CHAPTER 12b

REINFORCED CONCRETE
A Fundamental Approach - Fifth Edition

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FOOTINGS

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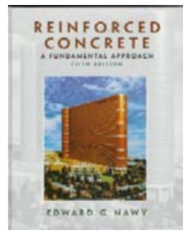

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Individual Reinforced Concrete Footings for Columns

- An individual reinforced concrete footing for a column, also termed an *isolated spread footing*, is probably the most common and most economical of the various types of footings used for structures.
- Individual column footings are generally square in plan.

Individual Reinforced Concrete Footings for Columns

- Rectangular shapes are sometimes used where dimensional limitations exits.
- The footing is a slab that directly supports a column.
- Often, a pedestal is placed between a column and a footing so that the base of the column need be set below the grade.

Individual Reinforced Concrete Footings for Columns

- The footing behavior under concentric load is that of two-way cantilever action extending out from the column or pedestal.
- 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.

Individual Reinforced Concrete Footings for Columns

- Therefore, the footing is reinforced by two layers of steel perpendicular to each other and parallel to the edges.
- The required footing-soil contact area is a function of, and determined by, the allowable soil bearing pressure and the column loads being applied to the footing.

Individual Reinforced Concrete Footings for Columns

- Design Consideration in Flexure
  - The maximum external moment on any section of a footing is determined on the basis of computing the factored moment of the forces acting on the entire area of footing on one side of a vertical plane assumed to pass through the footing.
  - The size and spacing of the footing reinforcing steel is primarily a function of the bending moment induced by the soil pressure.

Individual Reinforced Concrete Footings for Columns

- Design Consideration in Flexure
  - The footing behaves as a cantilever beam in two directions. It is loaded by soil pressure. The fixed end, or critical section for the bending moment, is located as follows:
    1. At the face of the column or pedestal, for a footing supporting a concrete column or pedestal (Figure 5a).
    2. Halfway between the face of the column and the edge of a steel base plate, for a footing supporting a column with a steel plate (Figure 5b).

Individual Reinforced Concrete Footings for Columns

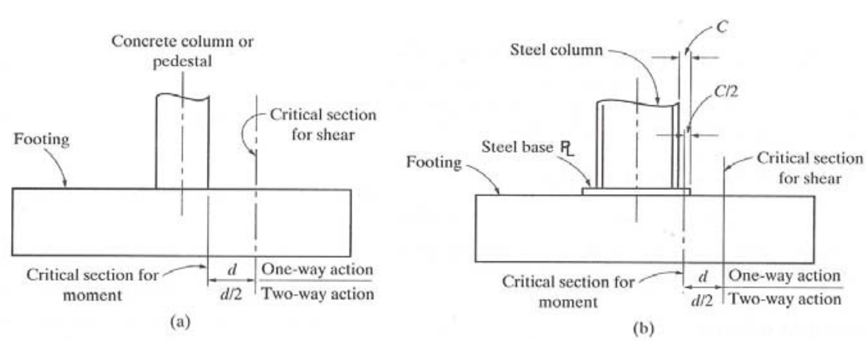


Figure 5. Critical sections for design of reinforced concrete footing supporting columns or pedestals.

Individual Reinforced Concrete Footings for Columns

- Design Consideration in Shear
  - The behavior of footings in shear is not different from that of beams and supported slabs.
  - Consequently, the same principles and expressions as those covered previously in Chapter 6 on shear and diagonal tension are applicable to the shear design of foundations.
  - The shear strength of slabs and footings in vicinity of column reactions are governed by:

Individual Reinforced Concrete Footings for Columns

- Design Consideration in Shear (cont'd)
  - Beam Action
    - The critical section for shear in slabs and footings is assumed to extend in a plane across the entire width and located at a distance d from the face of the concentrated load or reaction area. In this case, if only shear and flexure act, the nominal strength of the section is

$$V_c = 2\sqrt{f'_c}\,b_w d \qquad (5)$$

    - Where b_w = footing width, and V_c must be larger than $V_n = V_u/\phi$ unless shear reinforcement provided

Individual Reinforced Concrete Footings for Columns

- Design Consideration in Shear (cont'd)
  - Two-way Action
    - Since the footing is subject to two-way action, two different types of shear strength must be considered: two-way shear and one-way shear.
    - The footing thickness (depth) is generally established by the shear requirement.
    - 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 or pedestal.

