Lecture 09

Design of Wall and Column Footings

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Contents

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Introduction

- The substructure, or foundation, is the part of a structure that is usually placed below the surface of the ground and that transmits the load to the underlying soil or rock.
- Function of a foundation is to transfer the structural loads from a building safely into the ground.
- Foundation is regarded as the most important component of engineered systems.

Types of Foundations

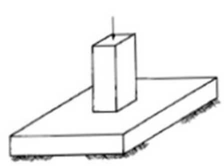
- Foundations can be divided into two broad categories depending on the depth of foundation;

  1. **Shallow Foundations**
     - Load transfer occur at shallower depths.
     - Isolated, Wall, Combined, Mat footings.
  2. **Deep Foundations**
     - Load transfer occur at deeper depths.
     - Piles, drilled piers, drilled caissons

Types of Foundations

- **Shallow Foundations**

  1. **Isolated Column Footing**
     - Isolated column footing carrying a single column is usually called spread footing.

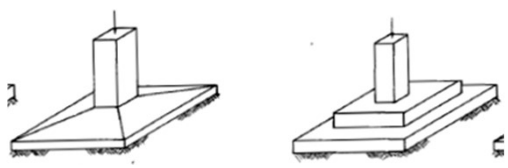


Spread Footing (Ordinary)

Types of Foundations

- **Shallow Foundations**

  1. **Isolated Column Footing**
     - Sometimes spread footings are stepped, or are tapered to save materials.



Spread Footing (Tapered)　　**Spread Footing (Stepped)**

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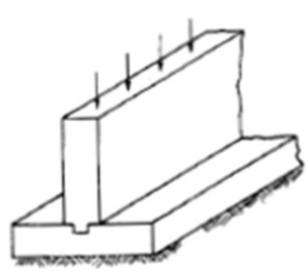
Types of Foundations

- **Shallow Foundations**

  2. **Wall Footing (Strip Footing)**
     - Wall footings or strip footings display essentially one-dimensional action, cantilevering out on each side of the wall.



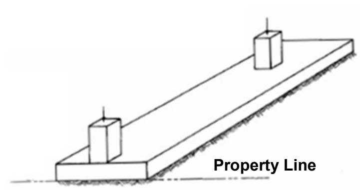
Types of Foundations

- **Shallow Foundations**

3. Combined Footing

- A combined footing is a type of footing supporting two or more than two columns. There are two common configurations of combined footings:

1. Two Column Footing
   - Such a footing is often used when one column is close to a property line.



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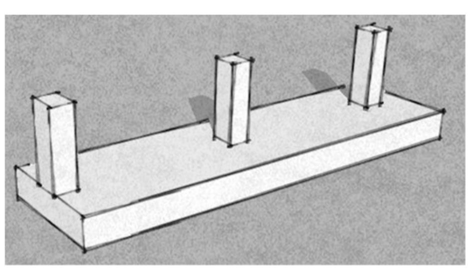
Types of Foundations

- **Shallow Foundations**

3. Combined Footing

2. Column Strip or Multiple Column Footing
   - A combined footing may also be used if the space between adjoining isolated footings is small.



Types of Foundations

- **Shallow Foundations**

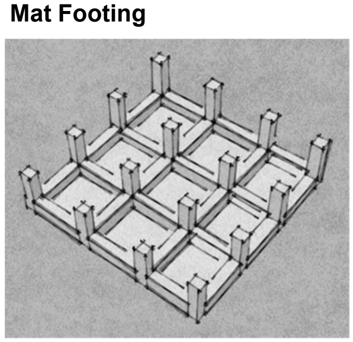
4. Mat Footing

- A mat or raft foundation transfers the loads from all the columns in a building to the underlying soil.
- Mat foundations are used when excessive loads are supported on a limited area or when very weak soils are encountered.
- Mat footings are essentially inverted slabs and hence they have as much configurations as typical slab systems have.

