Lecture Goals

- Footing Classification
- Footing Design
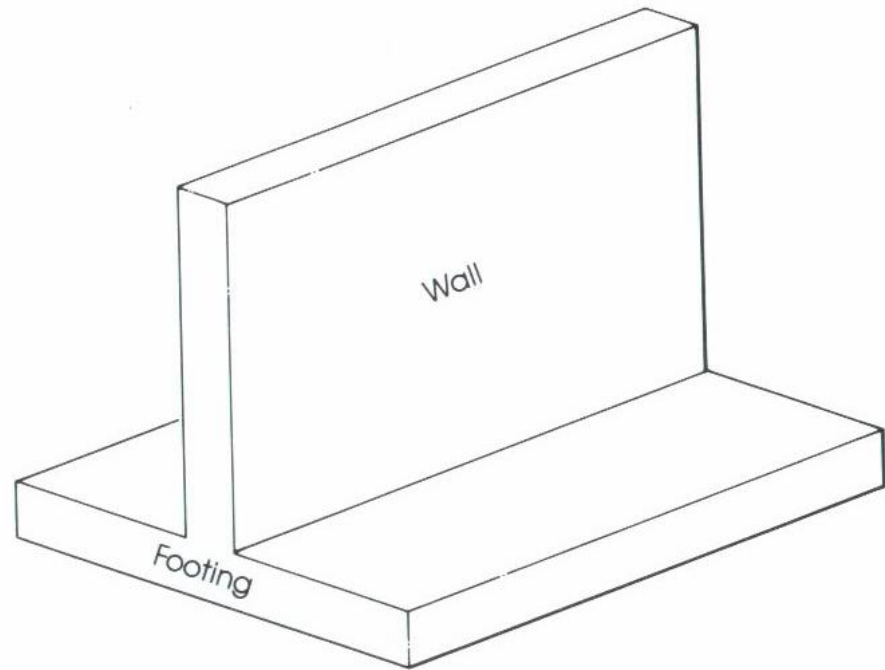
Footing

<u>Definition</u>

Footings are structural members used to support columns and walls and to transmit and distribute their loads to the soil in such a way that the load bearing capacity of the soil is not exceeded, excessive settlement, differential settlement,or rotation are prevented and adequate safety against overturning or sliding is maintained.
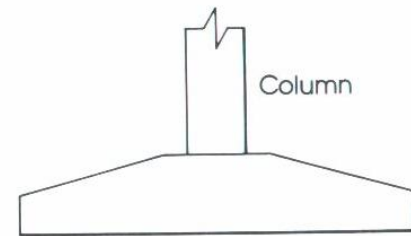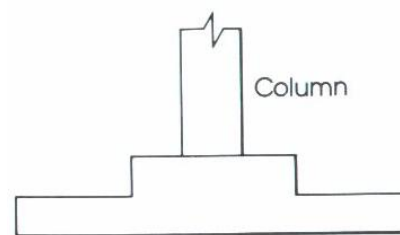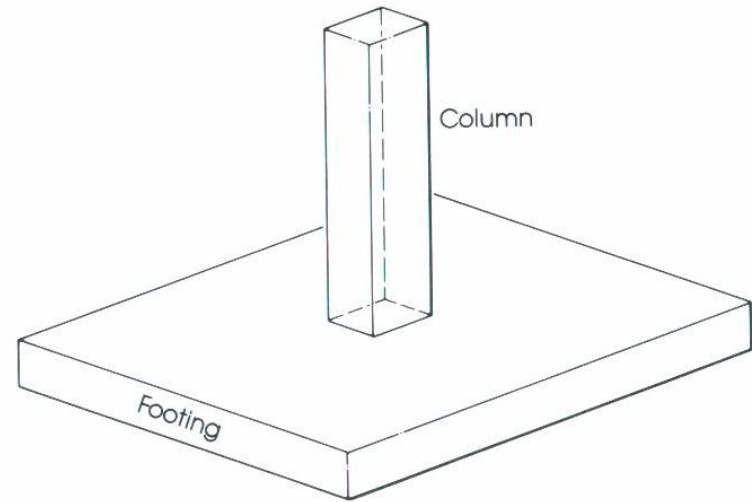
Types of Footing

Wall footings are used to support structural walls that carry loads for other floors or to support nonstructural walls.

Wall

Footing

Wall footing.

Types of Footing

Isolated or single footings are used to support single columns. This is one of the most economical types of footings and is used when columns are spaced at relatively long distances.
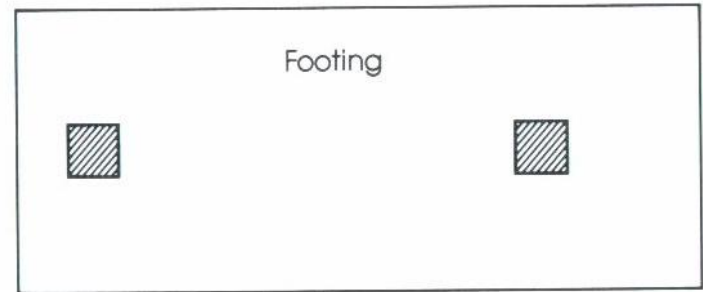
Column

