**Banha University**
**Faculty of Engineering - Shoubra**
**Civil Engineering Department**

# REINFORCED CONCRETE 1 - A

## For 2nd Year Civil – 1st Term

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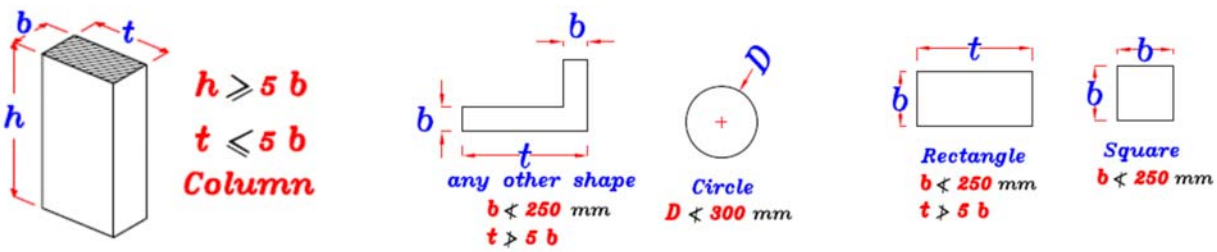
## Lectures (9,10&11)

# Chapter (6) Design of Sections Under Normal Forces- Part1

## 1- Introduction and Definitions

1- Columns are vertical members under axial compression loads with or without bending moments. The dimensions of column should satisfy the shown conditions:

**(For Short Column: $b \geq$ Max. (250mm,h/15)for rectangular; $D \geq$ Max. (300mm,h/12 for circular)**




2- According to **<u>eccentricity (e) of compression force</u>** (P), types of columns are (**e = M /P**):

a- Pure axial compression **e = 0**

b- Minimum eccentric compression **$e = e_{min}$** = Max. (0.05 t, 20 mm)

c- Small eccentric compression ($P_u$ Compression) , ( **$e / t \leq 0.5$** );

d- Big eccentric compression ($P_u$ Compression) , ( **$e / t > 0.5$** )

3- $\gamma_c$ **= 1.50 [(7/6) - (e/t) / 3] ≥ 1.50** $\gamma_s$**= 1.15 [(7/6) - (e/t) / 3] ≥ 1.15**

## 2- Code Provisions of Longitudinal Steel in Columns

Longitudinal steel ratio **μ =(area of longitudinal steel / area of concrete section) = $A_{sc} / A_c$**

1- Minimum steel ratio is: For tied column $A_{smin} = 0.008\ A_c$ or $0.006\ A_{given}$ (if $A_{given} > A_{creq.}$)

For spiral column $A_{smin} = 0.01\ A_c$ or $0.012\ A_k$

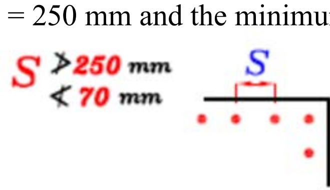
2- Maximum steel ratio $\mu_{max}$ = 4% for interior column, = 5% for edge column, =6% for corner column.

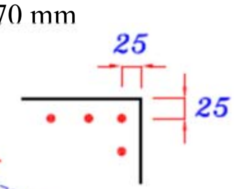
3- Minimum and maximum diameter of longitudinal bars **$\Phi_{min}$ = 12 mm, $\Phi_{max}$ = 25 mm**

**يجب اختيار اسياخ الحديد من قطر واحد او قطرين متتاليين في الجدول**

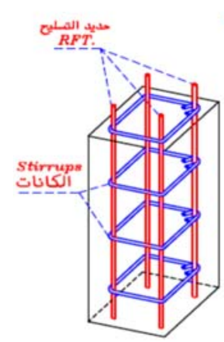
4- Min. no. of bars = 4 for R-section, = 6 for circular section

5- The maximum spacing (S) of vertical bars = 250 mm and the minimum spacing = 70 mm
The minimum concrete cover = 25 mm




## 3- Code Provisions of Confining steel (Stirrups & Spirals)




1- Minimum diameter of stirrups or spiral $\Phi_{S\ min}$ = 8 mm

2- Maximum & minimum spacing of stirrups $S_{max}$ = 200, $S_{min}$ = 100 mm

3- The range of pitch of spiral p = 30 – 80 mm

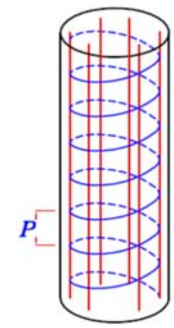
4- Volumetric ratio of stirrups $\mu_{st} = (A_{st}\, p_{st} / A_c S) \geq 0.0025$

