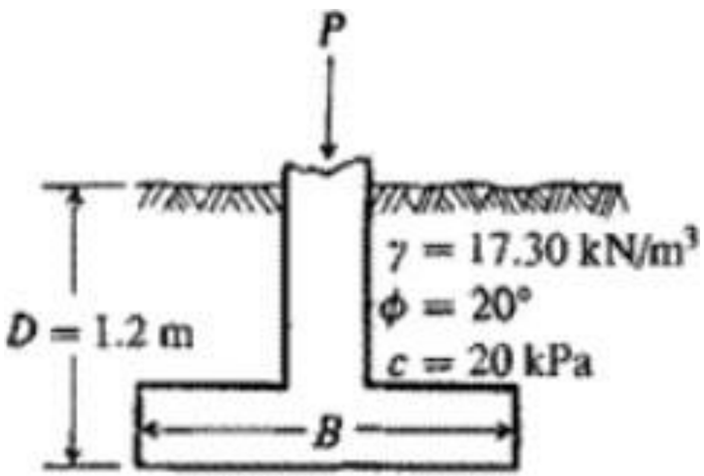
Problem-1 Terzaghi BC equation

Compute the allowable bearing pressure using the Terzaghi equation for the square footing of width B=1.5m shown in figure below. The soil data are obtained from a series of undrained U triaxial tests. Is the soil saturated?



The Soil is not saturated, since a U test gives a ϕ angle. A CU test might give similar data for a saturated soil.

Solution:

Terzaghi BC equation is

$qu = c\ Nc\ s_c + \gamma\ D\ Nq + ½\ \gamma\ B\ N\gamma\ s_\gamma$

BC factors: For $\varphi = 20°$, Nc = 17.7, Nq = 7.4 and $N\gamma = 5$

Shape factors: sc=1.3, and $s\gamma=0.8$

qu = 20×17.7 ×1.3 +

17.3 × 1.2 ×7.4 +

0.5 x 17.3 × 1.5 × 5 × 0.8

= 460.2 + 153.6 + 51.9

qu = 665 kN/m²

Problem-2, Effect of WT

i think this shows the gross pressure intensity.

A footing 2.5×2.5 m carries a pressure of 400 kN/m^2 at a depth of 1 m in a sand. The saturated unit weight of the sand is 20 kN/m^3 and the unit weight above the water table is 17 kN/m^3. The design shear strength parameters are $c' = 0$ and $\phi' = 40°$. Determine the factor of safety with respect to shear failure for the following cases:

(a) the water table is 5 m below ground level,

(b) the water table is 1 m below ground level,

(c) the water table is at ground level and there is seepage vertically upwards under a hydraulic gradient of 0.2.

Solution:

q_{app} = 400 kPa [Note that it is gross pressure acting at a depth of 1m]

BC factors: For φ = 40°, Nq = 81.3 and Nγ = 100.4

Shape factors: sc=1.3, and sγ=0.8

Find H, height of the soil wedge below footing:

