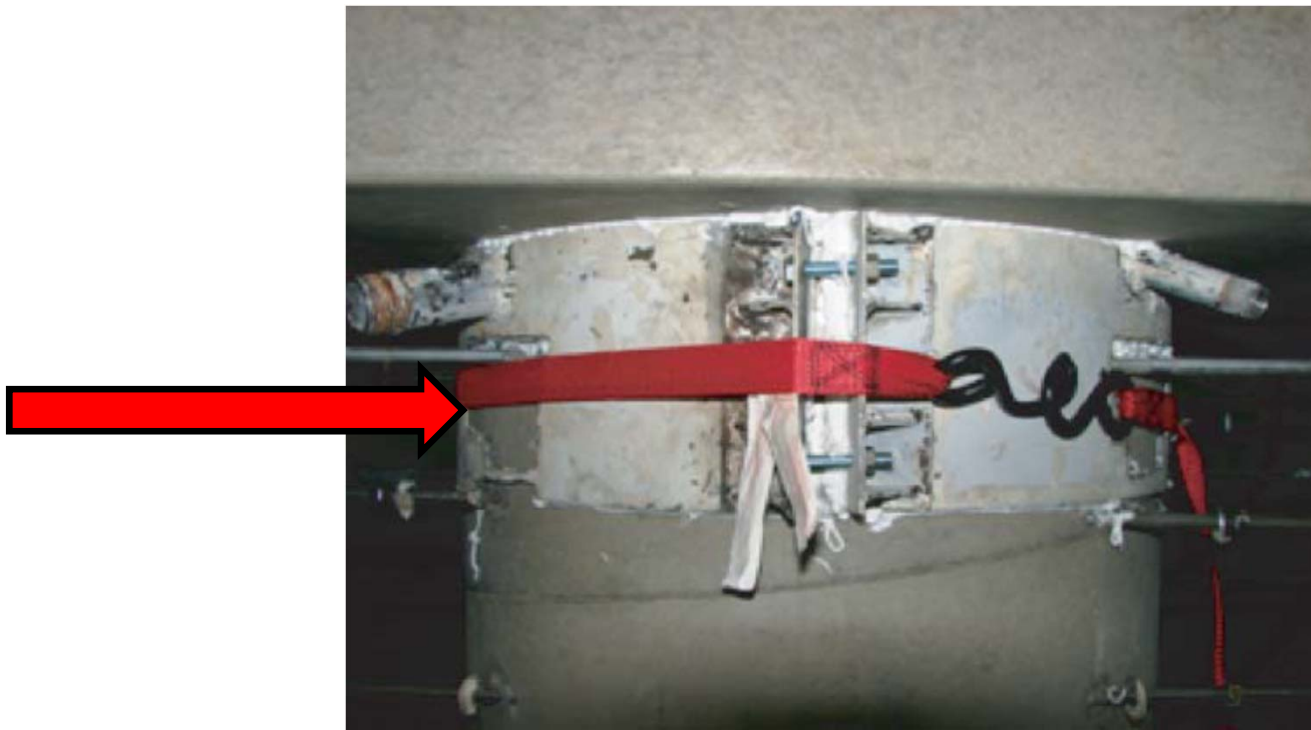
8.13.5.1.4—Horizontal J-Bars ★

Horizontal J-bars hooked around the longitudinal reinforcement on each face of the cap beam shall be provided as shown in Figure 8.13.5.1.1-1. At a minimum, horizontal J-bars shall be located at every other vertical-to-longitudinal bar intersection within the joint. The J-dowel reinforcement bar shall be at least a #4 size bar.

★ **ABC Exception:**
No J-bars required in precast bent cap
Ref. 70 (Restrepo, et al. 2011)



Additional reinforcement requirement for bedding layer (will see in the design example)



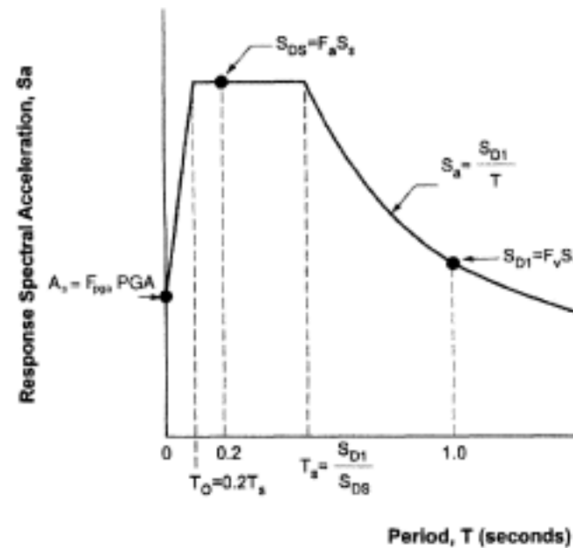
Design Example

Source: NCHRP 12-74 report; NCHRP 681 Ref. 70

Cap Pocket T-Joint Design Example for Seismic Design Categories (SDC) C and D

Value of $S_{D1} = F_v S_1$	SDC
$S_{D1} < 0.15$	A
$0.15 \leq S_{D1} < 0.30$	B
$0.30 \leq S_{D1} < 0.50$	C
$0.50 \leq S_{D1}$	D

