3.1 Types of Footings:

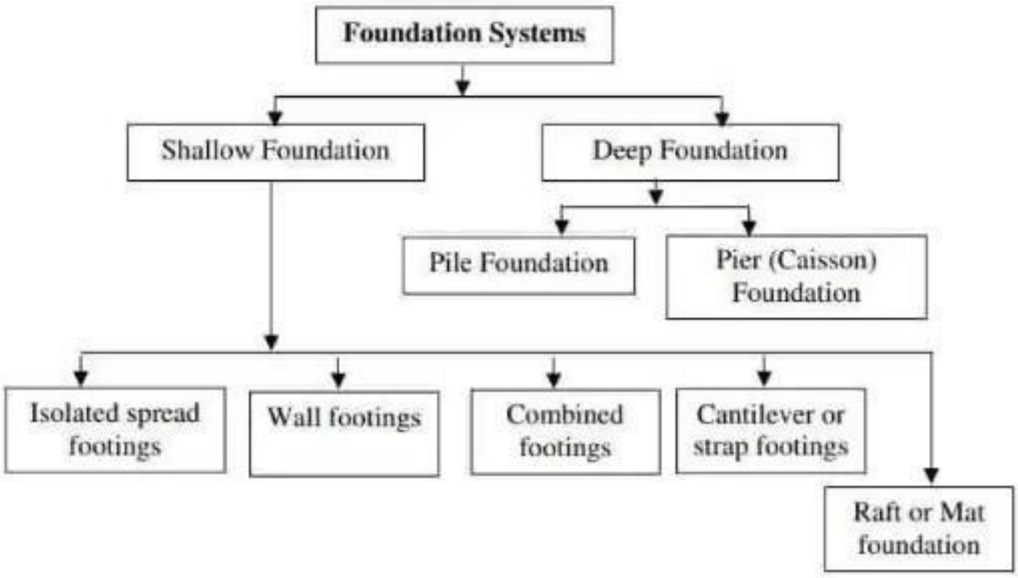


Fig 1Types of footing

[Fig1 https://civiconcepts.com/blog/types-of-foundation]

1. Types of Isolated Footings

There are various types of isolated footings such as spread footing, stepped footing, sloped footing etc. They are usually square, rectangular or circular in shape. Each type of footing is selected based on the soil condition and configuration of imposed loads. Isolated footings are one of the most economical types of footings and are used when columns are spaced at relatively long distances.

Isolated or single footings are structural elements used to transmit and distribute loads of single columns to the soil without exceeding its bearing capacity, in addition to preventing excessive settlement and providing adequate safety against sliding and overturning. Furthermore, they are used in the case of light column loads, when columns are not closely spaced and in the case of good homogeneous soil.

Use of Isolated Footing: Isolated footings are used as shallow foundation in order to transfer concentrated loads to the ground. To know the basic information, read Isolated footing.

Types of Isolated Footings

a. Flat, Pad, Plain, or Reinforced Isolated Footing

It is constructed under each column independently and is usually square, rectangular, or circular in shape. The thickness of flat isolated footing is uniform. It is provided so as to reduce the bending moments and shearing forces at their critical sections. It can be constructed from plain concrete or reinforced concrete to increase the ultimate load carrying capacity.

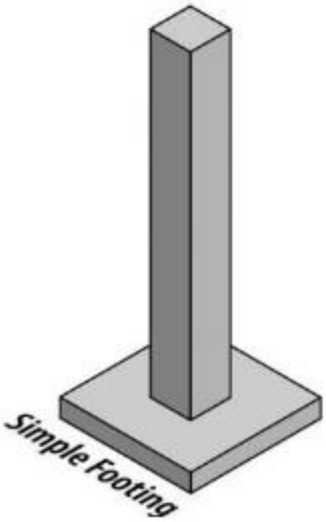


Fig. 2: Flat, Plain, or Reinforced Isolated Footing

[Fig 2 https://gharpedia.com/blog/various-types-of-footings-for-your-house/]

b. Sloped Isolated Footing

Sloped or trapezoidal footings are designed and executed with utmost attention to maintain a top slope of 45 degrees from all sides. The amount of reinforcement and concrete used in the sloped footing construction is less than that of plain isolated footing. Therefore, it decreases the utilization of concrete and reinforcement.

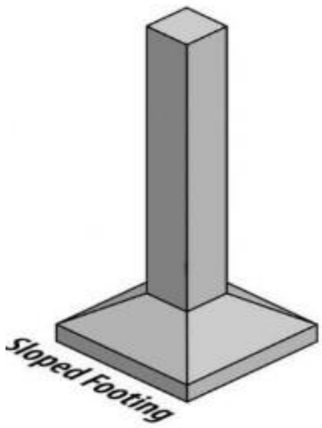


Fig. 3: Sloped Isolated Footing

[Fig 3https://gharpedia.com/blog/various-types-of-footings-for-your-house/]

c. Stepped isolated Footing

Previously, the construction of this type of isolated footing was popular, but its application has declined nowadays. It is generally used in the construction of residential buildings. Stepped footings are stacked upon one another as steps. By and large, three concrete cross-sections are stacked upon each other to create steps.

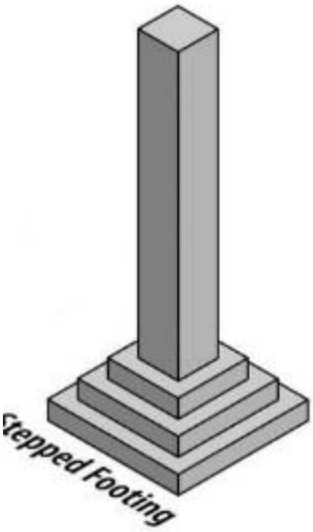


Fig. 4: Stepped Isolated Footing

[Fig 4 https://gharpedia.com/blog/various-types-of-footings-for-your-house/]

d. Shoe or eccentric footing

Shoe footing is the half cut-out from the original footing and it has a shape of shoe. They are constructed on property boundary, where there is no provision of setback area. It is constructed at the corner of the plot when the exterior column is close to the boundary or property line and hence there is no scope to project footing much beyond the column face. Column is provided or loaded at the edges of shoe footing. Shoe footings are constructed when the soil bearing capacity is 24KN/m^2

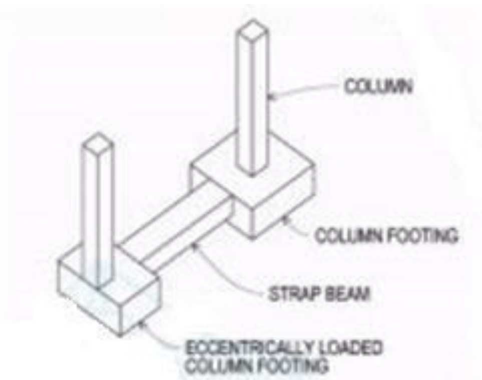


Fig5 Shoe or eccentric footing

[Fig 5https://civilread.com/different-types-footings/]

2. Continuous Wall Footing:

The footing which supports a long masonry or RCC wall is known as a continuous footing. It can be either simple or stepped.

Generally, width of the footing should be at least equal to twice the width of wall that is rested on it. In this case, the width of the footing is smaller than the length of the footing, offering continuous vertical support to the structure. Basically, it runs throughout the length of the wall. This type of footing is not economical.

Use of Continuous Wall Footing: Continuous wall footings are used to support the foundation walls and load-bearing walls.

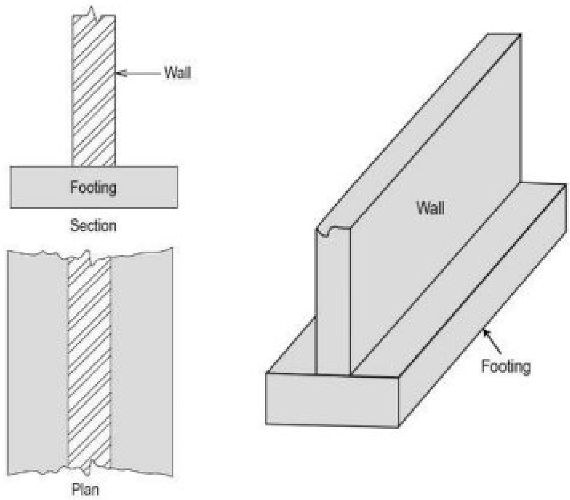


Fig 6 Continuous Wall Footing

[Fig 6 https://gharpedia.com/blog/various-types-of-footings-for-your-house/]

3. Combined footing: -

A footing which has more than one column is called as combined footing. This kind of footing is adopted when there is a limited space. Due to lack of space we cannot cast individual footing, therefore footings are combined in one footing. They are classified into two types based on their shape:

Use of Combined Footing: Combined footings are used to transfer loads of closely spaced column to the ground or when the column face the boundary of plot.

Rectangular combined footing: This rectangular footing is provided under two columns where the column is equal load.

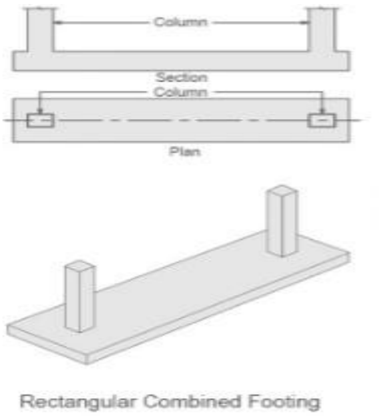


Fig7 Rectangular combined footing

[Fig 7 https://gharpedia.com/blog/various-types-of-footings-for-your-house/]

Trapezoidal combined footing: This trapezoidal footing are provided when the two columns are unevenly loaded.

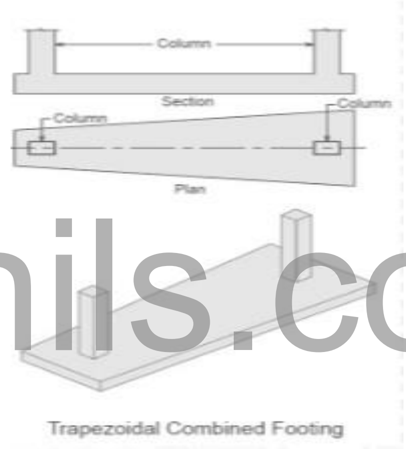


Fig8 Trapezoidal combined footing

[Fig8 https://gharpedia.com/blog/various-types-of-footings-for-your-house/]

4. Strap or Beam Combined Footing:

When a distance between the two columns supported on combined footing becomes large, the cost increases rapidly. The strap footing is an economical option in such cases.

Use of Strap Footing: Generally, strap footings are used in conjunction with columns of adjoining property.

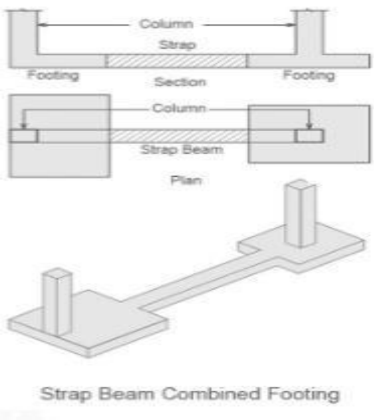


Fig 9 Strap beam combined footing

[Fig9 https://gharpedia.com/blog/various-types-of-footings-for-your-house/]

5.Raft footing

If loads transmitted by the columns in a structure are heavy and the allowable soil pressure is small, then footing requires more area. In such a case, it may be better to provide continuous footing under all columns and walls. Such kind of footing is called a Raft Footing.