H = B/2 tan (45+ϕ/2)= 2.5/2 tan(65)=2.68m

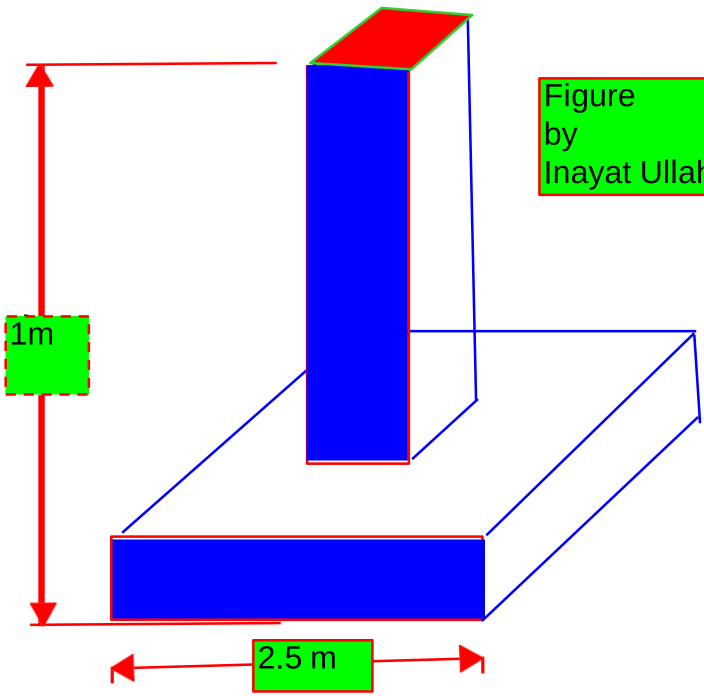


Figure by Inayat Ullah Khan

Problem-2, Effect of WT

Solution(a):

Effect of W.T

The W.T is 5m below ground level:

There is no effect of because W.T zw > H, use bulk unit weight $\gamma = 17 kN/m^3$.

Terzaghi BC equation is

$qu = c\ Nc\ s_c + \gamma D\ Nq + ½\ \gamma B\ N\gamma\ s_\gamma$ qu= 0 + 1382.1 + 1706.8 = 3088 kN/m2

FOS = qu / qapp = 3088/400 = 7.7

Note: 1- If net applied pressure were given than convert the qu into qu(net) i.e.

use FOS = (qu-γD)/ qapp(net)

Solution(b):

Effect of W.T

The W.T is 1m below ground level:

Only 3rd term of BC will be affected as zw < H,

For 2nd term use $\gamma = 17 kN/m^3$.

For 3rd term use $\gamma = \gamma sat - \gamma w$ = 20-9.8=10.2 kN/m3.

Terzaghi BC equation is

$qu = c\ Nc\ s_c + \gamma D\ Nq + ½\ \gamma B\ N\gamma\ s_\gamma$ qu= 0 + 1382.1 + 1024 = 2406 kN/m2

FOS = qu / qapp = 2406/400 = 6

Note: 1- If net applied pressure were given than convert the qu into qu(net) i.e.

use FOS = (qu-γD)/ qapp(net)

Problem-2, Effect of WT

Solution(a):

In this case both 2nd and 3rd terms will be affected. In addition to submergence of soil due to W.T, there will be further reduction in unit weight of soil due to vertical seepage.

$\gamma' = \gamma_{sub} - i\gamma_w = 10.2 - 0.2 \times 9.8 = 8.24$ kN/m^3.

Terzaghi BC equation is

$qu = c\ Nc\ s_c + \gamma' D\ Nq + \frac{1}{2}\ \gamma' B\ N\gamma\ s_\gamma$

$qu = 0 + 8.24 \times 1 \times 81.3 + 0.5 \times 8.24 \times 2.5 \times 100.4 \times 0.8$

$= 669.9 + 827.3 = 1497$ kN/m^2

FOS = qu / qapp = 1497/400 = 3.7

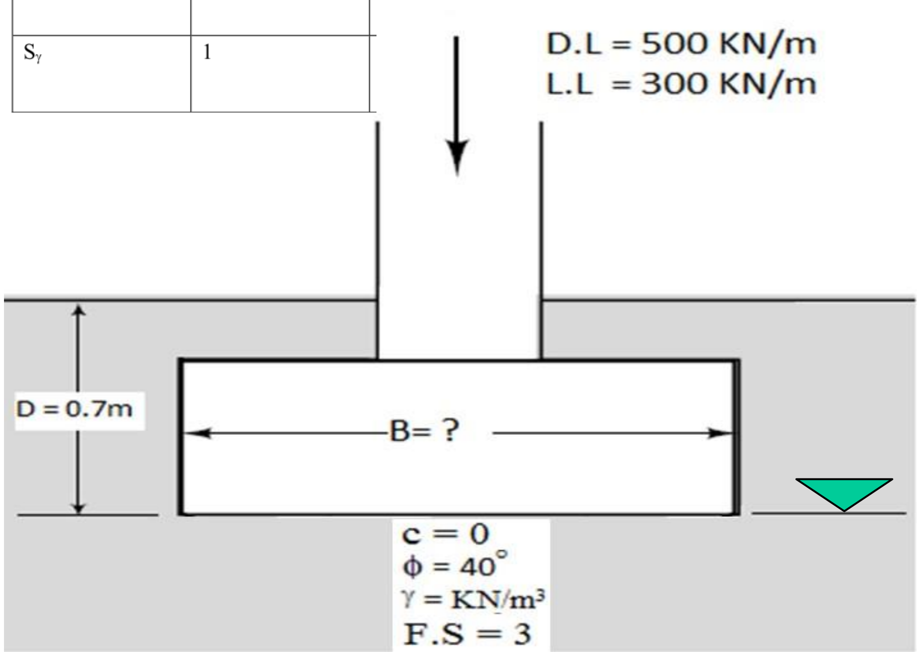
When it is said at this depth so it is gross pressure.

