CHAPTER

12a

REINFORCED CONCRETE
A Fundamental Approach - Fifth Edition

FOOTINGS

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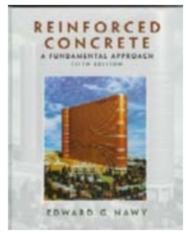
SPRING 2004



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ENCE 454 – Design of Concrete Structures
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Introduction

- The purpose of the structural portion of every building is to transfer applied loads safely from one part of the structure to another.
- The loads pass from their point of application into the superstructure, then to the foundation, and then into the underlying supporting material.

Introduction

- The foundation is generally considered to be the entire lowermost supporting part of the structure.
- Normally, a ***footing*** is the last, or nearly the last, structural element of the foundation through which the loads pass.
- The footing has as its function the requirement of spreading out the superimposed load.

Introduction

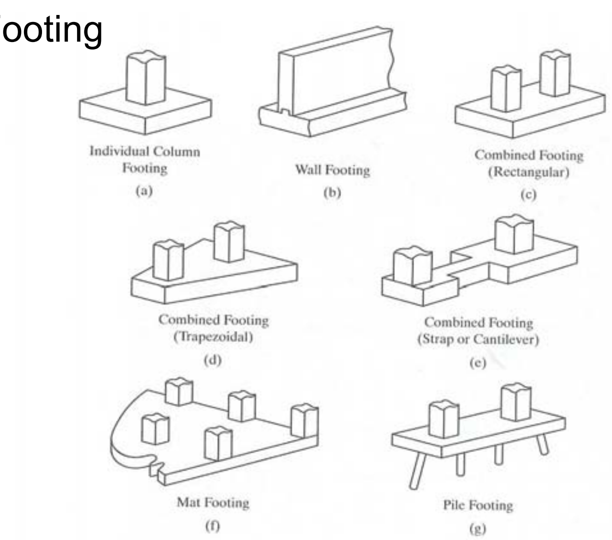
- However, the load is not to exceed the safe capacity of the underlying material, usually soil, to which it delivers the load.
- Also, the design of footings must take into account certain practical and, at times, legal consideration.
- The discussion of footings will include only spread footings as shown in Figures 1 and 2. Footings supported on piles are excluded.

Introduction

Figure 1. Column and Wall Footings

Introduction

Figure 2. Footing Types



Introduction

- Layout of structural supports vary widely and soil conditions differ from site to site and within a site.
- As a result, the type of foundation to be selected has to be governed by these factors and by optimal cost considerations.
- Basic knowledge of soil mechanics and foundation engineering is assumed when designing footings.

Introduction

- Background knowledge of the methodology of determining the resistance of cohesive and noncohesive soils is necessary to select the appropriate bearing capacity value for the particular site and the particular foundation system under consideration.

Introduction

- Bearing Capacity of Soils
  - The bearing capacity of soils is usually determined by
    - Borings
    - Test pits
    - Other soil investigations
  - If these are not available for the preliminary design, representative values at the footing level can normally be used from Table 1.

Introduction

Table 1. Presumptive Bearing Capacity (tons/ft^2)