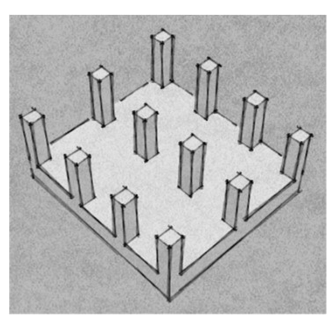
Types of Foundations

- **Shallow Foundations**

5. Mat Footing



Mat Footing with Beams

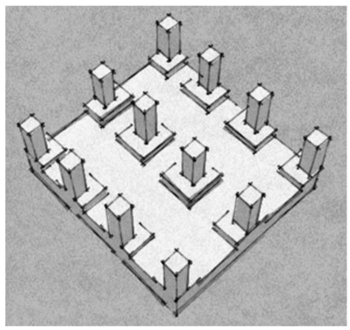


Mat Footing without Beams

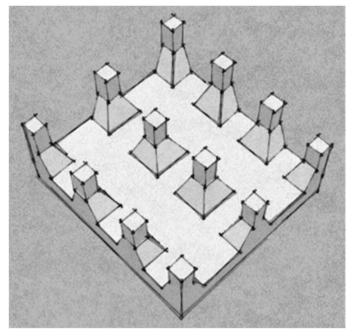
Types of Foundations

- **Shallow Foundations**

  5. Mat Footing



Mat Footing with Drop Panels



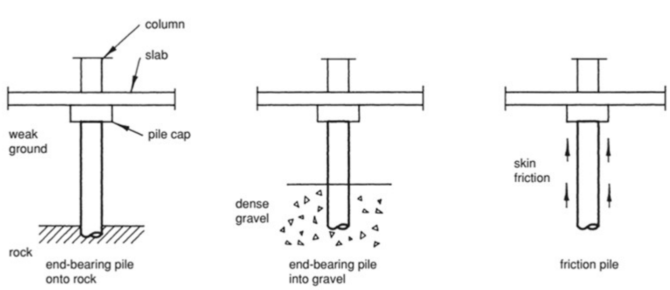
Mat Footing with Column Capitals

Types of Foundations

- **Deep Foundations**

  6. Pile Foundation

  - This type of foundation is essential when the supporting ground consists of structurally unsound layers of materials to large depths.
  - The piles maybe either end bearing, skin friction, or both.



Types of Foundations

- **Choice of Foundation**
  - The choice of foundation type is selected in consultation with geotechnical engineer.
  - Factors to be considered are:
    - Soil strength
    - Soil type
    - Variability of soil type over the area and with increasing depth
    - Susceptibility of the soil and the building to deflections.
    - Construction methods

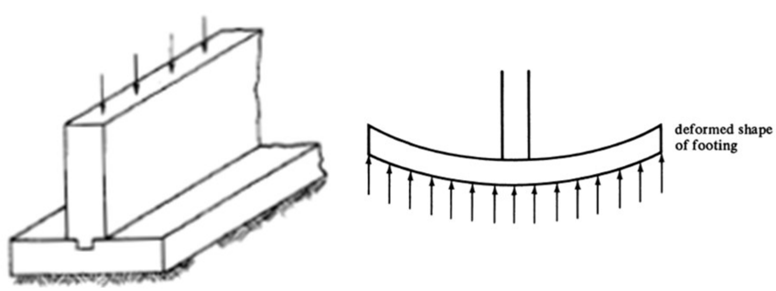
Following types of footing will be discussed in detail in the next slides:

1. **Wall Footing**
2. **Isolated Column Footing**

1. Wall Footing

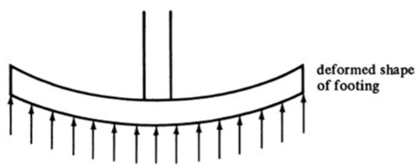
General

- **Behavior:**
  - A wall footing behaves similarly to a cantilever beam, where the cantilever extends out from the wall and is loaded in an upward direction by the soil pressure.



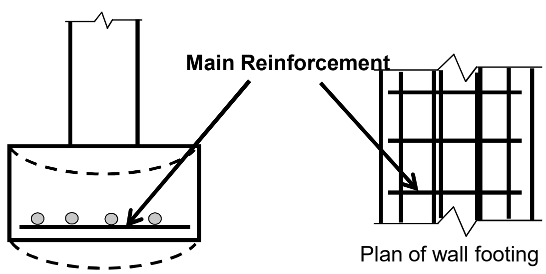
General

- **Behavior:**
  - The wall footing has bending in only one direction, it is generally designated in much the same manner as a one way slab, by considering a typical 12-in. wide strip along the wall length
  - The simple principles of beam action apply to wall footings with only minor modifications.



General

- **Reinforcement:**
  - Main reinforcement for flexure is placed at the bottom of the footing perpendicular to the wall along the short direction, as shown.
  - Temperature reinforcement is placed at the bottom of the footing parallel to the wall along the long direction.



Plan of wall footing

ACI Recommendations

- **ACI Chapter 13**
  - ACI section 13.3 contains provisions for shallow foundations.

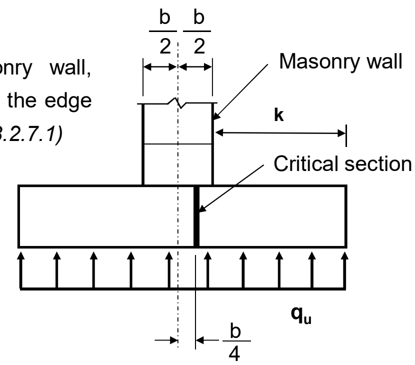
ACI Recommendations

- **Required Footing Area**
  - Footing bearing area is calculated based on unfactored forces or service loads (ACI 13.3.1.1)
  - **Bearing Area, A_{req} = Service Load/ q_e**
  - Where Effective bearing capacity, $q_e = q_a - W$

    (W = Weight of fill + weight of concrete)
- **Bearing pressure for strength design of footing, q_u:**
  - q_u = Factored load on column / A_{req}

ACI Recommendations

- **Design Considerations in Flexure**
  - The maximum factored moment is calculated at critical section.



