UNIT-5
LIMIT STATE DESIGN OF FOOTING

Design of wall footing - Design of axially and eccentrically loaded rectangular pad and sloped footings - Design of combined rectangular footing for two columns only.

Foundation - Introduction :-

The foundation or footing is a very important part of a structure, which is located below the ground level.

The foundations transfer and spread the loads from column or wall in to the ground soil evenly.

It is otherwise called as substructures.

A foundation should be designed to safely transmit the load of a structure on to a sufficient area of the soil.

Foundation shall not be provided directly on loose soil / filled earth.

In footings, the load coming from the column is transferred in to the base at dispersion angle of 45°.

Functions of foundation :-

① Foundation transfers live load and dead loads of the structure to the ground soil over a large area uniformly.

(2) It resists lateral forces such as wind, seismic etc.

(3) It resists uplift force due to ground water.

(4) It provides good support for walls and columns.

(5) It should not settle in the downward direction due to loads and soil condition.

(6) It provide differential settlement of building.

(7) To provide a plane surface for the convenience of construction.

Types of foundation :-

(1) Shallow foundation

- i) Isolated footing
- ii) Spread / Strip footing.
- iii) Combined footing.
- iv) Strap footing.
- v) Mat / Raft footing.

(2) Deep foundation.

- i) Pile foundation.
- ii) Well foundation.

Shallow foundation :-

Depth of the foundation is less than or equal to width of footing is called as shallow foundation.

Isolated footing :-

Isolated (or) pad foundations are provided under a single column. Shape of isolated footing may be square, rectangle, circle in plan depending upon shape of the column and loads.

Spread / Strip footing :-

Wide base slab is provided continuously under load bearing masonry walls of the building is called as spread / strip footing.

Combined footing :-

A combined footing is usually provided to support two (or) more columns of unequal loads.

Mat (or) raft foundation :-

One mat common footing is provided to connect all columns in a structure is called as mat / raft foundations.

This type of foundation is more expensive than other types.

Types of raft foundation :-

↳ Plane Slab Rafts.

↳ Beam and Slab.

↳ Slab with column pedestals.

↳ Cellular rafts.

↳ Piled rafts.

↳ Strip rafts / Grid rafts.

Deep foundation :-

Depth of the foundation is more than width of footing is called as deep foundation.

Types of pile foundation :-

→ Based on type of construction.

→ Based on function.

→ Based on material.

Safe bearing capacity of soil :-

It is the maximum intensity of load/pressure developed under the foundation without causing failure of soil. It's unit is kN/m^2.

Standard steps in the design calculations for rectangular combined footing :-

i) Assuming the self-weight of footing and weight of backfill = 10% of column loads.

b) Check for one way shear / vertical shear :-

i) Calculate V_u (ultimate max. shear force) at 'd' from face of column.

Factored shear force, V_u = Max S.F at 'd' from face of the column × 1.5

ii) From Table 19, IS 456-2000 calculate τ_c (design shear strength of concrete).

If shear resisted by concrete $= \tau_c \times b \times d > V_u$, the section is safe in one way shear.

c) Check for two way shear (or) punching shear :-

Punching shear is critical at section $(d/2)$ from periphery of the column all around.

i) Actual shear stress, $\tau_{v2} = \frac{V_{u2}}{B_2 d}$

V_{u2} = P × (Area of base − Hatched area around column 1 and column 2)

$$B_2 = \left[(d_1+d) + 2\left(b_1+\frac{d}{2}\right)\right] + 2\left[(b_2+d)+2(d_2+d)\right]$$

ii) Calculate allowable shear stress from formula,

$$\tau_{c2} = k_s\, 0.25\sqrt{f_{ck}}$$

$$k_s = 0.5 + \left(\frac{\text{short side dimension}}{\text{Long side dimension}}\right) \text{ of column, but} > 1.$$

$\tau_{v2} < \tau_{c2}$, section is safe in punching shear.

Problem :-

Design a RC footing for a 345mm thick masonry wall which supports a characteristic load of 250 kN/m including self-weight. Assume safe bearing capacity of soil is 150 kN/m² at a depth of 1.2m below ground level. Assume M20 concrete and Fe-415 steel are used.

