QATAR UNIVERSITY
COLLAGE OF ENGINEERING
COURSE: DESIGN OF REINFORCED CONCRETE STRUCTURES

STRUCTURAL DESIGN OF RAFT FOUNDATION

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Acknowledgment:

After completing this special project in Design of raft foundation for the course of Design of reinforced concrete structures, we are deeply indebted to the people who contributed in various ways towards its progress and completion

We are grateful to Dr. Mohammed Al-Ansari for his continuous goodness and encouragement. We would also like to express our deepest for our families and friends who helped in the success of this project.

Abstract:

In this report, a full discussion and clarification of the design of Raft foundation in loose sand will be shown in details. The columns loads calculation for this raft is also will be shown in terms of the turbidity area of the columns. Final design and detailing will be shown at the end of this report with SAFE software design out file attached.

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1. Introduction:

This foundation will be done for a storage 5 story building. The raft will be used for economical consideration. The justification of using raft foundation will be discussed in columns loads section 3.2.0.

The raft foundation is a kind of combined footing that may cover the entire area under the structure supporting several columns in one rigid body. In this project, the soil profile shows that the bearing stress is around 100 kN/m^2 . The raft foundation is usually used with this kind of soil. The columns have high axial loads. If spread footings used, the area of the footing required will be big as will be shown in column load section 3.2.0. In this big spread footing condition, the raft foundation could be much practical and economical.

In this project, the raft will be designed as flat plate, which has a uniform thickness and without any beams or pedestals.

2. Objective:

This report shows the structural design of the raft foundation. The raft is modeled in SAFE software. All analysis and design are based on the ACI code. Raft foundation can be design using several methods. In this special project the method used in the design called "the Conventional Rigid Method" and all design steps will be shown in the report.
All design parameters are shown in table 1.

Parameter	Notation	Value
Yield strength of steel	F_y	400 MPa
Strength of concrete	f_c	30 MPa
Young modules of elasticity	E	2000000
Dear load factor	D.L.F	1.2
Live load factor	L.L .F	1.6
Soil Unit weight	γ_{soil}	15 kN/m^3
Allowable Bearing stress	q_a	100 kN/ m^2
Concrete Unit weight	$\gamma_{concrete}$	25 kN/ m^3

Table 1, parmaters used in Raft Design

3. Raft Modeling and Analysis:

3.1.0 Raft dimensions:

Raft foundation has been modeled in SAFE software. The raft has x side spacing of 7 meters and y-side spacing of 6 meters. One meter edge is around the edges columns. The plan of the raft is shown in figure 1.

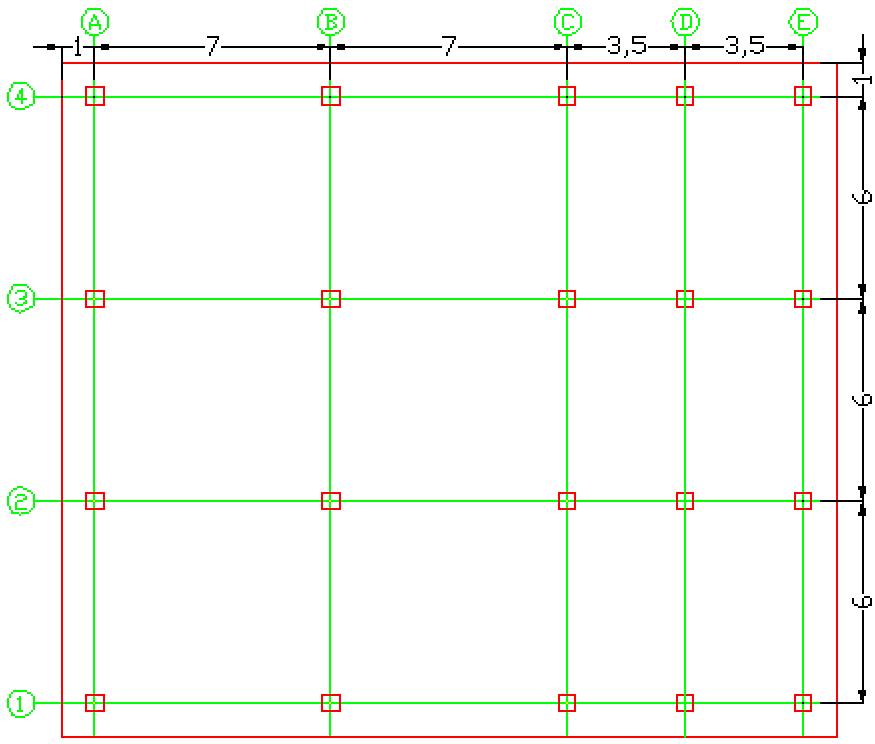

Figure 1, Raft layout

The total area of the raft = $\big((3*7)+1+1\big)*\big((3*6)+1+1\big)$

$$= 23*20 = 460\ m^2$$

3.2.0 Columns loads in Raft:

The industrial building that this raft is designed for has 5 stories with dead and live loads which are shown in table 2.

Load type	Load case	Load value (kN/m^2)
Services	Dead	2.5 kN/m^2
Slab own weight assumed	Dead	($25kN/m^3$)(0.2m) = 5 kN/m^2
Flooring	Dead	1 kN/m^2
Live loads	Live	7 kN/m2

Table 2, design loads

Figure 2 shows the columns notation and the yellow lines shows the turbidity areas that are covered by the columns.

