Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

21.6.1 — Scope

Requirements of this section apply to special moment frame members that form part of the seismic-force-resisting system and that resist a factored axial compressive force P_u under any load combination exceeding $A_g f'_c/10$. These frame members shall also satisfy the conditions of 21.6.1.1 and 21.6.1.2.

21.6.1.1 — The shortest cross-sectional dimension, measured on a straight line passing through the geometric centroid, shall not be less than 12 in.

21.6.1.2 — The ratio of the shortest cross-sectional dimension to the perpendicular dimension shall not be less than 0.4.

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

21.6.2 — Minimum flexural strength of columns

21.6.2.1 — Columns shall satisfy 21.6.2.2 or 21.6.2.3.

21.6.2.2 — The flexural strengths of the columns shall satisfy Eq. (21-1)

$$\Sigma M_{nc} \geq (6/5)\Sigma M_{nb} \qquad (21\text{-}1)$$

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

ΣM_{nc} = sum of nominal flexural strengths of columns framing into the joint, evaluated at the faces of the joint. Column flexural strength shall be calculated for the factored axial force, consistent with the direction of the lateral forces considered, resulting in the lowest flexural strength.

ΣM_{nb} = sum of nominal flexural strengths of the beams framing into the joint, evaluated at the faces of the joint. In T-beam construction, where the slab is in tension under moments at the face of the joint, slab reinforcement within an effective slab width defined in 8.12 shall be assumed to contribute to M_{nb} if the slab reinforcement is developed at the critical section for flexure.

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

21.6.3 — Longitudinal reinforcement

21.6.3.1 — Area of longitudinal reinforcement, A_{st}, shall not be less than $0.01A_g$ or more than $0.06A_g$.

21.6.3.2 — Mechanical splices shall conform to 21.1.6 and welded splices shall conform to 21.1.7. Lap splices shall be permitted only within the center half of the member length, shall be designed as tension lap splices, and shall be enclosed within transverse reinforcement conforming to 21.6.4.2 and 21.6.4.3.

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

21.6.4 — Transverse reinforcement

21.6.4.1 — Transverse reinforcement required in 21.6.4.2 through 21.6.4.4 shall be provided over a length ℓ_o from each joint face and on both sides of any section where flexural yielding is likely to occur as a result of inelastic lateral displacements of the frame. Length ℓ_o shall not be less than the largest of (a), (b), and (c):

(a) The depth of the member at the joint face or at the section where flexural yielding is likely to occur;

(b) One-sixth of the clear span of the member; and

(c) 18 in.

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21.6.4.2 — Transverse reinforcement shall be provided by either single or overlapping spirals satisfying 7.10.4, circular hoops, or rectilinear hoops with or without crossties. Crossties of the same or smaller bar size as the hoops shall be permitted. Each end of the crosstie shall engage a peripheral longitudinal reinforcing bar. Consecutive crossties shall be alternated end for end along the longitudinal reinforcement. Spacing of crossties or legs of rectilinear hoops, h_x, within a cross section of the member shall not exceed 14 in. on center.

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

21.6.4.3 — Spacing of transverse reinforcement along the length ℓ_o of the member shall not exceed the smallest of (a), (b), and (c):

(a) One-quarter of the minimum member dimension;

(b) Six times the diameter of the smallest longitudinal bar; and

(c) s_o, as defined by Eq. (21-2)

$$s_o = 4 + \left(\frac{14 - h_x}{3}\right) \quad (21\text{-}2)$$

The value of s_o shall not exceed 6 in. and need not be taken less than 4 in.

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

21.6.4.4 — Amount of transverse reinforcement required in (a) or (b) shall be provided unless a larger amount is required by 21.6.5.

(a) The volumetric ratio of spiral or circular hoop reinforcement, ρ_s, shall not be less than required by Eq. (21-3)

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

$$\rho_s = 0.12 f'_c / f_{yt} \qquad (21\text{-}3)$$

and shall not be less than required by Eq. (10-5).

(b) The total cross-sectional area of rectangular hoop reinforcement, A_{sh}, shall not be less than required by Eq. (21-4) and (21-5)

$$A_{sh} = 0.3 \frac{s b_c f'_c}{f_{yt}} \left[\left(\frac{A_g}{A_{ch}} \right) - 1 \right] \qquad (21\text{-}4)$$

$$A_{sh} = 0.09 \frac{s b_c f'_c}{f_{yt}} \qquad (21\text{-}5)$$

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

21.6.4.5 — Beyond the length ℓ_o specified in 21.6.4.1, the column shall contain spiral or hoop reinforcement satisfying 7.10 with center-to-center spacing, s, not exceeding the smaller of six times the diameter of the smallest longitudinal column bars and 6 in., unless a larger amount of transverse reinforcement is required by 21.6.3.2 or 21.6.5.

