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Kippap-Handout-SEC (38 RCD - Columns)

BS Civil Engineering (University of Manila)

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DESIGN OF REINFORCED CONCRETE COLUMNS USING NSCP 2015

410.6. REINFORCEMENT LIMITS

410.6.1.1. For non-prestressed columns and for pre-stressed columns with average $f_{pc} < 1.6$ MPa, area of longitudinal reinforcement shall be **at least $0.01A_g$ but shall not exceed $0.08A_g$**.

Minimum Concrete Cover

420.6.1.3. Specified concrete cover to primary reinforcement, stirrups, ties, spirals, and hoops for columns shall be **at least 40 mm**.

Minimum Reinforcement Spacing

425.2.3. For longitudinal reinforcement in columns, pedestals, struts, and boundary elements in walls, clear spacing between bars shall be **at least the greatest of:**

a) 40 mm;
b) $1.5d_b$;
c) 4/3 Maximum Agreggate Size (M.A.S.)

Minimum Number of Longitudinal Reinforcement

410.7.3.1. For non-prestressed columns and for prestressed columns with average $f_{pc} < 1..60$ MPa, the minimum number of longitudinal bars shall be (a), (b), or (c):

a) Three within triangular ties;
b) Four within rectangular or circular ties;
c) Six enclosed by spirals or for columns of special moment frames enclosed by circular hoops

AXIAL STRENGTH

422.4.2.1. The nominal axial strength, P_n, for non-prestressed columns is given by:

a) For tied columns: $\boldsymbol{P_n = 0.80P_0}$
b) For spiral columns: $\boldsymbol{P_n = 0.85P_0}$

422.4.2.2. The maximum available axial strength, P_0, for non-prestressed members and composite steel and concrete members is given by:

$$\boldsymbol{P_0 = 0.85f'_c(A_g - A_{st}) + f_yA_{st}}$$

STRENGTH REDUCTION FACTOR

For non-prestressed members under axial compression only, the strength reduction factors are given by:

a) For tied columns: $\boldsymbol{\phi = 0.65}$
b) For spiral columns: $\boldsymbol{\phi = 0.75}$

SOME NOTES:

1. P_0 is the maximum available axial strength, which is attained when both the concrete and steel reach full plastic state.

2. The nominal axial strength, P_n, which is equal to 80 to 85 percent of P_0, is also called the maximum usable axial strength.

425.7.2. TIES

425.7.2.1. Ties shall consist of a closed loop of deformed bar or deformed wire with spacing in accordance with (a) and (b):

a) Clear spacing of at least $\boldsymbol{4/3\ d_{agg}}$.
b) Center-to-center spacing shall not exceed **the least of $\boldsymbol{16d_b}$ of longitudinal bar, $\boldsymbol{48d_b}$ of tie bar, and smallest dimension of member**.

425.7.2.2. Diameter of tie bar or wire shall be at least (a) or (b):

a) 10-mm ϕ enclosing 32-mm ϕ or smaller longitudinal bars
b) 12-mm ϕ enclosing 36-mm ϕ or larger longitudinal bars

425.7.3. SPIRALS

425.7.3.1. Spirals shall consist of evenly spaced continuous bar or wire with clear spacing conforming to (a) and (b):

a) At least the greater of **25 mm** and $\boldsymbol{4/3\ d_{agg}}$.
b) Not greater than **75 mm**

425.7.3.2. For cast-in-place construction, spiral bar or wire diameter shall be at least **10 mm**.

425.7.3.3. Volumetric spiral reinforcement ratio, ρ_s, shall satisfy:

$$\boldsymbol{\rho_s \geq 0.45\left(\frac{A_g}{A_{ch}} - 1\right)\cdot\frac{f'_c}{f_{yt}}}$$

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The actual volumetric spiral ratio can be calculated as follows:

$$\rho_s = \frac{4a_s(D_c - d_s)}{sD_c^2}$$

Where:

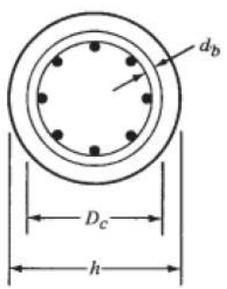
A_{ch} - area of the concrete core, measured out-to-out of spiral

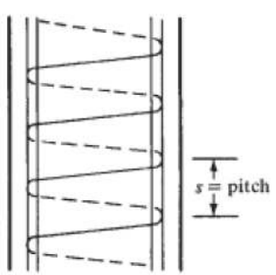
D_c – diameter of concrete core

a_s – cross-sectional area of spiral bar

d_s – diameter of spiral bar

s – pitch distance of spiral





UNSYMMETRICAL COLUMNS

⇒ All eccentricities for columns must be measured from the location of the *plastic centroid*

Plastic Centroid

The plastic centroid is the location of the resultant force produced by the steel and concrete. When the load is applied through this point, the entire section is subjected under uniform strain.

