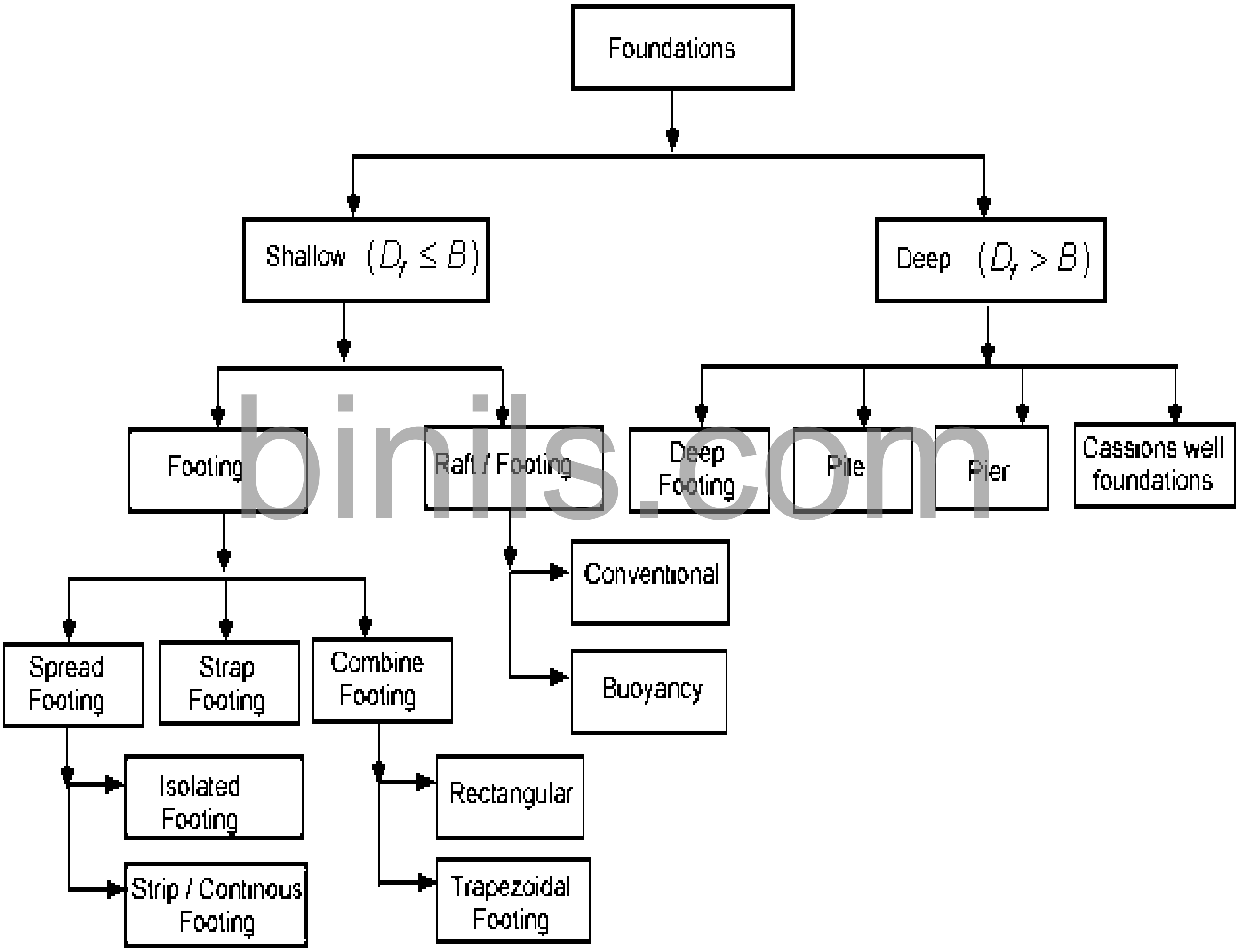
UNIT V DESIGN OF FOOTINGS

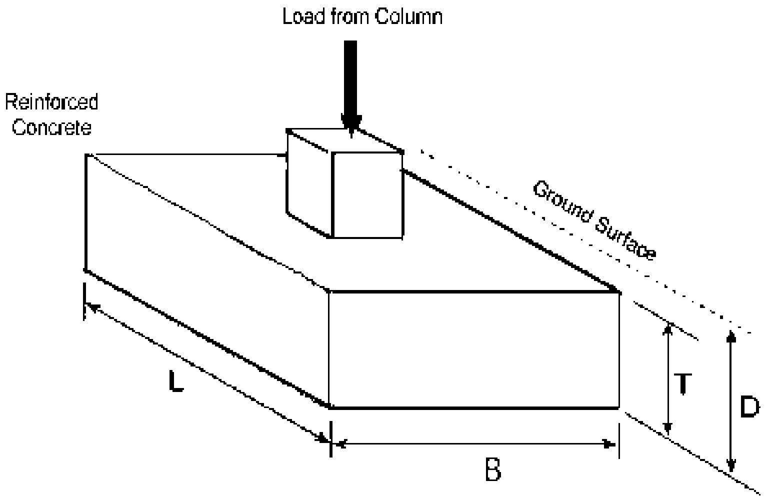
Concepts of Proportioning footings and foundations based on soil Properties-Design of wall footing – Design of axially and eccentrically loaded Square, Rectangular pad and sloped footings – Design of Combined Rectangular footing for two columns only.

A foundation is a integral part of the structure which transfer the load of the superstructure to the soil. A foundation is that member which provides support for the structure and it's loads.It includes the soil and rock of earth's crust and any special part of structure that serves to transmit the load into the rock or soil.



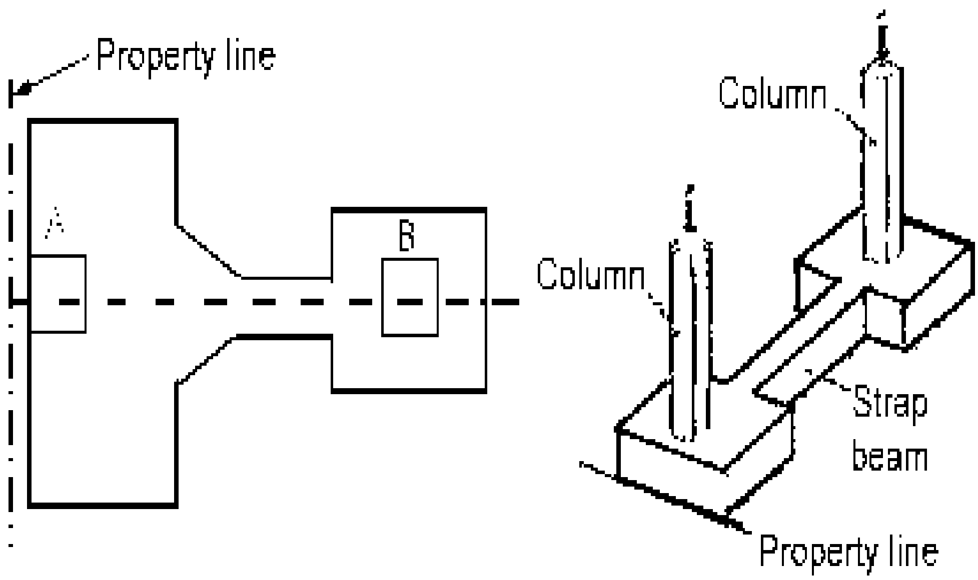
Spread Footing

It is circular, square or rectangular slab of uniform thickness. Sometimes, it is stepped to spread the load over a larger area. When spread footing is provided to support an individual column, it is called "Isolated footing"



