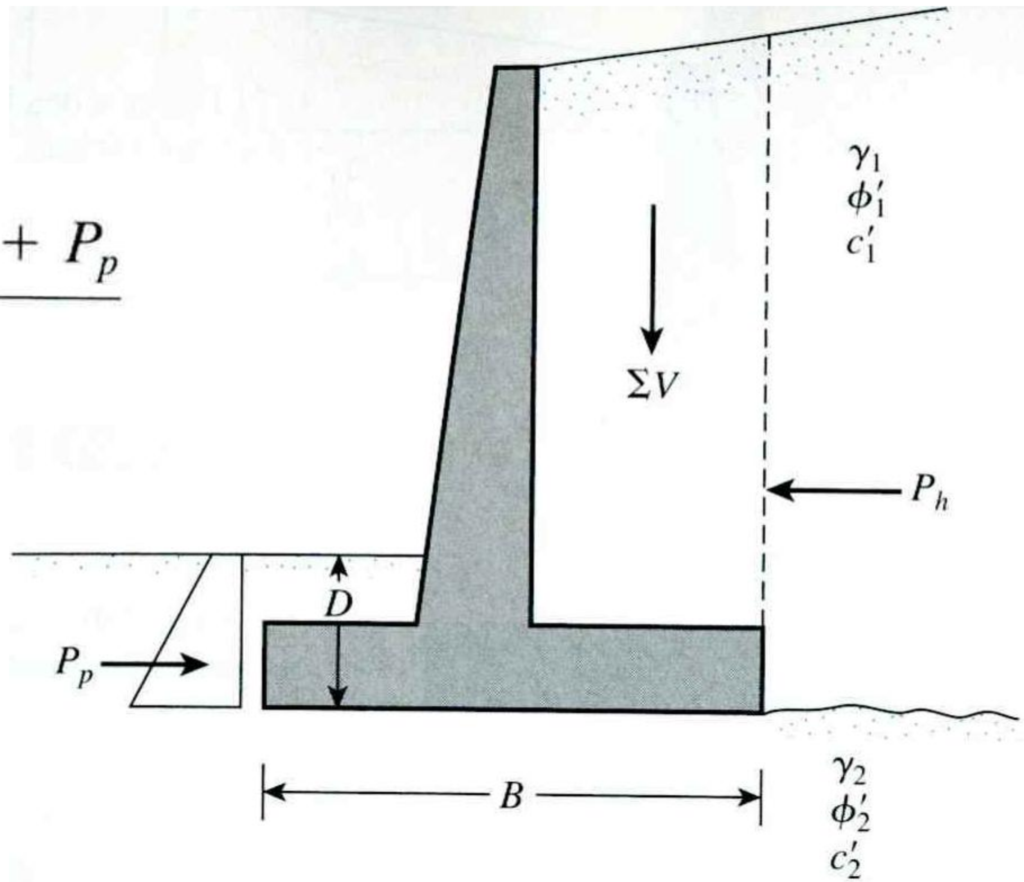
Stability of Cantilever Retaining Wall Against Sliding