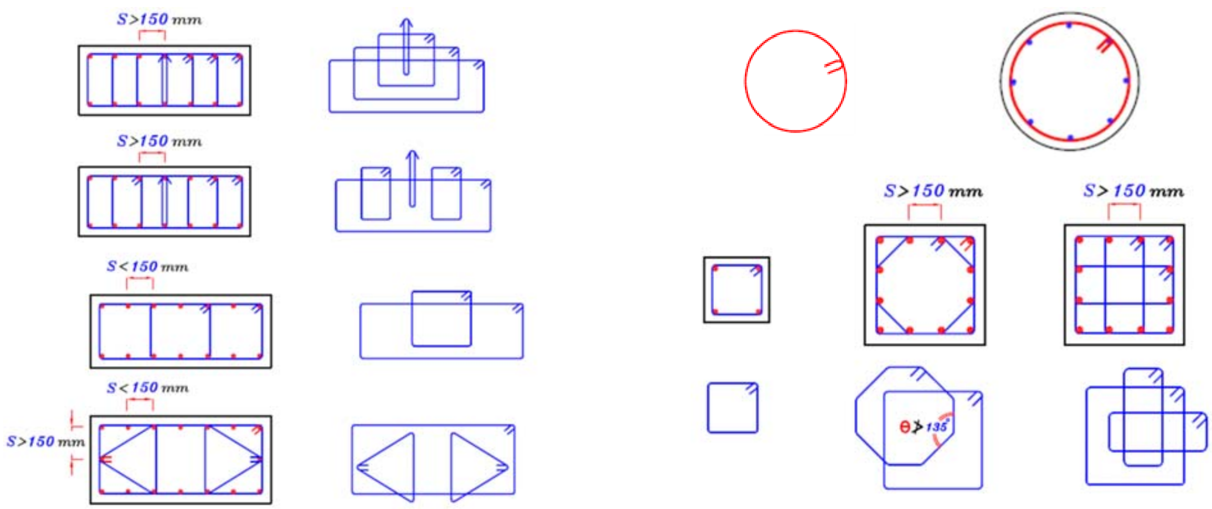
$p_{st}$ = perimeter of stirrup = sum of lengths of exterior & interior stirrups

5- Volumetric ratio of spiral $\mu_{sp} = V_{sp} / A_k \geq 0.36\, (f_{cu} / f_{yp})\, [A_c/A_k - 1]$

$V_{sp}$ = Volume of spiral = $A_{sp}\, P_{sp} / p = \Pi\, A_{sp}\, D_k / p$

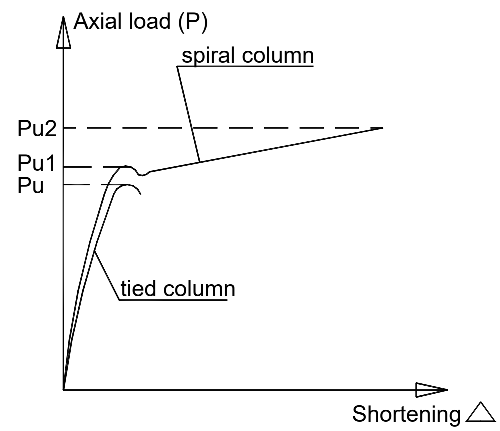
**6-** $S \leq 150$ mm for (untied-tied bars), $\leq 250$ mm for (tied-tied bars)




## 4- Design of Column Section Under Compression with $e < e_{min}$

### (A) Observed Behavior of Axially Loaded Columns




$P_u$ = Ultimate compression load at which tied column fails

$P_{u1}$= Ultimate compression load at which outer concrete shell spalls (spiral column)

$P_{u2}$= Ultimate compression load at which spiral breaks (spiral column)

Compared to tied column, spiral column has higher strength and ductility.

### (B) Design and Analysis of Tied Columns:

$$P_u = 0.35\, f_{cu}\, (A_c - A_{sc}) + 0.67\, f_y\, A_{sc} \quad (1)$$

$P_u = A_c\,[0.35\,f_{cu}\,(1 - \mu) + 0.67\,f_y\,\mu]$ (2)

$f_y$ = yield stress of longitudinal steel

$\mu$ = longitudinal steel ratio = $A_{sc} / A_g$

* Use Equation (1) for analysis, and Equation (2) for design of tied column.

**(B) Design & Analysis of Spiral Columns:**

$P_{u1} = 1.14\,[0.35\,f_{cu}\,(A_c - A_{sc}) + 0.67\,f_y\,A_{sc}]$ (3)

$P_{u1} = A_c\,[0.4\,f_{cu}\,(1 - \mu) + 0.76\,f_y\,\mu]$ (4)

$P_{u2} = 0.35\,f_{cu}\,(A_k - A_{sc}) + 0.67\,f_y\,A_{sc} + 1.38\,V_{sp}\,f_{yp}$ (5)

$P_{u2} = A_k\,[0.35\,f_{cu}\,(1 - \mu) + 0.67\,f_y\,\mu\,A_c/A_k + 1.38\,f_{yp}\,\mu_{sp}]$ (6)

$f_{yp}$ = Yield stress of spirals

$V_{sp}$ = Volume of spiral = $A_{sp}\,P_{sp} / p = \Pi\,A_{sp}\,D_k / p$

$\mu_{sp}$ = Volumetric ratio of spirals = $V_{sp} / A_k$

$A_{sp}$ = Area of spiral = $\Pi\,\Phi_{sp}^2 / 4$

$P_{sp}$ = Perimeter of spiral = $\Pi\,D_k$

$P_u$ = Ultimate compression load for spiral column = Min. $(P_{u1}, P_{u2})$

* Use Equations (3) &(5) for analysis, and Equations (4)&(6) for design of spiral column.

