

# Plain & Reinforced Concrete-II

CE-413

## Design of Foundations



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### ***Lecture Goals***

- Footing Classification
- Footing Design
- Footing Examples



# Footings



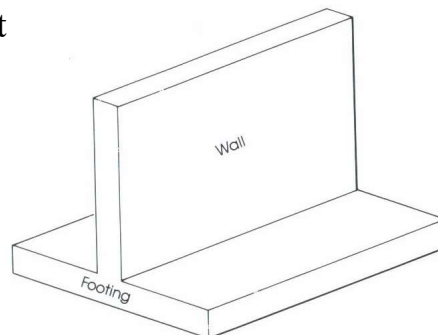
## Definition

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 Footings



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

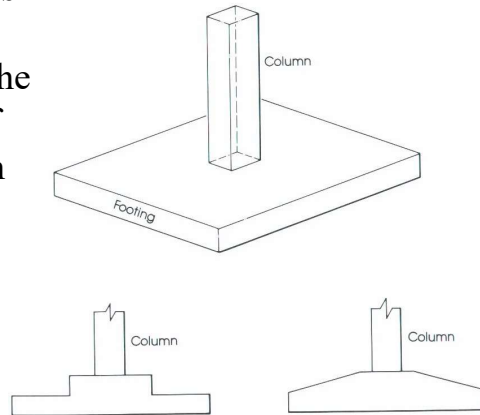


Wall footing.

## Types of Footings



*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.

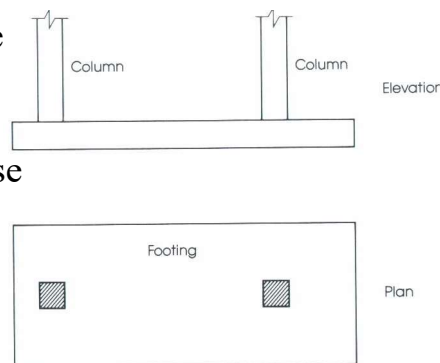


## Types of Footings



*Combined footings* usually support two columns, or three columns not in a row.

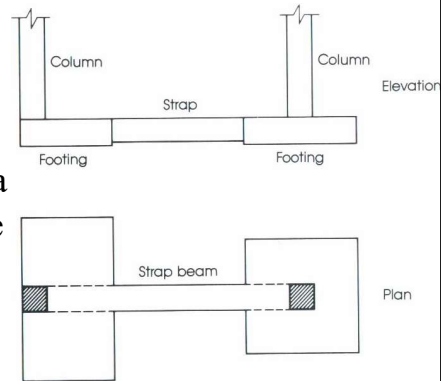
Combined footings are used when two columns are so close that single footings cannot be used or when one column is located at or near a property line.



## Types of Footings



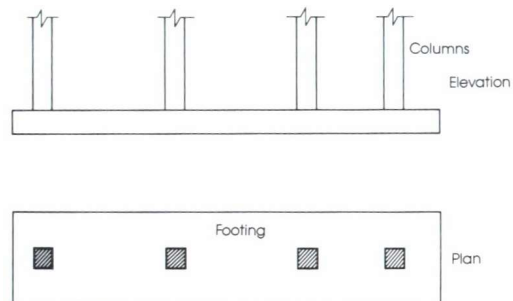
***Cantilever or strap footings*** consist of two single footings connected with a beam or a strap and support two single columns. This type replaces a combined footing and is more economical.



## Types of Footings



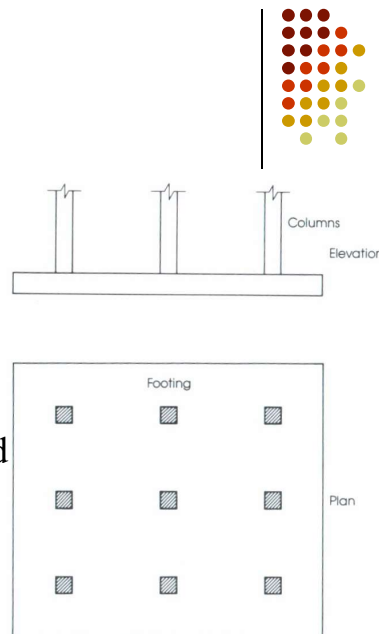
***Continuous footings*** support a row of three or more columns. They have limited width and continue under all columns.



## Types of Footings

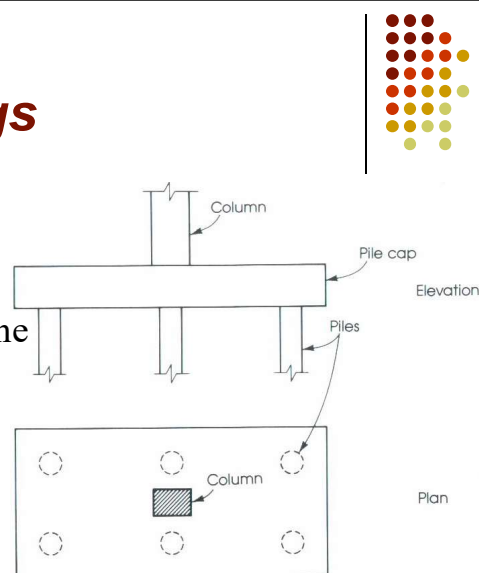
### *Rafted or mat foundation*

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 Footings

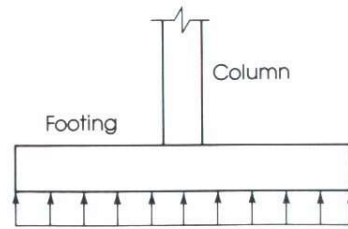
*Pile caps* are thick slabs used to tie a group of piles together to support and transmit column loads to the piles.



## ***Distribution of Soil Pressure***

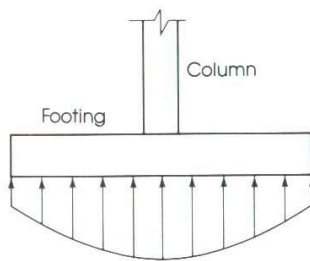


When the column load  $P$  is applied on the centroid of the footing, a uniform pressure is assumed to develop on the soil surface below the footing area.

