Concrete Columns (ACI 318)

- Types of columns
- Tied columns
- Spiral columns
- Interaction diagrams
- 3d printed forms

Compression Members

- **Pedestals** are compression members with an aspect less than or equal to 3:1. They can be used without reinforcing.

- **Columns** are any more slender members which carry primarily axial compressive loads.
  - Columns always require reinforcing
    - ACI 318-19 section 10.6.1
  - Minimum reinforcing to insure ductile failure:
    - 1% i.e. As/Ag ≥ 0.01
  - Maximum reinforcing to prevent blockage:
    - 8% i.e. As/Ag ≥ 0.08
    - In practice 4% is better.
Types of Columns

There are 3 types of columns based on how they are reinforced:

1. tied column (a)
2. spiral column (b)
3. composite column (c & d)

Column Reinforcing

Tied Columns

The ties restrain the expansion of the core concrete and the outward buckling of the longitudinal bars.

Longitudinal bars:
- minimum for square columns is 4.
- minimum for round columns is 6.
- maximum spacing is 6”

Ties:
- no less than #3 with #10 or less longitudinal steel.
- no less than #4 with #11 and greater longitudinal steel.
- tie spacing is the least of:
  - 16 x longitudinal bar diameter
  - 48 x tie diameter
  - least width column
- crossties brace alternate longitudinal bars or bars > 6” o.c.
Column Reinforcing
Spiral Columns

Clear spacing (the pitch, s) should be between 1” and 3”

spiral should be continuous or spliced must be welded or overlapped.

spacers (vertical bars with hooks) are used to hold spirals in place during casting.

Spiral columns are more ductile in failure and stronger than tied columns (by about 5%)

Column Design Considerations

High strength concrete is more effective than in beams.

Because steel is more expensive, it is better to increase column size and reduce steel needed.

Tied columns (particularly rectangular) are more economical than spiral.

But spiral columns with high strength concrete reduce column size.

Larger bar sizes reduce congestion when casting. Bars can also be bundled.
Column Modes of Failure

Stress distribution between steel and concrete varies under load and time, but ultimate failure is more predictable.

For design, failure is defined as the spalling of the cover concrete.

Even with the cover cracked the column will continue to carry load.

Spiral columns are tougher than tied

A column is a more critical member.
It supports a greater area.
Therefore the $\Phi$ factor is lower.
$\Phi = 0.65$ for tied columns
$\Phi = 0.75$ for spiral columns
Also:
columns are more difficult to cast,
and concrete carries more of the load than in beams

Ultimate Strength – (ACI 318 - 2014)

Reduced Nominal Strength $\geq$ Factored Load Effects

$\Phi S_n \geq U$

$\gamma$ Factored Loads (see ACSE 7)

1) $1.4D$
2) $1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$
3) $1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (1.0L \text{ or } 0.5W)$
4) $1.2D + 1.0W + 1.0L + 0.5(L_r \text{ or } S \text{ or } R)$
5) $1.2D + 1.0E + 1.0L + 0.2S$
6) $0.9D + 1.0W$
7) $0.9D + 1.0E$

Strength Reduction Factors, $\Phi$

| $M_n$ | Flexural ($\epsilon > 0.005$) | 0.90 |
| $V_n$ | Shear | 0.75 |
| $P_n$ | Compression (spiral) | 0.75 |
| $P_n$ | Compression (other) | 0.65 |
| $B_n$ | Bearing | 0.65 |
| $T_n$ | Torsion | 0.75 |
| $N_n$ | Tension | 0.90 |
| Combined stress | | 0.65 to 0.90 |

ACI 318 21.2.2

$\Phi = \frac{(\epsilon_f - \epsilon_y)}{(0.005 - \epsilon_y)}$

$\Phi = 0.65$ Compression controlled

$\Phi = 0.90$ Tension controlled
Axial Strength Calculation

Po is the nominal axial strength with no eccentricity.

Pn,max is Po with a factor for minimum moment.

For spiral and composite columns:
\[ P_u = \Phi P_n = \Phi 0.85 \left[ 0.85f'_c (A_g - A_s) + f_y A_s \right] \]

For tied columns:
\[ P_u = \Phi P_n = \Phi 0.80 \left[ 0.85f'_c (A_g - A_s) + f_y A_s \right] \]

22.4.2 Maximum axial compressive strength

22.4.2.1 Nominal axial compressive strength \( P_n \) shall not exceed \( P_{n,m} \), in accordance with Table 22.4.2.1, where \( P_n \) is calculated by Eq. (22.4.2.2) for non prestressed members and composite steel and concrete members, and by Eq. (22.4.2.3) for prestressed members.

Table 22.4.2.1—Maximum axial strength

<table>
<thead>
<tr>
<th>Member</th>
<th>Transverse reinforcement</th>
<th>( P_{n,m} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonprestressed</td>
<td>Ties conforming to 22.4.2.4</td>
<td>0.80( P_u )</td>
</tr>
<tr>
<td></td>
<td>Spindles conforming to 22.4.2.5</td>
<td>0.85( P_u )</td>
</tr>
<tr>
<td>Prestressed</td>
<td>Ties</td>
<td>0.80( P_u )</td>
</tr>
<tr>
<td></td>
<td>Spindles</td>
<td>0.85( P_u )</td>
</tr>
<tr>
<td>Composite steel and concrete columns in accordance with Chapter 19</td>
<td>All</td>
<td>0.85( P_u )</td>
</tr>
</tbody>
</table>

22.4.2.2 For non prestressed members and composite steel and concrete members, \( P_n \) shall be calculated by:
\[ P_n = 0.85f'_c (A_g - A_s) + f_y A_s \]  (22.4.2.2)
where \( A_s \) is the total area of non prestressed longitudinal reinforcement.