## 5- Design Steps for Column Sections Under Eccentric Compression

### (A) Check for cases of very large eccentricity & minimum eccentricity

1- Calculate the eccentricity ratio $e / t = M_u / (P_u * t)$ and $K = N_u / (f_{cu} * b * t)$

2- If $K \leq 0.04$, Neglect $N_u$ and design the steel of section on $M_u$ only (as Beams) using flexural charts for double reinforced sections (Take $A_s' > 0.2\,A_s$)

3- If $(e / t) \leq 0.05$, neglect $M_u$ and design the steel of the section according to Section 5-4 (Minimum eccentricity case)

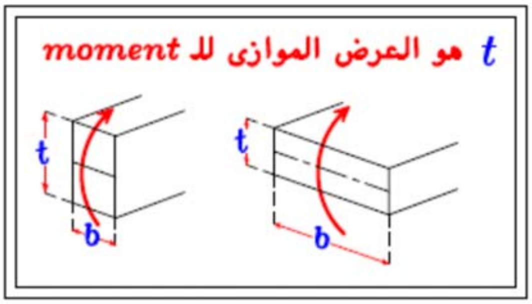
### (B) Interaction Diagrams for small eccentric compression $(e / t) < 0.5$

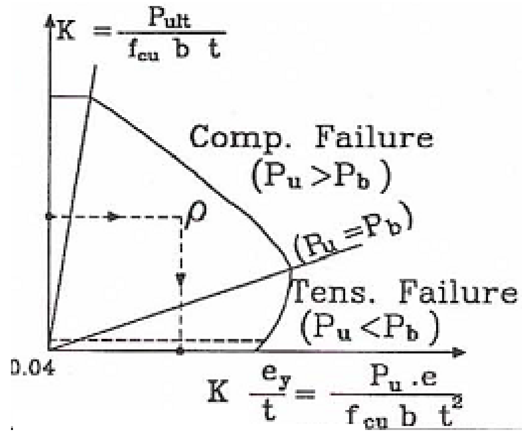
1- Determine the page and curve of suitable interaction diagram according to:

- شكل القطاع (دائري – مستطيل – مربع)
- وضع الحديد(منتظم التوزيع Uniform steel – علي الوجهين Top and bottom steel)
- اجهاد الخضوع للحديد الطولى $f_y$ (240 , 280, 360 and 400 MPa)

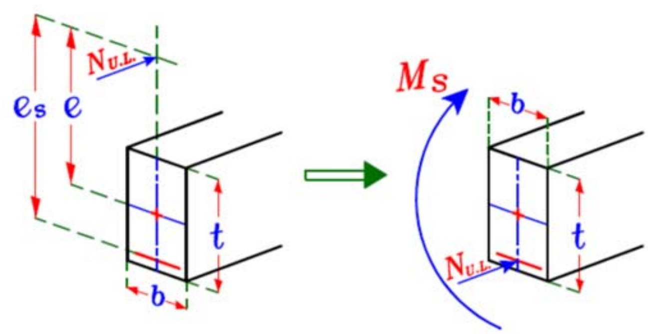
- النسبة ( ξ ) حيث { $\xi = (t - 2^* d`) / t$ } ($\xi$ = 0.7,0.8, and 0.9)
- في حالة الحديد علي الوجهين حسب النسبة $\alpha$ ($\alpha = A_{s`} / A_s$ = 0.8 and 1.0)

2- For analysis problems, use known values (e/t ; $\mu$, $\rho$) to calculate $P_u$. For design problems, use known values {K, K*(e/t)} to calculate ($\mu$, $\rho$).




**(C) MS Method for large eccentric compression (e/t) > 0.5**




$e_s = e + t/2 - d`$ = ----- mm > e

$M_{us} = P_u * e_s / 1000$ = -------- kN.m > $M_u$

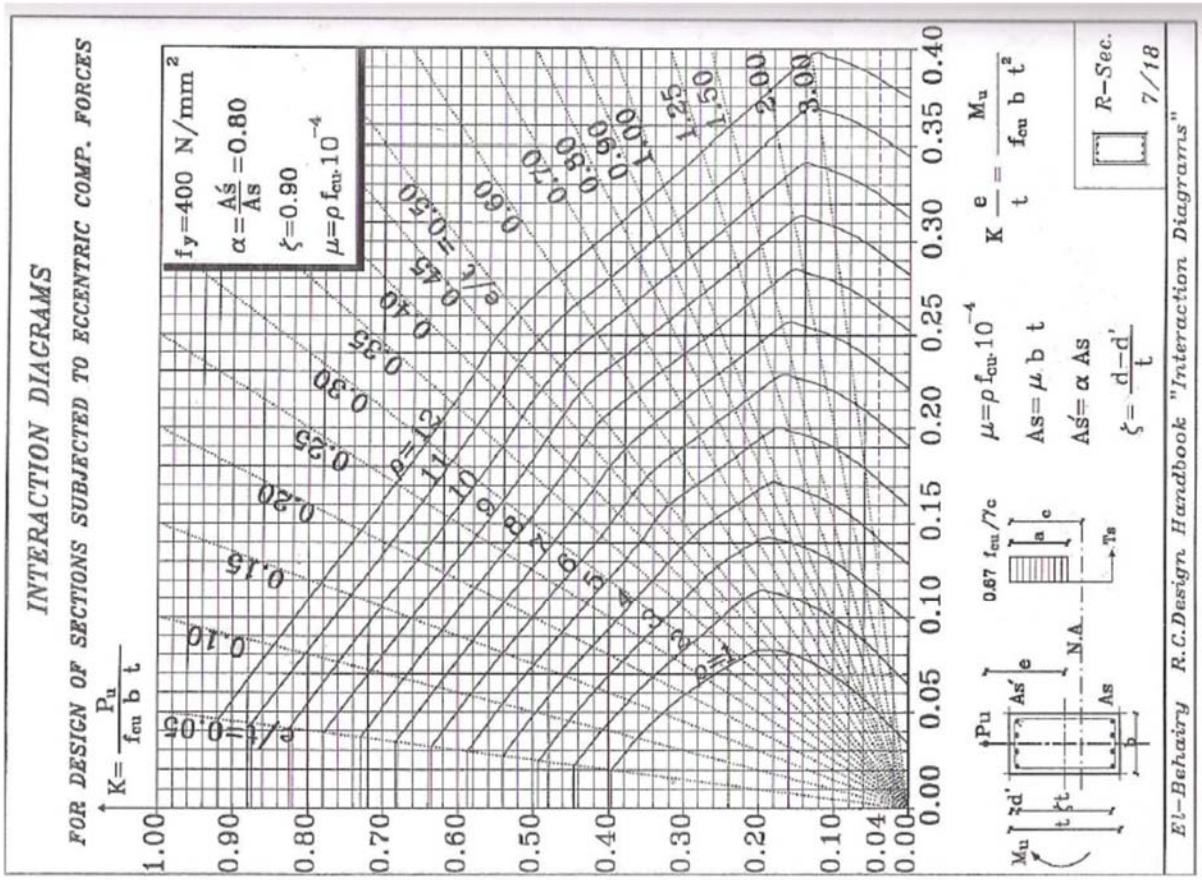
Get $A_{s1}$ ( = $\mu * b * d$ ) from flexural charts of double reinforced sections using $M_{su}\ 10^6 / (b*d^2)$ , $f_{cu}$ , $f_y$