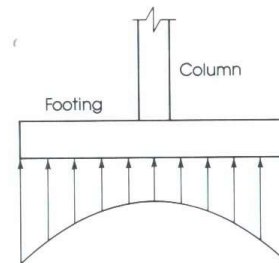


However the actual distribution of the soil is not uniform, but depends on many factors especially the composition of the soil and degree of flexibility of the footing.

## ***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 Footings



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

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

Strength design requirements

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

## ALLOWABLE DISTORTION



The value of distortion normally allowed in design is 1/3300 for  $l/h \leq 3.0$  in sandy soils, 1/2500 for  $l/h \leq 3.0$  in clay.

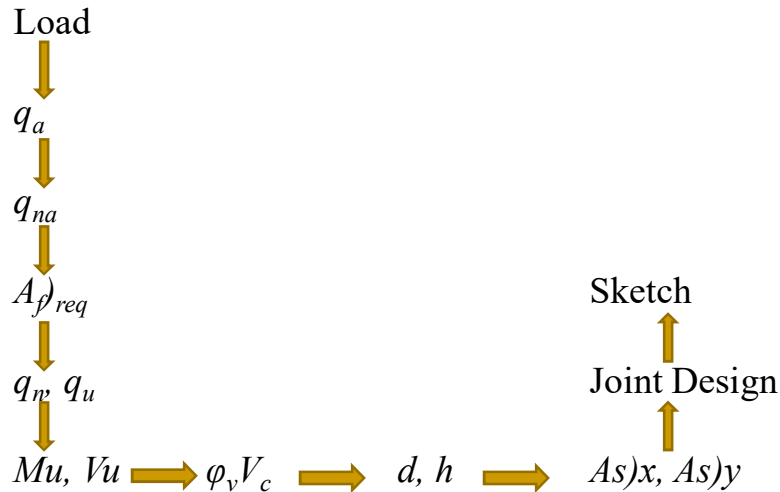
1/2000 for  $l/h \geq 5.0$  in sandy soils, 1/1400 for  $l/h \geq 5.0$  in clay.

where

$l$  = width of the building  
 $h$  = height of the building



## Flow Chart for Design of Footings



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## SHEAR



Footings may fail in shear as a wide beam or due to punching. These are referred to as one-way shear and two-way shear respectively.

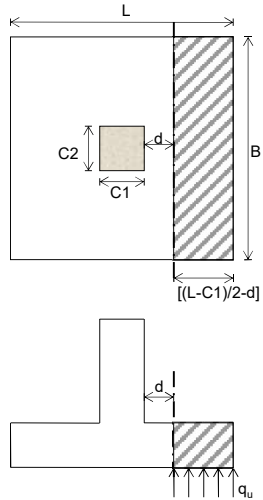
### One-Way Shear or Beam Shear

Critical section for one-way shear is taken at distance "d" from the face of the support.

*If shear is not satisfied no extra shear reinforcement is provided but the depth is increased.*

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## ONE-WAY SHEAR OR BEAM SHEAR (CONT.)



One-way shear is only calculated in longer direction because it will be smaller along the width. Applied one-way shear,  $V_u$  is given as

$$V_u = q_{nu} B \left[ \left( \frac{L - C_1}{2} \right) - d \right]$$

One-way shear strength,  $V_c$  is given as

$$V_c = \frac{1}{6} \sqrt{f'_c} B d$$

Where

$B$  = width of the footing

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## ONE-WAY SHEAR OR BEAM SHEAR (CONT.)



For a footing to be safe against one-way shear following condition should be satisfied

$$V_u \leq \phi_v V_c \quad \text{Where } \Phi_v = 0.75$$

If the above condition is not satisfied calculate revised  $d$  from following

$$d = \frac{V_u}{\phi_v \frac{1}{6} \sqrt{f'_c} B}$$

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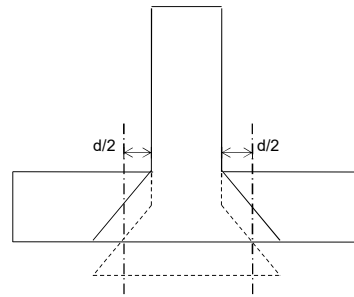
## TWO-WAY SHEAR OR PUNCHING SHEAR



It is a shear which acts all around the perimeter such that column punches down through foundation slab and starts settling.

It is very high in magnitude and most critical aspect in design of column footing.

Punching shear normally controls the depth of the column footing.

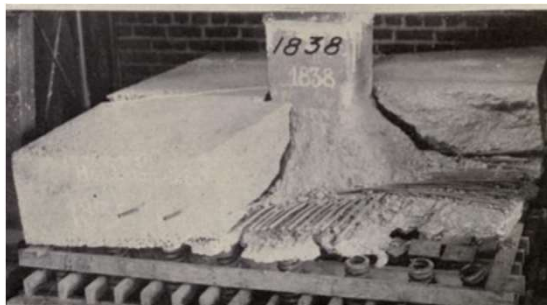


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## TWO-WAY SHEAR OR PUNCHING SHEAR (cont.)



Ref.:  
[ARTHUR N. TALBOT, 1913]



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## TWO-WAY SHEAR OR PUNCHING SHEAR (cont.)



Critical section for two-way shear is taken at a distance “ $d/2$ ” from the face of support in both directions.

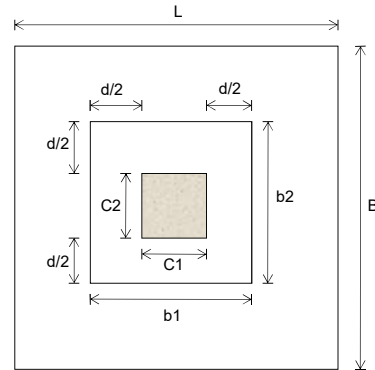
Critical perimeter for two-way shear is denoted by “ $b_o$ ”.