Problem-3, Effect of WT

A strip footing is to be designed to support a dead load of 500 kN/m and live load of 300 kN/m at a depth of 0.7m in a gravelly sand. Characteristic values of the shear strength parameters are c = 0 and φ = 40°. Determine the required width of the footing if the factor of safety of 3.0 against shear failure of the soil is specified.

Assuming that the WT may rise to foundation leve. The unit weight of the sand above the W.T. is is 17kN/m³ and below the WT the saturated unit weight is 20 kN/m³.

Shape factor	Strip footing
S_c	1
S_γ	1



Solution:

FOS= q_u/q_{app}

qu = FOS x q_{app} = 3 x 800/B=2400/B

For φ = 40° the Terzaghi BC factors are

Nq = 81.3 and Nγ = 100.4.

qu = cNc + γDNq+ ½ γBNγ

Use bulk unit weight (17 kN/m³) in 2nd Term and submerged unit weight ($\gamma' = \gamma_{sat} - \gamma_w$) = 20-9.8=10.2 kN/m³) in 3rd term of BC equation.

qu = 0 + 17 x 0.7 x 81.3 + 0.5 x 10.2 x B x100.4

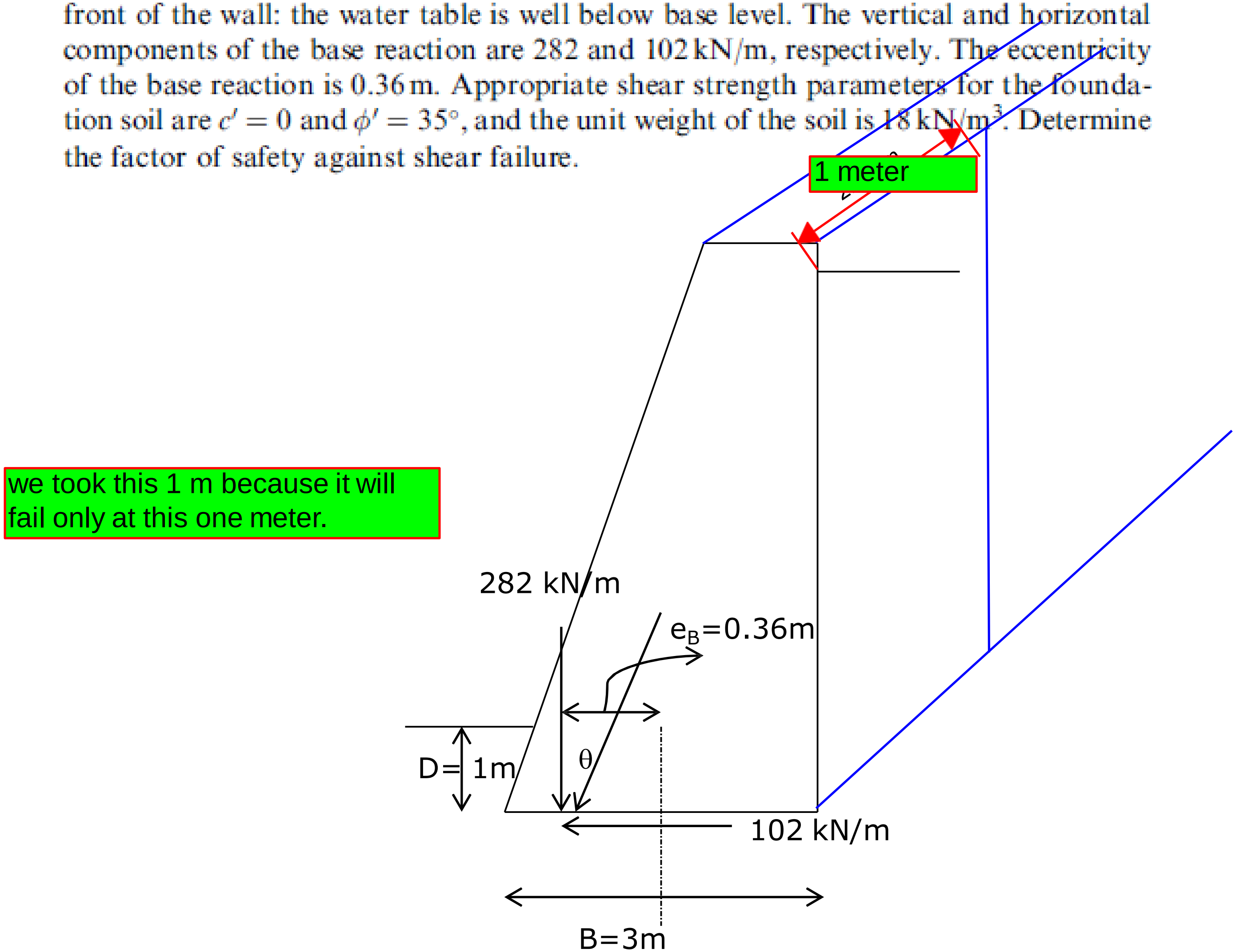
2400/B = 967.5 + 512B

2400 = 967.5B + 512B²

B = 2.8 m B = 1.42 m

Problem-4 Meyerhof BC equation: Review Problem

