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Structural Design of Raft Foundation - A Case Study of Lucknow Region in Uttar Pradesh, India

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Abstract

In this age of rapid growth in population in India, there is a scarcity of land in prime locations especially in metro cities of the country. So, to overcome this problem we are moving towards vertical constriction (that is towards high-rise buildings). The main problem in moving towards vertical construction is the foundation system, if the foundation system in high rise buildings is not planned and designed smartly and economically then there are different problems related to the foundation system that is going to arise, the soil in that area also plays a very important role in designing of the economical and stable foundation system. It is always beneficial to have a raft foundation on alluvial soil for high-rise buildings. But, however, it is a matter of great concern what foundation will be proposed on such types of natural soils or man-made refills. In this paper, an attempt has been made to design a raft foundation based on its geotechnical analysis. An extensive survey of research works devoted to studying the geotechnical parameters affecting the behavior of raft foundations is carried out with detailed experiments raft foundations are increasingly being recognized as an economical and effective foundation system for high-rise buildings. This paper sets out some principles of design for such foundations, including design for the geotechnical ultimate limit state, the structural ultimate limit state, and the serviceability limit state. Attention will be focused on the improvement in the foundation performance due to the raft being in contact with, and embedded within, the soil.

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Keywords

Raft foundation, High rise buildings, Alluvial region

1. Introduction

This Raft Foundation has been designed for (G+10) High Rise Building in Alluvial region. The Raft Foundation have been used for economical consideration. In column load section, justification has been given for using raft foundation. Raft foundation is a type of combined footing, in this the entire area under the structure is provided as one rigid body supporting several columns [1-3]. In this, the total allowable bearing stress have been taken as 100 KN/m2, since the soil is alluvial, the bearing stress is around 100 KN/m2.and in this type of soil raft foundation is most suitable type for high rise buildings. Since the columns have high axial loads, if spread footings are used, it will require large area under columns, which is not practical and economical, so in this condition we prefer using raft foundation. In this, the raft will be designed as flat plate, which has a uniform thickness and without any beams or pedestals [5-10].

2. The Foundation Design for a High-Rise Building of 10 Stories

Table 1. Parameters used in raft design

Parameter	Notation	Value
Young modules of elasticity	(E)	2000000
Strength of concrete	(f_c)	30 MPa
Yield strength of steel	(f_y)	400 MPa
Live load factor	(L.L.F)	1.6
Dear load factor	(D.L.F)	1.2
Allowable Bearing stress	(q_a)	100 KN/ m^2
Soil Unit weight	(ɣ soil)	15 KN/m^3
Concrete Unit weight	(ɣ concrete)	25 KN/ m^3

3. Geotechnical Properties of Alluvial Soil (Specially in Uttar Pradesh Region)

Table 2. Geotechnical properties of Alluvial soil

Engineering Test	Geotechnical Properties	Value
Compaction Test	Maximum Dry Density	1.79 g/cc
	Optimum Moisture Content	12.49 %
Direct Shear Test	Cohesion (C)	8^0
	Angle of internal friction (φ)	11.8 KN/m2

4. Calculation of Bearing Capacity

4.1 Using IS: 6403-1981

For $\varphi = 8°$
Bearing capacity factors , $N_c = 6.63, N_q = 1.63, N_\gamma = 0.50$
$Shape\ factors, S_C = S_q = 1.15, S_\gamma = 0.68$
$Depth\ factors, d_c = 1.01, d_q = d_\gamma = 1$
$Inclination\ factors, i_c = i_q = 0.97, i_y = 0.765$

4.2 For local shear failure

$$The\ net\ ultimate\ bearing\ capacity = \frac{2}{3}N_c S_c d_c i_c + q(N_q - 1)S_q d_q i_q + B_\gamma N_\gamma d_\gamma i_\gamma$$

$$The\ net\ ultimate\ bearing\ capacity = 143.70\ \frac{KN}{m^2}$$

$$Taking\ factor\ of\ safety\ (FOS) = 2.5$$

$$Safe\ Bearing\ Capacity\ (SBC) = \left(\frac{q_{nu}}{FOS}\right) + D_f = 100\frac{KN}{m^2}$$

5. Raft Analysis

5.1 Raft Dimensions

The spacing of raft in x- side is 6 meters and the spacing of the raft in y-side is also 6 meters. There is one meter of edge around the edge's columns [1]. In figure 1, the plan of the raft has been shown:

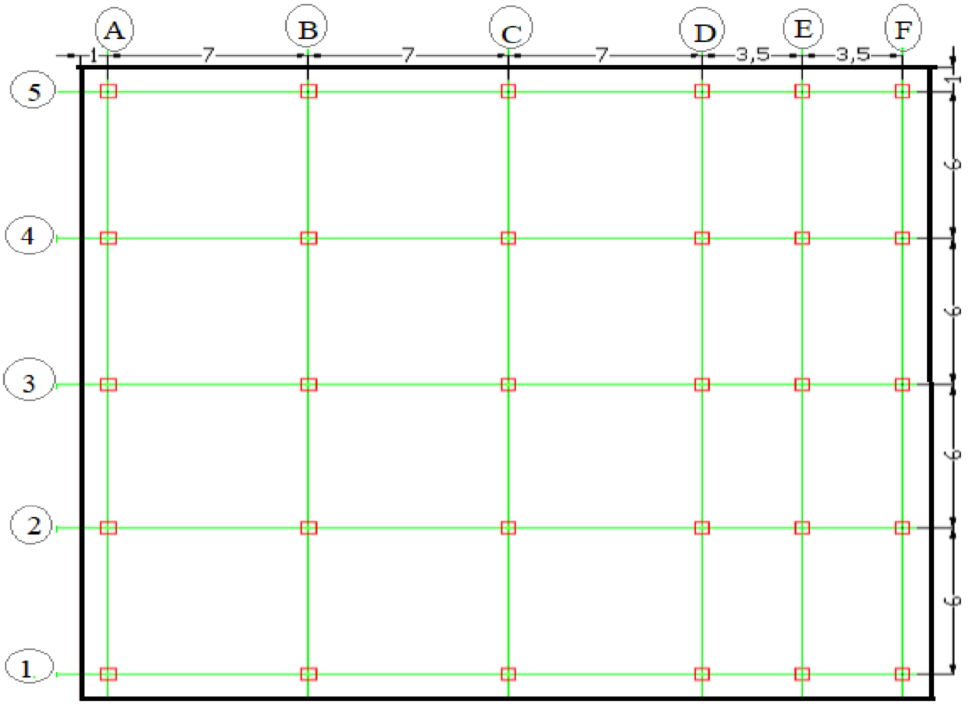

Figure 1. Raft Layout.

Total area of the raft under raft foundation = [(4x6) +1+1) x (4x7) +1+1)]

=(26x30)

=780 $m2$

5.2 LOADS OF COLUMNS IN RAFT

This raft has been designed for a residential building of 10 stories, considering all the dead and live loads [3].

