Determine size of footing

Column subjected to axial column load and uplift

Example 1: Determine footing sizes for axial loads and uplift.

Column subjected to both axial column load and moment or eccentric loading

Example 2: Determine maximum and minimum footing pressure for footing with eccentricity < B/6.

Example 3: Determine maximum footing pressure for footing with eccentricity > B/6

Column subjected to axial column load only

Since factor of safety is included in determining allowable soil bearing capacity, there is no need to add addition factor of safety in determine the footing sizes. But, since the bottom of footing is at a depth below ground surface, the weight of soil and footing above the bearing area should be subtracted from the allowable soil capacity. The required footing area is column load divided by the net allowable soil bearing capacity.

\[ A = \frac{P}{Q_{a\text{-net}}} \]  \[ (2.1) \]

Where

- \( A \): required footing area.
- \( P \): Axial column load
- \( Q_{a\text{-net}} \): net allowable soil bearing capacity.

The weight of footing and the soil above should be heavy enough to offset the uplift forces from wind or seismic.

\[ W_t \geq U \ast F.S. \]  \[ (2.2) \]

Where:

- \( W_t \): Total weight of footing
- \( U \): uplift force
- \( F.S. \): factor of safety.

This situation usually occurs at column at building bracing location. The factor of safety for uplift force in most of building codes is 1.5.

Example 1: Determine footing sizes for axial loads and uplift.

Given:

- Column loads:
  - Live load: 25 kips
  - Dead load: 25 kips
  - Uplift = 20 kips
  - Factor of safety for uplift = 1.5
- Footing information:
  - Top of footing at 1 ft below ground surface, unit weigh weight of soil: 100 lbs/ft³.
  - Allowable soil bearing capacity = 3000 psf
  - Unit weight of concrete: 150 lbs/ft³.

Requirement: Determine footing sizes for axial loads and uplift.

Solution:

1. Total column service load = 25+25=50 kips
2. Assume a footing depth of 1 ft,
3. Net allowable soil bearing capacity = 3000-150*1-100*1=2750 psf
4. Required footing area = 50*1000/2750=18.2 ft²
5. Try 4’x4’x6’ footing, footing area = 20.2 ft²
6. Required weight of footing to offset uplift = 20*1.5=30 kips
7. Weight of footing above footing = 100*4.5*4.5/1000=2.0 kips
8. Required weight of footing = 30-25-2=3 kips
9. Required volume of footing = 3.0, 15=20 ft³
10. Required depth of footing = 20/20.2 =1 ft
11. Use 4’x4’x6”x1’ footing.
Column subjected to both axial column load and moment or eccentric loading

Columns at the base of a moment revisiting frame are often subjected to moment in addition to axial load. Columns that at edge of buildings often have to be designed with eccentricity due to limitation of property line. The bearing pressure at the bottom of footing will distribute in trapezoidal or triangular shape. The footing has to be sized so that maximum footing pressure does not exceed allowable soil bearing capacity.

Eccentricity is within 1/6 width of footing

![Diagram](image)

When eccentricity is less than 1/6 width of footing, footing pressure under the footing is distributed in trapezoidal shape. When eccentricity equals to 1/6 width of footing, footing pressure distributes triangularly with zero pressure at one end of the footing.

The soil bearing capacity can be calculated as

\[
Q = \frac{P}{A} \pm \frac{M}{S}
\]  \[2.3\]

P: Axial column Load  
A: footing area  
M = P*e, column moment in the x direction, e is eccentricity in x direction.  
S = LB^2/6 section modulus of footing area in x direction

For a rectangular footing, the equation can be written as
\[ Q = \frac{P}{A} \pm \frac{M}{S} \]

\[ = \frac{P}{(BL)} \pm \frac{P*e}{(LB^2/6)} \]

\[ = \left(\frac{P}{A}\right) \left[1 \pm \frac{e*B}{6}\right] \] \hspace{1cm} [2.4]

L, B are length and width of footing.