The base of a long retaining wall is 3 m wide and is 1 m below the ground surface in front of the wall: the water table is well below base level. The vertical and horizontal components of the base reaction are 282 and 102 kN/m, respectively. The eccentricity of the base reaction is 0.36 m. Appropriate shear strength parameters for the foundation soil are $c' = 0$ and $\phi' = 35°$, and the unit weight of the soil is 18 kN/m^3. Determine the factor of safety against shear failure.



Problem-4 Meyerhof BC equation: Review Problem

Solution:

Eccentricity: $e_B = 0.36m$

Effective Footing Dimensions:

$B' = B - 2e_B = 2.28m$

Meyerhof's BC factors for $\phi = 35°$

$N_q = 33$, $N_\gamma = 41$

$K_p = \tan^2(45+\phi/2) = 3.69$

Shape factors:

this is both effective

Since L>>>B (long retaining wall),

$B'/L' \cong 0$, $s_c = s_q = s_\gamma = 1$

Depth factors:

$d_c = (1+0.2\sqrt{K_p}(D/B')) = 1.168$

$d_q = d_\gamma = (1+0.1\sqrt{K_p}(D/B')) = 1.084$

Inclination factors:

$\theta = \tan^{-1}(H/V) = 19.8°$

$i_c = i_q = (1-\theta/90)^2 = 0.6084$

$i_\gamma = (1-\theta/\phi)^2 = 0.1886$

Applying Meyrhof BC equation

$q_u = cN_c s_c d_c i_c + \gamma' D N_q s_q d_q i_q + 0.5\gamma' B N_\gamma s_\gamma d_\gamma i_\gamma$

$q_u = 0 + 18\times1\times33\times1\times1.084\times0.6084 + 0.5\times18\times2.28\times41\times1.084\times0.1886$