Given Data :-

SBC of soil = $150 kN/m^2$.

Characteristic load (P) = 250 kN/m.

Thickness of wall = 345 mm.

Depth of footing below ground level = 1.2m.

Grade of concrete = M_{20}

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

$f_y = 415 N/mm^2$.

Solution :-

(a) Width of footing calculation :-

Assume S.W. of footing and weight of = 10% of load, back fill

$= \frac{10}{100} \times 250$

$= 25\ kN/m.$

Total load $= 250 + 25 = 275\ kN/m.$

Considering 1m width of footing along the wall,

Required length of footing $= \frac{\text{Total load}}{\text{Safe bearing capacity of soil}}$

$= \frac{275}{150} = 1.83m.$

Provide 1.85m length footing.

b) Bending moment calculation

Projection from face wall, $x = \frac{\text{Length of footing - wall thns}}{2}$

$x = \frac{1.85 - 0.345}{2}$

$= 0.7525\ m.$

Upward soil pressure, $p = \frac{\text{Characteristic Load, P}}{\text{Area provided.}}$

$p = \frac{250}{185 \times 1} = 135\ kN/m^2.$

B.M @ face of wall $= \frac{px^2}{2}$

$M = \frac{135 \times (0.7525)^2}{2}$

$= 38.22\ kN\text{-}m.$

Factored moment $(M_u) = 38.22 \times 1.5$

$= 57.33$ kN-m.

c) Thickness of footing calculation

Eff. depth required, $d_{req} = \sqrt{\dfrac{M_u}{0.138 f_{ck} b}}$

$$d_{req} = \sqrt{\frac{57.33 \times 10^6}{0.138 \times 20 \times 1000}}$$

$= 144.13$ mm

provide 16 mm ϕ main rft,

$D_{req} = d_{req} + \text{clear cover} + \frac{\phi}{2}$

$= 144.13 + 50 + \frac{16}{2}$

$= 202.13$ mm.

Consider $D_{provided} = 2 \times D_{req}$ to avoid failure of footing in punching shear.

$D_p = 2 \times 202.13 = 404.26$ mm.

Provide 405 mm overall depth.

Eff. depth, $d_p = 405 - 50 - \frac{16}{2}$

$= 347$ mm.

b) Calculate required plan area of the footing using the following formula,

$$\text{Base area in } m^2 = \frac{P + \left(\frac{10}{100} \times P\right)}{\text{Safe bearing capacity of soil in } kN/m^2}$$

c) Location of resultant $\bar{x}$ calculation,

Moment of resultant about column 1 = Sum of moments of components about the same point.

$$P\bar{x} = P_2 \times S$$

$$\bar{x} = \frac{P_2 \times S}{P}$$

$$P = P_1 + P_2.$$

d) Length of footing calculation,

$$L = 2\left(\bar{x} + \frac{b_1}{2}\right)$$

e) Width of footing calculation,

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

f) Provide a rectangular footing of size = L x B.

g) Net upward soil pressure,

$$p = \frac{P}{\text{Area Provided}} < \text{SBC of soil.}$$

h) Using the pressure diagram, calculate shear force and bending moments of footing along its length, it is an inverse of double overhanging beam and plot S.F and B.M. diagram.

Intensity of load over the beam } = P.

Intensity of over the beam } = p x B.

= Net upward soil pressure } x width of footing.

i) Calculate depth of footing from maximum B.M.

$$d_{req} = \sqrt{\frac{M_{u\,max}}{0.138 f_{ck}\, b}}$$, For Fe415 steel.

Max. factored B.M (M_u) = Maximum B.M x 1.5.

$b = 1000$ mm

f_{ck} = characteristic comp. strength in N/mm².

Provide minimum clear cover as 50mm.

$$D_{req} = d_{req} + 50 + \frac{\phi}{2}$$

$D = 2 \times D_{req}$ to avoid failure of footing by punching shear.