$$FS_{(sliding)} = \frac{(\Sigma V)\tan\delta' + Bc'_a + P_p}{P_a \cos\alpha}$$

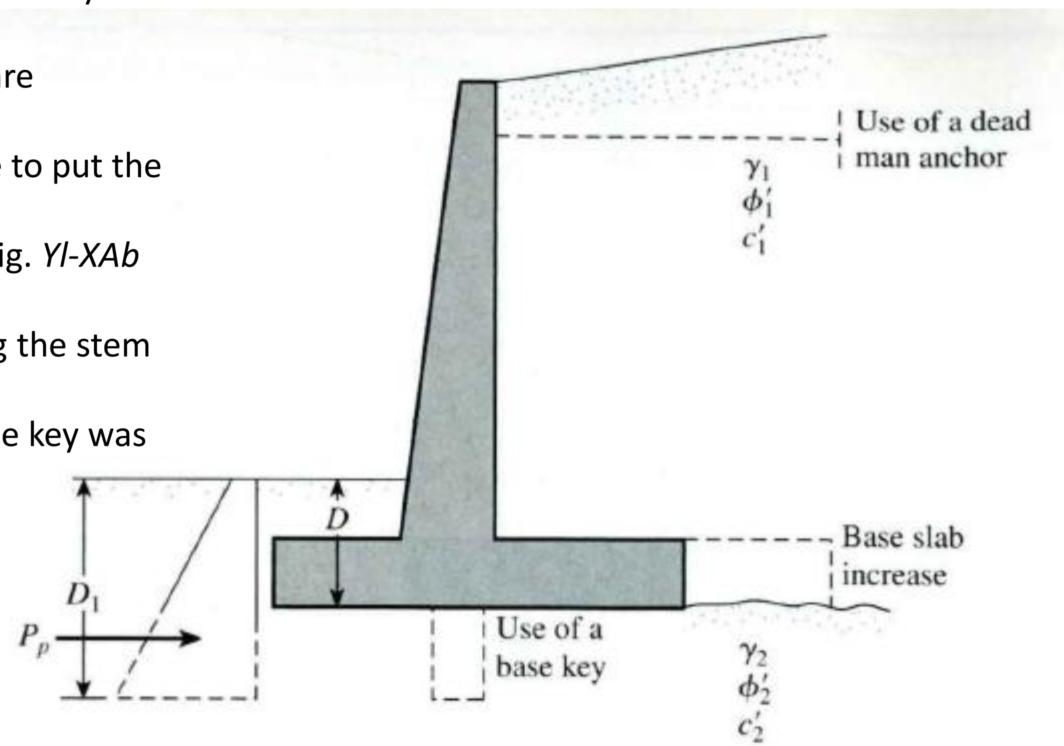


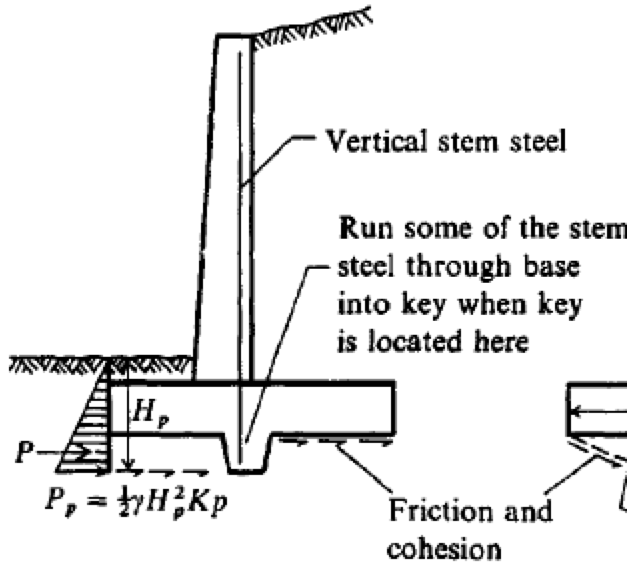
Alternatives for increasing the factor of safety with respect to sliding

1. Increase the width of the base slab (i.e., the heel of the footing).
2. Use a key to the base slab. If a key is included, the passive force per unit length of the wall becomes
3. Use a *deadman anchor at the stem of the retaining wall*

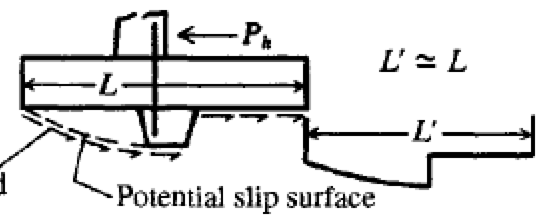
Base Key

Where sufficient sliding stability is not possible—usually for walls with large *H—a base key,*
as illustrated in Fig. 12-14, has been used. There are different opinions on the best location
for a key and on its value. It was common practice to put the key beneath the stem as in Fig.
12-14a, until it was noted that the conditions of Fig. *Yl-XAb were possible. This approach*
was convenient from the view of simply extending the stem reinforcement through the base
and into the key. Later it became apparent that the key was more effective located as in Fig.
12- 14c and, if one must use a key, this location is recommended. The increase in *H by the*
key depth may null its effect.