Critical perimeter “ $b_o$ ” is given as

$$b_o = 2(b_1 + b_2)$$

$$b_o = 2[(C_1 + d) + (C_2 + d)]$$

$$b_o = 2(C_1 + C_2 + 2d)$$



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## TWO-WAY SHEAR OR PUNCHING SHEAR (cont.)



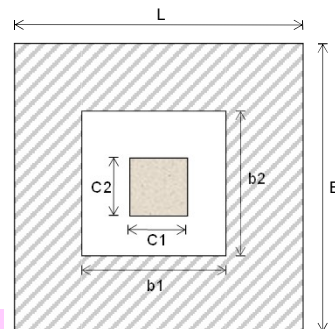
Applied two-way shear “ $V_u$ ” is given as

$$V_u = q_{nu} (\text{Area outside the critical perimeter})$$

$$V_u = q_{nu} (L \times B - b_1 \times b_2)$$

For a footing to be safe against two-way shear following condition should be satisfied

$$V_u \leq \phi_v V_c \quad \text{Where } \Phi_v = 0.75$$



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## TWO-WAY SHEAR OR PUNCHING SHEAR (cont.)



Punching shear strength “ $V_c$ ” is taken as  
Lesser of following

$$1) \quad V_c = \frac{1}{3} \sqrt{f'_c} b_o d \quad \text{Where } b_o \text{ is critical perimeter}$$

$$2) \quad V_c = \frac{1}{12} \left[ 2 + \frac{4}{\beta_c} \right] \sqrt{f'_c} b_o d \quad \text{where } \beta_c = \frac{\text{longer col. side}}{\text{shorter col. side}}$$

$$3) \quad V_c = \frac{1}{12} \left[ \frac{\alpha_s d}{b_o} + 2 \right] \sqrt{f'_c} b_o d$$

Where

$\alpha_s = 40$  for interior column

$\alpha_s = 30$  for exterior column

$\alpha_s = 20$  for corner column

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## BENDING MOMENT AND STEEL REINFORCEMENT



### Critical Section for Moment

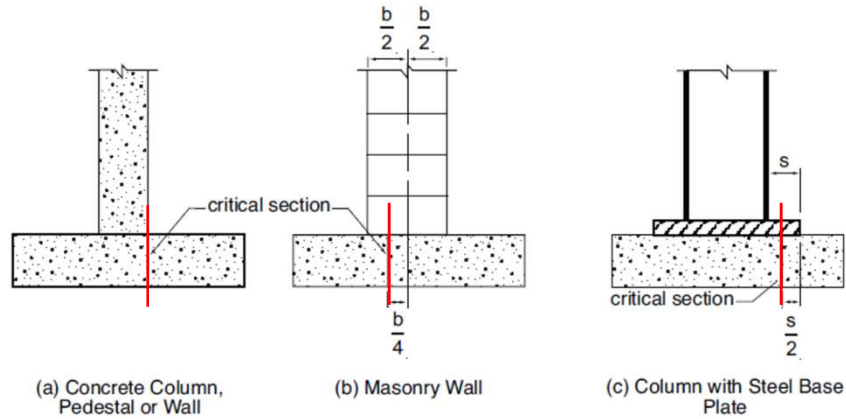
The critical sections for moment are taken as (ACI 15.3 and 15.4.2)

- For footings supporting square or rectangular concrete columns or walls, at the face of the column or wall.
- For footings supporting masonry walls, halfway between the middle and edge of the wall.
- For footing supporting a column with steel base plate, halfway between face of the column and edge of the base plate.

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## BENDING MOMENT AND STEEL REINFORCEMENT

### Critical Section for Moment (cont.)



[Ref.: PCA NOTES on ACI 318-08]

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## BENDING MOMENT AND STEEL REINFORCEMENT

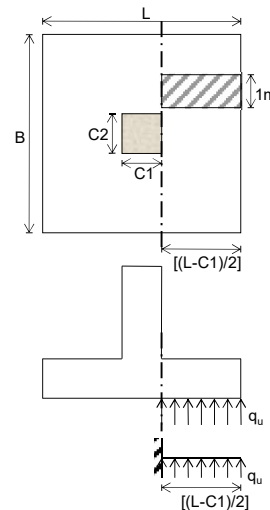
### Design Moment Calculation

Design moment is calculated considering a unit strip of a cantilever fixed at column and free at edges in both directions.

*Design moment along length for unit strip is given as*

$$Mu = q_u \left( \frac{L - C1}{2} \right) \times \frac{1}{2} \left( \frac{L - C1}{2} \right)$$

$$Mu = q_u \times \frac{1}{8} (L - C1)^2$$



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## BENDING MOMENT AND STEEL REINFORCEMENT

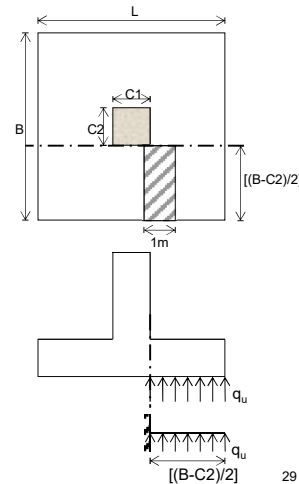


### Design Moment Calculation (cont.)

*Design moment along width for unit strip is given as*

$$M_u = q_u \left( \frac{B - C_2}{2} \right) \times \frac{1}{2} \left( \frac{B - C_2}{2} \right)$$

$$M_u = q_u \times \frac{1}{8} (B - C_2)^2$$



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## BENDING MOMENT AND STEEL REINFORCEMENT



Calculate area of steel corresponding to respective moments.

