Example 9.1 >

1) Design as a short column. (No slenderness effect)

$$P_u = (1.2)(230) + (1.6)(173) = 553 \text{ kips}$$

$$M_u = (1.2)(2) + (1.6)(108) = 175 \text{ ft-kips}$$

2) For interior column C3 (18 × 18 in)
with the clear cover of 1.5 in, D10 stirrups
and D32 longitudinal steel (No. 3) ~ 0.38 dia.
(No. 10) ~ 1.27 dia.

$$\gamma = (18 - 2 \times 1.5 - 2 \times 0.38 - 1.27) / 18 = 0.72$$

$$\frac{P_u}{A_g} \rightarrow \frac{P_u}{\phi f_c' A_g} = \frac{553}{(0.65)(4)(324)} = 0.656$$

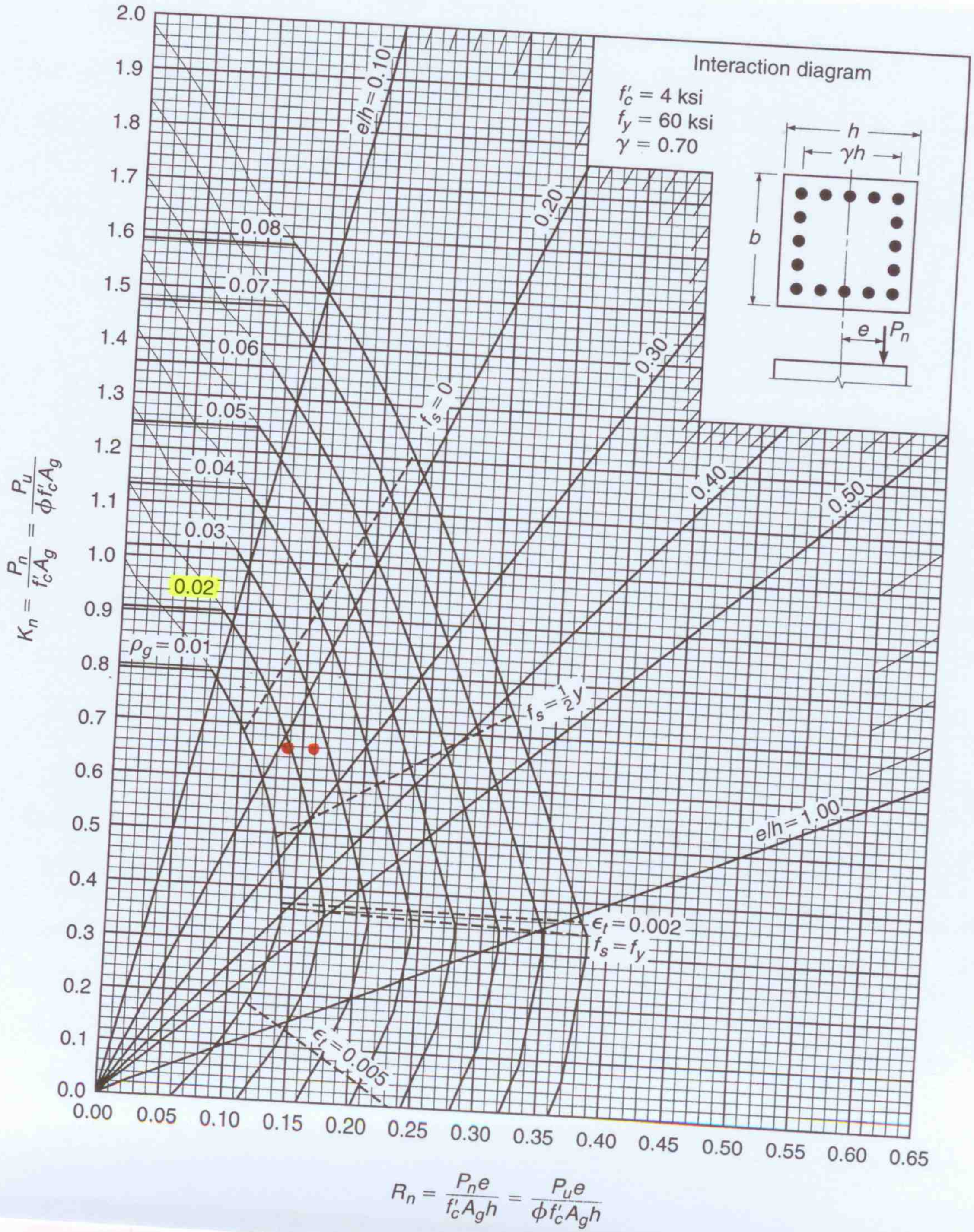
$$\frac{M_u}{A_g h} \rightarrow \frac{M_u}{\phi f_c' A_g h} = \frac{175 \times 12}{(0.65)(4)(324)(18)} = 0.138$$

from Design Aids $\rho_g = 0.02$ ~ is low enough
that an increase in steel area.

