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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Notation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield strength of steel</td>
<td>$F_y$</td>
<td>400 MPa</td>
</tr>
<tr>
<td>Strength of concrete</td>
<td>$f_c$</td>
<td>30 MPa</td>
</tr>
<tr>
<td>Young modules of elasticity</td>
<td>$E$</td>
<td>2000000</td>
</tr>
<tr>
<td>Dear load factor</td>
<td>D.L.F</td>
<td>1.2</td>
</tr>
<tr>
<td>Live load factor</td>
<td>L.L .F</td>
<td>1.6</td>
</tr>
<tr>
<td>Soil Unit weight</td>
<td>$\gamma_{soil}$</td>
<td>15 kN/m³</td>
</tr>
<tr>
<td>Allowable Bearing stress</td>
<td>$q_a$</td>
<td>100 kN/ m²</td>
</tr>
<tr>
<td>Concrete Unit weight</td>
<td>$\gamma_{concrete}$</td>
<td>25 kN/ m³</td>
</tr>
</tbody>
</table>

Table 1, parameters 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](image)

The total area of the raft = \((3 \times 7) + 1 + 1\) \(\times\) \((3 \times 6) + 1 + 1\)
= 23 \(\times\) 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.

<table>
<thead>
<tr>
<th>Load type</th>
<th>Load case</th>
<th>Load value (kN/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Services</td>
<td>Dead</td>
<td>2.5 kN/m²</td>
</tr>
<tr>
<td>Slab own weight</td>
<td>Dead</td>
<td>(25kN/m³)(0.2m) = 5 kN/m²</td>
</tr>
<tr>
<td>Flooring</td>
<td>Dead</td>
<td>1 kN/m²</td>
</tr>
<tr>
<td>Live loads</td>
<td>Live</td>
<td>7 kN/m²</td>
</tr>
</tbody>
</table>

Table 2, design loads

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

Loads per square meter are calculated as:

General Dead load stress = \((5 + 2.5 + 1)\frac{kN}{m^2} \times \text{no. of floors}\)

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

General Life load stress = \((7)\frac{kN}{m^2} \times 5 = 35 \text{ kN/m}^2\)
**Columns loads:**

*Axial Dead load* = Stress per unit area \( \frac{kN}{m^2} \) * Turbidity area

**Column type (1):**
Axial unfactored Dead load = 42.5 kN/m\(^2\) \(\times\) (4 \(\times\) 4.5) m\(^2\) = 765 kN
Axial unfactored Live load = 35 kN/m\(^2\) \(\times\) (4 \(\times\) 4.5)m\(^2\) = 630 kN
Total Sevice Axial load = 765 + 630 kN = 1395 kN
Ultimate axial load = 1.2(765) + 1.6(630) = 1926 kN

**Column type (2):**
Axial unfactored Dead load = 42.5 kN/m\(^2\) \(\times\) (4 \(\times\) 7)m\(^2\) = 1190 kN
Axial unfactored Live load = 35 kN/m\(^2\) \(\times\) (4 \(\times\) 7)m\(^2\) = 980 kN
Total Sevice Axial load = 1190 + 980 kN = 2170 kN
Ultimate axial load = 1.2(1190) + 1.6(980) = 2996 kN

**Column type (3):**
Axial unfactored Dead load = 42.5 kN/m\(^2\) \(\times\) (4.5 \(\times\) 6)m\(^2\) = 1148 kN
Axial unfactored Live load = 35 kN/m\(^2\) \(\times\) (4.5 \(\times\) 6)m\(^2\) = 945 kN
Total Sevice Axial load = 1148 + 945 kN = 2093 kN
Ultimate axial load = 1.2(1148) + 1.6(945) = 2889 kN

**Column type (4):**
Axial unfactored Dead load = 42.5 kN/m\(^2\) \(\times\) (7 \(\times\) 6)m\(^2\) = 1785 kN
Axial unfactored Live load = 35 kN/m\(^2\) \(\times\) (7 \(\times\) 6)m\(^2\) = 1470 kN
Total Sevice Axial load = 1785 + 1470 kN = 3255 kN
Ultimate axial load = 1.2(1785) + 1.6(1470) = 4494 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.

