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Project Title:	**Project Name**		Calc. By	Date	Rev.
			Author	today	0
Subject	**Reinforced Concrete Column Capacity - Axial Force Bending Moment Interaction (ACI318)**		Ckd. By	Date	
			Checker	today	

Input	Output
Column dimensions	Moment capacity
Reinforcement	Column interaction diagram
Materials (steel, concrete, bolts)	

RC Column Capacity - Axial Force - Bending Moment Interaction (ACI 318)

Axial force - bending moment interaction - ultimate limit state

Column dimensions

h =	10	in	
b =	18	in	
A_g = h * b =	180	in^2	RC Element Area

Reinforcement

cover	2.44	in	cover to the center of the bars
d =	7.56	in	depth of bottom reinforcement (h- cover)
d_c =	2.44	in	depth of top reinforcement (h- cover)

Tension side reinforcement

#	9		bar size
n =	3		no of bars
A_s =	3.00	in^2	area of tension reinforcement
$\rho_{tens.reinf}$ =	1.67	%	percentage of tension reinforcement

Compression side reinforcement

#	9		bar size
n =	3		no of bars
$A_{s.b}$ =	3.00	in^2	area of compression reinforcement
$\rho_{comp.reinf}$ =	1.67	%	percentage of compression reinforcement
$A_{s.t} = A_s + A_{s.b}$ =	6.00	in^2	total area of reinforcement
ρ =	3.33	%	element total percentage of reinforcement

per ACI 318
Section 10.9.1

Reinf percentage should be between 0.01Ag and 0.08Ag

Confinement reinforcement (tied or spiral)

tied

Materials

Concrete

f_c' =	4	ksi	concrete characteristic cylinder strength

Reinforcement type

	A 615		see reinforcement types here
Grade	60		
f_y =	60	ksi	reinforcement yield strength

References:
ACI318-05 - Building code requirements for structural concrete

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Reinforcement modulus of elasticity

E_s = 29000 ksi

per ACI 318
Section 8.5.2
Modulus of elasticity of reinforcement

Yield reinforcement strain:

f_y / E_s = 0.002

The relationship between concrete compressive stress and concrete strain is satisfied by an equivalent rectangular concrete stress distribution defined by a 0.85*f' uniform stress over an equivalent compression zone bounded by edges of the cross section and a straight line located parallel to the neutral axis at a distance a =β_1*c from the fiber of maximum compressive strain.

per ACI 318-05
Sections 10.2.6 and 10.2.7

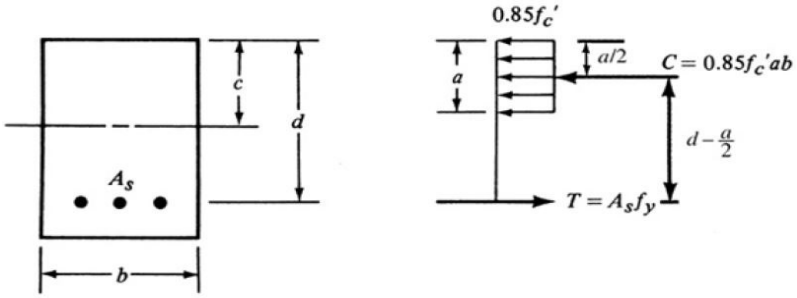
Section strength reduction factor

ϕ =	0.90	For tension controlled sections
	0.70	Compression controlled section with spiral reinforcement
	0.65	Compression controlled section other reinforced members

per ACI 318-05
Section 9.3
Values of ϕ strength reduction factor

Maximum usable strain at extreme concrete compression fiber is 0.003

per ACI 318-05
Section 10.2.3
Maximum usable strain at extreme concrete compression fiber shall be assumed equal to 0.003;
The relation between concrete compressive stress and concrete strain is assumed rectangular
Section 10.2.7.1
0.85f_c' value uniformly distributed over an equivalent compression zone bounded by edges of the cross section and a straigth line located parale to the neutral axis at a distance a = β_1*c from the fiber of max. compression strain



β_1 =	0.85	factor relating depth of equivalent rectangular compressive stress block to neutral axis depth	per ACI 318-05 Section 10.2.7.3 between 2500 and 4000 psi b1 = 0.85, above 4000 β_1 will be reduced lineary at a rate of 0.05 per 1000 psi but not lower than 0.65
a =	β_1 * c	depth of equivalent rectangular stress block	Section 10.2.7.1

Section 10.2.3
stress in reinforcement below f_y shall be taken as E_s times steel strain. For strains greater than that corresponding to fy, stress in reinforcement shall be considered independent of strain and equal to f_y.