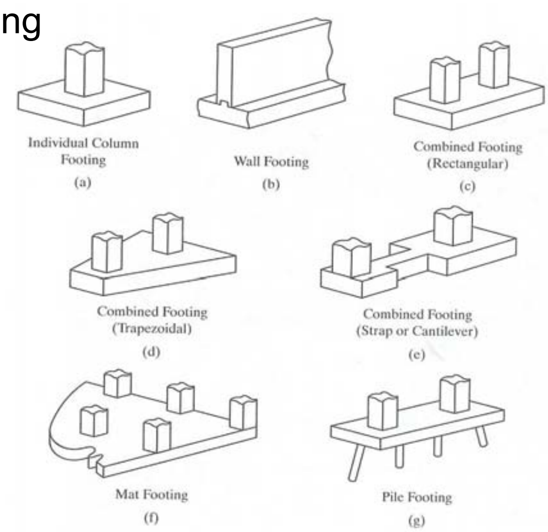
Type of Soil	Bearing Capacity
Massive crystalline bedrock, such as granite, diorite, gneiss, and trap rock	100
Foliated rocks, such as schist or slate	40
Sedimentary rocks, such as hard shales, sandstones, limestones, and siltstones	15
Gravel and gravel–sand mixtures (GW and GP soils)	
Densely compacted	5
Medium compacted	4
Loose, not compacted	3
Sands and gravely sands, well graded (SW soil)	
Densely compacted	$3\frac{3}{4}$
Medium compacted	3
Loose, not compacted	$2\frac{1}{4}$
Sands and gravely sands, poorly graded (SP soil)	
Densely compacted	3
Medium compacted	$2\frac{1}{2}$
Loose, not compacted	$1\frac{3}{4}$
Silty gravels and gravel–sand–silt mixtures (GM soil)	
Densely compacted	$2\frac{1}{2}$
Medium compacted	2
Loose, not compacted	$1\frac{1}{2}$
Silty sand and silt-sand mixtures (SM soil)	2
Clayey gravels, gravel–sand–clay mixtures, clayey sands, sand–clay mixtures (GC and SC soils)	2
Inorganic silts, and fine sands; silty or clayey fine sands and clayey silts, with slight plasticity; inorganic clays of low to medium plasticity; gravely clays; sandy clays; silty clays; lean clays (ML and CL soils)	1
Inorganic clays of high plasticity, fat clays; micaceous or diatomaceous fine sand or silty soils, elastic silts (CH and MH soils)	1

Types of Footings

- The more common types of footings may be categorized as follows:
  1. ***Individual column footing*** (Figure 2a): are often termed isolated spread footings and are generally square. If space limitations exists, the footing may be rectangular in shape.
  2. ***Wall footing:*** support walls that may be either bearing or nonbearing walls (Figure 2b)

Introduction

Figure 2. Footing Types



Types of Footings

3. ***Combined footings:*** support two or more columns and may be either rectangular or trapezoidal in shape (Figures 2c and 2d). If two isolated footings are joined be a strap beam, the footing is sometimes called a cantilever footing (Figure 2e).
4. ***Mat foundations:*** are large continuous footings that support all columns and walls of a structure. They are commonly used where undesirable soil conditions prevail (Figure 2f).

Types of Footings

5. ***Pile caps or pile footings:*** serve to transmit column loads to a group of piles, which will in turn transmit the loads to the supporting soil through frictions or to underlying rock in bearing (Figure 2g).

Types of Footings

- Wall Footings
  - Wall footings are commonly required to support direct concentric loads.
  - An exception to this is the footing for a retaining wall.
  - A wall footing may be of either plain or reinforced concrete.
  - Since it 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.

Types of Footings

- Wall Footings (cont'd)
  - Footings carrying relatively light loads on well-drained cohesive soil are often made of plain concrete.
  - A wall footing under concentric load 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.

Types of Footings

- Wall Footings (cont'd)
  - The flexural tensile stresses that are induced in the bottom of the footing are acceptable for an unreinforced concrete footing provided that these stresses do not exceed $5\phi\sqrt{f'_c}$.
  - Section 22.5 of the ACI Code stipulates that the average shear stress for one-way beam action in an unreinforced concrete footing must not exceed $4/3\phi\sqrt{f'_c}$.
  - These expressions apply only to normal-weight concrete.

Types of Footings

- Wall Footings (cont'd)
  - In a reinforced concrete wall footing, the behavior is identical to that just described.
  - Reinforcing steel is placed in the bottom of the footing in a direction perpendicular to the wall, however, thereby resisting the induced flexural tension, similar to a reinforced concrete beam or slab.

Types of Footings

- Wall Footings (cont'd)
  - In either case, the cantilever action is based on the maximum bending moment occurring at the face of the wall if the footing supports a concrete wall or at a point halfway between the middle of the wall and the face of the wall if the footing supports a masonry wall.
  - This difference is primarily because a masonry wall is somewhat less rigid than a concrete wall.

Types of Footings

- Wall Footings (cont'd)
  - For each type of wall, the critical section for shear in the footing may be taken at a distance from the face of the wall equal to the effective depth of the footing.

