Introduction to Concrete Column Design Flow Charts

The Column Design Section in Strunet contains two main parts: Charts to develop strength interaction diagrams for any given section, and ready -made Column Interaction Diagrams, for quick design of a given column.

Concrete column is one of the most interesting members in concrete structural design application. A structural design of a concrete column is quite complicated procedures. Evaluation, however, of a given column section and reinforcement is straightforward process. This is due to the fact that pure axial compression is rarely the case in column analysis. Some value of moment is always there due to end restraint, or accidental eccentricity due to out of alignment. ACI established the minimum eccentricity on a concrete column, regardless of the structural analysis proposed for the column, which is defined as the maximum axial compression load that a column can be designed for.

Column Design Charts in Bullets:

One of the demanding aspects in concrete column design is to define the controlling points on strength interaction diagram. The column strength interaction diagram is a curve plot of points; where each point has two ordinates. The first ordinate is bending moment strength and the second is the corresponding axial force. Both ordinates are linked with eccentricity. The shape of the curve, or the strength interaction diagram, can be defined by finding the ordinates of major seven points. Each point has specific requirement, as established by the code, and thus evaluating the requirement of this point will result of calculating the ordinates. The points and their respective requirements are as follows:

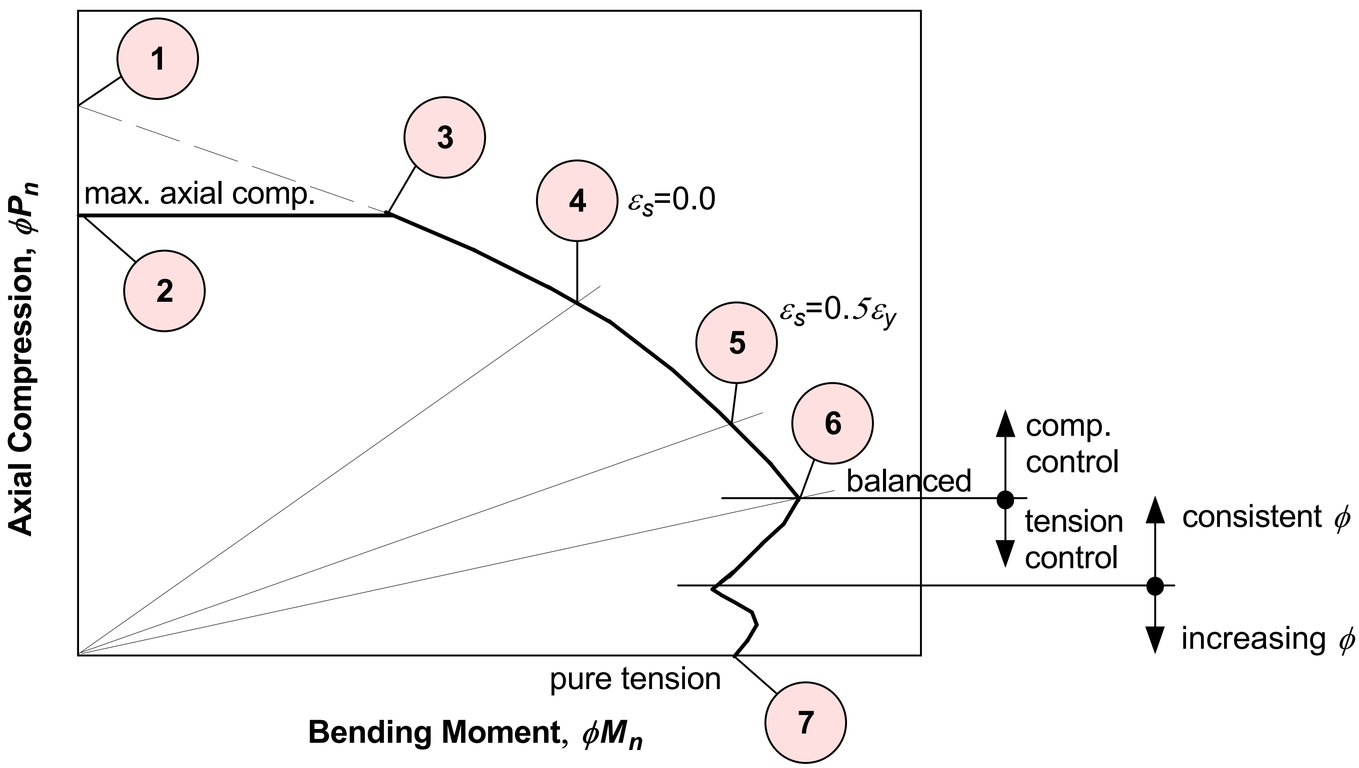
- Point 1: Pure compression.
- Point 2: Maximum compression load permitted by code at zero eccentricity.
- Point 3: Maximum moment strength at the maximum axial compression permitted by code.
- Point 4: Compression and moment at zero strain in the tension side reinforcement.
- Pont 5: Compression and moment at 50% strain in the tension side reinforcement.
- Point 6: Compression and moment at balanced conditions.
- Point 7: Pure tension.