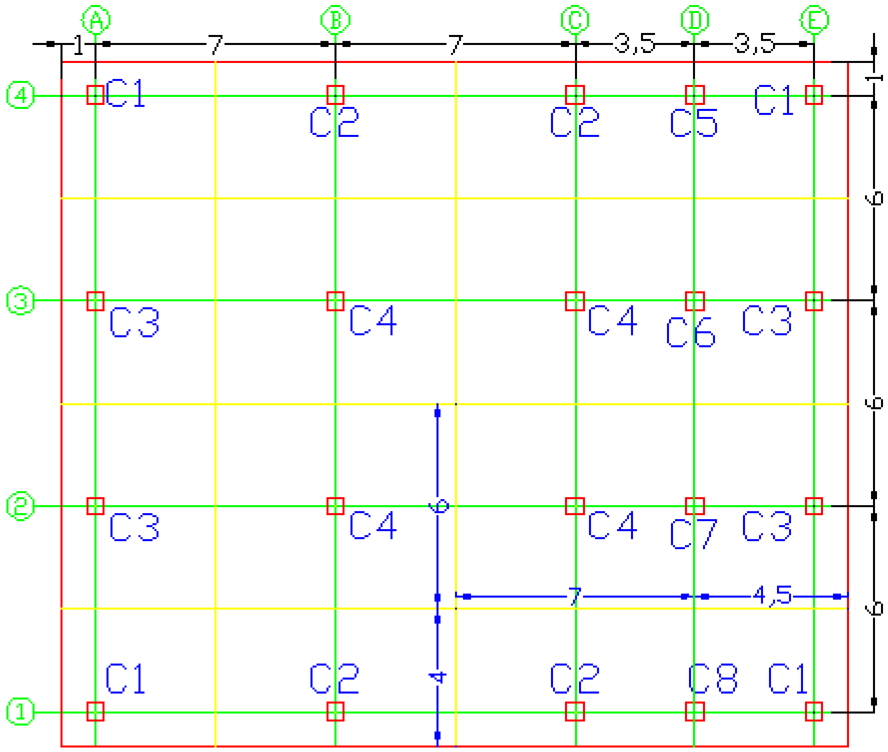

Figure 2, Raft dimension and column spacing

Loads per square meter are calculated as:

$$General\ Dead\ load\ stress = (5 + 2.5 + 1)\frac{kN}{m2} * no.of\ floors$$

$$General\ Dead\ load\ stress = (5 + 2.5 + 1)\frac{kN}{m2} * 5 = 42.5\ kN/m^2$$

$$General\ Life\ load\ stress = (7)\frac{kN}{m2} * 5 = 35\ kN/m^2$$

Columns loads:

$$Axial\ Dead\ load\ = Stess\ per\ unit\ area\,\frac{kN}{m^2} * Turbidity\ area$$

Column type (1):

$\text{Axial unfactored Dead load } = 42.5\ \text{kN/m}^2 * (4 * 4.5)\text{m}^2 = 765\ \text{kN}$

$\text{Axial unfactored Live load } = 35\ \text{kN/m}^2 * (4 * 4.5)\text{m}^2 = 630\ \text{kN}$

$\text{Total Sevice Axial load } = 765 + 630\ \text{kN} = 1395\ \text{kN}$

$\text{Ultimate axial load } = 1.2(765) + 1.6(630) = 1926\ \text{kN}$

Column type (2):

$\text{Axial unfactored Dead load } = 42.5\ \text{kN/m}^2 * (4 * 7)\text{m}^2 = 1190\ \text{kN}$

$\text{Axial unfactored Live load } = 35\ \text{kN/m}^2 * (4 * 7)\text{m}^2 = 980\ \text{kN}$

$\text{Total Sevice Axial load } = 1190 + 980\ \text{kN} = 2170\ \text{kN}$

$\text{Ultimate axial load } = 1.2(1190) + 1.6(980) = 2996\ \text{kN}$

Column type (3):

$\text{Axial unfactored Dead load } = 42.5\ \text{kN/m}^2 * (4.5 * 6)\text{m}^2 = 1148\ \text{kN}$

$\text{Axial unfactored Live load } = 35\ \text{kN/m}^2 * (4.5 * 6)\text{m}^2 = 945\ \text{kN}$

$\text{Total Sevice Axial load } = 1148 + 945\ \text{kN} = 2093\ \text{kN}$

$\text{Ultimate axial load } = 1.2(1148) + 1.6(945) = 2889\ \text{kN}$

Column type (4):

$\text{Axial unfactored Dead load } = 42.5\ \text{kN/m}^2 * (7 * 6)\text{m}^2 = 1785\ \text{kN}$

$\text{Axial unfactored Live load } = 35\ \text{kN/m}^2 * (7 * 6)\text{m}^2 = 1470\ \text{kN}$

$\text{Total Sevice Axial load } = 1785 + 1470\ \text{kN} = 3255\ \text{kN}$

$\text{Ultimate axial load } = 1.2(1785) + 1.6(1470) = 4494\ \text{kN}$

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 as will be shown. The axial loads of the original columns and extra columns are shown in the table 3.

Column no.	Dead load (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	660

Table 3, all columns loads

Columns Dimensions and Reinforcement:

Columns have been designed using the PCA columns. All columns have dimensions of 500 mm by 500 mm with 12Ø22 as shown in figure 3. This design of column will resists all columns loads up to the maximum load of 4494 kN

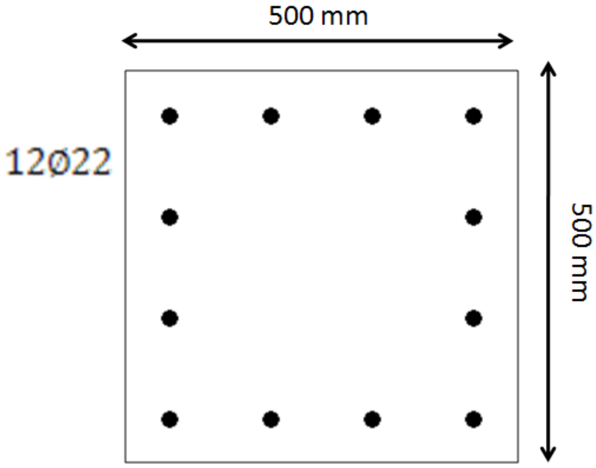

Figure 3, Column design

$$Pc = \emptyset P_n = (0.7)(0.8)\left[(0.85 f_c^{'} A_g + F_y A_{st})\right]$$

$$Pc = \emptyset P_n = (0.7)(0.8)[(0.85(30)(500)(500) + (400)(4562)]$$

Pc = 4592 kN > Pu = 4494 kN

3.3.0 Why Raft should be used:

If a single square footing need to be designed under the maximum axial load that is occurred in columns type 4.
This foundation will be used for a loose sand soil. The properties used in the analysis and the design of this raft foundation are shown in table 4.

