



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

EARTHQUAKE RESISTANT DESIGN OF FOUNDATIONS

Lecture 6: Combined Footings

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ERD of Foundations - Modules

1. Introduction
- 2. Shallow Foundations**
3. Pile Foundations
4. Well Foundations
5. SSI for Deep Foundations

Module - 2

Shallow Foundations



Module -2: Chapters

1. General Requirements
2. Bearing Capacity and Settlement
3. Combined Footings
4. Raft Foundations
5. Dynamic Bearing Capacity



Chapter 3: Combined Footing

- **Introduction**
- **General Principles of Combined Footing**
- **Types of Combined Footing**
- **Numerical Examples**

Introduction: Significance of Combined Footing

- In some situation, it is better and economical to combine the spread footings of two individual columns. Though this decision depends on the distance between columns, type of soil and amount of load to be transferred.
- A combined footing will perform better during earthquake compare to isolated or spread footing.
- The choice of the combined footing is preferred next to isolated footings.

Introduction: Combined Footing & Strap Footing

- A spread footing which supports two or more columns is termed as combined footing.
- If the independent spread footing of two columns are connected by a beam, it is called a strap footing.
- Combined Footing
 - Rectangular in shape, if both column carry almost equal loads
 - Trapezoidal- if the columns carry very unequal loads

General Principles of Combined Footing

- Usually constructed of reinforced concrete.
- It is assumed that the footing is rigid and rests on a homogeneous soil, therefore, it gives rise to linear stress distribution on the bottom of the footing.
- If the resultant of the soil pressure coincides with the resultant of the loads (and C.G. of the footing), the soil pressure is assumed to be uniformly distributed.

Types of Combined Footing

- a) Rectangular Combined Footing
- b) Trapezoidal Combined Footing
- c) Strap or Cantilever Footing

Rectangular Combined Footing

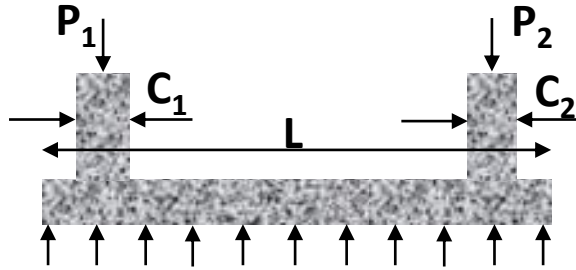
The design of rigid rectangular combined footing consists in determining the location of C.G. of the column loads and using length and width dimensions such that centroid of the footing and C.G. of the column load coincide. The resultant pressure distribution will be rectangular with the pressure intensity

$$q = \frac{P_1 + P_2}{B * L} < q_s$$

The column loads are considered concentrated loads and S.F. & B.M. are plotted. The maximum B.M. is adopted as the design value of RC footing.

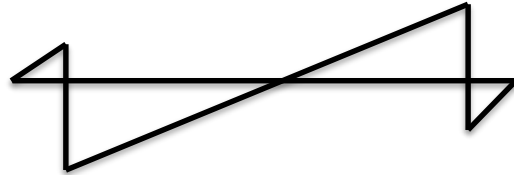
Rectangular Combined Footing (Continued...)

