“The most important thing is to keep the most important thing the most important thing”
Combined Footing

- A combined footing is a long footing supporting two or more columns in (typically two) one row.

- A combined footing is a rectangular or trapezoidal shaped footing.
Using of Combined Footing

Construction practice may dictate using only one footing for two or more columns due to:

a) Closeness of column (for example around elevator shafts and escalators); and

b) Due to property line constraint, which may limit the size of footings at boundary. The eccentricity of a column placed on an edge of a footing may be compensated by tying the footing to the interior column.
DESIGN OF COMBINED FOOTINGS BY RIGID METHOD:

The rigid method of design of combined footings assumes that:

1. The footing or mat is infinitely rigid, and therefore, the deflection of the footing or mat does not influence the pressure distribution,

2. The soil pressure is distributed in a straight line or a plane surface such that the centroid of the soil pressure coincides with the line of action of the resultant force of all the loads acting on the foundation.
(CONVENTIONAL METHOD)

The design of combined footing requires that the centroid of the area be as close as possible to the resultant of the two column loads for uniform pressure and settlement (if possible).

\[ \text{i.e.: eccentricity, } e = 0.0 \]
Combined Footing

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Plain Concrete Footing (P.C.)

For uniform stress, Resultant should be at mid of (A)

\[
\frac{A}{2} = X + C_1 + \frac{a_1}{2} + L_1 = X + C_2 + \frac{a_2}{2} + L_2
\]

Assume thickness of P.C.:

\[t = (0.25 \text{ to } 0.50)\]

\[X = (0.80 \text{ to } 1.0) t\]

Assume \(C_2 = 0.50m\)

\[R = (P_1 + P_2)\]

\[L_2 \times R = L \times P_1 \rightarrow \text{Get (L)}\]

\[\frac{A}{2} = X + C_2 + \frac{a_2}{2} + L_2 \rightarrow \text{Get (A)}\]

\[\text{Area} = A \times B = \frac{1.15(P_1 + P_2)}{q_a} \rightarrow \text{Get (B)}\]

\[\text{Dim. of P.C.} = A \times B \times t\]
Reinforced Concrete Footing (R.C.)

\[ A_1 = A - 2X \]

\[ B_1 = B - 2X \]

\[ p_n = \frac{1.50R}{A_1 * B_1} \]

\[ w = \frac{1.50R}{A_1} \]

\[ M_1 = w \frac{[C_1]^2}{2} \]

\[ M_2 = w \frac{[C_2]^2}{2} \]
Reinforced Concrete Footing (R.C.)

\[ wZ - P_2 = 0.0 \quad \text{Get } (Z) \]

\[ M_{\text{max}} = \frac{wZ^2}{2} - P_2 \left[ Z - \left( C_2 + \frac{a_2}{2} \right) \right] \]

\[ d = C \sqrt{\frac{M}{b \cdot F_{cu}}} \]

\[ t_1 = d + \text{cover} \]

Steel cover = 5.0 to 7.0 cm

\[ \text{Dim. of R.C.} = A_1 \ast B_1 \ast t_1 \]
Shear Stress

\[ Q_1 = -w * C_1 \]
\[ Q_2 = P_1 - w * (C_1 + a_1) \]
\[ Q_3 = w * (C_2 + a_2) - P_2 \]
\[ Q_4 = w * (C_2) \]
\[ Q_s = Q_2 - wd \]
\[ q_s = \frac{Q_s}{b*d} \leq q_{su} \]
\[ q_{su} = 0.75 \sqrt{\frac{f_{cu}}{\gamma_c}} \]

If \( q_s > q_{su} \), Increase \( d \)
Punching Stress

Column(1):

\[ Q_p = P_1 - p_n \ast \left[ (a_1 + d) \ast (b_1 + d) \right] \]

\[ A_{p1} = d \ast 2 \ast \left[ (a_1 + d) + (b_1 + d) \right] \]

\[ q_p = \frac{Q_p}{A_p} \]

\[ q_{\text{cup}} = \left[ 0.5 + \left( \frac{a}{b} \right) \right] \sqrt{f_{\text{cu}} / \gamma_c} \leq \sqrt{f_{\text{cu}} / \gamma_c} \]