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

General requirements (Section 20.5.1.2.1) The requirements of this section apply to columns and other flexural members that carry a factored axial load > $A_g f_c'/10$. These members should satisfy both of the following conditions (ACI 2008, Section 21.6):

1. Shortest cross-section dimension $\geq$ 12 in.
2. The ratio of shortest cross-sectional dimension to the perpendicular dimension $\geq$ 0.4

Longitudinal reinforcement requirements (Section 20.5.1.2.2) According to the ACI Code 2008, Section 21.5.2, the flexural strengths of columns should satisfy the following:

$$\sum M_{nc} \geq \frac{6}{5} \sum M_{nb} \tag{20.42}$$

where

$\sum M_{nc}$ = sum of nominal flexural strengths of the columns framing into the joint, evaluated at the faces of the joint.

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

$\sum M_{nb}$ = sum of nominal flexural strengths of the beams framing into the joint, evaluated at the faces of the joint.

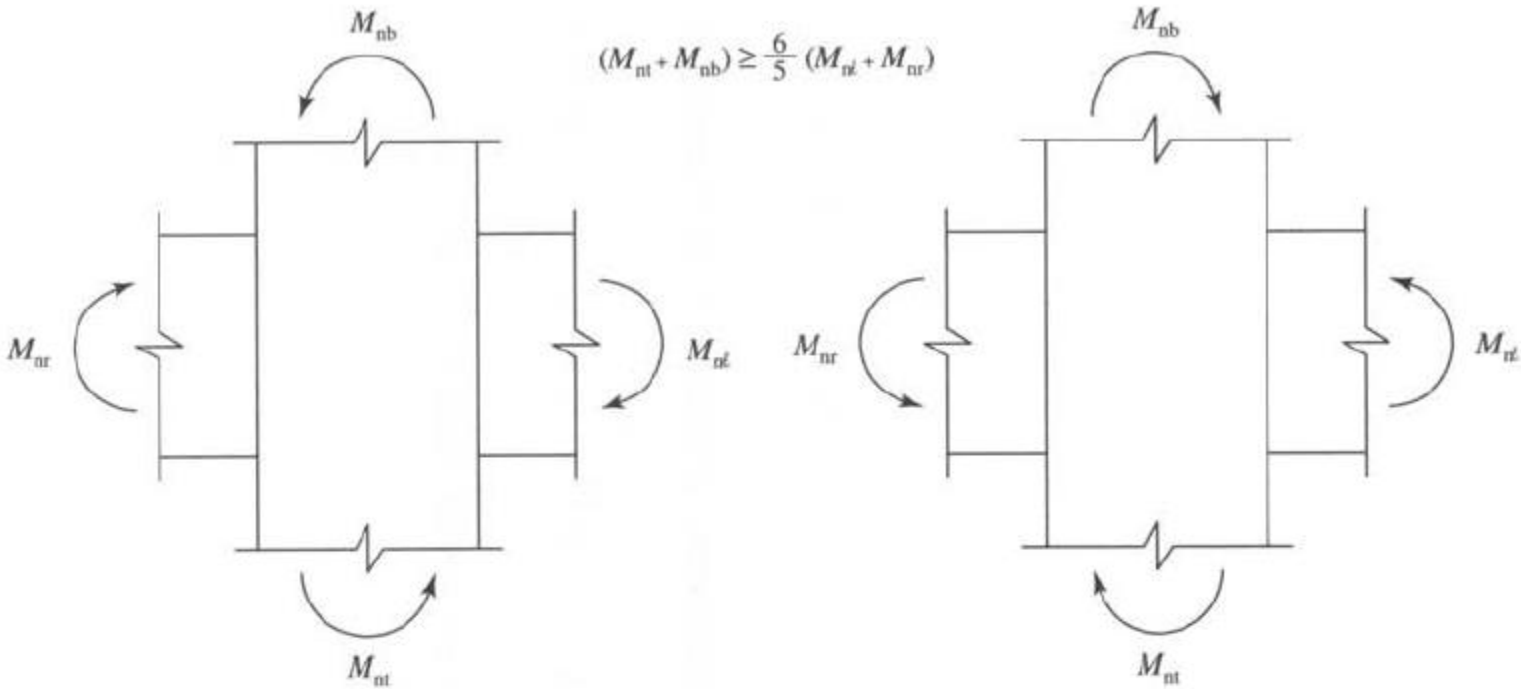
This approach, called strong column—weak beam concept (Fig. 20.18), ensures that columns will not yield before the beams. The main steel reinforcement should be chosen to satisfy Eq. 20.61.