When footing is subjected to moments or eccentricities in both direction, the equations become

\[ Q = \frac{P}{A} \pm \frac{M_x}{S_x} \pm \frac{M_y}{S_y} \] \hspace{1cm} [2.5]

Or

\[ Q = \left(\frac{P}{A}\right) \left[1 \pm \frac{e_x*B}{6} \pm \frac{e_y*L}{6}\right] \] \hspace{1cm} [2.6]

**Example 2: Determine maximum and minimum footing pressure for footing with eccentricity < B/6.**

**Given:**
- Column loads:
  - Live load: 25 kips
  - Dead load: 25 kips
- Live load moment = 20 ft-kips
- Dead load moment = 20 kips
- Footing information:
  - Footing sizes = 6 ft x 6 ft

**Requirement:** Determine maximum and minimum footing pressure.

**Solution:**
1. Total axial load = 25+25=50 kips
2. Total column moment = 20+20=40 ft-kips
3. Eccentricity = 40/50=0.8 ft \(< B/6 = 1 ft\)
4. Maximum footing pressure = \[ \frac{50,000}{(6x6)}[1+0.8*6/6] = 2500 \text{ psf} \]
5. Minimum footing pressure = \[ \frac{50,000}{(6x6)}[1-0.8*6/6] = 277 \text{ psf} \]

**Eccentricity exceeds 1/6 width of footing**

When eccentricity exceeds 1/6 width of footing, soil pressure under pressure distributes in a triangular shape with a portion of the footing have zero pressure. The resultant of footing pressure, R coincides with column load, P as shown below. Since the center of the resultant is at 1/3 length of the triangle, the length of the bearing area is three times of the distance from the center of the column load to the edge of footing.
$P = Q_{\text{max}} \left[ \frac{3(B/2-2)L}{2} \right]$

Then,

$Q_{\text{max}} = \frac{2P}{3(B/2-e)L}$ \[2.7\]

**Example 3: Determine maximum footing pressure for footing with eccentricity > B/6**

**Given:**
- Live load: 25 kips
- Dead load: 25 kips
- Live load moment = 30 ft-kips
- Dead load moment = 30 kips

**Footing information:**
- Footing sizes = 6 ft x 6 ft

**Requirement:** Determine maximum and minimum footing pressure.

**Solution:**

1. Total axial load = 25+25=50 kips
2. Total column moment = 30+30=60 ft-kips
3. Eccentricity = 60/50=1.2 ft > B/6 = 1 ft
4. Maximum footing pressure = $2*50,000\left[\frac{3*(6/2-1.2)}{6}\right] = 3086$ psf

**Determine depth of spread footings for shear**

This portion of reinforced concrete design of spreading footing follows the requirement of ACI code 318-99. Factored loads should be used instead of service load. Factored footing pressure is used to determine footing depth and reinforcement.

The topics include:
Determine depth of footing for punching shear and direct shear

The depth of footing usually governs by punching shear and direct shear because shear reinforcement is normally not used. For a square footing, punching shear usually governs the design. For a rectangular footing, direct shear may be more critical.

Punching shear (Two-way shear)

The critical section of punching shear is located at one half effective distance from the faces of column. Shear strength of concrete should be larger than factored shear stress at critical section as

\[ \bar{v}_c \geq v_\phi \]

The punching shear strength \( \phi v_c \) in ACI is

\[ \phi v_c = \left(2 + \frac{4}{\beta_c}\right)\sqrt{f'_c} \leq M_f \sqrt{f'_c} \]  \[2.8\]

where \( \beta_c = 0.85 \) for shear, \( c \) is the ratio of long to short sides of column, and \( f'_c \) is the compressive strength of concrete.

The punching shear stress is factored shear force at the critical section divided by the perimeter of the critical section and the effective depth of the footing. The factored shear force at the critical section is factored column load minus factored footing pressure under the critical section. It can be calculated as

\[ v_a = \frac{Q u_s \times \left[ BL - \frac{(b+d)(c+d)}{2(b+d)(c+d)} \right]}{2(b+d)(c+d)} \]  \[2.9\]

where

- \( v_a \) is punching shear stress,
- \( Q u_s \) is factor footing pressure,
- \( B, L \) are width and length of footing,
- \( b, c \) are width and length of square column
- \( d \) is effective depth of the footing.
The critical section of direct shear is at one effective distance from the face of column. The direct shear strength specified in ACI is

$$\frac{V_{c}}{f_{c}} \leq 2$$  \hspace{1cm} [2.10]

The factored shear stress at the critical section is the factored shear force divided by the width and depth of the footing at the critical section. The factored shear force at the critical section is the area from the critical section to the edge of the footing multiply average factored footing pressure in the area.
Example 4: Check footing depth for punching shear and direct shear for footing subjected to axial column load only

**Given:**
- Column loads:
  - Live load: 25 kips
  - Dead load: 25 kips
- Footing and column information:
  - Footing sizes = 4 ft x 4 ft x 1 ft
  - Column size: 1 ft x 1 ft
  - Concrete strength at 28 day = 3000 psi

**Requirement:** Check if the footing depth is adequate for punching shear and direct shear.

**Solution:**
- Factored column load = 1.4*25+1.7*25 = 77.5 kips
- Factored footing pressure = 77.5/16 = 4.84 ksf
Effective footing depth = 12"-3" (cover) – 0.5" (assumed diameter of #4 bar) = 8.5"

Check punching shear:

Area under critical section = \[(12"+8.5")/12\]^2 = 2.92 ft^2.