Use of raft footing: It is widely used when soil has low load bearing capacity. To know more, read the basic information of raft foundation and also know the various types of raft foundation.

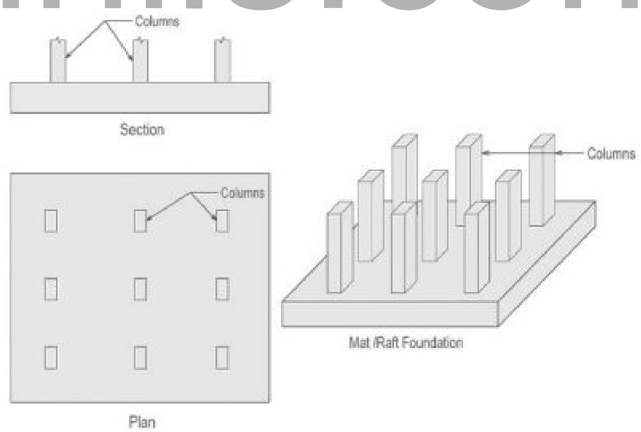


Fig 10 Raft footing

[Fig 10 https://gharpedia.com/blog/various-types-of-footings-for-your-house/]

When the soil has a low bearing capacity or the ground water level is high, pile footings are applied. Piles are common while building foundation for bridges, dam etc. in walls.

Use of Pile Footing: Piles are used as deep foundation where the soil is very week and has higher groundwater table.

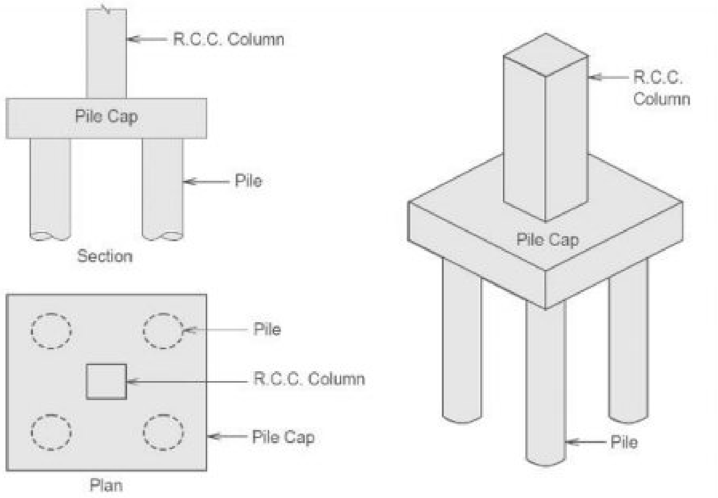


Fig 11 Pile Footing

[Fig 11 https://gharpedia.com/blog/various-types-of-footings-for-your-house/]

Drilled Shafts or Caisson Foundation:

Drilled shafts, also called as caissons, is a type of deep foundation and has an action similar to pile foundations discussed above, but are high capacity cast-in- situ foundations. It resists loads from structure through shaft resistance, toe resistance and/or combination of both of these. The construction of drilled shafts or caissons are done using an auger.

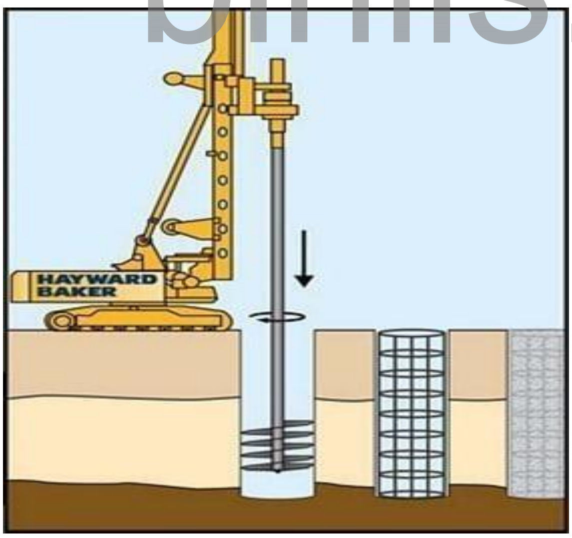


Fig:12 Drilled Shafts or Caisson Foundation (Source: Hayward Baker)

[Fig12https://theconstructor.org/geotechnical/soil-foundation-contact-pressure-distribution/5647/]

Drilled shafts can transfer column loads larger than pile foundations. It is used where the depth of hard strata below ground level is located within 10m to 100m (25 feet to 300 feet).

Drilled shafts or caisson foundation is not suitable when deep deposits of soft clays and loose, water-bearing granular soils exist. It is also not suitable for soils where caving formations are difficult to stabilize, soils made up of boulders, artesian aquifer exists.

3.2 Contact Pressure and settlement

The stability of structure is majorly depending upon soil – foundation interaction. Even though they are of different physical nature, they both must be act together to get required stability. So, it is important to know about the contact pressure developed between soil and foundation and its distribution in different conditions which is briefly explained below.

Generally, loads from the structure are transferred to the soil through footing. A reaction to this load, soil exerts an upward pressure on the bottom surface of the footing which is termed as contact pressure.

Contact Pressure Distribution under Footings:

The distribution of contact pressure under different types of footings on different types of soils are explained below.

1. Under Flexible Footing
2. Under Rigid Footing

1. Contact Pressure Distribution under Flexible Footing:

cohesive soil:

- For flexible footing on cohesive soil, settlement is maximum at center of footing and minimum at the edges which forms bowl like shape as shown in below figure. But the contact pressure is distributed uniformly along the settlement line or deflected line.

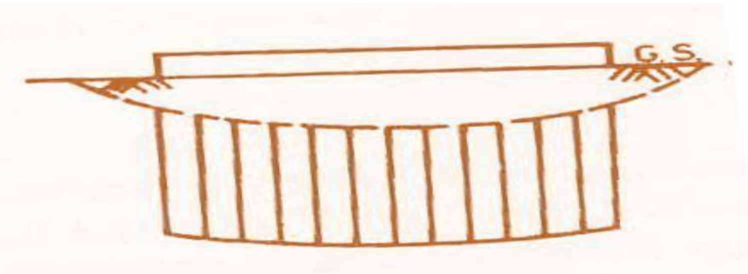


Fig 1: Contact Pressure Distribution - Flexible Footing - Cohesive Soil

[Fig1 https://theconstructor.org/geotechnical/soil-foundation-contact-pressure-distribution/5647/]

Cohesionless soil:

- When a flexible footing is laid on the Cohesionless soil, settlement at center becomes minimum while at edges it is maximum which exact opposite case of the settlement of flexible footing over cohesive soil.
- But in this case also contact pressure is uniform along the settlement line which is shown in below image.

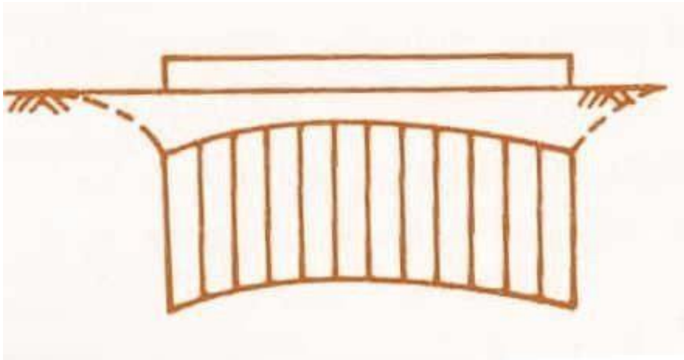


Fig 2: Contact Pressure Distribution - Flexible Footing - Cohesionless Soil

[Fig 2 https://theconstructor.org/geotechnical/soil-foundation-contact-pressure-distribution/5647/]

2. Contact Pressure Distribution under Rigid Footing

cohesive soils:

- For rigid footings resting on cohesive soils, settlement is uniform but contact pressure varies. At edges contact pressure is maximum and at center it is minimum which forms inverted bowl shape as shown in belowfigure.
- The values of stresses at edges becomes finite when plastic flow occurs inreal soils.

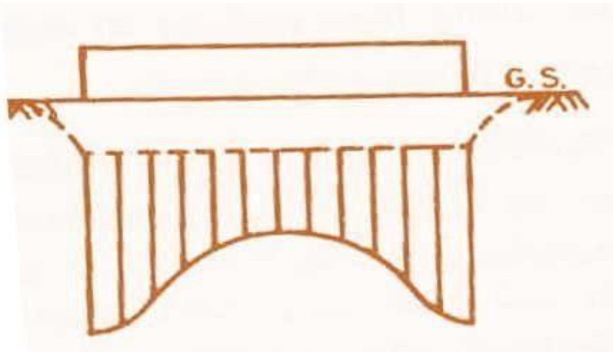
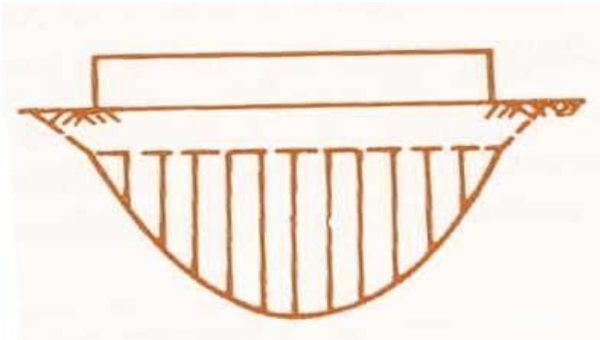


Fig 3: Contact Pressure Distribution - Rigid Footing - Cohesive Soil

[Fig 3 https://theconstructor.org/geotechnical/soil-foundation-contact-pressure-distribution/5647/]

Cohesion less soils:

- If the footing is resting on Cohesion less soils, contact pressure is maximum at center and gradually reduces to zero towards edges. Settlement is uniform in this case also.
- If the footing is embedded, then there may be some amount of contact pressure at the edges of rigid footing.



\\Fig 4: C.P Distribution - Rigid Footing - Cohesionless Soil

[Fig4 https://theconstructor.org/geotechnical/soil-foundation-contact-pressure-distribution/5647/]

Factors Effecting Contact Pressure Distribution:

Following are the factors effecting contact pressure distribution

- Stiffness of Footing
- Compressibility of soil
- Type of loading

1.Stiffness of Footing

- Contact pressure is uniform in case of flexible footings such as earth embankments. Contact pressure varies in case of rigid foundations such as R.C.C pad foundations etc. If the footing is partly flexible and partly rigid like raft foundation, contact pressure slightly varies.

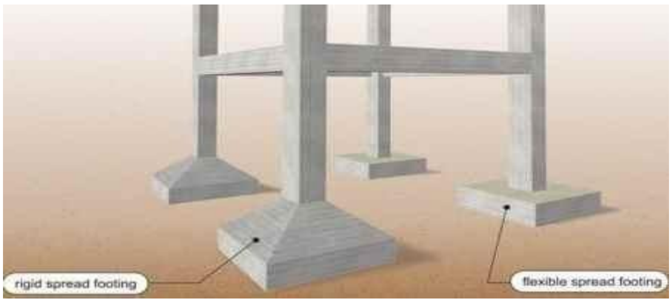


Fig 5: Flexible and Rigid Footings of a Structure

[Fig 5https://theconstructor.org/geotechnical/soil-foundation-contact-pressure-distribution/5647/]

2.Compressibility of soil:

Compressibility or stiffness of soil also plays a role in contact pressure distribution. If the soil is coarse grained, contact pressure is more at the centerof foundation than edges where as in case of clayey soils contact pressure is uniform.