Footing

Column

Column

Types of Footing

Combined footings usually support two columns, or three columns not in a row. Combined footings are used when two columns are so close that single footings cannot be used or when one column is located at or near a property line.
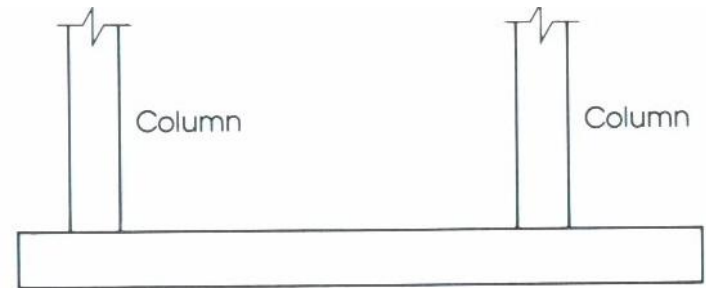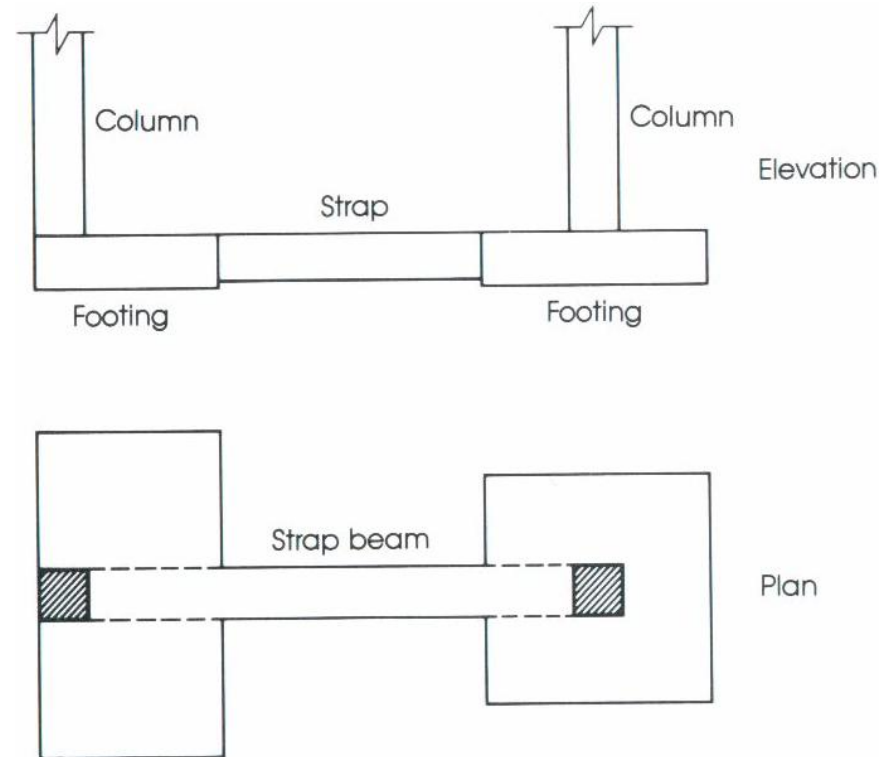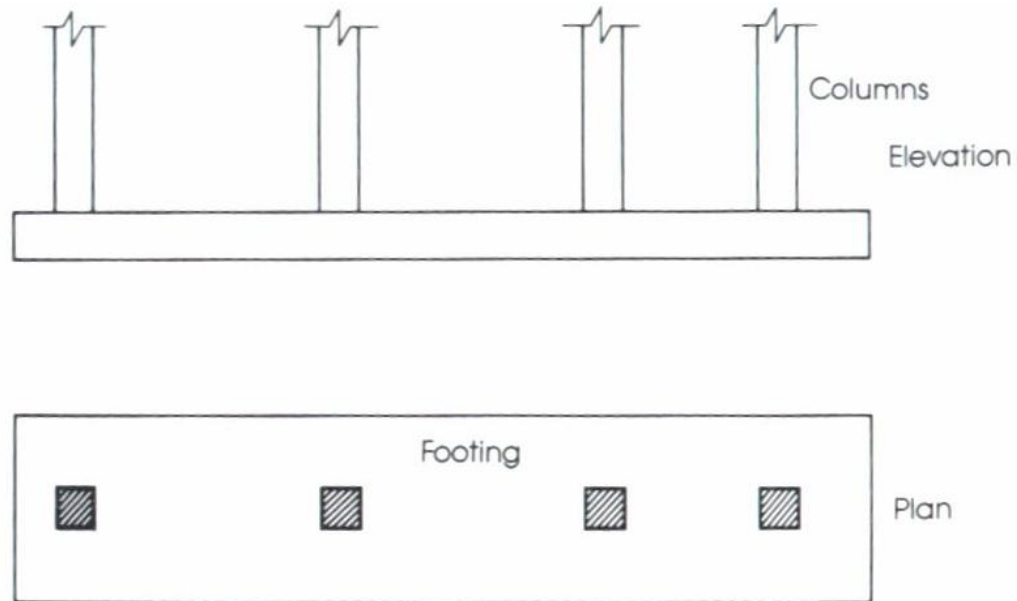
Types of Footing

Cantilever or strap footings consist of two single footings connected with a beam or a strap and support two single columns. This type replaces a combined footing and is more economical.
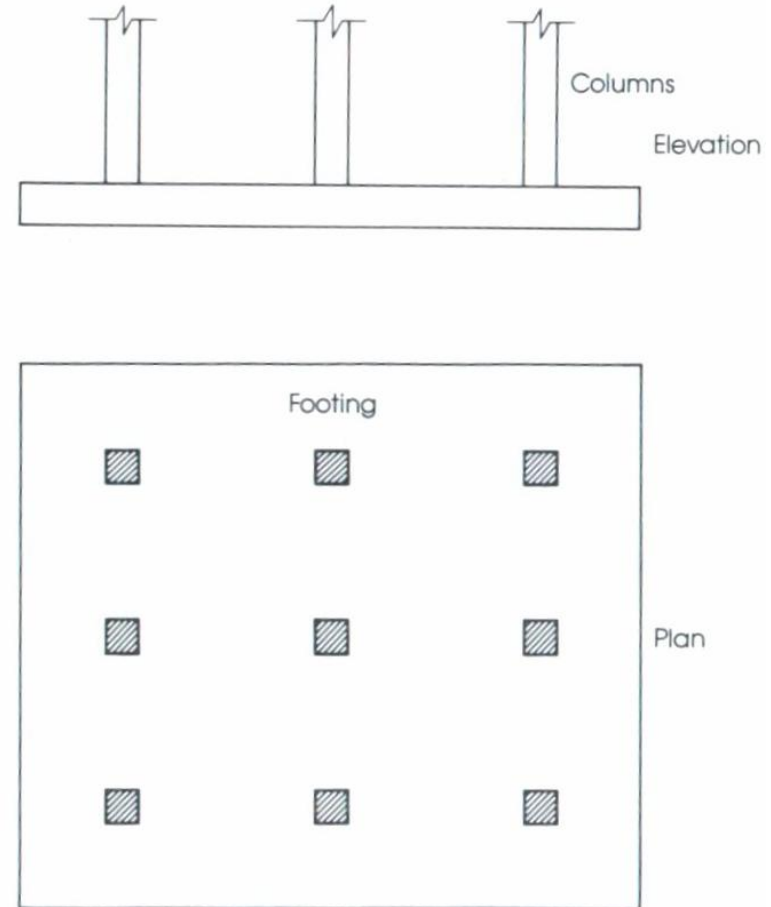
Types of Footing

Continuous footings
support a row of three or
more columns. They have
limited width and continue
under all columns.