Minimum flexural reinforcement is given as

$$A_{s_{\min}} = 0.002bh \quad \text{for } f_y = 300 \text{ MPa}$$

$$A_{s_{\min}} = 0.0018bh \quad \text{for } f_y = 420 \text{ MPa}$$

**NOTE:** Maximum spacing must not exceed 450mm.

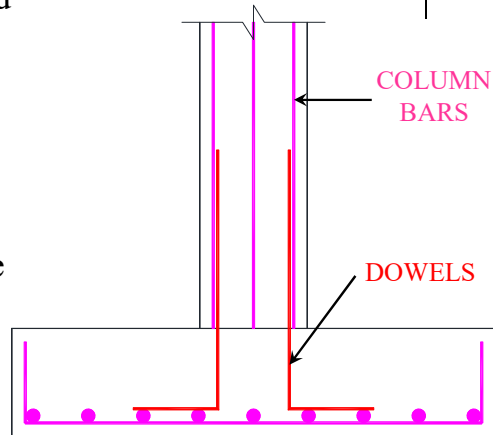
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## FORCE AND MOMENT TRANSFER AT COLUMN BASE



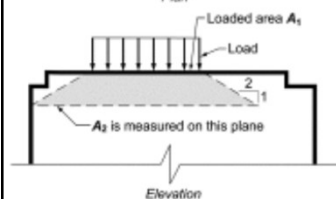
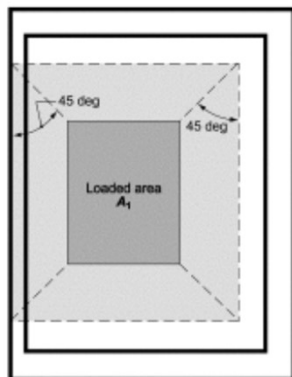
The concentrated load in the columns is transferred to the footing by

1. Direct bearing of the column over the footing (Producing bearing stresses at the interface)
2. By forces in the dowels or column main steel bars that cross the joint.



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## FORCE AND MOMENT TRANSFER AT COLUMN BASE



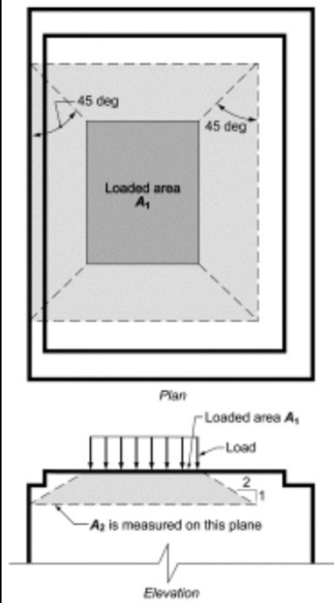
The maximum bearing load on the concrete is defined by ACI 318-14 Sec. 10.14.1 “Design bearing strength on concrete shall not exceed  $\phi(0.85 f_c' A_1)$ , except when the supporting surface is wider on all sides than the loaded area, then the design bearing strength on the loaded area shall be permitted to be multiplied by  $\sqrt{\frac{A_2}{A_1}}$  but not more than 2.”

The loaded area or the area of cross-section of column is denoted by  $A_1$ , whereas, a larger area of footing may be considered effective in resisting the bearing stresses and is denoted by  $A_2$ .

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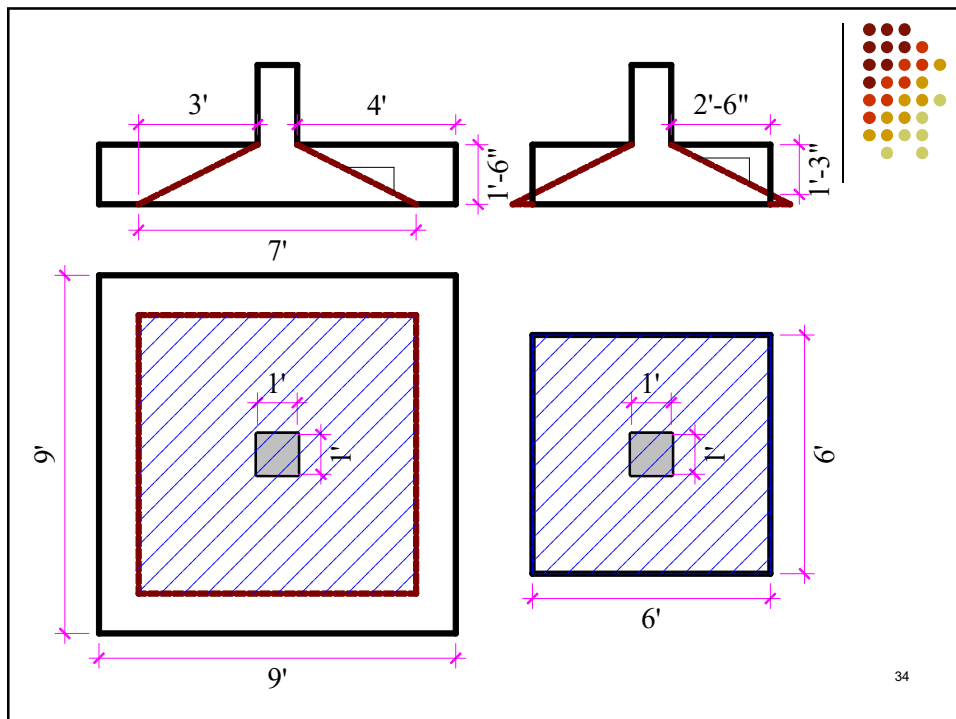