3.**Type of loading**

a) Concentrated Loading

- If concentrated loading is applied at the center of foundation resting on cohesive soil, contact pressure is not uniform irrespective of stiffness of foundation.
- For flexible foundation, contact pressure is maximum exactly under the load application.
- For rigid foundations, contact pressure is maximum at edges. So, application of point load on rigid foundations can be comparable to the application of uniform loading on rigid foundation resting on cohesive soil.

b) Uniform Loading

- Contact pressure distribution under uniform loading and deformed patterns of flexible and rigid foundations are already explained above with figures 1, 2, 3 and 4.

General Assumption of Contact Pressure Distribution

- In the design of foundations, Contact pressure is assumed to be uniform which is not a problem for flexible foundations since they have uniform contact pressure irrespective of stiffness of soil.
- But when it comes to rigid foundation, this assumption may lead to unsafe design since contact pressure is not uniform in this case. This happens when the soil acts as elastic material.
- However, the soil under footing acts as elasto-plastic material just before failure occurs. Hence, this assumption can be justified at the ultimate stage.

3.3 Design of footings:

Design Procedure for rectangular footing:

Step1) To find column load

$$Q=Q_1+Q_2$$

Q_1=load in exterior column

Q_2= load in interior column

Step2) Find the area of footing

$$A = \frac{Q}{q_{na}} = \frac{Q}{q_s}$$

$$q_{na} = Allowable\ bearing\ pressure$$

Step3) Locate the line of action of the column loads measured from the centre of the exterior column

$$\bar{x}_1 = \frac{Q_2 x_2}{Q_1 + Q_2}$$

X_2=centre to centre distance between the column

Step4) Define the total length of the footing

$$L = 2(\bar{x} + e_1)$$

$$e_1 = projection\ of\ footing$$

Step 5) Find the width of the footing

$$B = \frac{A}{L}$$

Step6) Find the actual area provided (A_o)

Step 7) Find the actual pressure

$$q_o = \frac{Q}{A_o}$$

$$q_{max} = \frac{Q}{A_o}(1 + \frac{6e}{L})$$

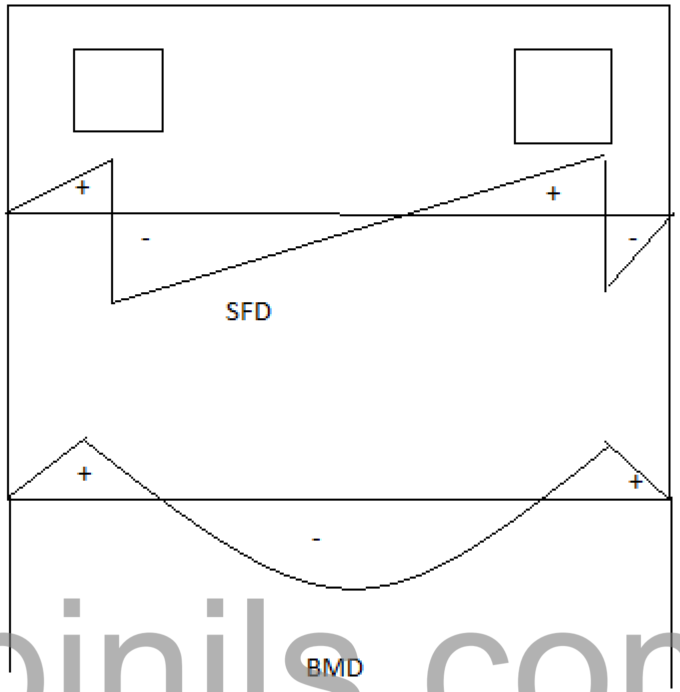
$$q_{min} = \frac{Q}{A_o}(1 - \frac{6e}{L})$$

Step 8) Draw the shear force and BM diagram

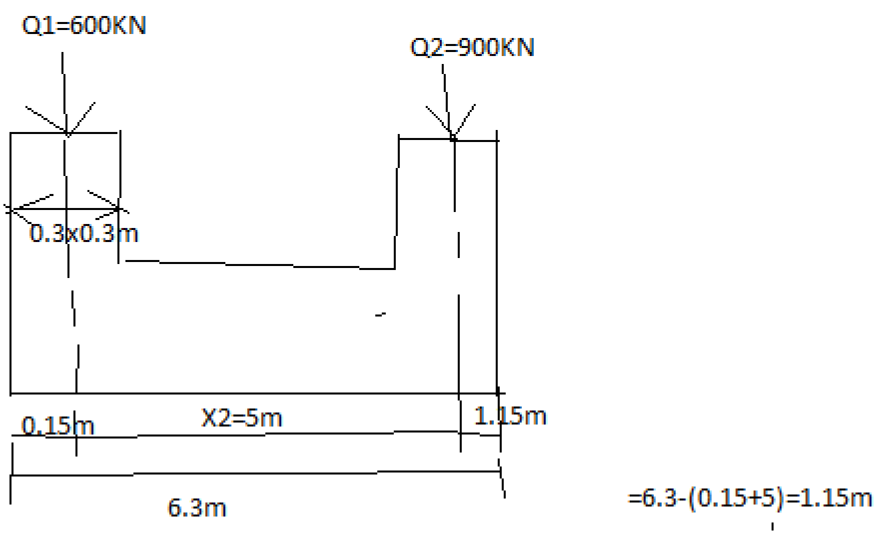
Step9)Determine the BM at the face of the column of maximum BM at the point of zero stress.

Step 10)Find the thickness of footing

Step11)Determine the required reinforcement for the maximum bending moment



1. Design a rectangular combined footing two column shown in figure. Take allowable soil pressure as 100KN/m^2.



Step1) To find column load

$Q=Q_1+Q_2=600+900=1500KN$

Step2) Find the area of footing

$$A = \frac{Q}{q_{na}} = \frac{Q}{q_s} = \frac{1500}{100} = 15m^2$$

$$q_{na} = Allowable\ bearing\ pressure$$

Step3) Locate the line of action of the column loads measured fronm the centre of the exterior column

$$\bar{x}_1 = \frac{Q_2 x_2}{Q_1 + Q_2} = \frac{900x5}{600 + 900} = 3m$$

X_2=centre to centre distance between the column

Step4) Define the total length of the footing

$$L = 2(\bar{x}_1 + e_1)$$

$$e_1 = \frac{B}{2} = \frac{0.3}{2} = 0.15m$$

$$L = 2(3 + 0.15) = 6.3m$$

$$e_1 = projection\ of\ footing$$

Step 5) Find the width of the footing

$$B = \frac{A}{L} = \frac{15}{6.3} = 2.38m = 2.4m$$

Step6) Find the actual area provided (A_o)

$$A_o = BxL = 2.4x6.3 = 15.12m^2$$

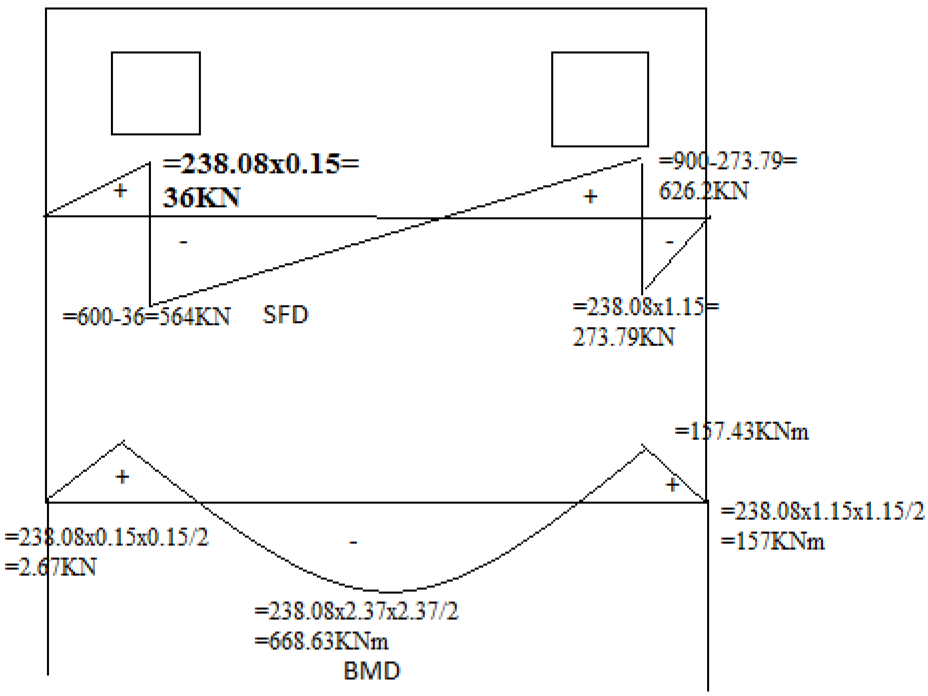
Step 7) Find the actual pressure

$$q_o = \frac{Q}{A_0}$$

$$q_o = \frac{1500}{15.12} = 99.2KN/m^2$$

Step8) Actual pressure per meter

$$q_o = 99.2x2.4 = 238.08KN/m$$



Design Procedure for trapezoidal footing:

Step1) To find column load

$$Q=Q_1+Q_2$$

Q_1=load in exterior column

Q_2= load in interior column

Step2)Find the area of footing

$$A=\frac{Q}{q_{na}}=\frac{Q}{q_s}$$

$$q_{na}= Allowable\ bearing\ pressure$$

Step3)Locate the line of action of the column loads measured fronm the centre of the exterior column

$$\bar{x}_1=\frac{Q_2x_2}{Q_1+Q_2}$$

X_2=centre to centre distance between the column

Step4) Find x'