$A_{st} = 471.92\ mm^2$

$$Spacing = \frac{Area\ of\ one\ bar}{A_{st}} \times 1000$$

$$Spacing\ (s) = \frac{201}{471.92} \times 1000$$

$$= 425.92\ mm\ c/c\ (\because 16mm\phi\ bars\ used).$$

$$Spacing = \frac{113}{471.92} \times 1000$$

$$= 239.45\ mm\ c/c.\ (\because 12mm\phi\ bars\ used).$$

Provide 12mm ϕ bars @ 230 mm c/c.

$$A_{st\ dist} = \frac{0.12}{100} \times 1000 \times 405$$

$$= 486\ mm^2.$$

Provide 12mm ϕ bars at 230mm c/c.

o) check for one way shear / vertical shear :-

$$A_{st\ prov} = \frac{Area\ of\ one\ bar}{Spacing\ provided} \times 1000$$

$$= \frac{113}{230} \times 1000 = 491.3\ mm^2.$$

$$P_t = \frac{100\ A_{st}}{b\ d} = \frac{100 \times 491.3}{1000 \times 349}$$

$$d = 405 - 50 - \frac{12}{2} = 349mm.$$

11

$p_t = 0.14\%$

From table -19, IS 456-2000 :

$$\tau_c = 0.28 \ N/mm^2.$$

$$V_{uc} = \tau_c \times b \times d = 0.28 \times 1000 \times 349$$

$$= 97720 \ N$$

$$V_{uc} = 97.72 \ kN.$$

$$V_u = 1.5 \times (p \times \text{shaded area})$$

$$V_u = 1.5 \times (135 \ kN/m^2 \times 0.403 \times 1)$$

$$V_u = 81.61 \ kN < 97.72 \ kN.$$

$$V_u < V_{uc}.$$

Hence safe in one way shear.

A solid footing has to transfer a dead load of 900 kN and an imposed load of 500 kN for a square column of size 400mm. Assume SBC of soil as 200 kN/m². Design a square footing to support the above column.

Given Data :-

Dead load, DL = 900 kN.

Imposed load = 500 kN

Size of column = 400 x 400 mm.

SBC of soil = 200 kN/m².

$f_{ck} = 20 N/mm^2$, $f_y = 415 N/mm^2$.

(a) Base area of footing calculation :-

Characteristic axial load, $P = DL + IL$
$= 900 + 500$
$= 1400\ kN$.

$$W = \frac{10}{100} \times 1400$$
$$= 140\ kN.$$

Total load $= DL + IL + W = 900 + 500 + 140$
$= 1540\ kN$.

$$A_{req} = \frac{\text{Total load}}{\text{SBC of soil}}$$

$$A_{req} = \frac{1540\ kN}{200\ kN/m^2} = 7.7\ m^2.$$

Size of square footing rqd $= \sqrt{7.7} = 2.77\ m$.

Provide $2.8\ m \times 2.8\ m$ square footing.

(b) Bending moment Calculation.

Maximum B.M occurs at face of the column.

Projected length, $x = \frac{\text{length of footing} - \text{column width}}{2}$

$$x = \frac{2.8 - 0.4}{2} = 1.2\ m.$$

Net upward soil pressure, $p = \frac{P}{A_{prov}}$

$$p = \frac{1400}{(2.8)^2} = 178.57\ kN/m^2.$$

c) Depth of footing calculation :-

Consider 1m width strip,

B.M @ face of the column, $M = p \times \frac{x^2}{2}$

$$= 178.57 \times \frac{(1.2)^2}{2}$$

$$= 128.57\ kN\text{-}m.$$

Factored b.M, $M_u = 1.5 \times 128.57$

$$= 192.86\ kN\text{-}m.$$

$$d_{req} = \sqrt{\frac{M_u}{0.138 f_{ck} b}}$$

$$= \sqrt{\frac{192.86 \times 10^6}{0.138 \times 20 \times 1000}}$$

$$d_{req} = 264.34\ mm.$$

Provide clear cover = 50mm & ϕ = 16mm.

$$D_{req} = d_{req} + \text{clear cover} + \frac{\phi}{2}$$

$$= 264.34 + 50 + \frac{16}{2}$$

$$= 322.34\ mm.$$

Provide overall depth, D_{prov}

$= 2 \times D_{req}$

$D_{prov} = 2 \times 322.34$

$= 644.68 mm.$

Overall depth, $D = 650mm.$

$d_{prov} = 650 - 58 = 592mm.$

d) Area of steel calulation

$$\frac{M_u}{bd^2} = \frac{192.86 \times 10^6}{1000 \times (592)^2} = 0.55$$

From table-2, SP-16.

