1

Find the maximum design axial load strength for the tied column of cross section shown in Figure 9-5. Check the ties. Assume a short column. Use $f'_c = 4000$ psi and $f_y = 60{,}000$ psi for both longitudinal steel and ties.

Solution:

1. Check the steel ratio for the longitudinal steel:

$$\rho_g = \frac{A_{st}}{A_g} = \frac{8.00}{(16)^2} = 0.0313$$

$$0.01 < 0.0313 < 0.08 \qquad \text{(O.K.)}$$

2. From Table A-14, using a 13-in. core (column size less cover on each side), the maximum number of No. 9 bars is eight. Therefore the number of longitudinal bars is satisfactory.
3. The maximum design axial load strength may now be calculated:

$$\begin{aligned}\phi P_{n(\max)} &= 0.80\phi[0.85f'_c(A_g - A_{st}) + f_yA_{st}]\\ &= 0.80(0.65)[0.85(4)(256 - 8) + 60(8)]\\ &= 688 \text{ kips}\end{aligned}$$

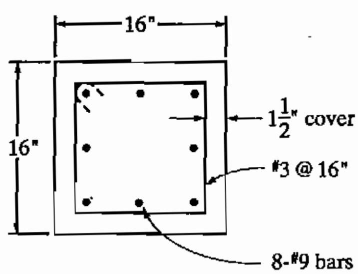

FIGURE 9-5 Sketch for Example 9-1.

4. Check the ties. Tie size of No. 3 is acceptable for longitudinal bar size up to No. 10. The spacing of the ties must not exceed the smaller of

$$\begin{aligned}\text{48 tie-bar diameters} &= 48(3/8) = 18 \text{ in.}\\ \text{16 longitudinal-bar diameters} &= 16(1.128) = 18 \text{ in.}\\ \text{least column dimension} &= 16 \text{ in.}\end{aligned}$$

Therefore the tie spacing is O.K. The tie arrangement for this column may be checked by ensuring that the clear distance between longitudinal bars does not exceed 6 in. Clear space in excess of 6 in. would require additional ties in accordance with the ACI Code, Section 7.10.5.3. Thus

$$\text{clear distance} = \frac{16 - 2(1\tfrac{1}{2}) - 2(\tfrac{3}{8}) - 3(1.128)}{2}$$
$$= 4.4 \text{ in.} < 6 \text{ in.}$$

Therefore no extra ties are needed.

2

Design a square tied column to carry axial service loads of 320 kips dead load and 190 kips live load. There is no identified applied moment. Assume that the column is short. Use ρ_g about 0.03, f'_c = 4000 psi, and f_y = 60,000 psi.

Solution:

1. Material strengths and approximate ρ_g are given.
2. The factored axial load is

$$P_u = 1.6(190) + 1.2(320) = 688 \text{ kips}$$

3. The required gross column area is

$$\text{required } A_g = \frac{P_u}{0.80\phi[0.85f'_c(1 - \rho_g) + f_y\rho_g]}$$
$$= \frac{688}{0.80(0.65)[0.85(4)(1 - 0.03) + 60(0.03)]}$$
$$= 260 \text{ in.}^2$$

4. The required size of the square column would be

$$\sqrt{260} = 16.1 \text{ in.}$$

Use a 16-in.-square column. This choice will require that the actual ρ_g be slightly in excess of 0.03:

$$\text{actual } A_g = (16 \text{ in.})^2 = 256 \text{ in.}^2$$

5. The load on the concrete area (this is approximate since ρ_g will increase slightly) is

$$\text{load on concrete} = 0.80\phi(0.85f'_c)A_g(1 - \rho_g)$$
$$= 0.80(0.65)(0.85)(4)(256)(1 - 0.03)$$
$$= 439 \text{ kips}$$

Therefore the load to be carried by the steel is

$$688 - 439 = 249 \text{ kips}$$

Since the maximum design axial load strength of the steel is $(0.80\phi A_{st}f_y)$, the required steel area may be calculated as

$$\text{required } A_{st} = \frac{249}{0.80(0.65)(60)} = 7.98 \text{ in.}^2$$

We will distribute bars of the same size evenly around the perimeter of the column and must therefore select bars in multiples of four. Use eight No. 9 bars (A_{st} = 8.0 in.^{2}). Table A-14 indicates a maximum of eight No. 9 bars for a 13-in. core (O.K.).

6. Design the ties. From Table A-14, select a No. 3 tie. The spacing must not be greater than

$$48 \text{ tie-bar diameters} = 48(3/8) = 18 \text{ in.}$$
$$16 \text{ longitudinal-bar diameters} = 16(1.128) = 18.0 \text{ in.}$$
$$\text{least column dimension} = 16 \text{ in.}$$

Use No. 3 ties spaced 16 in. o.c. Check the arrangement with reference to Figure 9-7. The clear space between adjacent bars in the same face is

$$\frac{16 - 3 - 0.75 - 3(1.13)}{2} = 4.43 \text{ in.} < 6.0 \text{ in.}$$

Therefore no additional ties are required by the ACI Code, Section 7.10.5.3.

7. The design sketch is shown in Figure 9-7.

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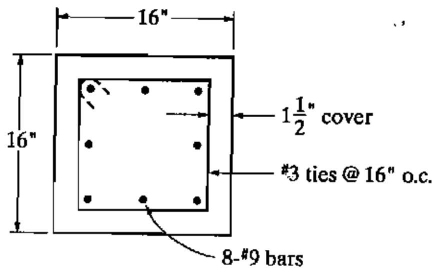

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3

Using the interaction diagrams of Appendix A, find the axial load strength ϕP_n and the moment strength ϕM_n for the column cross section with six No. 9 bars, as shown in Figure 9-19. Eccentricity $e = 5$ in., and use $f'_c = 4000$ psi and $f_y = 60{,}000$ psi. Compare the results with Example 9-5b.