Get $A_{s2}$ from $P_u * 10^3 / (f_y / \gamma_s)$ take $\gamma_s = 1.15$

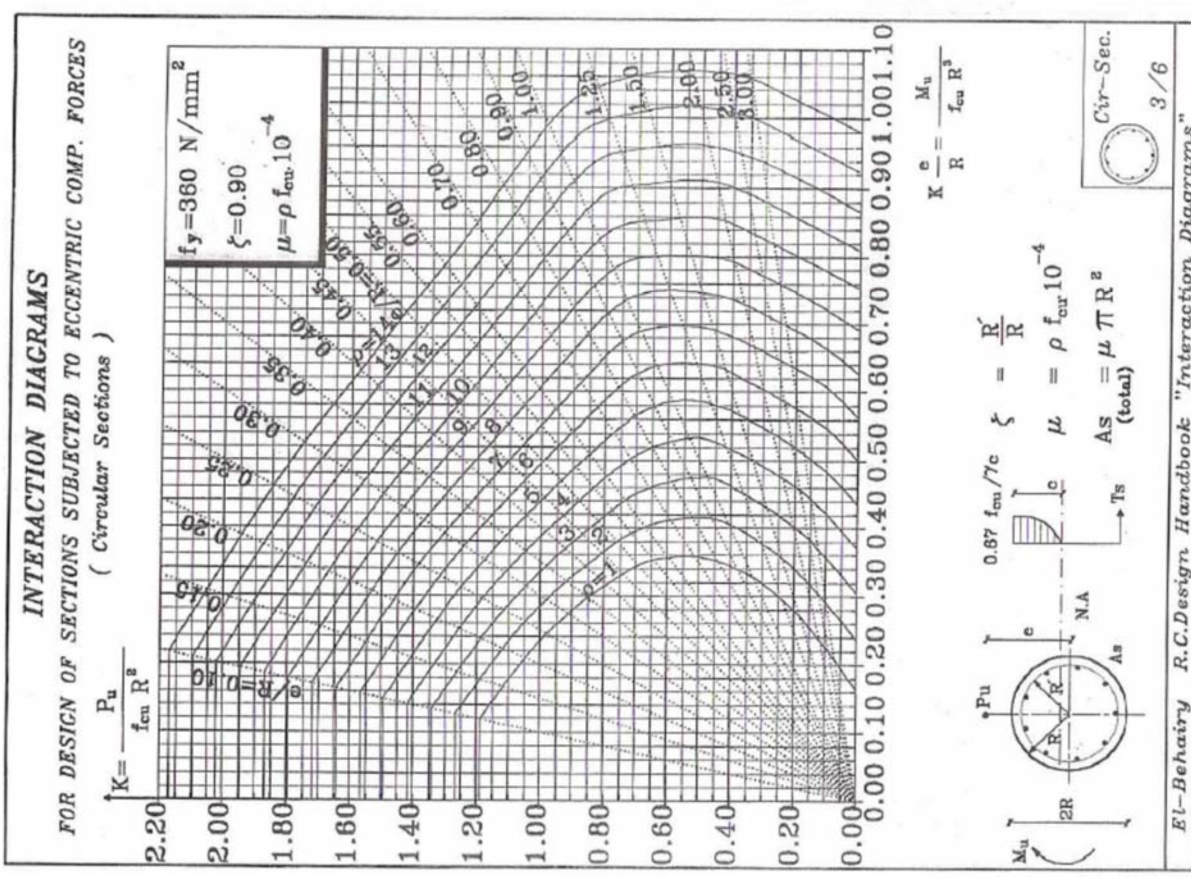
$A_{s\ final} = A_{s1} - A_{s2}$ = --------- mm$^2$ $\geq A_{s\ min}$

Where $A_{s\ min} = \mu_{min} * b * d$ $\mu_{min} = 1.1 / f_y$ (MPa)