Types of Footing

**Rafted or mat foundation** consists of one footing usually placed under the entire building area. They are used, when soil bearing capacity is low, column loads are heavy single footings cannot be used, piles are not used and differential settlement must be reduced.
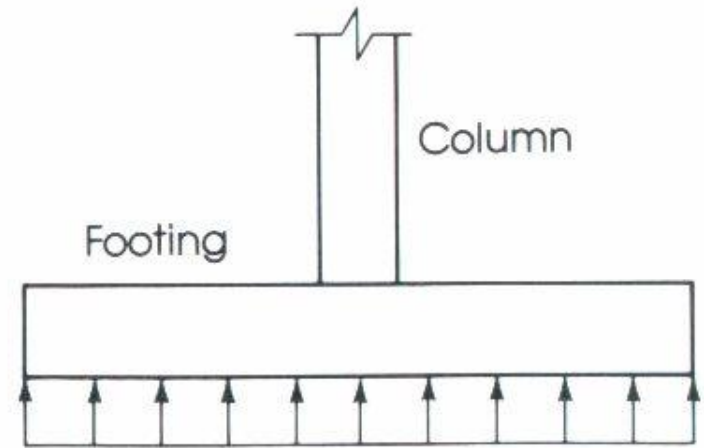
Types of Footing

Pile caps are thick slabs used to tie a group of piles together to support and transmit column loads to the piles.
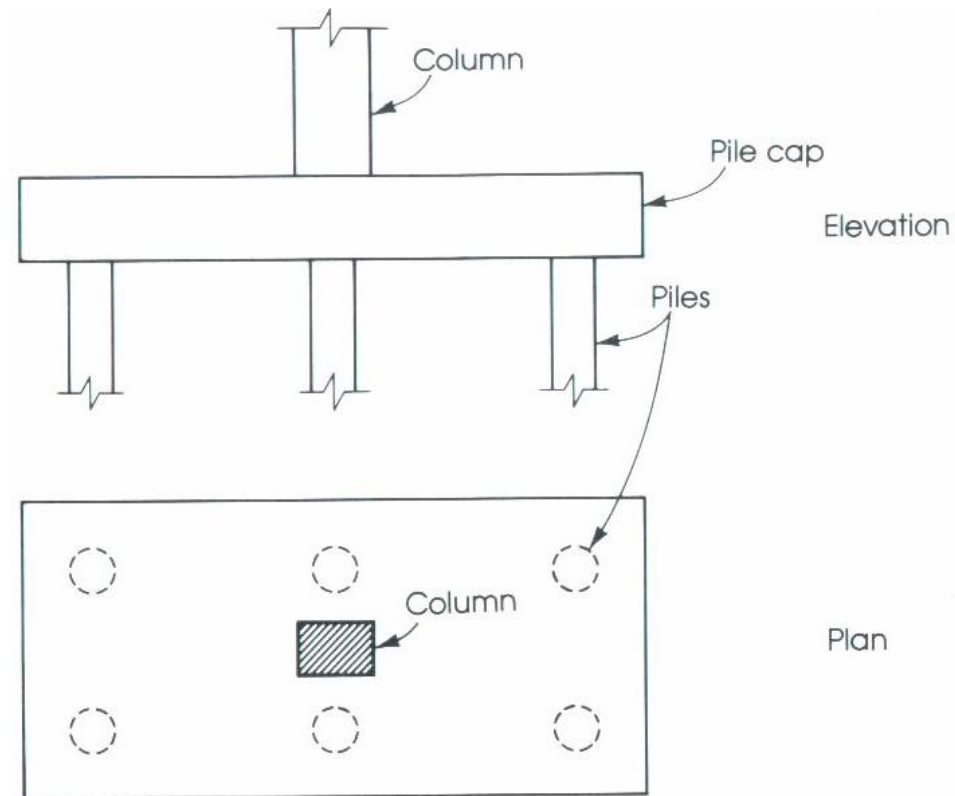
Distribution of Soil Pressure

When the column load P is applied on the centroid of the footing, a uniform pressure is assumed to develop on the soil surface below the footing area.

However the actual distribution of the soil is not uniform, but depends on may factors especially the composition of the soil and degree of flexibility of the footing.

Distribution of Soil Pressure
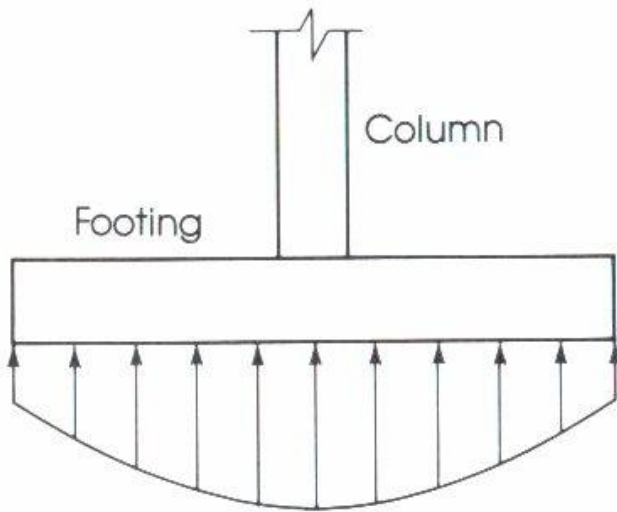
Soil pressure distribution in cohesionless soil.