$p_t = 0.158\%$

$$A_{st} = p_t bd = \frac{0.158}{100} \times 1000 \times 592$$

$= 935.36 mm^2.$

$$\text{Spacing } (s) = \frac{201}{935.36} \times 1000$$

$= 214.89mm.$

Provide 16mm ϕ @ 210mm c/c, both ways, since b.M along both directions are equal.

$= 957.14 \, mm^2$

$$P_{t\,(prov)} = \frac{100 \, A_s}{bd} = \frac{100 \times 957.14}{1000 \times 592}$$

$$P_{t(prov)} = 0.16\%$$

e) check for one way shear

One way shear is critical at section 'd' from face of the column.

$$\tau_c \simeq 0.28 \, N/mm^2$$

$$V_{uc} = \tau_c \, bd = 0.28 \times 1000 \times 592$$

$$V_{uc} = 165.76 \, kN$$

$$V_u = 1.5 \times (178.57 \, kN/m^2 \times 1\,m)(1.2 - 0.592$$

$$V_{uc} = 162.85 \, kN < V_c$$

f) check for two way / punching shear.

Punching shear is critical at section d/2 from face of the column.

$$p = 178.57 \, kN/m^2$$

$$= 0.178 \, N/mm^2$$

$$V_{u2} = 0.178\left[(2800)^2 - (400+592)^2\right]$$

$$= 0.178 \times 6855936$$

$$= 1220356.61 \text{ N}$$

$$V_{u2} = 1220.36 \text{ kN}.$$

$$\tau_v = \frac{V_{u2}}{bd} = \frac{1220.36 \times 10^3}{[4 \times (400+592) \times 592]}$$

$$= 0.52 \text{ N/mm}^2.$$

$$B_2 = 4(b_1 + d)$$

Allowable shear stress $= k_s \tau_c$

$$k_s = \left(0.5 + \frac{\text{Short side column dimension}}{\text{long side column dimension}}\right) \not> 1$$

$$k_s = \left(0.5 + \frac{0.4}{0.4}\right) = 0.5 + 1 = 1.5 \not> 1$$

$$k_s = 1.$$

$$\tau_c = 0.25\sqrt{f_{ck}} = 0.25\sqrt{20}$$

$$= 1.12 \text{ N/mm}^2.$$

Allowable shear stress $= k_s \times \tau_c = 1 \times 1.12 = 1.12 \text{ N/mm}^2$

$\tau_v < k\tau_c$. Hence safe in two way shear.

A rectangular RC column of size 300mm x 450mm carrying an axial load of 1500 kN. If the SBC of the soil is 120 kN/m², design a suitable footing. Consider M25 grade concrete and Fe-415 grade steel are used.

Given Data :-

Axial Load, $P = 1500$ kN.

Size of column, $= 300 \times 450$ mm.

SBC of soil $= 120$ kN/m².

$f_{ck} = 25$ N/mm².

$f_y = 415$ N/mm².

Solution :-

(a) Size of footing calculation. $= 10\%$ of Load, P.

$$= \frac{10}{100} \times 1500 = 150 \text{ kN}$$

Total load $= 1500 + 150 = 1650$ kN.

$$A_{req} = \frac{\text{Total load}}{\text{SBC of soil}}$$

$$A_{req} = \frac{1650}{120} = 13.75 \text{ m}^2$$

Consider length of footing $= 1.25 \times$ width of footing.

$$A_{req} = L \times B$$

$$13.75 = 1.25B' \times B$$

$$B = 3.32m.$$

$$L = \frac{A}{B} = \frac{13.75}{3.32} = 4.14m.$$

Provide 4.20m x 3.40m size footing.