$A_s' = 0.4\ A_s$



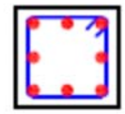
INTERACTION DIAGRAMS
FOR DESIGN OF SECTIONS SUBJECTED TO ECCENTRIC COMP. FORCES
$K=\frac{P_u}{f_{cu}\, b\, t}$
$f_y$=400 N/mm²
$\alpha=\frac{A's}{As}=0.80$
$\zeta$=0.90
$\mu=\rho\, f_{cu} \cdot 10^{-4}$
e/t=0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
e/t=0.45
0.50
0.60
0.70
0.80
0.90
1.00
1.25
1.50
2.00
3.00
ρ=1
2
3
4
5
6
7
8
9
10
11
ρ=12
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.04
0.00
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40
$K\frac{e}{t}=\frac{M_u}{f_{cu}\, b\, t^2}$
0.67 $f_{cu}/\gamma_c$
Pu
Mu
As'
As
N.A
Ts
$\mu=\rho\, f_{cu} \cdot 10^{-4}$
As= $\mu$ b t
As'= $\alpha$ As
$\zeta=\frac{d-d'}{t}$
R–Sec.
7/18
El–Behairy R.C.Design Handbook "Interaction Diagrams"

INTERACTION DIAGRAMS
FOR DESIGN OF SECTIONS SUBJECTED TO ECCENTRIC COMP. FORCES
( Circular Sections )
$K=\frac{P_u}{f_{cu}\, R^2}$
$f_y$=360 N/mm²
$\zeta$=0.90
$\mu=\rho\, f_{cu} \cdot 10^{-4}$
e/R=0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
e/R=0.50
0.55
0.60
0.70
0.80
0.90
1.00
1.25
1.50
2.00
2.50
3.00
ρ=1
2
3
4
5
6
7
8
9
10
11
12
ρ=13
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00 1.10
$K\frac{e}{R}=\frac{M_u}{f_{cu}\, R^3}$
0.67 $f_{cu}/\gamma_c$
Pu
Mu
2R
R
R'
As
N.A
Ts
$\zeta = \frac{R'}{R}$
$\mu = \rho\, f_{cu} \cdot 10^{-4}$
$As_{(total)} = \mu\, \pi\, R^2$
Cir–Sec.
3/6
El–Behairy R.C.Design Handbook "Interaction Diagrams"

## 6- Design Steps for Sections Under Axial and Eccentric Tension

### (A) Design of Tie Member Under Axial Tension ($T_u$ , $M_u$ = 0.0)

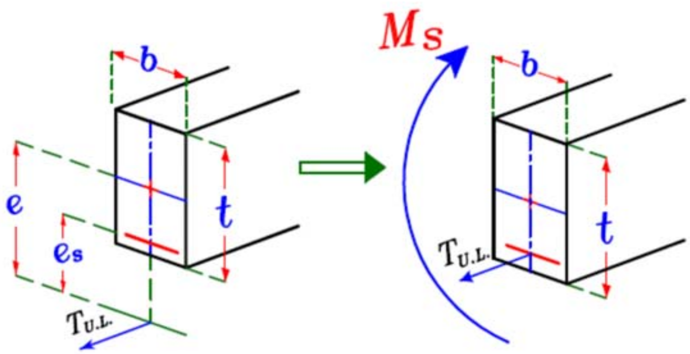


1- $A_s = T_u / (f_y/\gamma_s)$

2- Concrete area of section $A_c = 20 - 40\ A_s$

3- Use square section such as (250*250 ) , (300*300 ) , (400*400 ) mm.

### (B) MS Method for large eccentric tension (e/t) > 0.5




$e_s = e - t/2 + d` =$ -------mm < e

$M_{us} = P_u * e_s / 1000 =$ ------- kN.m < $M_u$

Get $A_{s1}$ ( = $\mu * b * d$ ) from flexural charts using $M_{su}\ 10^6 / (b*d^2)$ , $f_{cu}$ , $f_y$

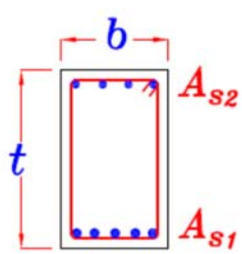
Get $A_{s2}$ from $P_u * 10^3 / (f_y / \gamma_s)$ ($\gamma_s = 1.15$)

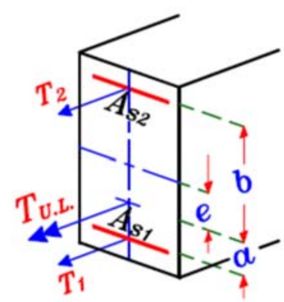
$A_{s\ final} = A_{s1} + A_{s2} =$ ------ $mm^2$

$\mu = A_{s\ total} / bd \leq \mu_{max\ R} + \mu`$

Where $\mu` = A_s` / b\ d$ $\mu_{max\ R} =$ ---- $f_{cu}$ (from the design book)

### (C) Design of tie member small eccentric compression (e / t) < 0.5




| | | |
|---|---|---|
| 1- $a = t/2 - d` - e$ | $b = e + t/2 - d`$ | $b > a$ |
| 2- $T_1 = (T * a_2) / (a_1 + a_2)$ | $T_2 = (T * a_1) / (a_1 + a_2)$ | $T_1 > T_2$ |
| 3- $A_{s1} = T_1 / (f_y / \gamma_s)$ | $A_{s2} = T_2 / (f_y / \gamma_s)$ | $A_{s1} > A_{s2}$ |

# Design Examples for Column Sections With Minimum Eccentricity

## Example (1): Design & draw a column section ($P_u$ = 2000 KN, $f_{cu}$= 30, $f_y$= 350 MPa)

**a- Square tied column:**

Assume $\mu = 1.0$ %

$2000 \times 10^3 = A_c [0.35(30)(1 - 0.01) + 0.67(1/100)(350)]$ -------- $A_c = 156986$ mm$^2$