<table>
<thead>
<tr>
<th>Column no.</th>
<th>Dead load (kN)</th>
<th>Live load (kN)</th>
<th>Total service load (kN)</th>
<th>Total factored load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>765</td>
<td>630</td>
<td>1395</td>
<td>1926</td>
</tr>
<tr>
<td>C2</td>
<td>1190</td>
<td>980</td>
<td>2170</td>
<td>2996</td>
</tr>
<tr>
<td>C3</td>
<td>1148</td>
<td>945</td>
<td>2093</td>
<td>2889</td>
</tr>
<tr>
<td>C4 (maximum)</td>
<td>1785</td>
<td>1470</td>
<td>3255</td>
<td>4494</td>
</tr>
<tr>
<td>C5 (extra)</td>
<td>500</td>
<td>300</td>
<td>800</td>
<td>1080</td>
</tr>
<tr>
<td>C6 (extra)</td>
<td>450</td>
<td>250</td>
<td>700</td>
<td>940</td>
</tr>
<tr>
<td>C7 (extra)</td>
<td>400</td>
<td>200</td>
<td>600</td>
<td>800</td>
</tr>
<tr>
<td>C8 (extra)</td>
<td>350</td>
<td>150</td>
<td>500</td>
<td>660</td>
</tr>
</tbody>
</table>

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 resist all columns loads up to the maximum load of 4494 kN

![Figure 3, Column design](image)

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

\[ P_c = \phi P_n = (0.7)(0.8)[(0.85)(30)(500)(500) + (400)(4562)] \]

\[ P_c = 4592 \text{ kN} > P_u = 4494 \text{ kN} \]
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.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Loose sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective bearing stress for the soil</td>
<td>$q_e = 100$ kN/m$^2$</td>
</tr>
<tr>
<td>Sub-grade modules</td>
<td>20,000 kN/m$^3$</td>
</tr>
<tr>
<td>Concrete strength of raft</td>
<td>30 MPa</td>
</tr>
<tr>
<td>Reinforcement Steel strength</td>
<td>400 MPa</td>
</tr>
</tbody>
</table>

Table 4, Properties taken in Raft Design

$q_e = 100$ kN/m$^2$
Total Maximum Sevice Axial load $= 1785 + 1470$ kN $= 3255$ kN
Area of single square footing $= \frac{1.1(3255)}{100} = 35.8$ m$^2$
$B \times B = 35.8 \rightarrow B = \sqrt{35.8} = 6$ m by 6 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.

\[
U = (b_o)(d)(\varnothing)(0.34)\sqrt{f'_c} \quad 11.12.2.1.c
\]

Where,
- \(U\) = factored column load
- \(\varnothing\) = 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.

\[
U = (b_o)(d)(\varnothing)(0.34)\sqrt{f'_c} \quad \text{ACI-05 11.12.2.1.c}
\]

\[
4.494 = (1.6 + 4d)(d)(0.75)(0.34)\sqrt{30}
\]
\[
4.494 = (1.6d + 4d^2)(1.397)
\]
\[
3.2169 = 1.6d + 4d^2
\]
\[
0 = 4d^2 + 1.6d - 3.2169
\]
\[
0 = 4d^2 + 1.6d - 3.2169
\]

Solving equation for \(d\)
\[
d = 0.689 \text{ m} = 689 \text{ mm} = 700 \text{ mm}
\]

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:

\[ V_u = \text{Maximum shear} - (d)(w_{soil}) \]

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](image)