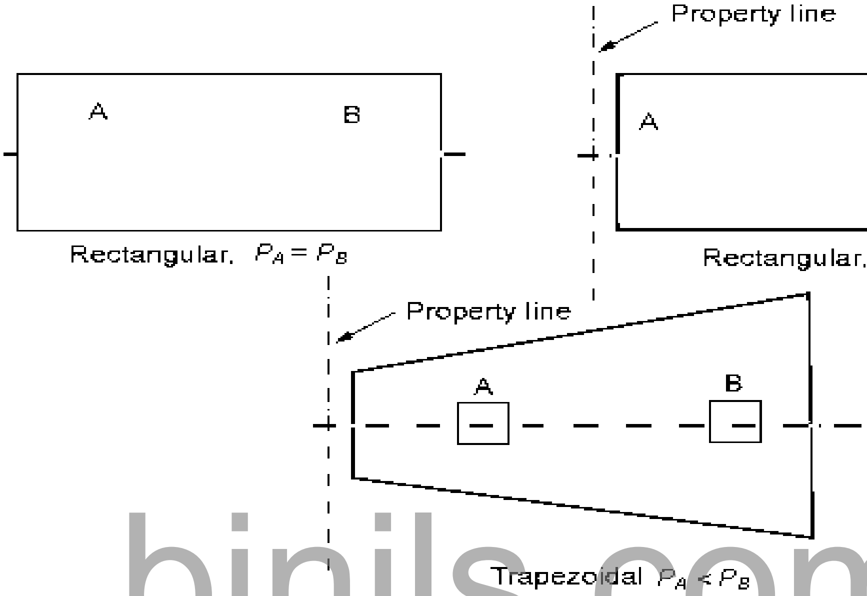
Strap Footing

It consists of two isolated footings connected with a structural strap or a lever. The strap connects the footing such that they behave as one unit. The strap simply acts as a connecting beam. A strap footing is more economical than a combined footing when the allowable soil pressure is relatively high and distance between the columns is large.



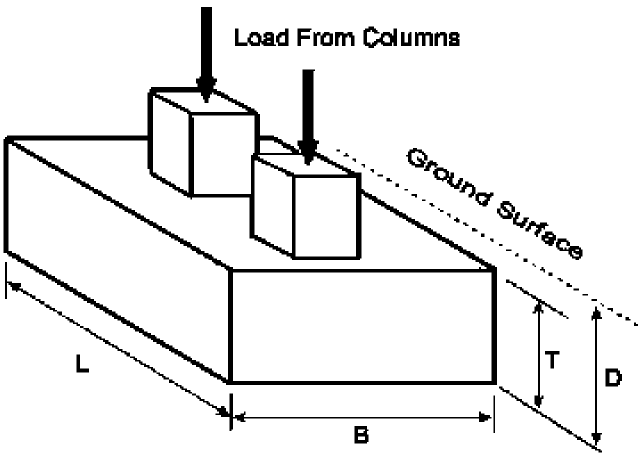
Combined Footing

It is used when the two columns are so close to each other that their individual footings would overlap. A combined footing is also provided when the property line is so close to one column that a spread footing would be eccentrically loaded when kept entirely within the property line. By combining it with that of an interior column, the load is evenly distributed. A combine footing may be rectangular or trapezoidal in plan. Trapezoidal footing is provided when the load on one of the columns is larger than the other column.



Strip/continuous footings

A strip footing is another type of spread footing which is provided for a load bearing wall. A strip footing can also be provided for a row of columns which are so closely spaced that their spread footings overlap or nearly touch each other. In such a cases, it is more economical to provide a strip footing than to provide a number of spread footings in one line. A strip footing is also known as "continuous footing"



Deep Foundations

The shallow foundations are used in case of small buildings or structures, which carry lesser loads, and hence the loads are dissipated into the soil mass at much lower depth. However when we are considering large structures, which carry heavy loads, the loads are dissipated at greater depths where usually the soil bearing capacity is quite high. One guideline of differentiating between the shallow and deep foundations is that in case of the deep foundations the depth of foundations is more than the dimension of the structure (usually the width is considered as the dimension).

Different Types of Deep Foundation

- Deep footings.
- Piles.
- Piers.
- Caissons /Well foundations.

REQUIREMENT FOR DEEP FOUNDATIONS

- Huge vertical load with respect to soil capacity.
- Very weak soil or problematic soil.
- Huge lateral loads eg. Tower, chimneys.
- Scour depth criteria.
- For fills having very large depth.
- Uplift situations (expansive zones)
- Urban areas for future large and huge construction near the existing building.

CLASSIFICATION OF PILES

1. Based on material

- Timber piles
- Steel piles
- Concrete piles
- Composite piles (steel + concrete)

2. Based on method of installation

- Driven piles (i) precast (ii) cast-in-situ.
- Bored piles.

3. Based on the degree of disturbance

- Large displacement piles (occurs for driven piles)
- Small displacement piles (occurs for bored piles)

UNIT V DESIGN OF FOOTINGS

Concepts of Proportioning footings and foundations based on soil Properties-Design of wall footing – Design of axially and eccentrically loaded Square, Rectangular pad and sloped footings – Design of Combined Rectangular footing for two columns only.

Sl.No	Sources	Shallow Foundation	Deep Foundation
1	Definition	Foundation which is placed near the surface of the earth or transfers the loads at shallow depth is called the shallow foundation.	Foundation which is placed at a greater depth or transfers the loads to deep strata is called the deep foundation.
2	The depth of the foundation	The depth of shallow foundation is generally about 3 meters or the depth of foundation is less than the footing with.	Greater than the shallow foundation.
3	Cost	A shallow foundation is cheaper.	Deep foundations are generally more expensive than shallow foundations.
4	Feasibility	Shallow foundations are easier to construct.	The construction process of a deep foundation is more complex.
5	Mechanism of load transfer	Shallow foundations transfer loads mostly by end bearing.	Deep foundations rely both on end bearing and skin friction, with few exceptions like end-bearing pile.
6	Advantages	Construction materials are available, less labor is needed, construction procedure is simple at an affordable cost, etc.	Foundation can be provided at a greater depth, Provides lateral support and resists uplift, effective when foundation at shallow depth is not possible, can carry a huge load, etc.
7	Disadvantages	Possibility of a settlement, usually applicable for lightweight structure, weak against lateral loads, etc.	More expensive, needs skilled labors, complex construction procedures, can be time-consuming and some types of deep foundations are not very flexible, etc.
8	Types	Isolated foundation, strip foundation, mat foundation, combined foundation, etc.	Pier foundation, pile foundation, caissons etc.

UNIT V DESIGN OF FOOTINGS

5.1 Concepts of Proportioning footings and foundations based on soil properties

1. Foundation structures should be able to sustain the applied loads, moments, forces and induced reactions without exceeding the safe bearing capacity of the soil.
2. The settlement of the structure should be as uniform as possible and it should be within the tolerable limits. It is well known from the structural analysis that differential settlement of supports causes additional moments in statically indeterminate structures. Therefore, avoiding the differential settlement is considered as more important than maintaining uniform overall settlement of the structure.

In addition to the two major requirements mentioned above, the foundation structure should provide adequate safety for maintaining the stability of structure due to either overturning and/or sliding It is to be noted that this part of the structure is constructed at the first stage before other components (columns / beams etc.) are taken up. So, in a project, foundation design and details are completed before designs of other components are undertaken. However, it is worth mentioning that the design of foundation structures is somewhat different from the design of other elements of superstructure due to the reasons given below. Therefore, foundation structures need special attention of the designers.

1. Foundation structures undergo soil-structure interaction. Therefore, the behaviour of foundation structures depends on the properties of structural materials and soil. Determination of properties of soil of different types itself is a specialized topic of geotechnical engineering. Understanding the interacting behaviour is also difficult. Hence, the different assumptions and simplifications adopted for the design need scrutiny. In fact, for the design of foundations of important structures and for difficult soil conditions, geotechnical experts should be consulted for the proper soil investigation to determine the properties of soil, strata wise and its settlement criteria.
2. Accurate estimations of all types of loads, moments and forces are needed for the present as well as for future expansion, if applicable. It is very important as the foundation structure, once completed, is difficult to strengthen in future.
3. Foundation structures, though remain underground involving very little architectural aesthetics, have to be housed within the property line which may cause additional forces and moments due to the eccentricity of foundation.
4. Foundation structures are in direct contact with the soil and may be affected due to harmful chemicals and minerals present in the soil and fluctuations of water table when it is very near to the foundation. Moreover, periodic inspection and maintenance are practically impossible for the foundation structures.
5. Foundation structures, while constructing, may affect the adjoining structure forming cracks to total collapse, particularly during the driving of piles etc. However, wide ranges of types of foundation structures are available. It is very important to select the appropriate type depending on the type of structure, condition of the soil at the location of construction, other surrounding structures and several other practical aspects as mentioned above.