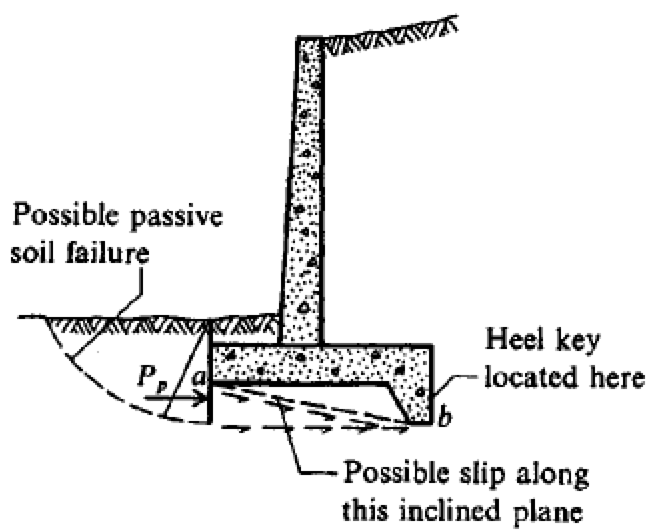




(*a*) Base key near stem so that stem steel may be extended into the key without additional splicing or using anchor bends.



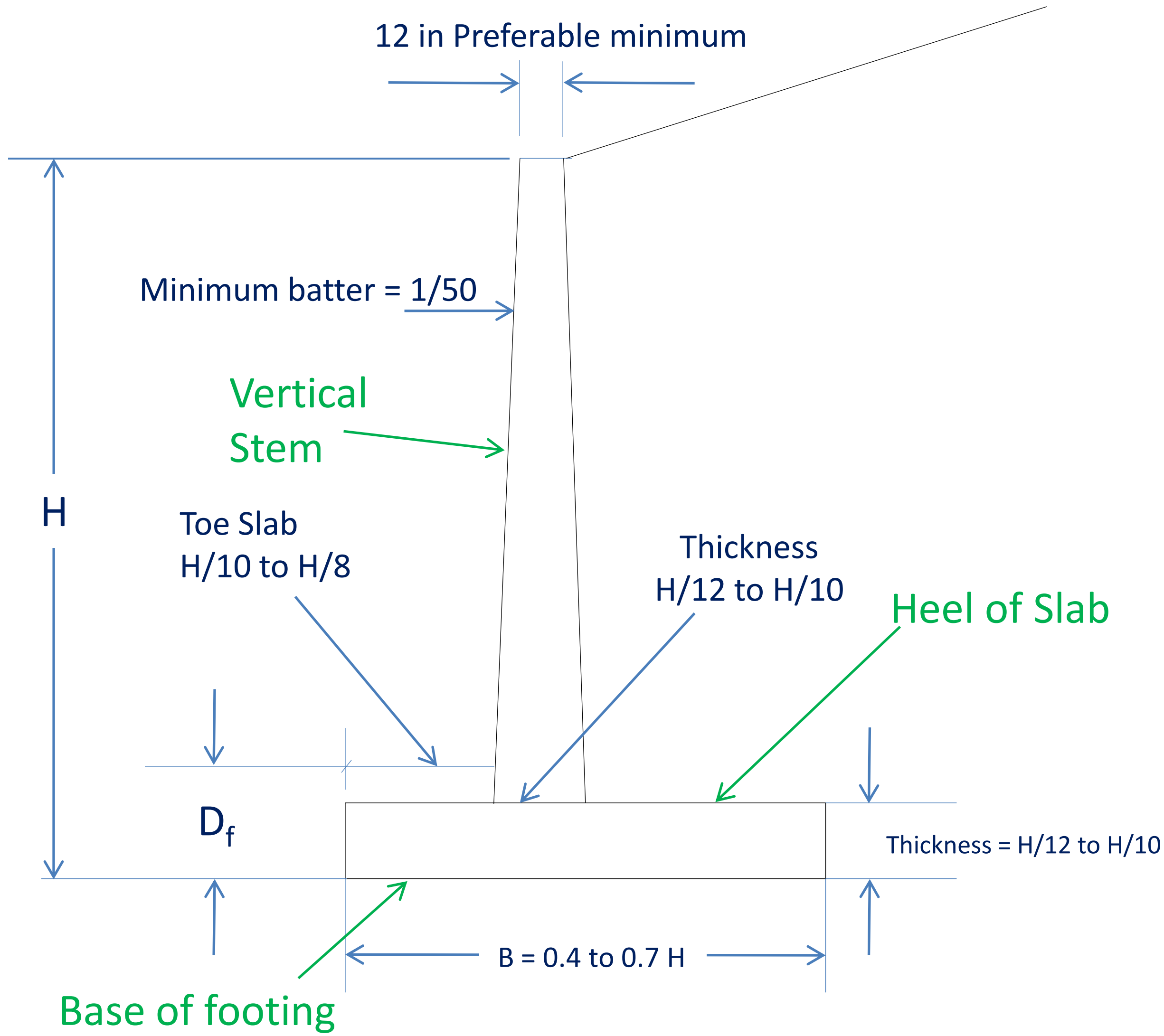
(*b*) Potential sliding surface using the key location of *a*. There may be little increase in sliding resistance from this key, if the slip surface develops as shown.