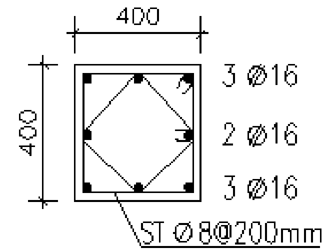
Use 400 x 400 mm section ($A_c = 160000$ mm$^2$)

$2000 \times 10^3 = 0.35(30)(160000 - A_{sc}) + 0.67A_{sc}(360)$

$A_{sc} = 1387$ mm$^2$ use 8 Ø 16

$S_{max} = \min[400, 200, 15(16)] = 200$ mm

Use S = 200 mm, $Ø_{st} = 8$ mm ($A_{st} = 50.3$ mm$^2$)




$\mu_{st} = 50.3[4(350) + 4(175)\sqrt{2}] / [400 \times 400 \times 200] = 0.38$ % > 0.25 % O.K.

**b- Spiral circular column (D = 400mm)**

$D_k = 350$ mm $A_k = (\prod/4)(350)^2 = 96250$ mm$^2$

$A_c = (\prod/4)(400)^2 = 125714$ mm$^2$

$2000 \times 10^3 = 0.4(30)(125714 - A_{sc}) + 0.76(350)A_{sc}$

$A_{sc} = 1935$ mm$^2$ use 8 Ø 18 (2080 mm$^2$)

$2000 \times 10^3 = 0.35(30)(96250 - 2080) + 0.67(350)(2080) + 1.38(240) V_{sp}$

$V_{sp} = 1580.5$ mm$^2$

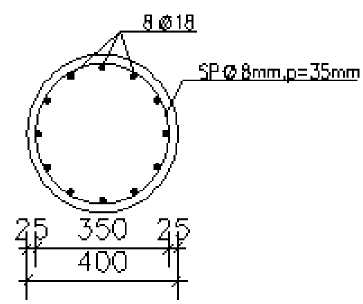
Assume $Ø_{sp} = 8$ mm, $A_{sp} = 50.3$ mm$^2$

$1580.5 = \prod(50.3)(350) / p$ ------------ p = 34.98 mm

Use spiral Ø8 with p = 35 mm

$\mu_{spmin} = 0.36(30/240)[(400/350)^2 - 1] = 0.0138$

$\mu_{sp} = V_{sp} / A_k = 0.0156 > \mu_{spmin}$ O.K.




## Example (2): Check safety of spiral column (D= 350mm, $P_u$= 2000kN, $A_s$ (6Ø22), $Ø_{sp}$= 8mm, p= 40 mm, $f_{cu}$= 30, $f_y$= 350 MPa)

D = 350 mm $A_c = (\prod/4)(350)^2 = 96250$ mm$^2$

$D_k = 300$ mm $A_k = (\prod/4)(300)^2 = 70714.3$ mm$^2$

$A_{sc}$ (6 Ø 22) = 2280 mm$^2$, $Ø_{sp} = 8$ mm, $A_{sp} = 50.3$ mm$^2$

$P_{u1} = 0.4(30)(96250 - 2280) + 0.76(2280)(360) = 1752$ KN

$V_{sp} = \prod(50.3)(300) / 40 = 1186$ mm$^2$

$P_{u2} = 0.35(30)(70714.3 - 2280) + 0.67(2280)(360) + 1.38(1186)(240) = 1661.8$ KN

$P_{uactual} = \min(1772, 1662) = 1662$ KN < 2000 KN Not safe

$F.O.S = 1.5(1662 / 2000) = 1.25 < 1.5$ Not safe

$\mu = (2280 / 96250) = 2.37\ \% > 1.0\ \%$ O.K.

$Ø_{spmin} = \max(8\ mm, 22/4) = 8\ mm = Ø_{spgiven}$ O.K.

$\mu_{spmin} = 0.36(30/240)[(350/300)^2 - 1] = 0.0163$

$\mu_{sp} = V_{sp} / A_k = 0.0168 > \mu_{spmin}$ O.K.

# Design Examples for Eccentric Compression

## Example (1) Design of R- sec. with large eccentric compression (MS Method)

**Given $M_u = 1000$ kN.m , $N_u = 500$ kN , $f_{cu} = 25$ MPa , $f_y = 360$ MPa**

**Required:** Design the R - sec. of girder

$e = M_u / N_u = 1000*10^6/ (500*10^3) = 2000$ mm

take b = 500 mm

take $\mu = 0.3\ \mu_{max} = 0.3 * 5*10^{-4} f_{cu} = 3.75*10^{-3}$

$M_u = \mu * b * d^2 * (f_y/\gamma_s)(1 - 0.75\mu * (f_y/\gamma_s)/ (f_{cu}/\gamma_c))$ , $\gamma_s = 1.15$ , $\gamma_c = 1.5$

$1000*10^6 = 3.75 *10^{-3} *500*d^2*(360/1.15)(1 - (0.75*3.75*10^{-3}*(360/1.15)/(25/1.5))$

d = 1340 mm

take d = 134 *1.1 ≈ 145 mm, t = 1500 mm , b = 500 mm

$e_s = e + t/2 - d` = 2000 + 750 - 50 = 2700$ mm = 2.7 m نبدأ من هنا في حالة b , t معلومين