## FORCE AND MOMENT TRANSFER AT COLUMN BASE

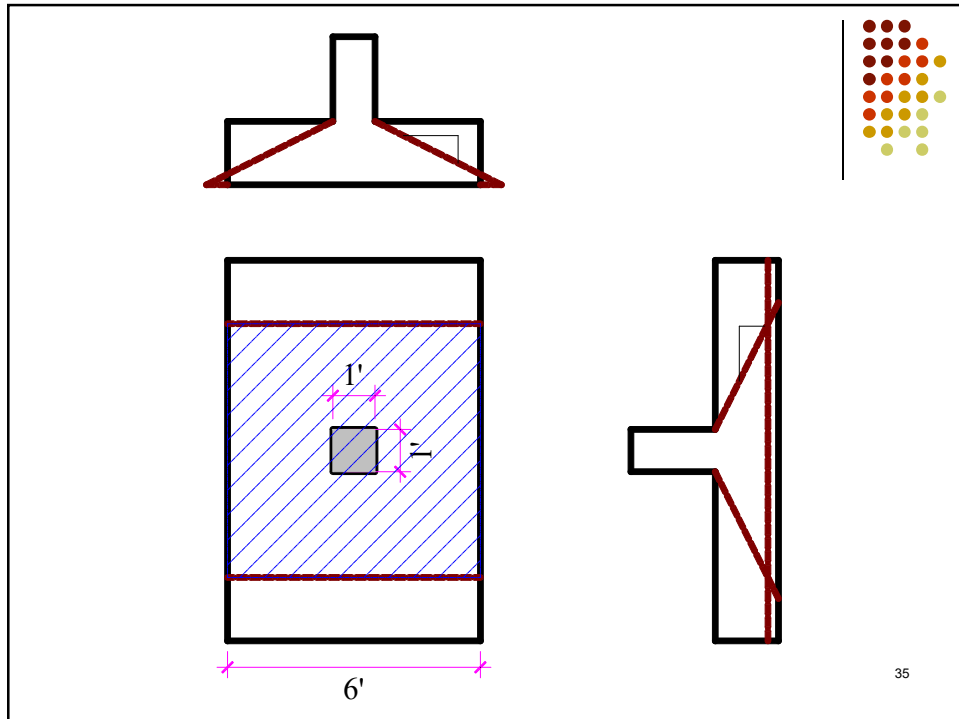


- The area  $A_2$  at a certain depth inside the footing is found by spreading the area  $A_1$  at a slope of lesser of 2 HZ. to 1 Ver. for solid footings and actually available steeper slope on each side.
- The concrete present in larger area  $A_2$  around the loaded area  $A_1$  provides lateral confinement to the concrete and causes increase in the bearing strength.

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### FORCE AND MOMENT TRANSFER AT COLUMN BASE

Bearing strength at the base of the column is given as

$$\phi P_n = \phi(0.85 f_c' A_1) \quad \text{Where } \phi = 0.65$$

Where,  $f_c'$  is the cylinder strength of the column concrete.

Bearing strength at the bottom of the footing is given as

$$\phi P_n = \phi(0.85 f_c' A_1) \sqrt{\frac{A_2}{A_1}} \leq \phi 2(0.85 f_c' A_1)$$

Where,  $f_c'$  is the cylinder strength of the footing concrete.

The above expression is used to check the concrete in the footing just below the column, without dowels having development length beyond this region.

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## FORCE AND MOMENT TRANSFER AT COLUMN BASE



### Dowel Bars

Excess force to be resisted by dowels, having development length beyond the bottom of the footing is

$$\text{Dowel Force} = P_u - \phi P_n$$

Area of steel required for dowels within the footing is

$$A_s = \frac{P_u - \phi P_n}{\phi f_y} \quad \text{where } \phi = 0.65 \quad (\text{ACI 15.8.1.2})$$

A **minimum area** of reinforcement of  **$0.005A_g$**  (but not less than four bars) has to be provided across the interface of the column and footing.  $A_g$  is the gross area of column cross section. (ACI 15.8.2.1)

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## FORCE AND MOMENT TRANSFER AT COLUMN BASE



### Dowel Bars (cont).

However, if some of the column steel is discontinued at the top of footing, the portion of the column just above the footing will be lacking fully developed bars.

The bearing strength of this portion of the column is to be checked. The continuing steel must provide a dowel steel area to develop a force equal to  $P_u - \phi 0.85 f_c' A_g$ .

Area of steel required for dowels within the column is

$$A_s = \frac{P_u - \phi 0.85 f_c' A_g}{\phi f_y} \quad \text{where } \phi = 0.65$$

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## FORCE AND MOMENT TRANSFER AT COLUMN BASE



### Dowel Bars (cont).

Dowels must have diameter less than or equal to No. 35 and must extend into the supported member by a distance equal to larger of

1. Development length in compression of the column main steel bars.
2. Compression splice length of the dowels.

Similarly, these dowels must extend into the footing by a minimum distance equal to the development length of dowels in compression. (ACI 318-11 15.8.2.3)

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## DEVELOPMENT AND SPLICING OF STEEL



### 1. Development Length in Tension

$$l_d = 0.63 \times \frac{f_y}{\sqrt{f_c'}} d_b \geq 300\text{mm} \quad \text{for top bars and } d_b \leq \text{No.20}$$

$$l_d = 0.485 \times \frac{f_y}{\sqrt{f_c'}} d_b \geq 300\text{mm} \quad \text{for bottom bars and } d_b \leq \text{No.20}$$

$$l_d = 0.788 \times \frac{f_y}{\sqrt{f_c'}} d_b \geq 300\text{mm} \quad \text{for top bars and } d_b > \text{No.20}$$

$$l_d = 0.606 \times \frac{f_y}{\sqrt{f_c'}} d_b \geq 300\text{mm} \quad \text{for bottom bars and } d_b > \text{No.20}$$

## DEVELOPMENT AND SPLICING OF STEEL



### 2. Development Length in Compression

$$l_{dc} = 0.24 \frac{f_y}{\sqrt{f_c'}} d_b \geq 200\text{mm} \quad \text{for } f_c' \leq 31\text{MPa}$$

$$l_{dc} = 0.043 f_y d_b \geq 200\text{mm} \quad \text{for } f_c' > 31\text{MPa}$$

Where  
 $d_b$  = Dia of bar

### 3. Tension Splice Length

$$\text{Class B Splice} = 1.3l_d \geq 300\text{mm}$$

Where  $l_d$  = Development length in tension

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## DEVELOPMENT AND SPLICING OF STEEL



### 4. Compression Splice Length

$$\text{Compression splice length} = 0.071 f_y d_b F \geq 300\text{mm} \quad \text{for } f_y \leq 420\text{MPa}$$

$$= (0.13 f_y - 24) d_b F \geq 300\text{mm} \quad \text{for } f_y > 420\text{MPa}$$

where, if  $f_c' > 20\text{MPa}$ ,  $F = 1.0$ , otherwise,  $F = 1.3$

When bars of different diameters are lap spliced in compression, the required splice length is to be taken larger of the development length in compression for the larger diameter bar and splice length for the smaller diameter bar.