The reinforcement ratio should satisfy the following:

Transverse reinforcement requirements (Section 20.5.1.2.3) Columns should be properly detailed to ensure column ductility in the case of plastic hinge formation, and should also have the adequate shear strength to prevent shear failure.

The following transverse reinforcement requirements need to be provided only over the length l_o greater or equal to depth of the member, $\frac{1}{6}$ clear span, 18 in., from the each joint face and on both sides of any section where yielding is likely to occur (ACI code 2008, Section 21.6.4.1). The requirements are

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)



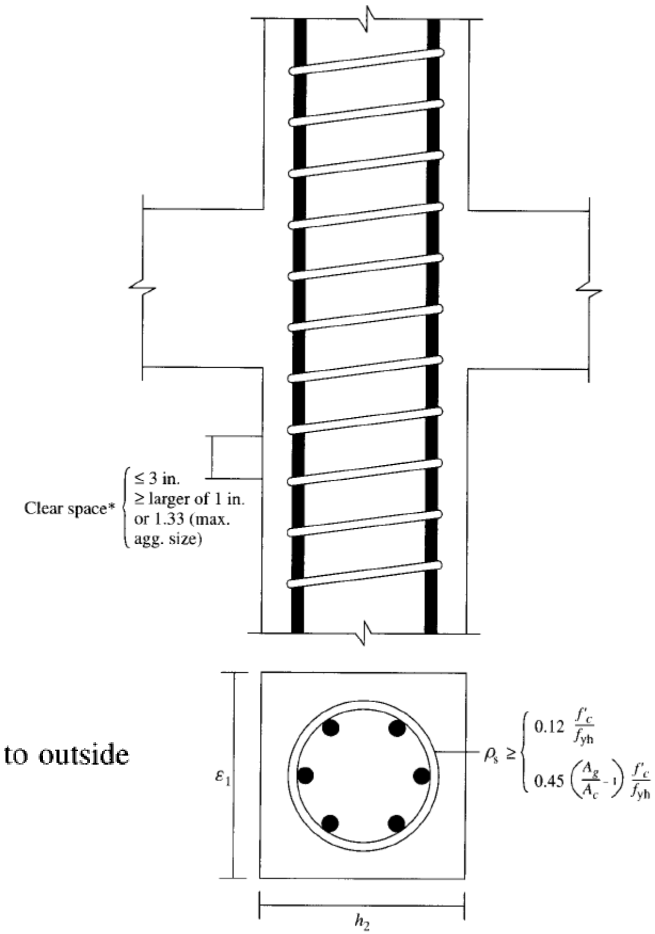
Subscripts ℓ, r, t, and b stand for left support, right support, top of column, and bottom of column, respectively.

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

1. Ratio of spiral reinforcement, ρ_s, should satisfy the following (Fig. 20.19):

$$\rho_s \geq \begin{cases} 0.12\dfrac{f'_c}{f_{yt}} \\ 0.45\left(\dfrac{A_g}{A_c} - 1\right)\dfrac{f_c}{f_{yt}} \end{cases}$$

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)