S_{D1} = Design EQ response spectral
acc. At 1-Sec. period



Geometry and Design Parameters

$f_c = 4.0$ ksi (specified compressive strength of bent cap) $f_{ce} = 1.3f_c = 5.2$ ksi (expected f_c of bent cap)

f_{c_pocket} (specified compressive strength of pocket fill) Select cap pocket strength to satisfy BCS.

$f_{c_pocket} = f_{ce} + 0.5$ ksi = 5.7 ksi (BCS 8.13.8.3.3a)

f_{yh} (yield stress of equivalent hoop)

$f_{yh} = 60$ ksi

f_{ye} (expected yield stress of column bars)

$f_{ye} = 68$ ksi

f_{yp} (nominal yield stress of steel pipe)

Bent cap width = 7.0 ft (B_{cap})

Bent cap height = 6.25 ft (D_s)

Stirrup bar size: #6

Requirements for Extreme I load case in cap:

Top cap reinf, $A_s^{cap_top} = 16.77$ in²

Bot cap reinf, $A_s^{cap_bot} = 11.40$ in²

Shear reinf, $A_v = 4.12$ in²/ft

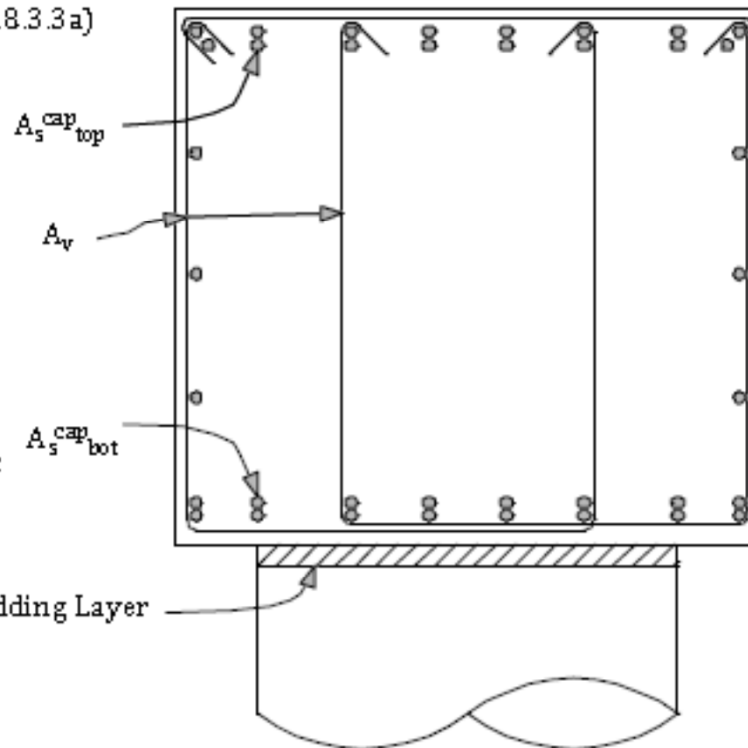
Column diameter = 5.0 ft (D_c)

$A_{st} = 31.2$ in² (#11 Tot 20)

Hoop bar size: #6

Hoop spacing = 4.0 in

1% Long. Steel



Typical cap section within D_c from face of column.

Note: Bent cap reinforcement shown reflects that required by Extreme Event I load combination before application of joint shear design requirements.

Joint Performance

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

Note: Capacity of the bent cap section needs to satisfy applicable load combinations, including the Strength load cases and capacity protection during Extreme Event load cases. The bent cap section capacity is not investigated in this design example.

Determine the idealized plastic moment capacity of the column, M_p , using section analysis program such as xSECTION, and calculate the overstrength moment capacity, M_{po} , per Article 8.5.