Axial Strength Design (no moment)
Tied Column Procedure

1. Find factored axial load \( P_u \) (apply \( \lambda \) factor for load case).
2. Choose \( \rho = A_s/A_g \) (0.01 min., 0.08 max.)
3. Find concrete \( A_g \) based on \( \rho \)
   \[ A_s = \rho A_g \]
   \[ P_u = \Phi P_n = \Phi 0.80 \left[ 0.85f'_c (A_g - A_s) + f_y A_s \right] \]
4. Choose column section based on \( A_g \)
5. Find steel \( A_s \) based on concrete \( A_g \).
   Choose bar size and number
6. Determine tie size.
   for longitudinal bar \( \leq \#10 \) use \#3 ties
   for \( > \#10 \) or bundled bars use \#4 ties
7. Find tie spacing.
   use the least of:
   a) \( 48 \times \) tie diameter
   b) \( 16 \times \) longitudinal steel diameter
   c) least column dimension
8. Check section dimensions.
Axial Strength Design  
(no moment)  
Tied Column Example

Given:  \( P_{DL} = 200 \text{ k} \), \( P_{LL} = 300 \text{ k} \)  
\( f'c = 4000 \text{ psi} \), \( f_y = 60000 \text{ psi} \)  
Required:  column size and reinforcement

1. Find factored axial load \( P_u \) (apply \( \lambda \) factor for load case).

\[
P_u = 1.4(200) + 1.7(300) = 280 + 510 = 790 \text{ k}
\]

2. Choose \( \rho = \frac{A_s}{A_g} \) (0.01 min., 0.08 max.)  
assume \( \rho = 0.02 \) (good economically).

3. Find concrete \( A_g \) based on \( \rho \)  
\( P_u = \Phi P_n = \Phi 0.80 \left[ 0.85f'c (A_g - A_s) + f_y A_s \right] \)

\[
P_u = 0.80 \left[ 0.85(4000)(A_g - 335.2) + 60(335.2) \right]
790 = 0.80 \left[ 0.85(4)(A_g - 0.02) + 60(0.02) \right]
\]

\( A_g = 335.2 \text{ in}^2 \)

Assume square section  
\( \sqrt{335.2} = 18.31 \text{ in} \)
Round up to whole inch, say 19" x 19"

4. Choose column section based on \( A_g \)

5. Find steel \( A_s \) based on concrete \( A_g \).
Choose bar size and number

\[
P_u = 0.65(0.80) \left[ 0.85(4)(361 - A_s) + 60A_s \right]
790 = 0.65(0.80) \left[ 0.85(4)(361 - A_s) + 60A_s \right]
790 = 638.2 + 29.43A_s
\]

\( A_s = 5.16 \text{ in}^2 \)

Use 6 #9 bars = 6.0 \text{ in}^2
Axial Strength Design
(no moment)
Tied Column Example

6. Determine tie size.
   for longitudinal bar ≤ #10 use #3 ties
   for > #10 or bundled bars use #4 ties

7. Find tie spacing.
   use the least of:
   a) 48 x tie diameter
   b) 16 x longitudinal steel diameter
   c) least column dimension

8. Check section dimensions.

---

Axial Strength Design
(no moment)
Spiral Column Procedure

1. Find factored axial load Pu (apply λ factor for load case).

2. Choose \( \rho = \frac{A_s}{A_g} \) (0.01 min., 0.08 max.)

3. Find concrete Ag based on \( \rho \)
   \[ P_u = \Phi P_n = \Phi 0.80 \left[ 0.85 f'_c (A_g - A_s) + f_y A_s \right] \]
   \( \Phi = 0.75 \)

4. Choose column diameter based on Ag

5. Find concrete core area, \( A_c = \frac{\pi D_c^2}{4} \)
   \( D_c = \) diameter of core, out to out of spiral

6. Find \( \rho_s \) min = 0.45 (Ag/Ac -1) \( \frac{f'_c}{f_y} \)
   \( \rho_s = \) ratio of volume of spiral steel to volume of concrete core

7. Choose spiral bar size. Minimum = 3/8"

8. Determine spiral pitch, 1" \leq s \leq 3"

---

TIE SIZE
\(*9 < *10 \rightarrow USE \#3 TIES*

TIE SPACING
\( a) \ 48 \times \frac{3}{4} = 18" \leftarrow USE SMLLEST\)
\( b) \ 16 \times 1.125 = 18.05"\)
\( c) \ LEAST DIM. = 19"\)

USE 18" TIE SPACING

---

FIND PITCH \( s \):
\[ s = \frac{4A_s (D_e - d_o)}{A_s D_s^2} \]
\( D_e = \) Diameter of \( \bar{A} \)
\( D_s = \) Diameter of spirale steel
\( d_o = \) Diameter of spiral steel

IF \( s < 1" \) CHOICE SMALLER BAR
IF \( s > 3" \) CHOICE LARGER BAR
OR BIGGER COLUMN DIAMETER
Combined Axial + Flexure

Bending moments are almost always present due to columns being continuously cast with beams. Solutions are normally found using interaction diagrams. Axial force is on the vertical axis and the flexure moment is the horizontal. Each curve is for a different \( \rho \). Graphs are for specific bar arrangements, \( f'c \) and \( fy \).

1. Choose section dimensions
2. Calculate \( Kn \) and \( Rn \)
3. Find \( \rho \)
4. Determine \( As = \rho Ag \)
5. Check bar spacing, \( Ag \) and ties.

3D printed / robotic fabrication
difficult to integrate longitudinal steel. could be used as forms for casting column

ETH, Zurich

Taubman College

Quinta da Boavista
SAMF Arquitectos