Individual Reinforced Concrete Footings for Columns

- Design Consideration in Shear (cont'd)
  - Two-way Action (cont'd)
    - The critical section for this two-way shear is taken perpendicular to the plane of the footing and located so that the perimeter b_0 is a minimum but does not come closer to the edge of the column or pedestal than one-half the effective depth of the footing.
    - Maximum allowable nominal shear strength is the smallest of

$$V_c = \left(2 + \frac{4}{\beta_c}\right)\sqrt{f'_c}\,b_0 d \qquad (6a)$$

Individual Reinforced Concrete Footings for Columns

- Design Consideration in Shear (cont'd)
  - Two-way Action (cont'd)

$$V_c = \left(\frac{\alpha_s d}{b_0} + 2\right)\sqrt{f'_c}\, b_0 d \qquad (6b)$$

$$V_c = 4\sqrt{f'_c}\, b_0 d \qquad (6c)$$

β_c = ratio of long side c_l/short side c_s of concentrated load or reaction area
b_0 = perimeter of the critical section, i.e., length of idealized failure plane
α_s = 40 for interior columns, 30 for edge columns, and 20 for corner columns

Individual Reinforced Concrete Footings for Columns

- Design Consideration in Shear (cont'd)
  - Two-way Action (cont'd)
    - In cases of both one-and two-way action, if shear reinforcement consisting of bars or wires is used, then

$$V_n = V_c + V_s \le 6\sqrt{f'_c}\, b_0 d \qquad (6c)$$

    - Where V_c as given by Eq. 5. It worthwhile to keep in mind that in most footing slabs, the use of shear reinforcement is not popular, due to practical considerations and the difficulty of holding the shear reinforcement in position.

Individual Reinforced Concrete Footings for Columns

- Design Consideration in Shear (cont'd)
  - Transfer of Load from Column into Footing
    - All loads applied to a column must be transferred to the top of the footing (through a pedestal, if there is one) by compression in the concrete, by reinforcement, or by both.
    - The permissible bearing stress on the actual area of the column base or footing top area of contact is

$$f_b = \phi(0.85 f_c') \approx 0.60 f_c' \qquad \text{where } \phi = 0.70 \qquad (7)$$

Individual Reinforced Concrete Footings for Columns

- Design Consideration in Shear (cont'd)
  - Transfer of Load from Column into Footing
    - As the footing supporting surface is wider on all sides than the loaded area, the Code allows the design bearing strength on the loaded area to multiplied by $\sqrt{A_2 / A_1}$, but this value cannot exceed 2.0.
    - A_1 is the loaded area and A_2 is the maximum area of the supporting surface that geometrically similar and concentric with the loaded area.

Individual Reinforced Concrete Footings for Columns

- Design Consideration in Shear (cont'd)
  - Transfer of Load from Column into Footing
    - 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 the footing even when the concrete bearing strength is not exceeded, A_g (in^2) being the gross area of the column cross section.
    - Lateral forces due to horizontal normal loads, wind, or earthquake can be resisted by shear-friction reinforcement, as described in Ch. 6, Sec. 10.

Individual Reinforced Concrete Footings for Columns

- Square Reinforced Concrete Footing
  - In this type of footing, the reinforcement should be uniformly distributed over the width of the footing in each direction.
  - Since the bending moment is the same in each direction, the reinforcing bar size and spacing should be the same in each direction.
  - However in reality, the effective depth is not the same in both directions.

Individual Reinforced Concrete Footings for Columns

- Square Reinforced Concrete Footing
  - It is common practice to use the same average effective depth for design computations for both directions.
  - It is also common practice to assume that the minimum tensile reinforcement for beams is applicable to two-way footings for each of the two directions, unless the reinforcement provided is one-third greater than required.

Individual Reinforced Concrete Footings for Columns

- Square Reinforced Concrete Footing
  - The minimum tensile reinforcement is determined from

$$A_{s,\min} = \frac{3\sqrt{f_c'}}{f_y} b_w d \geq \frac{200}{f_y} b_w d \qquad (8)$$

  - The use of a minimum reinforcement equal to that required for shrinkage and temperature steel in structural slabs of uniform thickness.
  - This will always be somewhat less than required by $A_{s,\min}$.