$M_s = N * e_s = 1350$ kN.m

$M_{su} = \mu * b * d^2 * (f_y/\gamma_s)(1 - 0.75\mu * (f_y/\gamma_s)/ (f_{cu}/\gamma_c))$

$\gamma_s = 1.36 - 0.43\ (e / t) \geq 1.15$,

$\gamma_c = 1.75 - 0.50\ (e / t) \geq 1.5$ take $\gamma_s = 1.15$ , $\gamma_c = 1.5$

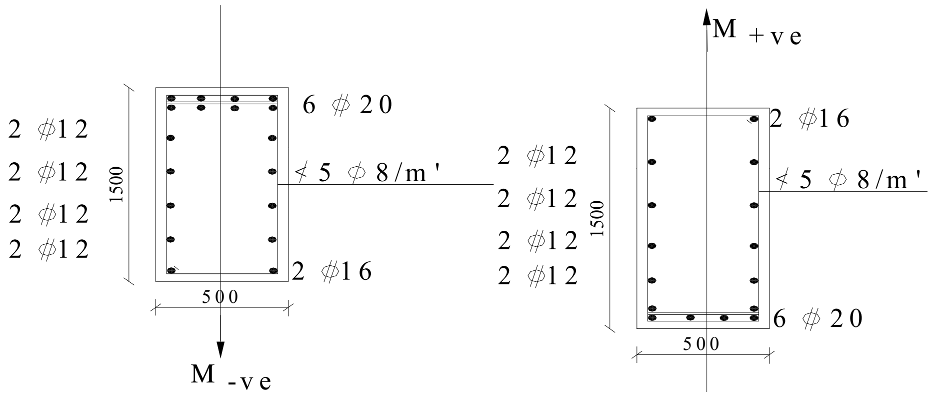
$1350*10^6 = \mu *500 * (1450)^2*(360/1.15) (1- 0.75 *\mu* (360/1.15)/(25/1.5))$

$14.087\mu^2 - \mu + 4.102*10^{-3} = 0.0$

**Or from flexural charts**: $\mu = 4.37145*10^{-3}$

$A_{s\ final} = \mu*b*d - (N*10^3/( f_y/\gamma_s)) = 3169 - 1597 = 15.72\ mm^2$ 6Φ20

Take 2Φ16 $A`_s = 10\%*\mu*b*d = 316.9\ mm^2$ ثانوي لتعليق الكانات




**** ملاحظات**

* تهمل $A`_s$ في عمل ال check لأنه لم تؤخذ في الاعتبار عند التصميم

• في حالة $A_s = -ve$ يكون القطاع كبير لأن N كبيرة وفى هذه الحالة نأخذ $A_s = \mu_{min} * b*d$

## <u>Example (2) Design of R- sec. with Small eccentric compression (ID Method)</u>

**<u>Given:-</u>** $f_{cu} = 25$ MPa , $f_y = 360$ MPa , b = 400 mm , $d^\backslash = 50$ mm

$0.75\ \% < \mu_{top} = \mu_{bot} < 1.0\ \%$ , $P_u = 3500$ kN , $M_u = 700$ kN.m , $\alpha = 0.8$

**<u>Required:</u>** Design the R - sec. of Column

For top and bottom reinforcement with $\alpha = 0.8$ use chart No. (4-16) for $\xi = 0.9$

OR use chart No. (4-17) for $\xi = 0.8$

$e = M_u * 10^6 / (P_u * 10^3) = 200$ mm

**<u>Trial No. 1:</u>** Take t = 800 mm

$\xi = (t - 2d^\backslash) / t = (800 - 2 * 50) / 800 = 0.875 = 0.9$ use chart No. (4-16)

$k = P_u * 10^3 / (f_{cu} * b * t) = 0.4375$

$e / t = 200 / 800 = 0.25$

From chart No. (4-16) $\rho = 6.2$

$\mu = \rho\ f_{cu} * 10^{-4} = 0.0155 = 1.55\ \% > 1.0\ \%$ So increase t

**<u>Trial No. 2:</u>** Take t = 1000 mm

$\xi = (t - 2d^\backslash) / t = (1000 - 2 * 50) / 1000 = 0.9$ use chart No. (4-16)

$K = P_u * 10^3 / (f_{cu} * b * t) = 0.35$

$e / t = 200 / 1000 = 0.2$

From chart No. (4-16) $\rho = 2.5$

$\mu = \rho\ f_{cu} * 10^{-4} = 0.00625 = 0.625\%$ $\mu < 0.75\ \%$

**Trial No. 3:** take t = 900 mm

$\xi = (t - 2d^{\backslash}) / t = (900 - 2 * 50) / 900 = 0.889$ take $\xi = 0.9$ use chart No. . (4-16)

$K = P_u * 10^3/ (f_{cu} * b * t) = 0.389$

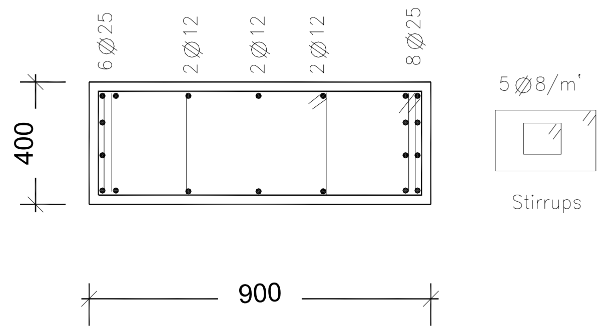
$(e / t) = 200 / 900 = 0.222$

From chart No. (4-16) $\rho \approx 4$

$\mu = \rho\ f_{cu} * 10^{-4} = 0.01 = 1.0\ \%$

$A_s = \mu\ b\ t = 3600\ mm^2$ 8 Φ 25

$A_s` = \alpha\ A_s = 2880\ mm^2$ 6 Φ 25




# Design Examples for Eccentric Tension

## Example (1) Tie Section Under Axial Tension

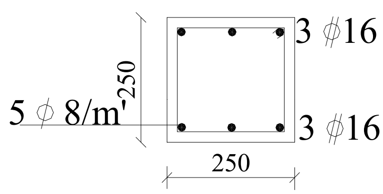
**Given : $T_u$ = 400 kN , $f_{cu}$ = 25 MPa , $f_y$ = 360 MPa**

