

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/m². Design a combined footing by providing a central beam joining the two columns. Use concrete grade M25 and mild steel reinforcement.

Solution: Data

$$f_{ck} = 25 \text{ N/mm}^2,$$

$$f_y = 250 \text{ N/mm}^2,$$

$$f_b = 130 \text{ kN/m}^2 \text{ (SBC)},$$

$$\text{Column A} = 350 \text{ mm} \times 350 \text{ mm},$$

$$\text{Column B} = 400 \text{ mm} \times 400 \text{ mm},$$

$$\text{c/c spacing of columns} = 4.6 \text{ m}, P_A = 700 \text{ kN and } P_B = 1000 \text{ kN}$$

Ultimate loads

$$P_{ua} = 1.5 \times 700 = 1050 \text{ kN},$$

$$P_{ub} = 1.5 \times 1000 = 1500 \text{ kN}$$

$$\text{Working load carried by column A} = P_A = 700 \text{ kN}$$

$$\text{Working load carried by column B} = P_B = 1000 \text{ kN}$$

$$\text{Self weight of footing } 10 \% \times (P_A + P_B) = 170 \text{ kN Total working load} = 1870 \text{ kN}$$

$$\text{Required area of footing} = A_f = \text{Total load} / \text{SBC}$$

$$=1870/130 = 14.38 \text{ m}^2$$

Let the width of the footing = $B_f = 2\text{m}$

Required length of footing = $L_f = A_f / B_f = 14.38/2 = 7.19\text{m}$

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

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

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

$$= 2.7 \text{ m from column A.}$$

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

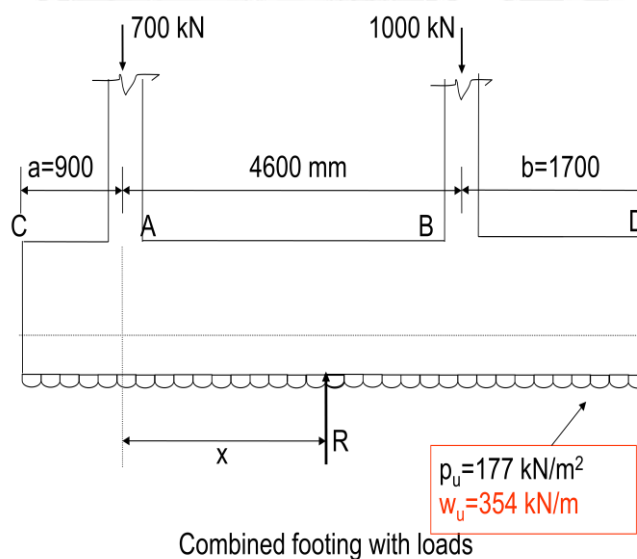
then, $a + 2.7 = L_f / 2 = 7.2/2$, Therefore $a = 0.9 \text{ m}$

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

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

Therefore $b = 3.6 - 1.9 = 1.7 \text{ m}$

The details are shown in Figure



Rectangular Footing with Central Beam:-Design of Bottom slab

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

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 = $w_u = 177 \text{ kN/m}^2$

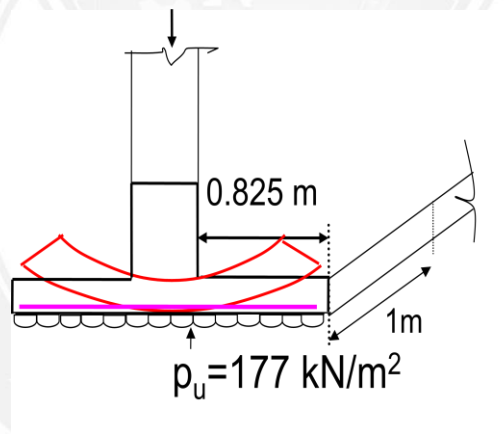
Consider one meter width of the slab ($b=1\text{m}$)

Load per m run of slab at ultimate = $177 \times 1 = 177 \text{ kN/m}$

Cantilever projection of the slab (For smaller column)

$$= 1000 - 350/2 = 825 \text{ mm}$$

Maximum ultimate moment = $177 \times 0.825^2/2 = 60.2 \text{ kN-m}$.



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

Required effective depth = $\sqrt{(60.2 \times 10^6 / (3.71 \times 1000))} = 128 \text{ mm}$

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

Using 20 mm diameter bars

Required total depth = $128 + 20/2 + 50 = 188 \text{ mm}$ say 200 mm

Provided effective depth = $d = 200 - 50 - 20/2 = 140 \text{ mm}$

Check the depth for one - way

shear considerations- At 'd' from face

Design shear force = $V_u = 177 \times (0.825 - 0.140) = 121 \text{ kN}$

Nominal shear stress = $\tau_v = V_u / bd = 121000 / (1000 \times 140) = 0.866 \text{ MPa}$

Permissible shear stress

$$P_t = 100 \times 2415 / (1000 \times 140) = 1.7 \%, \tau_{uc} = 0.772 \text{ N/mm}^2$$

Value of k for 200 mm thick slab = 1.2

$$\text{Permissible shear stress} = 1.2 \times 0.772 = 0.926 \text{ N/mm}^2$$

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

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

Check for development length

$$L_{dt} = [0.87 \times 250 / (4 \times 1.4)] \Phi = 39 \Phi$$

$$= 39 \times 20 = 780 \text{ mm}$$

$$\text{Available length of bar} = 825 - 25 = 800 \text{ mm}$$

> 780 mm and hence safe.