- For a footing supporting masonry wall, critical section is located between the edge and the middle of the wall. (*ACI 13.2.7.1)*

$$M_u = \frac{q_u\left(k + \frac{b}{4}\right)^2}{2}$$

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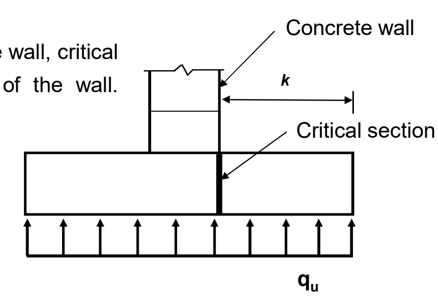
ACI Recommendations

- **Design Considerations in Flexure**
  - The maximum factored moment is calculated at critical section.

- For a footing supporting concrete wall, critical section is located at the face of the wall. (*ACI 13.2.7.1)*



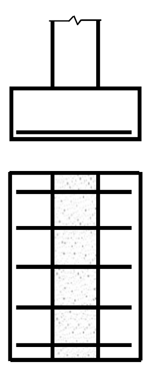
$$M_u = \frac{q_u k^2}{2}$$

ACI Recommendations

- **Design Considerations in Flexure**
  - Minimum reinforcement Requirement, A_{smin} (ACI 7.6.1.1):
    - For less than Grade 60, A_{smin} = 0.0020 bh
    - For Grade 60, A_{smin} = 0.0018 bh
  - Maximum spacing requirement
    - Maximum spacing = 3h or 18″
  - Clear cover
    - Minimum 3″ clear cover must be provided to protect the bars from corrosion.

ACI Recommendations

- **Distribution of Reinforcement**
  - *ACI 13.3.2.2* states that in one-way footings, reinforcement shall be distributed uniformly across entire width of footing.



ACI Recommendations

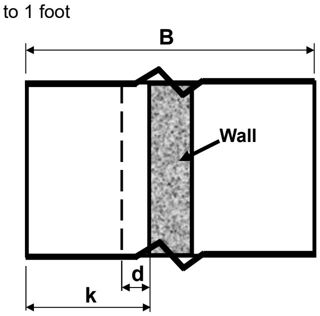
- **Design Considerations in Shear**
  - The behavior of footings in shear is similar to beams.
  - Only one-way shear or beam shear is significant in wall footing. Hence determining critical shear at critical section which is at a distance "d" from the face of support.

ACI Recommendations

- **Design Considerations in Shear**
  - **Calculation of Critical shear at distance 'd'**

$V_u = q_u b(k – d)$

Where b is unit width equal to 1 foot



ACI Recommendations

- **Design Considerations in Shear**
  - **Beam shear capacity (ΦV_c)**

    $\Phi V_c = \Phi 2 \sqrt{f'_c}\, b\, d$

    Where b is unit width equal to 1 foot

If $\Phi V_c < V_u$, the depth of footing is increased instead of providing any shear reinforcement.

Design Procedure

- **The design involves the following steps:**
  - **Step # 01: Estimate the thickness of footing, h**

    Assume thickness h of the footing which must satisfy the shear requirements. (Min. thickness of footing on soil = 9 in.).
  - **Step # 02: Calculate weight of fill + weight of concrete, W**

    $W = W_{conc} + W_{fill}$
  - **Step # 03: Calculate effective bearing capacity, q_e**

    $q_e = q_a - W$ (q_a = Allowable bearing capacity of soil)
  - **Step # 04: Calculate bearing area, A_{req}**

    A_{req} = service load / q_e

Design Procedure

- **The design involves the following steps:**
  - **Step # 05: Calculate design pressure on base of footing due to factored loads, q_u**

    q_u = Factored load / Bearing area

  - **Step # 06: Calculate the critical shear, V_u**

    $V_u = q_u b (k – d)$

  - **Step # 07: Check the shear capacity, $ΦV_c$**

    $ΦV_c = Φ2 \sqrt{f'_c}\, bd$

  $ΦV_c$ shall be equal to or greater than V_u , if $ΦV_c < V_u$, increase thickness of footing

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Design Procedure

- **The design involves the following steps:**
  - **Step # 08: Calculate maximum moment, M_u**

    $$M_u = \frac{q_u\left(k + \frac{b}{4}\right)^2}{2}$$ (Masonry wall) where; b = wall thickness

    $$M_u = \frac{q_u k^2}{2}$$ (Concrete wall)

  - **Step # 09: Calculate steel area, A_s**

    $A_s = M_u / Φf_y (d - a/2)$, $a = 0.2h$

    By trial and success method, find A_s

Design Procedure

- **The design involves the following steps:**
  - **Step # 10: Minimum reinforcement and maximum spacing check**
    - A_{smin} = 0.0020 bh For less than Grade 60
    - A_{smin} = A_{dist} = 0.0018 bh For Grade 60
    - Maximum spacing = 3h or 18″
  - **Step # 11: Bars Spacing/Placement**