$$p_1 = P_1/C_1$$

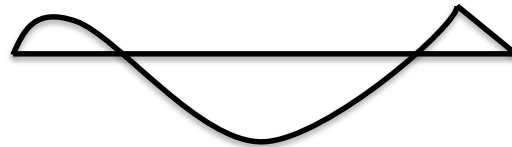


$$p_2 = P_2/C_2$$

(a) Loading and pressure distribution



(b) SFD



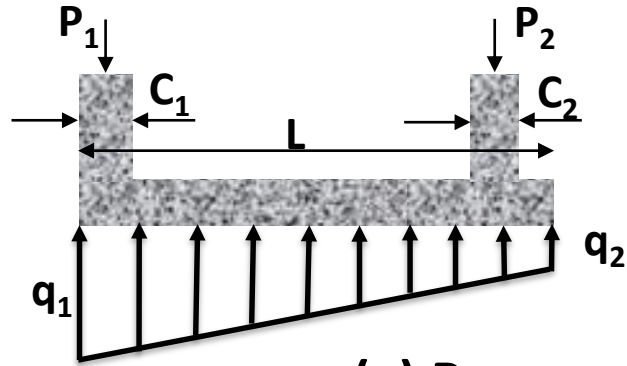
(c) BMD

Trapezoidal Combined Footing

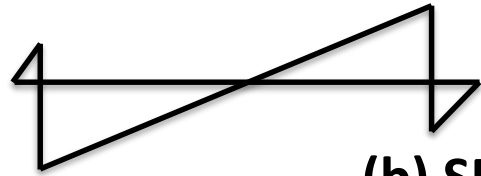
When the two column loads are unequal with the outer column coming heavier load and when there is space limitation beyond the outer column, a trapezoidal combined footing is provided. The resulting pressure distribution is linear (and not rectangular) as shown in next slide. In order to find the value of a and b

$$\text{Area } A = \left(\frac{a+b}{2}\right)L = \frac{P_1+P_2}{q_s} \quad \text{where } q_s \text{ is allowable pressure}$$
$$a + b = \frac{2}{L} \left(\frac{P_1+P_2}{q_s} \right) \quad (1)$$

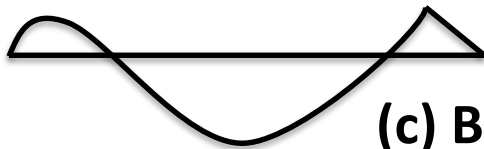
Trapezoidal Combined Footing (Continued...)



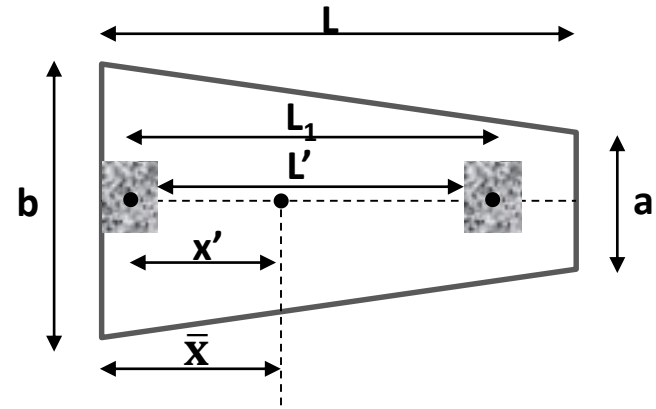
(a) Pressure distribution



(b) SFD



(c) BMD



(b) Footing Plan

Trapezoidal Combined Footing (Continued...)

Taking the moment about the center of column 1,

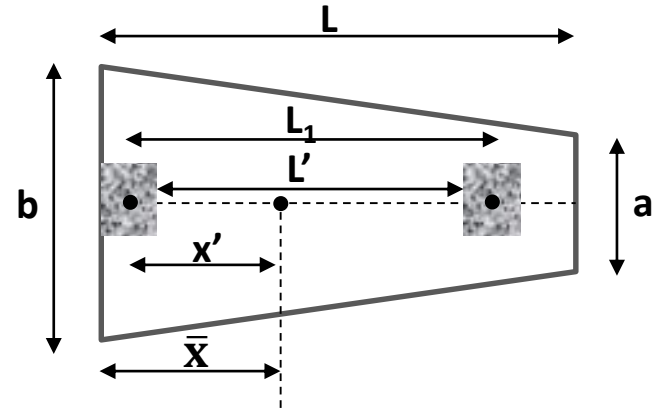
$$(P_1 + P_2) * x' = P_2 * L_1$$

$$x' = \frac{P_2 * L_1}{P_1 + P_2}$$

$$\bar{X} = \frac{C_1}{2} + \frac{P_2 * L_1}{P_1 + P_2} = \frac{L}{3} \left(\frac{2a+b}{a+b} \right)$$

$$\frac{2a+b}{a+b} = \frac{3}{L} \left(\frac{C_1}{2} + \frac{P_2 * L_1}{P_1 + P_2} \right) \quad (2)$$

Simultaneous solution of eqn. (1) and (2) gives the value of a and b .