$$x'=\bar{x}+\frac{b_1}{2}$$

Step 5) Find $\frac{L}{2}+\frac{L}{3}$

$$\frac{L}{3} < x' < \frac{L}{2}$$

Step 6) Find the width of the footing

$$B_2 = \frac{2A}{L}(\frac{3x'}{L} - 1)$$

$$B_1 = \frac{2A}{L} - B_2$$

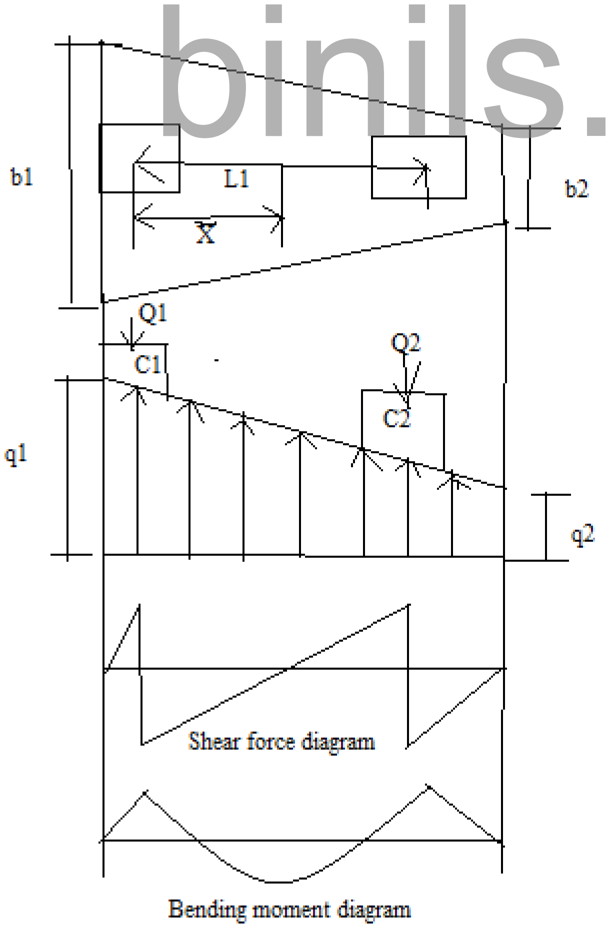
Step 7)Find the actual pressure

$$q_o = \frac{Q}{A_o}$$

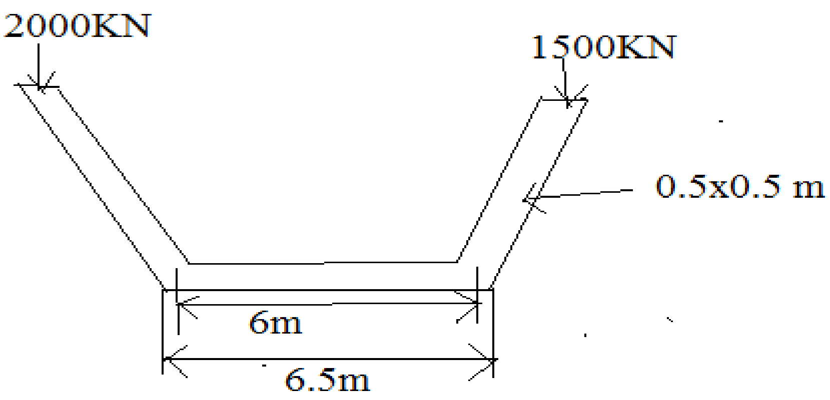
$$q_{max} = \frac{Q}{A_o}(1 + \frac{6e}{L})$$

$$q_{min} = \frac{Q}{A_o}(1 - \frac{6e}{L})$$

Step 8) Draw shear force and bending moment Diagram



3.Design a trapezoidal footing for the two column shown in figure .Take allowable soil pressure is 200KN/m^2.



Step1) To find column load

$$Q=Q_1+Q_2=2000+1500=35000KN$$

Q_1=load in exterior column

Q_2= load in interior column

Step2)Find the area of footing

$$A=\frac{Q}{q_{na}}=\frac{Q}{q_s}=17.5m^2$$

$$q_{na}=Allowable\ bearing\ pressure$$

Step3)Locate the line of action of the column loads measured fronm the centre of the exterior column

$$\bar{x}_1=\frac{Q_2x_2}{Q_1+Q_2}$$

$$\bar{x}_1=\frac{3000x6}{3500}=2.57m$$

X_2=centre to centre distance between the column

Step4) Find x'

$$x'=\bar{x}+\frac{b_1}{2}$$

$$x'=2.57+\frac{0.5}{2}=2.82m$$

Step 5) Find $\frac{L}{2},\frac{L}{3}$

$$\frac{L}{3}<x'<\frac{L}{2}$$

2.167<2.82<3.25

Step 6) Find the width of the footing

$$B_2 = \frac{2A}{L}(\frac{3x'}{L} - 1)$$

$$B_2 = \frac{2x17.5}{6.5}(\frac{3x2.82}{6.5} - 1) = 1.62m$$

$$B_1 = \frac{2A}{L} - B_2$$

$$B_1 = \frac{2x17.5}{6.5} - 1.62 = 3.76$$

Step 7)Find the actual pressure

$$q_o = \frac{Q}{A_o}$$

$$q_o = \frac{3500}{17.42} = 200.17KN/m^2$$

Step 7)Find the actual pressure per meter

$$q_o = 200.17xB_1$$

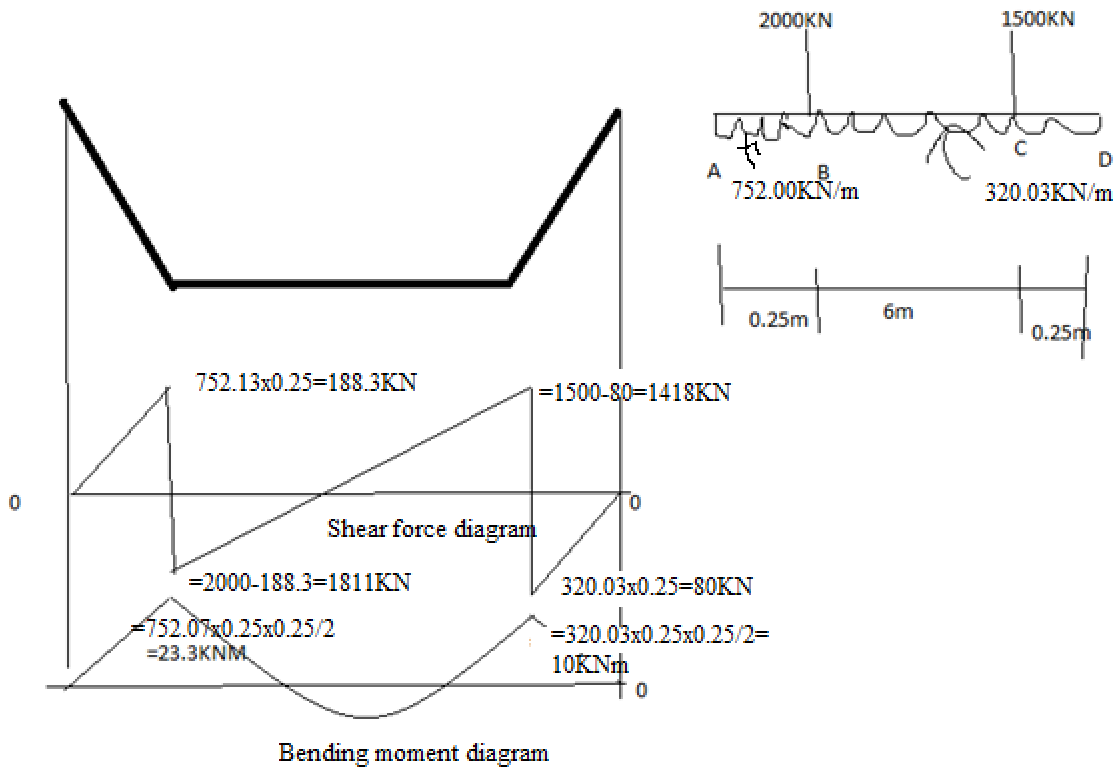
$$q_o = 200.17x3.76$$

=752.63KN/m

$$q_o = 200.17xB_2$$

$$q_o = 200.17x1.62$$

=320.03KN/m



Strap footing:

Design Procedure for strap footing:

Step 1: calculate length

$$L_1 = 2(e + 0.5b_1)$$

Step 2) calculate R_1

$$R_1 = \frac{Q_1 x_2}{S}$$

Step 3) calculate R_2

$$R_2 = (Q_1 + Q_2) - R_1$$

Step 4) calculate A_1

$$A_1 = \frac{R_1}{q_{na}}$$

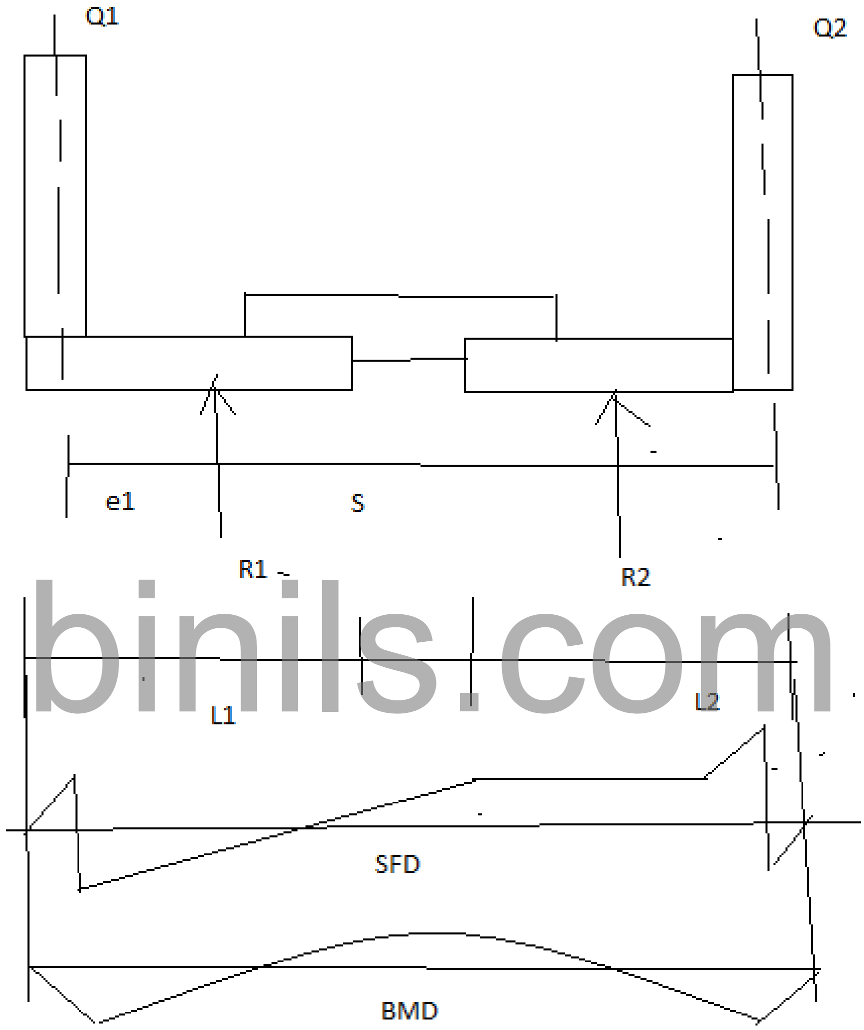
$$A_2 = \frac{R_2}{q_{na}}$$

Step 5)calculate Pressure intensity

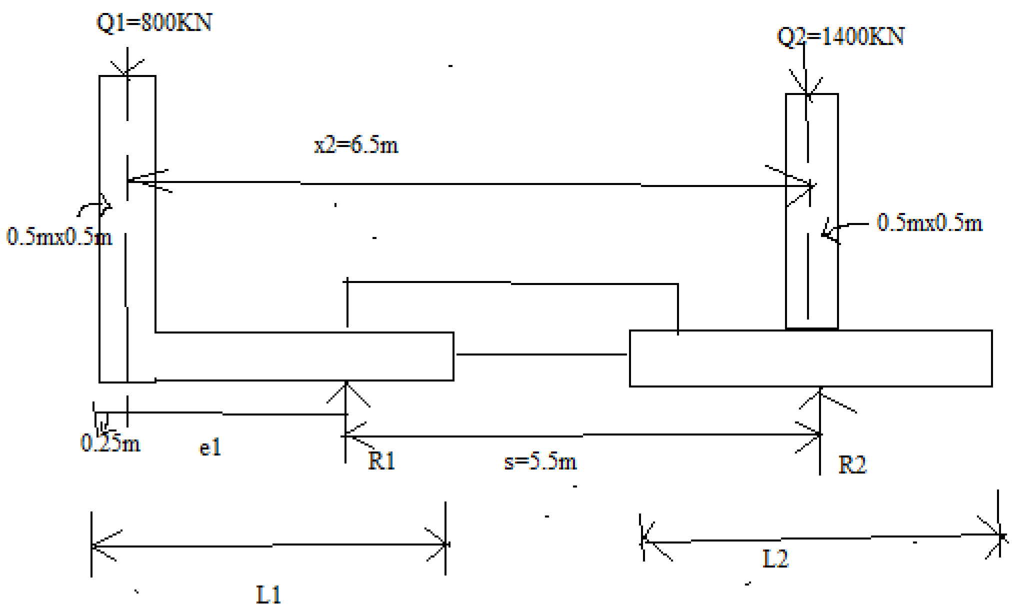
$$B_1 = \frac{A_1}{L_1}$$

$$q_1 = \frac{R_1}{L_1 x B_1} = \frac{R_1}{A_1}$$

$$q_2 = \frac{R_2}{L_2 x B_2} = \frac{R_2}{A_2}$$



3. Design a strap footing for two columns with Centre to center distance6.5m and distance between the reactions is 5.5 m. The allowable soil pressure is 120KN/m^2.take eccentricity of footing of column is 1.The size of the column is 0.5mx0.5m