Table 3. Design loads

Load type	Load case	Load value (KN/m²)
Slab own weight assumed	Dead	(25kN/m³) (0.2m) = 5 KN/m²
Services	Dead	2.5 KN/m²
Live loads	Live	2 KN/m2
Flooring	Dead	1 KN/m²

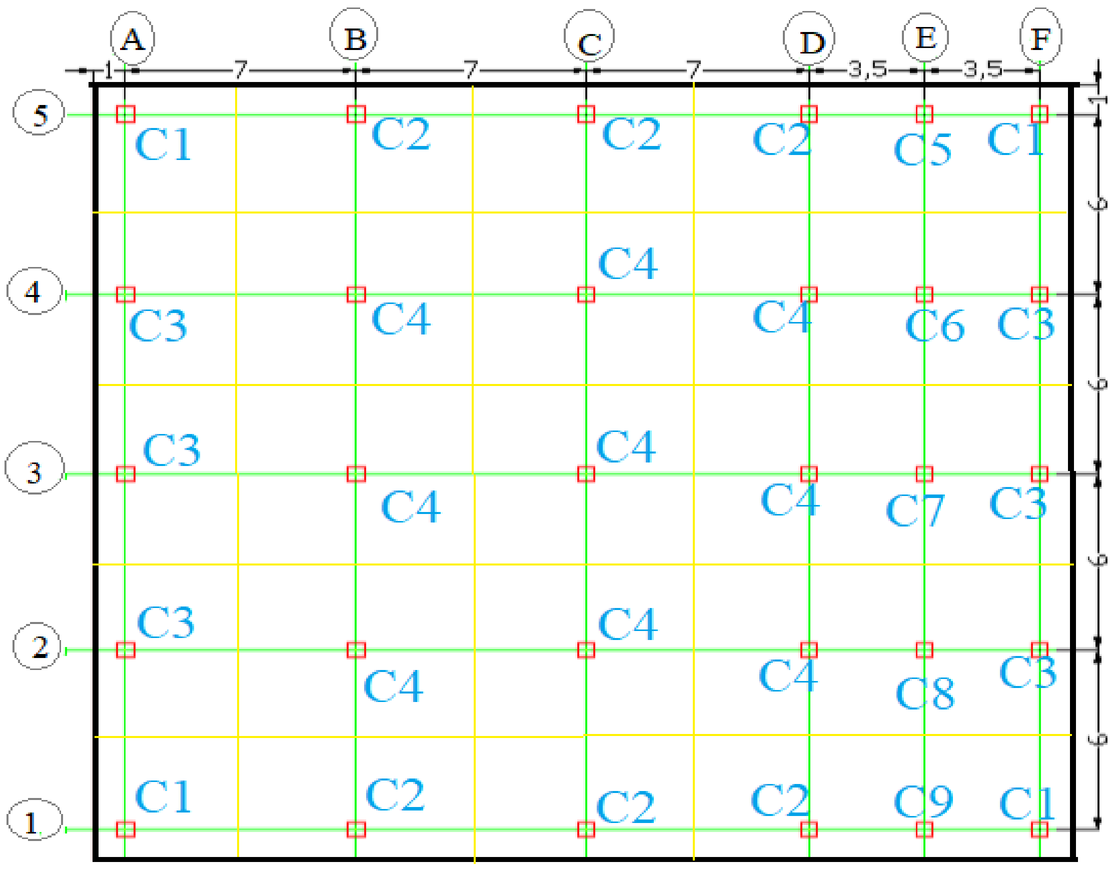

Figure 2. Raft dimensions and collumn spacing.

Loads per square meter are calculated as

$$General\ Dead\ load\ stress = (5 + 2.5 + 1)\frac{KN}{m^2} \times (number\ of\ floors)$$

$$General\ Dead\ load\ stress = (5 + 2.5 + 1)\frac{KN}{m^2} \times (10) = 85\frac{KN}{m^2}$$

$$General\ Life\ load\ stress = (2)\frac{KN}{m^2} \times (10) = 20\frac{KN}{m^2}$$

5.3 COLUMNS LOADS

$$Axial\ Dead\ load = stress\ per\ unit\ area\frac{KN}{m^2} \times Turbidity\ area$$

Column type (1)

$$\text{Axial unfactored Dead load} = 85\frac{KN}{m^2} \times 4 \times 4.5m^2 = 1530\ KN$$

$$\text{Axial unfactored Live load} = 20\frac{KN}{m^2} \times 4 \times 4.5m^2 = 360\ KN$$

$$\text{Total Service Axial load} = 1530\text{ KN} + 360\text{ KN} = 1890\text{ KN}$$

$$\text{Ultimate axial load} = 1.2(1530) + 1.6(360) = 2412\text{ KN}$$

Column type (2)

$$\text{Axial unfactored Dead load} = 85\frac{KN}{m^2} \times 4 \times 7m^2 = 2380\ KN$$

$$\text{Axial unfactored Live load} = 20\frac{KN}{m^2} \times 4 \times 7m^2 = 560\ KN$$

$$\text{Total Service Axial load} = 2380\text{KN} + 560\text{ KN} = 2940\text{ KN}$$

$$\text{Ultimate axial load} = 1.2(2380) + 1.6(560) = 3752\text{ KN}$$

Column type (3)

$$\text{Axial unfactored Dead load} = 85\frac{KN}{m^2} \times 4.5 \times 6m^2 = 2295\ KN$$

$$\text{Axial unfactored Live load} = 20\frac{KN}{m^2} \times 4.5 \times 6m^2 = 540\ KN$$

$$\text{Total Service Axial load} = 2295\text{ KN} + 540\text{KN} = 2835\text{ KN}$$

$$\text{Ultimate axial load} = 1.2(2295) + 1.6(540) = 3618\text{ KN}$$

Column type (4)

$$\text{Axial unfactored Dead load} = 85\frac{KN}{m^2} \times 7 \times 6m^2 = 3570\ KN$$

$$\text{Axial unfactored Live load} = 20\frac{KN}{m^2} \times 7 \times 6m^2 = 840\ KN$$

$$\text{Total Service Axial load} = 3570\text{ KN} + 840\text{ KN} = 4410\text{ KN}$$

$$\text{Ultimate axial load} = 1.2(3570) + 1.6(840) = 5628\text{ KN}$$

5.4 COLUMN LOADS

Table 4. All columns load.

Column no.	Dead load (KN)	Live load (KN)	Total service load (KN)	Total factored load (KN)
C1	1530	360	1890	2412
C2	2380	560	2940	3752
C3	2295	540	2830	3618
C4	3570	840	4410	5628
C5	550	350	900	1220
C6	500	300	800	1080
C7	450	250	700	940
C8	400	200	600	800
C9	350	150	599	660