Soil type	Loose sand
Effective bearing stress for the soil	$q_e = 100 \text{ kN/m}^2$
Sub-grade modules	20,000 kN/m^3
Concrete strength of raft	30 MPa
Reinforcement Steel strength	400 MPa

Table 4, Properties taken in Raft Design

$q_e = 100 \text{ kN/m}^2$

$\text{Total Maximum Sevice Axial load} = 1785 + 1470 \text{ kN} = 3255 \text{ kN}$

$$\text{Area of single sqaure footing} = \frac{1.1(3255)}{100} = 35.8 \text{ m}^2$$

$\text{B X B} = 35.8 \longrightarrow \text{B} = \sqrt{35.8} = 6 \text{ m by } 6 \text{ m}$

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 this foundation.

3.4.0 Raft thickness:

In Raft foundation, the thickness can be determined by checking the diagonal tension shear that will be imposed in the raft. The maximum ultimate column load will be used in the calculation.

$U = (b_o)(d)(\emptyset)(0.34)\sqrt{f_c'}$ 11.12.2.1.c

Where,

U = factored column load

Ø = Reduction factor = 0.85

b_o = The parameter of the sheared area

d = effective depth of raft

f_c' = Compressive strength of concrete

In this Raft,

$U = 4494 \text{ kN} = 4.494 \text{ MN}$

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

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

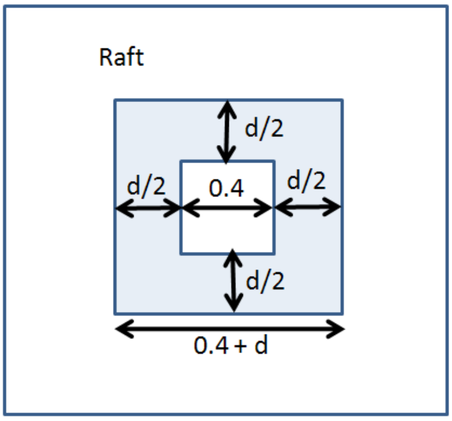

Figure 4, Diagonal tension shear area

$U = (b_o)(d)(\emptyset)(0.34)\sqrt{f_c'}$ ACI-05 11.12.2.1.c

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

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

$3.2169 = 1.6d + 4d^2$

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

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

Solving equation for d

d = 0.689 m = 689 mm = 700 mm

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

Thickness = 800 mm

3.5.0 Raft Depth check:

3.5.1 One way shear:

$V_u = Maximum\ shear - (d)(w_{soil})$

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 C4. Which is equal to 2173.51 kN

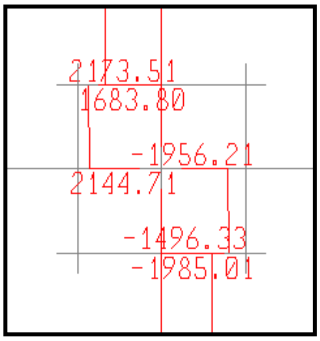

Figure 5, C4 shear diagram

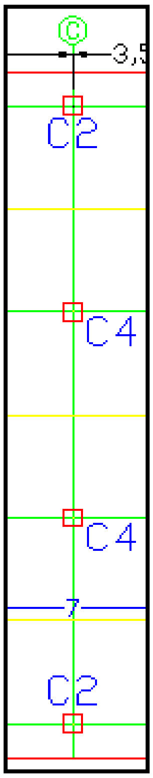

Figure 6, maximum shear in strips CSY3

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

$$q_{alt} = \frac{Total\ factored\ loads\ in\ strip\ CSY3}{Area\ of\ the\ strip}$$

$$q_{alt} = \frac{C2 + C4 + C4 + C2}{(width\ of\ strip)(length\ of\ strip)}$$

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

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

$$w_{soil} = (214\ kN/m^2)(width\ of\ strip) = (214\ kN/m^2)(3.5)$$

$$w_{soil} = 749kN/m$$

Assuming

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

$$V_u = Maximum\ shear - (d)(w_{soil})$$

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

$$V_u = 1630.5\ kN$$

$$d = \frac{(V_u)(1000)}{(0.75)(\sqrt{f_c'})\left(\frac{1}{6}\right)(B)} = \frac{(1630.5)(1000)}{(0.75)(\sqrt{30})\left(\frac{1}{6}\right)(3500)} = 680.4\ mm$$

$d = 680.4\ mm < d = 725$ *ok*

3.5.1 Two way shear (interior column):

$V_u = Column\ Axial\ Load - (d+a)^2(w_{soil})$

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

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

Assuming

$d = 800 - 75 = 725\ mm$

$V_u = Column\ Axial\ Load - (d+a)^2(w_{soil})$

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

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

$$d_{III} = \frac{(V_u)(1000)}{(0.75)(\sqrt{f_c'})\left(\frac{1}{3}\right)(b_o)} = \frac{(4172.9)(1000)}{(0.75)(\sqrt{30})\left(\frac{1}{3}\right)(4900)}$$

$d_{III} = 622.6\ mm$

$d = 622.6\ mm < d = 725$ ok

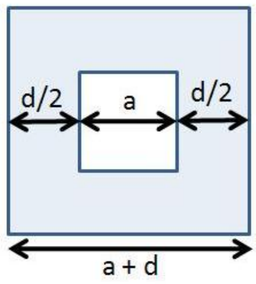

Figure 7, two way shear area

3.5.2 SAFE Punching Shear check:

Safe software has command of checking the punching shear of the raft or any slab that is modeled in safe. And in this project, the punching shear has been checked using the SAFE software and all the factors are less than 1. This means that the load shear is less than the raft shear resistance. The punching shear factors are shown in the following figure:

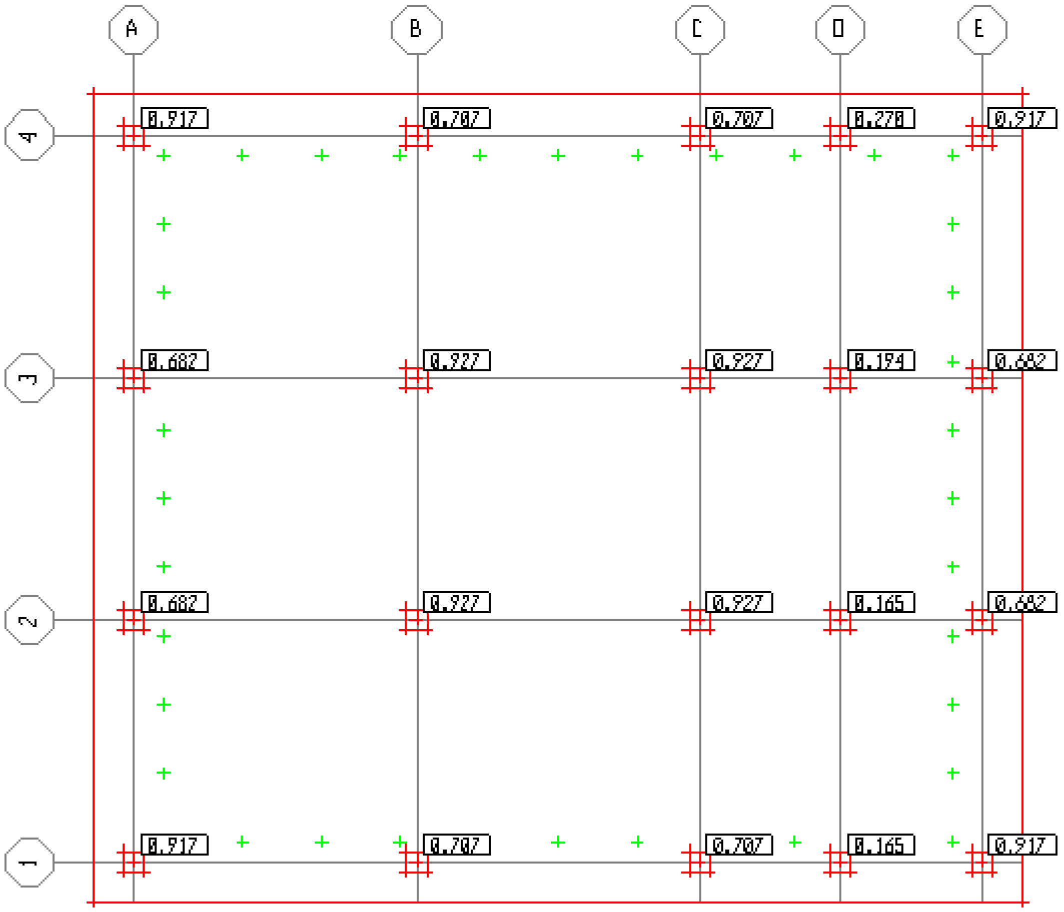

Figure 8, punching shear factors for the raft

3.5.0 Soil Pressure Check:

In this section, the soil net pressure should be checked in each point of the raft foundation. The raft foundation is not symmetric around x-axis nor y-axis due to difference in the columns positions and loads. Moments effects on the raft should be checked to assure that the stresses of the raft under all columns are less than the net allowable stress which is equal to $100\ \mathrm{kN/m^2}$.

$$q = \frac{Q}{A} \mp \frac{M_y x}{I_y} \mp \frac{M_x y}{I_x}$$

$$A = Area\ of\ the\ mat = \big((7)(3) + 1 + 1\big) * \big((6)(3) + 1 + 1\big) = (23) * (20)$$