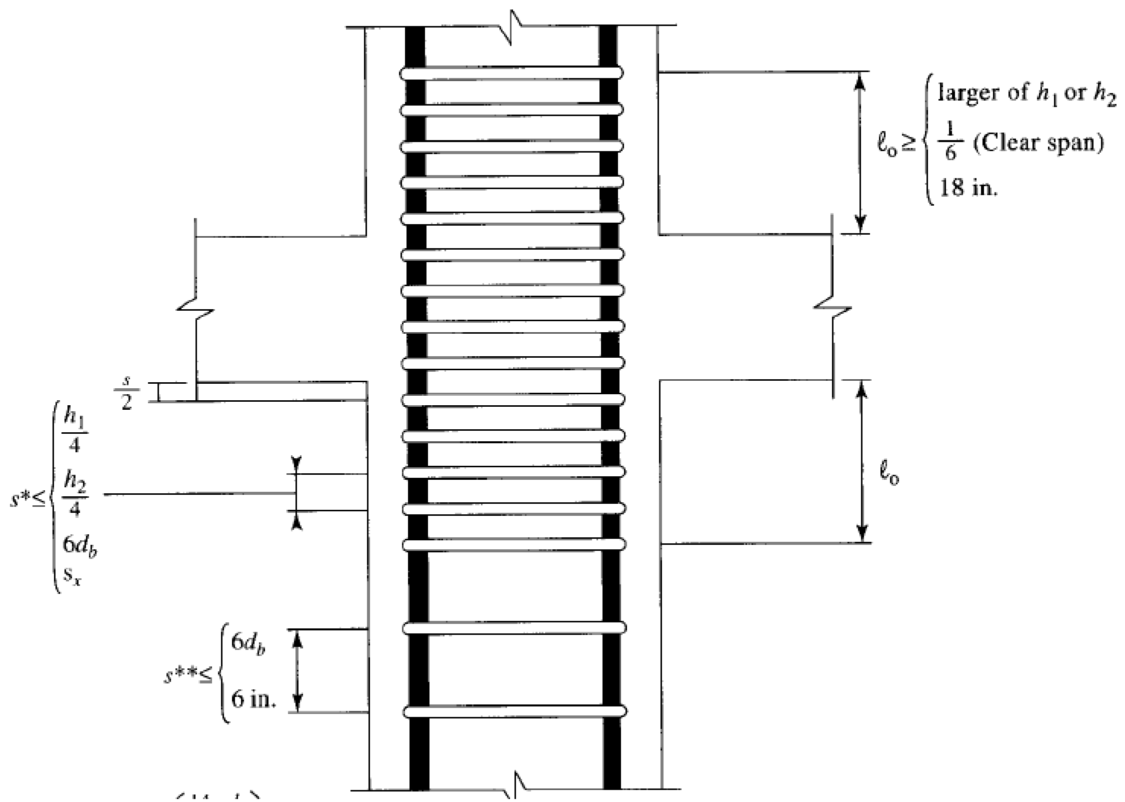
where

f_{yt} = yield stress of transverse reinforcement

A_c = area of core of spirally reinforced compression member measured to outside diameter of spiral

A_g = gross area of section

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)



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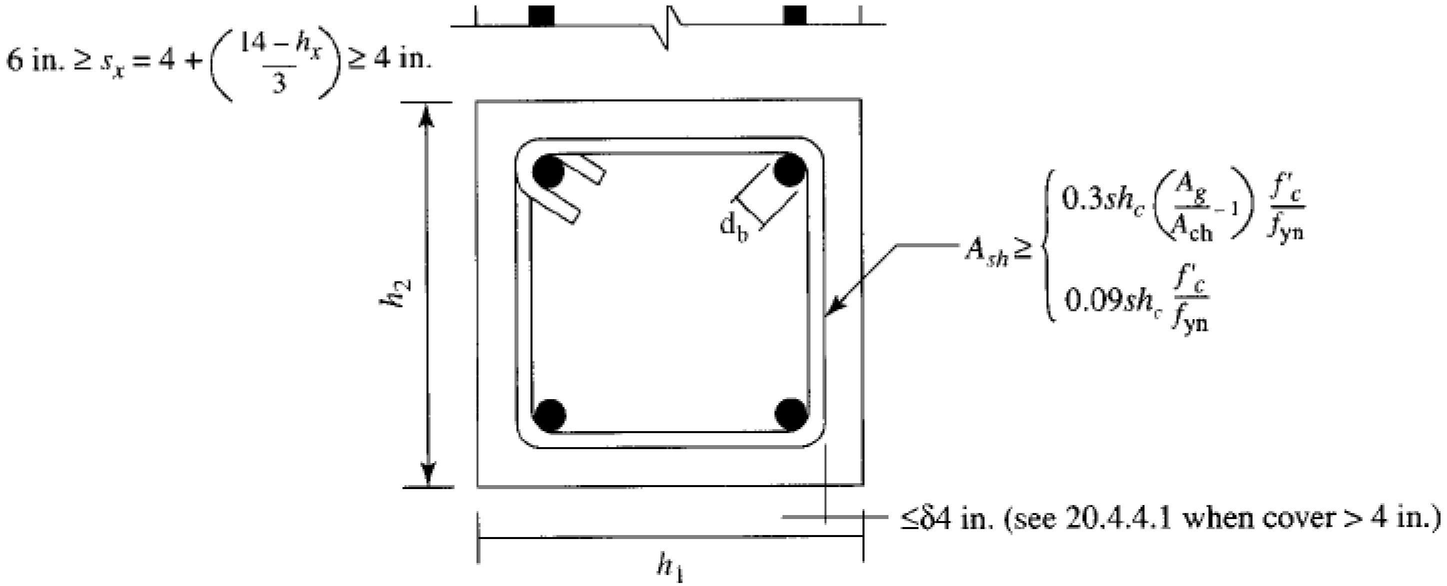


2. Total cross-section area of rectangular hoop reinforcement, A_{sh}, should satisfy the following (Fig. 20.20):

$$A_{sh} \geq \begin{cases} 0.3 \left(\frac{s h_c f'_c}{f_{yt}}\right)\left(\frac{A_g}{A_{ch}} - 1\right) \\ 0.09 \frac{s h_c f'_c}{f_{yt}} \end{cases} \quad (20.45)$$

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

where

s = spacing of transverse reinforcement

h_c = cross-section dimension of column core measured center-to-center of the confining reinforcement.

