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Subject : Advanced Concrete Designs

Department : Civil Engineering

MS : Construction Engineering and Management

Assignment

Q:- Design Raft footing for reinforced concrete multi Story Structure :

It Should cover :

(1) ALL design Steps
(2) Proper loading Criteria
(3) Proper Structural Drawing

Answer: First of all we have to know about what is raft foundation ;

"Def": Raft foundation is type of combined footing that may cover the entire area under the structure Supporting Several columns in one rigid body.

Now this raft foundation will be done for 5 story building. The raft will be used for economical Consideration. The raft foundation is usually used in Soil where the bearing Stress is around 100 kN/m^2. In this project, the raft will be designed as flate Plate, which has a uniform thickness and without any beams or pedestals. All analysis and design are based on the ACI code. Two methods are used for design of raft foundations. But the method here we used is "Conventional Method".

(i) Conventional method
(ii) Soil Line method

Solution:

Given Data :-

Yield Strength of Steel = F_y = 400 Mpa

Strength of concrete = f_c = 30 Mpa

Concrete unit weight = γ_c = 25 kN/m³

Soil unit weight = γ_{soil} = 15 kN/m³

Allowable Bearing Stress = q_a = 100 kN/m²

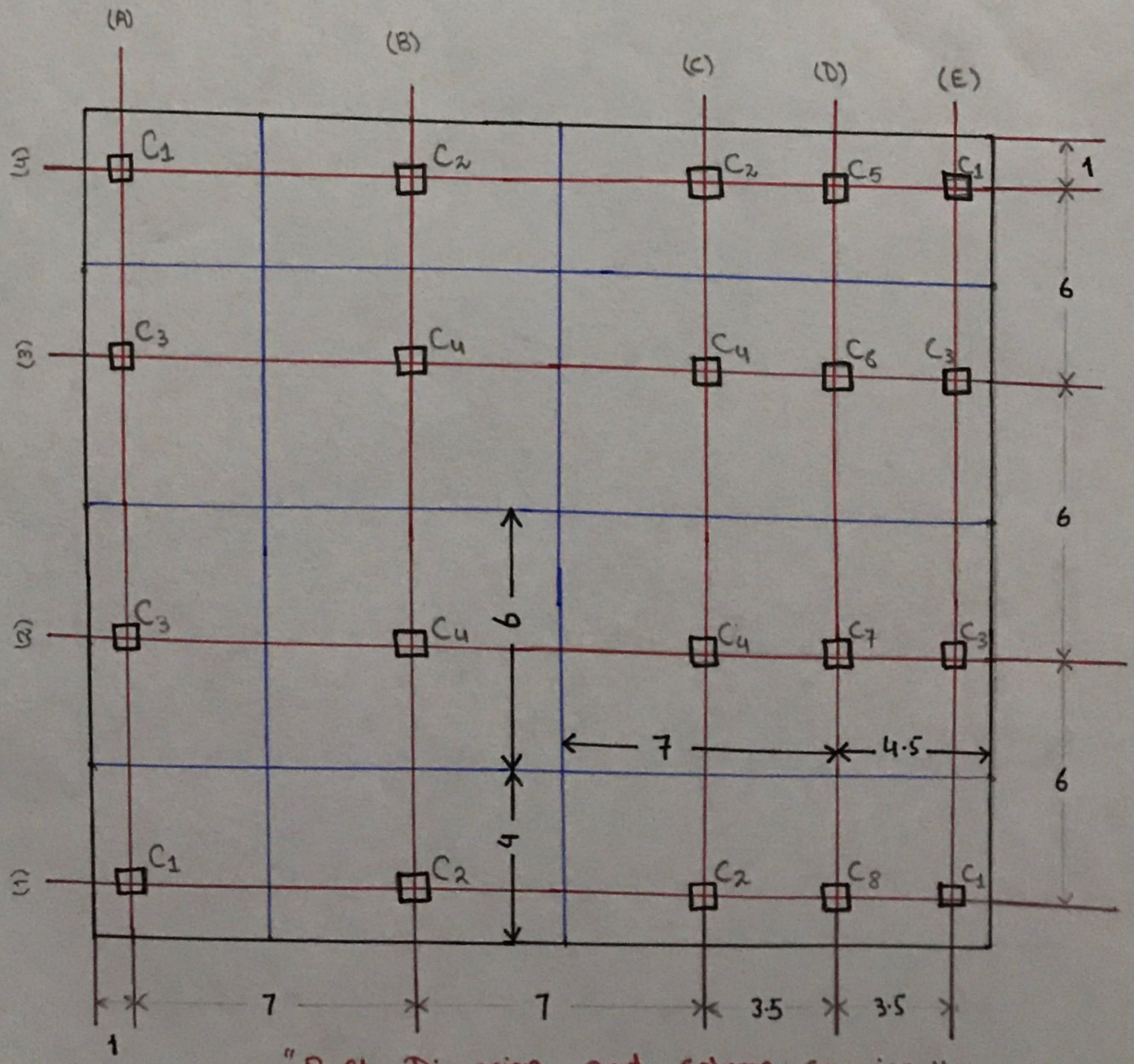
Young Modulos of elasticity = E = 2000000