    Main Bars: Spacing = A_b x 12 / A_s

    Distribution Bars: Spacing = A_b x 12 / A_s

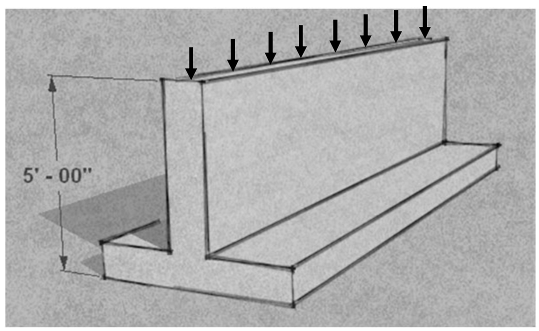
    A_s = Area of steel
    A_b = Area of bar to be used
- **Step # 12: Drafting**

Example 9.1

- **Design Example: Wall Footing**
  - A 12-in thick concrete wall carries a service dead load of 10 kips/ft and a service live load of 12.5 kips/ft. the allowable soil pressure, q_a, is 5000 psf at the level of the base of the footing, which is 5 ft below the final ground surface. Design a wall footing using f'_c = 3000 psi and f_y = 60,000 psi. The density of soil is 120 lb/ft^3.

Example 9.1

- **Design Example: Wall Footing**



Example 9.1

- **Step # 01: Estimate the thickness of footing, h**
  - Assuming a trial thickness, h = 12 in.
  - Effective depth, d = 12 – 3 in. cover – ½ (bar diameter) ≈ 8.5 in.
- **Step # 02: Calculate weight of fill and weight of concrete, W**
  - $W = W_{conc} + W_{fill} = 1 \times 0.15 + 4 \times 0.12 = 0.63$ ksf
- **Step # 03: Calculate effective bearing capacity, q_e**
  - $q_e = q_a - W$

    $q_e = 5 - 0.63 = 4.37$ ksf

Example 9.1

- **Step # 04: Calculate bearing area, A_{req}**
  - A_{req} = service load / q_e

    Service load = 10 + 12.5 = 22.5 kips/ft

    A_{req} = 22.5/4.37 = 5.15 ft^2 per foot of length
  - Trying a footing 5 ft 2 in. wide
- **Step # 05: Calculate design pressure on base of footing due to factored loads, q_u**

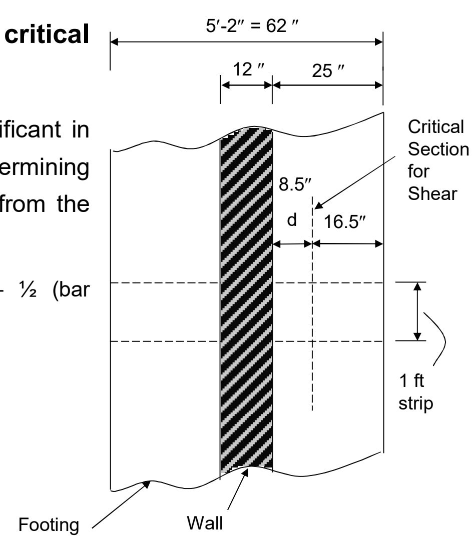
    q_u = Factored load / Bearing area

    Factored loads = 1.2(10) + 1.6(12.5) = 32 kips
  - q_u = 32/5.17 = 6.19 ksf

Example 9.1

- **Step # 06: Calculate the critical shear, V_u**
  - Only one-way shear is significant in wall footing, hence determining critical shear at distance d from the face of support.
    - d = 12 – 3 in. cover – ½ (bar diameter) ≈ 8.5 in.
    - $V_u = q_u b(k – d)$
    - V_u = 6.19 x 1 {(25 – 8.5)/12}

      = 8.51 kips/ft



Example 9.1

- **Step # 07: Check the shear capacity, ΦV_c**
  - **Check the Thickness for Shear**
    - Shear capacity, $\phi V_c = \phi\, 2 \sqrt{f'_c}\, bd$

      $= \{0.75 \times \sqrt{(3000)} \times 12 \times 8.5\}/1000$

      $\phi V_c = 9.50$ kips
    - Since $V_u < \phi V_c$, the footing depth is OK. If V_u is larger or considerably smaller than ϕV_c then chose a new thickness and repeat the previous steps.
    - Using 12 in thick and 5 ft 2 in wide footing.