For symmetric columns, the plastic centroid coincides with the geometric centroid of the gross section.

To locate the plastic centroid:

$$\overline{x} = \frac{0.85f'_cA_g \cdot x_c + (f_y - 0.85f'_c) \cdot A_{st} \cdot x_s}{0.85f'_cA_g + (f_y - 0.85f'_c) \cdot A_{st}}$$

Or:

$$\overline{x} = \frac{0.85f'_cA_g \cdot x_c + (f_y - 0.85f'_c) \cdot A_{st} \cdot x_s}{P_0}$$

Where:

x_c – location of the centroid of the gross concrete section

x_s – location of the centroid of the steel reinforcement

PRACTICE PROBLEMS

Problem 1. A reinforced concrete tied column carries an axial dead load of 600 kN and an axial live load of 750 kN. Suppose that the steel ratio is not to exceed 3%. If $f_c = 24$ MPa and $f_y = 420$ MPa, determine:

1. The dimension required for the column, in mm, considering a square cross-section. ***[350 x 350]***
2. The number of 20-mm ϕ bars to be used as longitudinal reinforcement. ***[12]***
3. The spacing required for the 10-mm ϕ lateral reinforcement. ***[300]***

Problem 2. A circular spiral column is to support an axial dead load of 1000 kN and an axial live load of 1350 kN. Assume that the longitudinal steel is limited at 2%. $f'_c = 28$ MPa, $f_y = 420$ MPa, and $f_{yh} = 275$ MPa.

1. What is the required diameter of the column, in mm? ***[475]***
2. How many 25-mm ϕ longitudinal bars are needed? ***[8]***
3. What is the required pitch, s, of the 10-mm spirals? ***[30]***

Problem 3. The corner column shown in Fig. RCD-01 is supported by 12 25-mm ϕ longitudinal bars. Suppose that $f'_c = 24$ MPa and $f_y = 420$ MPa.

1. What is the location of the plastic centroid measured from the x-axis? ***[246.114]***
2. What is the location of the plastic centroid measured from the y-axis? ***[201.979]***
3. What is the moment induced by a factored load of 2000 kN applied at a point 150 mm from the y-axis and 250 mm from the x-axis? ***[214.886]***

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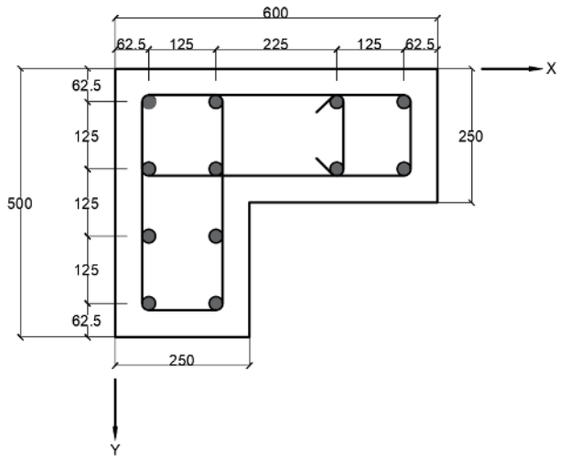


Fig. RCD-01

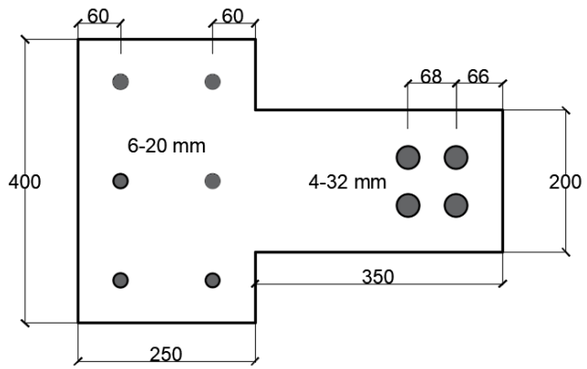


Fig. RCD-02

Problem 4. The cross-section of a column is shown in Fig. RCD-02. It is to be reinforced by six 20-mm ϕ bars at the left side and four 32-mm ϕ bars at the right side. Suppose that $f_c' =$ 21 MPa and $f_y = 420$ MPa.

1. What is the location of the geometric centroid of the gross concrete area, measured from the leftmost face? ***[248.529]***
2. What is the location of the plastic centroid measured from the leftmost face? Neglect the effects of displaced concrete? ***[295.267]***
3. What is the moment induced by a 2500 kN load applied at a point 100 mm to the left of the geometric centroid? ***[366.844]***

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SOLUTIONS TO PRACTICE PROBLEMS:

Problem 1.