Axial load acting on column per extreme event load case = 820.0 kips (P_u)

f'_{ce} (expected concrete compressive strength) = $1.3 \times f'_c$ 5.2 ksi

f_{ye} (expected steel yield stress) = 68 ksi

$M_p = 5970$ kip-ft

$M_{po} = \lambda_{ms} M_p$

$\lambda_{ms} = 1.2$ (ASTM A706)

$M_{po} = 7164$ kip-ft

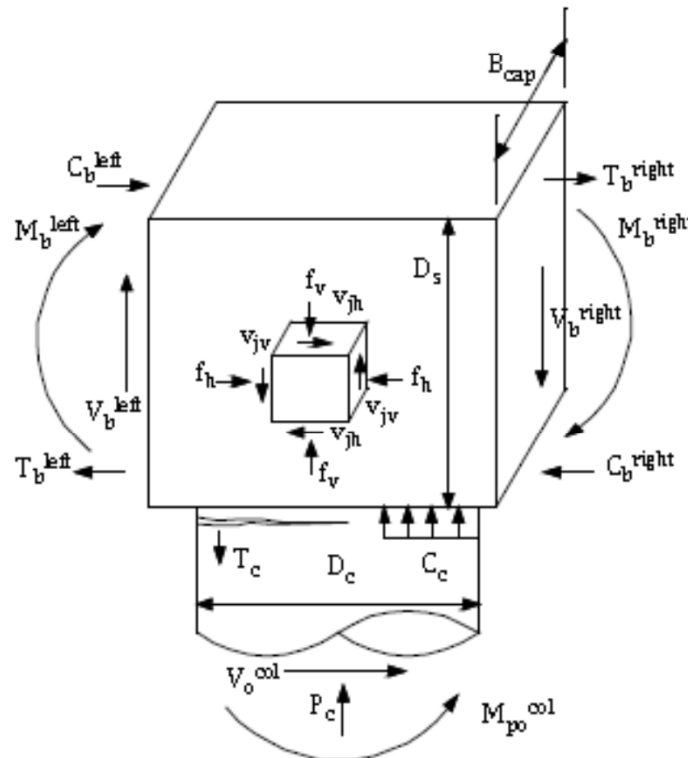
Joint Proportioning

Principal Stresses

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

Principal compression, p_c : $p_c \leq 0.25 f'_c = 1.00$ ksi maximum

Principal tension, p_t : $p_t \leq 0.38 \sqrt{f'_c} = 0.76$ ksi maximum



$B_{cap} =$	84.0 in	(7.0 ft x 12" /ft)
$D_c =$	60.0 in	(5.0 ft x 12" /ft)
$D_s =$	75.0 in	(6.25 ft x 12" /ft)
$l_{ac} =$	72.0 in	Note 1
$P_c =$	820 kips	
$P_b =$	0 kips	Note 2
$h =$	3.79 ft	Note 3
$M_{po} =$	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.

$$p_t = \left| \left(\frac{f_h + f_v}{2} \right) - \sqrt{\left(\frac{f_h - f_v}{2} \right)^2 + v_{jv}^2} \right| = \left| \left(\frac{0.0 + 0.072}{2} \right) - \sqrt{\left(\frac{0.0 - 0.072}{2} \right)^2 + 0.313^2} \right| = 0.278 \text{ ksi}$$

$$p_c = \left(\frac{f_h + f_v}{2} \right) + \sqrt{\left(\frac{f_h - f_v}{2} \right)^2 + v_{jv}^2} = \left(\frac{0.0 + 0.072}{2} \right) + \sqrt{\left(\frac{0.0 - 0.072}{2} \right)^2 + 0.313^2} = 0.351 \text{ ksi}$$

$$v_{jv} = T_c / A_{jv} = 1890 \text{ k} / 6048.0 \text{ in}^2 = 0.313 \text{ ksi}$$

$$A_{jv} = l_{ac} B_{cap} = 72.0 \text{ in} \times 84.0 \text{ in} = 6048.0 \text{ in}^2$$

$$f_v = P_c / A_{jh} = 820 \text{ k} / 11340 \text{ in}^2 = 0.0723 \text{ ksi}$$

$$A_{jh} = (D_c + D_s) B_{cap} = (60.0 \text{ in} + 75.0 \text{ in}) \times 84.0 \text{ in} = 11340 \text{ in}^2$$

$$f_h = \frac{P_b}{B_{cap} D_s} = 0.0 \text{ k} / (84.0 \text{ in} \times 75.0 \text{ in}) = 0.0 \text{ ksi}$$

$$T_c = M_{po} / h = 7164 \text{ kip-ft} / 3.79 \text{ ft} = 1890 \text{ kips}$$

$p_c = 0.351 \text{ ksi} \leq 1.00 \text{ ksi maximum}$ OK
 $p_t = 0.278 \text{ ksi} \leq 0.76 \text{ ksi maximum}$ OK

Joint proportions are acceptable based
 on principal stress requirements.