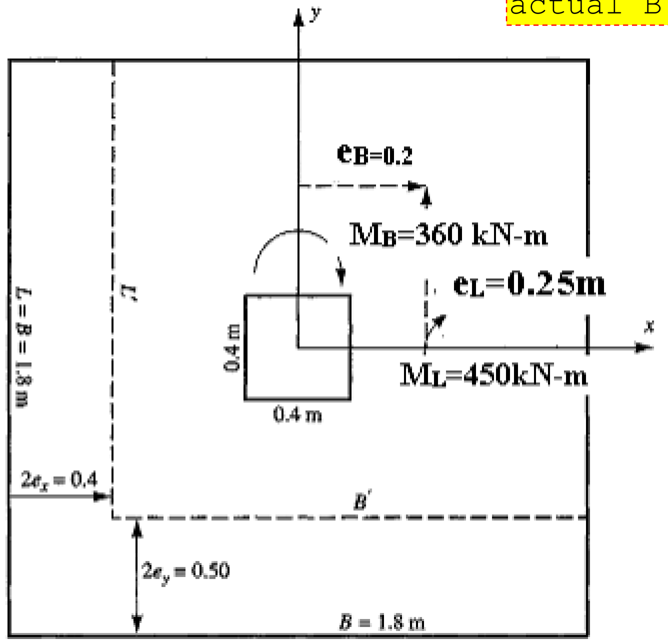
$= 391 + 172 = 563$ kPa

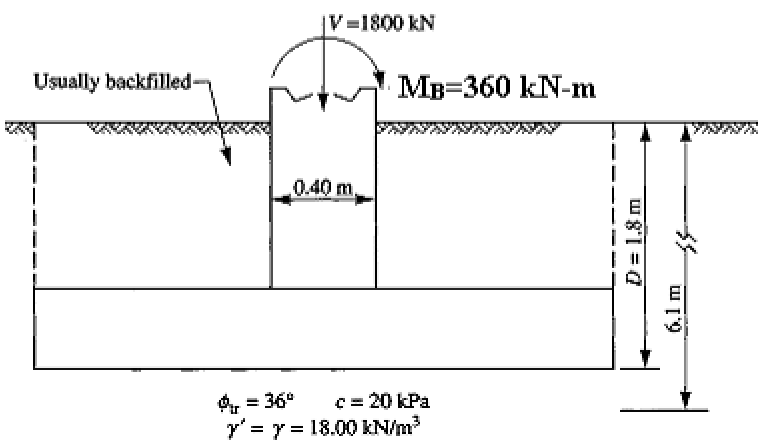
Ultimate Load = $P_u = 563\times2.28 = 1283$ kN/m

FOS = $P_u/P_{app} = 1283/282 = 4.5$

Problem-4 Meyerhof BC equation: Review Problem

What is the allowable soil pressure (FOS=3) using Meyerhof's Bearing capacity equation.





actual B used.

Solution:

Effect of W.T

$H = B/2 \tan(45+\phi/2) = 2.5/2 \tan(63) = 1.76m < z_w$ so no effect of WT

Eccentricities

$e_B = 360/1800 = 0.2m$, $e_L = 450/1800 = 0.25m$

Effective Footing Dimensions:

$B' = B - 2e_B = 1.4m$, $L' = L - 2e_L = 1.3m$

Since $B' > L'$, therefore swap the values that is $B' = 1.3m$ and $L' = 1.4m$

Meyerhof's BC factors for $\phi = 36°$ Nq=37.7, Nc=50.5, Nγ=44.4

Shape factors:

$Kp = \tan^2(45+\phi/2) = 3.85$

$sc = (1 + 0.2Kp(B'/L')) = 1.715$

Problem-4 Meyerhof BC equation: Review Problem

$sq = s\gamma = (1+0.1Kp(B'/L')) = 1.358$

Depth factors:

$dc = (1+0.2\sqrt{Kp}(D/B')) = 1.543$

$dq = d\gamma = (1+0.1\sqrt{Kp}(D/B')) = 1.272$

Inclination factors:

$\theta = \tan^{-1}(H/V) = 0$ (no inclination of loads), so all

$Ic = iq = i\gamma = 1$

Applying Meyrhof BC equation

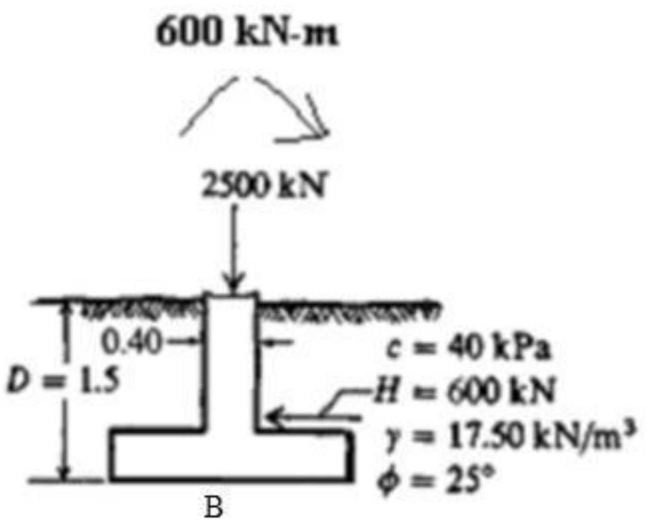
$qu = cNcs_c d_c i_c + \gamma' DNqs_q d_q i_q + 0.5\gamma' BN\gamma s_\gamma d_\gamma i_\gamma$

$qu = 2678.6 + 2112 + 897.5 = 5688$ kPa

$qs = qu/FOS = 5674/3 = 1896$ kPa >1800

Problem-5
Meyerhof BC equation: Design Problem

Find the size of rectangular footing using Meyerhof's equation. The footing is subjected to both horizontal and moment as shown in the figure. Assume B in the direction of M, and H



Solution:

Assume footing dimensions $B \times L = 2.5m \times 3m$. Assuming B in the direction of H and M as shown in figure:

Eccentricities:

$e_B = M_B/V = 600/2500 = 0.24$ m, $e_L = 0$

Effective Footing Dimensions:

$B' = B - 2e_B = 2.02m$, $L' = L - 2e_L = 3m$ $B' < L'$ OK

Meyerhof's BC factors for $\phi = 25°$

$N_q = 10.7$, $N_c = 20.7$, $N_\gamma = 6.8$

Shape factors:

$K_p = \tan^2(45 + \phi/2) = 1.966$

$s_c = (1 + 0.2K_p(B'/L')) = 1.331$

$s_q = s_\gamma = (1 + 0.1K_p(B'/L')) = 1.354$

Depth factors:

$d_c = (1 + 0.2\sqrt{K_p}(D/B')) = 1.233$

$d_q = d_\gamma = (1 + 0.1\sqrt{K_p}(D/B')) = 1.116$

Inclination factors:

$\theta = \tan^{-1}(H/V) = 13.5°$

$i_c = i_q = (1 - \theta/90)^2 = 0.7226$

$i_\gamma = (1 - \theta/\phi)^2 = 0.2117$

Problem-5, Meyerhof BC equation Design Problem

Applying Meyrhof BC equation

$qu = cN_c s_c d_c i_c + \gamma' D N_q s_q d_q i_q + 0.5\gamma' B N_\gamma s_\gamma d_\gamma i_\gamma$

qu=983.5+263.2+32.9=1280 kPa

Effective Area of footing $A' = B' \times L' = 6.06$ m2

Applied stress: qapp= $V/A' = 412.5$ kPa

FOS= qu/qapp = 3.1 < 5 (required)

One way is to assume larger dimensions and recalculate FOS. Another easy approach is as follow:

qu= 1280kPa, qs=qu/FOS=1280/5=255.9kPa

$A' = B'L' = V/qs = 2500/255.9 = 9.769$ m2

Assume

$(B'/L') = ((B'/L')\text{previous} = (2.02/3) = 0.673$

Solving for B′ and L′, $B' = 2.56$ m, $L' = 3.81$ m

$B = B' + 2e_B = 3.04$ m, $L = L' + 2e_L = 3.81$ m

Are the required size of footing.

Solution is over here!