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## PROCEDURE FOR DESIGN OF ISOLATED FOOTING



### **Step1:**

Collect all the required information i.e. allowable bearing capacity, depth of footing, type of load coming and decide type of footing.

### **Step2:**

For service DL, LL and net allowable bearing capacity find the size of the footing.

### **Step3:**

Calculate the net factored contact pressure " $q_u$ " at the interface of soil and concrete surface.

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## PROCEDURE FOR DESIGN OF ISOLATED FOOTING



### **Step4:**

Select or assume a suitable thickness of footing satisfying two-way punching shear.

### **Step5:**

Calculate one-way shear in longer direction and check for its capacity.

### **Step6:**

Calculate the moment in shorter and longer direction.

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## PROCEDURE FOR DESIGN OF ISOLATED FOOTING



### Step 7:

Calculate the total amount of steel in shorter and longer direction and find the spacing.

### Step 8:

Check the bearing pressure at the bottom of column.

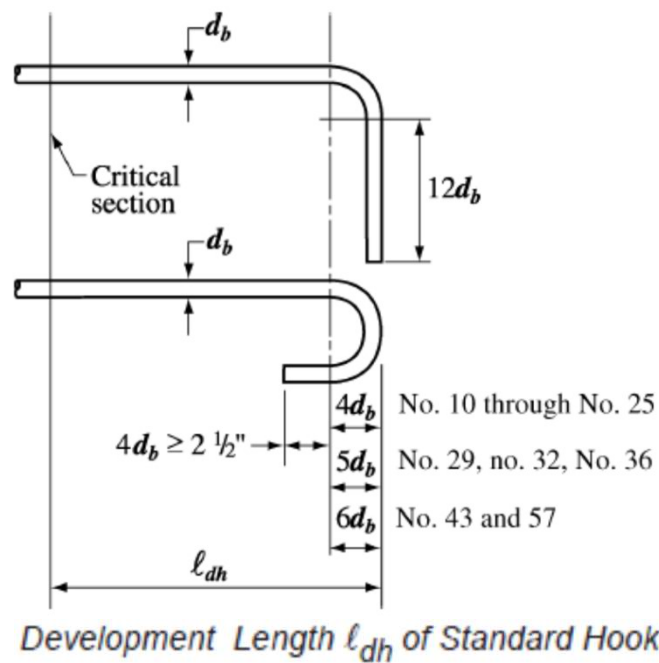
### Step 9:

Check the development length for the steel provided.

### Step 10:

Show reinforcement using neat sketches.

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## FOR RECTANGULAR FOOTINGS



**According to ACI 15.4.4** — In two-way rectangular footings, reinforcement shall be distributed in accordance with **ACI 15.4.4.1 and 15.4.4.2**.

**15.4.4.1** — Reinforcement *in long direction* shall be distributed uniformly across entire width of footing.

**15.4.4.2** — For reinforcement *in short direction*, a portion of the total reinforcement,  $\gamma_s A_s$ , shall be distributed uniformly over a band width (centered on centerline of column or pedestal) equal to the length of short side of footing. Remainder of reinforcement required in short direction,  $(1 - \gamma_s) A_s$ , shall be distributed uniformly outside center band width of footing.

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## FOR RECTANGULAR FOOTINGS



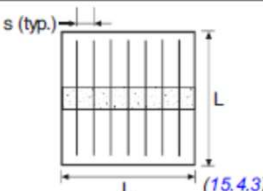
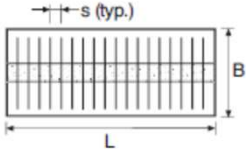
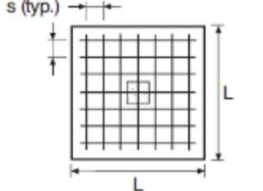
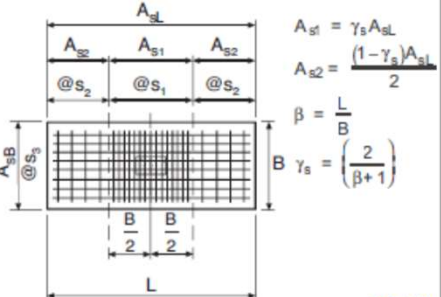
$$\gamma_s = \frac{2}{\beta + 1}$$

Where

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

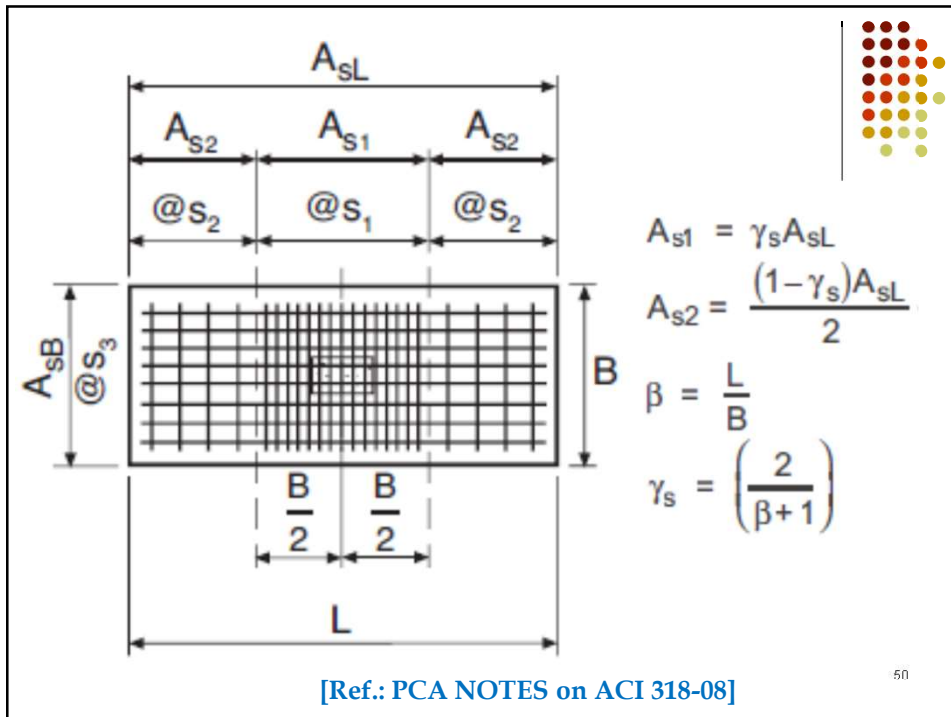
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Footing Type	Square Footing	Rectangular Footing
One-way	 <p>(15.4.3)</p>	 <p>(15.4.3)</p>
Two-way	 <p>(15.4.3)</p>	 <p>(15.4.4)</p> $A_{s1} = \gamma_s A_{sL}$ $A_{s2} = \frac{(1 - \gamma_s) A_{sL}}{2}$ $\beta = \frac{L}{B}$ $\gamma_s = \left( \frac{2}{\beta + 1} \right)$