Factored shear force at critical section = 77.5*4.84*2.92 = 63.4 kips

Perimeter of critical section = 4 (12" + 8.5") = 82"

Factor shear stress at critical section = 63.4/82*8.5 = 90.9 psi

Punching shear strength of concrete = 0.85*(4√3000) = 186 psi > 90.9 psi O.K.

Check direct shear:

Distance from critical section to edge of footing = 4/2-1/2-8.5/12 = 0.83'

Factored shear force = 4.84*0.83*4 = 16.1 kips

Factored shear stress = 16.100/(4*12*8.5) = 39.5 psi

Direct shear stress of concrete = 0.85*(2√3000) = 93 psi > 39.5 psi O.K.

Example 5: Check footing depth for punching shear and direct shear for footing subjected to axial column load

Given:

- Column loads:
  - Live load: 25 kips
  - Dead load: 25 kips

- Live load moment = 25 ft-kips
- Dead load moment = 25 ft-kips

- Footing and column information:
  - Footing sizes = 6 ft x 4 ft x 1 ft
  - Column size: 1 ft x 1 ft

- Concrete strength at 28 day = 3000 psi

Requirement: Check if the footing depth is adequate for punching shear and direct shear.

Solution:

Factored column load = 1.4*25+1.7*25 = 77.5 kips

Factored column moment = 1.4*25+1.7*25 = 77.5 ft-kips

Eccentricity of factored column load = 77.5/77.5 = 1 ft

Maximum footing pressure = [77.5/(4x6)][1+1*6/6] = 6.46 ksf

Minimum footing pressure = [77.5/(4x6)][1-1*6/6] = 0 ksf

Effective footing depth = 12"-3" (cover) – 0.5" (assumed diameter of #4 bar) = 8.5".

Check punching shear:

Average factored footing pressure = (6.46+0)/2 = 3.23 ksf

Area under critical section = \[(12"+8.5")/12\]^2 = 2.92 ft^2.

Factored shear force at critical section = 77.5*3.23*2.92 = 68.1 kips

Perimeter of critical section = 4 (12" + 8.5") = 82"

Factor shear stress at critical section = 68.100/(4*12*8.5) = 97.8 psi

Punching shear strength of concrete = 0.85*(4√3000) = 186 psi > 90.9 psi O.K.

Check direct shear:

Distance from critical section to edge of footing = 6/2-1/2-8.5/12 = 1.83'

Factor footing pressure at the location of critical section = 6.46*4.17 = 6.49 ksf

Factored shear force = (6.46+4.49)/2 = 1.83*4 = 40.1 kips

Factored shear stress = 40.100/(4*12*8.5) = 98.3 psi

Direct shear stress of concrete = 0.85*(2√3000) = 93 psi > 98.3 psi N.G. Need to increase footing depth.

Design reinforcement for spread footings

This portion of reinforced concrete design of spreading footing follows the requirement of ACI code 318-99. Factored loads should be used instead of service load. Factored footing pressure is used to determine footing reinforcement.

The topics include:

- Moment calculation
- Calculating Reinforcement
- Minimum and maximum reinforcements
- Example 6: Determine footing reinforcement for footing subjected to axial column load
Design footing reinforcements

Moment calculation

The footing needs to be reinforced for the bending moment producing from upward footing pressure. According to ACI code, the critical section is at the face of column. The factored moment at the critical section can be calculated as

\[ M_u = Q_u \times l^2 / 2 \]  \hspace{1cm} \text{[2.11]}

Where
\[ Q_u \] is factored footing pressure
\[ l \] is the distance from the face of column to the edge of footing.
Calculating Reinforcement