Types of Foundation Structures Foundations are mainly of two types:

(i) shallow and
(ii) deep foundations.

The two different types are explained below: (A) Shallow foundations Shallow foundations are used when the soil has sufficient strength within a short depth below the ground level. They need sufficient plan area to transfer the heavy loads to the base soil. These heavy loads are sustained by the reinforced concrete columns or walls (either of bricks or reinforced concrete) of much less areas of cross-section due to high strength of bricks or reinforced concrete when compared to that of soil.

Isolated footings

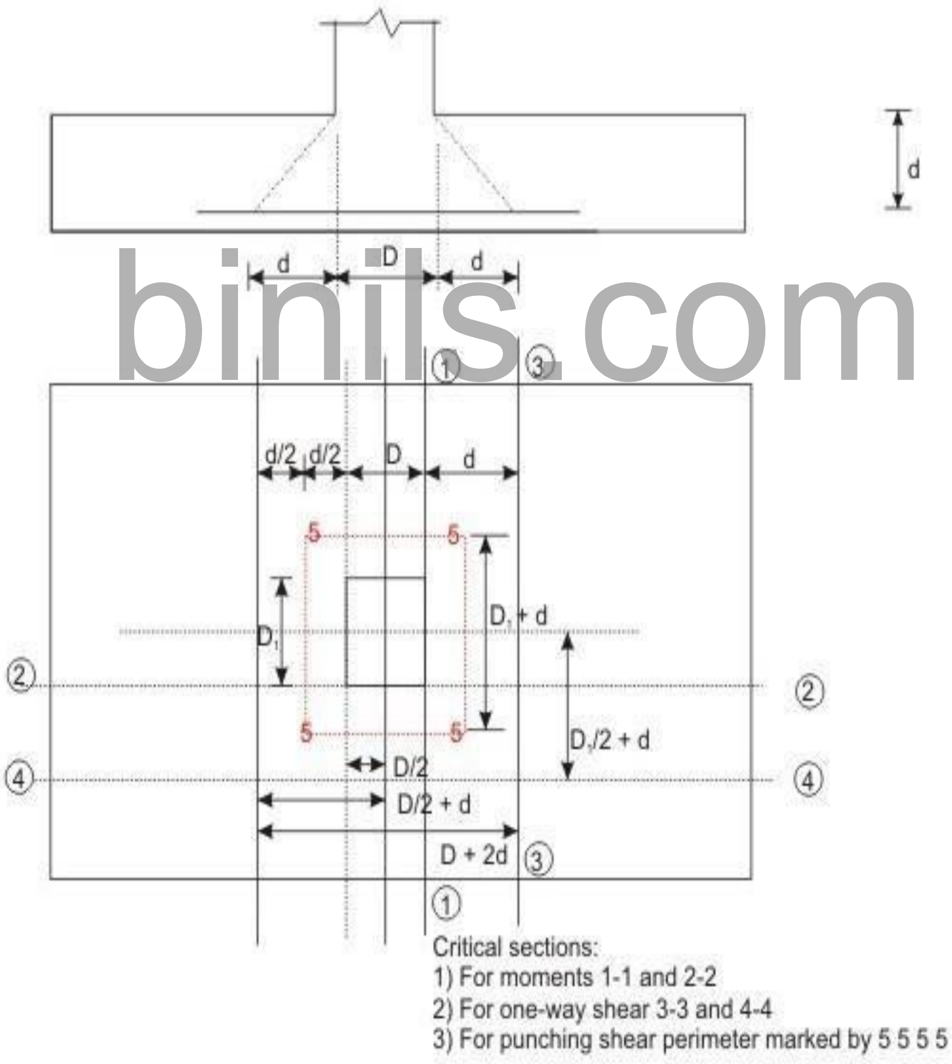


Figure: uniform and rectangular footing

Source:https://nptel.ac.in/content/storage2/courses/105105104/pdf/m11l29.pdf

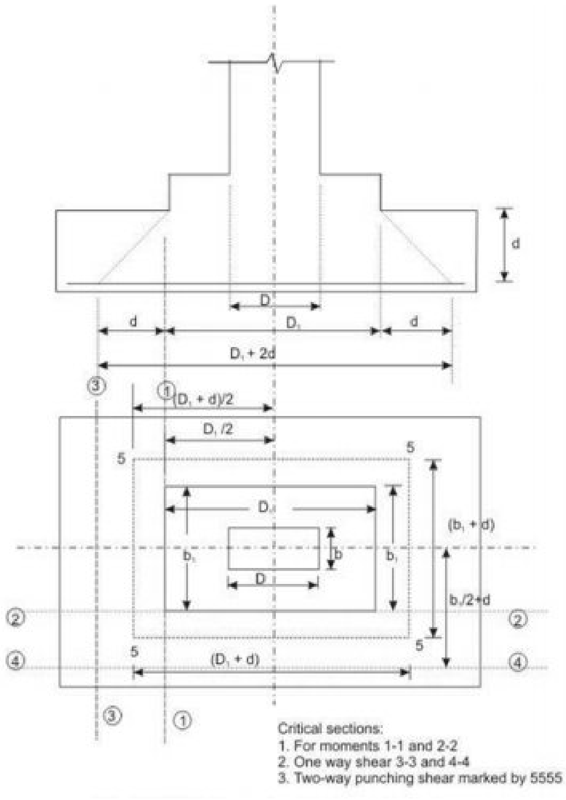
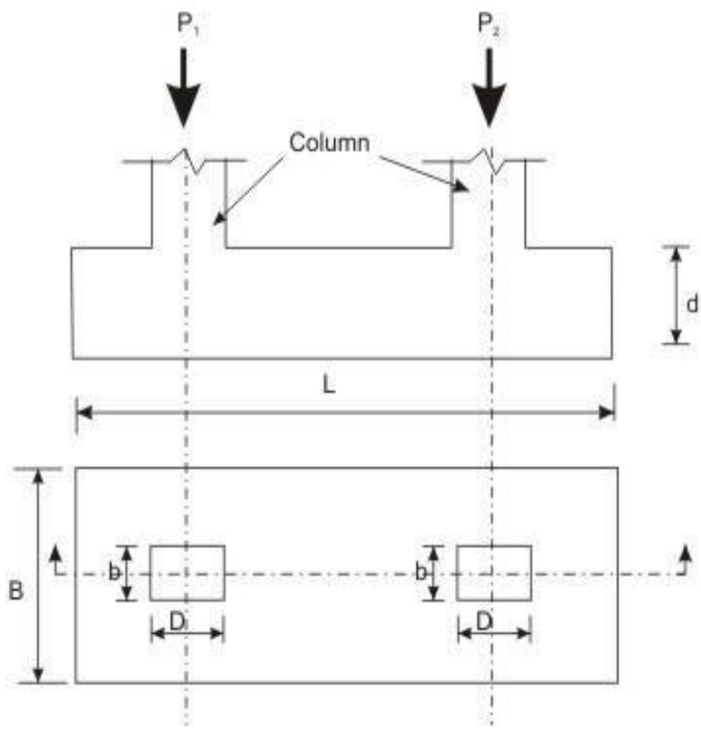


Figure: Stepped and rectangular footing

Source:https://nptel.ac.in/content/storage2/courses/105105104/pdf/m11l29.pdf

Combined footings



combined footing

Source:https://nptel.ac.in/content/storage2/courses/105105104/pdf/m11l29.pdf

UNIT V DESIGN OF FOOTINGS

Design of axially and eccentrically loaded Square, Rectangular pad and sloped footings

Design of Isolated Column Footing

The objective of design is to determine

1 Area of footing

2 Thickness of footing

3 Reinforcement details of footing (satisfying moment and shear considerations)

4 Check for bearing stresses and development length

This is carried out considering the loads of footing, SBC of soil, Grade of concrete and Grade of steel. The method of design is similar to the design of beams and slabs. Since footings are buried, deflection control is not important. However, crack widths should be less than 0.3 mm.