Step 1:calculate length

$$L_1 = 2(e + 0.5b_1)$$

$$L_1 = 2(1 + 0.5x0.5) = 2.5m$$

Step 2) calculate R_1

$$R_1 = \frac{Q_1 x_2}{S}$$

$$R_1 = \frac{800x0.5}{5.5} = 945.45KN$$

Step 3) calculate R_2

$$R_2 = (Q_1 + Q_2) - R_1$$

$$R_2 = (800 + 1400) - 945.45 = 1254.55KN$$

Step 4) calculate A_1

$$A_1 = \frac{R_1}{q_{na}} = \frac{945.45}{120} = 7.878m^2$$

$$A_2 = \frac{R_2}{q_{na}} = \frac{1254.5}{120} = 10.45m^2$$

Step 5)calculate Pressure intensity

$$B_1 = \frac{A_1}{L_1} = \frac{7.878}{2.5} = 315m$$

$$q_1 = \frac{R_1}{L_1 x B_1} = \frac{R_1}{A_1} = \frac{945.45}{7.878} = 120KN/m^2$$

$$q_2 = \frac{R_2}{L_2 x B_2} = \frac{R_2}{A_2} = \frac{1254.55}{10.45} = 120KN/m^2$$

$$B_2 = \sqrt{A_2} = \sqrt{10.45} = 3.23$$

$$B_2 = \frac{A_2}{L_2}$$

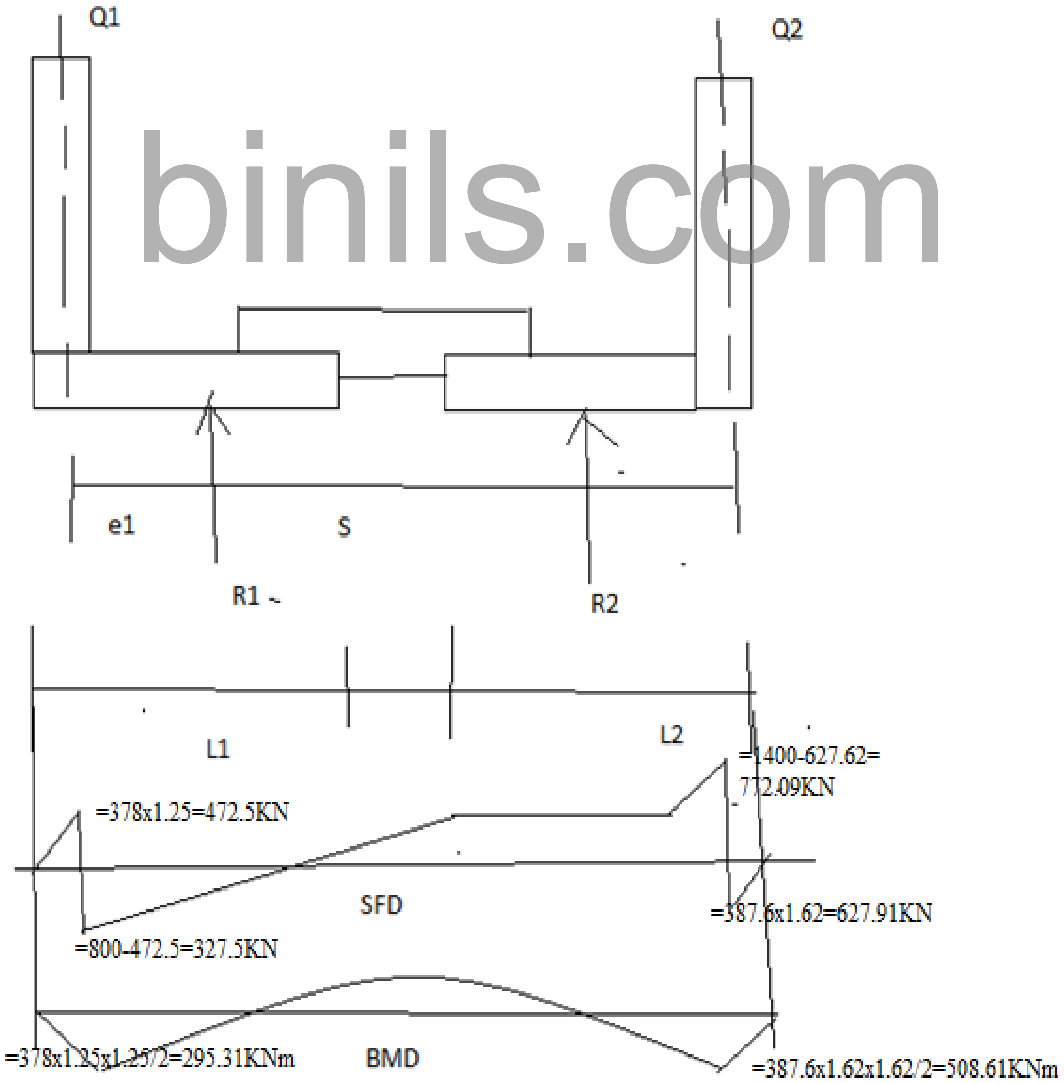
$$3.23 = \frac{10.45}{L_2}$$

$$L_2 = 3.23m$$

Pressure intensity per meter,

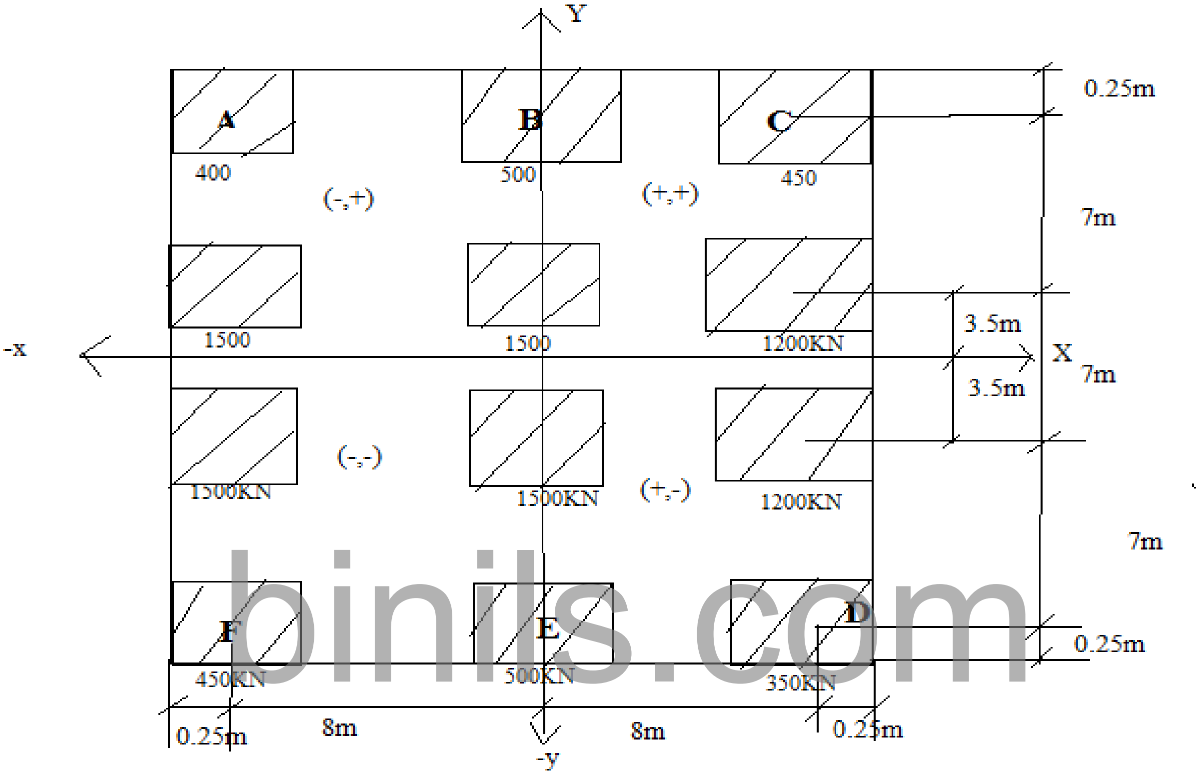
$$q_1 = 120x3.15 = 378KN/m$$

$$q_2 = 120x3.2 = 387.6KN/m$$



Mat Foundation:

4. A plan of raft foundation with column load as shown in figure .Calculate the soil pressure at point A,C,D,F The size of mat is16.5x21.5m all column are 0.5x0.5m in the section .The allowable soil pressure is 60KN/m^2.Determine the soil pressure at the point.