The footing reinforcements are designed based on ACI strength design method. At ultimate stress situation, the concrete at top portion is subjected to compression. The compressive stresses distribute uniformly over a depth $a$. The resultant of compressive stress, $C$, is located at a distance, $a/2$, from the top surface. Tensile force is taken by rebars at an effective distance, $d$, from the top surface.
According to ACI code, the ultimate compressive is \( 0.85f'_c \), where \( f'_c \) is compressive strength of concrete. Therefore, the compressive stress, 
\[ C = 0.85f'_c \ a \ b \]  
By equilibrium, the tensile force is equal to the compression resultant, 
\[ T = C = 0.85f'_c \ a \ b \]  
Therefore, 
\[ a = \frac{T}{0.85f'_c b} \]  
The nominal moment strength of the section, 
\[ M_n = T \ (d-a/2) \]  
ACI code requires that the factored moment, 
\[ M_u \leq \phi M_n \]  
Where, \( \phi = 0.9 \), is the strength reduction factor for beam design. Then, the tensile force, 
\[ T = \frac{M_u}{\phi(d-a/2)} \]  
and, the area of reinforcement is 
\[ A_r = \frac{T}{F_y} \]  
where \( F_y \) is the yield strength of reinforcing steel.

There are many ways to determine reinforcements. One simple method is using a trial and error method by assuming the depth of compression block, \( a \). The steps are as follows

1. Assume a depth of the stress block, \( a \).
2. Calculate tensile force, \( T \) using equation [2.16]
3. Calculate new depth of the stress block, \( a \), using equation [2.14]
4. If the new depth, \( a \), is not close to the assumed, \( a \), in step 1, repeat step 2 and 3 with new depth, \( a \).
5. If the new depth, \( a \), is close to the assume, \( a \), calculate area of reinforcement using equation [2.16]

**Minimum and maximum reinforcements**

ACI code requires the minimum reinforcement ratio,
Where, \( A_s \) is the area of reinforcements. In addition, it also said that the minimum reinforcement does not need to be more than \( \frac{4}{3} \rho \) of the calculated value,

\[
\rho_{\min} \leq \frac{4}{3} \rho
\]

Example 6: Determine footing reinforcement for footing subjected to axial column load

**Given:**
- Column loads:
  - Live load: 25 kips
  - Dead load: 25 kips
- Footing and column information:
  - Footing sizes = 4 ft 6 in. x 4 ft 6 in. x 1 ft
  - Column size: 1 ft x 1 ft
  - Concrete strength at 28 day = 3000 psi
  - Yield strength of rebars = 60 ksi

**Requirement:** Calculate footing reinforcements

**Solution:**
1. Calculate factored column load,
2. \( P_u = 1.4 \times 25 + 1.7 \times 25 = 77.5 \) kips
3. Factored footing pressure = \( \frac{77.5}{(4.5 \times 4.5)} = 3.827 \) ksf
4. Distance from critical section to edge of footing = \( \frac{(4.5-1)}{2} = 1.75' \)
5. Factored moment at critical section = \( (3.827) \times 1.75^2 \times 2 = 5.86 \) ft-kips/ft
6. Effective depth = 12" - 3" (cover) - 0.5" (rebar size) = 8.5"
7. Assume \( a = 1" \)
8. \( T = \frac{(5.86 \times 12)}{\left[0.85 \times (8.5 - 0.5/2)\right]} = 10.3 \) kips/ft
9. Check \( a = 10.3 / (0.85 \times 3 \times 12) = 0.34" \)
10. Assume \( a = 0.34" \)
11. \( T = \frac{(5.86 \times 12)}{\left[0.85 \times (8.5 - 0.34/2)\right]} = 9.9 \) kips
12. Check \( a = 9.9 / (0.85 \times 3 \times 12) = 0.32" \) (close enough)
13. \( A_s = 9.9 \times 60 = 0.165 \) in²/ft
14. The reinforcement ratio, \( \rho = 0.165 / (8.5 \times 12) = 0.0016 \)
15. Less than \( \rho_{\min} = 0.0033 \) or \( \rho_{\min} = (4/3) \times 0.00162 = 0.00216 \)
16. For a footing width of 4'6", \( A_s = 0.216 \times 8.5 \times 4.5 = 0.99 \) in².
17. Use 5#/4 in both direction, \( A_s = 5 \times 0.2 = 1.0 \) in².

**Placing reinforcements.**

Reinforcements should be placed at the tension side at the bottom of the footing.

For a square footing, rebars are placed uniformly in both directions. ACI code requires that the rebars be placed not more than 18 inch apart.