Dead load factor = DLF = 1.2

Live load factor = LLF = 1.6

The raft has X-side spacing of 7 meters and Y-side spacing of 6 meters. One meter edge is round the edges columns.

Columns notation and the blue lines shows the turbidity areas that are covered by the columns.



"Raft Dimension and column spacing"

The total area of the raft $= [(3\times7)+1+1] \times [(3\times6)+1+1]$

$= 23 + 20 = 460\, m^2$

The industrial buiding this raft is designed for has 5 Stories with dead and live loads ;

Load type	Load Case	Load value (kN/m^2)
Services	Dead	$2.5\, kN/m^2$
Slab own weight assumed	Dead	$(25\, kN/m^3)(0.2m) = 5\, kN/m^2$
Flooring	Dead	$1\, kN/m^2$
Live loads	Live	$7\, kN/m^2$

⇒ Loads per Square meter are calculated as :

General Dead load stress $= (5+2.5+1)\, kN/m^2 \times$ Number of floors

$= (5+2.5+1)\, kN/m^2 \times 5 = 42.5\, kN/m^2$

General Live load stress $= (7)\, kN/m^2 \times 5 = 35\, kN/m^2$

⇒ Columns Loads :-

Axial Dead load = Stress per unit area × Turbidity area

(a) Column type (1) :-

Axial unfactored D.L $= 42.5\, kN/m^2 \times (4\times4.5)\, m^2 = 765\, kN$

Axial unfactored L.L $= 35\, kN/m^2 \times (4\times4.5)\, m^2 = 630\, kN$

Total service Axial load $= 765 + 630\, kN = 1395\, kN$

Ultimate axial load $= 1.2(765) + 1.6(630) = 1926\, kN$

(b) Column type (2) :-

Axial unfactored D.L = 42.5 kN/m² × (4×7) m² = 1190 kN
Axial unfactored L.L = 35 kN/m² × (4 ×7) m² = 980 kN
Total Service Axial load = 1190 + 980 = 2170 kN
Ultimate Axial load = 1.2(1190) + 1.6(980) = 2996 kN

(c) Column type (3) :-

Axial unfactored D.L = 42.5 kN/m² × (4.5×6) m² = 1148 kN
Axial unfactored L.L = 35 kN/m² × (4.5×6) m² = 945 kN
Total Service Axial load = 1148 + 945 = 2093 kN
Ultimate Axial load = 1.2(1148) + 1.6(945) = 2889 kN

(d) Column type (4) :-

Axial unfactored D.L = 42.5 kN/m² × (7×6) m² = 1785 kN
Axial unfactored L.L = 35 kN/m² × (7×6) m² = 1470 kN
Total Service Axial load = 1785 + 1470 kN = 3255 kN
Ultimate axial load = 1.2(1785) + 1.6(1470) = 4494 kN

(e) Extra Column loads :