**Required :-** Design the hunger or the tie section as square section

$T_u = A_s*f_y/\gamma_s$

$A_s = T_u/( f_y/\gamma_s) = 400*10^3/ (360/1.15) = 1277.7\ mm^2$ 6Φ16

Take $A_c$ = 250*250 mm




## Example (2) Beam or Tie Section Under Large Eccentric Tension (MS Method)

**Given:** $M_u$ = 500 kN.m , $T_u$ = 800 kN , $f_{cu}$ = 25 MPa , $f_y$ = 360 MPa , beam sec. 300*800

**Required**: Design R-sec.

$e = (M_u\ 10^6)/ (T_u\ 10^3 ) = 500\ 10^6/( 800*10^3 ) = 625$ mm $e / t > 0.5$

$e_s = e - t/2 + d` = 625 - 400 + 50 = 275$ mm = 0.275 m

$M_{su} = e_s *T_u = 0.275 * 800 = 220$ kN.m

d = 800 - 50 = 750 mm

$M_{us} = \mu * b*d^2*(f_y/\gamma_s)(1- 0.75\mu *(f_y /\gamma_s)/ (f_{cu}/\gamma_c))$

$220*10^6 = \mu * 300*(750)^2*(360/1.15)\ (1- 0.75* \mu*(360/1.15)/(25/1.5))$

$14.087\ \mu^2 - \mu + 4.1646 *10^{-3} = 0.0$

$\mu = 4.44263 *10^{-3}$

$A_{s1} = \mu *b * d = 1000\ mm^2$

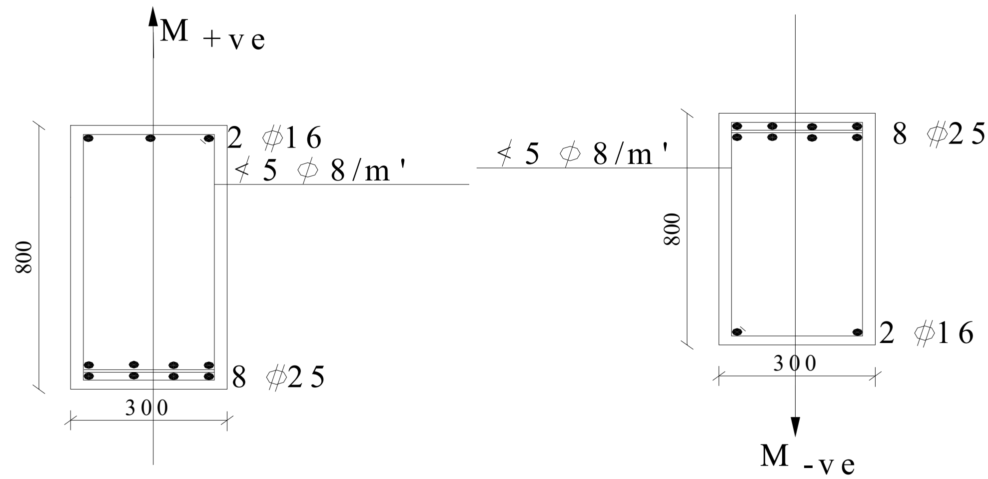
**Or from flexural charts**:

$M_{su} * 10^6 / (b*d^2) = 1.304$ , $f_{cu} = 25$ MPa , $f_y = 360$ MPa

Then $\mu\% * 100 = .....$ $\mu = ......$

$A_{s\ final} = A_{s1} + (T_u * 10^3)/(f_y/\gamma_s) = 3555\ mm^2 \approx 8\Phi 25$

$A`_s = 10\% * A_s = 350\ mm^2$ take $2\Phi 16$ ( حديد لتعليق الكانات )




**Example (3) Tie Section Under Eccentric Tension with Small Eccentricity**

**Given :-** $M_u = 90$ kN.m , $T_u = 900$ kN , $f_{cu} = 25$ MPa , $f_y = 360$ MPa

**Required :-** Design the tie sec. as square section

Take tie sec. 400 *400

$e = (M_u * 10^6)/(T_u * 10^3) = 90*10^6/900*10^3 = 100$ mm

$e/t = 0.25 < 0.5$ small eccentricity

$a = t/2 - d` - e = 200 - 50 - 100 = 50$ mm

$b = e + t/2 - d` = 100 + 200 - 20 = 250$ mm

$T_1 = T_u * a_2 / (a_1 + a_2) = 750$ kN

$T_2 = T - T_1 = 150$ kN

$A_{s1} = T_1 / (f_y/\gamma_s) = 2396\ mm^2$ 8 $\phi$ 22

$A_{s2} = T_2 / (f_y/\gamma_s) = 478\ mm^2$ 3 $\phi$ 16