The steps followed in the design of footings are generally iterative. The important steps in the design of footings are;

- Find the area of footing (due to service loads)
- Assume a suitable thickness of footing
- Identify critical sections for flexure and shear
- Find the bending moment and shear forces at these critical sections (due to factored loads)
- Check the adequacy of the assumed thickness
- Find the reinforcement details
- Check for development length
- Check for bearing stresses

Limit state of collapse is adopted in the design pf isolated column footings. The various design steps considered are;

- Design for flexure
- Design for shear (one way shear and two way shear)
- Design for bearing

- Design for development length

The materials used in RC footings are concrete and steel. The minimum grade of concrete to be used for footings is M20, which can be increased when the footings are placed in aggressive environment, or to resist higher stresses.

Cover: The minimum thickness of cover to main reinforcement shall not be less than 50 mm for surfaces in contact with earth face and not less than 40 mm for external exposed face. However, where the concrete is in direct contact with the soil the cover should be 75 mm. In case of raft foundation the cover for reinforcement shall not be less than 75 mm.
Minimum reinforcement and bar diameter: The minimum reinforcement according to slab and beam elements as appropriate should be followed, unless otherwise specified. The diameter of main reinforcing bars shall not be less 10 mm. The grade of steel used is either Fe 415 or Fe 500.

Problem

Design an isolated footing of uniform thickness for RCC bearing a vertical load 600 KN and having a box of size 500mm x 500mm. The Safe Bearing Capacity of soil is take is 120 KN/m^2, M_{20} , Fe_{415}.

Step 1:

Size of column = 500 x 500 mm

Weight of column 'w' = 600 KN

S.B.C = 120 KN/m^2

f_y = 415 KN/mm^2

f_{ck} = 20 N/mm^2

Step 2:

Size of footing

W = 600 KN

Self weight of footing = 10% of column load

= $\frac{600 \times 10}{100}$

= 60 KN

Total load = 600 + 60

= 660 KN

Area of footing = $\frac{Load}{SBC}$

$$= \frac{660}{120}$$

$$= 5.5 m^2$$

Area of Square $= a^2 = 5.5$

$\Rightarrow a = \sqrt{5.5}$

$= 2.35$m

Size of Footing = (2.35 x 2.35) m

Step 3:

Net upward pressure

$$p_o = \frac{Load}{Width\ (Area\ of\ footing)}$$

$$= \frac{600}{5.5}$$

$$= 109.01\ KN/m^2$$

Step 4:

a) Depth on basis of Bending Compression

$$M = \frac{P_0}{8} (B - b)\ (B - b/4\ )$$

$$= \frac{109.01}{8} [(2.35 - 0.5)\ (2.35 - 0.5/4\ )]$$

M = 56.08 KNm

Factored Moment = 1.5 x 56.08

M_u = 84.12 KNm

$$M_u \lim = \frac{0.36\ xu\ max}{d} f_{ck} [1 - \frac{0.42\ xu\ max}{d}]\ bd^2$$

$$= 0.36 \times 0.48 \times 20\ [1 - 0.42\ (0.48)]\ (bd^2)$$

M_u lim = $2.76\ bd^2$

` M_u lim = M_u

$(2.759 \times 2350)\ d^2 = 84.13 \times 10^6$

d = 113.91 ≅ 115mm

D = d + cover

= 115 + 60

$D = 175mm$

b) Depth on basis of two way shear

Assume, p_t = 0.3%

τ_c from IS 456 Pg No: 73 $0.25 \rightarrow 0.36$

$0.50 \rightarrow 0.48$

$\tau_c = 0.38$

Permissible shear stress, $\tau_v = \tau_c \times K$

D = 175 mm(IS 456 – 72 P) , K = 1.25

$\tau_v = 0.38 \times 1.25$

$\tau_v = 0.475$

Critical section lies 'd' distance from the face of the unit,

$$a = \frac{B}{2} - \frac{b}{2}$$

$$= \frac{2350}{2} - \frac{500}{2}$$

$$a = 425\ mm^2$$

$$V_u = 1.5\ P_o\ a$$

$$= 1.5 \times 109.01 \times 0.925$$

$$V_u = 151.36\ N/m^2$$

$$\tau_v = \frac{Vu}{bd}$$

$$0.475 = \frac{355.44}{2350 \times d}$$

$$d = 318.7mm \cong 320mm$$

c) Depth on basis of two way shear,

$$b_0 = \frac{d}{2} + \frac{d}{2} + b$$

$$d = 320mm$$

$$b_0 = 820mm$$

Shear force, $F = P_o\ [B^2 - b_0{}^2]$

$$= 110\ [2.35^2 - 0.820^2]$$

$$F = 532.61\ KN \cong 530\ KN$$

F_u = 1.5 x 530

= 795 KN

Shear stress

$\tau_v = \frac{Fu}{4 \times b_0 \times d}$

$= \frac{795 \times 10^3}{4 \times 820 \times 320}$

τ_v = 0.757 N/mm^2

Permissible shear stress

$\tau_v \leq k_s\tau_c$

$k_s = 0.5 + B_c$

$B_c = \frac{shoter\ side\ of\ column}{Longer\ side\ of\ column}$

$= \frac{500}{500} = 1$

k_s = 0.5 + 1

k_s = 1.5

Take, k_s = 1

$\tau_c = 0.25\sqrt{f_{ck}}$

$= 0.25\sqrt{20}$

τ_c = 1.118 N/mm^2

k_s x τ_c = 1 x 1.118

= 1.118 N/mm^2

$\tau_v < k_s\tau_c$

Hence Safe

Step 4: Design of Reinforcement

$M_u = 0.87\ f_y\ Ast\ d\ [1-\frac{f_y Ast}{bd\ f_{ck}}]$

$84.195 \times 10^6 = 0.87 \times 415 \times Ast \times 320\ [1-\frac{415 \times Ast}{20 \times 320 \times 2350}]$

= 115536 x Ast (1$-$ 2.7 $\times$ 10^{-5}Ast)

Ast = 743.66 ≅ 745 mm

Provide 7nos of 12mm ∅ bars at 150mm spacing C/C.

Step 5:

Check for development length

i. $L_d = 47 \times \emptyset$

$= 47 \times 12$

$= 564$ mm

ii. Length of bar, $L_o = {}^{1}/_{2}\,(B - b) - d_c$

$= {}^{1}/_{2}\,(2350 - 500) - 60$

$= 865$ mm

$\because L_o > L_d$

Hence safe against development length.