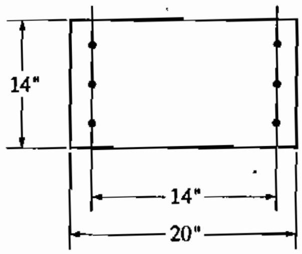

FIGURE 9-19 Sketch for Example 9-6.

Solution:

First, determine which interaction diagram to use, based on the type of cross section, the material strengths, and the factor γ.

$$\gamma h = 14 \text{ in.}$$

$$\gamma = \frac{14}{20} = 0.7$$

Therefore, use interaction Diagram A-15.

$$\rho_g = \frac{6.00}{14(20)} = 0.0214$$

$$0.01 \le 0.0214 \le 0.08 \qquad \text{(O.K.)}$$

Next, calculate the slope of the radial line from the origin, which relates h and e:

$$\text{slope} = \frac{h}{e} = \frac{20}{5} = 4$$

A straight edge and some convenient values (e.g., $K_n = 1.0$ and $R_n = 0.25$) may be used to intersect this radial line with an estimated $\rho_g = 0.0214$ curve. At this intersection, we read $K_n \approx 0.64$ and $R_n \approx 0.16$. Since this combination of load and moment is above the $f_s/f_y = 1.0$ line, this is a compression-controlled section and $\phi = 0.65$.

$$\phi P_n = \phi K_n f'_c A_g$$
$$= 0.65\,(0.64)\,(4)\,(20)\,(14) = 465 \text{ kips}$$

$$\phi M_n = \phi R_n f'_c A_g h$$
$$= \frac{0.65\,(0.160)\,(4)\,(20)\,(14)\,(20)}{12 \text{ in./ft}} = 194 \text{ ft-kips}$$

or

$$\phi M_n = \phi P_n e = \frac{465 \text{ ft-kips } (5 \text{ in.})}{12 \text{ in./ft}} = 194 \text{ ft-kips}$$

This compares reasonably well with the results of Example 9-5b: $\phi P_n = 476$ kips and $\phi M_n = 198$ ft-kips.

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4

Design a square-tied reinforced concrete column to support a design load $P_u = 1300$ kips and a design moment $M_u = 550$ ft-kips. Use $f'_c = 4000$ psi and $f_y = 60{,}000$ psi.

Solution:

Estimate the column size required based on $\rho_g = 1\%$ and axial load only.

$$\text{required } A_g = \frac{P_u}{0.80\,\phi[0.85 f'_c(1-\rho_g) + f_y\rho_g]}$$
$$= \frac{1300}{0.80(0.65)[0.85(4)(0.99) + 60(0.01)]}$$
$$= 631 \text{ in.}^2$$

Try a 26-in.-square column ($A_g = 676$ in.^{2}).

If No. 9 bars are eventually chosen (refer to Figure 9-22):

$$\gamma h = 26 - 2(1\tfrac{1}{2}) - 2\left(\frac{3}{8}\right) - 1.13 = 21.12 \text{ in.}$$
$$\gamma = \frac{21.12}{h} = \frac{21.12}{26} = 0.812$$

Therefore, use Diagram A-18 from Appendix A (ACI Interaction Diagram R4-60.8).

Next, determine the required ρ_g. Assume that this column will be compression-controlled ($\phi = 0.65$) subject to later check.

Recognizing that required $P_n = P_u/\phi$ and required $P_ue = M_u/\phi$, we can calculate the values of required K_n and R_n:

$$\text{required } K_n = \frac{P_u}{\phi f'_c A_g} = \frac{1300}{0.65(4)(676)} = 0.740$$
$$\text{required } R_n = \frac{M_u}{\phi f'_c A_g h} = \frac{550(12)}{0.65(4)(676)(26)} = 0.144$$

From Diagram A-18, $\rho_g \approx 0.023$. Note that this well above the $f_s/f_y = 1.0$ line; therefore, the column is compression-controlled and the assumption that $\phi = 0.65$ is O.K.

$$\text{required } A_s = \rho_g A_g = 0.023(676) = 15.55 \text{ in.}^2$$

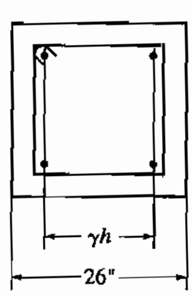

FIGURE 9-22 Sketch for Example 9-8.

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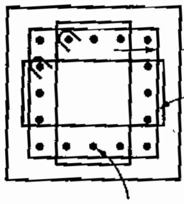

FIGURE 9-23 Design sketch for Example 9-8.

Select 16 No. 9 bars (A_s = 16.00 in.^{2}). Check the maximum number of No. 9 bars from Table A-14: 20 (O.K.).

Design the ties. Use a 3/8-in.-diameter tie, because the vertical bar size (No. 9 bar) is not greater than a No. 10.

The maximum tie spacing is the smallest of the following:

$$16\text{ (bar diameter)} = 16 \times 1.13 = 18\text{ in.}$$
$$48\text{ (tie diameter)} = 48 \times \frac{3}{8} = 18\text{ in.}$$
$$\text{least column dimension} = 26\text{ in.}$$

Therefore, use No. 3 ties at 18-in. spacing. The design is shown in Figure 9-23.