Transverse reinforcement

$$\text{Required } A_{st} = 0.15bD/100$$

$$= 0.15 \times 1000 \times 200 / 100 = 300 \text{ mm}^2$$

$$\text{Using } \Phi 8 \text{ mm bars, Spacing} = 1000 \times 50 / 300$$

$$= 160 \text{ mm}$$

Provide distribution steel of $\Phi 8$ 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

$$= w_u = 177 \times 2 = 354 \text{ kN/m}$$

Shear Force and Bending Moment

$$V_{AC} = 354 \times 0.9 = 318.6 \text{ kN}, V_{AB} = 1050 - 318.6 = 731.4 \text{ kN}$$

$$V_{BD} = 354 \times 1.7 = 601.8 \text{ kN}, V_{BA} = 1500 - 601.8 = 898.2 \text{ kN}$$

Point of zero shear from left end C

$$X_1 = 1050 / 354 = 2.97 \text{ m from C or}$$

$$X_2 = 7.2 - 2.97 = 4.23 \text{ m from D}$$

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

$$M_{uE} = 354 \times 4.23^2 / 2 - 1500 (4.23 - 1.7) = -628 \text{ kN.m}$$

Bending moment under column A = $M_{uA} = 354 \times 0.9^2 / 2 = 143.37 \text{ kN.m}$

Bending moment under column B = $M_{uB} = 354 \times 1.7^2 = 511.5 \text{ kN.m}$

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

Then, $M_x = 1050x - 354(x + 0.9)^2 / 2 = 0$

Therefore $x = 0.206 \text{ m}$ 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.

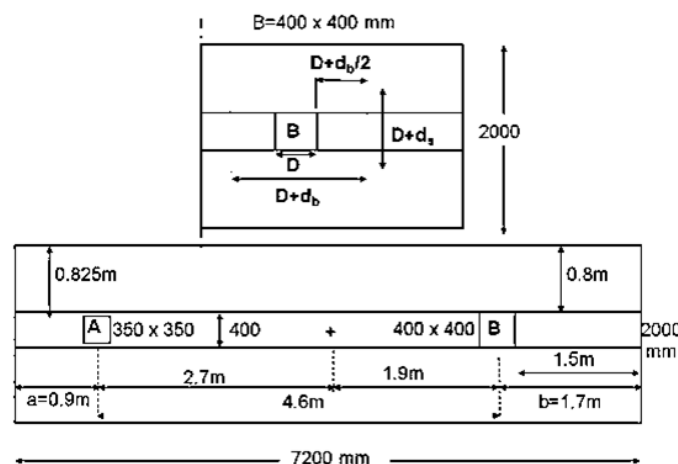
The beam acts as a rectangular section in the cantilever portion, where the maximum positive moment = 511.5 kN.m .

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

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

Effective depth provided = $d = 750 - 70 = 680 \text{ mm}$

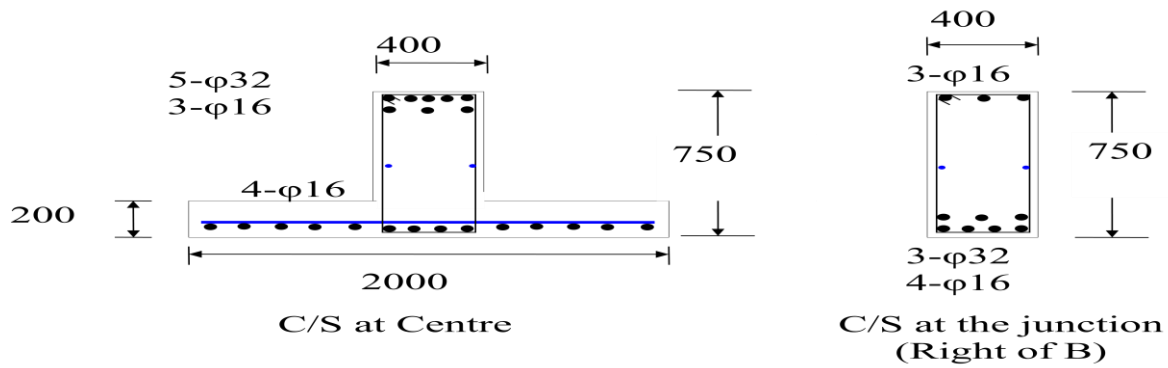
(Less than 750 mm and hence no side face steel is needed)



In this case $b=D=400 \text{ mm}$, $d_b=680 \text{ mm}$, $d_s=140 \text{ mm}$

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

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

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

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

$$= 1377.65 \times 1000 / 885600 = 1.56 \text{ MPa}$$

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

where,

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

$$K_s = 0.5 + d / D = 0.5 + 400 / 400 = 1.5 \leq 1 \quad \text{Hence } K_s = 1$$

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

Therefore Unsafe