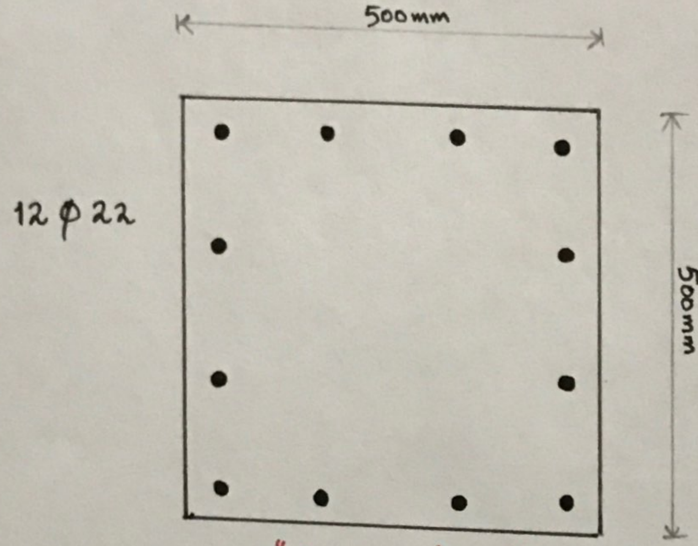
These columns are placed in the right edge of the raft, and they are external columns that are carried by the raft and will cause moments around x-axis and y-axis. The axial loads of the original columns and extra columns.

ALL Column Loads

Column No.	D.L (kN)	Live Load (kN)	Total Service load (kN)	Total factored load (kN)
C1	765	630	1395	1926
C2	1190	980	2170	2996
C3	1148	945	2093	2889
C4 (maximum)	1785	1470	3255	4494
C5 (extra)	500	300	800	1080
C6 (extra)	450	250	700	940
C7 (extra)	400	200	600	800
C8 (extra)	350	150	500	860

⇒ Columns Dimensions and Reinforcement :-

Columns have been designed using the PCA Columns. All Columns have dimensions of 500mm x 500mm with 12ϕ22. The design of column will resists all columns loads upto the maximum load of 4494 KN.



"Column design"

Critical load = $P_c = \phi P_n = (0.7)(0.8)[(0.85 f'_c A_g + F_y A_{st})]$

$= (0.7)(0.8)[(0.85(30)(500 \times 500) + (400)(4562)]$

$P_c = 4592 \text{ KN} > P_u = 4494 (\text{KN})$. where P_u ⇒ "Axial force due to factored load."

⇒ Why Raft Should be Used :-

If Single Square footing need to be designed under the maximum axial load that occured in Column type 4. This foundation is used for loose Sand Soil. The properties Used in the analysis and the design of this raft foundation are ;

Soil type → loose Sand

Effective Bearing Stress of Soil = q_e = 100 kN/m²

Sub-grade modulus = 20,000 kN/m³

Concrete Strength of raft = 30MPa

Reinforcement Steel Strength = 400MPa

$q_e = 100 kN/m^2$

Total maximum Service axial load = 1785 + 1470 kN = 3255 kN

Area of Single Square footing = $\frac{1.1(3255)}{100}$ = $35.8 m^2$

$B \times B = 35.8 \rightarrow B = \sqrt{35.8} = 6m$ by 6m

This area is considered to be very big to be excavated under one column. So the raft foundation will be much efficient and more economical for the foundation

⇒ **Raft Thickness :** Thickness can be determined by checking the diagonal tension shear that will be imposed in the raft. The max. ultimate column load will be used in the calculation.

$$U = (b_o)(d)(\phi)(0.34)\sqrt{f_c'}$$

where ;

U = factored column load
ϕ = Reduction factor = 0.85
b_o = The parameter of the sheared area
d = effective depth of raft
f_c' = Compressive Strength of concrete.

In the Raft ; $U = 4494 kN = 4.494 MN$

$b_o = 4(0.4+d) = 1.6+4d$

And by using the equation above, the required depth of the raft can be determined ;

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$$U = (b_o)(d)(\phi)(0.34)\sqrt{f_c'}$$

$$4.494 = (1.6+4d)(d)(0.75)(0.34)\sqrt{30}$$

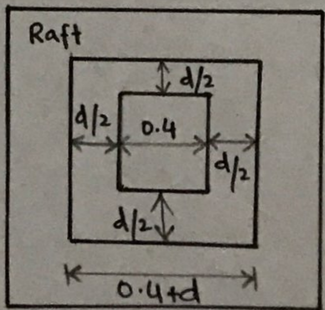
$$4.494 = (1.6d+4d^2)(1.397)$$

$$3.2169 = 1.6d - 3.2169$$

$$0 = 4d^2 + 1.6d - 3.2169$$

$$0 = 4d^2 + 1.6d - 3.2169$$

Solving equation for "d"