Step 6:

Transfer of load at column base

$$\frac{2}{1} = \frac{b'}{385}$$

$b' = 770$mm

$A_1 = (500 + 770 + 770)^2 = 2040^2$

$A_2 = 500^2$

Adopt minimum value, $\sqrt{\frac{A_1}{A_2}} = 2 \dashrightarrow$ **(IS 456 pg: 65)**

$$= \sqrt{\frac{2040^2}{500^2}} = 4.08$$

Adopt value of $\sqrt{\frac{A_1}{A_2}} = 2$

Permissible bearing pressure $= 0.45\ f_{ck}\sqrt{\frac{A1}{A_2}}$

$= 0.45 \times 20 \times 2$

$= 18$ N/mm^2

Step 7:

Actual bearing pressure

$$\text{A.B.P} = \frac{Load}{Area} = \frac{600 \times 10^3}{500 \times 500}$$

$= 2.8$ N/mm^2

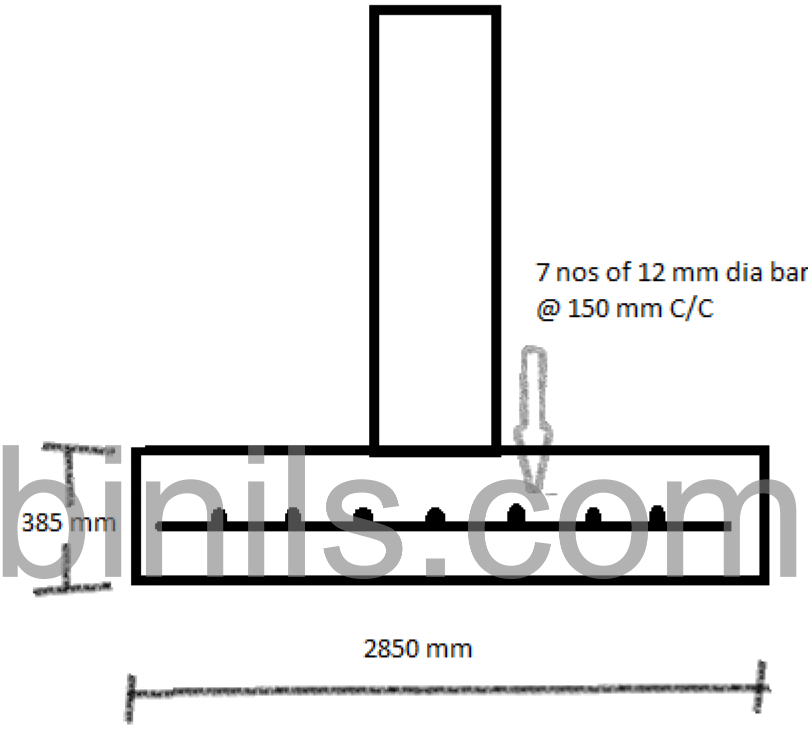
Check :

Actual bearing pressure & permissible bearing pressure

2.4 < 18

Hence safe

Reinforcement Details



Design of wall footing

Problem

Design a footing for 250mm thick has masonry wall with supports to carry a design load of 200kn/m at service state. Consider unit weight of soil 20KN/m^3. Angle of repose = 30°. Allowable bearing capacity 150KN/m^2, M_{20}, Fe_{415} .

Given Data:

q_0 = $150 KN/m^2$

γ = $20\ KN/m^3$

B = 250mm

p_u = 200 KNm

∅ = 30°

f_{ck} = $20\ N/mm^2$

f_y = $415\ N/mm^2$

Step 2:

Determination of depth of foundation

$$h = \frac{q0}{\gamma} \text{ x } [\,1 - sin\emptyset/1 + sin\emptyset\,]^2$$

$$= \frac{150}{20} \text{ x } [\,1 - sin30/1 + sin30\,]^2$$

$$= 0.83 \cong 1\text{m}$$

Step 3:

Find width of footing

$$B = \frac{Load}{S.B.C}$$

$$= \frac{200}{150} = 1.35 \text{ m}$$

Step 4:

Find total load

Self weight of footing = $(L \times B \times D)\,\gamma$

= $(1 \times 1.35 \times 1)$ 25

= $33.75 \cong 34$

Total Load = p_u + self weight

= 200 + 34

= $234\ KN/m^2$

Step 5:

Actual width of footing

Actual width = $\frac{234}{150}$ = $1.56 \cong 1.6$ m

Step 6:

Net upward pressure

P_o = $\frac{Load(given)}{Width \times 1(m\ given)}$

= $\frac{200}{1.6}$ = $125 KN/m^2\ /m\ length$

Step 7:

a) Depth of Basis of Bending Compression

M = $\frac{PO}{8}$ x (B – b) x (B - $\frac{b}{4}$)

= $\frac{125}{8}$ x (1.6 – 250 x 10^{-3}) x (1.6 – $\frac{250 \times 10^{-3}}{4}$)

M = 32.43 KNm

Factored Moment = 1.5 x M

= 1.5 x 32.43

M_u = 48.645 KNm

M_u lim = $\frac{0.36\, x_{u\,max}}{d}$ f_{ck} [1- $\frac{0.42 x_{u\,max}}{d}$] bd^2

= 0.36 x 0.48 x 20 [1- 0.42 x 0.48]bd^2

= 2.759 bd^2

M_u lim = M_u

2.759 bd^2 = 48.645 x 10^3

2.759 x 10^{-3}x 10^3xd^2 = 48.645 x 10^3

d = 132.78 mm

D = d + cover

= 132.78 + 60

$= 192.78$ mm

$D = 200$ mm

b) Depth on basis of one way shear

Assume, $p_t = 0.3\%$

$\tau_v = \tau_c \times K$

τ_c ref IS456 Pg No: 73

$0.25 \rightarrow 0.36$

$0.50 \rightarrow 0.48$

$\tau_c = 0.38$

Permissible shear stress, $\tau_v = 0.38$ K

K ref IS 456 Pg No : 73

$K = 1.20$

$\tau_v = 0.38 \times 1.20$

$\tau_v = 0.456$

c)Critical section lies 'd' distances from face of wall

$V_u = 1.5\ P_o\ a$

$a = \frac{B}{2} - \frac{b}{2}$

$= \frac{1.35}{2} - \frac{250}{2}$

$a = 675$ mm

$a = 0.675$ m

$V_u = 1.5 \times P_o \times a$

$= 1.5 \times 125 \times 0.675 = 126.56\ N/m^2$

$\tau_v = \frac{Vu}{bd}$

$0.456 = \frac{126.56 \times 10^3}{1000 \times d}$

$d = 277.54$ mm $\cong 280$ mm.

$D = d + d_c$

$= 280 + 60 = 340$ mm

Design Reinforcement

$M_u = 0.87\ f_y\ Ast\ d\ [1 - \frac{fyAst}{bd\ f_{ck}}]$

$$48.65 \times 10^6 = 0.87 \times 415 \times Ast \times 270 \left[1 - \frac{415\ Ast}{1000 \times 270 \times 20}\right]$$

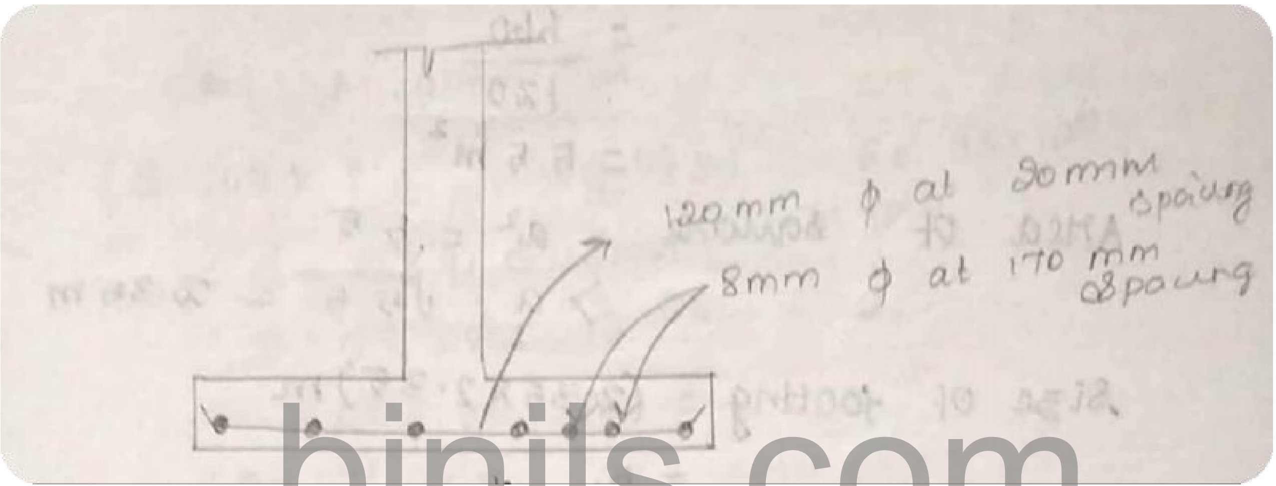
Ast = 519.83

Provide 12mm ∅ at 200mm C/C.