3. If the thickness of the concrete outside the confining transverse reinforcement exceeds 4 in., additional transverse reinforcement should be provided at a spacing $\leq$ 12 in. Concrete cover on additional reinforcement should not exceed 4 in.
4. Spacing of the transverse reinforcements should satisfy the following:

$$s \leq \begin{cases} \dfrac{h}{4} \\ 6 \times \text{longitudinal diameter bar} \\ s_o \end{cases} \qquad (20.46)$$

$$\text{Also, } 4\text{ in.} \leq s_o = 4 + \frac{14 - h_x}{3} \leq 6\text{ in.} \qquad (20.47)$$

where

s_o = longitudinal spacing of transverse reinforcement within the length l_o.

h_x = maximum horizontal spacing of hoop or crosstie legs on all faces of the column.

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

The remaining member length should be reinforced with the spiral or hoop transverse reinforcement spaced as follows:

$$s \leq \begin{cases} 6 \times \text{longitudinal bar diameter} \\ 6 \text{ in.} \end{cases} \tag{20.48}$$

Transverse reinforcement should be designed to resist the design shear force. Design shear force for flexural members of special moment frames can be determined using the following equation:

$$V_u = \frac{M_{\mathrm{Pr}_t} + M_{\mathrm{Pr}_b}}{l_c} \tag{20.49}$$

index t is for top and index b is for bottom of the column) where,
l_c = length of the column

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

Shear Reinforcement

The transverse reinforcement also must be designed for shear. The design shear force V_{sway} is computed by assuming inelastic action in either the columns or the beams.

(a) The shear corresponding to plastic hinges at each end of the column given by

$$V_{sway} = \frac{M_{prc,\,top} + M_{prc,\,btm}}{\ell_u} \tag{19-21}$$

where $M_{prc,\,top}$ and $M_{prc,\,btm}$ are the probable moment capacities at the top and bottom of the column and ℓ_u is the clear height of the column. These are obtained from an interaction diagram for the probable strength, $P_n - M_{pr}$ of the column, for the range of factored loads on the member for the load combination under consideration.

(b) It need not be more than

$$V_{sway} = \frac{\Sigma M_{prb,\,top} DF_{top} + \Sigma M_{prb,\,btm} DF_{btm}}{\ell_u} \tag{19-22}$$

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

where $\Sigma M_{\text{prb, top}}$ and $M_{\text{prb, btm}}$ are the sum of the probable moment capacities of the beams framing into the joints at the top and bottom of the column for the frame swaying to the left or right, and DF_{top} and DF_{btm} are the moment-distribution factors at the top and bottom of the column being designed. This reflects the strong-column–weak-beam philosophy and Eq. (19-16), which requires that the beams are weaker than the columns.

(c) but not less than the factored shear from a frame analysis.

Transverse reinforcement is designed for shear according to ACI Code Section 11.1.1, and V_c may be increased to allow for the effect of axial loads, except that, within the length ℓ_o, defined in the discussion of confinement reinforcement, V_c shall be taken equal to zero when the earthquake-induced shear force makes up half or more of the maximum shear force in the lengths ℓ_o and *if* the factored compression force is less than $A_g f'_c/20$ (ACI Code Section 21.6.5.2). Columns with such low axial loads essentially behave like a beam. Thus, the concrete contribution to shear, V_c, is set equal to zero in potential plastic hinging zones at the ends of a column, just as was done for plastic hinging zones at the end of beams.

Weak beams and Strong columns problem

Problem:-

The exterior joint shown in Fig. 20.14 is part of a reinforced concrete frame designed to resist earthquake loads. A 6 in. slab, not shown, is reinforced with No. 5 (No. 16) bars spaced 10 in. center to center at the same level as the flexural steel in the beams. The member section dimensions and reinforcement are as shown.