Soil pressure distribution in cohesive soil.

Design Considerations

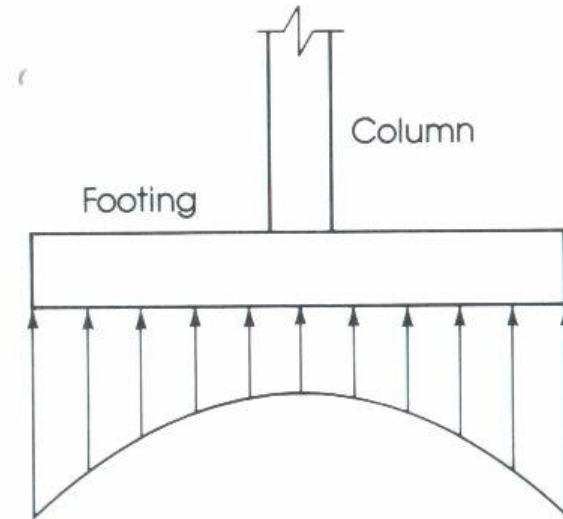Footings must be designed to carry the column loads and transmit them to the soil safely while satisfying code limitations.

1. The area of the footing based on the allowable bearing soil capacity

2. Two-way shear or punch out shear.

3. One-way bearing

4. Bending moment and steel reinforcement required

Design Considerations

Footings must be designed to carry the column loads and transmit them to the soil safely while satisfying code limitations.

1. Bearing capacity of columns at their base

2. Dowel requirements

3. Development length of bars

4. Differential settlement

Size of Footing

The area of footing can be determined from the actual external loads such that the allowable soil pressure is not exceeded.

$$\text{Area of footing} = \frac{\text{Total load}\,(\text{including self - weight})}{\text{allowable soil pressure}}$$

Strength design requirements

$$q_u = \frac{P_u}{\text{area of footing}}$$

Two-Way Shear (Punching Shear)

For two-way shear in slabs (& footings) V_c is smallest of

$$V_c = \left(2 + \frac{4}{\beta_c}\right)\sqrt{f_c}\, b_0 d \qquad \text{ACI 11-35}$$

where, $\beta_c =$ long side/short side of column concentrated load or reaction area < 2

$b_0 =$ length of critical perimeter around the column

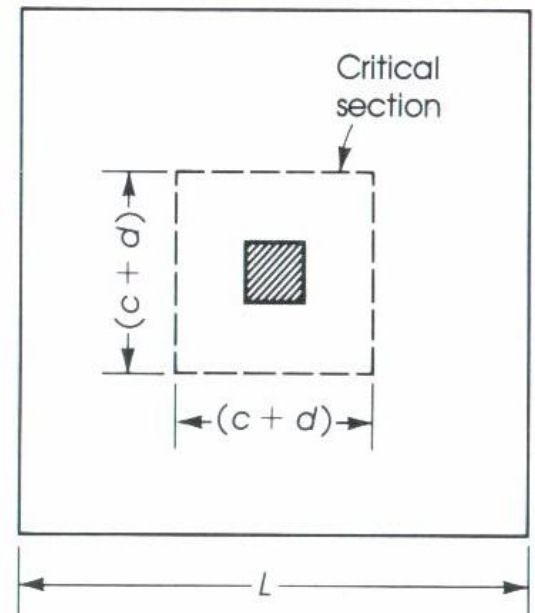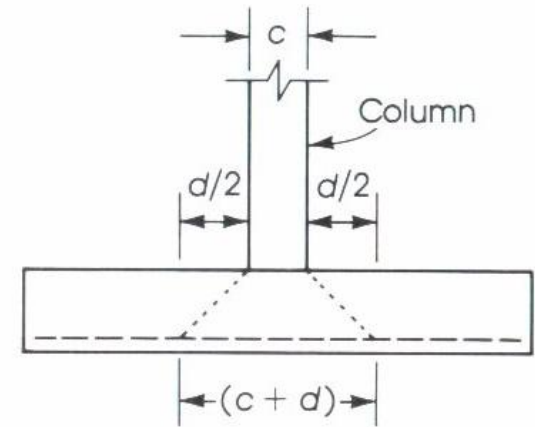When $\beta > 2$ the allowable V_c is reduced.

Design of two-way shear

1. Assume d.

2. Determine b_0.

   $b_0 = 4(c+d)$ for square columns where one side = c
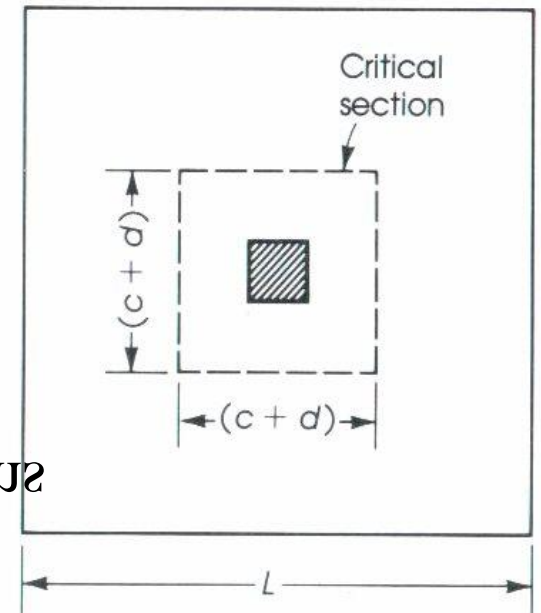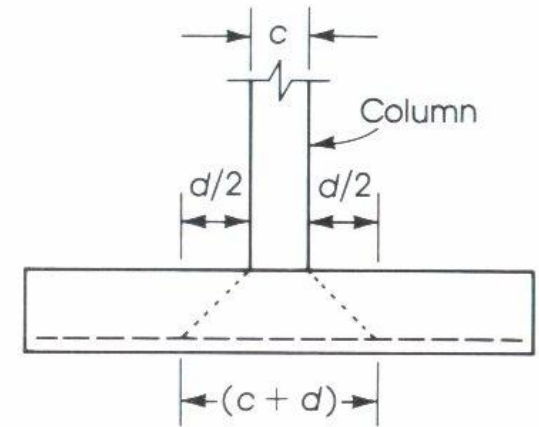
   $b_0 = 2(c_1+d) + 2(c_2+d)$

   for rectangular columns of sides c_1 and c_2.