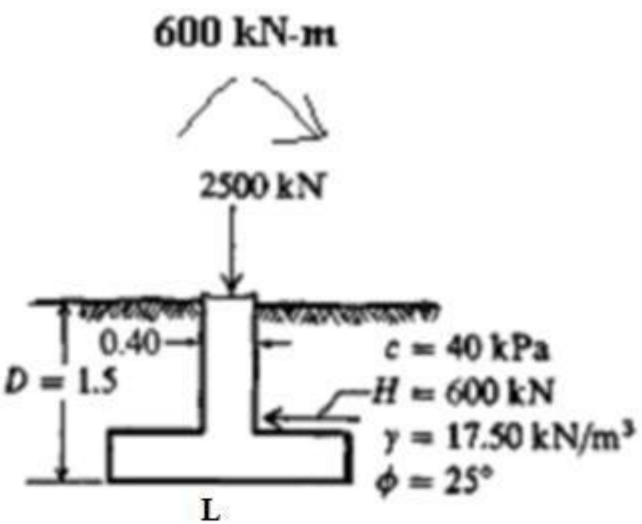
Notes:

- If these new dimensions (3.04mx3.81m) are used and FOS recalculated, the FOS will be very closed to 5.
- Because in recalculations, the BC factors will remain same as previous, shape factors will also remain unchanged as (B′/L′) is kept equal to previous ratio, inclination factors are also unchanged. The only change will occur in depth factors, and 3rd term of BC because they will use new value of B′. But these two will not greatly affect qu, and hence FOS will be closed to 5.
- Unless there is large difference in the old (2.5x3) and new footing dimensions, recalculating FOS is not necessary.
- Let us recycle the calculations FOS=4.84 for new dimensions, fairly closed to 5.
- More refined dimensions giving exactly FOS=5 are 3.08mx3.87m

q=925+299+48=1272
= 1272*2.6*3.87=X/2500 =5 ok

Problem-5
Meyerhof BC equation: Design Problem

Find the size of rectangular footing using Meyerhof's equation. The footing is subjected to both horizontal and moment as shown in the figure. Assume L in the direction of M, and H



Solution:

Assume footing dimensions B×L=2.5m × 3m. Assuming L in the direction of H and M as shown in figure:

Eccentricities:

e_B= M_L/V = 600/2500 = 0.24 m, e_B = 0

Effective Footing Dimensions: B′=B-2e_B = 2.5m, L′=L-2e_L=2.52m B′<L′ OK

Meyerhof's BC factors for ϕ=25°

Nq=10.7, Nc=20.7, Nγ=6.8

Shape factors:

$Kp=\tan^2(45+\phi/2)=1.966$

sc= (1+0.2Kp(B′/L′))=1.489

sq= sγ=(1+0.1Kp(B′/L′))=1.244

Depth factors:

dc= (1+0.2√Kp(D/B′)= 1.188

dq=dγ= (1+0.1√Kp(D/B′)= 1.094

Inclination factors:

θ=tan-1(H/V)= 13.5°

$ic=iq=(1-\theta/90)^2=0.7226$

$i\gamma=(1-\theta/\phi)^2=0.2117$

Problem-5, Meyerhof BC equation Design Problem

Applying Meyrhof BC equation

$qu = cN_c s_c d_c i_c + \gamma' D N_q s_q d_q i_q + 0.5\gamma' B N_\gamma s_\gamma d_\gamma i_\gamma$

qu=1059.6+275.4+42.7=1377 kPa

Effective Area of footing $A' = B' \times L' = 6.3 m^2$

Applied stress: qapp= V/A′=396.8 kPa

FOS= qu/qapp = 3.47 < 5 (required)

One way is to assume larger dimensions and recalculate FOS. Another easy approach is as follow:

qu= 1377kPa, qs=qu/FOS=1377/5=275.5kPa

$A' = B' \times L'$=V/qs=2500/255.9=9.073m2

Assume

(B′/L′)=((B′/L′)previous=(2.5/2.52)=0.992

Solving for B′ and L′, B′=3m, L′=3.024m

$B = B' + 2e_B = 3m$, $L = L' + 2e_L = 3.5m$

Are the required size of footing.

Solution is over here!

Notes:

- Same notes apply as for previous example.
- Just for interest: Let us recycle the calculations FOS=4.9 for new dimensions, fairly closed to 5.
- More refined dimensions giving exactly FOS=5 are 3.03mx3.53m
- Total area of footing for previous example is 3.04x3.81=11.58 m2.
- Total area of footing in the present example is 3x3.5=10.5m2.
- Note the economy gained in using L in the direction of M and H.