Types of Footings

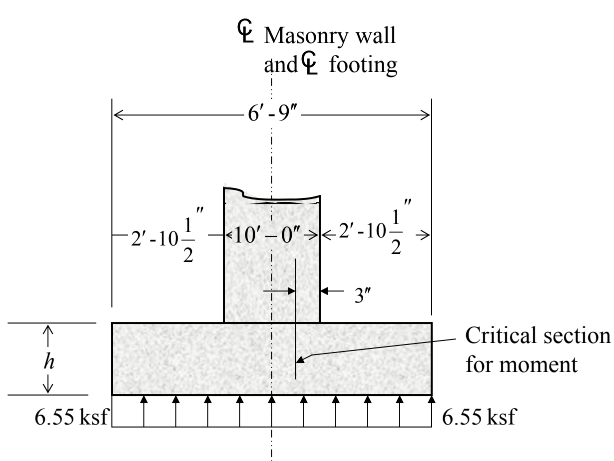
- Example 1

Design a plain concrete wall footing to carry a 12-in. concrete block masonry wall, as shown in the figure. The service loading may be taken as 10 kips/ft dead load (which includes the weight of the wall) and 22.5 kips/ft live load. Use f_c' = 3000 psi. The allowable soil pressure is 5000 psf (5.0 ksf), and the weight of earth w_e = 100 lb/ft^3.

To be discussed and solved in class.

Types of Footings

- Example 1 (cont'd)



Types of Footings

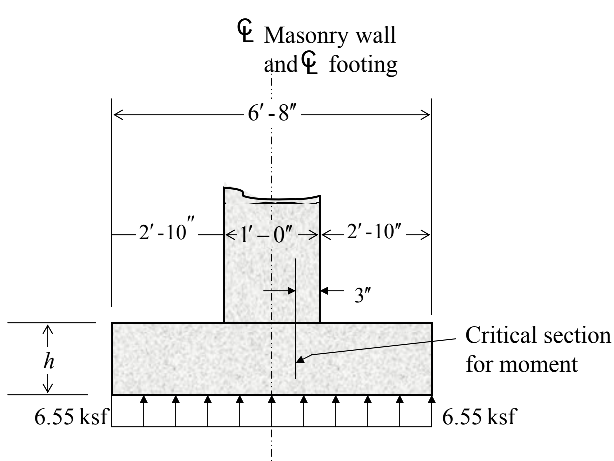
- Example 2

  Design a reinforced concrete wall footing to carry a 12-in. concrete block masonry wall, as shown in the figure. The service loading is 10 kips/ft dead load (which includes the weight of the wall) and 22.5 kips/ft live load. Use = 3000 psi, f_y = 60,000 psi, weight of earth = 100 lb/ft, and allowable soil pressure = 5000 psf. The bottom of the footing is to be 4 ft. below the finished ground line.

To be discussed and solved in class.

Types of Footings

- Example 2 (cont'd)



Soil Bearing Pressure at Base of Footings

- Distribution of Soil Bearing Pressure
  - The distribution of soil bearing pressure on the footing depends on the manner in which the column or wall loads are transmitted to the footing slab and the degree of the rigidity of the footing.
  - The soil under the footing is assumed to be homogeneous elastic material, and the soil bearing pressure can be considered uniformly distributed if the load acts through the axis of the footing slab area.

Soil Bearing Pressure at Base of Footings

- Distribution of Soil Bearing Pressure (cont'd)
  - If the load is not axial or symmetrically applied, the soil pressure distribution becomes trapezoidal due to the combined effects of axial load and bending.

Soil Bearing Pressure at Base of Footings

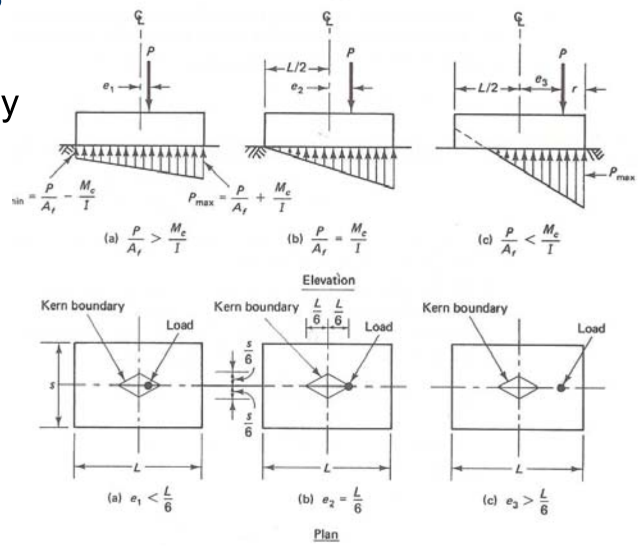
- Eccentric Load Effect on Footings
  - Exterior column footings and combined footings can be subjected to eccentric loading.
  - When the eccentric moment is very large, tensile stress on one side of the footing can result, since the bending stress distribution depends on the magnitude of load eccentricity.