$$A = 460\mathrm{m}^2$$

$$I_x = \frac{bh^3}{12} = \frac{23(20)^3}{12} = 15333.3\ \mathrm{m}^4$$

$$I_y = \frac{bh^3}{12} = \frac{20(23)^3}{12} = 20278.3\ \mathrm{m}^4$$

$$Q = sum\ of\ all\ service\ colums\ loads$$

$$Q = 4(C1) + 4(C2) + 4(C3) + 4(C4) + extra\ column\ loads$$

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

$$Q = 38252\ kN$$

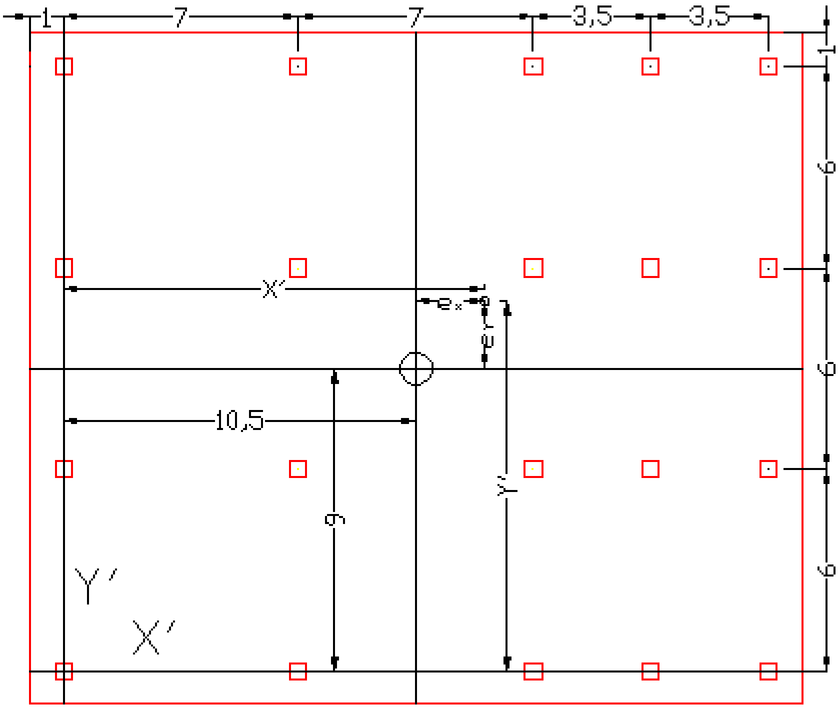

Figure 9, resultant position due to column loads

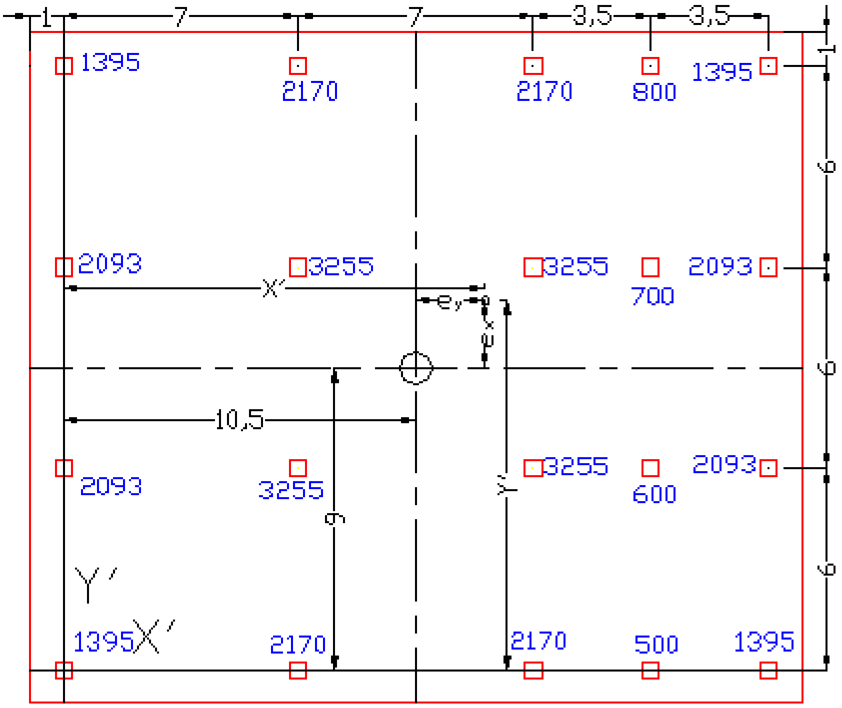

Figure 10, columns total service loads (DL+LL)

Calculate M_y:

$$e_x = X' - 10.5$$
$$Q * X' = Q1(x'1) + Q2(x'2) + \cdots$$
$$X' = \frac{Q1(x'1) + Q2(x'2) + \cdots}{Q}$$
$$X' = \frac{1}{38252}[(7)(2170 + 3255 + 3255 + 2170) + (14)(2170 + 3255 + 3255 + 2170) + (17.5)(800 + 700 + 600 + 500) + (21)(1395 + 2093 + 2093 + 1395)]$$
$$X' = \frac{1}{38252}[227850 + 45500 + 146496]$$
$$X' = 10.976\, m$$
$$e_x = 10.976 - 10.5 = 0.4758\, m$$
$$M_y = Qe_x = 38252 * 0.4758 = 18200\, kN.m$$

Calculate M_x:

$$e_y = Y' - 9$$
$$Q * Y' = Q1(y'1) + Q2(y'2) + \cdots$$
$$Y' = \frac{Q1(y'1) + Q2(y'2) + \cdots}{Q}$$

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

$$Y' = \frac{1}{38252}[142740 + 136752 + 67776]$$

$$Y' = 9.07843\, m$$

$$e_y = 9.07843 - 9 = 0.07843\, m$$

$$M_x = Qe_y = 38252 * 0.07843 = 3000\ kN.m$$

Calculate Soil pressure due to total service axial loads and moments:

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

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/m^2, to make sure that no tension could occur in any part of the raft

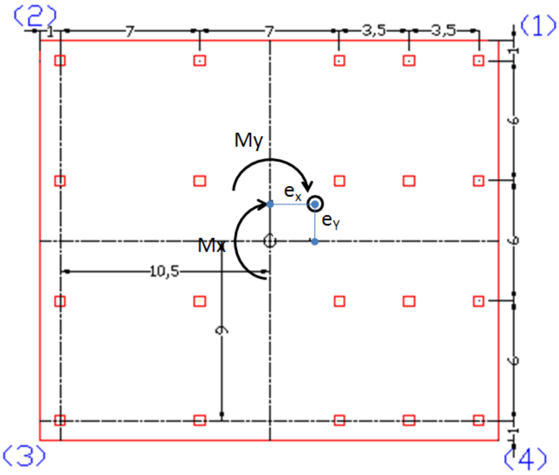

Figure 11, corners of raft

$$q_i = -\frac{Q}{A} \mp \frac{M_y x}{I_y} \mp \frac{M_x y}{I_x}$$

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

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

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

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

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

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

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

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

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

$$q_3 = -70.89 < q_{net} = 100\ kN/m^2 \text{ ok}$$

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

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

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

All pressure values are in compression and they are less than the net bearing stress of the soil which is equal to 100 kN/m^2

3.6.0 SAFE Settlement Analysis:

SAFE software has been used in the modeling of the raft, because the SAFE is specified slabs, footing and mat foundations modeling. Figure 11 shows the settlements contours that are analyzed by SAFE software. The maximum settlement occurred is equal to 28.5 millimeter. Settlement of 28.5 millimeters is considered to be acceptable, because the maximum allowable settlement is equal to 100 mm.

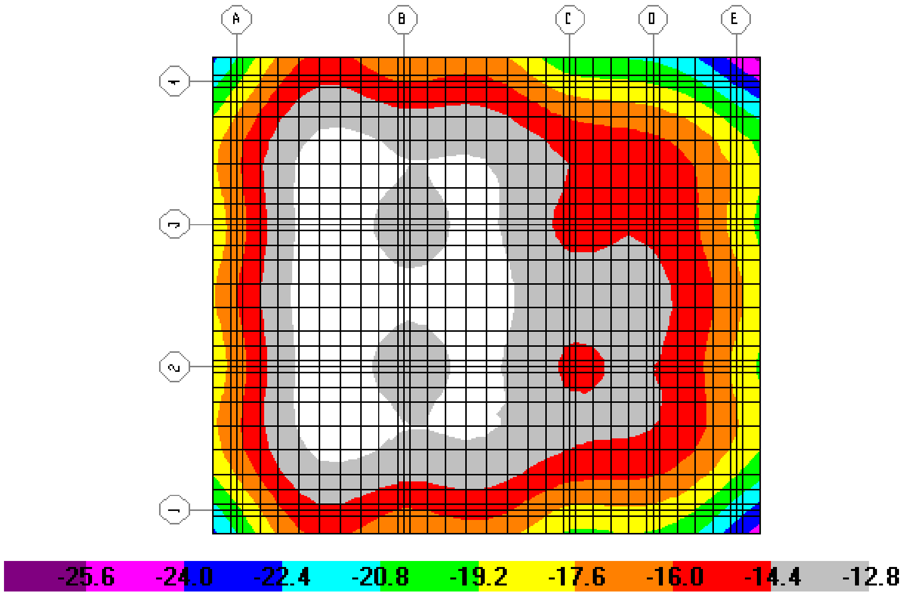

Figure 12, settlement of Raft using SAFA software

3.7.0 Moments Strips SAFE results:

In SAFE software, the raft is automaticity divided to different strips. Each direction has a column strip and middle strips. The moments analyzed by SAFE software are the strip moments per one meter width of the strip.