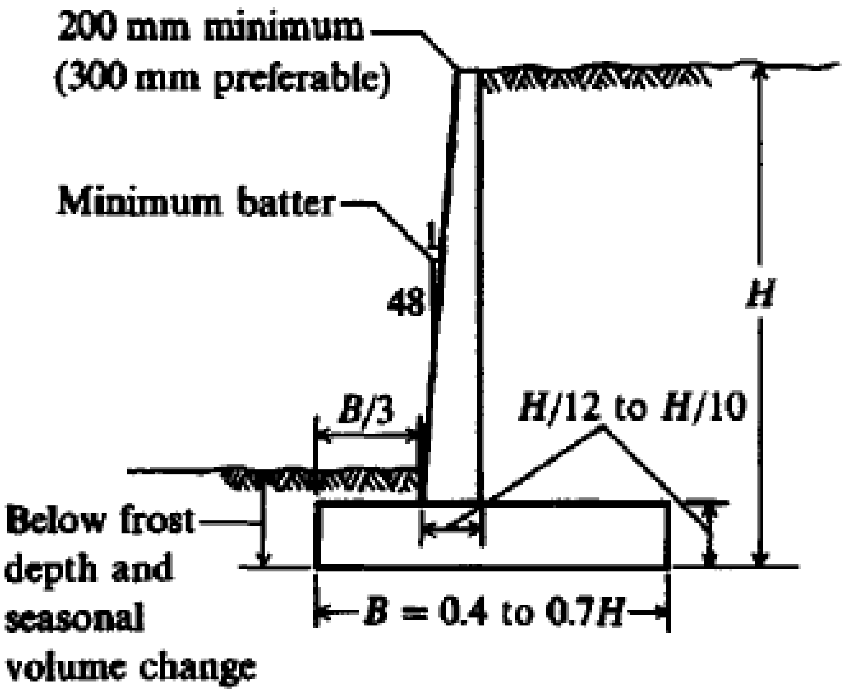


(*c*) Possible sliding modes when using a heel key.

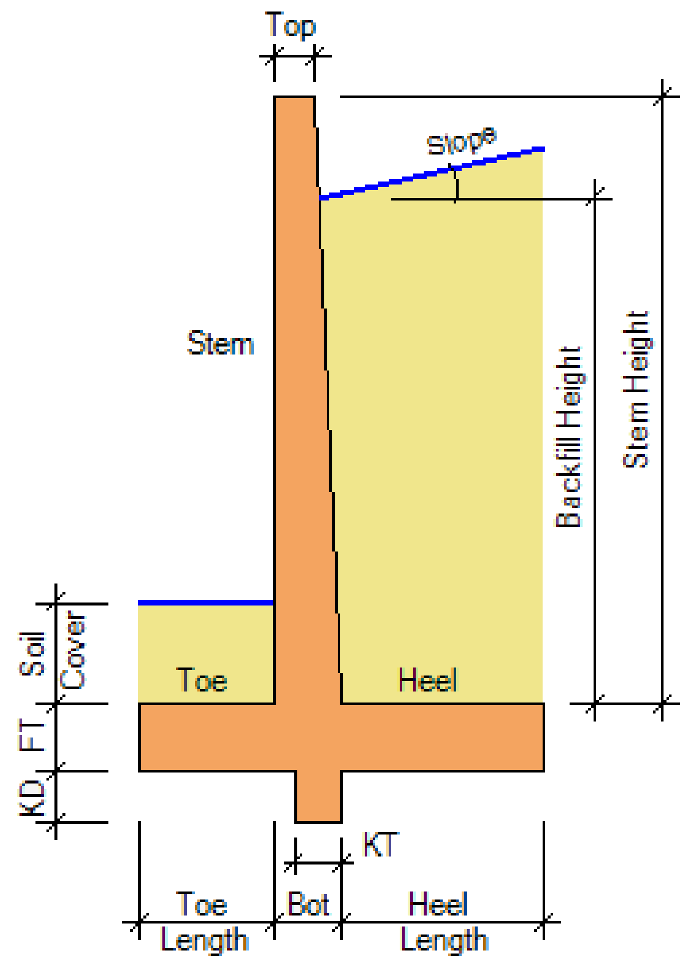
Figure 12-14 Stability against sliding by using a base key.