Soil Bearing Pressure at Base of Footings

- Eccentric Load Effect on Footings (cont'd)
  - It is always advisable to proportion the area of these footings such that the load falls within the middle kern, as shown in Figures 3 and 4.
  - In such a case, the location of the load is in the middle third of the footing dimension in each direction.
  - Thereby, avoiding tension in the soil that can theoretically occur prior to stress redistribution.

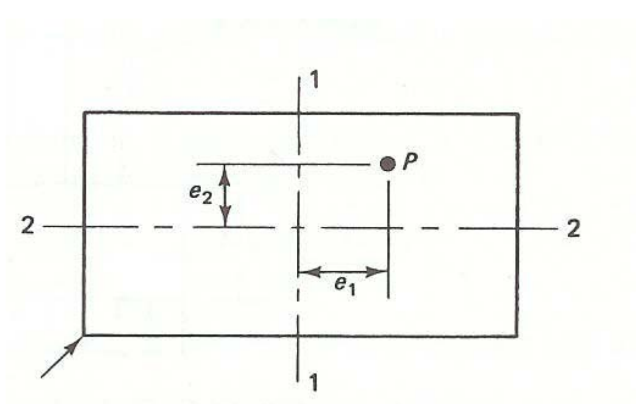
Soil Bearing Pressure at Base of Footings

Figure 3. Eccentrically Loaded Footings



Soil Bearing Pressure at Base of Footings

Figure 4. Biaxial Loading of Footing



Soil Bearing Pressure at Base of Footings

- Eccentricity Cases:
  - ***Eccentricity Case 1:*** $e_1 < L/6$
    - In this case, the direct stress P/A_f is larger than the bending stress Mc/I (see Figure 3a).
    - The stress is given by

$$P_{\max} = \frac{P}{A_f} + \frac{Pe_1c}{I} \qquad (1a)$$

$$P_{\min} = \frac{P}{A_f} - \frac{Pe_1c}{I} \qquad (1b)$$

Soil Bearing Pressure at Base of Footings

- Eccentricity Cases (cont'd):
  - ***Eccentricity Case 2:*** $e_2 = L/6$
    - The direct stress and bending stress are give by (see Figure 3b)

$$\text{direct stress} = \frac{P}{A_f} = \frac{P}{sL} \qquad (2a)$$

$$\text{bending stress} = \frac{Mc}{I} = Pe_2 \times \frac{c}{I} \qquad (2b)$$

$$\frac{c}{I} = \frac{L/2}{s\left(L^3/12\right)} = \frac{1}{s\left(L^2/6\right)} = \frac{6}{sL^2} \qquad (2c)$$

Soil Bearing Pressure at Base of Footings

- Eccentricity Cases (cont'd):
  - **Eccentricity Case 2 (cont'd): $e_2 = L/6$**
    - Where s and L are the width and length of the footing, respectively.
    - In order to find the limiting case where no tension exists on the footing, the direct stress P/A_f has to equivalent to the bending stress so that

$$\frac{P}{A_f} - Pe_2\frac{c}{I} = 0 \qquad \text{(2d)}$$

Soil Bearing Pressure at Base of Footings

- Eccentricity Cases (cont'd):
  - **Eccentricity Case 2 (cont'd): $e_2 = L/6$**
    - Substituting for P/A_f and c/I from Eqs. 2b and 2c into Eq. 2d, yields

$$\frac{P}{sL} - Pe_2 \times \frac{6}{sL^2} = 0 \Rightarrow e_2 = \frac{L}{6} \qquad \text{(2e)}$$

    - Consequently, the eccentric load has to act within the middle third of the footing dimension to avoid tension on the soil.