Solution:

Step1) Area of mat

$A = bxd$=16.5x21.5=354.75m^2

Step2)Calculate the moment of inertia

$$I_{xx} = \frac{bd^3}{12} = \frac{16.5x21.5^3}{12} = 13665.26m^4$$

$$I_{yy} = \frac{db^3}{12} = \frac{21.5x16.5^3}{12} = 8048.3m^4$$

Step 3) Calculate Moment:

$$M_y = Qxe_x$$

$$e_x = x' - \frac{B}{2}$$

$$x' = \frac{Q_1x_1 + Q_2x_2 + \cdots . + Q_nx_n}{Q}$$

$$= \frac{1}{11000}[(400 + 1500 + 1500 + 400)x0.25]$$
$$+ [(500 + 1500 + 1500 + 500)x8.25]$$
$$+ [(450 + 1200 + 1200 + 30)x16.25]$$

$$x' = 7.81m$$

$$e_x = 7.81 - \frac{16.5}{2} = -0.44m$$

$$M_y = 11000x(-0.44) = -4840KNm$$

$$M_x = Qxe_y$$

$$e_y = y' - \frac{d}{2}$$

$$y' = \frac{Q_1y_1 + Q_2y_2 + \cdots . + Q_ny_n}{Q}$$

$$= \frac{1}{11000}[(400 + 500 + 450)x0.25] + [(1500 + 1500 + 1200)x7.25]$$
$$+ [(1500 + 1500 + 1200)x14.25] + [(400 + 500 + 350)x21.25$$

$$y' = 10.65m$$

$$e_y = 10.65 - \frac{21.5}{2} = 0.1m$$

$$M_x = 11000x0.1 = 1100KNm$$

Step 4) Calculate soil Pressure:

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

$$q = \frac{11000}{354.75} \pm \frac{4840x}{8048.39} \pm \frac{1100y}{13665.27}$$

$$q = 31 \pm 0.6x \pm 0.08y$$

Soil pressure at A=$31 - 0.6x8.25 + 0.08x10.75 = 26.91KN/m^2$

Soil pressure at C=$31 + 0.6x8.25 + 0.08x10.75 = 31.81KN/m^2$

Soil pressure at D=$31 + 0.6x8.25 - 0.08x10.75 = 35.09KN/m^2$

Soil pressure at E=$31 - 0.6x8.25 - 0.08x10.75 = 25.19KN/m^2$

3.4 Proportion of footings:

- A structure is usually supported on a number of column .These column usually carry a different load depending on their location with respect to structure.
- Differential settlements are minimized by proportioning the footing for the various columns so as to equalize the average bearing pressure under all columns. But each column load consists of dead load (DL)+Live load(LL).The full LL does not act all the time(wind load)
- Hence DL+ full LL is not a realistic criterion for producing equal settlement.
- For ordinary building the actual load expected on the building is D.L+50% L.L.

Procedure:

i. DL inclusive self weight of column and estimated value for footing is noted for each column footing.

ii. LL for each column is calculated(IS code)

iii. The ratio of LL to DL is calculated for each column footing and the maximum value of ratio is noted.

iv. The allowable bearing pressure is calculated by Terazaghi equation.

v. For the footing with largest LL to DL ratio the area of footing required is calculated by total load by allowable bearing pressure.

$$A = \frac{Q}{allowable\ pressure}$$

vi. The service load for the column is calculated by adding appropriate fraction LL to DL.

vii. The design bearing capacity(q_d) is obtained by dividing the service load of maximum LL to DL ratio by the area of footing

$$q_d = \frac{Service\ load}{A}$$

viii. This pressure is less than the pressure computed in(iv)

ix. The area of footing for each of the column is obtained by dividing the corresponding service load by the allowable bearing pressure

$$A = \frac{\text{service load for that column}}{q_d}$$

Design Procedure for Proportioning of rectangular footing:

Consider dead load + reduced live load

Step1) To find column load

$$Q=Q_1+Q_2$$

Q_1=load in exterior column

Q_2= load in interior column

Step2) Find the area of footing

$$A = \frac{Q}{q_{na}} = \frac{Q}{q_s}$$

$$q_{na} = Allowable\ bearing\ pressure$$

Step3) Locate the line of action of the column loads measured from the centre of the exterior column

$$\bar{x}_1 = \frac{Q_2 x_2}{Q_1 + Q_2}$$

X_2=centre to centre distance between the column

Step4) Define the total length of the footing

$$L = 2(\bar{x} + e_1)$$

$$e_1 = projection\ of\ footing$$

Step 5) Find the width of the footing

$$B = \frac{A}{L}$$

Step6) Find the actual area provided(A_o)

Step 7)Find the actual pressure

Consider dead load +full live load

$$q_{max} = \frac{Q}{A_o}(1 + \frac{6e}{L})$$

$$q_{min} = \frac{Q}{A_o}(1 - \frac{6e}{L})$$

Step 8) Check the Pressure

Actual pressure<allowable pressure

1.Proportion a rectangular combined footing for a uniform pressure under DL+reduced LL with the following data allowable pressure

DL+reduced LL=180 KN/m^2

DL+LL=270 KN/m^2

Column Load

Load	Column A	Column B
DL	500KN	660KN
LL	400KN	840KN

C/C distance of column 5m,Projection of footing is 0.5m

Soln:

Column load	Column A	Column B	Total load
DL+reducedLL	=500+0.5x400 =700KN	$= 660 + \frac{50}{100} 840$ $= 1080KN$	=700+1080=1780KN
DL+LL	=500+400=900KN	=660+840=1500KN	=900+1500=2400KN

Consider full dead load+50% reduced live load

Step1) To find column load

$$Q=Q_1+Q_2=700+1080=1780KN$$

Step2)Find the area of footing

$$A=\frac{Q}{q_{na}}=\frac{Q}{q_s}=\frac{1780}{180}=9.88m^2$$

$$q_{na}=Allowable\ bearing\ pressure$$

Step3)Locate the line of action of the column loads measured fronm the centre of the exterior column

$$\bar{x}_1=\frac{Q_2x_2}{Q_1+Q_2}=\frac{1080x5}{700+1080}=3.03m$$

X_2=centre to centre distance between the column

Step4)Define the total length of the footing

$$L=2(\bar{x}_1+e_1)$$

$$L=2(3.03+0.5)=7.06m$$

$$e_1=projection\ of\ footing$$

Step 5) Find the width of the footing

$$B=\frac{A}{L}=\frac{9.88}{7.06}=1.39m=1.4m$$

Step6) Find the actual area provided(A_o)

$$A_o=BxL=1.4x7.06=9.88m^2$$

Step 7)Find the actual pressure

$$q_{max}=\frac{Q}{A_o}(1+\frac{6e}{L})$$

$$q_{min}=\frac{Q}{A_o}(1-\frac{6e}{L})$$

$$e=\bar{x}_1-\bar{x}_2$$

Find uniform pressure under full DL+LL

$$\bar{x}_2 = \frac{Q_2 x_2}{Q_1 + Q_2}$$

$$\bar{x}_2 = \frac{1500x5}{900 + 1500} = 3.125m$$

$$e = 3.03 - 3.125 = 0.095 = 0.1m$$

$$q_{max} = \frac{(900 + 1500)}{9.89}(1 + \frac{6x0.1}{7.06}) = 263.04KN/m^2 < 270KN/m^2$$

$$q_{min} = \frac{(900 + 1500)}{9.89}(1 - \frac{6x0.1}{7.06}) = 222.7 < 270KN/m^2$$

Hence ok

Provide rectangular footing of size 7.06x1.4m

Proportioning of trapezoidal footing:

2. Proportion a trapezoidal combined footing for uniform pressure under a dead load +reduced live load with the following data

Allowable bearing pressure:

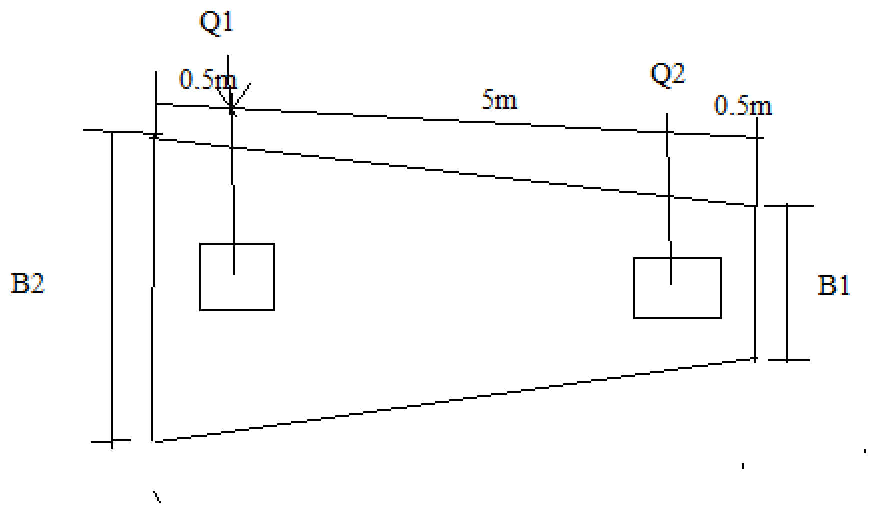
DL+reducedLL=180KN/m^2

DL+LL=280KN/m^2

Column load	A	B
DL	500KN	660KN
LL	400KN	840KN

Distance between c/c column=5m

Projection beyond column A=0.5m



Solution:

Column load	A	B	total
DL + reduced LL	700KN	1080KN	1780KN
DL+LL	900KN	1500KN	2400KN

For uniform pressure under DL+ reduced LL

Area:

$$A = \frac{Q}{q_{na}} = \frac{1780}{180} = 9.89m^2$$

$$\bar{x} = \frac{Q_2 x_2}{Q_1 + Q_2}$$

$$= \frac{1080x5}{1780} = 3.03m$$

Length of footing:

Length=C/c distance + projection on both sides

=5+0.5+0.5=6m

$$A = \frac{L}{2}(B_1 + B_2)$$

$$9.89 = \frac{6}{2}(B_1 + B_2)$$

$$B_1 + B_2 = 3.30 \ldots .(1)$$

We know that

$$\frac{L}{3}(\frac{B_1+2B_2}{B_1+B_2}) = \bar{x}+e$$

$$\frac{6}{3}(\frac{B_1+2B_2}{B_1+B_2}) = 3.03+0.5$$

$$(\frac{B_1+2B_2}{B_1+B_2}) = 1.77$$

$$-B_1+0.43\ B_2 = 0 --- (2)$$

Solve (1)&(2)

B_1=1m

B_2=2.40m

Total area provided=$\frac{2.40+1}{2}x6$=10.2 m^2

For dead load +live load calculations

$$\bar{x} = \frac{6}{3}(\frac{1+2x2.4}{1+2.4}) = 3.41m$$

Location of resultant DL+LL for exterior column

$$= \frac{Q_2x_2}{Q} = \frac{1500x5}{2400} = 3.125m$$

Location of resultant from the outer edge of the footing

=3.125+0.5=3.625m

Eccentricity e=3.625-3.43=0.195m

Determination of pressure:

$$moment\ of\ inertia = [\frac{B_1^2+4B_1B_2+B_2^2}{36(B_1+B_2)}]\ L^3$$

$$moment\ of\ inertia = [\frac{1^2+4x1x2.40+2.4^2}{36(1+2.4)}]\ 6^3$$

$$= 28.87m^4$$

$$q_{max} = \frac{Q}{A}+[\frac{QxexX}{I}]$$

$$= \frac{2400}{10.2}+[\frac{2400x0.195x(6-3.41)}{28.87}] = 277 < 280KN/m^2$$

$$q_{max} = \frac{Q}{A}-[\frac{QxexX}{I}]$$

$$= \frac{2400}{10.2} - [\frac{2400x0.195x(6-3.41)}{28.87}]$$

$$= 193.3 < 280KN/m^2$$

Hence OK

Proportioning of strap footing:

3. Proportioning of strap footing for the following data:

Allowable pressure=150KN/m^2 for DL+reduced LL

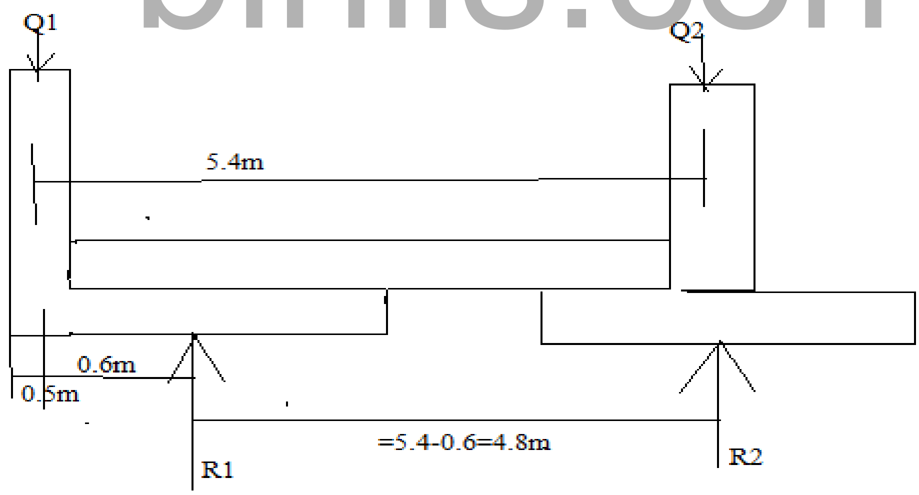
Allowable pressure=225KN/m^2 for DL+ LL

Column Load	A	B
DL	500KN	600KN
LL	450KN	800KN

Proportion the footing for uniform pressure under DL+reduced LL centre to centre spacing between column =5.4m.projection beyond column A should not exceed 0.5m

Solution:

Step 1:Assume eccentricity e=0.6m



Column load	A	B	total
DL+reduced LL	725KN	1000KN	1725KN
DL+LL	950KN	1400KN	2350KN

Step 2) Determine the length of footing of exterior column

$$L_1 = 2(e + 0.5b_1)$$

$$L_1 = 2(0.6 + 0.5x1) = 2.2m$$

Consider DL+reduced LL

Steps 3) compute the reaction R_1 by taking moment about the line of action of the reaction

$$R_1 = \frac{Q_1 x_2}{S} = \frac{725x5.4}{4.8} = 815KN$$

Steps 4) compute R_2

$$R_2 = (Q_1 + Q_2) - R_1$$

=1725-815=910KN

Steps 5) compute the area of footing A1

$$A_1 = \frac{R_1}{q_{na}} = \frac{815}{150} = 5.4m^2$$

$$A_2 = \frac{R_2}{q_{na}} = \frac{910}{150} = 6.07m^2$$

Step 6) calculate width of footing

$$B_1 = \frac{A_1}{L_1} = \frac{5.4}{2.2} = 2.45m$$

Provide a width of 2.50m

Consider B_1=B_2=2.5m

$$B_2 = \sqrt{A_2}$$

$$B_2 = \frac{A_2}{L_2}$$

$$L_2 = \frac{A_2}{B_2} = \frac{6.07}{2.5} = 2.43m$$

Provide the length is 2.5m

Step 7) calculate Pressure intensity

$$q_1 = \frac{R_1}{L_1 x B_1}$$

$$= \frac{815}{2.2x2.5}$$

$$= \frac{148.18KN}{m^2} < 150KN/m^2$$

$$q_2 = \frac{R_2}{L_2 x B_2}$$

$$= \frac{910}{2.5x2.5}$$

$$= \frac{145.6KN}{m^2} < 150KN/m^2$$

Provide the strap footing of size

2.2x2.5m and 2.5x2.5m

3.5 Mat Foundation:

Mat foundation is also known as the raft foundation. It is a continuous thick concrete slab on the soil that extends the entire footprint of the building and increases the earth-bearing capacity power. This foundation supports the whole building loads and safely transfers them to the ground.

Raft/Mat foundation is used in those places where we have less bearing capacity of the soil. At those places, we use mat foundations to distribute the whole loads of the structure to the earth (When the footing area increases, then the soil load-bearing capacity will also increase) because this foundation reduces the stress on the soil at the same place.

USE MAT FOUNDATION:

- There is a lot the critical reason for the use of mat foundations. We use this foundation if the bearing capacity of the soil is weak and not capable of transferring the load of the building to the ground.
- A column is placed near the property line, and walls are so close that individual footing would overlap.
- If a deep foundation (Pile foundation) cost is higher than the raft foundation, we use it to make the structure economical.
- When a spread footing, columns can cover up to 50% of the foundation area.

TYPES OF MAT/RAFT FOUNDATION:

There are the following types of mat foundation,

1. Flat plate raft
2. Plate thickened under columns.
3. Two-way slab and beam
4. Piled mat
5. Rigid frame raft
6. Cellular mat foundation

1: FLAT PLATE RAFT:

- A flat plate raft is used in the small and lightweight load structure. This type of foundation is suitable when the soil is not compressible. The reinforcement bars are provided in both directions, top and bottom, in the form of a mesh (cage).
- A minimum of 6 inches of thick RCC slab is used in this foundation.

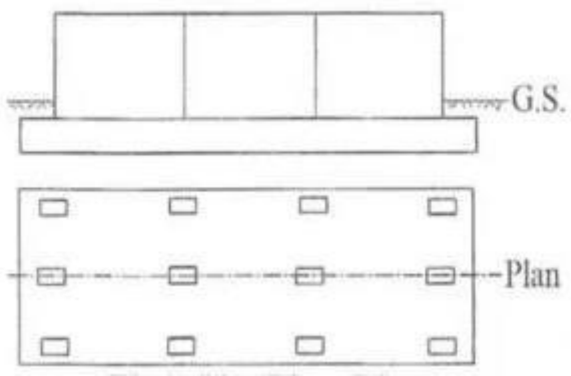


Fig 1 FLATPLATERAFT

[Fig1 https://www.civilclick.com/mat-foundation/]

2: THICKENED PLATE UNDER COLUMNS:

- The Slab thickness should be increased when the upcoming column loads are weighty. The flat plate foundation is not suitable in those structures where the column loads are very high, then the thickened flat plate is used.
- The heavy loads create the diagonal shear in the slab and create a negative bending moment on columns, so the thickness of the RCC slab under the column should be thickened.

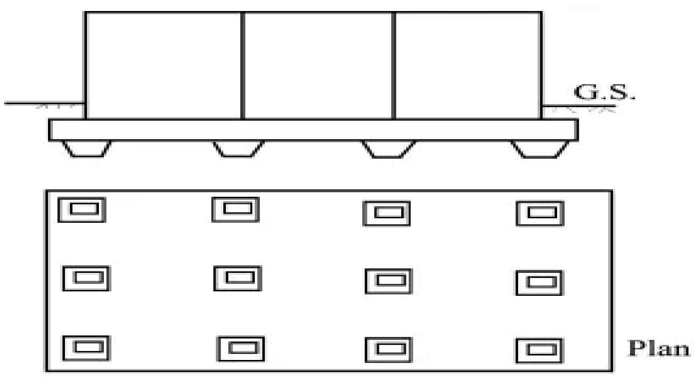


Fig2 ThickenedPlateUnderColumns

[Fig 2 https://bestengineeringprojects.com/mat-foundation-types-of-mat-foundation/]

3: TWO-WAY SLAB AND BEAM:

- In this type of mat foundation, beams are placed in perpendicular directions, and all the beams are connected by an RCC slab. The columns are placed at the intersection of beams.
- A two-way slab and beam raft foundation is suitable when the columns are carrying unequal loads and the spacing is large between them.

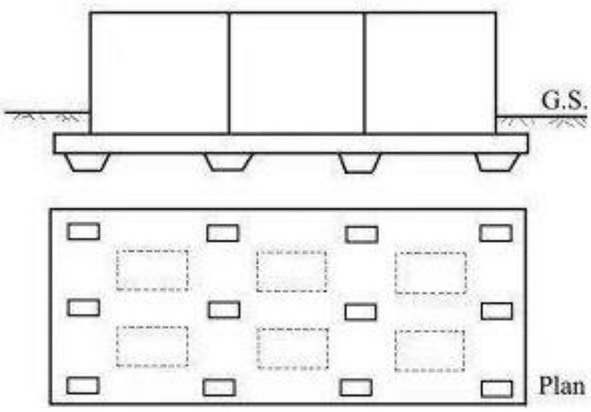


Fig3 Two-Way Slab and Beam

[Fig 3 https://www.civilclick.com/mat-foundation/]

4: PILED RAFT FOUNDATION:

- This foundation is supported by piles in the soil. The piled raft foundation is suitable for the ground of high compressibility and where the water table is high. Piled raft foundation is mainly used for high-rise buildings.
- The piles were used to reduce the amount of soil settlement(With time) and increase the soil load-bearing capacity.

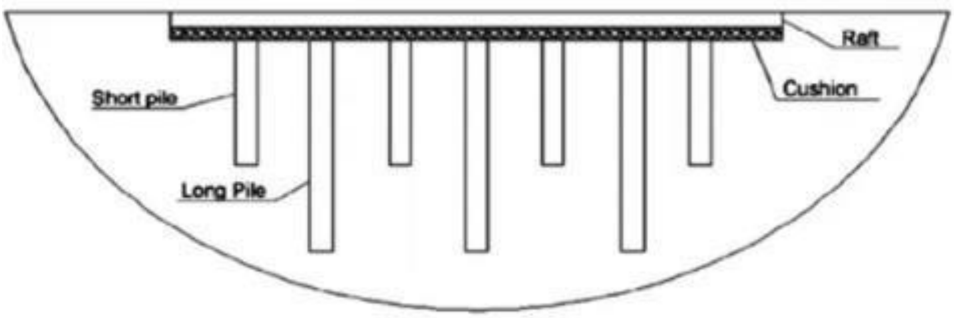


Fig 4 Piled Raft Foundation

[Fig 4 https://www.civilclick.com/mat-foundation/]

5: RIGID FRAME RAFT:

- A rigid frame mat is used when the columns have a very high load on them. In rigid frame mat design, the basement RCC wall acts as a deep beam or ribs.
- If the foundation depth is greater than 90 cm, then the rigid frame raft is used.

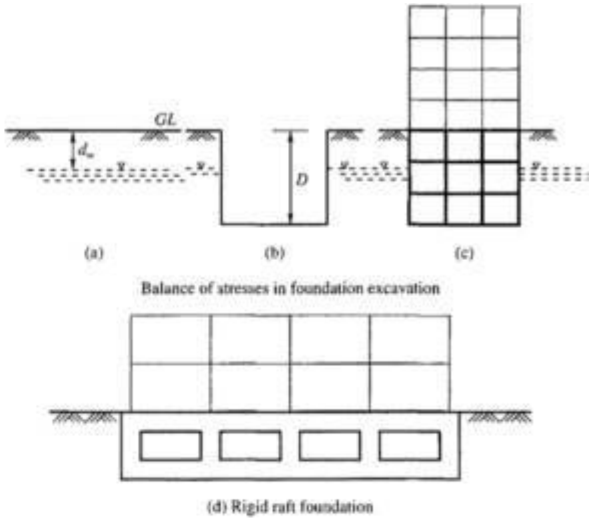


Fig 5 RigidFrameRaft

[Fig 5 https://www.civilclick.com/mat-foundation/]

6: CELLULAR MAT FOUNDATION:

- It is also termed a box mat foundation. In the cellular mat foundation, the structures of boxes are formed, and the walls of every box act as beams. The walls are connected by slabs at the top and bottom.
- This type of foundation is suitable for loose soil.