Diagonal tension Shear Area

$d = 0.689\,m = 689\,mm = 700\,mm$

Thickness of the raft = 700+75+25 (assumed bar diameter)

Thickness = 800mm

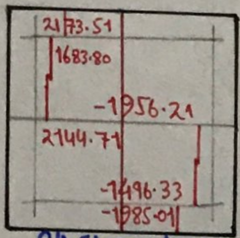
⇒ Raft depth check :-

★ One way Shear :

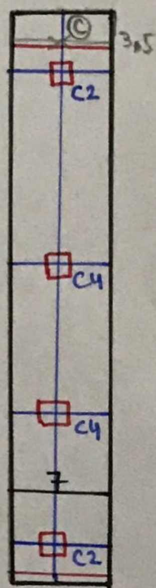
$$V_u = \text{Max. Shear} - (d)(W_{soil})$$

To determine the W_{soil}, the average soil pressure should be determined in the maximum loads stripes.

For the y-strips, CSY4 have maximum shear value in C_4. Which is equal to 2173.51 kN



C4 Shear diagram



Maximum Shear in Strip CSY3.

CSY3 will be analyzed seperately to calculate the ultimate bearing stress of the soil.

$$q_{ult} = \frac{\text{Total factored load in strip CSY3}}{\text{Area of the strip}}$$

$$q_{ult} = \frac{C_2 + C_4 + C_4 + C_2}{(\text{width of strip})(\text{length of strip})}$$

$$q_{ult} = \frac{2996 + 4494 + 4494 + 2996}{(3.5)(20)} = 214\,kN/m^2$$

$$q_{ult} = 214\,kN/m^2$$

$$W_{soil} = (214\,kN/m^2)(\text{width of strip})$$
$$= (214)(3.5) = \boxed{749\,kN/m}$$

Assuming

$d = 800 - 75 = 725\,mm$

$V_u = \text{Max. shear} - (d)(W_{soil})$

$V_u = 2173.5 - (0.725)(749)$

$V_u = 1630.5\ kN$

$$d = \frac{(V_u)(1000)}{(0.75)(\sqrt{f'_c})(1/6)(B)} = \frac{(1630.5)(1000)}{(.75)(\sqrt{30})(1/6)(3500)}$$

$= 680.4\ mm$

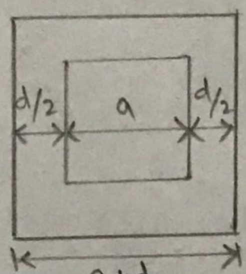
$d = 680.4\ mm < d = 725$ OK

★ Two way Shear (Interrior column):

$V_u = \text{Column Axial load} - (d+a)^2 (W_{soil})$

To determine the W_{soil}, the average soil pressure should be determined in the max. loads stripes.

$q_{alt} = 214\ kN/m^2$



Two way Shear Area

Assuming

$d = 800 - 75 = 725\,mm$

$V_u = \text{Column Axial load} - (d+a)^2 (W_{soil})$

$V_u = 4494 - (0.725 + 0.5)^2 (214) = 4172.9\,kN$

$b_o = 4(a+d) = 4(500 + 725) = 4900\,mm$

$$d_{III} = \frac{(V_u)(1000)}{(0.75)(\sqrt{f'_c})(1/3)(b_o)} = \frac{(4172.9)(1000)}{(0.75)(\sqrt{30})(1/3)(4900)}$$

$d_{III} = 622.6\,mm$

$d = 622.6 < d = 725$ OK

⇒ Soil pressure Check:- soil net pressure should be checked in each point of raft foundation. The raft foundation is not symmetric around x-axis and nor y-axis due to difference in the column positions and loads. Moments affect on the raft foundation should be checked to assure that the stress of the raft under all columns are less than the net allowable stress which is equal to $100\ kN/m^2$.