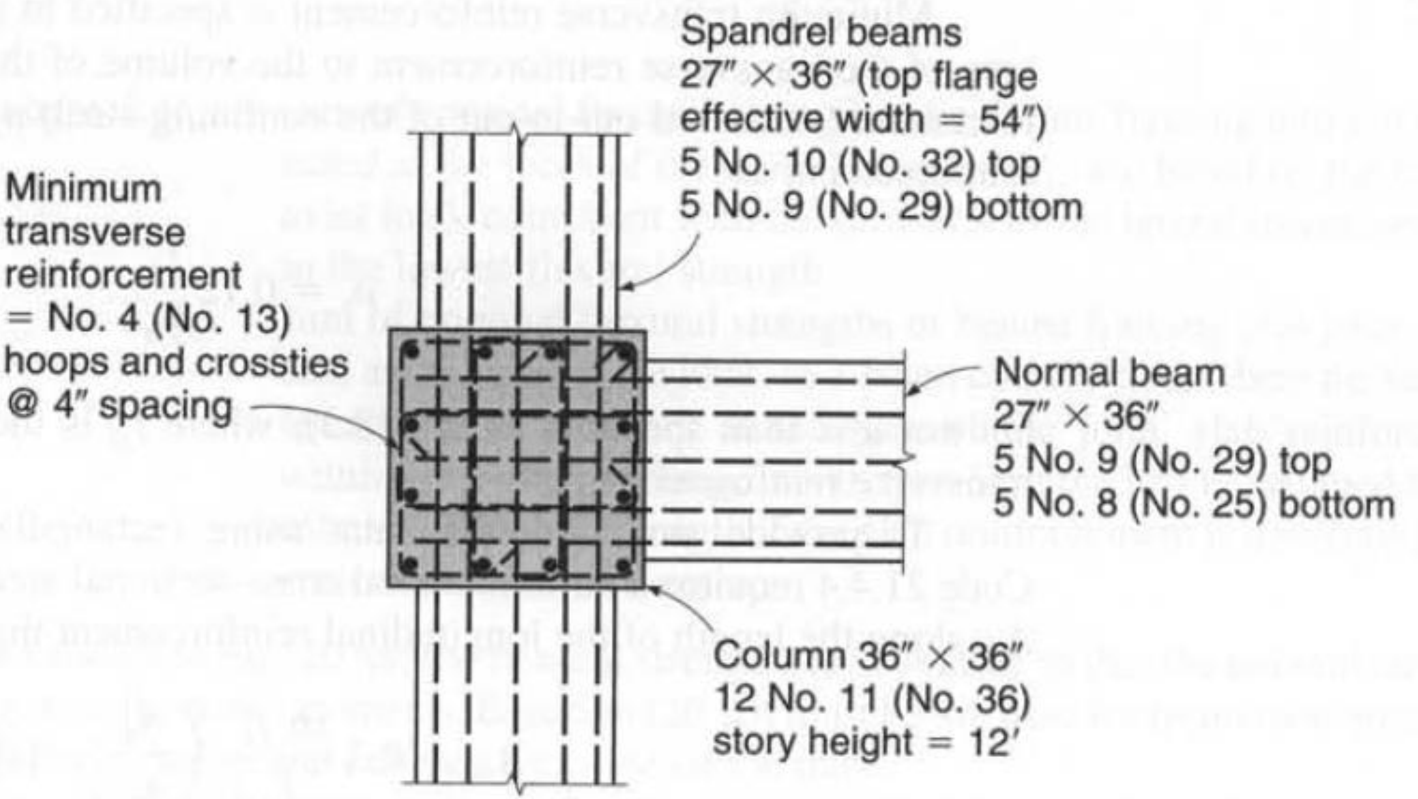
The frame story height is I2 ft. Material strengths are fc' = 4000 psi and fy= 60,000 psi.