Minimum Development Length of Column Longitudinal Reinforcement

$$l_{dc} \geq \frac{2.3d_b f_{ye}}{f_{c,pocket}}$$

$$d_b = 1.41 \text{ in} \quad (\#11 \text{ rebar})$$

$$f_{ye} = 68 \text{ ksi}$$

$$f_{c,pocket} = 5.7 \text{ ksi} \quad (\text{cap pocket concrete}) = \min(5.7 \text{ ksi}, 7.0 \text{ ksi}) \text{ per Article 8.15.2.2.2}$$

$$l_{dc} = 38.7 \text{ in} \quad (\text{minimum})$$

Extend column reinforcement as far as practically possible, assume 3" clear from opposite face, per Article 8.15.2.2.2.

$$l_{dc} = D_s - 3" = 6.25 \text{ ft} \times 12"/\text{ft} - 3" = 72.0 \text{ in}$$

$$72.0 \text{ in} \geq 38.7 \text{ in (minimum)} \quad \text{OK} \quad \text{Extend to top face of cap less 3 in cover.}$$

Minimum Joint Shear Reinforcing for Precast Bent Cap Connections

Where principal tension in the joint is greater than or equal to $0.11\sqrt{f_c}$ and joint proportioning is acceptable per Article 8.15.2, additional transverse joint reinforcement for cap pocket connections per Article 8.15.5.2.3 is to be added, and Eqs. 8.15.3.1-1 and 8.15.3.1-2 are to be satisfied.

Check if principal tension, p_t is $\geq 0.11\sqrt{f_c}$ (condition for likely joint cracking)

$$\text{Calculated tension} = 0.278 \text{ ksi}$$

$$\text{Limit, } 0.11\sqrt{f_c} = 0.220 \text{ ksi}$$

$p_t = 0.278 \text{ ksi} \geq 0.220 \text{ ksi limit}$ Additional joint reinforcement (A_s^{jvo} , A_s^{jvi} , and A_s^j) is required.

Calculate required volumetric ratio of transverse joint reinforcement:

$$\text{Maximum of: } \rho_s \geq 0.11 \sqrt{f_c} / f_{yh}$$

$$\rho_s \geq 0.40 A_{st} / l_{ac}^2$$

$$A_{st} = 31.20 \text{ in}^2$$

$$l_{ac} = 72.0 \text{ in}$$

$$\text{Maximum of: } 0.11 \sqrt{f_c} / f_{yh} = 0.0037 \quad \text{governs}$$

$$0.40 A_{st} / l_{ac}^2 = 0.0024$$

$$\text{Use } \rho_s \geq 0.0037$$

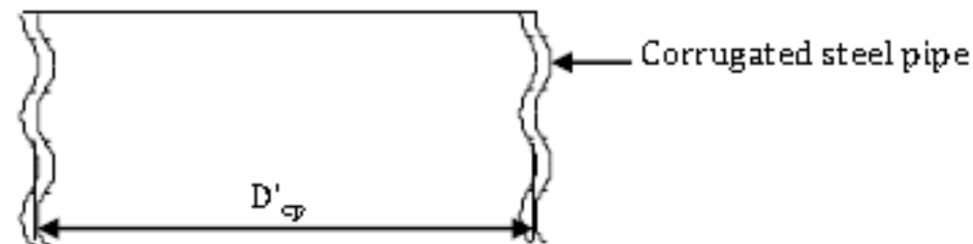
Use the minimum volumetric ratio to calculate the required number of equivalent #6 hoops per unit length of corrugated steel pipe. Use a unit length of 1 foot. Use a 54" ID corrugated pipe based on the outer diameter of column reinforcement pattern.

$$\rho_s = \frac{4A_{sp}}{D'_{cp} s} \quad s = \frac{4A_{sp}}{D'_{cp} \rho_s}$$

$$A_{sp} = 0.44 \text{ in}^2 \quad (\text{assume \#6 hoop to match column transverse reinforcement})$$

$$D'_{cp} = 54.75 \text{ in} \quad (\text{average confined dia. of column between corrugated steel pipe walls})$$

$$\rho_s = 0.0037 \quad (\text{minimum volumetric ratio})$$



D'_{cp} = Nominal inside diameter of corrugated pipe + average wall corrugation width.

$$s = 8.8 \text{ in max spacing}$$

Therefore, the number of equivalent hoops per foot is $12" / s = 1.369 \text{ hoops/ft}$

Calculate the nominal confining hoop force of the equivalent hoops.

$$F_H = n_h A_{sp} f_{yh}$$

$$n_h = 1.369 \text{ ea} \quad (\text{number of equivalent hoops per unit length})$$

$$A_{sp} = 0.44 \text{ in}^2 \quad (\text{area of \#6 equivalent hoop})$$

$$f_{yh} = 60.0 \text{ ksi} \quad (\text{yield stress of equivalent hoop})$$

$$F_H = 36.14 \text{ kips/ft}$$

Calculate the thickness of the corrugated steel pipe that provides the same nominal confinement as standard hoop reinforcement.