3.7.1 X direction strips

In x-strips, the column strips have a dimension of 2.5 meter width and the middle strips have a dimension of 3 meters width. Moments computed are analyzed base on one meter unit width of the strip. Moment Diagram of x-strips are shown in figure 13.

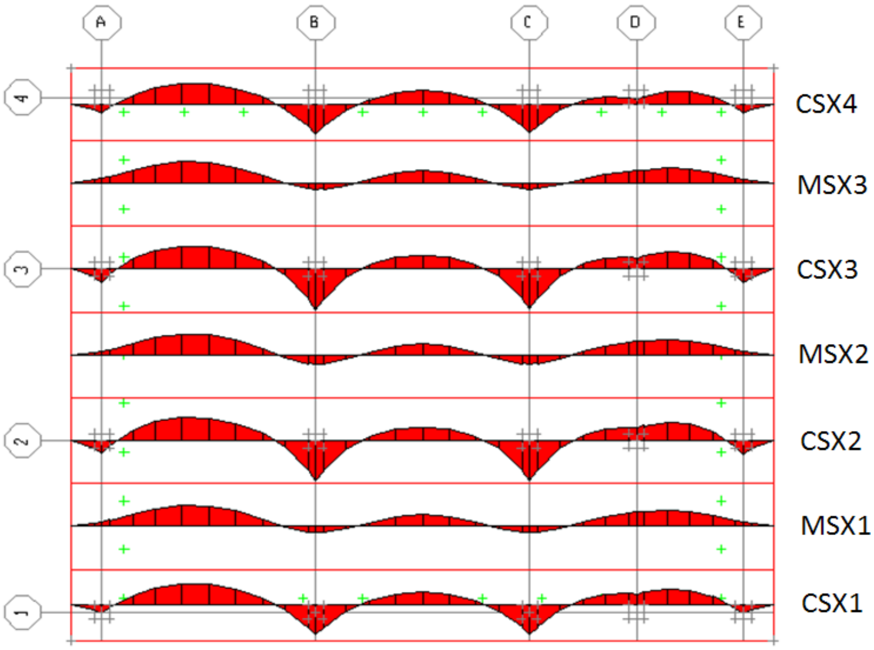

Figure 13, X-strip moment diagram

Table 5 shows the analysis outputs for x-strip moments. Negative moments will be designed for Top Reinforcement, and Positive moments will be designed for Bottom Reinforcement.

Strip notation	Strip Field	Maximum Moment Value (kN.m)	
		Positive	Negative
CSx1	Column strip	1144	1049.3
MSx1	Middle strip	319.1	1063.0
CSx2	Column strip	**1532**	1142.0
MSx2	Middle strip	476.6	1039.0
CSx3	Column strip	1523	**1142.3**
MSx3	Middle strip	303.4	1064.3
CSx4	Column strip	1119	1052.2

Table 5, x-strips moments values

3.7.2 Y direction strips

In y-strips, the column strips have a dimension of 2.75 meter width and the middle strips have a dimension of 3.5 meters width. Moments computed are analyzed base on one meter unit width of the strip. Moment Diagram of x-strips are shown in figure 14.

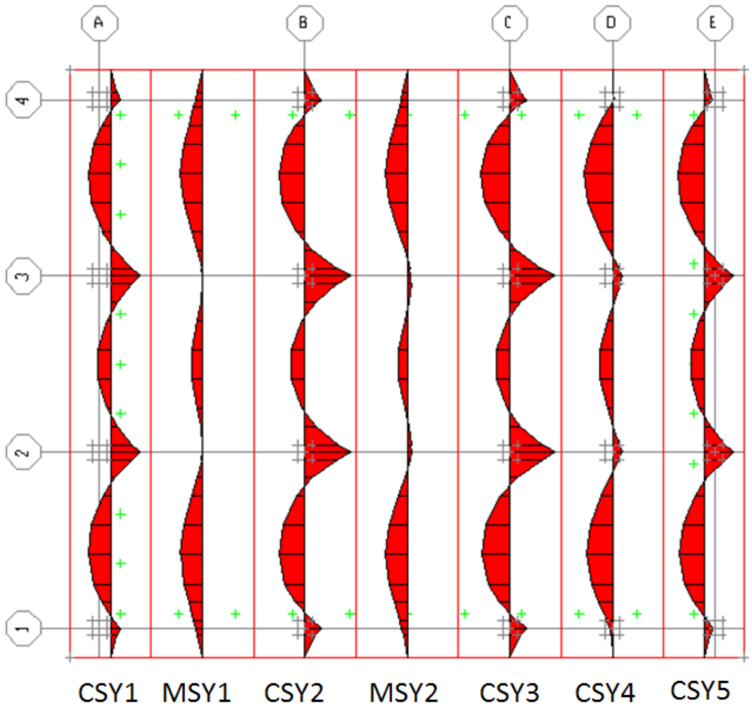

Figure 14, Y-strip moment diagram

Table 6 shows the analysis outputs for Y-strip moments. Negative moments will be designed for Top Reinforcement, and Positive moments will be designed for Bottom Reinforcement.

Strip notation	Strip Field	Maximum Moment Value (kN.m)	
		Positive	Negative
CSY1	Column strip	943	960.3
MSY1	Middle strip	26.1	927.7
CSY2	Column strip	**1450**	1107.3
MSY2	Middle strip	166.2	948.3
CSY3	Column strip	1445	**1230.3**
CSY4	Middle strip	344	1193.0
CSY5	Column strip	939.7	1117.5

Table 6, y-strips moments values

4. Manual & Computer Design:

Using the SAFE software analysis, the moments of x and y strips will be used to design the top and the bottom reinforcement for the raft. The maximum moments in each direction will be used to design the reinforcement in all raft strips. SAFE software design output will be compared with the manual design for those maximum positive and negative moments

4.1.0 X-strip Design:

4.1.1 Positive moments (Bottom Reinforcement):

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

$d = 800 - 75 = 725\ mm$

$M_u^+(maximum) = 1532\ kN.m/\mathrm{m}$

$$\frac{M_u^+}{\emptyset bd^2} = \frac{1532e6}{(0.9)(1000)(725)^2} = 3.238$$

$\rightarrow Go\ to\ q_u\ table \rightarrow\ \rho = 0.0088 > \rho_{min}\ = 0.0035$