Trapezoidal Combined Footing (Continued...)

Knowing a and b , the pressure intensities q_1 and q_2 are calculated

$$q_1 = b * q_s \quad \text{and} \quad q_2 = a * q_s$$

The B.M. and S.F. can be drawn as shown in previous slide.

For a rectangular combined footing $\bar{x} = L/2$

For $a = 0$ triangular footing with $\bar{x} = L/3$,

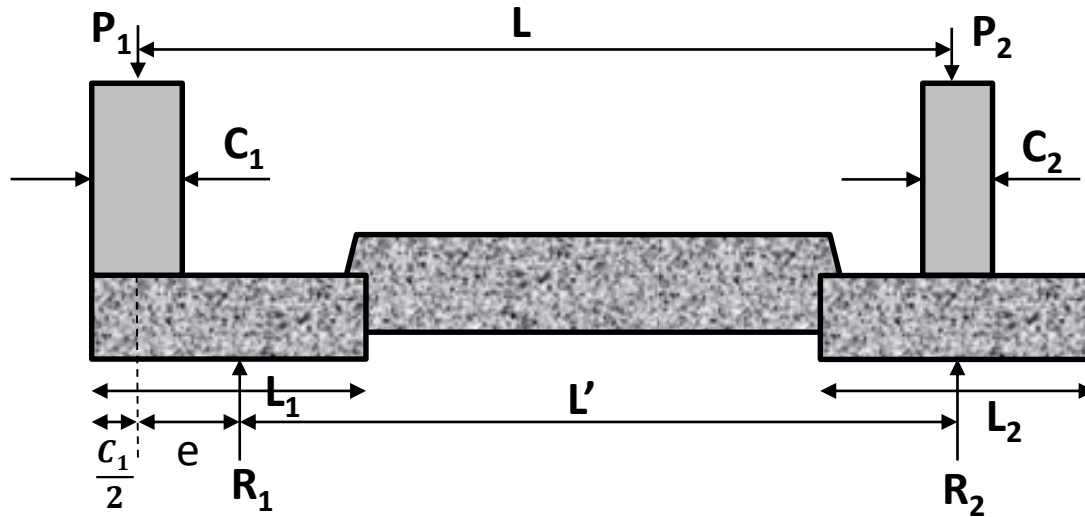
Hence combined footing solution exist between

$$L/3 < \bar{x} < L/2$$

Strap or Cantilever Footing

This footing can be used where the distance between the column is so great that the combined trapezoidal footing become quite narrow, with high B.M. or where $\bar{x} < L/3$. a strap footing consist of spread footing of two columns, connected by a strap beam. The strap beam does not remain in contact with soil and thus does not transfer the any pressure to the soil. The strap assumed to be infinitely stiff, serves to transfer the column load on to the soil with equal and uniform soil pressure under both footings.

Strap or Cantilever Footing (Continued...)



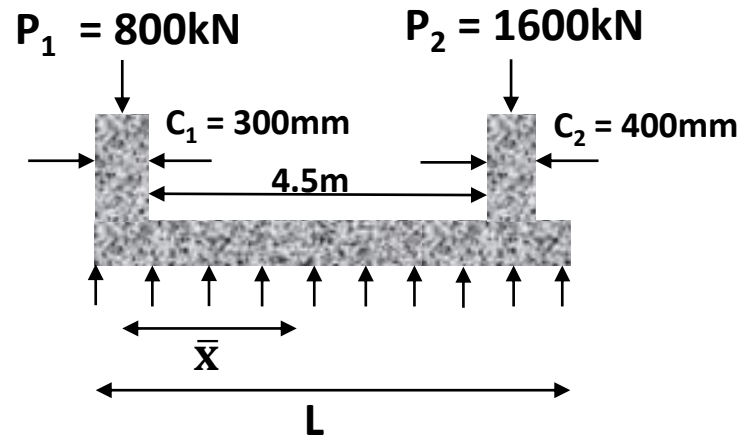
$$R_1 = P_1 * L / L' \quad (\text{taking moment about } P_2) \quad \text{and} \quad R_1 + R_2 = P_1 + P_2$$

$$L_1 = 2\left(e + \frac{c_1}{2}\right), \quad \text{if } B \text{ is the width of footing } B = R_1 / (L_1 * q_s)$$

$$q_s * L_1 * B * (L - e) = P_1 * L \quad \text{if } e \text{ is known find the value of } B$$