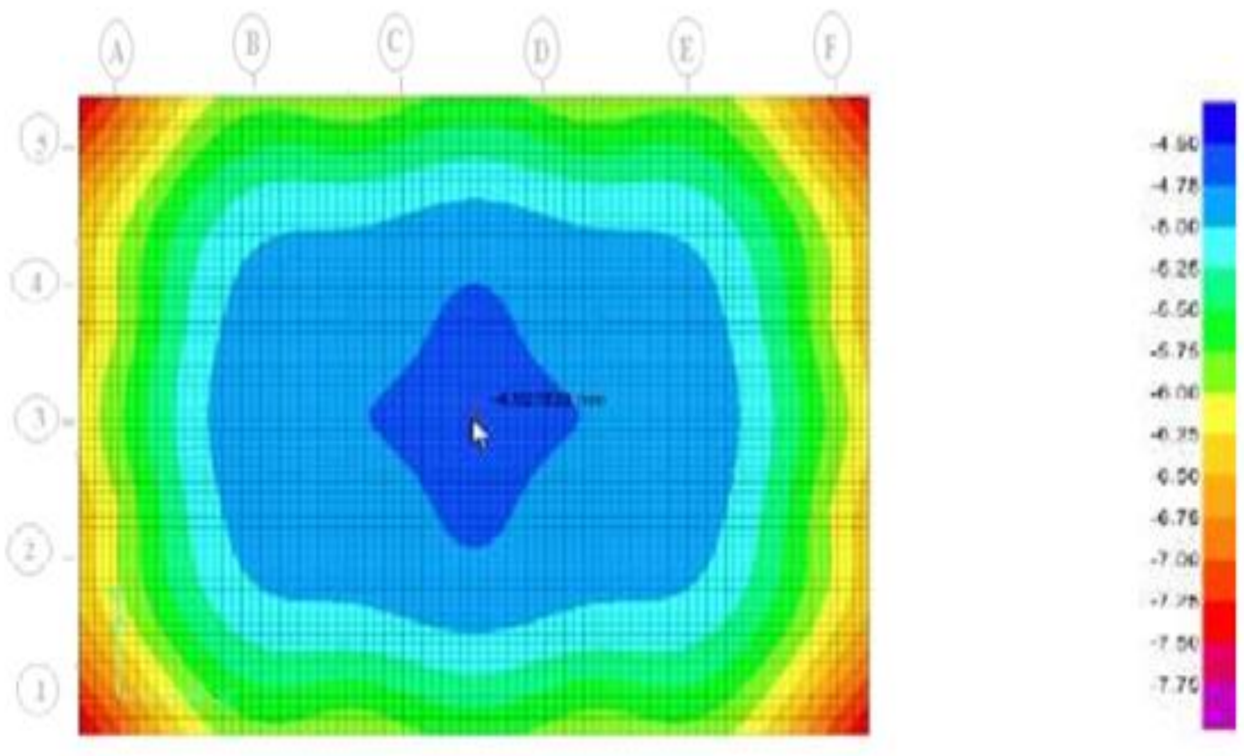

Figure 3. Columns laod.

5.5 Dimensions of Columns and Reinforcement Provided

The dimensions of columns are 650 mm by 650 mm with 12Ø22 as shown in the figure below. The maximum load that this design of column will resist is around 6432 KN.

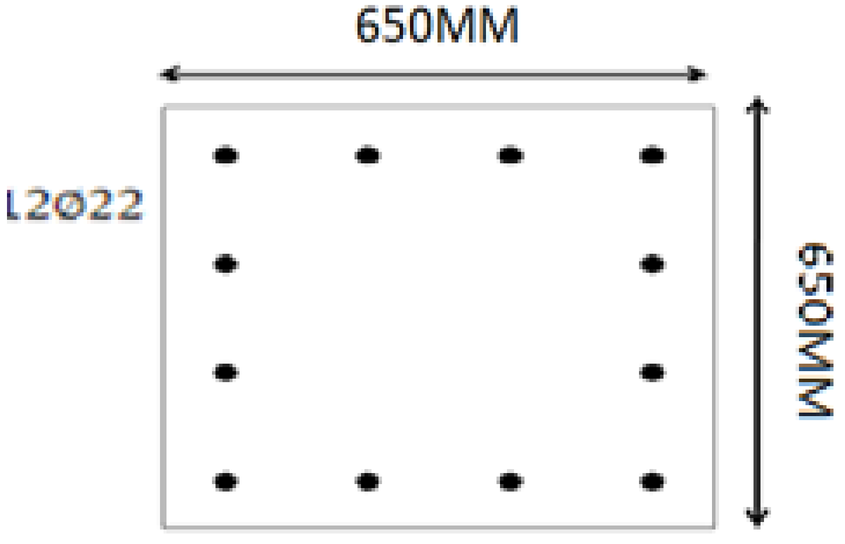

Figure 4. Dimentions of columns.

$$Let's\ assume\ \%\ of\ steel\ as\ 1\%\ of\ A_g$$
$$A_{sc} = 0.01A_g$$
$$A_c = A_g - A_{sc}$$
$$A_c = 0.99A_g$$
$$P_U = (0.45\, f_{ck}A_c) + (0.67 f_y A_{SC})$$
$$6432 \times 10^3 = \left(0.45 \times 30 \times 0.99A_g\right) + (0.67 \times 415 \times 0.01A_g)$$
$$A_g = 378352\ mm^2$$

$$Let\ Assume\ it\ as\ a\ Square\ column$$
$$S = \sqrt{378352}$$
$$S = 650$$
$$A_g = (650)^2 = 422500\ mm^2$$

$$\text{To find Area of steel :} -$$
$$P_u = (0.45 f_{ck}A_c) + (0.67 f_y A_{SC}$$
$$A_C = A_g - A_{SC}$$

$$6432 \times 10^3 = (0.45 \times 30 \times (A_g - A_{SC}) + (0.67 \times 415 \times A_{SC})$$
$$6432 \times 10^3 = (5703750 - 13.5A_{SC}) + (278.05A_{SC})$$
$$6432 \times 10^3 = (5703750 + 264.55A_{SC})$$
$$A_{SC} = 2743mm^2$$
$$P_C = \emptyset P_n = 0.7 \times 0.8(0.85f_{c'}A_g + f_yA_{st}$$
$$P_C = \emptyset P_n = (0.7)(0.8)[0.85(30)(650)(650)] + (415)(2743)$$
$$P_C = 7172KN > P_U = 6432KN$$

5.6 Rationale of raft utilization

The maximum axial load is occurred in column type 3, and if we had to design a single square footing in alluvial region. The properties that are used in the analysis and design of raft foundation in alluvial soil are [14]:

Table 5. Properties taken in raft design.

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

$$q_e = 100\frac{KN}{m^2}$$
$$\text{Total Maximum Service Axial load} = 4080\text{KN} + 960\text{KN} = 5040\text{KN}$$
$$\text{Area of single square footing} = \frac{1.1(5040)}{100}$$
$$\text{B} \times \text{B} = 55.44$$
$$\text{B} = \sqrt{55.44m^2}$$
$$\text{B} = 8\text{m} \times 8\text{m}$$

As the area is very big that must be excavated under one column. So, the raft foundation will be more economical and efficient for this kind of foundation in alluvial region [13].

5.7 Raft Thickness

With the help of diagonal tension shear, the thickness of the raft in raft foundation can be determined. For calculation, maximum ultimate column load will be used [4].

$$U = (b_o)(d)(\emptyset)(0.34)f_{c'}$$
$$Where,$$
$$U = Factored\ column\ load$$

$$\emptyset = Reduction\ Factor = 0.85$$
$$b_o = The\ parametre\ of\ the\ sheared\ area$$
$$d = effective\ depth\ of\ raft$$
$$f_{c'} = Compressive\ strength\ of\ concrete$$

$In\ this\ Raft$

$U = 6432KN = 6.432MN$

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

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

$$U = (b_o)(d)(\emptyset)(0.34)f_{c'}$$
$$6.432 = (1.6 + 4d)(d)(0.75)(0.34)(30)$$
$$6.432 = (1.6d + 4d^2)(1.397)$$
$$4.604 = 1.6d + 4d^2$$
$$0 = 4d^2 + 1.6d - 4.604$$
$$0 = 4d^2 + 1.6d - 4.604$$

Solving equation for d = 0.860 m = 860 mm = 900 mm Thickness of the raft = 700 + 75 + 25 (assumed bar diameter) Thickness = 1000 mm