Notations for Concrete Column Design Flow Charts

a = depth of equivalent rectangular stress block, in.
a_b = depth of equivalent rectangular stress block at balanced condition, in.
A_g = gross area of column, in^2.
A_s = area of reinforcement at tension side, in^2.
A'_s = area of reinforcement at compression side, in^2.
A'_{st} = Total area of reinforcement in column cross section, in^2.
b = column width dimension, in.
c = distance from extreme compression fiber to neutral axis, in.
c_b = distance from extreme compression fiber to neutral axis at balanced condition, in.
C_c = compression force in equivalent concrete block.
C_s = compression force in tension-side reinforcement, if any.
C'_s = compression force in compression-side reinforcement.
d = distance from extreme compression fiber to centroid of tension-side reinforcement
d' = distance from extreme compression fiber to centroid of compression-side reinforcement
e = eccentricity, in.
e_b = eccentricity at balanced condition, in.
E_s = modulus of elasticity of reinforcement, psi.
f'_c = specified compressive strength of concrete, psi.
f_y = specified tensile strength of reinforcement, psi.
f_s = stress in tension-side reinforcement at strain ε_s , ksi.
f'_s = stress in compression-side reinforcement at strain ε'_s , ksi.
h = overall column depth, in.
M_b = nominal bending moment at balanced condition.
M_n = nominal bending moment at any point.
P_o = nominal axial load strength at zero eccentricity.
P_b = nominal axial force at balanced condition.
P_{lim} = limit of nominal axial load value at which low or high axial compression can be defined in accordance with ACI 9.3.2.2.
P_n = nominal axial load strength at any point.
T = tension force in tension-side reinforcement.
$\beta?$ = factor as defined by ACI 10.2.7.3.
ε_s = strain in tension-side reinforcement at calculated stress f_s
ε'_s = strain in compression-side reinforcement at calculated stress f'_s
ε_y = yield strain of reinforcement.
ϕ = strength reduction factor