References:
ACI318-05 - Building code requirements for structural concrete

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Point 1 - Pure compression

ϕ = 0.65 compression controlled section — Section strength reduction factor

$\phi P_{n,max}$ = 0.80 $\phi[0.85f_c'(A_g-A_{st})+f_yA_{st}]$ — per ACI 318 eq. 10-1 and 10-2

$\phi P_{n,max}$ = 494.83 kips — Maximum allowable value of the nominal axial strength of cross section multiplied by the strength reduction factor

Point 2 - $f_s = 0$

Concrete strain: 0.003 — Concrete has reached ultimate concrete design compressive shortening strain and $f_s = 0$

The neutral axis is located in the center of the bottom reinforcement

c = d = 7.56 in — Neutral axis location - in this case in the center of the bottom reinforcement

Top reinforcement strain (compression): 0.003 $*(c-d_c)/c=$ 0.0020

Yield reinforcement strain: 0.002 => Compression reinforcement has not reached yield

ϕ = 0.65 compression controlled section — Section strength reduction factor

a = $\beta_1 * c$ = 6.43 in — depth of equivalent rectangular stress block

$\phi P_n = \phi * [\ 0.85* f_c' * a * b + 0.002*Es* A_{s.b}]$

ϕP_n = 370.52 kips

$\phi M_n = \phi * [(0.85* f_c' * a * b) * (h/2 - a/2) + (0.002*Es* A_{s.b}) * (h/2 - d_c)]$

ϕM_n = 62.58 ft -kips

Point 3 - $f_s = 0.5 * f_y$

Concrete strain: 0.003 — Concrete has reached ultimate concrete design compressive shortening strain and $f_s = 0.5 * f_y$

Bottom reinforcement strain (tension): $\varepsilon_t = (0.5 * f_y) / E_s$ = 0.0010

c = 5.62 in — From the relation $[c / (d - c)] = 0.003 / \varepsilon_t$

Top reinforcement strain (compression): 0.003 $*(c-d_c)/c$ = 0.0017

Yield reinforcement strain: 0.002 => Compression reinforcement has not reached yield

ϕ = 0.65 compression controlled section — Section strength reduction factor

a = $\beta_1 * c$ = 4.78 in — depth of equivalent rectangular stress block

$\phi P_n = \phi * [\ 0.85* f_c' * a * b + 0.0017*Es* A_{s.b} - \varepsilon_t * E_s * A_s\ ]$

ϕP_n = 227.60 kips

$\phi M_n = \phi * [(0.85* f_c' * a * b) * (h/2 - a/2) + (0.0017*Es* A_{s.b}) * (h/2 - d_c) + \varepsilon_t * E_s * A_s * (d - h/2)]$

ϕM_n = 74.32 ft -kips

References:

ACI318-05 - Building code requirements for structural concrete

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Point 4 - $f_s = f_y$ (Balanced point) per ACI 318-05

Concrete strain: 0.003 Section 10.3.2

Concrete has reached ultimate concrete design

Bottom reinforcement strain (tension): $\varepsilon_t = f_y / E_s =$ 0.0021 compressive shortening strain and tension reinforcement reaches the strain corresponding to f_y ($f_s = f_y$)

$c =$ 4.47 in From the relation $[c / (d - c)] = 0.003 / \varepsilon_t$

Top reinforcement strain (compression): 0.003 $*(c-d_c)/c =$ 0.0014

Yield reinforcement strain: 0.002 => Compression reinforcement has not reached yield