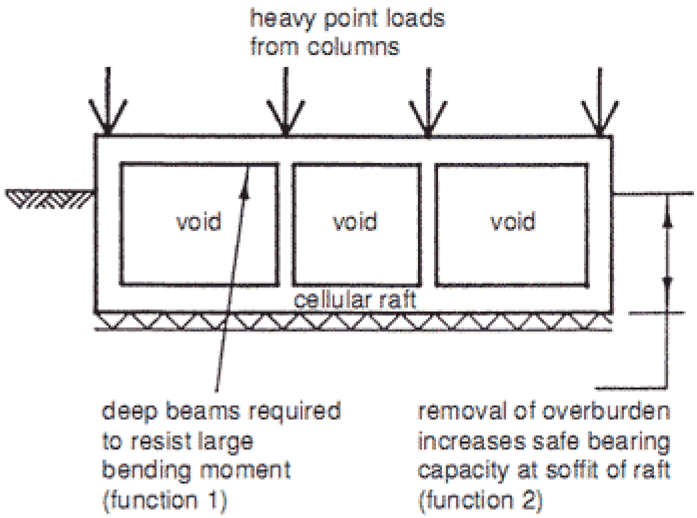


Fig6 CellularMatFoundation

[Fig 6 https://www.civilclick.com/mat-foundation/]

Advantages:

- The foundation and ground floor slab are poured simultaneously, which reduces our construction time and material.
- It requires less excavation.
- It is provided where the shallow foundation is possible, but the condition of the soil is poor.
- Reduces the cost of constructing a floor slab (But not entirely economical).
- It helps in the transferring of loads over a wide area.
- It shows good resistance and cannot slide during the flood.
- We can handle more heavy loads as compared to other types of foundations..

Disadvantages:

- Raft foundation requires a large quantity of steel and concrete.
- This foundation is costly (The volume of footing was increasing).
- It is not suitable and used for domestic home construction.
- Unique measurement is needed in the case of concentrated loads.
- In the mat foundation, skilled laborers are required.

Floating foundation:

A floating foundation is a type of foundation constructed by excavating the soil in such a way that the weight of structure built on the soil is nearly equal to the total weight of the soil excavated from the ground including the weight water in the soil before the construction of structure.

A Floating Foundation, also known as Balancing Raft is a type of foundation where the weight of the building is approximately equal to the full weight of the soil and water removed from the site of the building prior to construction.

Problems During in the Design of a Floating Foundation:

The following problems are to be considered during the design and construction stage of a floating foundation.

1. Excavation
2. De watering
3. Critical depth

Bottom heave

Excavation:

The excavation for the foundation has to be done with care. The sides of the excavation should suitably be supported by sheet piling, soldier piles and timber or some other standard method.

Dewatering:

It is better to examine the water table level prior to the excavation. If the depth of the excavation is below the water table then dewatering is essential. Care has to be taken to see that the adjoining structures are not affected due to the lowering of the water table.

Critical Depth:

If the shear strength of the soil is low and there is a theoretical limit to the depth to which an excavation can be made. Terzaghi (1943) has proposed the following equation for computing the critical depth Dc,

$$D_c = \frac{5.7\,s}{\gamma - (s/B)\sqrt{2}}$$

γ=unit weight of soil

s= Shear strength

B=width of foundation

L=Length of foundation

- Skempton (1951) proposes the following equation for D_c which is based on actual failures in excavations,

$$D_c = N_c \frac{S}{\gamma}$$

Where Nc= Skempton's bearing capacity factor.

- By using any one the above two equations, the critical depth or maximum depth of excavation can be determined.

Bottom Heave

When the soil is excavated up to some depth, the pressure of the soil below this depth is lowered which results the formation of heave.

The formed heave causes settlement to the structure or foundation. We cannot prevent the formation of heave but there are some methods to minimize the formation of heave.

There are two possible causes of heave:

- Plastic inward movement of the surrounding soil.
- Elastic movement of the soil as the existing overburden pressure is removed.

Principle of Floating Foundation

- The main principle of floating foundation is to balance the weight of removed soil by a structure of same weight which causes zero settlement to the structure. So, this foundation is also called as balancing raft foundation.
- Let's consider a ground with water table at the top .The ground is excavated up to certain depth which is below water table. Now in the next step, a building is constructed which is as same weight as of the removed soil and water.
- Even the depth of excavation is below the table the total vertical pressure in the soil below the foundation is unchanged because of its balancing weight. But here one point is to be noted that we cannot build a structure immediately after the excavation.
- During the time of construction, the effective vertical pressure under the depth of excavation may slightly increase because of unbalancing weight. So, this type of foundations can also be called as partly compensated foundations instead of fully floating or compensated foundations.

Advantages of floating foundation:-

Low Load-bearing Capacity

Floating foundations are best in areas of low load-bearing capacity — when constructing a building over loose soil — or if the soil has varying degrees of compression compatibility. Construction of deep foundations will not be viable in new fill, sand and loose soil areas but, because floating foundations spread the support over a large area, there are no points of pressure taking a heavy load. To make the floating foundation stronger it might contain beams or ribs.

Nearby buildings:

A floating foundation can be poured when other building foundations are close. To build deep foundations would interfere with the structure of other buildings.

Moisture:

Floating foundations can be used on high moisture soils. The positioning of the foundation above the earth, rather than in it, helps create a moisture barrier between the ground and the structure.

Trenches

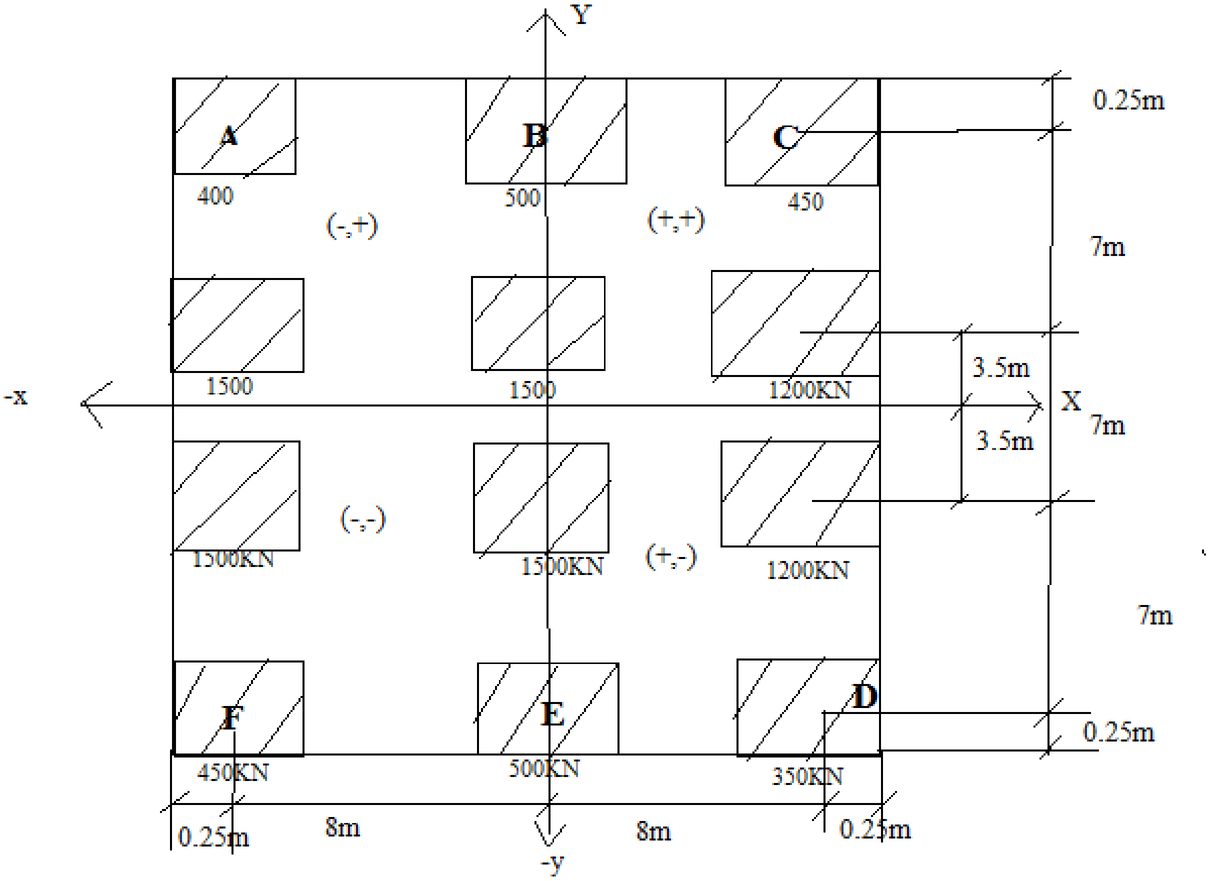
Floating foundations require far less digging because deep footer trenches are not needed. In addition, there is no need to disturb the earth beneath the building where there might be long-established tree roots or ground water.

Movement

If the earth is expected to move due to high underground moisture or high levels of vibration – as in the case of mining areas or heavily used highways -floating foundations will not be compromised.

Problem:

1.A plan of raft foundation with column load as shown in figure .Calculate the soil pressure at point A,C,D,F The size of mat is16.5x21.5m all column are 0.5x0.5m in the section .The allowable soil pressure is 60KN/m^2.Determine the soil pressure at the point.



Solution:

Step1) Area of mat

$$A = bxd = 16.5x21.5 = 354.75m^2$$

Step2) Calculate the moment of inertia

$$I_{xx} = \frac{bd^3}{12} = \frac{16.5x21.5^3}{12} = 13665.26m^4$$

$$I_{yy} = \frac{db^3}{12} = \frac{21.5x16.5^3}{12} = 8048.3m^4$$

Step 3) Calculate Moment:

$$M_y = Qxe_x$$

$$e_x = x' - \frac{B}{2}$$

$$x' = \frac{Q_1x_1 + Q_2x_2 + \cdots . + Q_nx_n}{Q}$$

$$= \frac{1}{11000}[(400+1500+1500+400)x0.25]$$

$$+[(500+1500+1500+500)x8.25]$$

$$+[(450+1200+1200+30)x16.25]$$

$$x' = 7.81m$$

$$e_x = 7.81 - \frac{16.5}{2} = -0.44m$$

$$M_y = 11000x(-0.44) = -4840KNm$$

$$M_x = Qxe_y$$

$$e_y = y' - \frac{d}{2}$$

$$y' = \frac{Q_1y_1 + Q_2y_2 + \cdots . + Q_ny_n}{Q}$$

$$= \frac{1}{11000}[(400+500+450)x0.25] + [(1500+1500+1200)x7.25]$$

$$+[(1500+1500+1200)x14.25] + [(400+500+350)x21.25$$

$$y' = 10.65m$$

$$e_y = 10.65 - \frac{21.5}{2} = 0.1m$$

$$M_x = 11000x0.1 = 1100KNm$$

Step 4) Calculate soil Pressure:

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

$$q = \frac{11000}{354.75} \pm \frac{4840x}{8048.39} \pm \frac{1100y}{13665.27}$$

$$q = 31 \pm 0.6x \pm 0.08y$$

Soil pressure at A=$31 - 0.6x8.25 + 0.08x10.75 = 26.91KN/m^2$

Soil pressure at C=$31 + 0.6x8.25 + 0.08x10.75 = 31.81KN/m^2$

Soil pressure at D=$31 + 0.6x8.25 - 0.08x10.75 = 35.09KN/m^2$

Soil pressure at E=$31 - 0.6x8.25 - 0.08x10.75 = 25.19KN/m^2$