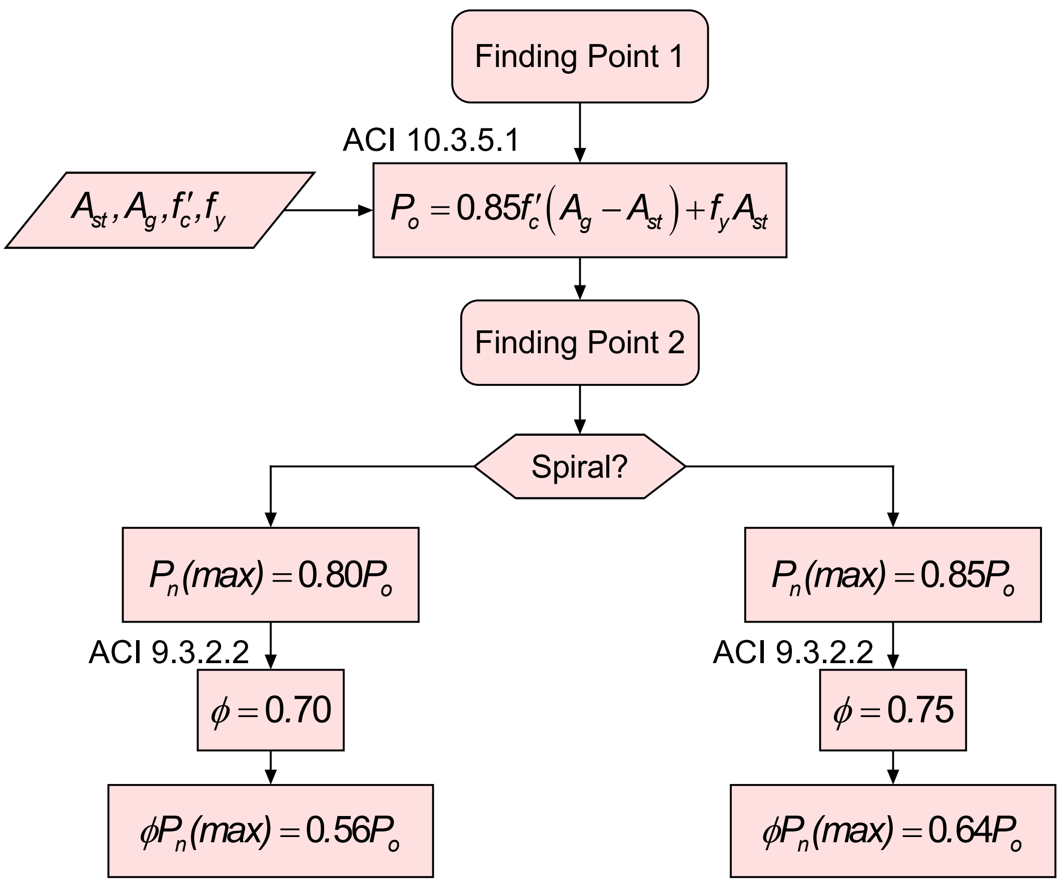
STRUNET
CONCRETE DESIGN AIDS

Main Points of Column Interaction Diagram



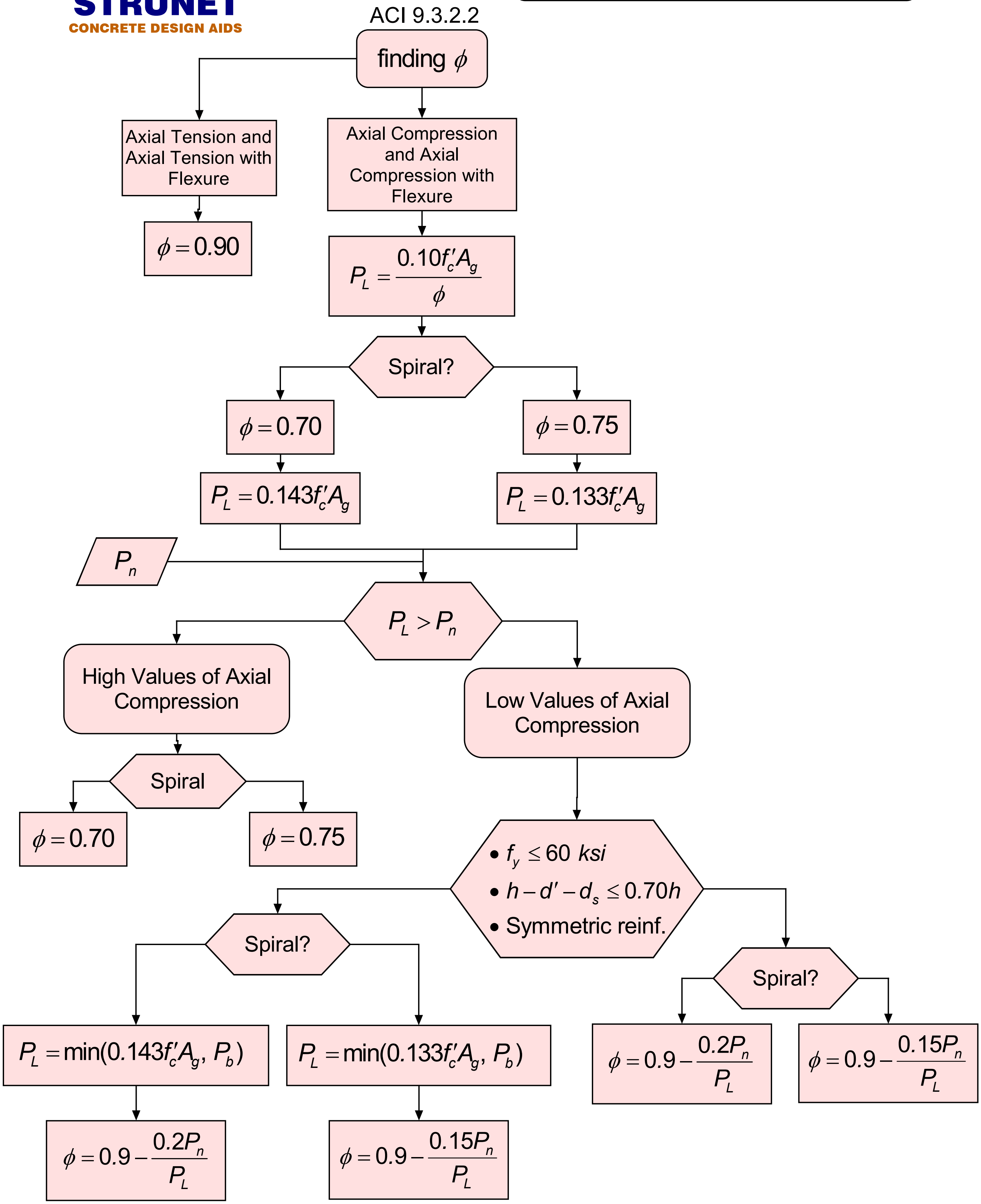
Point 1: axial compression at zero moment.
Point 2: maximum permissible axial compression at zero eccentricit.
Point 3: maximum moment strength at maximum permissible axial compression.
Point 4: axial compression and moment strength at zero strain.
Point 5: axial compression and moment strength at 50% strain.
Point 6: axial compression and moment strength at balanced conditions.
Point 7: moment strength at zero axial force.