Distribution Reinforcement

$$= \frac{0.12}{100} \times 1000 \times 250$$

= 300mm



RECTANGLE COLUMN FOOTING

Problem

Design a rectangular isolated footing of uniform thickness of R.C column, bearings vertical load of 600 KN, have base size 400 x 600 mm, and have SBC of 120 KN/m^2. Use M_{20} and Fe_{415} grades.

Step 1:

b = 400 mm

d = 600 mm

w = 600 KN

S.B.C = 120 KN/m^2

f_y = 415 N/mm^2

f_{ck} = 20 N/mm^2

Step 2:

Size of footing

W = 600 KN (Weight of column)

Self weight of footing = 10% (column load)

$= \frac{10}{100} \times 600$

= 60 KN

Total load = 600 + 60

= 660 KN

Area of footing $= \frac{Load}{S.BC}$

$\frac{660}{120}$

= 5.5 m^2

A = 5.5

B x L = A = 5.5 m^2

B $= \frac{2}{3}$ L

$\frac{2}{3}$ x L x L = 5.5

$L = 2.87\text{ m} \cong 3\text{m}$

$B = 1.91\text{ m} \cong 2\text{m}$

B = 2m , L = 3m

Step 3: Section Design

a) Depth on basis of Bending compression

$$\text{Net upward pressure } P_o = \frac{Given\ \ load}{Area\ of\ footing}$$

$$= \frac{600}{3\times2}$$

$$= 100\ KN/m^2$$

Along x−x axis

$$M_x = P_o \times B \times 1.2 \times \frac{1.2}{2}^2$$

$$= 100 \times 2 \times 1.2 \times \frac{1.2}{2}^2$$

$$M_x = 172.8$$

$$M_{ux} = 1.5 \times M = 259.2$$

Along y−y axis

$$M_y = P_o \times L \times 0.8 \times \frac{0.8}{2}^2$$

$$= 100 \times 3 \times 0.8 \times \frac{0.8}{2}^2$$

$$= 76.8$$

$$M_{uy} = 115.2$$

M_u lim = Take greater one

M_u lim = $259.2 \cong 260$ KNm

b) Depth from $M_u$lim

$$M_u\ lim = 0.36\ \frac{Mumax}{d}\ f_{ck}\ (1-\frac{0.42\ xumax}{d})\ bd^2$$

$$260 \times 10^6 = 0.36 \times 0.48 \times 20\ [1-0.42(0.48)]\ bd^2$$

$$260 \times 10^6 = 3.456\ (1-0.2016)\ bd^2$$

$$bd^2 = 94227807.47$$

$$2 \times 10^3\ d^2 = 94227807.47$$

$$d = 217.0 \cong 220\text{ mm}$$

$D = d + d'$

$= 220 + 60$

$= 280$ mm

c) Depth of basis of one way shear

$a = 1.2 - d$

Shear force, $V_u = 1.5 \times P_o \times B \times a$

$= 1.5 \times 100 \times 2(1.2 - d)$

$V_u = 360 - 300d$

$\tau_v = \frac{Vu}{bd}$

$\tau_v = \frac{360-300d}{2d}$ ---> 1

Assume, $P_t = 0.3\%$

(τ_c ref IS 456 Pg No: 73) $0.25 \rightarrow 0.36$

$0.50 \rightarrow 0.48$

$\tau_c = 0.38$ N/mm^2

Permissible shear stress, $\tau_v = \tau_c \times K$

$K = 1.05$

D=280mm ---> (IS 456 Pg: 72)

$275 \rightarrow 1.05$

$300 \rightarrow 1.00$

$\tau_v = K \times \tau_c$

$= 0.38 \times 1.05$

$= 0.4$ N/mm^2

$\tau_v = 400$ KN/m^2 ---> 2

Eqn 1&2

$\frac{360-300d}{2d} = 400$

$360-300d = 800d$

$360 = 1100d$

$d = 0.327$ m

$d = 3.27 \cong 330$ mm

$D = 390$ mm

Depth on basis of 2 way shear

Area of footing, AF = $6m^2$ (3 x 2)

$BC = B + \frac{d}{2} + \frac{d}{2}$

$= 400 + \frac{330}{2} + \frac{330}{2}$

BC = 730mm

$AB = 600 + \frac{330}{2} + \frac{330}{2}$

AB = 930mm

Area = BC x AB

= 730 x 930

= 678900 mm^2

Shear force = P_o [AF – Area of ABCD]

$= 100[6 – 678900 \times (10^{-3})^2]$

= 532.11 KN

F_u = 1.5 x 532.11

= 798.17 KN

Length of ABCD = (930 x 2) + (730 x 2)

= 3320 mm

$\tau_v = \frac{F_u}{Length\ of\ ABCD \times d}$

$= \frac{798.17 \times 10^6}{3320 \times 330} = 0.73$ N/mm^2

Permissible stress = $k_s \times \tau_c$

$k_s = 0.5 + \beta_c$

$\beta_c = \frac{Short\ side\ of\ column}{Long\ side\ of\ column}$

$= \frac{400}{600} = 0.667$

$k_s = 0.5 + 0.667$

$= 1.167$

But k_s is not greater than one, so $k_s = 1$

$$\tau_c = 0.25\sqrt{f_{ck}}$$

$$= 0.25 \text{ x } \sqrt{20}$$

$$= 1.118 \text{ N/mm}^2$$

$$k_s\tau_c = 1.167 \text{ x } 1.118$$

$$= 1.3 \text{ N/mm}^2$$

$$\tau_v < k_s\tau_c$$

Hence safe

Step 4: Design of Reinforcement

Find Ast_x :

$$Mu_x = 0.87\, f_y\, Ast_x\, d\, [1 - \frac{f_y Ast_x}{bd\, f_{ck}}]$$

$$260 \text{ x } 10^6 = 0.87 \text{ x } 415 \text{ x } Ast_x \text{ x } 330\, [1 - \frac{415\ Astx}{20 \times 2000 \times 330}]$$

$$Ast_x = 2356.82 \text{ mm}^2$$

12mm Ø bar @ 50mm in x- direction C/C spacing.

$$Mu_y = 0.87\, f_y\, Ast_y\, d\, [1 - \frac{f_y Ast_y}{bd\, f_{ck}}]$$

$$120 \text{ x } 10^6 = 0.87 \text{ x } 415 \text{ x } Ast_y \text{ x } 330\, [1 - \frac{415\ Ast_y}{20 \times 2000 \times 330}]$$

$$Ast_y = 987 \text{ mm}^2$$

12mm Ø bar @ 110mm spacing.

Check of development length

i. $L_d = 47 \text{ x } Ø$

$= 47 \text{ x } 12 = 564 \text{ mm}$

ii. Length of bar,

$$L_o = {}^1\!/_2 \times (B - b) - d_c$$

$$= {}^1\!/_2 \times (2000 - 400) - 60$$

$= 740mm$

$L_o > L_d$ Hence safe.

$A_1 = 2160 \times 1960$

$A_2 = 600 \times 400$

$$\sqrt{\frac{A_1}{A_2}} = \sqrt{\frac{2160 \times 1960}{600 \times 400}}$$

$= 4.2$

Adopt values, $\sqrt{\frac{A1}{A_2}} = 2$

Permissible bearing stress $= 0.45\ f_{ck}\sqrt{\frac{A1}{A_2}}$

$= 0.45 \times 20 \times 2$

$= 18\ N/mm^2$

Actual bearing pressure $= \frac{Load}{Area}$

$= \frac{600 \times 10^3}{600 \times 400}$

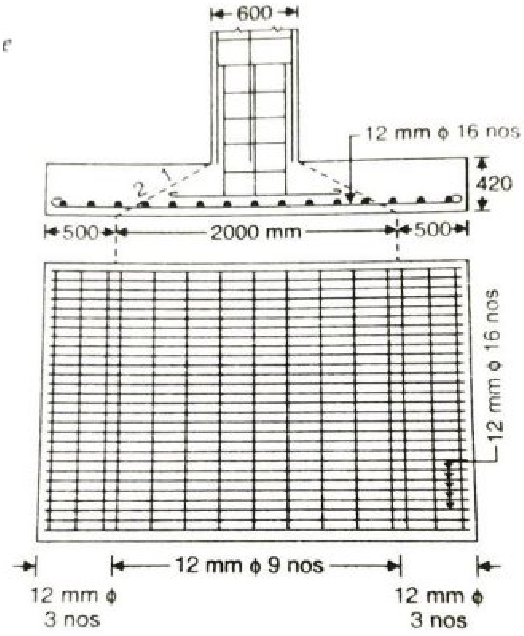
$= 2.5\ N/mm^2$

Actual bearing pressure $<$ Permissible bearing stress

$2.5 < 18\ N/mm^2$

Hence safe.