$$t_{pipe} \geq \max \left\{ \begin{array}{l} \frac{F_H}{H_p f_{yp} \cos \theta} \\ 0.060 \text{ in} \end{array} \right.$$

$$\begin{aligned}
 F_H &= 36.1 \text{ kips/ft} \\
 H_p &= 12.0 \text{ in/ft} \quad (\text{specified unit length}) \\
 f_{yp} &= 30.0 \text{ ksi} \quad (\text{manufacturer specified}) \\
 \theta &= 20.0 \text{ deg} \quad (\text{manufacturer specified})
 \end{aligned}$$

$$t_{pipe} \geq 0.1068 \text{ in}$$

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 in the SGS commentary:

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

$$t_{pipe} \geq 0.14 \frac{A_{st} D'_{cp} f_{yh}}{l_{ac}^2 f_{yp} \cos \theta} = 0.0982 \text{ in} \quad \text{and} \geq 0.06 \text{ in} \quad \text{Eq.}$$

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 refined equation reduces the required pipe thickness, especially for larger diameter pipes.

Nonintegral Bent Cap Joint Shear Design

Depth of the cap with respect to the column diameter determines the method of joint shear design. When the following equation is satisfied, the joint shear design provisions of Article 8.15.5.2 apply. If the equation below is not satisfied, Strut-and-Tie model provisions of AASHTO LRFD Bridge Design Specifications apply.

$$D_c \leq d \leq 1.25D_c$$

$$D_c = 60.0 \text{ in}$$

$$d = 75.0 \text{ in}$$

$$60.0 \text{ in} \leq 75.0 \text{ in} \leq 75.0 \text{ in} \quad \text{OK} \quad \text{Provisions of 8.15.5.2 apply}$$

Additional Joint Shear Reinforcement

Vertical Stirrups Outside the Joint Region:

$$A_s^{lvo} \geq 0.175 A_{st}$$

$$A_{st} = 31.20 \text{ in}^2$$

$$A_s^{lvo} \geq 5.46 \text{ in}^2$$

A_s^{Ivo} is placed transversely within a distance D_c extending from each face of the column. This is in addition to the A_v of 4.12 in^2 provided for Extreme I load case analysis per Article 8.15.5.1.1.

$$A_s^{Ivo} \geq 546 \text{ in}^2 / D_c = 1.092 \text{ in}^2/\text{ft}$$

$$A_v^{total} = A_v + A_s^{Ivo}$$

$$A_v^{total} = 4.12 \text{ in}^2/\text{ft} + 1.09 \text{ in}^2/\text{ft} = 5.21 \text{ in}^2/\text{ft}$$

Find the spacing of the #6 stirrups within the distance D_c on both sides of the column with the assumption of #6 stirrups having four vertical legs in each pattern.

$$\text{Area of one stirrup pattern} = 4 \text{ legs} \times 0.44 \text{ in}^2/\text{leg} = 1.76 \text{ in}^2$$

$$\text{Number of stirrup patterns required per foot} = A_v^{total} / 1.76 \text{ in}^2 = 2.96 \text{ stirrups/ft}$$

$$\text{Use 3 stirrups per foot, 4" spacing. } A_{sv}^{total} = 5.28 \text{ in}^2/\text{ft} \geq 5.21 \text{ in}^2/\text{ft} \quad \text{OK}$$

Vertical Stirrups Inside the Joint Region:

$$A_s^{int} \geq 0.12 A_{st}$$

$$A_{st} = 31.2 \text{ in}^2$$

$$A_s^{int} \geq 3.74 \text{ in}^2$$

Use #6 single U stirrups, Tot 5 patterns placed evenly through joint.

$$A_s^{int} = 5 \text{ patterns} \times 2 \text{ legs/pattern} \times 0.44 \text{ in}^2/\text{leg} = 4.40 \text{ in}^2 \geq 3.74 \text{ in}^2 \quad \text{OK}$$

There must be a minimum of 2 stirrups per Article 8.15.5.2.3 c with a bar size no smaller than that used for bent cap stirrups.