Rectangular Combined Footing (Numerical)

Example 1: Design the rectangular combined footing given that allowable soil pressure $q_s = 150\text{kPa}$



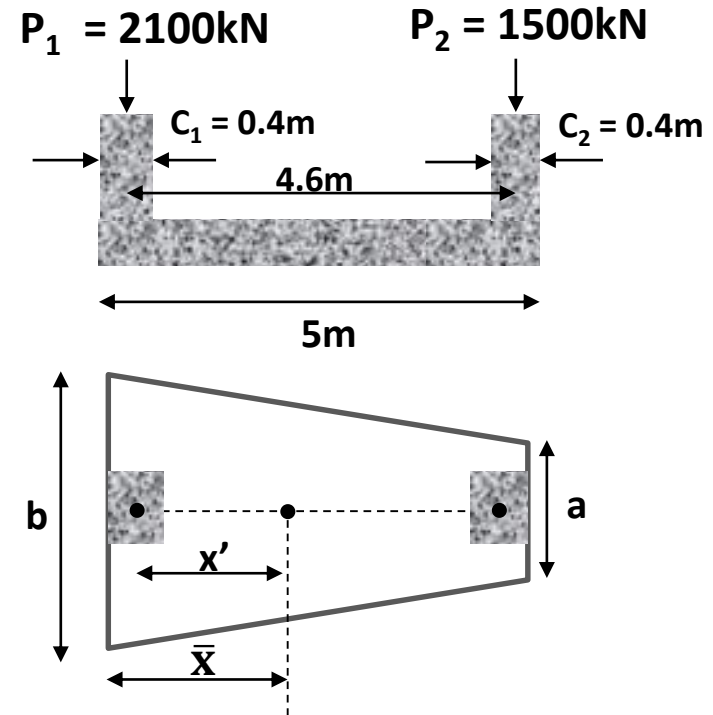
Rectangular Combined Footing (Numerical)

Solution: Find L & B ?

- Resultant force, $R = P_1 + P_2 = 800 + 1600 = 2400 \text{ kN}$
- Taking the moment about the center of column 1, $R \cdot \bar{x} = P_2 \cdot 4.5$
$$\bar{x} = 1600 \cdot 4.5 / 2400 = 3 \text{ m}$$
- $L = 2 \cdot \left(\bar{x} + \frac{c_1}{2} \right) = 2 \cdot (3 + 0.15) = 6.3 \text{ m}$ **Ans**
- Area of footing, $A = R / q_s = 2400 / 150 = 16 \text{ m}^2$
- Width of footing, $B = A / L = 16 / 6.3 = 2.54 \text{ m}$ **Ans**

Trapezoidal Combined Footing (Numerical)

Example 2: Design the trapezoidal combined footing given that allowable soil pressure $q_s = 150\text{kPa}$



Trapezoidal Combined Footing (Numerical)

Solution:

- Check the solution for trapezoidal footing exist
Take the moment about the center of column 1,

$$x' = \frac{P_2 * L_1}{P_1 + P_2} = \frac{1500 * 4.6}{3600} = 1.92\text{m}$$

$$\bar{x} = (x' + \frac{C_1}{2}) = 0.2 + 1.92 = 2.12\text{m}$$

It can be seen that $\bar{x} > L/3$ as $2.12 > 5/3$
and $\bar{x} < L/2$ as $2.12 < 5/2$

Trapezoidal Combined Footing (Numerical)

$$\text{Area of footing, } A = \left(\frac{a+b}{2}\right)L = \left(\frac{a+b}{2}\right)*5 \quad (1)$$

$$\text{However Area, } A = \frac{P_1+P_2}{q_s} = \frac{2100+1500}{150} = \frac{3600}{150} = 24\text{m}^2 \quad (2)$$

$$\text{Thus using eqn (1) and (2), } a + b = 9.6\text{m, } b = 9.6 - a \quad (3)$$