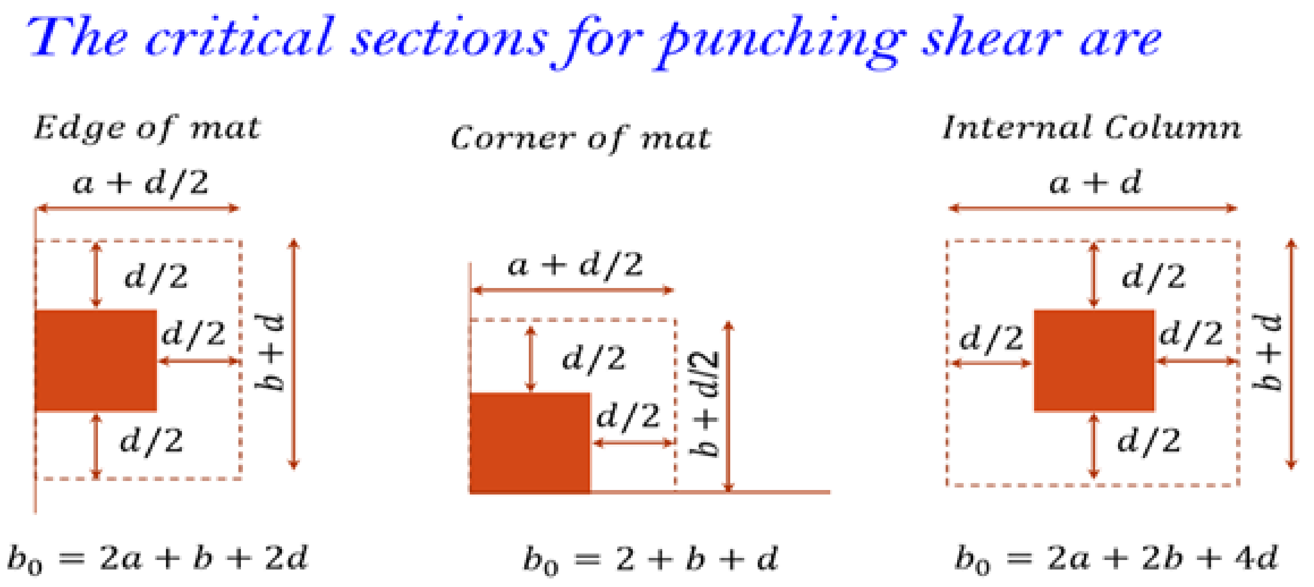

Figure 5. The critical sections for punching shear

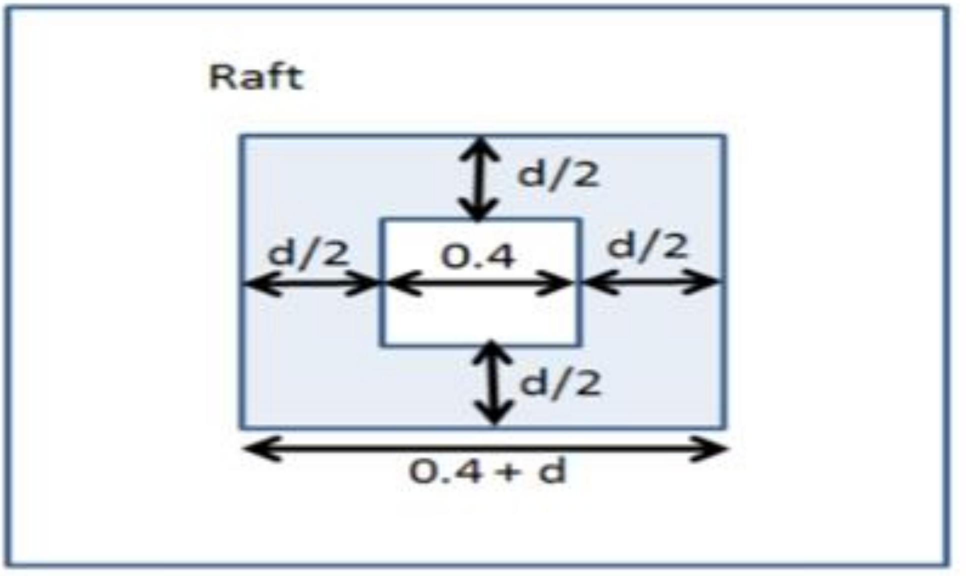

Figure 6. Diagonal shear area

5.8 Raft Depth Check

5.8.1 One-way Shear

Vu = $Maximum\ shear$- (d) $(wsoil)$

To determine the $wsoil$, On the maximum load's stripe, the average soil pressure should be determined.

Ultimate bearing stress of the soil:

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

$$q_{alt} = \frac{C_2 + C_4 + C_4 + C4 + C_2}{(width\ of\ strip)(length\ of\ strip)}$$

$$q_{alt} = \frac{(2940 + 4410 + 4410 + 4410 + 2940)}{(3.5) \times (26)}$$

$$q_{alt} = \frac{(19110)}{91}$$

$$q_{alt} = 210\frac{KN}{m^2}$$

$$W_{soil} = (210\ KN/m^2)(width\ of\ strip)$$

$$W_{soil} = (210\ KN/m^2)(3.5)$$

$$W_{soil} = 735KN/m$$

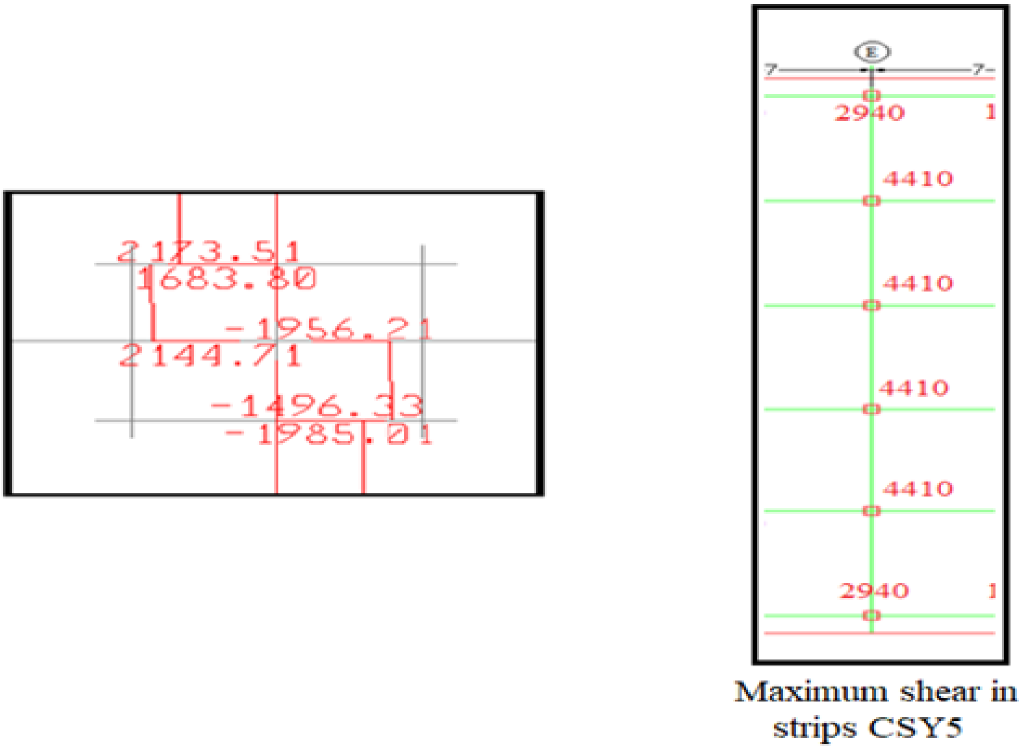

Figure 7. Shear Diagram.