Additional Longitudinal Cap Beam Reinforcement

$$A_s^{fl} \geq 0.245 A_{st}$$

$$A_{st} = 31.2 \text{ in}^2$$

$$A_s^{fl} \geq 7.64 \text{ in}^2 \quad (\text{individual amount applied to top and bottom faces of cap})$$

$$\left. \begin{array}{l} \text{Top cap reinf, } A_s^{cap}_{top} = 16.77 \text{ in}^2 \\ \text{Bot cap reinf, } A_s^{cap}_{bot} = 11.40 \text{ in}^2 \end{array} \right\} \text{ Per design requirements of Extreme I load case.}$$

$$\text{Total top cap reinf, } A_s^{total}_{top} = A_s^{cap}_{top} + A_s^{fl} = 16.77 \text{ in}^2 + 7.64 \text{ in}^2 = 24.41 \text{ in}^2$$

$$\text{Total bot cap reinf, } A_s^{total}_{bot} = A_s^{cap}_{bot} + A_s^{fl} = 11.40 \text{ in}^2 + 7.64 \text{ in}^2 = 19.04 \text{ in}^2$$

$$\text{Use \#11 Tot 16 on top and bottom of bent cap, } A_s = 24.96 \text{ in}^2$$

Note: A_s^{fl} is added to the A_s^{cap} of the bent cap required under the seismic extreme event load case only. These $A_s^{total}_{top}$ and $A_s^{total}_{bot}$ values are to be compared to the respective requirements of the applicable Strength load cases, and the larger value governs. Thus, the value shown above may not necessarily govern required bent cap flexural reinforcement.

Note: Horizontal J-bars are not required in the joint region, as confirmed by research.