Common Proportions of Cantilever Wall





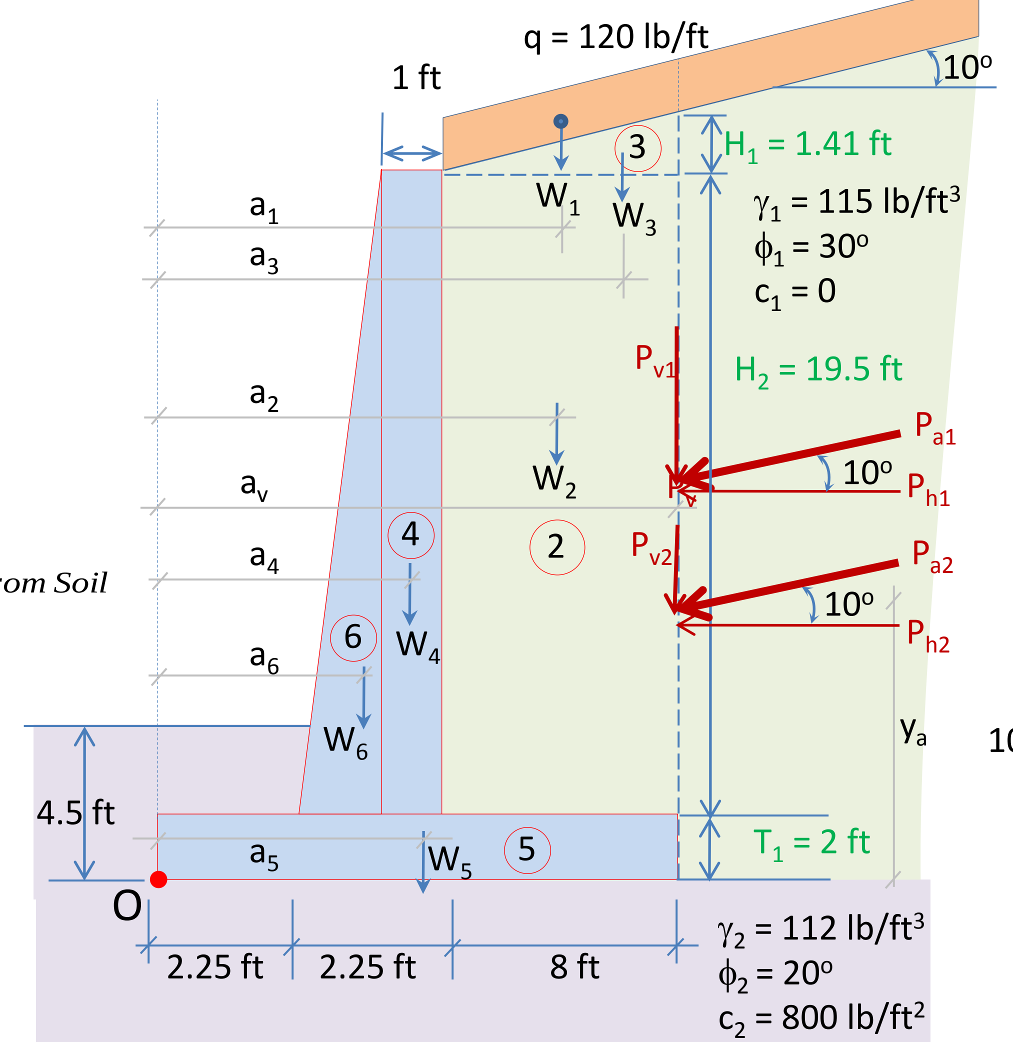
Tentative design dimensions for a cantilever retaining wall. Batter shown is optional.