$\phi =$ 0.65 compression controlled section Section strength reduction factor

$a = \beta_1 * c =$ 3.80 in depth of equivalent rectangular stress block

$\phi P_n = \phi * [0.85 * f_c' * a * b + 0.0014*Es* A_{s.b} - f_y * A_s]$

$\phi P_n =$ 111.42 kips

$\phi M_n = \phi * [(0.85 * f_c' * a * b) * (h/2 - a/2) + (0.0014*Es* A_{s.b}) * (h/2 - d_c) + f_y * A_s * (d - h/2)]$

$\phi M_n =$ 80.48 ft -kips

Point 4b - $f_s = f_y$ Transition from Compression controlled section to Tension Controlled per ACI 318-05

Concrete strain: 0.003 Section 9.3.2.2

For sections in which the net tensile strain at nominal strength ε_t is between the limits for compression controlled ans tension controlled sections f will be linearly increased from that for compression controlled to 0.9

Bottom reinforcement strain (tension): $\varepsilon_t = f_y / E_s =$ 0.0030

$c =$ 3.75 in From the relation $[c / (d - c)] = 0.003 / \varepsilon_t$

Top reinforcement strain (compression): 0.003 $*(c-d_c)/c =$ 0.0010

Yield reinforcement strain: 0.002 => Compression reinforcement has not reached yield

$\phi =$ 0.73 transition from compression controlled to tension controlled section Section strength reduction factor

$a = \beta_1 * c =$ 3.19 in depth of equivalent rectangular stress block

$\phi P_n = \phi * [0.85 * f_c' * a * b + 0.001*Es* A_{s.b} - f_y * A_s]$

$\phi P_n =$ 78.01 kips

$\phi M_n = \phi * [(0.85 * f_c' * a * b) * (h/2 - a/2) + (0.001*Es* A_{s.b}) * (h/2 - d_c) + f_y * A_s * (d - h/2)]$

$\phi M_n =$ 83.05 ft -kips

References:

ACI318-05 - Building code requirements for structural concrete

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Point 4c - $f_s = f_y$ Transition from Compression controlled section to Tension Controlled per ACI 318-05

Concrete strain: 0.003 Section 9.3.2.2

Concrete has reached ultimate concrete design compressive shortening strain and tension reinforcement is in transition from tension controlled to tensin controlled

Bottom reinforcement strain (tension): $\varepsilon_t = f_y / E_s =$ 0.0040

c = 3.23 in From the relation $[c / (d - c)] = 0.003 / \varepsilon_t$

Top reinforcement strain (compression): 0.003 $*(c-d_c)/c =$ 0.0007

Yield reinforcement strain: 0.002 => Compression reinforcement has not reached yield

ϕ = 0.82 transition from compression controlled to tension controlled section Section strength reduction factor

a = $\beta_1 * c =$ 2.74 in depth of equivalent rectangular stress block

$\phi P_n = \phi * [0.85 * f_c' * a * b + 0.0007*Es* A_{s.b} - f_y * A_s]$

ϕP_n = 42.30 kips

$\phi M_n = \phi * [(0.85 * f_c' * a * b) * (h/2 - a/2) + (0.0007*Es* A_{s.b}) * (h/2 - d_c) + f_y * A_s * (d - h/2)]$

ϕM_n = 83.95 ft -kips

Point 5 - ε_t = 0.005 - tension controlled section

Concrete strain: 0.003 Concrete has reached ultimate concrete design compressive shortening strain and et has reached 0.005

Bottom reinforcement strain (tension): $\varepsilon_t =$ 0.0050 corresponding to ϕ = 0.9 (tension controlled section)

c = 2.84 in From the relation $[c / (d - c)] = 0.003 / \varepsilon_t$

Top reinforcement strain (compression): 0.003 $*(c-d_c)/c =$ 0.0004

Yield reinforcement strain: 0.002 => Compression reinforcement has not reached yield