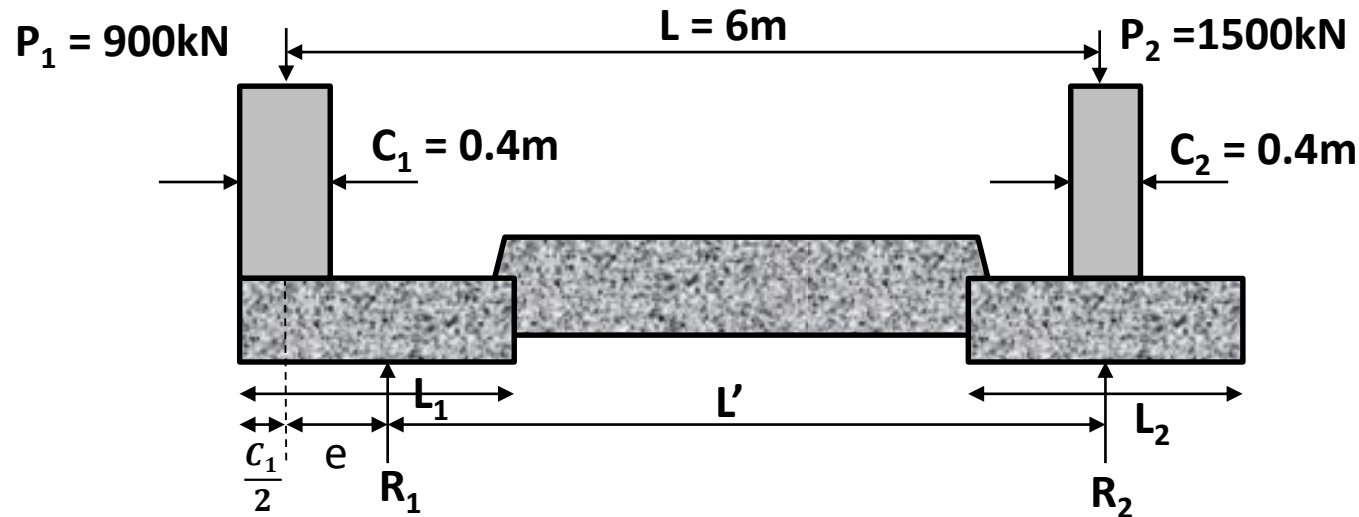
$$\begin{aligned} \text{Now,} \quad \bar{X} &= \frac{L}{3} \left(\frac{2a+b}{a+b} \right) \\ 2.12 &= \frac{5}{3} \left(\frac{2a+b}{a+b} \right) \end{aligned} \quad (4)$$

Solving equation (3) and (4),

$$a = 2.592\text{m and } b = 7.008\text{m}$$

Strap Footing (Numerical)

Example 3: Design the strap footing. Given that allowable soil pressure $q_s = 150\text{kPa}$



Strap Footing (Numerical)

Solution:

- Let's assume the eccentricity, $e = 1\text{m}$ then $L' = (L - e) = (6 - 1) = 5\text{m}$
- Taking the moment about column 2, $R_1 = P_1 * L / L' = 900 * 6 / 5 = 1080\text{ kN}$
 $R_2 = (P_1 + P_2) - R_1 = 2400 - 1080 = 1320\text{ kN}$
- Footing dimension for column 1,

$$L_1 = 2 * (e + \frac{C_1}{2}) = 2 * (1 + \frac{0.4}{2}) = 2.4\text{m}$$

$$B_1 = \frac{R_1}{L_1 * q_s} = \frac{1080}{2.4 * 150} = 3\text{m}$$

Strap Footing (Numerical)

- Footing dimension for column 2,
let's assume square footing ($L_2 = B_2$)

$$B_2^2 * q_s = R_2 , \quad B_2 = \sqrt{\frac{R_2}{q_s}} = \sqrt{\frac{1320}{150}} = 3\text{m}$$

- Since the width of both footing are almost equal, the settlement should be nearly equal and no need to revise the design.

Thank You