Design of two-way shear

3. The shear force V_u acts at a section that has a length $b_0 = 4(c+d)$ or $2(c_1+d) + 2(c_2+d)$ and a depth d; the section is subjected to a vertical downward load P_u and vertical upward pressure q_u.

Column

d/2 d/2

(c + d)

Critical section

(c + d)

(c + d)

L

$$V_u = P_u - q_u(c_1 + d)(c_2 + d) \text{ for rectangular columns}$$

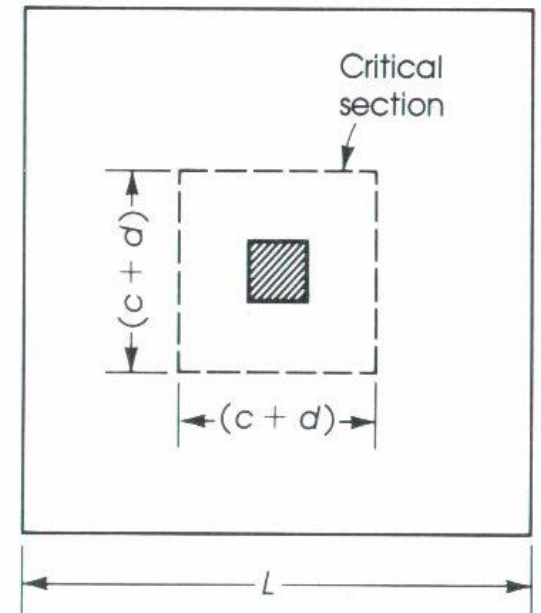$$V_u = P_u - q_u(c + d)^2 \text{ for square columns}$$
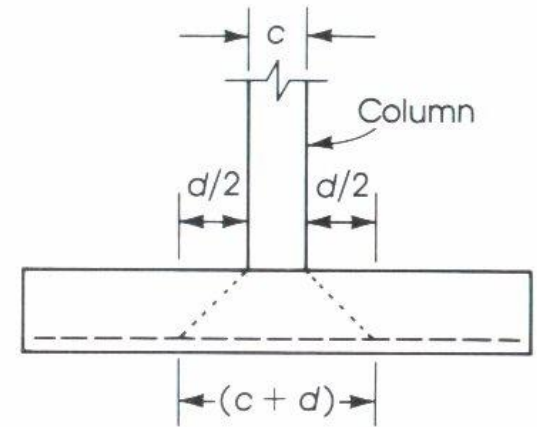
Design of two-way shear

4. Allowable $\phi V_c = 4\phi \sqrt{f_c}\, b_0 d$

Let $V_u = \phi V_c$

$$d = \frac{V_u}{4\phi \sqrt{f_c}\, b_0}$$

If d is not close to the assumed d, revise your assumptions

Design of one-way shear

For footings with bending action in one direction the critical section is located a distance d from face of column

$$\phi V_c = 2\phi \sqrt{f_c}\, b_0 d$$
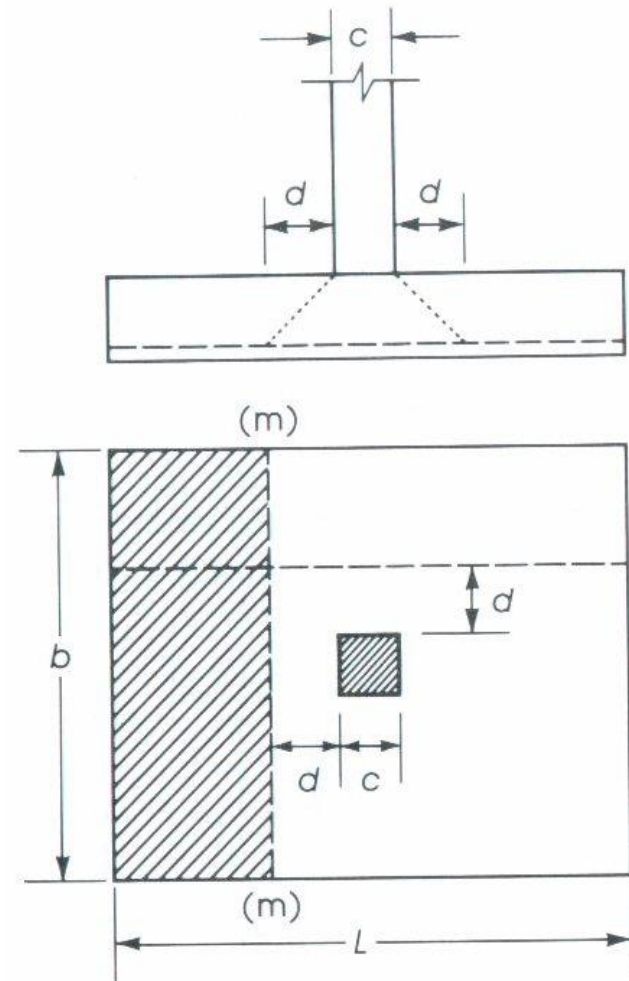
Design of one-way shear