Point 1: Axial Compression at Zero Moment
Point 2: Maximum Permissible Axial Compression at Zero Eccentricity



Strength Reduction Factor

STRUNET
CONCRETE DESIGN AIDS



STRUNET
CONCRETE DESIGN AIDS

Point 3: Maximum Moment Strength at Maximum Permissible Compression

ACI 10.2.7.3

$f'_c \le 4000\ psi$

$$\beta_1 = 0.85 - 0.05\left(\frac{f'_c - 4000}{1000}\right) \ge 0.65$$

$$\beta_1 = 0.85$$

finding distance c

$$C_c = 0.85 f'_c (\beta_1 c) b$$

$$C'_s = A'_s (f_y - 0.85 f'_c)$$

$$\varepsilon_s = \frac{(c-d)0.003}{c}$$

$$f_s = \varepsilon_s E_s$$

$$C_s = A_s (f_s - 0.85 f'_c)$$

$$C_s = A_s\left(\frac{(c-d)0.003}{c} E_s - 0.85 f'_c\right)$$

$$P_n = C_c + C'_s + C_s$$

P_n of point 2

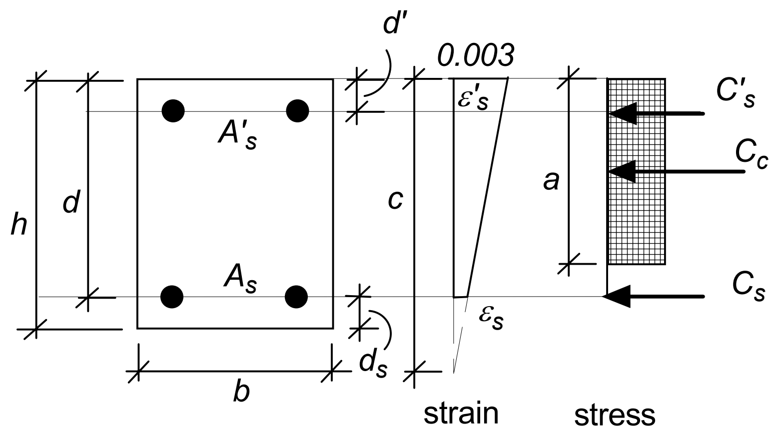
$$P_n = 0.85 f'_c (\beta_1 c) b + A'_s (f_y - 0.85 f'_c) + A_s\left(\frac{(c-d)0.003}{c} E_s - 0.85 f'_c\right)$$