If \( q_p > q_{\text{cup}} \), Increase \( d \)

Repeat Check for column (2)
Footing Reinforcement

Which is required?
Top or bottom RFT
why?

\[ A_{top} = \frac{M_{max}}{f_y \cdot d \cdot j} \]

\[ A_{bot} = \frac{M_1}{f_y \cdot d \cdot j} \]
Design of Hidden Beams

\[ w_1 = \frac{P_1}{B_1} \]

\[ M_{HB1} = w_1 \left( \frac{(B_1 - b_1)/2}{2} \right)^2 \]

\[ d_1 = C \sqrt{\frac{M}{b * F_{cu}}} \]

\[ b = b_1 + d \]

\[ d_1 < d \rightarrow \text{safe} \]

\[ d_1 > d \rightarrow \text{take } d = d_1 \]

\[ A_{sh1} = \frac{M_1}{f_y * d * j} \]
Example (1):

Make a complete design for a combined footing for the two columns shown in figure (1). The net allowable pressure is 1.10 kg/cm² and the foundation level is 2.0m below ground surface.

\[ a_1 = 0.90 \text{m} \quad b_1 = 0.30 \text{m} \quad P_1 = 140 \text{t} \]
\[ a_2 = 0.50 \text{m} \quad b_2 = 0.30 \text{m} \quad P_2 = 90 \text{t} \]
\[ q_a = 1.10 \text{kg/cm}^2 = 11.0 \text{t/m}^2. \]

\[ f_{cu} = 250 \text{kg/cm}^2. \]
\[ f_y = 3600 \text{kg/cm}^2 \]
Plain Concrete Footing (P.C.)

For uniform stress, Resultant should be at mid of (A)

\[
\frac{A}{2} = X + C_1 + \frac{a_1}{2} + L_1 = X + C_2 + \frac{a_2}{2} + L_2
\]

Assume thickness of P.C.:

\[ t = 0.30 \]

\[ X = t = 0.30 \]

Assume \( C_2 = 0.50m \)

\[ R = (P_1 + P_2) = 140 + 90 = 230t \]

\[ L_2 \times 230 = 3.20 \times 140 \implies L_2 = 1.95 \]

\[ \frac{A}{2} = 0.30 + 0.50 + \frac{0.50}{2} + 1.95 = 3.00m \]

\[ A = 6.00m \]

\[ Area = A \times B = \frac{1.15(P_1 + P_2)}{q_a} = \frac{1.15 \times 230}{11} = 24.10m^2 \]

\[ B = 4.02 = 4.05m \]

\[ \text{Dim. of P.C.} = 6.00 \times 4.05 \times 0.30 \]
Reinforced Concrete Footing (R.C.)

\[ A_1 = A - 2X = 6.00 - 2 \times 0.30 = 5.40 \text{m} \]

\[ B_1 = B - 2X = 4.05 - 2 \times 0.30 = 3.45 \text{m} \]

\[ p_n = \frac{R}{A_1 \times B_1} = \frac{1.50 \times 230}{5.40 \times 3.45} = 18.52 \text{t} / \text{m} \]

\[ w = \frac{R}{A_1} = \frac{1.50 \times 230}{5.40} = 63.90 \text{t} / \text{m}^2 \]

\[ M_1 = w \left( \frac{C_1}{2} \right)^2 = 63.90 \left( \frac{0.90}{2} \right)^2 = 25.88 \text{m} \text{t} \]

\[ M_2 = w \left( \frac{C_2}{2} \right)^2 = 63.90 \left( \frac{0.50}{2} \right)^2 = 8.00 \text{m} \text{t} \]
Reinforced Concrete Footing (R.C.)