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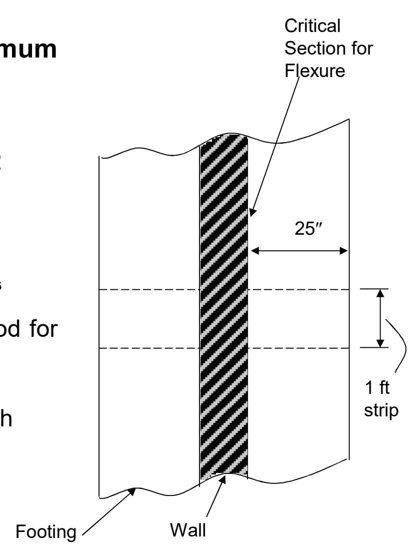
Example 9.1

- **Step # 08: Calculate maximum moment, M_u**
  - $M_u = \frac{q_u k^2}{2}$ = 6.19((25/12)^2 × 1)/2

    = 13.43 ft-kips/ft of length
- **Step # 09: Calculate steel area, A_s**
  - Now, using trial and success method for determining A_s,

    $A_s = M_u / \Phi f_y (d - a/2)$, $a = 0.2h$
  - A_s = 0.390 in^2 per foot.



Example 9.1

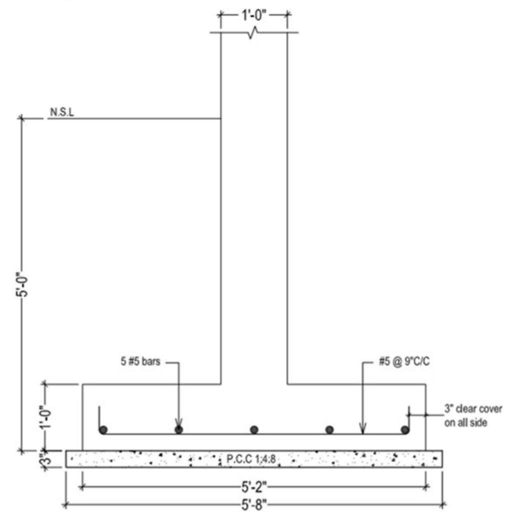
- **Step # 10: Minimum reinforcement and maximum spacing check**
  - Min reinforcement
    - $A_{s,min}$ = 0.0018bh = 0.0018 × 12 × 12 = 0.26 in^2/ft
    - $A_s > A_{smin}$ O.K
  - Max spacing = 3h or 18″ = 3(12) = 36″ or 18″ (OK)

Example 9.1

- **Step # 11: Bars Spacing/Placement**
  - Main Bars: Spacing = A_b x 12 / A_s
    - Using #5 bars, spacing = 0.31 x 12 / 0.390 = 9.53 ≈ 9 in. c/c
  - Distribution Bars:
    - A_{st} = 0.0018bh = 0.0018 × 12 × 12 = 0.26 in^2 ,
    - Using #5 bars, spacing = 0.31 x 12 / 0.26 = 14.3 c/c
    - We will use 5 #5 bars at equal spacing in the total footing width of 62 in. – 3 in. cover on one side – 3 in. cover on other side = 56″

Example 9.1

- **Step # 12: Drafting**



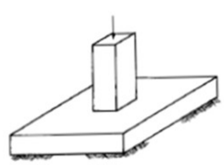
Example 9.2

- **Design Example: Wall Footing**
  - A 12-in thick concrete wall carries a service dead load of 15 kips/ft and a service live load of 10 kips/ft. The allowable soil pressure, q_a, is 5000 psf at the level of the base of the footing, which is 5 ft below the final ground surface. Design a wall footing using f'_c = 3500 psi and f_y = 50,000 psi. The density of soil is 120 lb/ft^3.

2. Isolated Column Footing

General

- **Shape:**
  - Individual column footings are generally square in plan.
  - Rectangular shapes are sometimes used where dimensional limitations exists.



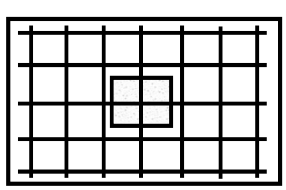
Spread Footing (Ordinary)

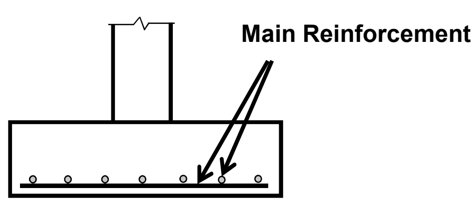
General

- **Behavior:**
  - The footing is a slab that directly supports a column.
  - Isolated footings display essentially two-dimensional action, cantilevering out on both orthogonal sides of the column.
  - The footing is loaded in an upward direction by the soil pressure.
  - Tensile stresses are induced in each direction in the bottom of the footing.

General

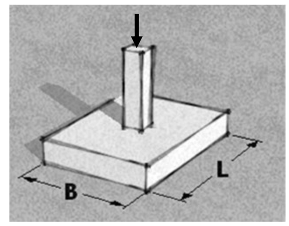
- **Reinforcement:**
  - A spread footing will typically have reinforcement in two orthogonal directions at the bottom of the footing for flexure.