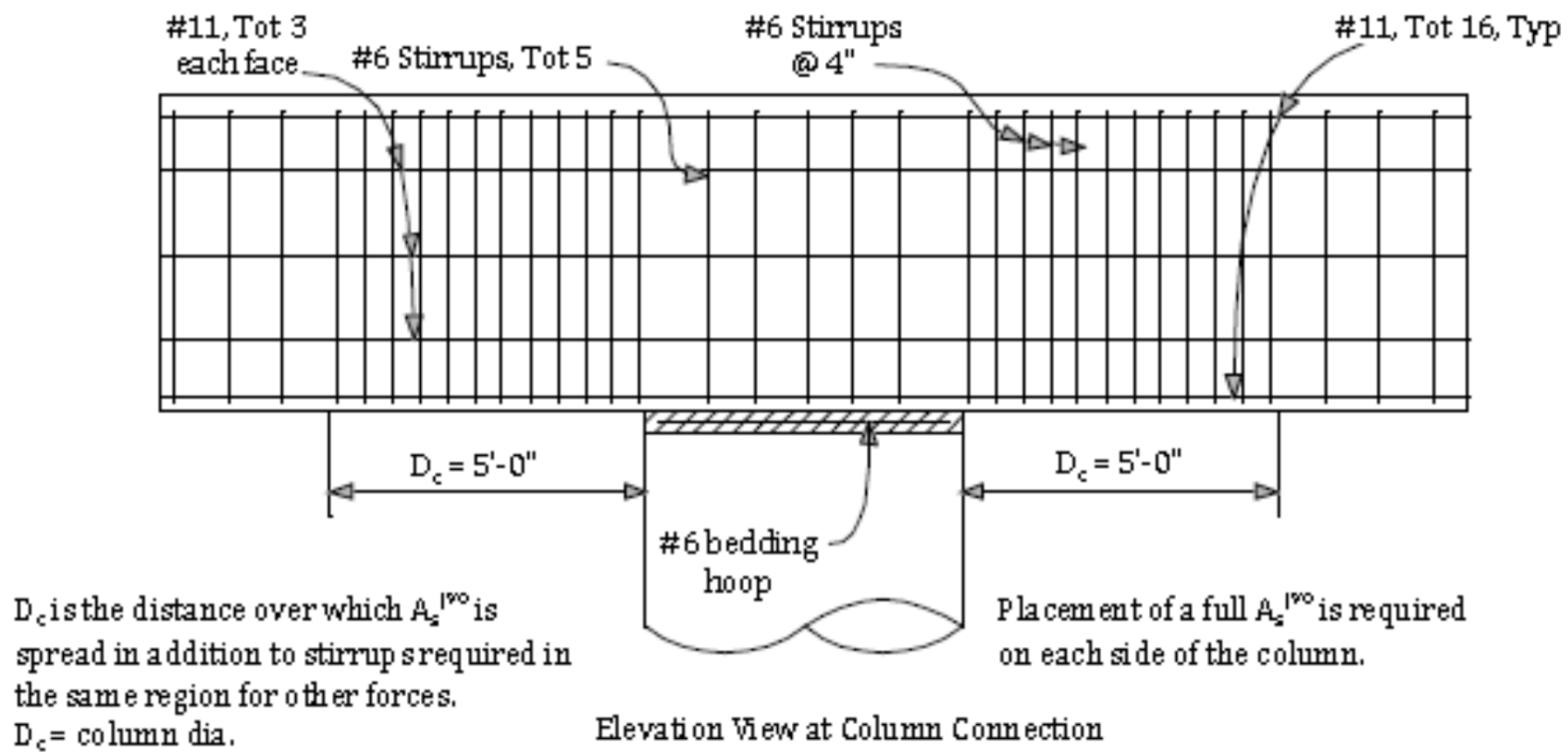
Bedding Layer Reinforcement

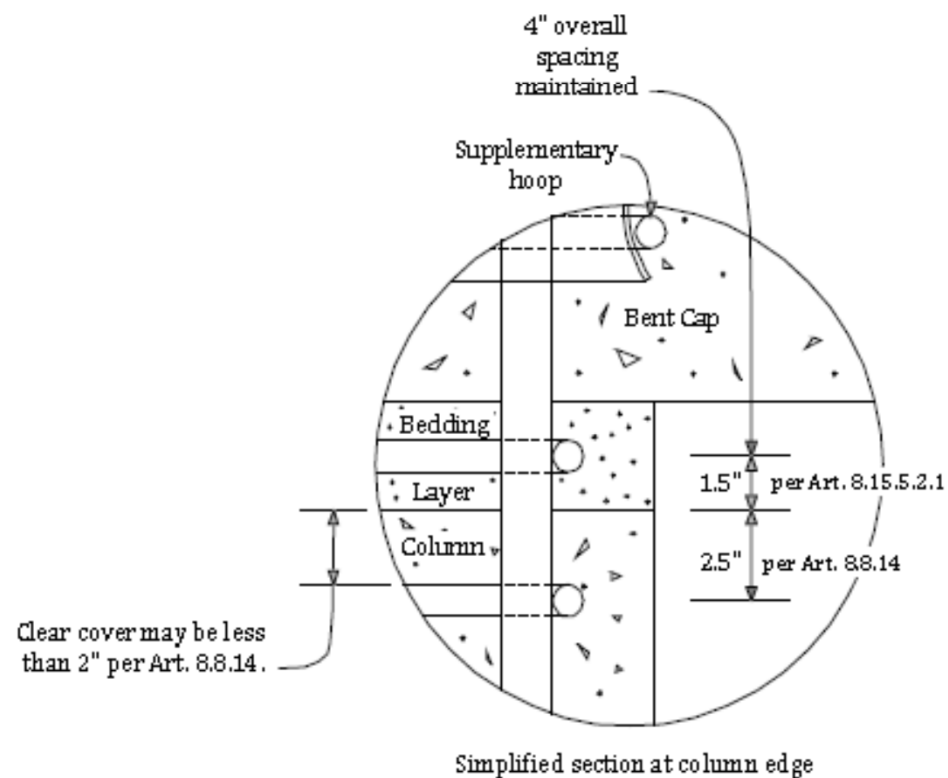
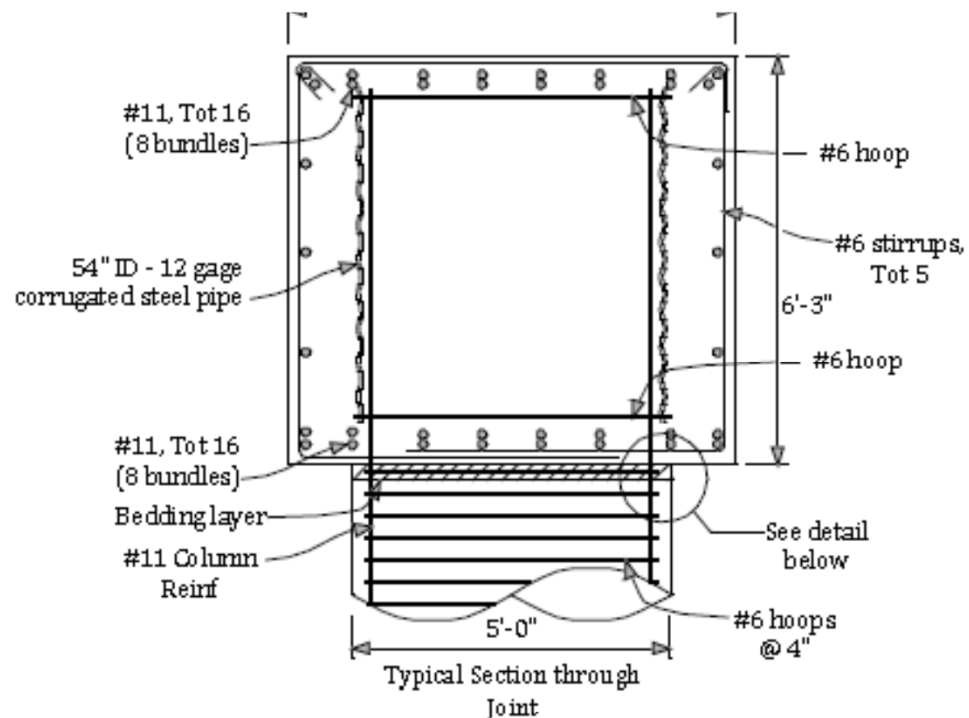
Provide bedding layer transverse reinforcement to match the size and type used in the column plastic hinging region (#6 bar). Hoop will be placed at mid-height in the bedding layer; bedding layer to be 3" thick. Cover on top column hoop to be 2" as shown in figures below, and resulting center-to-center spacing of transverse reinforcement is 4" throughout, in accordance with Article 8.8.14.