\[ wZ - P_2 = 63.90 \times 2.11 - 1.50 \times 90 \rightarrow Z = 2.11 \]

\[ M_{\text{max}} = \frac{wZ^2}{2} - P_2 \left[ Z - \left( C_2 + \frac{a_2}{2} \right) \right] \]

\[ M_{\text{max}} = \frac{63.90 \times 2.11^2}{2} - 1.50 \times 90 \times \left( 2.11 - \left( 0.50 + \frac{0.5}{2} \right) \right) = 41.36 \text{m} \text{t} \]

\[ d = C \sqrt{\frac{M}{b \times F_{cu}}} = 5 \times \sqrt{\frac{41.36 \times 10^5}{345 \times 250}} = 34.6 = 35 \text{cm} \]

\[ t_1 = d + \text{cover} = 35 + 5 = 40 \text{cm} \]

\textit{Dim. of R.C.} = 5.80 \times 3.20 \times 35
Shear Stress

\( Q_1 = -63.95 \times 0.90 = 57.55t \)

\( Q_2 = 210 - 63.95 \times (0.90 + 0.90) = 95.89t \)

\( Q_3 = 63.95 \times (0.50 + 0.50) - 135 = 71.05t \)

\( Q_4 = 63.95 \times (0.50) = 31.98t \)

\( Q_s = 95.89 - 63.95 \times 0.35 = 73.51t \)

\( q_s = \frac{73.51 \times 10^3}{345 \times 30} = 7.10 \text{ kg/cm}^2 \)

\( q_{su} = 0.75 \sqrt{\frac{f_{cu}}{\gamma_c}} = 0.75 \sqrt{\frac{250}{1.50}} = 9.68 \)
Punching Stress

**Column (1):**

\[
Q_p = P_1 - p_n \left[ (a_1 + d) \times (b_1 + d) \right]
\]

**Example:**

\[
Q_p = 210 - 18.52 \times (0.90 + 0.35) \times (0.30 + 0.35) = 194.95t
\]

\[
A_{p1} = d \times 2 \times \left[ (a_1 + d) + (b_1 + d) \right]
\]

**Example:**

\[
A_{p1} = 0.35 \times 2 \times (0.90 + 0.35) + (0.30 + 0.35) = 1.33m^2
\]

\[
q_p = \frac{Q_p}{A_p} = \frac{194.95 \times 10^3}{1.33 \times 10^4} = 15.98kg/cm^2
\]

\[
q_{cup} = \left[ 0.5 + (b/a) \right] \sqrt{f_{c u} / \gamma_c} \leq \sqrt{f_{c u} / \gamma_c}
\]

\[
q_{cup} = \left[ 0.5 + (0.30/0.90) \right] \sqrt{250/1.50} = 10.75kg/cm^2
\]

\[q_p > q_{cup} \text{, Increase } d = 45cm\]

Repeat Check for column (2)
Design of Hidden Beams

\[ w_1 = \frac{P_1}{B_1} = \frac{210}{3.45} = 60.87t / m' \]

\[ M_{HB1} = 60.87 \left[ \frac{(3.45 - 0.30)/2}{2} \right]^2 = 75.50mt \]

\[ b = b_1 + d = 0.30 + 0.30 = 0.65 \]

\[ d_1 = 5 \sqrt{\frac{75.50 \times 10^5}{75 \times 250}} = 100.3 = 105cm \]

\[ d_1 > d \rightarrow \text{take } d = 105 \]

\[ A_{SH1} = \frac{M_I}{f_y \cdot d \cdot j} = \frac{75.5 \times 10^5}{3600 \times 105 \times 0.826} = 24.2cm^2 \]

\[ 7 \phi 22 \]
Footing Reinforcement

\[ A_{\text{top}} = \frac{M_1}{f_y \cdot d \cdot j} = \frac{25.88 \times 10^5}{3600 \times 110 \times 0.826} = 8.30 \text{ cm}^2 \]

5 \( \phi \) 12/ m'

\[ A_{\text{bot}} = \frac{M_{\text{max}}}{f_y \cdot d \cdot j} = \frac{40.36}{3600 \times 105 \times 0.826} = 12.93 \text{ cm}^2 \]

5 \( \phi \) 12/ m'

\[ M_{\text{max}} = 40.36 \]

\[ M_2 = 8.0 \]

\[ M_1 = 25.88 \]