Result: c

$$a = \beta_1 c$$

Compute: C_c , C'_s from above Eqs.

$$M_n = 0.5 C_c (h - a) + C'_s (0.5h - d') - C_s (0.5h - d_s)$$



STRUNET
CONCRETE DESIGN AIDS

Point 4: Axial Compression and Moment at Zero Strain

Finding Point 4

$$\varepsilon_s = 0.0$$

$$c = d$$

$$a = \beta_1 c$$

See Finding β_1 in point 3

$$C_c = 0.85 f'_c ab$$

$$\varepsilon'_s = \left(\frac{c - d'}{c}\right) 0.003$$

$$f'_s = \min(\varepsilon'_s E_s, f_y)$$

$$C'_s = A'_s \left(f'_s - 0.85 f'_c\right)$$

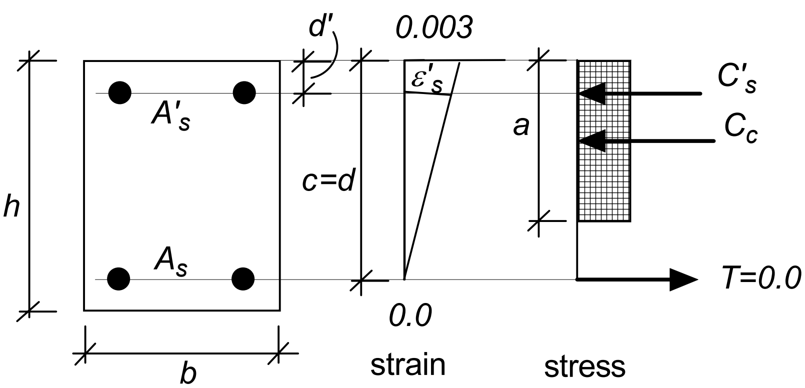
$$P_n = C_c + C'_s$$

$$M_n = C_c\left(\frac{h}{2} - \frac{a}{2}\right) + C'_s\left(\frac{h}{2} - d'\right)$$

$$e = \frac{M_n}{P_n}$$

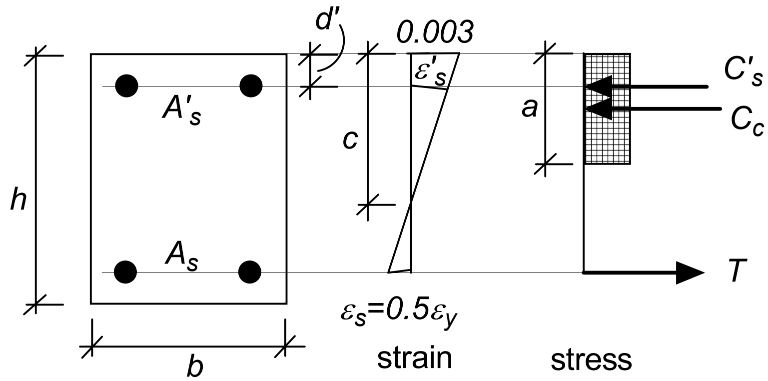
$$\phi M_n \ \& \ \phi P_n$$

See finding ϕ



STRUNET
CONCRETE DESIGN AIDS

Point 5: Axial Compression and Moment Strength at 50% Strain



Finding Point 5

$$\varepsilon_y = \frac{f_y}{E_s}$$

$$\varepsilon_s = 0.5\varepsilon_y$$

$$c = \left(\frac{d}{1 + \frac{\varepsilon_s}{0.003}} \right)$$

$$a = \beta_1 c$$

See Finding β_1 in point 3

$$C_c = 0.85 f'_c ab$$

$$\varepsilon'_s = \left(\frac{c - d'}{c} \right) 0.003$$

$$f'_s = \min(\varepsilon'_s E_s, f_y)$$

$$C'_s = A'_s \left(f'_s - 0.85 f'_c \right)$$

$$T = A_s \left(0.5 f_y \right)$$

$$P_n = C_c + C'_s - T$$

$$M_n = C_c \left(\frac{h}{2} - \frac{a}{2} \right) + C'_s \left(\frac{h}{2} - d' \right) + T \left(d - \frac{h}{2} \right)$$