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

\[ q_{alt} = \frac{\text{Total factored loads in strip CSY3}}{\text{Area of the strip}} \]
\[ q_{alt} = \frac{\text{Area of the strip}}{C2 + C4 + C4 + C2} \]

\[ q_{alt} = \frac{(\text{width of strip})(\text{length of strip})}{2996 + 4494 + 4494 + 2996} = 214 \text{ kN/m}^2 \]

\[ q_{alt} = 214 \text{ kN/m}^2 \]

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

\[ w_{soil} = 749 \text{ kN/m} \]

Assuming

\[ d = 800 - 75 = 725 \text{ mm} \]

\[ V_u = \text{Maximum shear} - (d)(w_{soil}) \]

\[ V_u = 2173.5 - (0.725)(749) \]

\[ V_u = 1630.5 \text{ kN} \]

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

\[ d = 680.4 \text{ mm} < d = 725 \text{ mm ok} \]
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

\[ d = 800 - 75 = 725 \, mm \]

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

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

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

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

\[ d_{III} = 622.6 \, mm \]

\[ d = 622.6 \, mm < d = 725 \, ok \]

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:
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 kN/m².

\[ q = \frac{Q}{A} \pm \frac{M_y x}{I_y} \pm \frac{M_x y}{I_x} \]

\[ A = \text{Area of the mat} = (7)(3) + 1 + 1 \times (6)(3) + 1 + 1 = 23 \times 20 \]

\[ A = 460 m^2 \]

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

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

\[ Q = \text{sum of all service columns loads} \]

\[ Q = 4(C1) + 4(C2) + 4(C3) + 4(C4) + \text{extra column loads} \]

\[ Q = 4(1395) + 4(2170) + 4(2093) + 4(3225) + 800 + 700 + 600 + 500 \]

\[ Q = 38252 kN \]
**Calculate M_y:**

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

**Calculate M_x:**

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


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

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

\[ Y' = 9.07843 \text{ m} \]

\[ e_y = 9.07843 - 9 = 0.07843 \text{ m} \]

\[ M_x = Qe_y = 38252 \times 0.07843 = 3000 \text{ kN} \cdot \text{m} \]

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

\[ q_i = -\frac{Q}{A} + \frac{M_yx}{I_y} + \frac{M_xy}{I_x}, \text{ } i = 1, 2, 3 \text{ and } 4 \]

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 occur in any part of the raft.

\[ q_1 = -\frac{38252}{460} \times \frac{18200(11.5)}{18200(11.5)} - \frac{3000(10.5)}{15333.3} - \frac{108157 - 10.321 - 2.054}{10.5} = 100 \text{ kN/m}^2 \text{ ok} \]

\[ q_2 = -\frac{38252}{460} \times \frac{18200(11.5)}{18200(11.5)} + \frac{15333.3}{3000(10.5)} - \frac{108157 + 10.321 - 2.054}{10.5} = 95.532 < q_{net} = 100 \text{ kN/m}^2 \text{ ok} \]

\[ q_3 = -\frac{38252}{460} \times \frac{18200(11.5)}{18200(11.5)} + \frac{15333.3}{3000(10.5)} - \frac{108157 + 10.321 + 2.054}{10.5} = 70.89 < q_{net} = 100 \text{ kN/m}^2 \text{ ok} \]

\[ q_4 = -\frac{38252}{460} \times \frac{18200(11.5)}{18200(11.5)} + \frac{15333.3}{3000(10.5)} - \frac{108157 - 10.321 + 2.054}{10.5} = 91.424 < q_{net} = 100 \text{ kN/m}^2 \text{ ok} \]

All pressure values are in compression and they are less than the net bearing stress of the soil which is equal to 100 kN/m².
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.

![Settlement Contours](image)

*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](image)

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.