Problem-6

A strip footing will be constructed on a nonplastic silty sand deposit that has the shear strength properties $c'=0, \phi=30°$). Groundwater table is located 1.2m below the ground surface. Saturated unit weight of the soil both above and below the W.T is19.7 kN/m^3. The proposed strip footing will be 1.2m wide and embedded 0.6m below the ground surface. Using FOS=3 against shear failure of the soil, determine the safe bearing pressure and the maximum concentric load the strip footing can support for the nonplastic silty sand. Use Terzaghi equation with Meyerhof BC factors.

Solution:

Effect of W.T: zw (depth of WT below the footing level) = 1.2-0.6=0.6m

H = B/2 tan $(45+\phi/2)$= 1.04m>zw

so WT will affect the 3rd term. γ' in 3rd term will be = [(19.7×0.6) + (19.7-9.8)(1.04-0.6)]/1.04=15.5 kN/m^3

Terzaghi BC equation

$q_u = cN_c s_c + \gamma' D N_q + 0.5\gamma' B N_\gamma s_\gamma$

Meyerhof's BC factors for $\phi=30°$

$N_q=18.4$, $N_c=30$, $N_\gamma=15.6$

Shape factors: $s_c= s_\gamma= 1$ (for strip footing)

qu=0+217.9+146=363 kPa

qs=qu/FOS=363/3=121 Pa

Psafe=qs x (Bx1) = 145 kN/m

Problem-8, Drained and Undrained Analyses

A strip footing will be constructed over heavily over-consolidated clay that has an undrained shear strength su = 200 kPa (i.e. cu=200 kPa, ϕu=0), and a drained shear strength of ϕ′=28°, c′=5kPa. The proposed strip footing will be 1.2m wide, and embedded 0.6m below the ground surface. Assume the W.T is located at a depth of 1.2m below the ground surface. The saturated unit weight of the clay is 19.7 kN/m³ both above and below the W.T. Perform both a total stress analysis and an effective stress analysis, determine the allowable load using Terzaghi equation with Meyerhof BC factors.

8.1 A load of 425 kN/m is carried on a strip footing 2 m wide at a depth of 1 m in a stiff clay of saturated unit weight 21 kN/m³, the water table being at ground level. Determine the factor of safety with respect to shear failure (a) when $c_u = 105\,\text{kN/m}^2$ and $\phi_u = 0$ and (b) when $c' = 10\,\text{kN/m}^2$ and $\phi' = 28°$.

8.1

1 (a) The ultimate bearing capacity is given by Equation 8.3

$$q_f = cN_c + \gamma D N_q + \frac{1}{2}\gamma B N_\gamma$$

For $\phi_u = 0$:

$$N_c = 5.14,\ N_q = 1,\ N_\gamma = 0$$
$$\therefore\ q_f = (105 \times 5.14) + (21 \times 1 \times 1) = 540 + 21\,\text{kN/m}^2$$

The net ultimate bearing capacity is

$$q_{nf} = q_f - \gamma D = 540\,\text{kN/m}^2$$

The net foundation pressure is

$$q_n = q - \gamma D = \frac{425}{2} - (21 \times 1) = 192\,\text{kN/m}^2$$

The factor of safety (Equation 8.6) is

$$F = \frac{q_{nf}}{q_n} = \frac{540}{192} = 2.8$$

2 $F = \frac{q_{nf}}{q_n} = \frac{540}{192} = 2.8$

(b) For $\phi' = 28°$:

$$N_c = 26,\ N_q = 15,\ N_\gamma = 13 \quad \text{(from Figure 8.4)}$$
$$\gamma' = 21 - 9.8 = 11.2\,\text{kN/m}^3$$
$$\therefore\ q_f = (10 \times 26) + (11.2 \times 1 \times 15) + \left(\frac{1}{2} \times 11.2 \times 2 \times 13\right)$$
$$= 260 + 168 + 146 = 574\,\text{kN/m}^2$$

$$q_{nf} = 574 - 11.2 = 563\,\text{kN/m}^2$$
$$F = \frac{563}{192} = 2.9$$

($q_n = 192\,\text{kN/m}^2$ assumes that backfilled soil on the footing slab is included in the load of 425 kN/m.)