$P_u = 1.2(600) + 1.6(750) = 1920$ kN

$P_u = \phi[0.80P_0]$

$1920 = 0.65(0.80P_0)$

$P_0 = 3692.308$ kN

$P_0 = A_g\left[0.85f_c' + \rho_g\left(f_y - 0.85f_c'\right)\right]$

$3692.308 \cdot 1000 = A_g\left[0.85(24) + (0.03)\left(420 - 0.85(24)\right)\right]$

$A_g = 114{,}002.337$ mm^2

Calculating the required column dimension,

$A_g = b^2$

$114{,}002.337 = b^2$

$b = 337.642$ mm, say, $b = 350$ mm

∴ Use 350 mm x 350 mm column. Ans. #1

$A_{st} = \rho_g A_{st} = 0.03(350)^2$

$A_{st} = 3675$ mm^2

$n = \dfrac{A_{st}}{A_b} = \dfrac{3675}{\frac{\pi}{4}(20^2)}$

$n = 11.698$, say, 12 bars

∴ Use 12 20 − mm ϕ longitudinal bars (4 each face). Ans. #2

Calculating the spacing of ties,

$$s \leq \begin{cases} 16d_b = 16(20) = 320 \text{ mm} \\ 48d_s = 48(10) = 480 \text{ mm} \\ \text{least dimension} = 350 \text{ mm} \end{cases}$$

We take $s = 320$ mm, or, say $s = 300$ mm

∴ Use 10 − mm ϕ ties @ 300 mm o. c. spacing. Ans. #3

Problem 2.

$P_u = 1.2(1000) + 1.6(1350) = 3360$ kN

$P_u = \phi[0.85P_0]$

$3360 = 0.75(0.85P_0)$

$P_0 = 5270.588$ kN

$P_0 = A_g\left[0.85f_c' + \rho_g\left(f_y - 0.85f_c'\right)\right]$

$5270.588 \cdot 1000 = A_g\left[0.85(28) + (0.02)\left(420 - 0.85(28)\right)\right]$

$A_g = 166{,}138.830$ mm^2

Calculating the required dimension of the column,

$A_g = \dfrac{\pi}{4}D^2$

$166{,}138.530 \text{ mm}^2 = \dfrac{\pi}{4}D^2$

$D = 459.929$ mm, say, $D = 475$ mm

∴ Use 475 − mm ϕ circular spiral column. Ans. #1

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$A_{st} = \rho_g A_g = 0.02\left(\frac{\pi}{4}\right)(475^2) = 3544.109 \text{ mm}^2$

$n = \frac{A_{st}}{A_b} = \frac{3544.109}{\frac{\pi}{4}(25^2)}$

$n = 7.22, \quad \text{say, } 8 \text{ bars}$

$\therefore$ Use 8 25 − mm ϕ longitudinal bars. Ans. #2

Calculating the required pitch of the spirals,

$A_g = \frac{\pi}{4}(475^2) = 177{,}205.461 \text{ mm}^2$

$D_c = D - 2C_c = 475 - 2(40) = 395 \text{ mm}$

$A_{ch} = \frac{\pi}{4}D_c^2 = \frac{\pi}{4}(395^2) = 122{,}541.748 \text{ mm}^2$

$a_s = \frac{\pi}{4}d_s^2 = \frac{\pi}{4}(10^2) = 78.540 \text{ mm}^2$

$\rho_s = \frac{4a_s(D_c - d_s)}{sD_c^2} \geq 0.45\left(\frac{A_g}{A_{ch}} - 1\right)\cdot\frac{f_c'}{f_{yt}}$

$\frac{4(78.540)(395-10)}{s(395^2)} = 0.45\left(\frac{177205.461}{122541.748} - 1\right)\cdot\frac{28}{275}$

$s = 37.928 \text{ mm}, \quad \text{say, } s = 30 \text{ mm}$

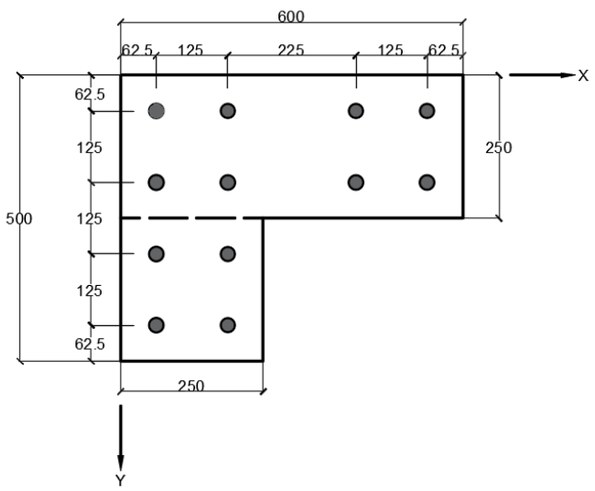
$s_{\min} = 25 \text{ mm} < s = 30 \text{ mm} < s_{\max} = 75 \text{ mm} \qquad \therefore \text{ OK!}$

$\therefore$ Use a pitch distance of 30 mm for the 10 − mm ϕ spirals. Ans. #3

Problem 3.