Assuming d=1000–75=925 mm

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

$$V_u = (2173.5) - (0.925) \times (735)$$

$$V_u = 1493.625KN$$

$$d = \frac{V_u \times (1000)}{(0.75)(\sqrt{f'_c})(\frac{1}{6})(B)}$$

$$d = \frac{(V_u)(1000)}{(0.75)(\sqrt{30})(^1/_6)(6000)}$$

$$d = 431.13mm$$

$$d = 431.13mm < d = 725\ ok$$

5.8.2 Two-Way Shear (Interior Column)

$Vu{=}Column\ Axial\ Load{-}\ (d{+}a)\ ^2(wsoil)$

To determine the w_{soil}, On the maximum load's stripe, the average soil pressure should be determined.

$$q_{alt} = 160.8KN/m^2$$

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

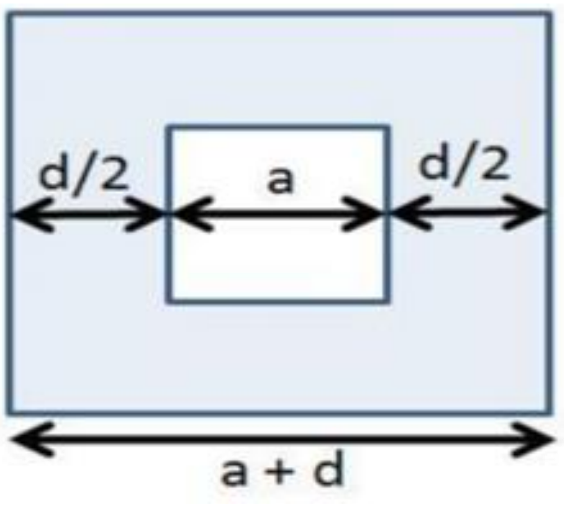

Figure 8. Tow-way Shear.

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

$$V_u = (5628) - (0.725 + 0.65)^2 (735)$$

$$V_u = 5215.95KN$$

$$b_o = 4(a + d)$$

$$b_o = 4(650 + 725) = 5500mm$$

$$d = \frac{V_u \times (1000)}{(0.75)(\sqrt{f'_c})(\frac{1}{3})(b_o)}$$

$$d = \frac{(5212) \times (1000)}{(0.75)(\sqrt{30})(\frac{1}{3})(5500)}$$

$$d = 696.54mm$$

$$d = 696.54mm < d = 725ok$$

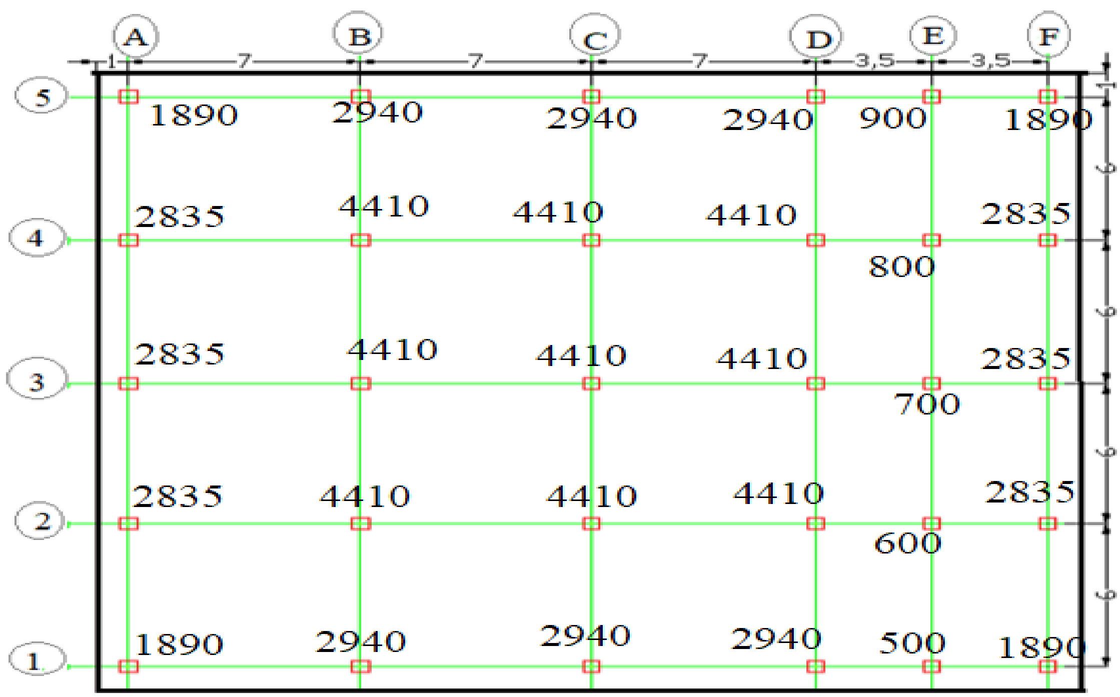

Figure 9. Columns total service loads (DL + LL).

6. Soil Pressure Check

In soil pressure check, the net pressure must be checked at every point of the raft foundation. The effect of moments that is they're on the raft must be checked to make sure that the stresses on the raft under all columns are less than the net allowable stress, that is equal to 100KN/m2 [12].

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

$$A = Area\ of\ the\ mat = [(4 \times 6) + 1 + 1) \times (4 \times 7) + 1 + 1)]$$

$$A = (26 \times 30) = 780m^2$$

$$I_x = \frac{bh^3}{12}$$

$$I_x = \frac{(26) \times (30)^3}{12} = 58500\ m^4$$

$$I_y = \frac{bh^3}{12}$$

$$I_y = \frac{(30) \times (26)^3}{12} = 43940\ m^4$$

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

$$Q = 4(C1) + 6(\text{C2}) + 6\ (\text{C3}) + 9\ (\text{C4}) + \text{C5} + \text{C6} + \text{C7} + \text{C8} + \text{C9}$$

$$Q = 4(1890) + 6(2940) + 6\ (2835) + 9\ (4410) + 900 + 800 + 700 + 600 + 500$$

$$Q = 7560 + 17640 + 17010 + 39690 + 900 + 800 + 700 + 600 + 500$$

$$Q = 85400KN$$

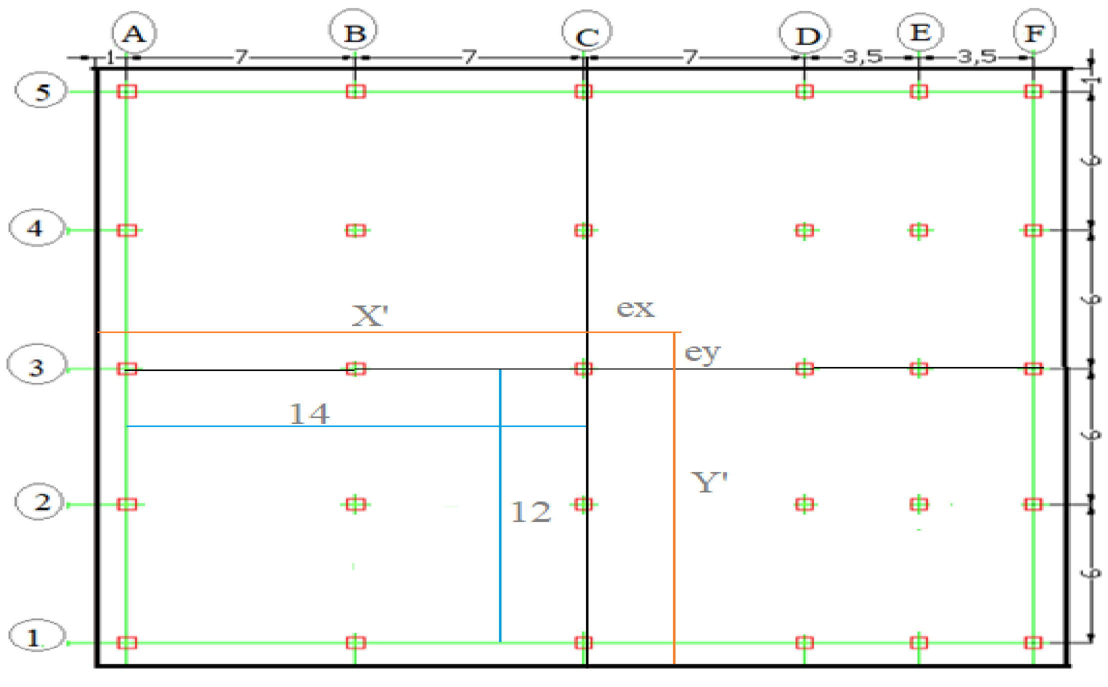

Figure 10. Resultant position due to column load.