Individual Reinforced Concrete Footings for Columns

- Example 4

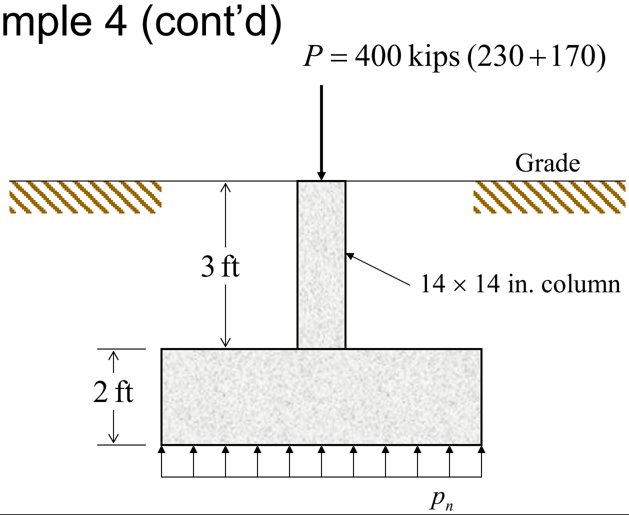
  Design the footing thickness and reinforcement distribution for the isolated square footing of Example 3 if the total load P = 400 kips comprises 230 kips dead load and 170 kips live load. Given:

  $$f'_c = 3000 \text{ psi, normal-weight concrete (footing)}$$
  $$f'_c = 5500 \text{ psi in column}$$
  $$f_y = 60{,}000 \text{ psi}$$

Check solution in Ex. 12.3 Text.

Individual Reinforced Concrete Footings for Columns

- Example 4 (cont'd)



Individual Reinforced Concrete Footings for Columns

- Rectangular Reinforced Concrete Footings
  - Rectangular footings are generally used where space limitations require it.
  - The design of these footings is similar to that of the square footing with the one major exception that each direction must be investigated independently.
  - Shear is checked for two-way action in the normal way, but for one-way action, it is checked across the shorter side only

Individual Reinforced Concrete Footings for Columns

- Rectangular Reinforced Concrete Footings
  - In two-way rectangular footing supporting one column, the bending moment in the short direction is taken as equivalent to the bending moment in the long direction.
  - The distribution of reinforcement differs in the long and short directions.
  - The effective depth is assumed without meaningful loss of accuracy to be equal in both the short and long directions.

Individual Reinforced Concrete Footings for Columns

- Rectangular Reinforced Concrete Footings
  – The following is the recommended reinforcement distributions:
    1. Reinforcement in the long direction is to be uniformly distributed across the entire width of the footing.
    2. For reinforcement in the short direction, a central band (Fig. 6) of width equal to the width of footing in the short direction shall contain a major portion of the reinforcement total areas as in the following

Individual Reinforced Concrete Footings for Columns

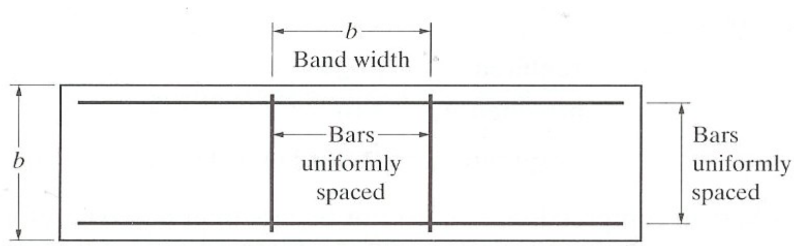


Figure 6. Rectangular Footing Plan.

Individual Reinforced Concrete Footings for Columns

- Rectangular Reinforced Concrete Footings
  - Equation uniformly distributed along the band width

$$\frac{\text{reinforcement in band width}}{\text{total reinforcement in short direction, } A_s} = \frac{2}{\beta + 1} \qquad (9)$$

  - Where β = ratio of long to short side of footing. The remainder of the reinforcement required in the short direction is uniformly distributed outside the center band of the footing.

Individual Reinforced Concrete Footings for Columns

- Rectangular Reinforced Concrete Footings
  - In all cases, the depth of the footing above the reinforcement has to be at least 6 in. for footings on soil and at 12 in. for footings on piles (footings on piles must always be reinforced).
  - A practical depth for column footings should not be less than 9 in.