General

- **Required Footing Area**
  - Bearing Area, A_{req} (B x L) = Service Load/ q_e



- **q_u (bearing pressure for strength design of footing):**
  - q_u = factored load on column / A_{req}

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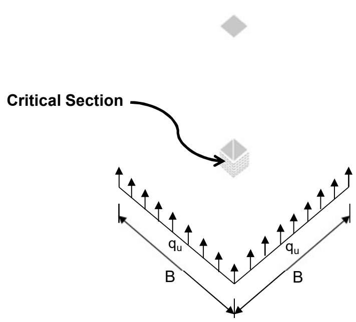
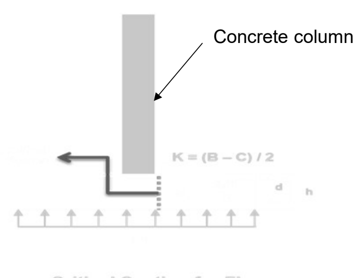
ACI Recommendations

- **Design Considerations in Flexure**
  - The maximum factored moment is calculated at critical section.
    - For an isolated footing, critical section is located at the face of the column.
    - $M_u = q_u B k^2/2$, where; $k = (B – C)/2$



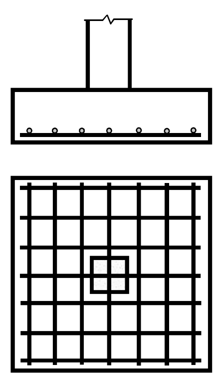


ACI Recommendations

- **Design Considerations in Flexure**
  - Minimum Reinforcement (A_{smin}):
    - $A_{smin} = 0.005Bd_{avg}$
  - Maximum Spacing Requirement (ACI 7.7.2.3):
    - Least of 3h or 18”

ACI Recommendations

- **Distribution of Reinforcement**
  - *ACI 13.3.3.2* states that in two-way square footings, reinforcement shall be distributed uniformly across entire width of footing.



ACI Recommendations

- **Design Considerations in Shear**
  - The footing thickness (depth) is generally established by the shear requirement.
  - The footing is subjected to two-way action. The two-way shear is commonly termed Punching shear, since the column or pedestal tends to punch through the footing, induces stresses around the perimeter of the column.
  - Beam shear is not usually a problem in a isolated footing.

ACI Recommendations

- **Design Considerations in Shear**
  - Two-Way Shear (Punching Shear)
  - The critical section for this two-way shear is taken at d/2 from the face of the column.

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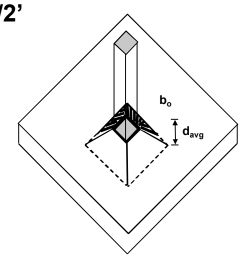
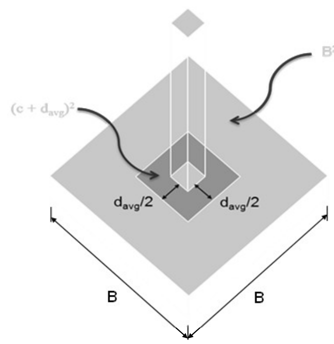
ACI Recommendations

- **Design Considerations in Shear**
  - **Calculation of Critical shear at distance 'd/2'**

$V_{up} = q_uB^2 – q_u(c + d_{avg})^2$

$V_{up} = q_u \{B^2 – (c + d_{avg})^2\}$





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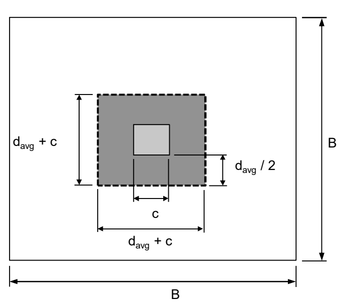
ACI Recommendations

- **Design Considerations in Shear**
  - Punching shear capacity (ΦV_{cp})

$\Phi V_{cp} = \Phi 4 \sqrt{f'_c}\, b_o\, d_{avg}$

Where b_o is Critical Shear Parameter, $b_o = 4 \times (c + d_{avg})$



ACI Recommendations

- **Design Considerations in Shear**

  ΦV_{cp} should be equal to or greater than V_{up}, If $\Phi V_{cp} < V_{up}$, the depth of footing is increased instead of providing any shear reinforcement.

Design Procedure

- **The design involves the following steps:**
  - **Step # 01: Estimate the thickness of footing, h**

    Assume thickness h of the footing which must satisfy the shear requirements. (Min. thickness of footing on soil = 6 in.). Also find 'd'.
  - **Step # 02: Calculate weight of fill + weight of concrete, W**

    $W = W_{conc} + W_{fill}$
  - **Step # 03: Calculate effective bearing capacity, q_e**

    $q_e = q_a - W$ (q_a = Allowable bearing capacity of soil)
  - **Step # 04: Calculate bearing area, A_{req}**

    A_{req} = service load / q_e

Design Procedure

- **The design involves the following steps:**
  - **Step # 05: Calculate critical shear parameter, b_o**

    Critical Perimeter, $b_o = 4 \times (c + d_{avg})$

  - **Step # 06: Calculate design pressure on base of footing due to factored loads, q_u**

    q_u = Factored load / Bearing area

  - **Step # 07: Calculate the punching shear force, V_{up}**

    $V_{up} = q_u \{B^2 – (c + d_{avg})^2\}$

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Design Procedure

- **The design involves the following steps:**
  - **Step # 08: Check the punching shear capacity, ΦV_{cp}**