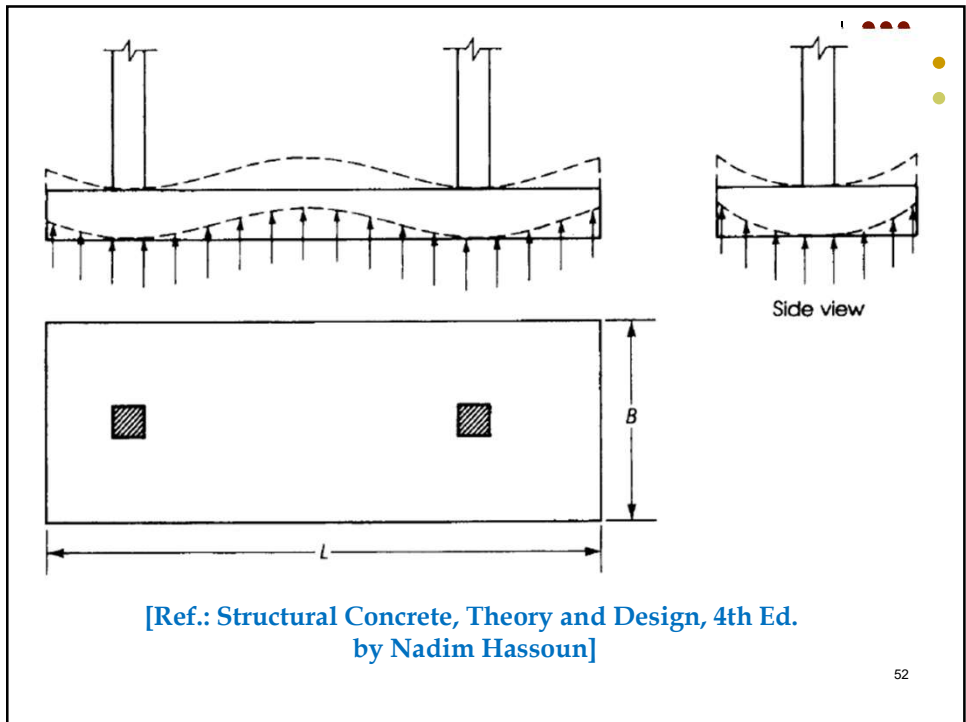
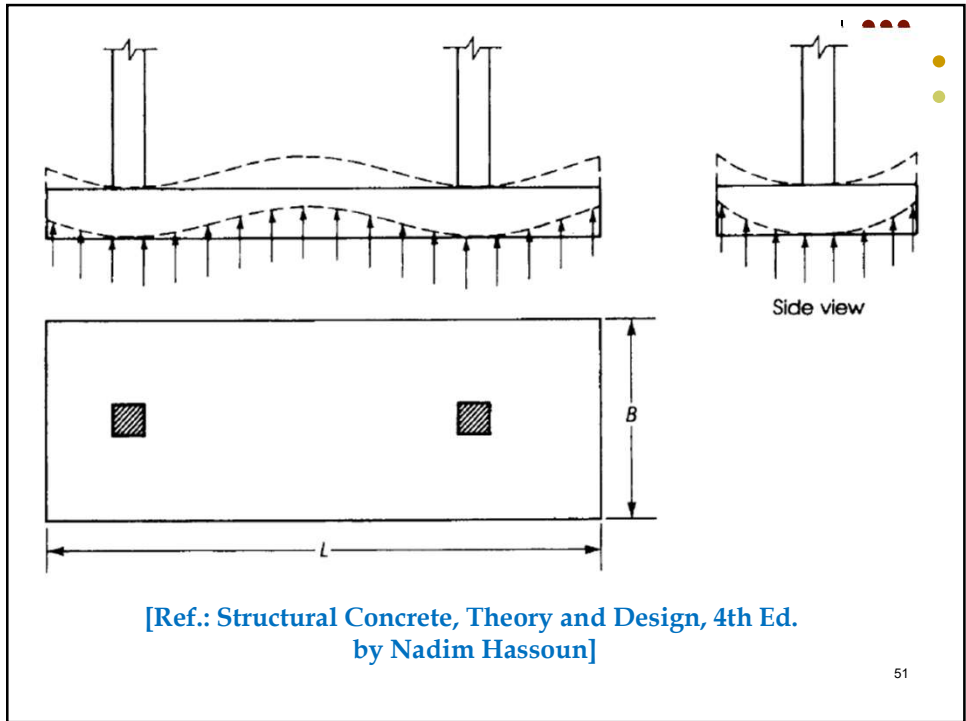
[Ref.: PCA NOTES on ACI 318-08]

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[Ref.: PCA NOTES on ACI 318-08]

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## Problem 1



A 3.9 m × 3.9 m square footing with 825 mm thickness supports a tied rectangular column having dimensions 750 mm × 300 mm reinforced with 6-No. 25 longitudinal bars. For the following data, check force transfer at interface of column and footing. Footing flexural steel is #19@200 c/c (B.W.)