6.1 Calculate My

$$e_x = X' - 15$$

$$Q \times X' = Q_1(x_1) + Q_2(x_2) + \cdots$$

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

$$X' = \frac{1}{85400} \times [(7)(2940 + 4410 + 4410 + 4410 + 4410 + 2940)$$
$$+ (14)(2940 + 4410 + 4410 + 4410 + 4410 + 2940)$$
$$+ (21)(2940 + 4410 + 4410 + 4410 + 4410 + 2940) + (24.5)(900 + 800 + 700 + 600 + 500)$$
$$+ (28)\,(1890 + 2835 + 2835 + 2835 + 2835 + 1890)$$

$$X' = \frac{1}{85400} \times [133770 + 267540 + 401310 + 343980 + 85750]$$

$$X' = \frac{1}{85400} \text{x} [\,1232350]$$

$$X' = 14.43m$$

$$e_x = 14.43 - 14 = 0.43m$$

$$M_y = Q_{ex} = 85400 \times 0.43m = 36722KN.m$$

6.2 Calculate Mx

$$e_y = Y' - 9$$

$$Q \times Y' = Q_1(y_1) + Q_2(y_2) + \cdots$$

$$Y' = \frac{Q_1\left(y'_1\right) + Q_2\left(y'_2\right) + \cdots}{Q}$$

$$Y' = \frac{1}{85400} \times [(24)(1890 + 2940 + 2940 + 2940 + 900 + 1890) + (18)(2835 + 4410 + 4410 + 4410 + 800 + 2835)$$
$$+ (12)(2835 + 4410 + 4410 + 4410 + 700 + 2835)$$
$$+ (6)(2835 + 4410 + 4410 + 4410 + 600 + 2835)]$$

$$Y' = \frac{1}{85400} \times [324000 + 354600 + 235200 + 117000]$$

$$Y' = \frac{1}{85400} \text{x} [1030800] = 12.070 \text{ m}$$

$$e_y = 12.070 - 12 \;=\; 0.071 \text{ m}$$

$$M_x = Q_{ey} = 85400 \times 0.071\, m = 60634KN.$$

7. Soil Pressure Due to Total Service Axial Loads and Moments

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

In the above equation (-) minus signs indicates compression stress. In all the four corners of the raft, soil pressure will be checked with the help of the above equation. The calculated soil pressure should not be more than the allowable stress of the soil and not less than 0 KN/m2, this is to make sure that no tension could occur in any part of the raft [8, 9, 10].

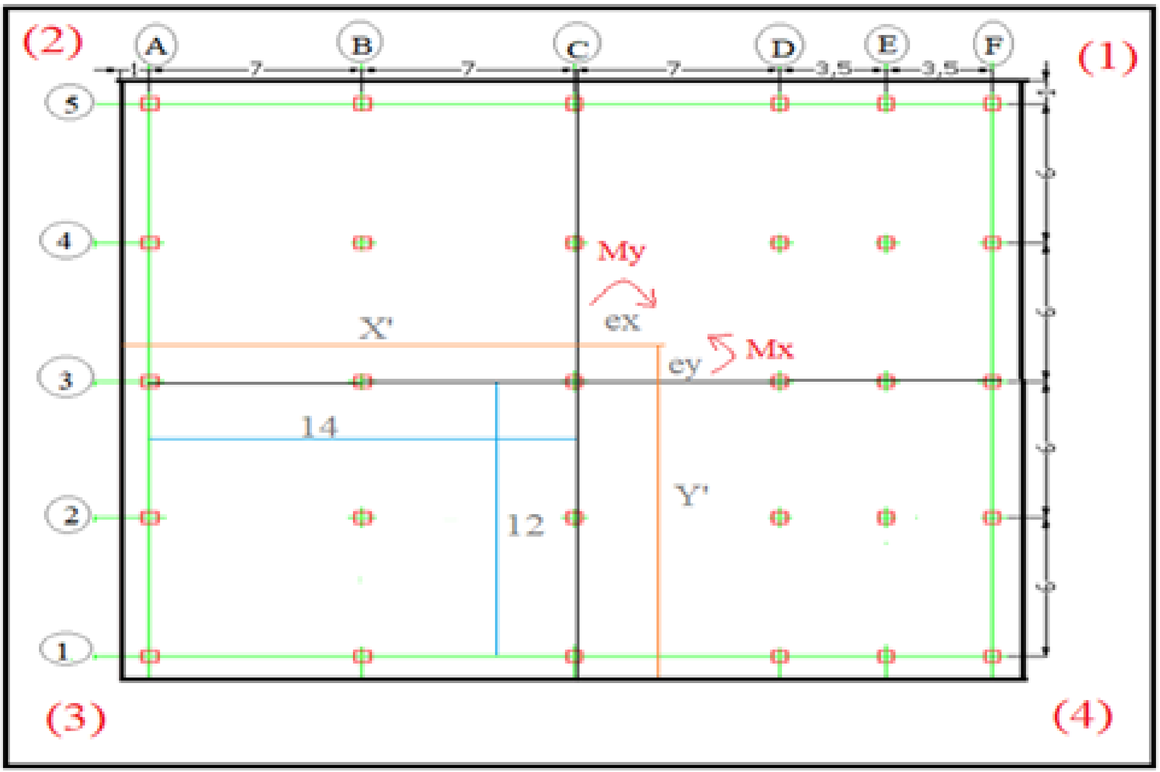

Figure 11. Resultant position due to column load.

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

$$q_1 = -\frac{(85400)}{(780)} - \frac{(36722) \times (15)}{(43940)} - \frac{(60634) \times (13)}{(58500)}$$

$$q_1 = -100 - 17 - 10$$

$$q_1 = -117 < q_{net} = 120\, KN/m^2\ OK$$

$$q_2 = -\frac{(85400)}{(780)} + \frac{(36722) \times (15)}{(43940)} - \frac{(60634) \times (13)}{(58500)}$$

$$q_2 = -100 + 17 - 10$$

$$q_2 = -93 \; < q_{net} = 120 \, KN/m^2 \; OK$$

$$q_3 = -\frac{(85400)}{(780)} + \frac{(36722) \times (15)}{(43940)} + \frac{(60634) \times (13)}{(58500)}$$

$$q_3 = \; -100 + 17 + 10$$

$$q_3 = -83 \; < q_{net} = 120 \, KN/m^2 \; OK$$

$$q_4 = -\frac{(85400)}{(780)} - \frac{(36722) \times (15)}{(43940)} + \frac{(60634) \times (13)}{(58500)}$$