$q = Q/A \mp M_y x/I_y \mp M_x y/I_x$

A = Area of the mat $= ((7)(3)+1+1) \times ((6)(3)+1+1) = (23) \times (20) = 460 m^2$

$I_x = bh^3/12 = 23(20)^3/12 = 15333.3 m^4$

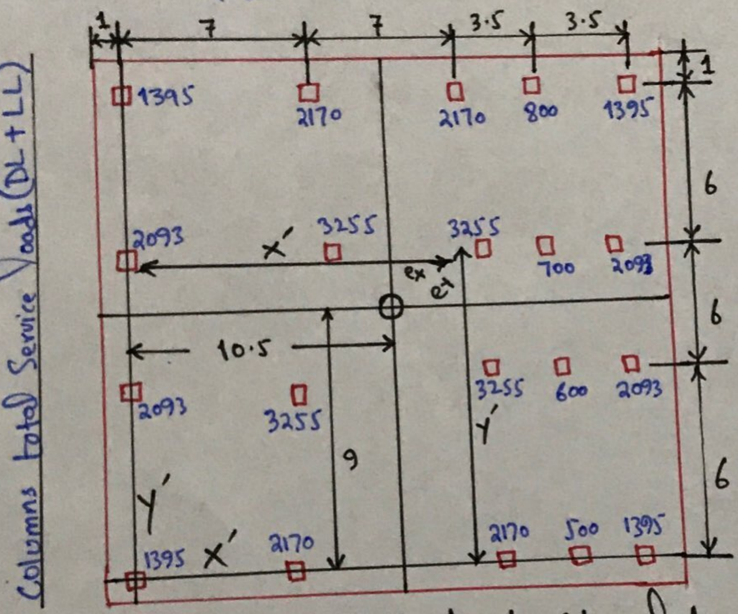
$I_y = bh^3/12 = 20(23)^3/12 = 20278.3 m^4$

Q = Sum of all Service columns loads

$Q = 4(C_1) + 4(C_2) + 4(C_3) + 4(C_4) +$ extra column loads

$Q = 4(1395) + 4(2170) + 4(2093) + 4(3225) + 800 + 700 + 600 + 500$

$Q = 38252 KN$



Resultant Position due to Column loads

- Calculate "M_y" :-

$e_x = x' - 10.5$

$Q * x' = Q_1(x'_1) + Q_2(x'_2) + \dots$

$x' = \frac{Q_1(x'_1) + Q_2(x'_2)}{Q}$

$x' = 1/38252 [(7)(2170+3255+3255+2170) + (14)(2170+3255+3255+2170) + (17.5)(800+700+600+500) + (21)(1395+2093+2093+1395)]$

$x' = 1/38252 [227850 + 45500 + 146496]$

$x' = 10.976 m$

$e_x = 10.976 - 10.5 = 0.4758 m$

$M_y = Qe_x = 38252 \times 0.4758 = \boxed{18200 KN.m}$

- Calculate "M_x" :-

$e_y = y' - 9$

$Q * y' = Q_1(y'_1) + Q_2(y'_2) + \dots$

$y' = Q_1(y'_1) + Q_2(y'_2) / Q$

$y' = \frac{1}{38252}[(18)(1395+2170+2170+800+1395) + (12)(2093+3255+3255+700+2093) + (6)(2093+3255+3255+600+2093)]$

$y' = 1/38252 [142740 + 136752 + 67776]$

$y' = 9.07843 m$

$e_y = 9.07843 - 9 = 0.07843 m$

$M_x = Qe_y = 38252 \times 0.07843 = \boxed{3000 KN.m}$

Calculate Soil pressure due to total Service axial loads and moments:-

$$q_i = -Q/A \mp M_y x/I_y \mp M_x y/I_x, \; i = 1,2,3 \text{ and } 4$$

where (−) minus Signs refers to Compression Stress.
Soil pressure will be checked in the four corners of the raft. Soil pressure should not be more than the allowable Stress of the Soil and not less than 0 kn/m², to make Sure that no tension could occure in any part of the raft.