    $\Phi V_{cp} = \Phi 4 \sqrt{f'_c}\, b_o d_{avg}$ **$\Phi V_{cp} \geq V_{up}$**

    ΦV_{cp} shall be equal to or greater than V_{up}, if $\Phi V_{cp} < V_{up}$, increase thickness of footing

  - **Step # 09: Calculate maximum moment, M_u**

    $M_u = q_u B k^2/2$, where; $k = (B – C)/2$

  - **Step # 10: Calculate steel area, A_s**

    $A_s = M_u / \Phi f_y (d - a/2)$, $a = 0.2d_{avg}$ By trial and success method, find A_s

Design Procedure

- **The design involves the following steps:**
  - **Step # 11: Minimum reinforcement check, A_{smin}**

    A_{smin} = 0.005Bdavg
  - **Step # 12: Bars Placement**
  - **Step # 13: Drafting**

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Example 9.3

- **Design of a square column footing**

A column 18″ square with f_c' = 3 ksi reinforced with 8 #8 bars of f_y = 40 ksi, supports a service load of 81.87 kips (factored load = 103.17 kips). The allowable soil pressure is 2.204 k/ft^2. Design a square footing with base 5′ below surface. Take unit weight of soil as 100 psf.

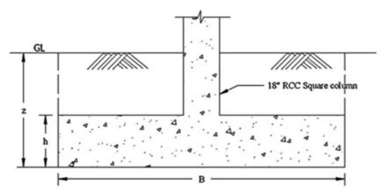
Example 9.3

- **Data Given:**
  - Column size = 18″ × 18″
  - f_c' =3 ksi
  - f_y = 40 ksi
  - q_a = 2.204 k/ft^2
  - Factored load on column = 103.17 kips (Reaction at the support)
  - Service load on column = 81.87 kips (Reaction at the support due to service load)

Example 9.3

- **Step # 01: Estimate the thickness of footing, h**
  - Assume h = 15 in.
  - d_{avg} = h – clear cover – one bar dia

    = 15 – 3 – 1(for #8 bar) = 11 in.



- **Step # 02: Calculate overburden pressure, W**
  - Assume depth of the base of footing from ground level (z) = 5′
  - Weight of fill and concrete footing, $W = W_{conc} + W_{fill}$

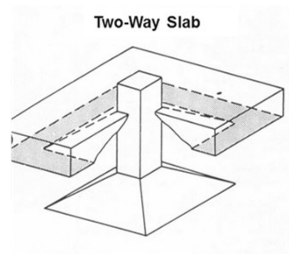
    $W = \gamma_{fill}(z - h) + \gamma_c h$ =100 × (5 – 1.25) +150 × (1.25)

    W = 562.5 psf = 0.5625 ksf

Example 9.3

- **Step # 03: Calculate effective bearing capacity, q_e**
  - Effective bearing capacity, $q_e = q_a - W$

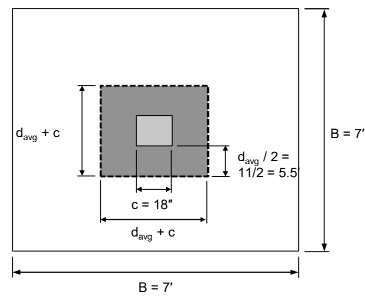
    $= 2.204 - 0.5625 = 1.642$ ksf



- **Step # 04: Calculate bearing area, A_{req}**
  - Bearing area, A_{req} = Service Load/ q_e

    $= 81.87/1.642 = 49.86$ ft^2

  A_{req} = B x B = 49.86 ft^2 => B = 7 ft.



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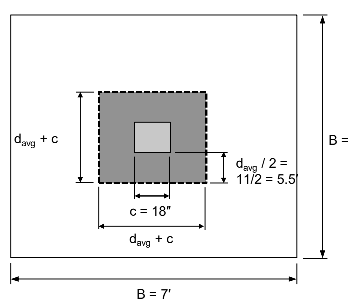
Example 9.3

- **Step # 05: Calculate critical shear parameter, b_o**
  - Critical Perimeter, $b_o = 4 \times (c + d_{avg})$

    $= 4 \times (18 + 11) = 116$ in

- **Step # 06: Calculate design pressure on base of footing due to factored loads, q_u**
  - q_u = factored load on column / A_{req}

  $q_u = 103.17 / (7 \times 7) = 2.105$ ksf



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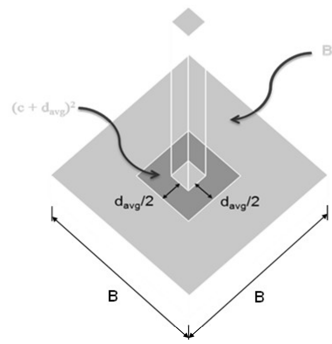
Example 9.3