$$q_4 = \; -100 - 17 + 10$$

$$q_4 = -107 \; < q_{net} = 120 \, KN/m^2 \; OK$$

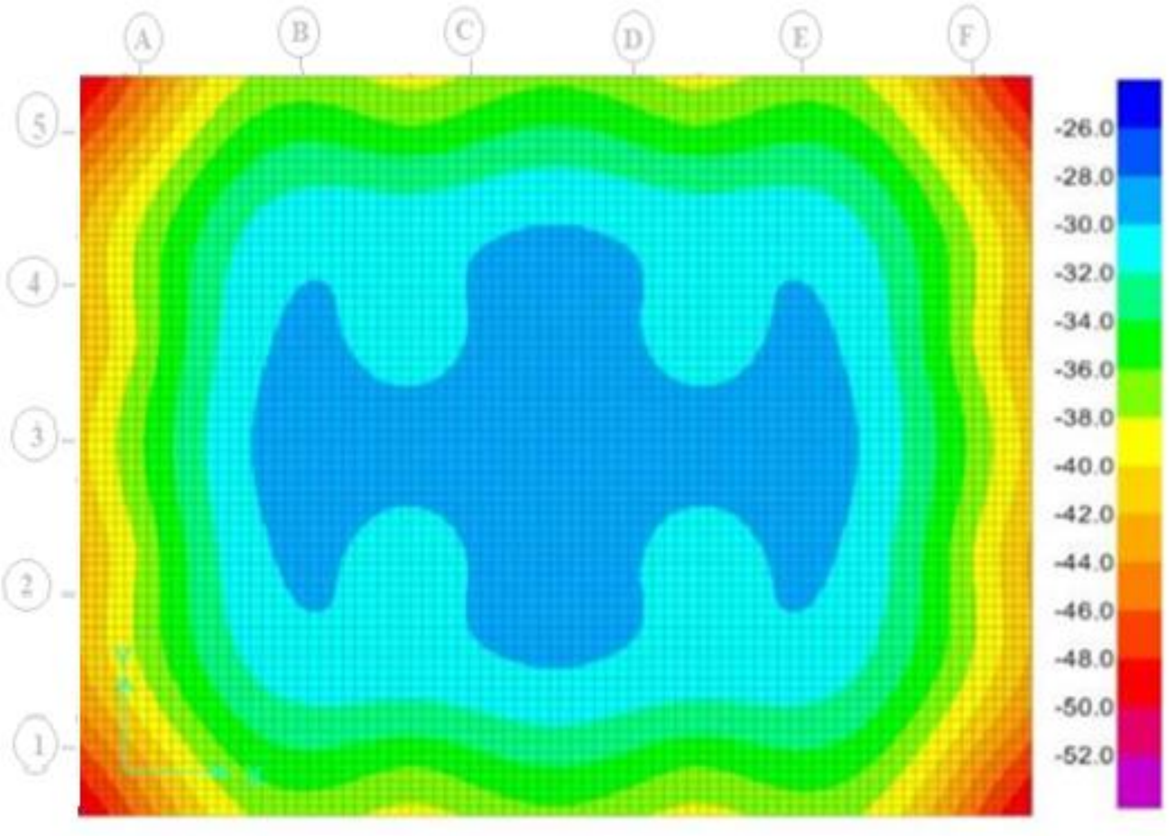

Figure 12. Soil Pressure.

The pressure values that have been calculated above are in compression and all the values are coming less than the net bearing stress of the soil which is equal to 100 KN/m^2. So, from this it can be said that soil is safe against any type of soil failure [6].

8. Settlement Analysis

The maximum settlement that was recorded was equal to 28.5 mm. This amount of settlement is acceptable, that is 28.5mm, because according to IS 1904-1986, the maximum allowable settlement is equal to 50 mm [7].

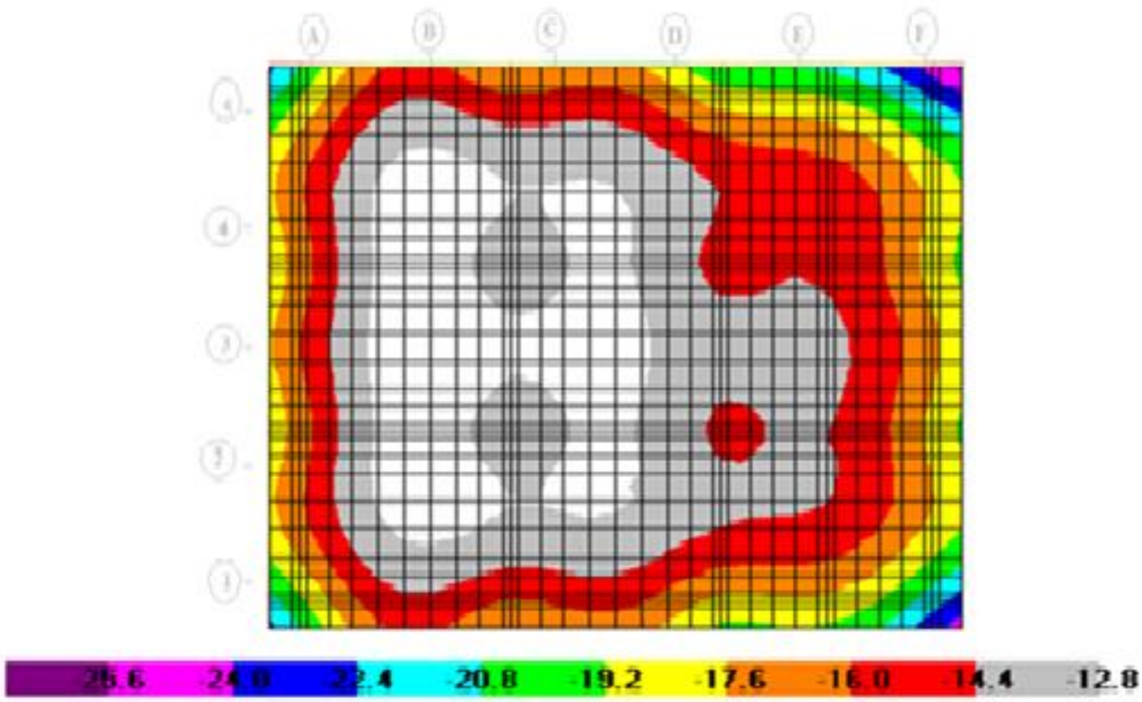

Figure 13. Settlement of raft foundation.

9.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 [11-16].

9.1 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 based on one meter unit width of the strip. Moment Diagram of x-strips are shown in figure 14.

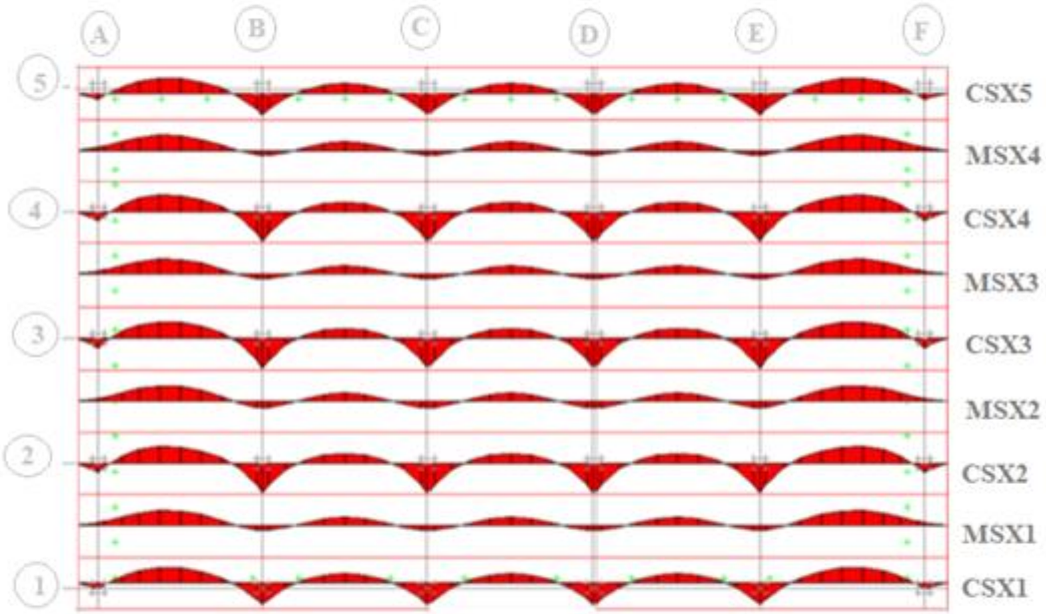

Figure 14. X-Strip moment diagram.