$$q_i = -Q/A \mp M_y x/I_y \mp M_x y/I_x$$

$$q_i = -\frac{38252}{460} - \frac{18200(11.5)}{20278.3} - \frac{3000(10.5)}{15333.3}$$

$$q_1 = -\frac{38252}{460} - \frac{18200(11.5)}{20278.3} - \frac{3000(10.5)}{15333.3}$$

$$q_1 = -83.157 - 10.321 - 2.054$$

$$q_1 = -95.532 < q_{net} = 100\,kN/m^2 \text{ Ok}$$

$$q_2 = -\frac{38252}{460} + \frac{18200(11.5)}{20278.3} - \frac{3000(10.5)}{15333.3}$$

$$q_2 = -83.157 + 10.321 - 2.054$$

$$q_2 = -75.265 < q_{net} = 100\,kN/m^2 \text{ Ok}$$

$$q_3 = -\frac{38252}{460} + \frac{18200(11.5)}{20278.3} + \frac{3000(10.5)}{15333.3}$$

$$q_3 = -83.157 + 10.321 + 2.054$$

$$q_2 = -70.89 < q_{net} = 100\,kN/m^2 \text{ Ok}$$

$$q_4 = -\frac{38252}{460} - \frac{18200(11.5)}{20278.3} + \frac{3000(10.5)}{15333.3}$$

$$q_4 = -83.157 - 10.321 + 2.054$$

$$q_4 = -91.424 < q_{net} = 100\,kN/m^2 \text{ Ok}$$

All pressure values are in compression and they are less than the net bearing Stress of the Soil which is 100 kN/m².

⇒ X - Strip Design :-

* Positive Moment (Bottom Reinforcement):

Design of reinforcement will be based on one meter unit of the Strip. The distance to the rebar center is equal to 75mm, so effective raft depth equal to :

$d = 800 - 75 = 725mm$

M_u^+ (maximum) = 1532 kN.m/m

$$M_u^+/\phi b d^2 = \frac{1532e6}{(0.9)(1000)(725)^2} = 3.238$$

→ from table $q_u \Rightarrow \rho = 0.0088 > \rho_{min} = 0.0035$

$\rho = 0.0088 < \rho_{max} = 0.0244$

$A_s = 0.0088 (b)(d) = 0.0088(1000)(725)$

$A_s = 6380 \ mm^2/m$

Use 13 ϕ25/m , $A_s = 6381 \ mm^2/m$

$$S = \frac{1000}{13-1} = 83 \quad \text{Use } S = 80mm < S_{max} = 450mm$$

Use ϕ25 @ 80mm

Check "M_c" :

$$a = \frac{A_s \cdot F_y}{0.85 f_c \cdot b} = \frac{6381 \times 400}{0.85 \times 30 \times 1000} = 100.1 mm$$

$C = a/B_1 = 100.1/0.85 = 117.7 mm$

$d = h - cover = 800 - 75 = 725mm$

$$\epsilon_t = \left(\frac{d-c}{c}\right) \times 0.003 = \left(\frac{725 - 117.7}{117.7}\right) \times 0.003 = 0.0154 > 0.005$$

(tension control)

then use $\phi = 0.9$

$M_c = \phi (A_s)(F_y)(d - a/2)$

$M_c = (0.9)(6381)(400)\left(725 - \frac{100.1}{2}\right) e^{-6}$

$M_c = 1550.4 \ kN.m$ Ok

$> M_u = 1532 kN.m$

Use ϕ25 @ 80mm for Positive moments X - direction - bottom Reinforcement

* Negative moments (Top Reinforcement) :-

Design of reinforcement will ;

$d = 800 - 75 = 725\,mm$

M_u^- (maximum) $= 1142.3\ kN.m/m$

$$M_u^{\pm}/\phi b d^2 = \frac{1142.3\,e6}{(0.9)(1000)(725)^2} = 2.415$$

→ from "q_u" table

$\rho = 0.0064 > \rho_{min} = 0.0035$

$\rho = 0.0064 < \rho_{max} = 0.0244$

$A_s = 0.0064(b)(d) = 0.0064(1000)(725)$

$A_s = 4640\ mm^2/m$

Use $10\ \phi 25/m$ $\quad A_s = 4909\ mm^2/m$

$S = 1000/10-1 = 111.1$ Use $S = 110\,mm < S_{max} = 450\,mm$

Use $\phi 25$ @ 110mm

Check "M_c" :-

$$a = \frac{A_s F_y}{0.85 f_c b} = \frac{4909 \times 400}{0.85(30)(1000)} = 77\,mm$$