- **Step # 07: Calculate the punching shear force, V_{up}**
  - $V_{up} = q_u \{B^2 – (c + d_{avg})^2\}$
  - $V_{up} = q_u B^2 – q_u(c + d_{avg})^2$
  - $V_{up} = 2.105 [7^2 – \{(18+11)/12\}^2]$

    $= 90.85$ kip



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Example 9.3

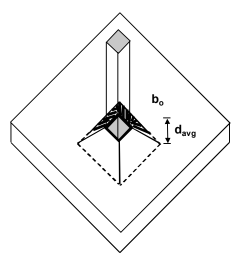
- **Step # 08: Check the punching shear capacity, ΦV_{cp}**
  - $V_{up} = 90.85$ kip

    Punching shear capacity (ΦV_{cp})

    $\Phi V_{cp} = \Phi 4 \sqrt{f'_c}\, b_o d_{avg}$

    $\Phi V_{cp} = 0.75 \times 4 \times \sqrt{3000} \times 116 \times 11/1000$

    $\Phi V_{cp} = 209.66$ k $> V_{up}$, O.K



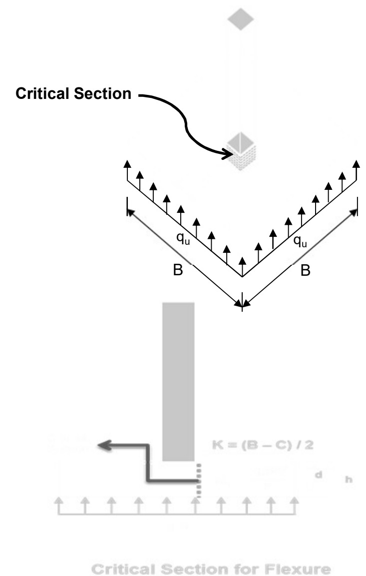
Example 9.3

- **Step # 09: Calculate maximum moment, M_u**
  - $M_u = q_u B k^2/2$
  - k = (B – C)/2 = (7 x 12 –18)/2

    = 33 in = 2.75´
  - M_u = 2.105 × 7 × 2.75 × 2.75/2

    = 55.72 ft-k

    = 668.60 in-kip



Example 9.3

- **Step # 10: Calculate steel area, A_s**
  - M_u = 668.60 kip-in

    $a = 0.2d_{avg}$ = 0.2 × 11 = 2.2″

    $A_s = M_u/ \{\Phi f_y(d_{avg} – a/2)\}$ = 668.60/ {0.9 × 40 × (11 – 2.2/2)} = 1.87 in^2

    $a = A_s f_y/ (0.85 f_c' B)$ = 1.83 × 40/ (0.85 × 3 × 7 × 12) = 0.35″

    After trials, A_s = 1.71 in^2

Example 9.3

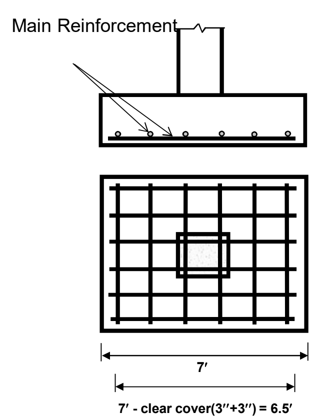
- **Step # 11: Minimum reinforcement check, A_{smin}**

$$A_{smin} = 0.005\ B\ d_{avg} = 4.62\ in^2$$

A_{smin} = 4.62 in^2 so A_{smin} governs

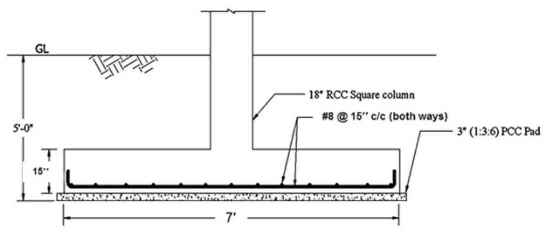
Example 9.3

- **Step # 12: Bars Placement**
  - Now, the spacing can be calculated as follows:
  - Using #8 bars: No. of bars = 4.62/0.79 ≈ 6 bars.
  - Spacing = 6.5 × 12 / 5 = 15 in. c/c
  - Hence 6 bars can be provided in the foundation if they are placed 15 in. c/c (Max. spacing should not exceed 3h or 18 in.)



Example 9.3

- **Step # 13: Drafting**



FOOTING DETAIL

Example 9.4

- **Design of a square column footing**

A column 18″ square with f_c' = 3ksi reinforced with 8 #8 bars of f_y = 60 ksi, supports a dead load of 220 kips and live load of 175 kips. The allowable soil pressure is 5 k/ft^2. Design a square footing with base 5′ below surface. Take unit weight of soil equal to 100 psf.

Assignment # 04

- Submit Example # 9.4 of Lecture 09-Design of Column and Wall Footings in the next class.

References

- Design of Concrete Structures 14th / 15th edition by Nilson, Darwin and Dolan.
- ACI 318-14