Individual Reinforced Concrete Footings for Columns

- Example 5

  Determine the size and distribution of the bending reinforcement of an isolated rectangular footing subjected to concentric factored column load P_u = 680 kips and having an area 10 ft × 15 ft. Given:

  $f'_c = 3000$ psi, normal-weight concrete (footing)

  $f_y = 60{,}000$ psi

  column size = 14 in. × 18 in.

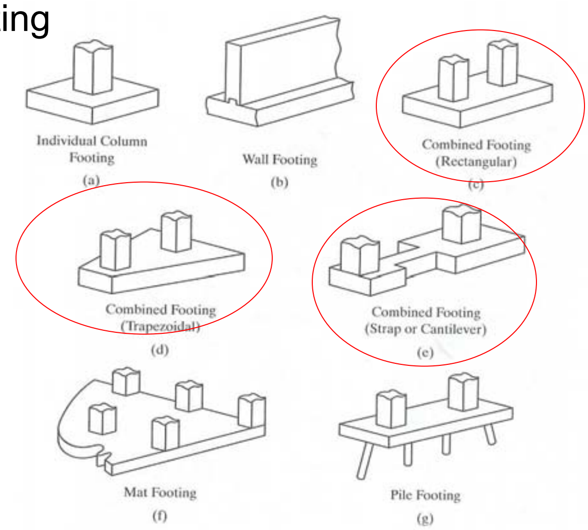
Check solution in Ex. 12.4 Text.

Combined Footings

- Combined footings are footings that support more than one column or wall.
- The two-column type of combined footing, which is relatively common, generally results from necessity.
- Two conditions that may lead to its use are
  1. an exterior column that is immediately adjacent to a property line where it is impossible to use an individual column footing.

Combined Footings

Figure 2. Footing Types



Combined Footings

2. two columns that are closely spaced, causing their individual footings to be closely spaced.

- In these situations, a rectangular or trapezoidal combined footing would usually be used.
- The choice of which shape to use is based on the difference in column loads as well as on physical (dimensional) limitations.

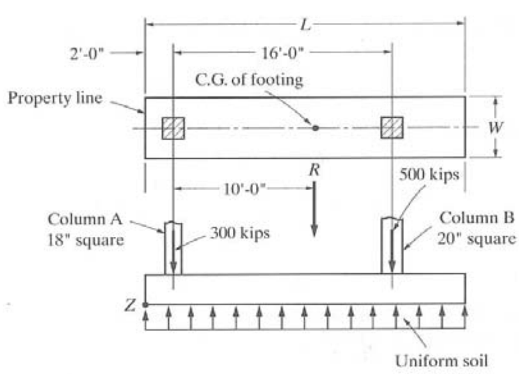
Combined Footings

- The physical dimensions (except thickness) of the combined footing are generally established by the allowable soil pressure.
- In addition, the centroid of the footing area should coincide with the line of action of the resultant of the two column loads.
- These dimensions are usually determined using service loads in combination with an allowable soil pressure.

Combined Footings

- Example 6

  Determine the shape and proportions of a combined footing subject to two column loads, as shown in the figure.



Combined Footings

- Example 6 (cont'd)
  1. The design data are as follows: Service load on the footing from column A is 300 kips ad from column B is 500 kips, and the allowable soil pressure is 6.00 ksf.
  2. Locate the resultant column load by a summation of moments at point Z in the figure:

$$\sum M_z = 300(2) + 500(18) = 800x$$

from which

$$x = 12 \text{ ft} \qquad (\text{measured from } Z)$$

Combined Footings

- Example 6 (cont'd)
  3. Assuming a rectangular shape, establish the length of footing L so that the centroid of the footing area coincide with the line of action of resultant force R:

$$\text{required } L = 12(2) = 24 \text{ ft}$$

  4. Assume a footing thickness of 3 ft. Therefore, its weight = 0.150 (3) = 0.45 ksf, and the allowable soil pressure for superimposed loads = 6 – 0.45 = 5.55 ksf. This neglects any soil on the footing.

Combined Footings

- Example 6 (cont'd)

5. The footing area required is

$$\frac{R}{5.55} = \frac{800}{5.55} = 144.1\ \text{ft}^2$$

6. With a length = 24 ft, the footing width W required is

$$\frac{144.1}{24} = 6\ \text{ft}$$

7. The actual uniform soil pressure is

$$\frac{800}{6(24)} + 0.45 = 6.0\ \text{ksf}$$

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