$f_c'$  (column) = 35 MPa, normalweight concrete

$f_c'$  (footing) = 20 MPa, normalweight concrete

$f_y$  = 420 MPa

$P_u$  = 3825 kN

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## Problem 2



For the design conditions given below, check for transfer of force between the column and footing. 300 mm × 300 mm tied reinforced column with 4-No. 43 longitudinal bars.

Footing Size 2800 × 2800 × 450 mm

$f_c'$  = 28 MPa (column and footing),

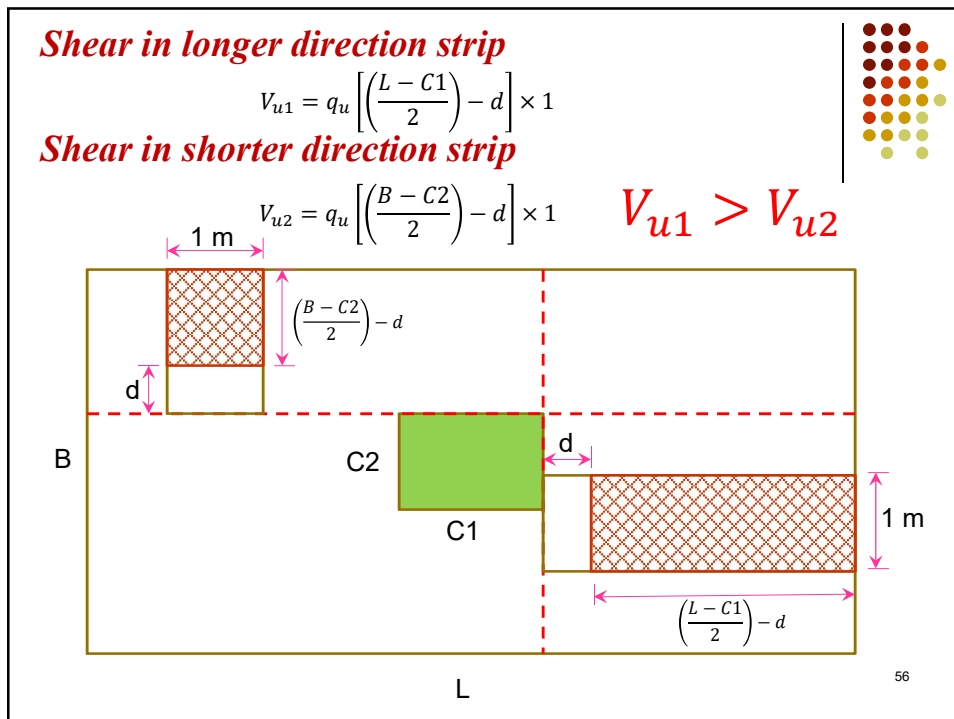
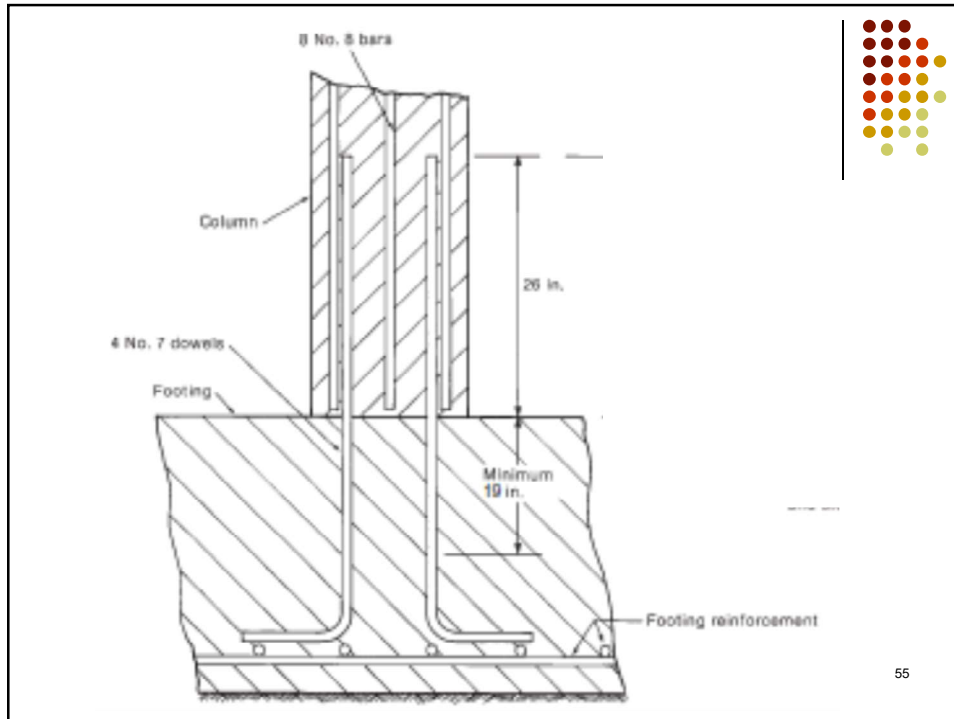
Concrete = Normal weight concrete

$f_y$  = 420 MPa

$P_D$  = 890 kN

$P_L$  = 445 kN

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$$V_u = q_u (\text{Area outside the critical perimeter})$$

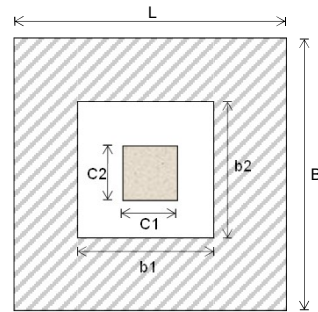


$$V_u = q_u (L \times B - b_1 \times b_2)$$

$$V_u = q_u (L \times B) - q_{mu} (b_1 \times b_2)$$

$$P_u = q_u (L \times B)$$

$$V_u = P_u - q_u (b_1 \times b_2)$$



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**END OF LECTURE**



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