The ultimate shearing force at section m-m can be calculated

$$V_u = q_u \, b \left(\frac{L}{2} - \frac{c}{2} - d \right)$$

If no shear reinforcement is to be used, then d can be checked

Design of one-way shear

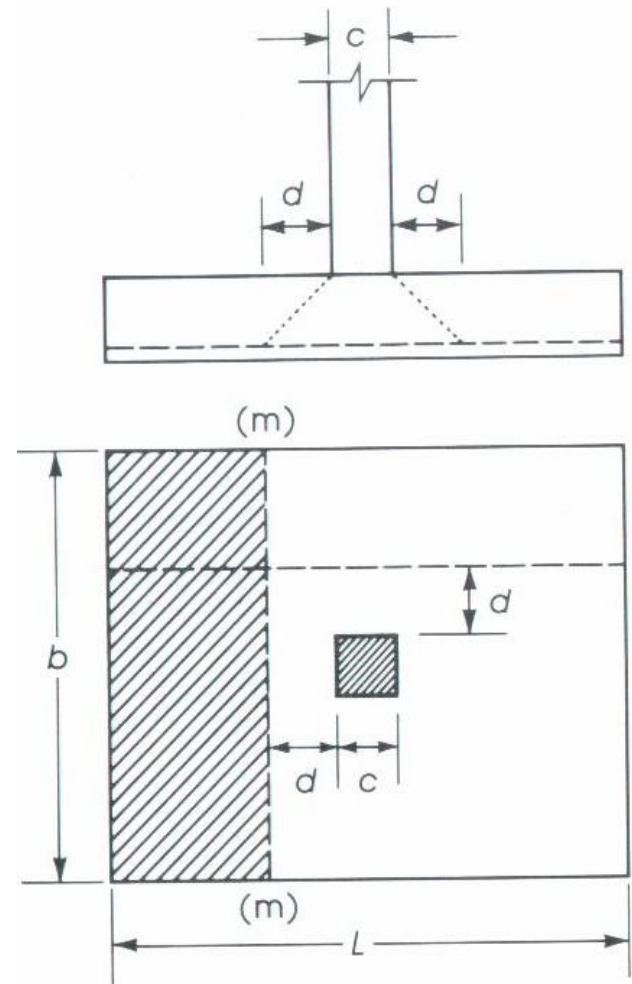If no shear reinforcement is to be used, then d can be checked, assuming $V_u = \phi V_c$

$$d = \frac{V_u}{2\phi\sqrt{f_c}\, b}$$
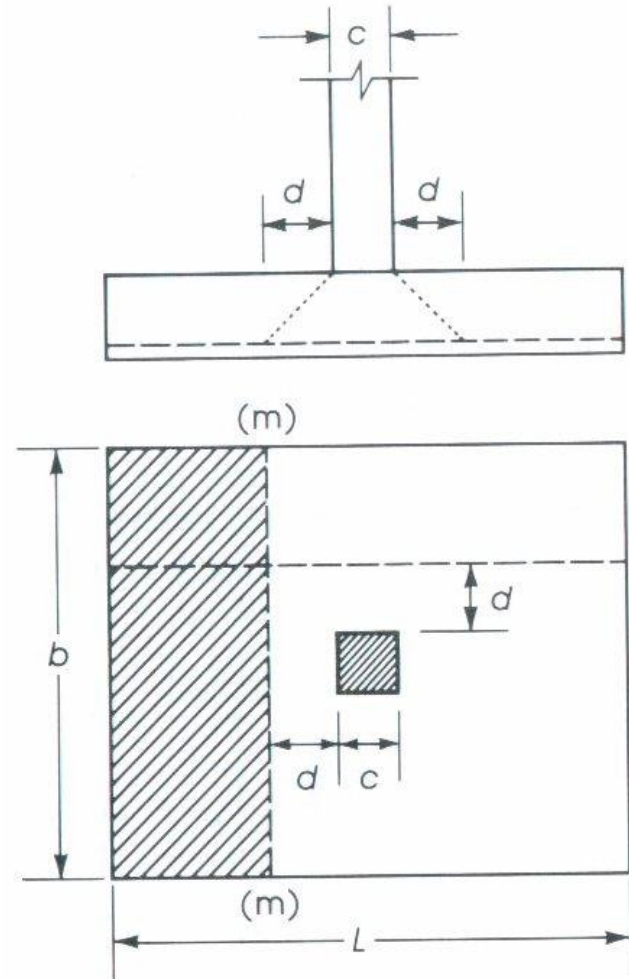
Flexural Strength and Footing reinforcement

The bending moment in each direction of the footing must be checked and the appropriate reinforcement must be provided.

$$A_s = \frac{M_u}{\phi f_y \left(d - \dfrac{a}{2} \right)}$$
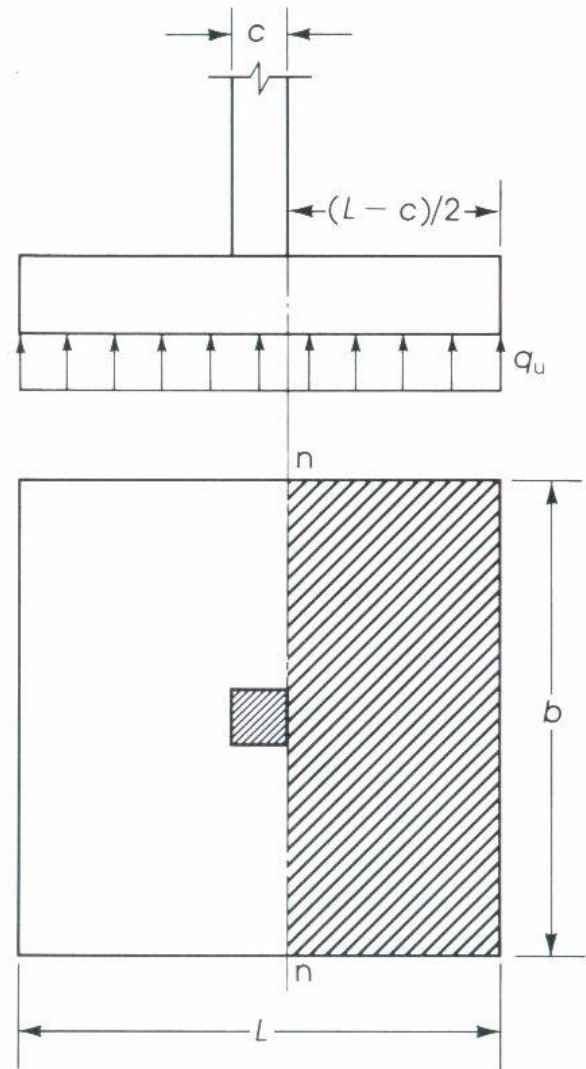
Flexural Strength and Footing reinforcement