Reinforcement details



[Source:R.C.C Designs by Dr.B.C.Punmia,page 1091]

DESIGN OF COMBINED RECTANGULAR FOOTING FOR TWO COLUMNS

Whenever two or more columns in a straight line are carried on a single spread footing, it is called a combined footing. Isolated footings for each column are generally the economical. Combined footings are provided only when it is absolutely necessary, as

1.When two columns are close together, causing overlap of adjacent isolated footings

2.Where soil bearing capacity is low, causing overlap of adjacent isolated footings

3. Proximity of building line or existing building or sewer, adjacent to a building column.

Problem

Two interior columns A and B carry 700 kN and 1000 kN loads respectively. Column A is 350 mm x 350 mm and column B is 400 mm X 400 mm in section. The centre to centre spacing between columns is 4.6 m. The soil on which the footing rests is capable of providing resistance of 130 kN/m^2. Design a combined footing by providing a central beam joining the two columns. Use concrete grade M25 and mild steel reinforcement.

Solution: Data

fck = 25 N/mm2,

fy= 250 N/mm2,

fb = l30 kN/m2 (SBC),

Column A = 350 mm x 350 mm,

Column B = 400 mm x 400 mm,

c/c spacing of columns = 4.6 m, PA = 700 kN and PB = 1000 kN

Ultimate loads

P_{ua} = 1.5 x 700 = 1050 kN,

P_{ub} = 1.5 x 1000 = 1500 kN

Working load carried by column A = P_A = 700 kN

Working load carried by column B = P_B = 1000 kN

Self weight of footing 10 % x (P_A + P_B) = 170 kN Total working load = 1870 kN

Required area of footing = A_f = Total load /SBC

=1870/130 = 14.38 m^2

Let the width of the footing = B_f = 2m

Required length of footing = $L_f = A_f / B_f = 14.38/2 = 7.19$m

Provide footing of size 7.2m X 2m, $A_f = 7.2 \times 2 = 14.4 \text{ m}^2$

For uniform pressure distribution the C.G. of the footing should coincide with the C.G. of column loads. Let x be the distance of C.G. from the centre line of column A

Then $x = (P_B \times 4.6)/(P_A + P_B) = (1000 \times 4.6)/(1000 + 700)$

= 2.7 m from column A.

If the cantilever projection of footing beyond column A is 'a'

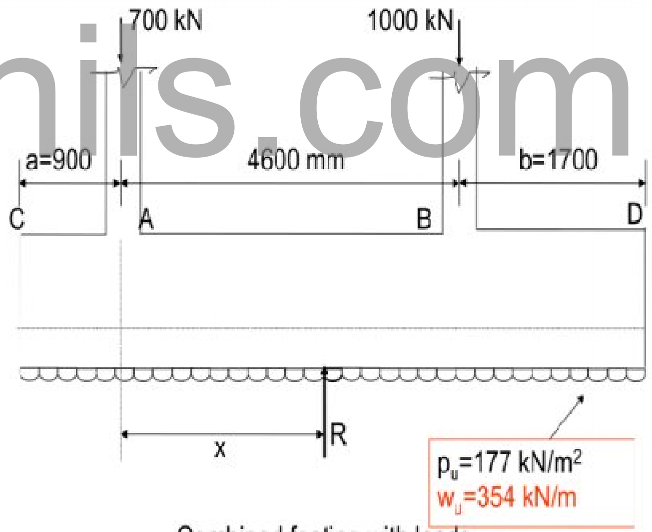
then, $a + 2.7 = L_f/2 = 7.2/2$, Therefore a = 0.9 m

Similarly if the cantilever projection of footing beyond B is 'b'

then, $b + (4.6-2.7) = L_f/2 = 3.6$ m,

Therefore b = 3.6 - 1.9 = 1.7 m

The details are shown in Figure



Combined footing with loads

Rectangular Footing with Central Beam:-Design of Bottom slab

Total ultimate load from columns = $P_u = 1.5(700 + 1000) = 2550$ kN.

Upward intensity of soil pressure $w_u = P/A_f = 2550/14.4 = 177 \text{ kN/m}^2$

Design of slab

Intensity of Upward pressure = w_u =177 kN/m^2

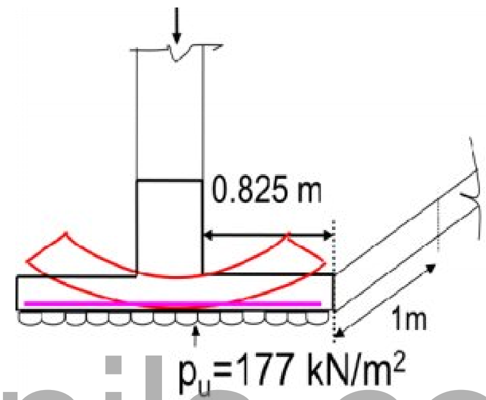
Consider one meter width of the slab (b=1m)

Load per m run of slab at ultimate = 177 x 1 = 177 kN/m

Cantilever projection of the slab (For smaller column)

=1000 - 350/2 = 825 mm

Maximum ultimate moment = 177 x 0.825^2/2 = 60.2 kN-m.



For M25 and Fe 250, $Q_{u\,max}$ = 3.71 N/mm^2

Required effective depth = √ (60.2 x 10^6/(3.71 x 1000)) = 128 mm

Since the slab is in contact with the soil clear cover of 50 mm is assumed.

Using 20 mm diameter bars

Required total depth = 128 + 20/2 + 50 =188 mm say 200 mm

Provided effective depth = d = 200-50-20/2 = 140 mm

Check the depth for one - way

shear considerations- At 'd' from face

Design shear force=V_u=177x(0.825-0.140)=121kN

Nominal shear stress=τ_v=V_u/bd=121000/(1000x140) =0.866MPa

Permissible shear stress

P_t = 100 x 2415 /(1000 x 140) = 1.7 %, τ_{uc} = 0.772 N/mm^2

Value of k for 200 mm thick slab =1.2

Permissible shear stress = 1.2 x 0.772 = 0.926 N/mm^2

$\tau_{uc} > \tau_v$ and hence safe

The depth may be reduced uniformly to 150 mm at the edges.

Check for development length

L_{dt}= [0.87 x 250 / (4 x 1.4)]Φ =39 Φ

= 39 x 20 = 780 mm

Available length of bar=825 - 25 = 800mm

> 780 mm and hence safe.

Transverse reinforcement

Required A_{st}=0.15bD/100

=0.15x1000 x 200/100 = 300mm^2

Using Φ8 mm bars, Spacing=1000x50/300

= 160 mm

Provide distribution steel of Φ8 mm at 160 mm c/c,<300, <5d

Design of Longitudinal Beam

Load from the slab will be transferred to the beam.