Weak beams and Strong columns problem

Problem:-

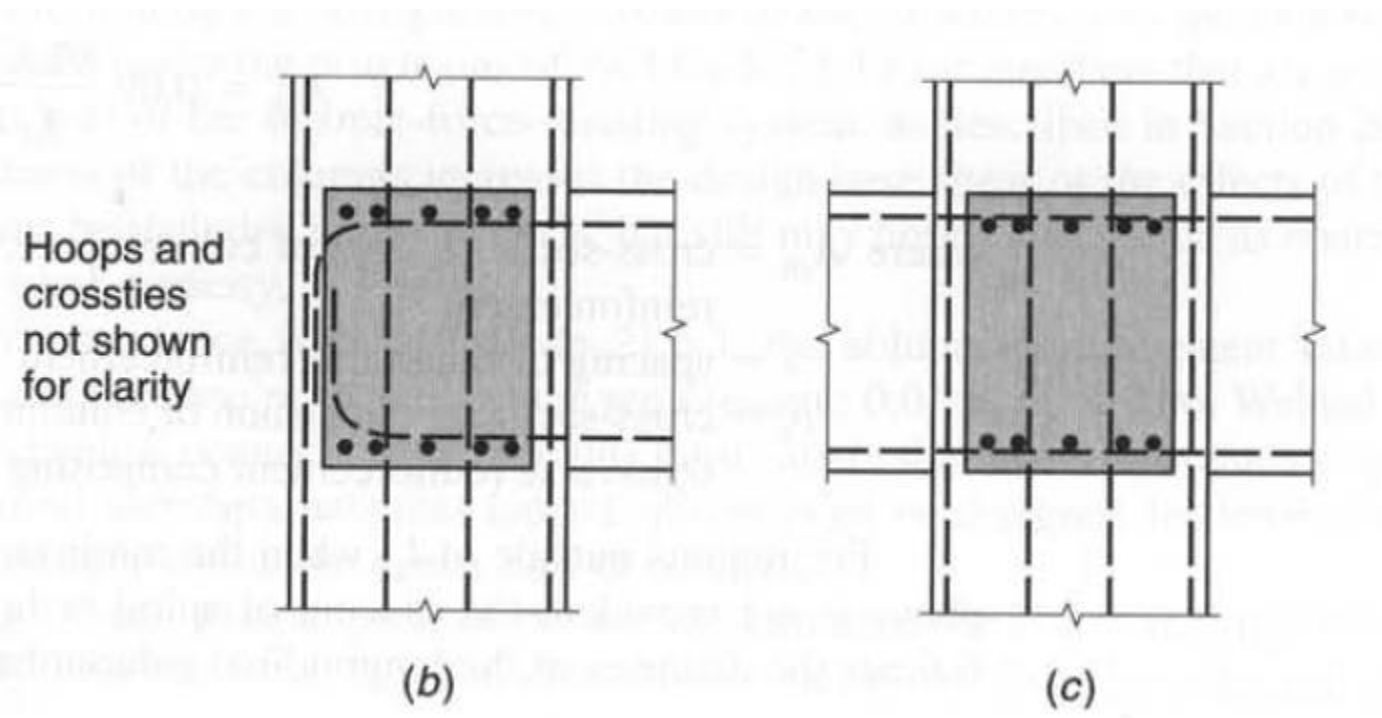
The maximum factored axial load on the upper column framing into the joint is 2210 kips, and the maximum factored axial load on the lower column is 2306 kips. Determine if the nominal flexural strengths of the columns exceed Spandrel beams by at least 20%.

Weak beams and Strong columns problem

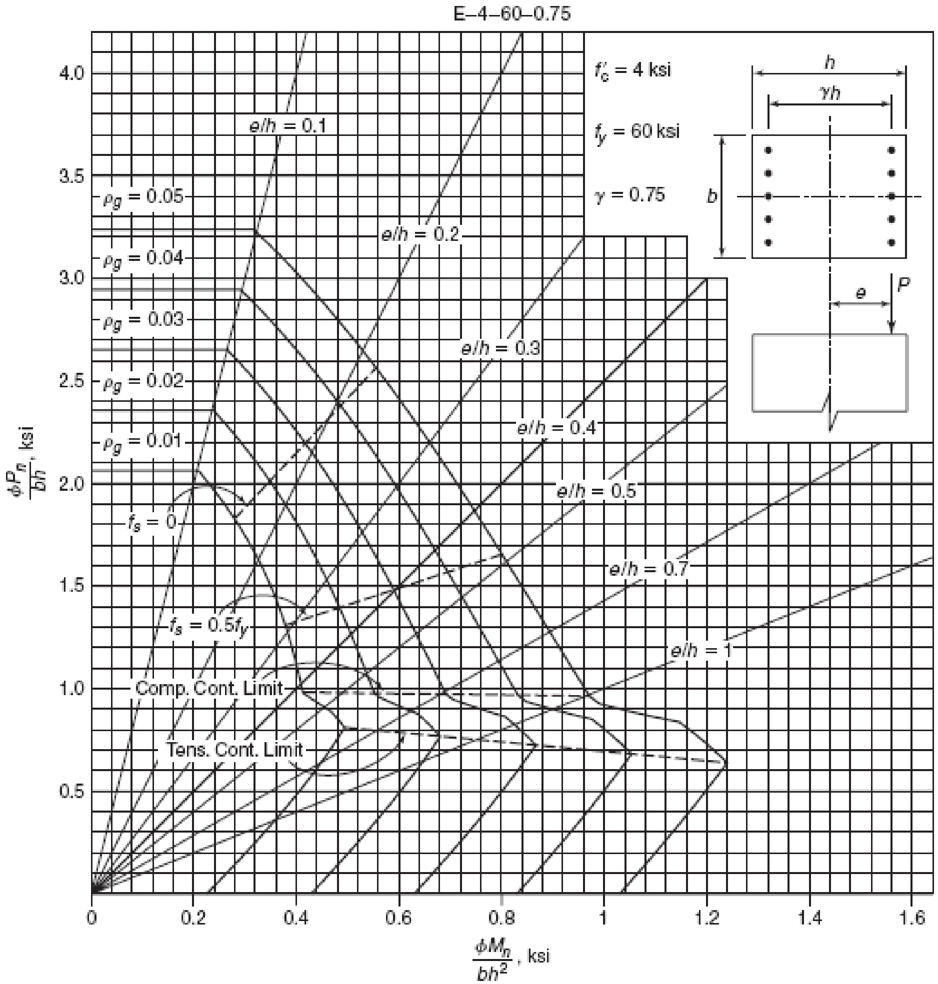


(a)