Another approach is to calculated $R_u = M_u / bd^2$ and determine the steel percentage required ρ . Determine A_s then check if assumed a is close to calculated a

$$a = \frac{f_y A_s}{0.85 f_c\, b}$$
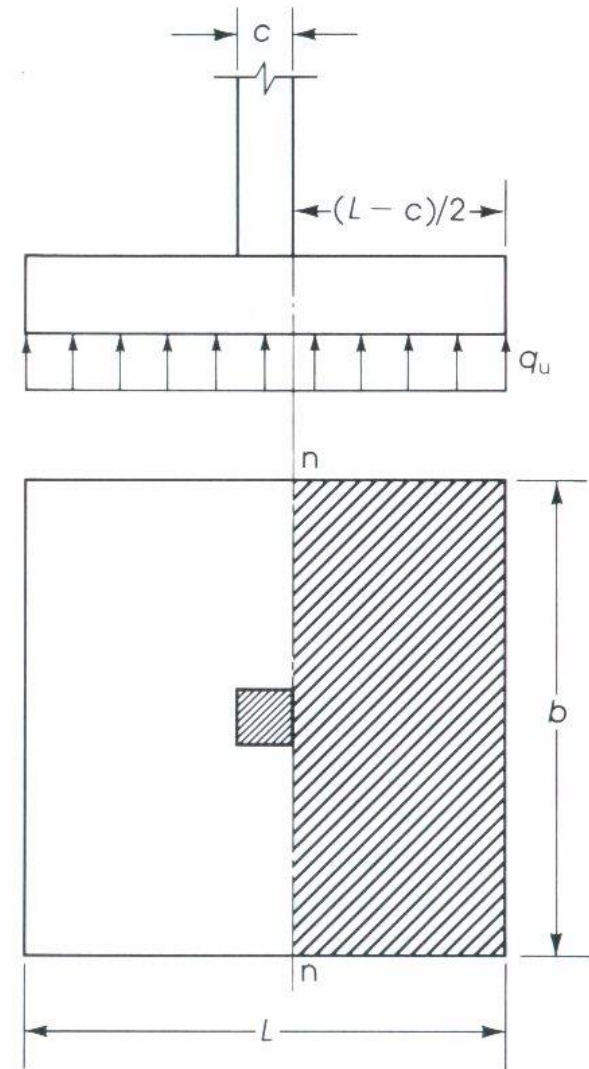
Flexural Strength and Footing reinforcement

The minimum steel percentage required in flexural members is $200/f_y$ with minimum area and maximum spacing of steel bars in the direction of bending shall be as required for shrinkage temperature reinforcement.
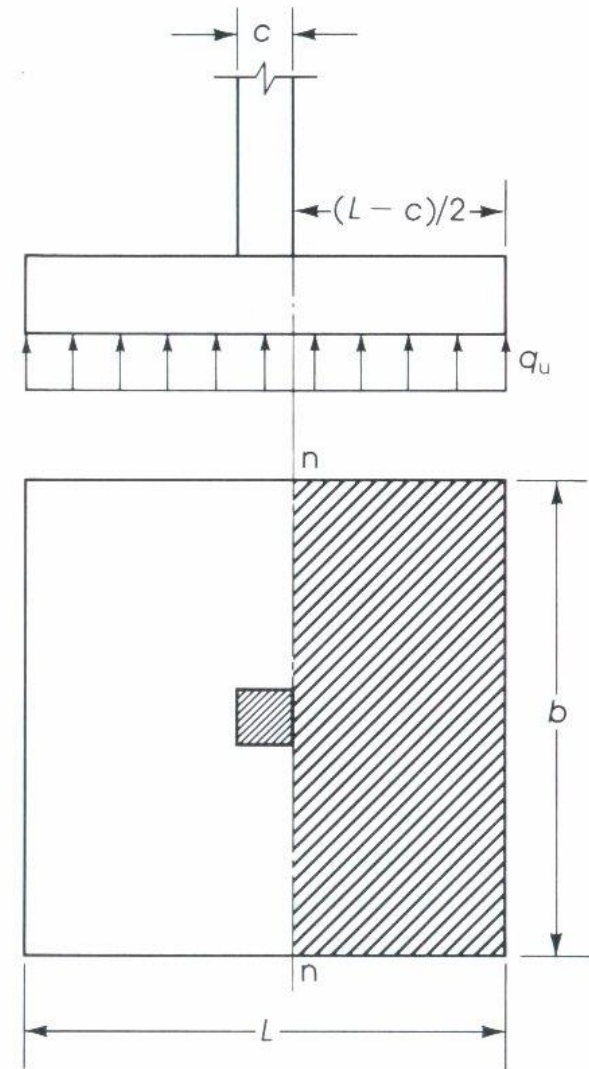
Flexural Strength and Footing reinforcement

The reinforcement in one-way footings and two-way footings must be distributed across the entire width of the footing.
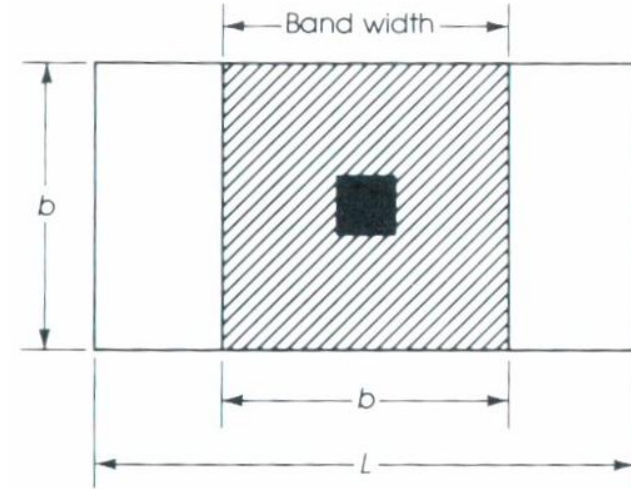
$$\frac{\text{Reinforcement in band width}}{\text{Total reinforcement in short direction}} = \frac{2}{\beta + 1}$$

where

$$\beta = \frac{\text{long side of footing}}{\text{short side of footing}}$$

Bearing Capacity of Column at Base

The loads from the column act on the footing at the base of the column, on an area equal to area of the column cross-section. Compressive forces are transferred to the footing directly by bearing on the concrete. Tensile forces must be resisted by reinforcement, neglecting any contribution by concrete.