2) Sway or Nonsway? Nonsway from problem

3), 4) check slenderness with $k = 1.0$

$$\frac{k l_u}{r} = \frac{(1.0)(13)(12)}{0.3 \times 18} = 28.9$$



Interaction diagram
$f'_c = 4$ ksi
$f_y = 60$ ksi
$\gamma = 0.70$
h
γh
b
e
P_n
$K_n = \frac{P_n}{f'_c A_g} = \frac{P_u}{\phi f'_c A_g}$
$R_n = \frac{P_n e}{f'_c A_g h} = \frac{P_u e}{\phi f'_c A_g h}$
$\rho_g = 0.01$
0.02
0.03
0.04
0.05
0.06
0.07
0.08
$e/h = 0.10$
0.20
0.30
0.40
0.50
$e/h = 1.00$
$f_s = 0$
$f_s = \frac{1}{2}f_y$
$\epsilon_t = 0.002$
$f_s = f_y$
$\epsilon_t = 0.005$
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65

Slenderness limit for nonsway frames

$$34 - 12\frac{M_1}{M_2}$$

$$M_1 = (1.2)(-2) + (1.6)(100) = 158$$

$$M_2 = (1.2)(2) + (1.6)(108) = 175$$

$$\rightarrow 34 - 12\frac{158}{175} = 23.2 < \frac{kl_u}{r} = 28.9$$

Therefore, slenderness must be considered!

→ A more refined calculation of k is required.

5) Refine k based on the alignment chart.

Member stiffness $\frac{EI}{l}$

where Es are the same for both beam and column. So only I/l can be considered for simplicity.

- For column

$$0.7\,I_g = 0.7 \times \frac{18 \times 18^3}{12} = 6{,}124 \text{ in}^4$$

$$\rightarrow I/l_c = (6124)/(14 \times 12) = 36.5 \text{ in}^3$$

→ For beam

$$0.35\,I_g = 0.35 \times 2 \times \frac{48 \times 12^3}{12} = 4{,}838 \text{ in}^4$$

I_g is taken as 2 times the gross moment of inertia of the web

$$\rightarrow I/l_c = (4838)/(24 \times 12) = 16.8 \text{ in}^3$$

Rotational restraint factors ψ_a (top) and ψ_b (bottom) are the same and are

$$\psi_a = \psi_b = \frac{36.5 + 36.5}{16.8 + 16.8} = 2.17$$

from the alignment chart. k is 0.87

Consequently

(6) $$\frac{kl_u}{r} = \frac{(0.87)(13 \times 12)}{(0.3)(18)} = 25.1 > 23.2$$ slenderness limit.

(7) Check the minimum moment

$$M_{2,min} = P_u(\overset{0.6}{\cancel{1.5}} + 0.03h)$$

$$= 553(\overset{0.6}{\cancel{1.5}} + 0.03 \times 18)/12 = 53 \text{ ft-kips}$$

$$< M_2 = 175$$

$\therefore$ the minimum moment does not control!

(8) Calculate equivalent uniform moment factor C_m

$$C_m = 0.6 + 0.4\frac{M_1}{M_2}$$

$$= 0.6 + 0.4\frac{158}{175} = 0.96$$

(9) Calculate the factor β_d based on the ratio of the maximum factored SUSTAINED axial load (the dead load in this case) to the maximum factored axial load.

$$\beta_d = \frac{(1.2)(230)}{(1.2)(230) + (1.6)(173)} = 0.5$$

simpler equation

From Eq. (18) for relatively low reinforcement ratio

$$EI = \frac{0.4\, E_c I_g}{1 + \beta_d}$$

$$= \frac{(0.4)(3.6 \times 10^6)(18 \times \frac{18^3}{12})}{1 + 0.5} = 8.4 \times 10^9 \text{ in-lb}$$

The critical load P_{cr} is

$$P_{cr} = \frac{\pi^2 EI}{(kl_u)^2} = \frac{\pi^2 \times (8.4 \times 10^9)}{(0.87 \times 13 \times 12)} = 4.5 \times 10^6 \text{ lb}$$

10) The moment magnification factor

$$\delta_{ns} = \frac{C_m}{1 - P_u/0.75P_c} = \frac{0.96}{1 - \frac{553}{0.75 \times 4500}}$$

$$= 1.15$$

The magnified design moment is

$$\delta_{ns} M_2 = (1.15)(175) = 201 \text{ ft-kips}$$

$$\frac{P_u}{\phi f_c' A_g} = \underline{\hspace{3cm}} = 0.657$$

instead of 115

$$\frac{M_u}{\phi f_c' A_g h} = \frac{(201)}{\hspace{3cm}} = 0.159$$

From the design aid. $\rho_g = 0.026$ (previously 0.02)

The required steel reinforcement amount is

$$A_{st} = 0.026 \times (18 \times 18) = 8.42 \text{ in}^2$$