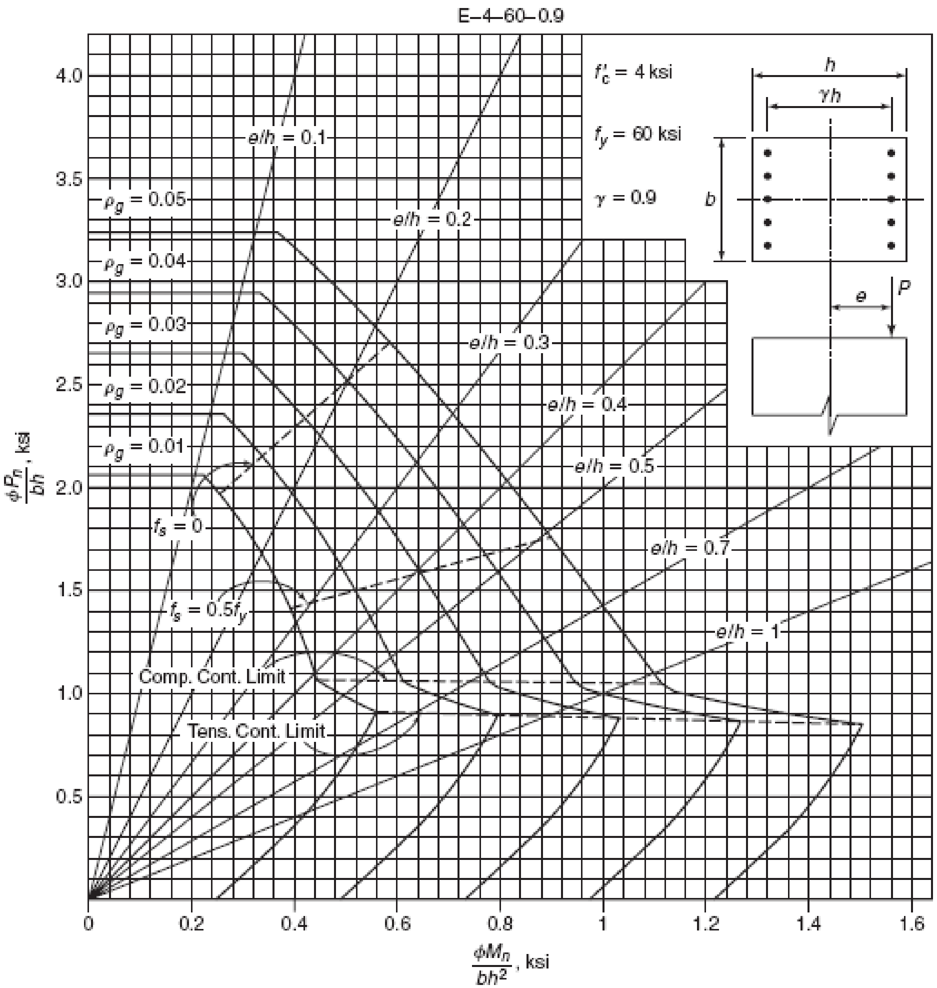
Weak beams and Strong columns problem



Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)



Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)



Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

Joints of the special moment-resisting frame (Section 20.5.1.3). Joint of special moment-resisting frame should be detailed according to the ACI Code 2008, Section 20.5, as follows:

Longitudinal Reinforcement Requirements (Section 20.5.1.3.1) The development length l_{dh} for a bar with a standard 90° hook using normal-weight concrete, for bar size no. 3 through no. 11, should be determined according to the following (Fig. 20.22):

$$l_{dh} \geq \begin{cases} \dfrac{f_y d_b}{65\sqrt{f_c'}} \\ 8d_b \\ 6 \text{ in.} \end{cases} \tag{20.50}$$

where d_b is the diameter of longitudinal reinforcement.

The development length, l_d, for a strait bar for bar size no. 3 through no. 11 should not be less than

1. 2.5 l_{dh} if the depth of the concrete cast in one lift beneath the bar does not exceed 12 in.
2. 3.5 l_{dh} if the depth of the concrete cast in one lift beneath the bar exceeds 12 in.

Special Moment frames (Section 21.5, ACI-2008) (Member subjected to Axial and Bending Moments)

When the longitudinal reinforcement passes through the joint, the column dimension parallel to the beam reinforcement should not be less than 20 times the diameter of the largest longitudinal bar for normal-weight concrete. For lightweight concrete, this dimension should not be less than 26 times the bar diameter.