$C = a/B_1 = 77/0.85 = 90.6\,mm$

$d = h - Cover - Stirrups - d_b/2 = 800 - 75 = 725\,mm$

$$\epsilon_t = \left(\frac{d-c}{c}\right) \times 0.003 = \left(\frac{725 - 90.6}{90.6}\right) \times 0.003 = 0.021 > 0.005 \text{ (Tension control)}$$

then use $\phi = 0.9$

$M_c = \phi\,(A_s)(F_y)(d - a/2) = (0.9)(4909)(400)(725 - 77/2)\,e^{-6}$

$M_c = 1213.2\ kN.m > M_u = 1532\ kN.m$ Ok

Use $\phi 25$ @ 110 mm for negative moment x-direction-top Reinforcement

⇒ Y- Strip Design :-

* positive moments (Bottom Reinforcement) :-

Design of reinforcement is based on one meter unit of strip. The distance to the rebar center is 75mm + 25mm, because y- direction reinforcement will be under the reinforcement of x- direction, so effective raft depth will be;

$d = 800 - (75 + 25) = 700\ mm$

$M_u^+ (max) = 1532\ KN.m/m$

$$M_u^+/\phi b d^2 = \frac{1450\ e^6}{(0.9)(1000)(700)^2} = 3.288$$

→ from "q_u" table → $\rho = 0.009 > \rho_{min} = 0.0035$

$\rho = 0.009 < \rho_{max} = 0.0244$

$A_s = 0.009 (b)(d) = 0.009 (1000)(700)$

$A_s = 6300\ mm^2/m$

Use $13\ \phi 25/m$, $A_s = 6381\ mm^2/m$

$S = 1000/13-1 = 83$ Use $S = 80mm < S_{max} = 450\ mm$

Use $\phi 25$ @ 80mm

Check "M_c" :-

$$a = \frac{6381 \times 400}{0.85 \times 30 \times 1000} = 100.1\ mm$$

$C = 100.1/0.85 = 117.7\ mm$

$d = 800 - 75 = 725\ mm$

$$\epsilon_t = \left(\frac{725 - 117.7}{117.7}\right) \times 0.003 = 0.0154 > 0.005 \text{ (Tension Control)}$$

then use $\phi = 0.9$

$$M_c = (0.9)(6381)(400)\left(725 - \frac{100.1}{2}\right) e^{-6}$$

$M_c = 1550.4\ KN.m > M_u = 1450\ KN.m$ OK

Use $\phi 25$ @ 80mm for +ve moments Y- direction – bottom Reinforcement

* Negative moments (top Reinforcement) :-

Design of reinforcement will be ;

$d = 800 - (75+25) = 700mm$

$M_u^- (max) = 1532 kN.m/m$

$M_u^{\pm}/\phi b d^2 = \frac{1230.3 e6}{0.9(1000)(700)^2} = 2.790$

$\rightarrow \rho = 0.0076 > \rho_{min} = 0.0035$

$\rho = 0.0076 < \rho_{max} = 0.0244$

$A_s = 0.0076(b)(d) = 0.0076(1000)(700)$

$A_s = 5300 mm^2/m$

Use $11 \phi 25/m$, $A_s = 5400 mm^2/m$

$S = 1000/10-1 = 100$ Use $S = 100mm < S_{max} = 450mm$

Use $\phi 25$ @ 100 mm

Check "M_c" :-

$a = \frac{5400 \times 400}{0.85 \times 30 \times 1000} = 84.7mm$

$C = 84.7/0.85 = 99.6mm$

$d = 800 - 75 - 25 = 700mm$

$\epsilon_t = \left(\frac{700-99.6}{99.6}\right) \times 0.003 = 0.0181 > 0.005$ (Tension control)

then Use $\phi = 0.9$

$M_c = \phi (A_s)(F_y)(d - a/2)$

$M_c = (0.9)(5400)(400)(700 - 84.7/2) e^{-6}$

$M_c = 1278.5 kN.m > M_u = 1230.3 kN.m$ OK

Use $\phi 25$ @ 100 mm for negative moments Y-direction-top reinforcement.