Table 6 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 6. Analysis outputs for x-strip moments.

Strip notation	Strip Field	Maximum Moment Value (kN.m)	
		Positive	Negative
CSx1	Column strip	1233	1259.3
MSx1	Middle strip	419.1	1313.0
CSx2	Column strip	1632	1242.0
MSx2	Middle strip	776.6	1339.0
CSx3	Column strip	**1858.7**	1442.3
MSx3	Middle strip	603.4	1264.3
CSx4	Column strip	967.8	**1845.3**
MSx4	Middle strip	668	1335.2
CSx5	Column strip	1284.7	1124.6

9.2 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 based on one meter unit width of the strip. Moment Diagram of y-strips are shown in figure 15.

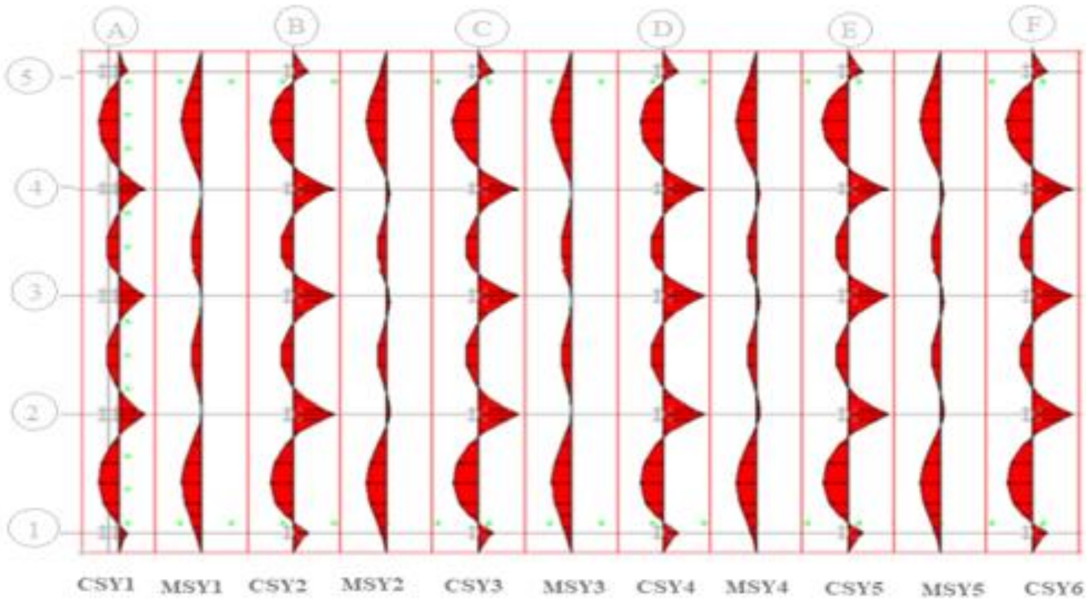

Figure 15. Y-Strip moment diagram

Table 7. Analysis outputs for Y-strip moments**.**

Strip notation	Strip Field	Maximum Moment Value (kN.m)	
		Positive	Negative
CSY1	Column strip	1043	1060.3
MSY1	Middle strip	426.1	1027.7
CSY2	Column strip	6450	1407.3
MSY2	Middle strip	466.2	1048.3
CSY3	Column strip	**1876**	1430.3
MSY3	Middle strip	844	1393.0
CSY4	Column strip	1076	**2456.7**
MSY4	Middle strip	954.4	1087.6
CSY5	Column strip	853.8	1145.3
MSY5	Middle strip	1102.1	1213.6
CSY6	Column strip	1023.5	979.5

10. Conclusion

As per the Indian Standards, safety requirements were provided while designing the Raft foundation corresponding to Alluvial type of soil. In this paper, the design of the raft foundation along with its reference to various geotechnical aspects are studied and implemented in the design required to be completed. For loose soil bending moment is sagging in nature, over entire of raft. However, as soil stiffness increases tension zone is created. From the edge as we proceed toward center the intensity and extent of tension zone goes increasing. However, the effect is more in X direction as compared to Y direction. For loose soil, pressure distribution beneath the raft is lower at edge and goes on increasing towards the center. In the central zone, in between column, it remains almost constant. For medium soil, at the edge, pressure distribution is high and goes on reducing towards the center with very mild rate. For hard soil, pressure distribution at the edges is high, reduces under the edge columns and then after increases in the central part. The punching shear factors are less than 1 and settlement is less than 50 mm.

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Appendix I

a = depth of rectangular stress distribution from compression fiber to distance $\beta 1c$

As = area of tension steel

Ab = area of individual bar

As,min = minimum tension reinforcement

b = width of compression face

bo = perimeter of critical section for two −way shear in slabs and footings, mm

Ca = coefficient of aticve earth pressure

Cc = clear cover from the nearest surface in tension to the surface of the flexural tension reinforcement, mm

Cm = factor relating the actual moment diagram of a slender column to an equivelant uniform moment diagram

Cm = moment coefficient

Cp = coefficient of passie earth pressure

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

d' = distance from extreme −compression fiber to centroid of comression renforcement,mm

db = nominal diameter of bar ,wire ,or prestressing strand ,mm

D = dead load

e = eccentricity

Ec = modulus of elasticity of concrete MPa

EI = Flexural stiffness of compression member, N −mm2

Es = modulus of elasticity of reinforcement MPa

$f c'$ = compressive strength in concrete due 28−day, psi or MPa

$f s$ = calculated stress in reinforcement at service loads, MPa or N/mm2

fy = yeild strength of nonprestressed reinforcement

h = overall depth or thickness of slab or beam

I = moment of inertia of a section, mm4

jd = distance between the resultants of the internal compressive and tensile force on cross section

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

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

$ld = development\ length$

$ln = clear\ span\ measured\ face\ to\ face\ of\ supports.$

$M = moment$

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

$Mu = factored\ moment\ due\ to\ factored\ load$

$PE = buckling\ load\ of\ an\ elastic,\ hinged{-}end\ column$

$Pn = nominal\ axial\ load\ strength\ at\ given\ eccentricity$

$P\ o = nominal\ axial\ load\ strength\ at\ zero\ eccentricity$

$Pu = axial\ force\ due\ to\ factored\ load$

$S = spacing\ between\ bars$

$V\ c = Nominal\ shear\ strength\ of\ concrete$

$W = weight$

$\beta 1 = ratio\ of\ depth\ pf\ rectangular\ stress\ block,\ a,\ to\ depth\ to$

$neutral\ axis, c$

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

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