For a rectangular footing, rebars in the long direction are placed uniformly but not the short direction. ACI code requires a certain portion of reinforcements in short direction to be placed within a band equal to the width of footing in the short direction. The distribution ratio is calculated based on the aspect ratio of footing as

\[
r = \frac{2}{\beta + 1}
\]

where \( \beta \) is the ratio of length to short side.

**Design column dowels**

Dowel rebars that go from the bottom of footing into the footing need the meet the following requirements:
1. Transfer vertical column forces when column load exceeds the compressive strength of concrete.
2. Transfer moment at column base
3. Meet minimum reinforcement in ACI code
4. Meet splice requirement for column reinforcement.

**Bearing strength of concrete at base of column**

The bearing strength of column at the column base

$$\phi P_c = 0.7 \times 0.85 f'_c A_g$$

Where $A_g$ is the gross section area of column

The bearing strength of footing at the column base is

$$\phi P_c = 0.7 \times 0.85 f'_c \alpha A_g$$

$$\alpha = \sqrt{A_2/A_1} \leq 2.$$  

Edge length of $A_1, A_2$ are shown in the figure below.

**Reinforcement required at the base of column**

Where there is no moment at the column base, the area reinforcement through column base can be calculated as

$$A_s = \frac{P_u - \phi P_c}{f_y}$$  \[2.20\]

$P_u$ is factored column load. When $P_u < \phi P_c$, ACI code requires that the minimum reinforcement for dowel through column base is $0.005 A_g$. $A_g$ is the cross section area of column. The diameter of the dowel should not exceed the longitudinal reinforcement of column by 0.15 in.

When the column base is subjected to both axial loads and moments, the column dowel needs to be designed to resist column moment. The design procedure is the same as design of beam-columns.

**Length of dowel for compression**

The length of dowel that below the column base need to meet minimum development length of ACI code.

Basic development length for compression member is the larger of

$$L_{db} = 0.02 \left( \frac{f_{yd}}{f'_c} \right)$$  \[2.21\]

$$L_{db} = 0.0003 f_{yd} d_b$$  \[2.22\]

Where $d_b$ is the diameter of rebar

The length of dowel is modified by the area of reinforcement as

$$L_d = \frac{A_s \text{ required}}{A_s \text{ provided}} (L_{db})$$  \[2.23\]

The length of dowel that projects above the footing needs to meet the compression splice requirement of column reinforcement.

When $f_y \leq 60,000$ psi,  $L_{ap} = 0.0005 f_{yd} d_b$,  $L_d > L_{ap}$ or 12”  \[2.24\]
When, \( fy > 60,000 \text{ psi} \),  
\[ \text{Lap} = (0.0009 \text{ fy} - 24) d_b > Ld \text{ or } 12'' \]  
[2.25]  

When column base is subject to moment and the rebars are in tension, length of splice and anchor should be designed based on tension requirement.

**Example 7: Design of column dowel**

**Given:**
- Column loads:
  - Live load: 20 kips
  - Dead load: 40 kips
- Footing and column information:
  - Footing sizes = 4 ft x 4 ft x 1 ft
  - Column size: 1 ft x 1 ft
  - Concrete strength at 28 day for footing = 3000 psi
  - Concrete strength at 28 day for column = 4000 psi
  - Yield strength of rebars = 60 ksi
  - Column reinforcement: 4#6
  - Footing reinforcement: 4#4
- Requirement:
  - Design column dowels including sizes and length

**Solution:**
1. Determine number and size of rebar
2. Factored column load = 1.4*40+1.7*20=90 kips
3. Bearing strength of column = 0.7*0.85*4*12=342 kips >90 kips
4. Effective depth = 12-3-1=8 in.
5. Edge length of \( A_2 \) = 12+8*2*2 = 44'' < 48''
6. Area of \( A_2 \) = 44*44=1936 in^2.
7. \( A_1 = 12*12=144 \text{ in}^2. \)
8. \( \alpha = \sqrt{rac{A_2}{A_1}} = \sqrt{1936/144}=3.7 >2 \) Use 2.
9. The bearing strength of footing at column base = 0.7*0.85*2*3*144=514 kips >90 kips
10. Use minimum reinforcement, \( A_s = 0.005*144=0.72 \text{ in}^2 \)
11. Use 4#4, \( A_s = 0.8 \text{ in}^2 \)

**Length of dowel in footing:**
1. Basic development for #4 bars:
2. \( L_d = 0.02 \frac{fyd_b}{\sqrt{f'c'}} = 0.02(60,000*0.5/3000) = 11'' \)
3. \( L_d = 0.0003 fyd_b = 0.0003*60000*0.5 = 9 \text{ in.} \)
4. Required development length, \( L_d = 11''*0.72/0.8 = 9.9'' \)
5. Since the distance from the top of footing to the #4 bottom reinforcement is 7.5'', use dowel with 90 degree hook, 7.5 in vertical and 2.5 in turn.