As the width of the footing is 2 m, the net upward soil pressure per meter length of the beam

= w_u = 177 x 2 = 354 kN/m

Shear Force and Bending Moment

V_{AC}= 354 x 0.9 =318.6 kN, V_{AB} = 1050-318.6 =731.4 kN

V_{BD}= 354 x 1.7 = 601.8kN, V_{BA} = 1500-601.8 = 898.2 kN

Point of zero shear from left end C

X_1 = 1050/354 = 2.97m from C or

X_2 = 7.2-2.97 = 4.23 m from D

Maximum B.M. occurs at a distance of 4.23 m from D

M_{uE} = 354 x 4.23^2 / 2 - 1500 (4.23 - 1.7) = -628 kN.m

Bending moment under column A= M_{uA}=354x0.9^2 /2 = 143.37 kN.m

Bending moment under column B = M_{uB} = 354 x 1.7^2 = 511.5 kN-m

Let the point of contra flexure be at a distance x from the centre of column A

Then, M_x= I050x - 354 (x + 0.9)^2/ 2 = 0

Therefore x = 0.206 m and 3.92 m from column A

i.e. 0.68 m from B.

Depth of beam from B.M.

The width of beam is kept equal to the maximum width of the column i.e. 400 mm. Determine the depth of the beam where T- beam action is not available.

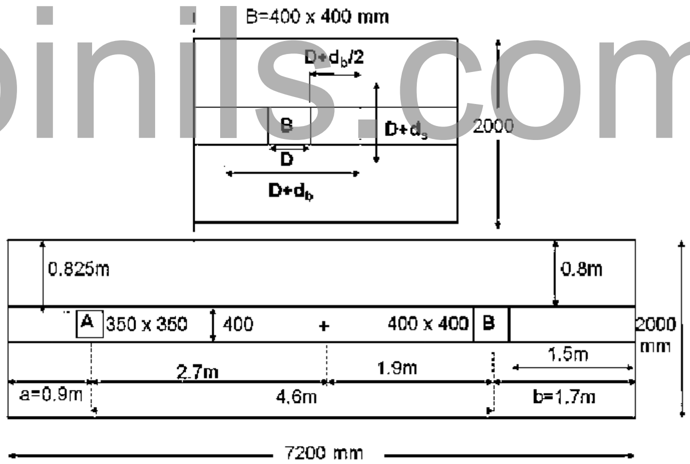
The beam acts as a rectangular section in the cantilever portion, where the maximum positive moment = 511.5 kN/m.

$$d = \sqrt{(511.5 \times 10^6 / (3.73 \times 400))} = 586 \text{ mm}$$

Provide total depth of 750 mm. Assuming two rows of bars with effective cover of 70 mm.

Effective depth provided = d= 750-70 = 680 mm

(Less than 750mm and hence no side face steel is needed



In this case b=D=400 mm, d_b=680 mm, d_s=140 mm

Area resisting two - way shear

$$= 2(b \times d_b + d_s \times d_s) + 2(D + d_b)d_s$$

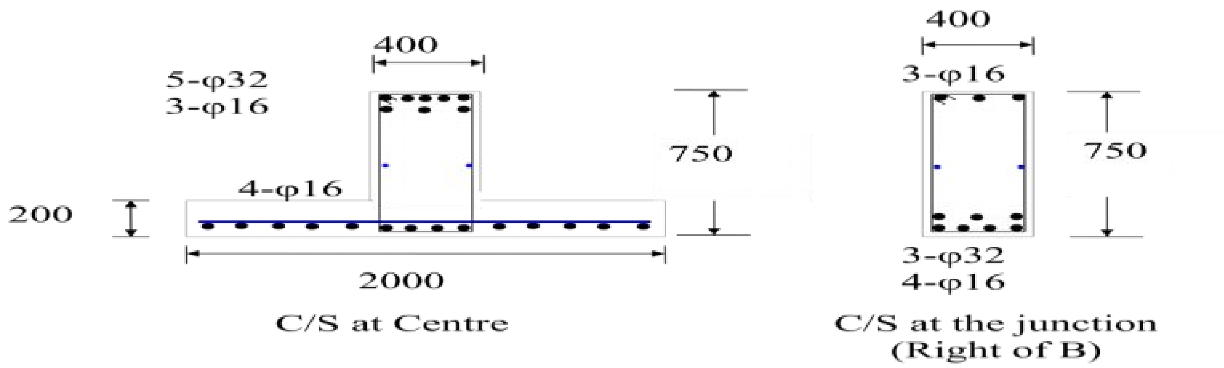
$$= 2(400 \times 680 + 140 \times 140) + 2(400+680)\,140 = 885600 \text{ mm}^2$$

Design shear=P_{ud}= column load – W_u x area at critical section

$$= 1500 - 177 \times (b + d_s) \times (D + d_b)$$

$$= 1500 - 177 \times (0.400+0.140) \times (0.400+0.680) \quad = 1377.65 \text{kN}$$

$$\tau_v = P_{ud}/b_o d$$



= 1377.65x1000/885600=1.56 MPa

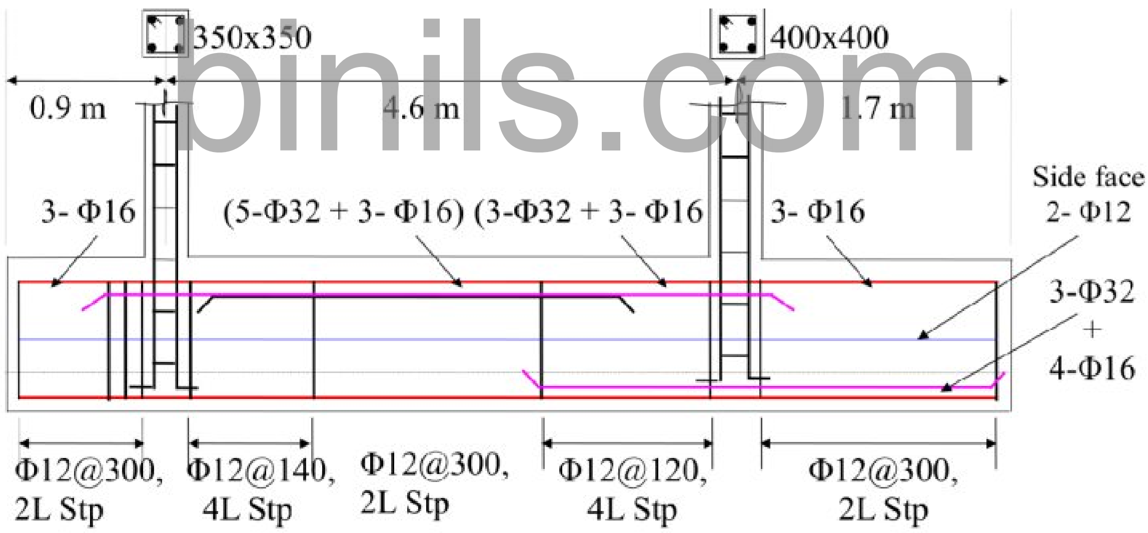
Shear stress resisted by concrete = $\tau_{uc} = \tau_{uc}$ x K_s

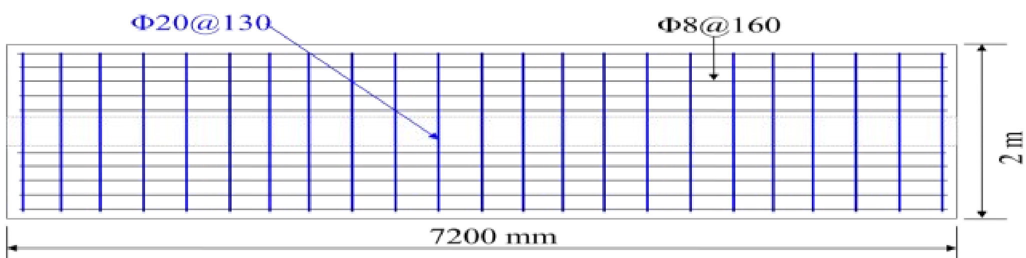
where, $\tau_{uc} = 0.25 \sqrt{f_{ck}} = 0.25\sqrt{25} = 1.25$ N/mm^2

$K_s = 0.5 + d / D = 0.5 + 400/400 = 1.5 \leq 1$ Hence $K_s = 1$

$\tau_{uc} = 1 \times 1.25 = 1.25$ N/mm^2.

Therefore Unsafe





Plan of footing slab