Bearing Capacity of Column at Base

Force acting on the concrete at the base of the column must not exceed the bearing strength of the concrete

$$N_1 = \phi\left(0.85 f_c A_1\right)$$

where $\phi = 0.7$ and

A_1 = bearing area of column
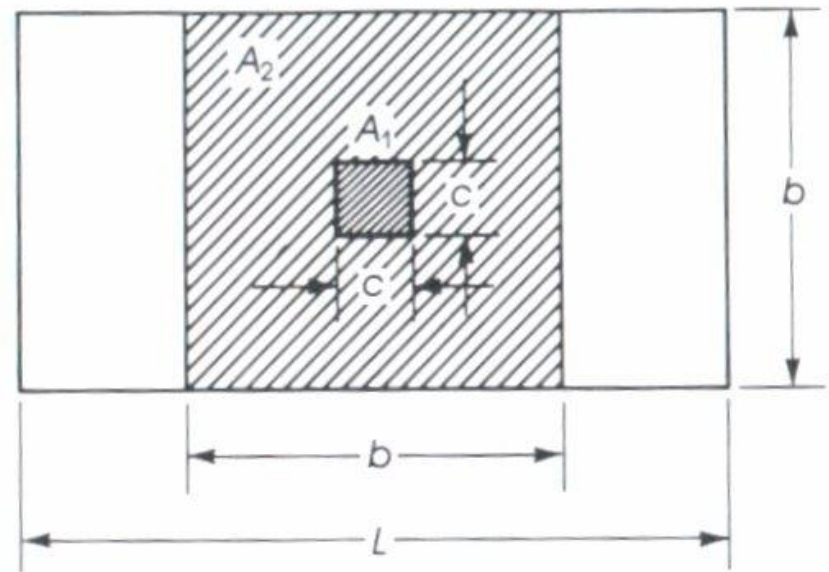
Bearing Capacity of Column at Base

The value of the bearing strength may be multiplied by a factor $\sqrt{A_2 / A_1} \leq 2.0$ for bearing on footing when the supporting surface is wider on all sides than the loaded area.

The modified bearing strength

$$N_2 \leq \phi\left(0.85 f_c A_1\right)\sqrt{A_2 / A_1}$$

$$N_2 \leq 2\phi\left(0.85 f_c A_1\right)$$

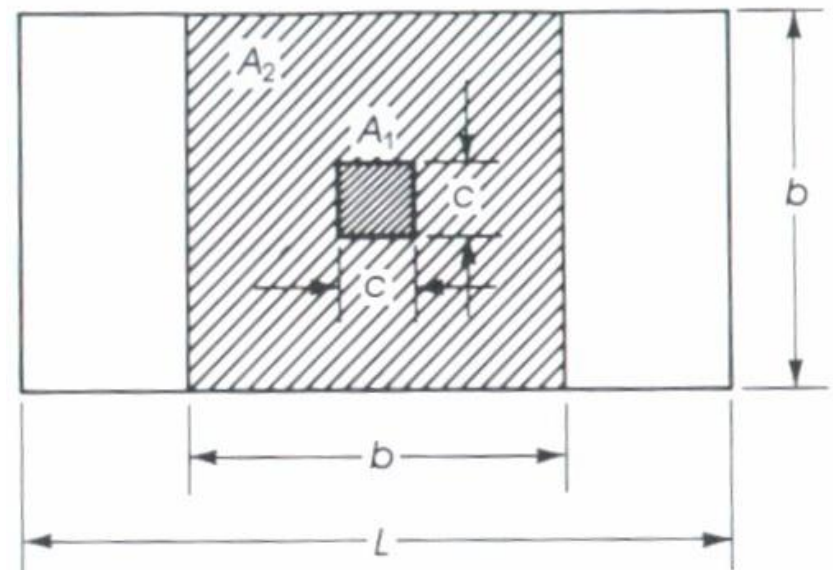# *Dowels in Footings*

A minimum steel ratio $\rho = 0.005$ of the column section as compared to $\rho = 0.01$ as minimum reinforcement for the column itself. The number of dowel bars needed is four these may be placed at the four corners of the column. The dowel bars are usually extended into the footing, bent at the ends, and tied to the main footing reinforcement. The dowel diameter shall not exceed the diameter of the longitudinal bars in the column by more than 0.15 in.

Development length of the Reinforcing Bars

The development length for compression bars was given

$$l_d = 0.02 f_y d_b / \sqrt{f_c}$$

but not less than

$$0.003 f_y d_b \geq 8 \text{ in.}$$

Dowel bars must be checked for proper development length.

Differential Settlement

Footing usually support the following loads:

1. Dead loads from the substructure and superstructure

2. Live load resulting from material or occupancy

3. Weight of material used in back filling

4. Wind loads

General Requirements for Footing Design

1. A site investigation is required to determine the chemical and physical properties of the soil.

2. Determine the magnitude and distribution of loads form the superstructure.

3. Establish the criteria and the tolerance for the total and differential settlements of the structure.

General Requirements for Footing Design

4. Determine the most suitable and economic type of foundation.

5. Determine the depth of the footings below the ground level and the method of excavation.

6. Establish the allowable bearing pressure to be used in design.

General Requirements for Footing Design

7. Determine the pressure distribution beneath the footing based on its width

8. Perform a settlement analysis.