<table>
<thead>
<tr>
<th>Strip notation</th>
<th>Strip Field</th>
<th>Maximum Moment Value (kN.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Positive</td>
</tr>
<tr>
<td>CSx1</td>
<td>Column strip</td>
<td>1144</td>
</tr>
<tr>
<td>MSx1</td>
<td>Middle strip</td>
<td>319.1</td>
</tr>
<tr>
<td>CSx2</td>
<td>Column strip</td>
<td>1532</td>
</tr>
<tr>
<td>MSx2</td>
<td>Middle strip</td>
<td>476.6</td>
</tr>
<tr>
<td>CSx3</td>
<td>Column strip</td>
<td>1523</td>
</tr>
<tr>
<td>MSx3</td>
<td>Middle strip</td>
<td>303.4</td>
</tr>
<tr>
<td>CSx4</td>
<td>Column strip</td>
<td>1119</td>
</tr>
</tbody>
</table>

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](image)

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.

<table>
<thead>
<tr>
<th>Strip notation</th>
<th>Strip Field</th>
<th>Maximum Moment Value (kN.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Positive</td>
</tr>
<tr>
<td>CSY1</td>
<td>Column strip</td>
<td>943</td>
</tr>
<tr>
<td>MSY1</td>
<td>Middle strip</td>
<td>26.1</td>
</tr>
<tr>
<td>CSY2</td>
<td>Column strip</td>
<td><strong>1450</strong></td>
</tr>
<tr>
<td>MSY2</td>
<td>Middle strip</td>
<td>166.2</td>
</tr>
<tr>
<td>CSY3</td>
<td>Column strip</td>
<td>1445</td>
</tr>
<tr>
<td>CSY4</td>
<td>Middle strip</td>
<td>344</td>
</tr>
<tr>
<td>CSY5</td>
<td>Column strip</td>
<td>939.7</td>
</tr>
</tbody>
</table>

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

\[ d = 800 - 75 = 725 \text{ mm} \]

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

\[ M_u^+ = \frac{1532 e 6}{(0.9)(1000)(725)^2} = 3.238 \]

→ Go to qu table → \( \rho = 0.0088 > \rho_{\text{min}} = 0.0035 \)

→ \( \rho = 0.0088 < \rho_{\text{max}} = 0.0244 \)

\[ A_s = 0.0088(b)(d) = 0.0088(1000)(725) \]

\[ A_s = 6380 \text{ mm}^2/\text{m} \]

use 13Ø25/m  \( A_s = 6381 \text{ mm}^2/\text{m} \)

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

Use Ø25@80mm

Check Mc:

\[ a = \frac{A_s * F_y}{0.85 * f_c * b} = \frac{6381 * 400}{0.85 * 30 * 1000} = 100.1 \text{ mm} \]

\[ a = \frac{100.1}{0.85} = 117.7 \text{ mm} \]

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

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

then use \( \phi = 0.9 \)

\[ M_c = \phi (A_s)(F_y) \left( d - \frac{a}{2} \right) \]

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

\[ M_c = 1550.4 \text{ kN.m} > Mu = 1532 \text{ kN.m ok} \]

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 
\[ d = 800 - 75 = 725 \text{ mm} \]

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

\[ \frac{1142.3 \times 10^6}{(0.9)(1000)(725)^2} = 2.415 \]

→ Go to q u table 
\[ \rho = 0.0064 > \rho_{\text{min}} = 0.0035 \]
\[ \rho = 0.0064 < \rho_{\text{max}} = 0.0244 \]
\[ A_s = 0.0064(b)(d) = 0.0064(1000)(725) \]
\[ A_c = 4640 \text{ mm}^2 / \text{m} \]
use \( 10\Phi25 / \text{m} \) \( A_s = 4909 \text{ mm}^2 / \text{m} \)

\[ S = \frac{1000}{10 - 1} = 111.1 \text{ use } S = 110 \text{ mm} < S_{\text{max}} = 450 \text{ mm} \]
Use \( \Phi25@110 \text{ mm} \)