Soil Bearing Pressure at Base of Footings

- Eccentricity Cases (cont'd):
  - **Eccentricity Case 3: $e_3 > L/6$**
    - As the load acts outside the middle third, tensile stress results at the left side of the footing, as shown in Figure 3c.
    - If the maximum bearing pressure $p_{\max}$ due to load P does not exceed the allowable bearing capacity of the soil, no uplift is expected at the left end of the footing, and the center of gravity of the triangular bearing stress distribution coincides with the point of action of load P in Figure 3c.

Soil Bearing Pressure at Base of Footings

- Eccentricity Cases (cont'd):
  - **Eccentricity Case 3 (cont'd): $e_3 > L/6$**
    - The distance from the load P to the top of footing is $r = (L/2) - e_3$ = distance of the centroid of the stress triangle from the base of the triangle.
    - Therefore, the width of the triangle is

$$3r = 3[(L/2) - e_3]$$

    - Hence, the maximum compressive bearing stress is

$$P_{\max} = \frac{P}{\frac{3r \times s}{2}} = \frac{2P}{3s\left(\frac{L}{2} - e_3\right)} \qquad (3)$$

Soil Bearing Pressure at Base of Footings

- Eccentricity Cases (cont'd):
  - ***Eccentricity Case 4: biaxial Loading***
    - In this case we consider eccentricity about two axes, biaxial loading (Figure 4).
    - In the case where a concentrated load has an eccentricity in two directions (both within respective kern points), the stresses are

$$P_{\max} = \frac{P}{A_f} \pm \frac{Pe_1c_1}{I_1} \pm \frac{Pe_2c_2}{I_2} \qquad (4)$$

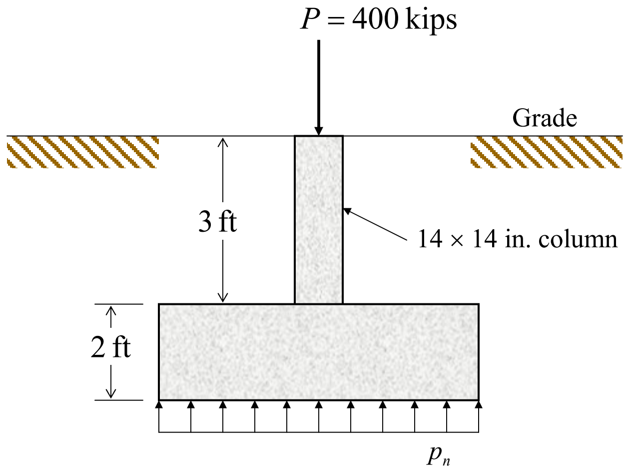
Soil Bearing Pressure at Base of Footings

- Example 3
  - A column support transmits axially a total service load of 400 kips to a square footing at the frost line (3 ft below grade), as shown in the figure. The frost line is the sub-grade soil level below which the groundwater does not freeze throughout the year. Test borings indicate a densely gravel-sand soil. Determine the required area of the footing and the net soil pressure intensity P_n to which it is subjected. Given:

    Unit weight of soil γ = 135 lb/ft^3
    Footing slab thickness = 2 ft

Soil Bearing Pressure at Base of Footings

- Example 3 (cont'd)



Soil Bearing Pressure at Base of Footings

- Example 3 (cont'd)
  - Since the footing is concentrically loaded, the soil pressure is considered uniformly distributed assuming the footing is rigid.
  - From the soil test borings and Table 1, the bearing capacity of the soil is 5 tons/ft^2 (10,000 lb/ft^3) at the level of the footing.
  - Assume the average weight of the soil and concrete above the footing is 135 pcf.

Soil Bearing Pressure at Base of Footings

- Example 3 (cont'd)
  - Since the top of the footing has to be below the frost line (minimum 3 ft below grade), the net allowable pressure is

$$P_n = 10{,}000 - (5 \times 135 + 100) = 9225 \text{ psf}$$

$$\text{minimum area of footing } A_f = \frac{400 \times 1000}{9{,}225} = 43.26 \text{ ft}^2$$

$$\sqrt{43.26} = 6.58 \text{ ft} \Rightarrow \text{select square footing } 6 \text{ ft } 8 \text{ in.} \times 6 \text{ ft } 8 \text{ in}$$

$$A_f = 44.44 \text{ ft}^2 > 43.26 \text{ ft}^2 \quad \text{OK}$$