$$e = \frac{M_n}{P_n}$$

$$\phi M_n \ \& \ \phi P_n$$

See finding ϕ

STRUNET
CONCRETE DESIGN AIDS

Point 6: Axial Compression and Moment Strength at Balanced Conditions

Finding Point 6

$$\varepsilon_s = \varepsilon_y = \frac{f_y}{E_s}$$

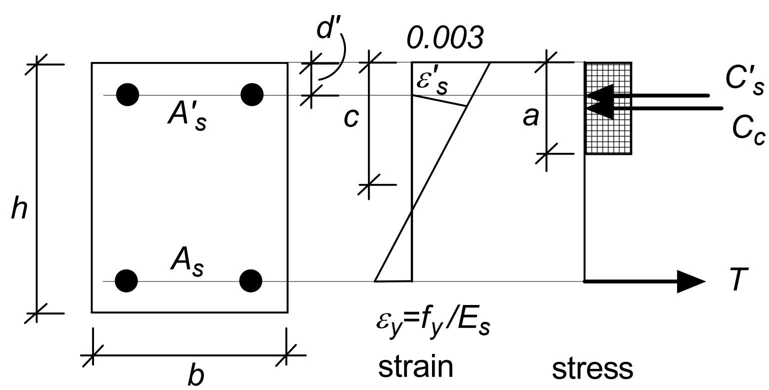
$$c_b = \left(\frac{0.003}{0.003+\varepsilon_y}\right)0.003$$

$$a_b = \beta_1 c_b$$

See Finding β_1 in point 3

$$C_c = 0.85 f'_c a_b b$$

$$\varepsilon'_s = \left(\frac{c_b - d'_s}{c_b}\right)0.003$$



$$f'_s = \min(\varepsilon'_s E_s, f_y)$$

$$C_s = A'_s\left(f'_s - 0.85 f'_c\right)$$

$$T = f_y A_s$$

$$P_b = C_c + C_s - T$$

$$M_b = C_c\left(\frac{h}{2}-\frac{a_b}{2}\right) + C_s\left(\frac{h}{2}-d'\right) + T\left(d-\frac{h}{2}\right)$$

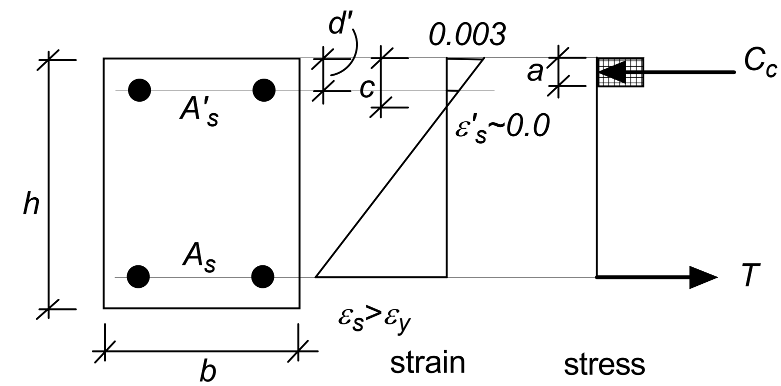
$$e_b = \frac{M_b}{P_b}$$

$$\phi M_n \ \& \ \phi P_n$$

See finding ϕ

STRUNET
CONCRETE DESIGN AIDS

Point 7: Moment Strength at Zero Axial Force



Finding Point 7

↓

$$C_c = 0.85 f'_c a b$$

↓

$$T = f_y A_s$$

↓

$$a = \frac{A_s f_y}{0.85 f'_c b}$$

↓

$$c = \frac{a}{\beta_1}$$

← See Finding β_1 in point 3

↓

$$\varepsilon_s = \left(\frac{0.003}{c}\right) d - 0.003 > \varepsilon_y$$

↓

$$C_c = 0.85 f'_c a_b b$$

↓

$$T = f_y A_s$$

↓

$$M_n = C_c \left(\frac{h}{2} - \frac{a}{2}\right) + T\left(d - \frac{h}{2}\right)$$

↓

$$\phi = 0.9$$

← See finding ϕ

↓

$$\phi M_n$$