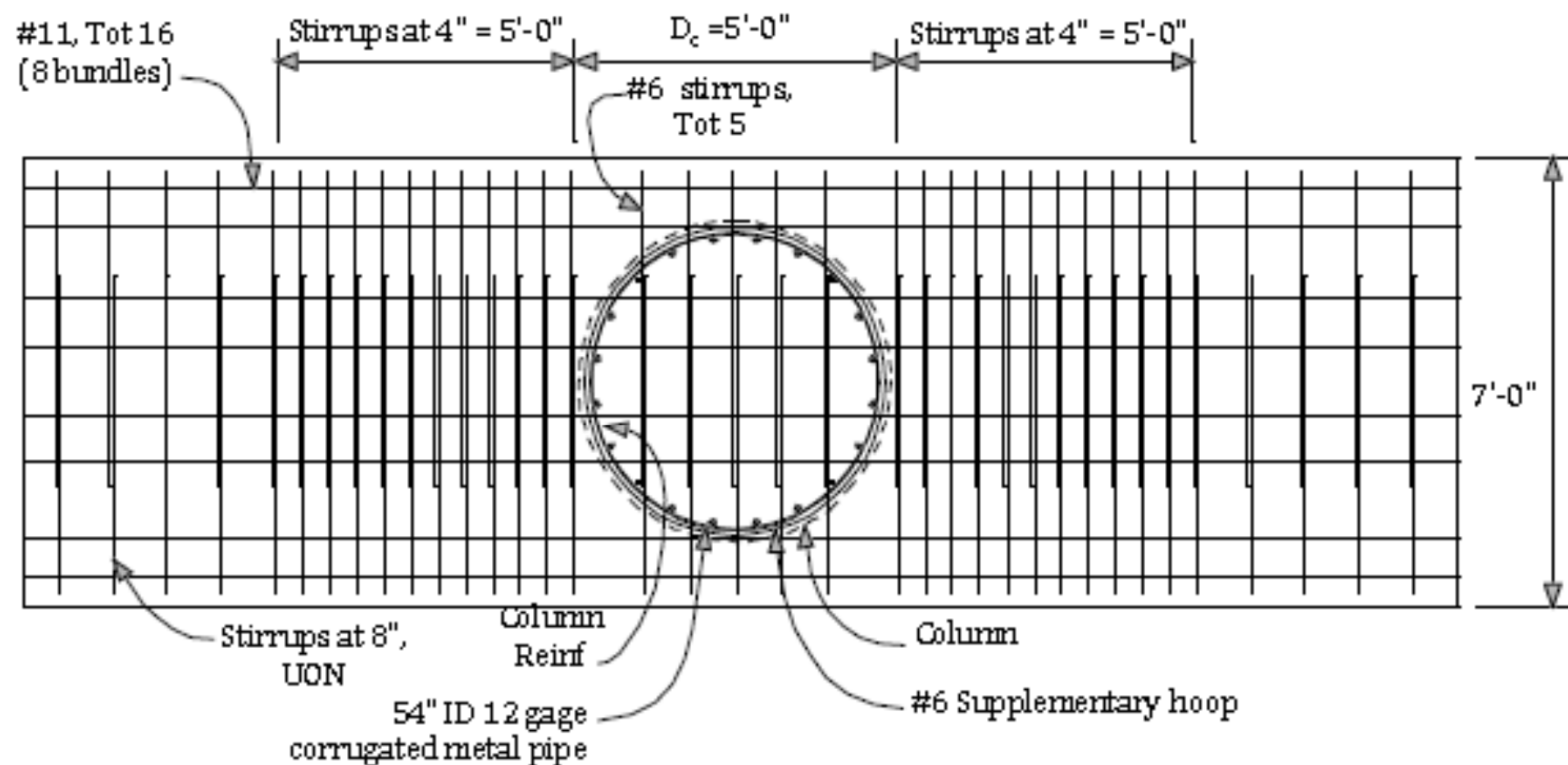
Supplementary Hoops

Provide a supplementary #6 hoop placed one inch from each end of the corrugated steel pipe. The area of this bar is to be no less than that provided in the column plastic region (#6 bar).

Design Drawings







Plan View at Column Connection