ϕ = 0.90 tension controlled section Section strength reduction factor

a = $\beta_1 * c =$ 2.41 in depth of equivalent rectangular stress block

$\phi P_n = \phi * [0.85 * f_c' * a * b + 0.0004*Es* A_{s.b} - f_y * A_s]$

ϕP_n = 3.46 kips

$\phi M_n = \phi * [(0.85 * f_c' * a * b) * (h/2 - a/2) + (0.0004*Es* A_{s.b}) * (h/2 - d_c) + f_y * A_s * (d - h/2)]$

ϕM_n = 83.52 ft -kips

References:
ACI318-05 - Building code requirements for structural concrete

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Point 6 - Pure Bending

Concrete strain: 0.003

Concrete has reached ultimate concrete design compressive shortening strain and et has reached 0.005 corresponding to $\phi = 0.9$ (tension controlled section)

Bottom reinforcement strain (tension): $\varepsilon_t =$ 0.0055

c = 2.67 in

From the relation $[c / (d - c)] = 0.003 / \varepsilon_t$

Top reinforcement strain (compression): 0.003 $*(c-d_c)/c =$ 0.0003

Yield reinforcement strain: 0.002 => Compression reinforcement has not reached yield

$\phi =$ 0.90 tension controlled section — Section strength reduction factor

$a = \beta_1 * c =$ 2.27 in — depth of equivalent rectangular stress block

$\phi P_n = \phi * [\, 0.85 * f_c' * a * b + 0.0003 * Es * A_{s.b} - f_y * A_s \,]$

$\phi P_n =$ -16.99 kips

$\phi M_n = \phi * [(0.85 * f_c' * a * b) * (h/2 - a/2) + (0.0003 * Es * A_{s.b}) * (h/2 - d_c) + f_y * A_s * (d - h/2)]$

$\phi M_n =$ 79.09 ft -kips

Point 7 - Maximum tension

$\phi =$ 0.90 tension controlled section — Section strength reduction factor

$\phi P_n = = - \phi * f_y * [A_{s.b} + A_s]$

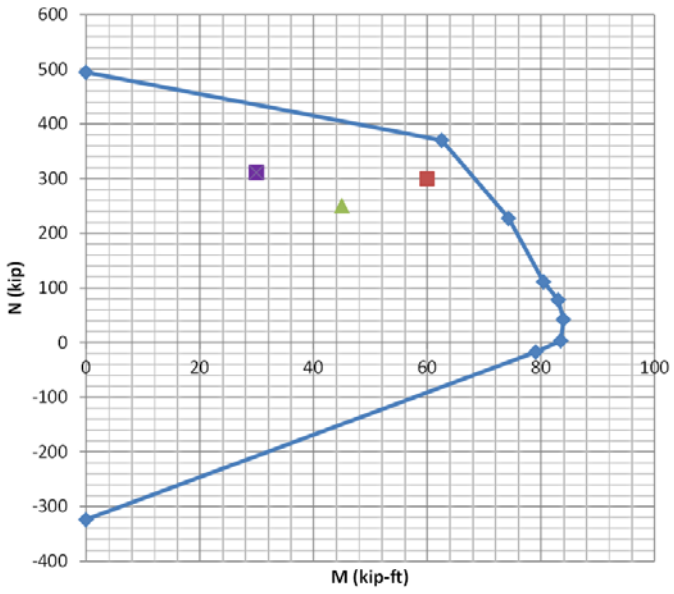
$\phi P_n =$ -324.00 kips

$\phi M_n =$ 0.00 ft -kips

Data for the M-N interaction graph:

	N_{cap}	M_{cap}
Point 1	494.83	0.00
Point 2	370.52	62.58
Point 3	227.60	74.32
Point 4	111.42	80.48
Point 4b	78.01	83.05
Point 4c	42.30	83.95
Point 5	3.46	83.52
Point 6	-16.99	79.09
Point 7	-324.00	0.00

	N_{eff}	M_{eff}
CO1	300.0	60
CO2	250.0	45
CO3	311.0	30



References:
ACI318-05 - Building code requirements for structural concrete