For locating the plastic centroid, we can use the STAT Mode of the calculator for more convenient calculation.

Initially, we try to decompose the figure into simpler component figures.



Note: Before toggling the STAT Mode of the calculator, make sure that Frequency is switched on. To do this on Canon F-789SGA, just toggle **SHIFT – MODE (Set-up) – Down Arrow – 4 (STAT) – 1 (Frequency ON)**

Now, to toggle the Linear STAT Mode, just press **Mode – 3 (STAT) – 2 (LIN)**

For the entries, we set regions 1 and 2 to be the divisions of the gross concrete area. Regions 3 to 6, meanwhile, represent the 4 rows of bars.

	X	Y	Freq
1	300	125	$0.85(24)(600)(250)$
2	125	375	$0.85(24)(250)(250)$
3	300	62.5	$[420 - 0.85(24)](4)\left(\frac{\pi}{4}\right)(25^2)$

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4	300	187.5	$[420-0.85(24)](4)\left(\frac{\pi}{4}\right)(25^2)$
5	125	312.5	$[420-0.85(24)](2)\left(\frac{\pi}{4}\right)(25^2)$
6	125	437.5	$[420-0.85(24)](2)\left(\frac{\pi}{4}\right)(25^2)$

Now, solving for the location of the plastic centroid,

[**SHIFT – APPS – 5 (S-VAR) – 2**]

$\bar{x} = 246.114$ mm Ans. #2

[**SHIFT – APPS – 5 (S-VAR) – 5**]

$\bar{y} = 201.979$ mm Ans. #1

Calculating the moment induced by the eccentric load,

$e = \sqrt{(246.114-150)^2 + (250-201.979)^2} = 107.443$ mm

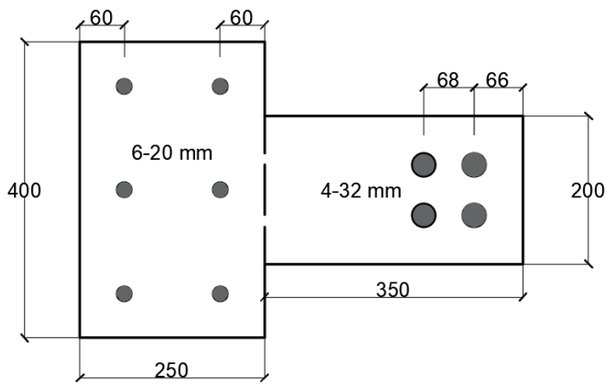
$M = Pe = 2000(107.443) \div 1000$

$M = 214.886$ kN · m Ans. #3

Problem 4.

For this problem, we take note that the reinforcements are placed symmetrically with respect to the vertical. Hence, single-variable statistics will suffice here.

Decomposing the figure first,



Now, to toggle single-variable statistics, press **MODE – 3 (STAT) – 1 (SD)**

We set Region 1 to be the 400 x 250 rectangle, Region 2 to be 350 x 200, while Regions 3 to 6 are the columns of bars from left to right.

Plugging in all corresponding values to locate the centroid of the gross concrete first,

	X	Freq
1	125	(400)(250)
2	425	(350)(200)

[**SHIFT – APPS – 5 (S-VAR) – 2**]

$\bar{x} = 248.529$ mm Ans. #1

Now, modifying the entries to include the steel reinforcements,

	X	Freq
1	125	(0.85)(21)(400)(250)
2	425	(0.85)(21)(350)(200)

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3	60	$(420)(3)\left(\frac{\pi}{4}\right)(20^2)$
4	190	$(420)(3)\left(\frac{\pi}{4}\right)(20^2)$
5	466	$(420)(2)\left(\frac{\pi}{4}\right)(32^2)$
6	534	$(420)(2)\left(\frac{\pi}{4}\right)(32^2)$

Locating the plastic centroid,

$\overline{x_p} = 295.267$ mm Ans. #2

Solving for the induced moment,

$M = Pe$

$M = 2500\big(295.267 - (248.529 - 100)\big) \div 1000$

$M = 366.844\ \text{kN} \cdot \text{m}$ Ans. #3

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