1. Calculate unfactored axial forces and moments for the columns in the frame due to DL, LL and WL. Then calculate factored loads using as a minimum the following two load combinations:

   LC I:  \(1.2D + 1.6L + 0.5L_r\)  \((ACI\ 9-2)\)  (largest total gravity load)
   LC II:  \(1.2D + 1.01L + 0.5L_r + 1.62W\)  \((ACI\ 9-4)\)  (largest gravity load and sidesway loads)

2. Determine the preliminary column size using the load combination with the largest factored gravity loads.

   \[A_g \approx \frac{P_u}{45(f'_c + \rho f_y)},\]  let \(\rho = 1.5\%\), round up each column dimension to the nearest even number

3. Determine if the frame is sway or non-sway.

   Method 1, computer analysis: the column is slender if the increase in column-end moments due to second-order effects (P-\(\Delta\)) is > 0.05

   Method 2, hand calculations: the frame is a sway frame if \(Q = \sum \frac{P_u \Delta_{a}}{V_u l_c} > 0.05\)

   \(P_u = \) the total factored vertical load on a story
   \(V_u = \) the factored horizontal shear on a story
   \(\Delta_o = \) the relative story deflection due to \(V_u\)
   \(l_c = \) the column height, measured from center-of-joint to center-of-joint

   In modeling the frame, use:

   \(I_g \approx 2b_w h^3/12\)  for T-beams
   \(I_{\text{beams}} = 0.35 I_g\)
   \(A_{\text{col}} = 0.7 I_g\)

4. Determine if the column is slender

   a. For non-sway frames, the column is slender if \(\frac{k l_u}{r} > 34 - 12 \left(\frac{M_1}{M_2}\right) \leq 40\)

   \(k = \) the effective length factor. \(k\) is a function of the rotational restraint at the column ends. Column ends with large rotational restraint \(\rightarrow \) small \(\psi\) \(\rightarrow \) small effective length factor.

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1 May be reduced to 0.5 except for garages, places of public assembly and when \(L > 100\text{psf}\)
2 May be reduced to 1.3 if wind directionality factor has not been applied
\[ \psi = \frac{\sum EI_{col}}{l_c} \left( \frac{EI_{beam}}{l} \right) \]

where \( l_c \) and \( l \) are the lengths of the column and beam, respectively, measured center-of-joint to center-of-joint.

\( k \) is calculated using the alignment chart on pg 127 in ACI.

\( l_u \) is the unsupported length of the compression member in inches

\( r = \) the radius of gyration \( \approx 0.3h \) for rectangular columns

\( M_2 \) is the larger between \( M_1 \) and \( M_2 \)

\( \frac{M_1}{M_2} \) is positive if the column is in single curvature, and negative if the column is in double curvature

b. For sway frames, the column is slender if \( \frac{k l_u}{r} > 22 \).

5. Calculate the factored moments (\( M_u \)) for each load combination. If the column is slender and it is part of a non-sway frame then:

\[ M_u = M_c = \delta_{ns} M_2, \quad \text{where} \]

\( \delta_{ns} \) = moment magnification factor for frames braced against sidesway to reflect effects of member curvature between ends of compression member

\[ \delta_{ns} = \frac{C_m}{1 - \frac{P_u}{0.75P_c}}, \quad P_c = \frac{\pi^2 EI}{(kl_u)^2}, \quad EI = \frac{0.4EI_c l_u}{1 + \beta_d}, \]

\( \beta_d \) reflects the increased lateral deflections of a column due to creep

\[ \beta_d = \frac{\text{factored sustained axial load}}{\text{factored total axial load}} \]

\[ C_m = 0.6 + 0.4 \frac{M_1}{M_2} \geq 0.4, \quad C_m = 1.0 \text{ for columns with transverse loads} \]

the min. \( M_2 \) in the equation for \( M_c \) above = \( P_u (0.6 + 0.03h) \), 0.6 and \( h \) are in inches
b. sway frame then:

\[ M_u = \text{larger of the moments at the column ends}, = \max [M_1, M_2] \]

where:

\[ M_1 = M_{1ns} + \delta_s M_{1s} \]

\[ M_2 = M_{2ns} + \delta_s M_{2s} \]

where \( M_{ns} \) = the factored moment due to loads that cause no appreciable sidesway calculated by a first-order analysis

i) \( \delta_s M_s \) can be calculated three different ways according to ACI, two of which are shown below.

Method 1: \( \delta_s M_s \) can be calculated by a computer program using a second-order (P-Δ) analysis

Method 2 (Method 3 in ACI): \( \delta_s \) can be calculated by hand using ACI Eqn 10-18

\[ \delta_s = \frac{1}{1 - \frac{\sum P_u}{0.75 \sum P_c}} \geq 1.0, \]

where \( \sum P_u = \text{the sum of } P_u \text{ for the story and} \)

\[ \sum P_c = \text{the sum of } P_c \text{ for all the sway-resisting columns in a story} \]

ii) The maximum moment occurs between the column ends if

\[ \frac{l}{r} \geq \frac{35}{\sqrt{f_c A_g}} \]

If the max. moment occurs between the column ends, then

\[ M_u = \delta_{ns} M_2 = \delta_{ns} (M_{2ns} + \delta_s M_{2s}) \]

where \( \delta_{ns} \) is calculated following the procedure for columns in non-sway frames

iii) check for instability under gravity loads alone

iv) If the magnified moments were calculated using a computer program (ACI 10.14.4.1), then

\[ \Delta^{LC I + \text{any Lat}} \text{ from } 2^{nd}-\text{order analysis} \text{ must be } < 2.5 \Delta^{LC I + \text{any Lat}} \text{ from } 1^{st}-\text{order analysis} . \]

Any lateral load may be used to cause the sidesway.

v) If the magnified moments were calculated using hand calculations (ACI 10.13.4.3)

the moment magnifier (\( \delta_s \)) must be < 2.5

Calculate \( \beta_d \) as the “ratio of the maximum factored sustained axial load to the maximum factored axial load” (ACI 10.13.6), likely using LC 9-2.