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

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

$A_s = 6380\ mm^2/\mathrm{m}$

use 13Ø25/m $\quad A_s = 6381\ mm^2/\mathrm{m}$

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

Use Ø25@80mm

<u>Check Mc:</u>

$$\mathrm{a} = \frac{\mathrm{As} * \mathrm{Fy}}{0.85 * \mathrm{fc} * \mathrm{b}} = \frac{6381 * 400}{0.85 * 30 * 1000} = 100.1\ \mathrm{mm}$$

$$\mathrm{c} = \frac{\mathrm{a}}{\mathrm{B1}} = \frac{100.1}{0.85} = 117.7\ \mathrm{mm}$$

$\mathrm{d} = \mathrm{h} - \mathrm{cover} -= 800 - 75 = 725\ \mathrm{mm}$

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

then use $\emptyset = 0.9$

$$\mathrm{M_c} = \emptyset(\mathrm{As})(\mathrm{Fy})\left(\mathrm{d} - \frac{\mathrm{a}}{2}\right)$$

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

$\mathrm{M_c} = 1550.4\ \mathrm{kN.m} > Mu = 1532\ \mathrm{kN.m\ ok}$

Use Ø25@80mm for positive moments x − direction − bottom Reinforcement

4.1.2 Negative moments (Top Reinforcement):

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

$d = 800 - 75 = 725\ mm$

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

$$\frac{M_u^{\pm}}{\emptyset bd^2} = \frac{1142.3e6}{(0.9)(1000)(725)^2} = 2.415$$

$\rightarrow Go\ to\ q_u\ table \rightarrow\ \rho = 0.0064 > \rho_{min}\ = 0.0035$

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

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

$A_s = 4640\ mm^2/\text{m}$

use $10\emptyset 25/\text{m}$ $\quad A_s = 4909\ mm^2/\text{m}$

$$S = \frac{1000}{10-1} = 111.1\ use\ S = 110\ mm < S_{max}\ = 450\ mm$$

Use $\emptyset 25@110\ mm$

<u>Check Mc:</u>

$$\mathrm{a} = \frac{\mathrm{As} * \mathrm{Fy}}{0.85 * \mathrm{fc} * \mathrm{b}} = \frac{4909 * 400}{0.85 * 30 * 1000} = 77\ \mathrm{mm}$$

$$\mathrm{c} = \frac{\mathrm{a}}{\mathrm{B1}} = \frac{77}{0.85} = 90.6\ \mathrm{mm}$$

$$\mathrm{d} = \mathrm{h} - \mathrm{cover} - \mathrm{stirrups} - \frac{\mathrm{d_b}}{2} = 800 - 75 = 725\ \mathrm{mm}$$

$$\epsilon_{\mathrm{t}} = \left(\frac{\mathrm{d}-\mathrm{c}}{\mathrm{c}}\right) \times 0.003 = \left(\frac{725\ - 90.6}{90.6}\right) \times 0.003 = 0.021 > 0.005\ \ (\mathrm{Tension\,Control})$$

then use $\emptyset = 0.9$

$$\mathrm{M_c}\ = \emptyset(\mathrm{As})(\mathrm{Fy})\left(\mathrm{d} - \frac{\mathrm{a}}{2}\right)$$

$$\mathrm{M_c}\ = (0.9)(4909)(400)\left(725 - \frac{77}{2}\right)\mathrm{e}^{-6}$$

$\mathrm{M_c}\ = 1213.2\ \mathrm{kN.m} > Mu = 1532\ \mathrm{kN.m\ ok}$

Use $\emptyset 25@110\mathrm{mm}$ for negative moments x − direction − top Reinforcement

4.2.0 Y-strip Design:

4.2.1 Positive moments (Bottom Reinforcement):

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

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

$M_u^+(maximum) = 1532\ kN.m/\text{m}$

$$\frac{M_u^+}{\emptyset bd^2} = \frac{1450e6}{(0.9)(1000)(700)^2} = 3.288$$

$\rightarrow Go\ to\ q_u\ table \rightarrow\ \rho = 0.009 > \rho_{min}\ = 0.0035$

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

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

$A_s = 6300\ mm^2/\text{m}$

use 13Ø25/m $\quad A_s = 6381\ mm^2/\text{m}$

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

Use $\emptyset 25@80mm$

<u>Check Mc:</u>

$$\text{a} = \frac{\text{As} * \text{Fy}}{0.85 * \text{fc} * \text{b}} = \frac{6381 * 400}{0.85 * 30 * 1000} = 100.1\ \text{mm}$$

$$\text{c} = \frac{\text{a}}{\text{B1}} = \frac{100.1}{0.85} = 117.7\ \text{mm}$$

$\text{d} = \text{h} - \text{cover} -= 800 - 75 = 725\ \text{mm}$

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

then use $\emptyset = 0.9$

$$\text{M}_\text{c} = \emptyset(\text{As})(\text{Fy})\left(\text{d} - \frac{\text{a}}{2}\right)$$

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

$\text{M}_\text{c} = 1550.4\ \text{kN.m} > Mu = 1450\ \text{kN.m ok}$

Use Ø25@80mm for positive moments Y − direction − bottom Reinforcement

4.2.2 Negative moments (Top Reinforcement):

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

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

$M_u^-(maximum) = 1532\ kN.m/\text{m}$

$$\frac{M_u^{\pm}}{\emptyset bd^2} = \frac{1230.3e6}{(0.9)(1000)(700)^2} = 2.790$$

$\rightarrow Go\ to\ q_u\ table \rightarrow\ \rho = 0.0076 > \rho_{min}\ = 0.0035$

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

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

$A_s = 5300\ mm^2/\text{m}$

use $11\emptyset 25$/m $\quad A_s = 5400\ mm^2/\text{m}$

$$S = \frac{1000}{10-1} = 100\ use\ S = 100\ mm < S_{max}\ = 450\ mm$$

Use $\emptyset 25@100\ mm$

<u>Check Mc:</u>

$$\text{a} = \frac{\text{As} * \text{Fy}}{0.85 * \text{fc} * \text{b}} = \frac{5400 * 400}{0.85 * 30 * 1000} = 84.7\ \text{mm}$$

$$\text{c} = \frac{\text{a}}{\text{B1}} = \frac{84.7}{0.85} = 99.6\ \text{mm}$$

$\text{d} = \text{h} - \text{cover} - \text{stirrups} - \text{d}_\text{b} = 800 - 75 - 25 = 700\ \text{mm}$