Check Mc:
\[ a = \frac{A_s \times F_y}{0.85 \times f_c \times b} = \frac{4909 \times 400}{0.85 \times 30 \times 1000} = 77 \text{ mm} \]
\[ c = \frac{a}{B1} = \frac{77}{0.85} = 90.6 \text{ mm} \]

\[ d = h - \text{cover} - \text{stirrups} - \frac{d_b}{2} = 800 - 75 = 725 \text{ mm} \]

\[ \varepsilon_t = \left( \frac{d - c}{c} \right) \times 0.003 \left( \frac{725 - 90.6}{90.6} \right) \times 0.003 = 0.021 > 0.005 \text{ (Tension Control)} \]
then use \( \Phi = 0.9 \)
\[ M_c = \Phi(A_s)(F_y) \left( d - \frac{a}{2} \right) \]
\[ M_c = (0.9)(4909)(400) \left( 725 - \frac{77}{2} \right) e^{-6} \]
\[ M_c = 1213.2 \text{ kN.m} > Mu = 1532 \text{ kN.m} \text{ ok} \]
Use \( \Phi25@110 \text{ mm} \) 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

\[ d = 800 - (75 + 25) = 700 \text{ mm} \]

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

\[ M_u^+ = \frac{\phi bd^2}{(0.9)(1000)(700)^2} = 3.288 \]

\[ \rightarrow \text{Go to } q_u \text{ table } \rightarrow \rho = 0.009 > \rho_{\text{min}} = 0.0035 \]

\[ \rho = 0.009 < \rho_{\text{max}} = 0.0244 \]

\[ A_s = 0.009(b)(d) = 0.009(1000)(700) \]

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

use 13\( \phi \)25/m \( A_s = 6381 \text{ mm}^2/\text{m} \)

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

Use \( \phi \)25@80mm

Check Mc:

\[ a = \frac{A_s \times F_y}{0.85 \times f_c \times b} = 6381 \times 400 \]

\[ c = \frac{100.1}{0.85} = 117.7 \text{ mm} \]

\[ d = h - \text{cover}_{\text{=}} = 800 - 75 = 725 \text{ mm} \]

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

then use \( \phi = 0.9 \)

\[ M_c = \phi(A_s)(F_y) \left( d - \frac{a}{2} \right) \]

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

\[ M_c = 1550.4 \text{ kN.m} > M_u = 1450 \text{ kN.m ok} \]

Use \( \phi \)25@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

\[ d = 800 - (75 + 25) = 700 \text{ mm} \]

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

\[ \frac{\phi bd^2}{\mu} = \frac{1230.3e6}{(0.9)(1000)(700)^2} = 2.790 \]

\[ \rightarrow \text{Go to } q_u \text{ table } \rho = 0.0076 > \rho_{\text{min}} = 0.0035 \]

\[ \rightarrow \rho = 0.0076 < \rho_{\text{max}} = 0.0244 \]

\[ A_s = 0.0076(b)(d) = 0.0076(1000)(700) \]

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

use 11\( \varnothing 25/\text{m} \)  

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

Use \( \varnothing 25@100 \text{ mm} \)

Check Mc:

\[ a = \frac{As \times F_y}{0.85 \times fc \times b} = \frac{5400 \times 400}{0.85 \times 30 \times 1000} = 84.7 \text{ mm} \]

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

\[ d = h - \text{cover} - \text{stirrups} - d_b = 800 - 75 - 25 = 700 \text{ mm} \]

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

then use \( \varnothing = 0.9 \)

\[ M_c = \varnothing (As)(Fy) \left( d - \frac{a}{2} \right) \]

\[ M_c = (0.9)(5400)(400) \left( 700 - \frac{84.7}{2} \right) e^{-6} \]

\[ M_c = 1278.5 \text{ kN.m} > Mu = 1230.3 \text{ kN.m} \text{ ok} \]

Use \( \varnothing 25@100 \text{mm} \) for negative moments Y - direction - top Reinforcement
4.3.0 Comparison Table:

<table>
<thead>
<tr>
<th></th>
<th>Moment Value kN.m/m</th>
<th>Manual Design</th>
<th>SAFE design</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>X-strip</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom As</td>
<td>1532</td>
<td>Ø25@80mm</td>
<td>6381 mm²/m</td>
</tr>
<tr>
<td>Top As</td>
<td>1142.3</td>
<td>Ø25@110mm</td>
<td>4909 mm²/m</td>
</tr>
<tr>
<td><strong>Y-strip</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom As</td>
<td>1450</td>
<td>Ø25@80mm</td>
<td>6381 mm²/m</td>
</tr>
<tr>
<td>Top As</td>
<td>1230.3</td>
<td>Ø25@100mm</td>
<td>5400 mm²/m</td>
</tr>
</tbody>
</table>

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,


- Al-Ansari notes in Course: Design of Reinforced Concrete Structure, Fall 2008, Qatar University
7. Index:

\[ a = \text{depth of rectangular stress distribution from compression fiber to distance } \beta_1 c \]
\[ A_s = \text{area of tension steel} \]
\[ A_b = \text{area of individual bar} \]
\[ A_{s, \text{min}} = \text{minimum tension reinforcement} \]
\[ b = \text{width of compression face} \]
\[ b_o = \text{perimeter of critical section for two} \]
\[ \text{way shear in slabs and footings, mm} \]
\[ C_a = \text{coefficient of active earth pressure} \]
\[ C_c = \text{clear cover from the nearest surface in tension to the surface of the flexural tension reinforcement, mm} \]
\[ C_m = \text{factor relating the actual moment diagram of a slender column to an equivalent uniform moment diagram} \]
\[ C_p = \text{coefficient of passive earth pressure} \]
\[ d = \text{effective depth from compression surface to center of steel in tension zone.} \]
\[ d' = \text{distance from extreme compression fiber to centroid of compression reinforcement, mm} \]
\[ d_b = \text{nominal diameter of bar, wire, or prestressing strand, mm} \]
\[ D = \text{dead load} \]
\[ e = \text{eccentricity} \]
\[ E_c = \text{modulus of elasticity of concrete MPa or } \frac{N}{mm^2} \]
\[ EI = \text{Flexural stiffness of compression member, } N - mm^2 \]
\[ E_s = \text{modulus of elasticity of reinforcement MPa or } \frac{N}{mm^2} \]
\[ f_c' = \text{compressive strength in concrete due 28-day, psi or MPa} \]
\[ f_s = \text{calculated stress in reinforcement at service loads, MPa or N/mm}^2 \]
\[ f_y = \text{yield strength of nonprestressed reinforcement} \]
\[ h = \text{overall depth or thickness of slab or beam} \]
\[ I = \text{moment of inertia of a section, mm}^4 \]
\[ j_d = \text{distance between the resultants of the internal compressive and tensile force on cross section} \]
\[ k = \text{effective length factored for compression member} \]
\[ l = \text{span length of beam or one} \]
\[ \text{way slab, generally center to center of supports} \]
\[ l_d = \text{development length} \]
\[ l_n = \text{clear span measured face to face of supports.} \]
\[ M = \text{moment} \]
\[ M_c = \text{factored moment to be used for design of a slender compression member KN} \]
\[ -m \]
\[ M_u = \text{factored moment due to factored load} \]
\[ P_c = \text{critical load} \]
\[ P_E = \text{buckling load of an elastic, hinged - end column} \]
\[ P_n = \text{nominal axial load strength at given eccentricity} \]
\[ P_o = \text{nominal axial load strength at zero eccentricity} \]
\[ P_u = \text{axial force due to factored load} \]
\[ S = \text{spacing between bars} \]
\[ V_c = \text{Nominal shear strength of concrete} \]
\[ V_u = \text{shear force due to factored load} \]
\[ W = \text{weight} \]
\[ \beta_1 = \text{ratio of depth of rectangular stress block, a, to depth to neutral axis, c} \]
\[ \gamma = \text{ratio of the distance between the outer layers of reinforcement in a column to the overall depth of the column} \]
\[ \rho = \text{ratio of tension steel} \]