**Splice length in column:**
1. For #6 bars in column,
2. Lap = 0.0005 fyd_b = 0.0005*60000*0.75=22.5 in
3. Ld = 0.02*60000*0.75/40000=14 in.
4. \( L_d = 0.0003*60000*0.75=13.5 \text{ in.} \)
5. Use Lap = 22.5 in.

**Design of square footings**

The procedure for designing a square footing is as follows:

**Service load design:**
1. Determine size of footing.

**Reinforced concrete design:**
2. Determine depth of footing for punching shear and direct shear
3. Determine footing reinforcement for bending moment
4. Determine column dowel to transfer column load.

**Example 8: Design of a square footing**

**Given:**
- Column loads:
  - Live load: 100 kips
Dead load: 100 kips
Footing uplift: 0 kips
Column size: 1 ft. x 1 ft.
Soil information:
Allowable soil bearing capacity: 4000 psf
Soil cover above footing: 1 ft
Unit weight of soil: 120 pcf
Materials used:
Concrete strength at 28 day = 3000 psi
Yield strength of rebars = 60 ksi

Requirement: Determine size, depth, and reinforcement for a square footing.

Solution:

Service load design:

1. Determine footing sizes:
   1. Assume a footing depth of 18", net soil bearing capacity,
   2. \( Q_{net} = 4000 - 150 \times 18/12 - 120 \times 1 = 3655 \) psf
   3. Required footing area, \( A = (100+100) \times (1000) / 3655 = 54.7 \) ft
   4. Use 7'-6" by 7'-6" square footing. The footing area is 56.3 ft

Reinforced concrete design:

2. Determine footing depth
   The factored footing pressure can be calculated as
   \( Q_u = (1.4 \times 120 + 1.7 \times 80) / 56.3 = 5.5 \) psf

   a. Check punching shear
      1. Assume the reinforcements are #6 bars, the effective depth
      2. \( d = 18" - 3" \) (cover) - 0.75" (one bar size) = 14.3" = 1.2'
      3. The punch shear stress can be calculated as
      \[ \tau_p = \frac{5.5 \times (1.5^2 - (1+1.2)^2 \times 1000)}{4 \times 1.2 \times (1.5+1.2) \times 144} = 186 \text{ psi} \]
      5. The shear strength of concrete is
      \[ \phi \tau_c = 0.85 \times 4 \times 3000 = 186 \text{ psi} \]
      O.K.

   b. Check direct shear:
      1. The distance from the critical section of direct shear to the edge of the footing,
      2. \( l = (7.5)(12)/2 - 1/2 = 24.75" = 2.05' \)
      3. The direct shear stress is
      \[ \tau_d = \frac{(5.5)(1000)(2.05)}{(12)(14.3)} = 65.7 \text{ psi per foot width of footing.} \]
      5. The shear strength of concrete for direct shear is
      \[ \phi \tau_c = 0.85 \times 2 \times 3000 = 93 \text{ psi} > 65.7 \text{ psi} \]
      O.K.

3. Determine footing reinforcement
   1. The distance from face of column to the edge of the footing is
   2. \( l = 7.5/2 - 1/2 = 3.25' \)
   3. The factored moment at the face of the column is
   4. \( M_u = (5.5)(3.25)^2/2 = 29 \) k-ft. per foot width of footing
   5. Use trial method for reinforcement design
   6. Assume \( a = 0.9". \)
   7. \( T = \frac{M_u}{k(d - a/2)} = \frac{(29)(12)}{(0.9)(14.3 - 0.9/2)} = 27.9 \text{ kips} \)
   8. Calculate new \( a, \)
   9. \[ a = \frac{T}{0.85f_y} = \frac{27.9}{0.85(3)(12)} = 0.91 \text{ in.} \]
      \[ a = 0.9" \]
   10. \[ A_y = \frac{T}{f_y} = \frac{29}{60} = 0.48 \text{ in}^2 \]
      at one foot section.
   11. The reinforcement ratio is
   12. \[ \rho = \frac{A_y}{bd} = \frac{0.48}{(12)(14.3)} = 0.0028 \]