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

then use $\emptyset = 0.9$

$$\text{M}_\text{c} = \emptyset(\text{As})(\text{Fy})\left(\text{d} - \frac{\text{a}}{2}\right)$$

$$\text{M}_\text{c} = (0.9)(5400)(400)\left(700 - \frac{84.7}{2}\right)\text{e}^{-6}$$

$\text{M}_\text{c} = 1278.5\ \text{kN.m} > Mu = 1230.3\ \text{kN.m ok}$

Use $\emptyset 25@100\text{mm for negative moments Y} - \text{direction} - \text{top Reinforcement}$

4.3.0 Comparison Table:

	Moment Value kN.m/m	Manual Design		SAFE design
X-strip				
Bottom As	1532	$\emptyset 25@80mm$	$6381\ mm^2/m$	$13\emptyset 25 = 6381\ mm^2/m$
Top As	1142.3	$\emptyset 25@110mm$	$4909\ mm^2/m$	$10\emptyset 25 = 4909\ mm^2/m$
Y-strip				
Bottom As	1450	$\emptyset 25@80\mathrm{mm}$	$6381\ mm^2/m$	$12\emptyset 25 = 5890 mm^2/m$
Top As	1230.3	$\emptyset 25@100\mathrm{mm}$	$5400\ mm^2/m$	$11\emptyset 25 = 5400 mm^2/m$

Table 7, comparison between manual and computer design

4.4.0 Detailing:

Reinforcement detailing will be shown in the next page.

5. Conclusion:

At the end of this special project, we are really happy that we have been involved in the Raft manual design. The raft foundation is considered to be a very common foundation type especially here in Qatar.

We also have been involved in using SAFE analysis and design software which is really professional and helped us for this project.

6. References:

- MacGregor, Wight, Reinforced Concrete Mechanics And Design, 4th edition, University of Michigan,
- Braja M.Das, Principles of Foundation Engineering, 6th edition, 2007 by Nelson, Chris Carson
- Al-Ansari notes in Course: Design of Reinforced Concrete Structure, Fall 2008, Qatar University

7. Index:

$a = depth\ of\ rectangular\ stress\ distribution\ from\ compression\ fiber\ to$
$distance\ \beta_1 c$

$A_s \quad = area\ of\ tension\ \ steel$

$A_b \quad = area\ of\ individual\ bar$

$A_{s,min} = minimum\ tension\ reinforcement$

$b \quad = width\ of\ compression\ face$

$b_o \quad = perimeter\ of\ critical\ section\ for\ two$
$- way\ shear\ in\ slabs\ and\ footings\ , mm$

$C_a \quad = coefficient\ of\ aticve\ earth\ pressure$

C_c
$= clear\ cover\ from\ the\ nearest\ surface\ in\ tension\ to\ the\ surface\ of\ the\ flexural$
$tension\ reinforcement, mm$

$C_m \quad = factor\ relating\ the\ actual\ moment\ diagram\ of\ a\ slender$
$column\ to\ an\ equivelant\ uniform\ moment\ diagram$

$C_m \quad = moment\ coefficient$

$C_p \quad = coefficient\ of\ passie\ earth\ pressure$

d
$= effective\ depth\ from\ compression\ surface\ to\ center\ of\ steel\ in\ tension\ zone.$

$d' \quad = distance\ from\ extreme\ \ - compression\ fiber\ to\ centroid\ of\ comresssion$
$renforcement, mm$

$d_b = nominal\ diameter\ of\ bar\ , wire\ , or\ prestressing\ strand\ , mm$

$D \quad = dead\ load$

$e \quad = eccentricity$

$E_c = modulus\ of\ elasticity\ of\ concrete\ MPa\ or \frac{N}{mm^2}$

$EI = Flexural\ stiffness\ of\ compression\ member\ , N - mm^2$

$E_s = modulus\ of\ elasticity\ of\ reinforcement\ MPa\ or \frac{N}{mm^2}$

$f_c' \quad = compressive\ strength\ in\ concrete\ due\ 28 - day, psi\ or\ MPa$

$f_s \quad = calculated\ stress\ in\ reinforcement\ at\ service\ loads\ , MPa\ or\ N/mm^2$

$f_y \quad = yeild\ strength\ of\ nonprestressed\ reinforcement$

$h \quad = overall\ depth\ or\ thickness\ of\ slab\ or\ beam$

$I \quad = moment\ of\ inertia\ of\ a\ section\ , mm^4$

$j_d \quad = distance\ between\ the\ resultants\ of\ the\ internal\ compressive\ and$
$tensile\ force\ on\ \ cross\ section$

$k \quad = effectivr\ length\ factored\ for\ compression\ member$

$l \quad = span\ length\ of\ beam\ or\ one$
$- way\ slab\ , generally\ center\ to\ center\ of\ supports$

$l_d \quad = development\ length$

$l_n \quad = clear\ span\ measured\ face\ to\ face\ of\ supports.$

$M \quad = moment$

M_c

$= factored\ moment\ to\ be\ used\ for\ design\ of\ a\ slender\ compression\ member\ KN - m$

$M_u \quad = factored\ moment\ due\ to\ factored\ load$

$P_c \quad = critical\ load$

$P_E \quad = buckling\ load\ of\ an\ elastic\ , hinged - end\ column$

$P_n \quad = nominal\ axial\ load\ strength\ at\ given\ eccentricity$

$P_o \quad = nominal\ axial\ load\ strength\ at\ zero\ eccentricity$

$P_u \quad = axial\ force\ due\ to\ factored\ load$

$S \quad = spacing\ between\ bars$

$V_c \quad = Nominal\ shear\ strength\ of\ concrete$

$V_u \quad = shear\ force\ due\ to\ factored\ load$

$W \quad = weight$

$\beta_1 \quad = ratio\ of\ depth\ pf\ rectangular\ stress\ block\ , a, to\ depth\ to\ neutral\ axis, c$

γ

$= ratio\ of\ the\ distance\ between\ the\ outer\ layers\ of\ reinforcement\ in\ a\ column\ to\ the\ overall\ depth\ of\ the\ column\ .$

$\rho \quad = ratio\ of\ tension\ steel$