$$A_{prov} = 4.20m \times 3.40m = 14.28m^2 > 13.75m^2.$$

Net upward soil pressure, $p = \frac{P}{A_{prov}} = \frac{1500}{14.28}$

$$= 105.04\ kN/m^2.$$

b) Depth of footing and area of steel calulation :-

i) projection, $x = \frac{4.2 - 0.45}{2} = 1.875m.$

B.M @ y-y axis, $M_y = p \cdot \frac{x^2}{2} = \frac{105.04 \times (1.875)^2}{2}$

$$= 184.64\ kN\text{-}m.$$

$$M_{uy} = 184.64 \times 1.5$$

$$= 276.96\ kN\text{-}m.$$

$$d_{req} = \sqrt{\frac{M_u}{0.138 f_{ck} b}} = \sqrt{\frac{276.96 \times 10^6}{0.138 \times 25 \times 1000}}$$

$$= 283.33\ mm$$

Provide 20mm ϕ bar and clear cover = 50mm.

Overall depth, $D_{req} = d_{req} + \text{clear cover} + \frac{\phi}{2}$

$= 283.33 + 50 + \frac{20}{2}$

$= 343.33$ mm.

$D_{prov} = 2 \times D_{req}$

$D_{prov} = 2 \times 343.33 = 686.67$ mm.

Overall depth, $D = 700$ mm, $d = 700 - 50 - \frac{20}{2}$

$= 640$mm.

$$\frac{M_{uy}}{bd^2} = \frac{272.96 \times 10^6}{1000 \times (640)^2} = 0.67\ N/mm^2.$$

$$p_t \approx \frac{0.186 + 0.201}{2} = 0.1935\%$$

$$A_{req} = p_t bd = \frac{0.1935}{100} \times 1000 \times 640$$

$= 1238.4\ mm^2$.

$$\text{Spacing } (s) = \frac{314}{1238.4} \times 1000$$

$= 253.55$ mm.

Provide 20 mm ϕ bar at 250 c/c.

(ii) Projection, $y = \frac{3.4 - 0.3}{2}$

$= 1.55m.$

B.M @ x-x axis, $M_x = p \cdot \frac{y^2}{2} = \frac{105.04 \times 1.55^2}{2}$

$= 126.18$ kN-m.

$M_{ux} = 126.18 \times 1.5 = 189.27$ kN-m.

D = 700mm, $d = 700 - 50 - 20 - \frac{20}{2}$

$= 620$mm.

$\frac{M_{ux}}{bd^2} = \frac{189.27 \times 10^6}{1000 \times (620)^2} = 0.49 \, N/mm^2.$

$p_t = 0.143$ %

$A_{st} = p_t b d = \frac{0.143}{100} \times 1000 \times 620$

$= 886.6 \, mm^2$

$S = \frac{314}{886.6} \times 1000 = 354.16$ mm

Provide 20mm ϕ bar @ 350 c/c.

c) Check for one way shear :-

One way shear is critical @ section 'd' from face of the column.

21

$V_U = 1.5\,[105.04 \times 1 \times (1.875 - 0.64)]$

$V_U = 194.58$ kN.

$$pt_{prov} = \frac{100\,A_{sp}}{bd}$$

$$p_t = \frac{100 \times 1256}{1000 \times 640} = 0.20\,\%.$$

$$\tau_c = \frac{0.29 + 0.36}{2} = 0.325\ N/mm^2.$$

$V_{uc} = \tau_c b d$

$V_{uc} = 0.325 \times 1000 \times 640 = 208\ kN > V_U$

Hence section is safe in one way shear.

d) Check for two way / punching shear.

$$p = 105.04\ kN/m^2 = \frac{105.04 \times 10^3}{10^6}\ N/mm^2$$

$$= 0.105\ N/mm^2.$$

$V_{U2} = 1391.817$ kN.

$\tau_V = 0.53\ N/mm^2.$

$$k_s = \left(0.5 + \frac{0.3}{0.45}\right) = 1.17 \not> 1$$
$$= 1$$

Allowable shear stress $= k_s \tau_c = 1 \times 1.25 = 1.25\ N/mm^2$

Hence the section is safe in two way / punching shear.