Example 1

Given

The cross section of a cantilever retaining wall is shown in Figure 1. Calculate the factors of safety with respect to overturning, sliding, and bearing capacity.



Solution

From the figure,

H' = H1 + H2 + T1 = 8 tan 10° + 19.5 + 2 = 22.91 ft

The Rankine active force per unit length of wall =

$$K_a = \cos\alpha \frac{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}}$$

$$K_a = \cos 10 \frac{\cos 10 - \sqrt{\cos^2 10 - \cos^2 30}}{\cos 10 + \sqrt{\cos^2 10 - \cos^2 30}} = 0.34$$

$$P_a = \text{Lateral Pressure from Surcharge} + \text{Lateral Pressure from Soil}$$

$$P_{a1} = q\,H'\,k_a$$

$$P_{a2} = \frac{1}{2}\gamma H'^2 k_a$$

$$P_{a1} = 120x22.9x0.34$$

$$Y_{a1} = \frac{22.9}{2} = 11.45\ ft$$

$$P_{a2} = 10252.22 = 11186.54\ lb/ft$$

$$Y_{a1} = \frac{22.9}{3} = 7.63\ ft$$

Section no.[a]	Area (m^2)	Weight/unit length (kN/m)	Moment arm from point *C* (m)	Moment (kN-m/m)
1	$6 \times 0.5 = 3$	70.74	1.15	81.35
2	$\frac{1}{2}(0.2)6 = 0.6$	14.15	0.833	11.79
3	$4 \times 0.7 = 2.8$	66.02	2.0	132.04
4	$6 \times 2.6 = 15.6$	280.80	2.7	758.16
5	$\frac{1}{2}(2.6)(0.458) = 0.595$	10.71	3.13	33.52
		$P_v = 28.29$	4.0	113.16
		$\Sigma V = 470.71$		$1130.02 = \Sigma M_R$

[a]For section numbers, refer to Figure 8.12

$\gamma_{concrete} = 23.58 \text{ kN/m}^3$

The overturning moment

$$M_o = P_h\left(\frac{H'}{3}\right) = 160.43\left(\frac{7.158}{3}\right) = 382.79 \text{ kN-m/m}$$

and

$$FS_{(overturning)} = \frac{\Sigma M_R}{M_o} = \frac{1130.02}{382.79} = \mathbf{2.95 > 2, OK}$$

Factor of Safety against Sliding

From Eq. (8.11),

$$FS_{(sliding)} = \frac{(\Sigma V)\tan(k_1\phi_2') + Bk_2c_2' + P_p}{P_a\cos\alpha}$$

Let $k_1 = k_2 = \frac{2}{3}$. Also,

$$P_p = \tfrac{1}{2}K_p\gamma_2 D^2 + 2c_2'\sqrt{K_p}D$$

$$K_p = \tan^2\left(45 + \frac{\phi_2'}{2}\right) = \tan^2(45 + 10) = 2.04$$

and

$$D = 1.5\text{ m}$$

So

$$P_p = \tfrac{1}{2}(2.04)(19)(1.5)^2 + 2(40)(\sqrt{2.04})(1.5)$$
$$= 43.61 + 171.39 = 215\text{ kN/m}$$

Hence,

$$FS_{\text{(sliding)}} = \frac{(470.71)\tan\left(\frac{2 \times 20}{3}\right) + (4)\left(\frac{2}{3}\right)(40) + 215}{160.43}$$

$$= \frac{111.56 + 106.67 + 215}{160.43} = \mathbf{2.7 > 1.5,\ OK}$$

Note: For some designs, the depth D in a passive pressure calculation may be take
be *equal to the thickness of the base slab.*

Factor of Safety against Bearing Capacity Failure

Combining Eqs. (8.16), (8.17), and (8.18) yields

$$e = \frac{B}{2} - \frac{\Sigma M_R - \Sigma M_o}{\Sigma V} = \frac{4}{2} - \frac{1130.02 - 382.79}{470.71}$$

$$= 0.411 \text{ m} < \frac{B}{6} = \frac{4}{6} = 0.666 \text{ m}$$

Again, from Eqs. (8.20) and (8.21)

$$q_{\substack{\text{toe}\\\text{heel}}} = \frac{\Sigma V}{B}\left(1 \pm \frac{6e}{B}\right) = \frac{470.71}{4}\left(1 \pm \frac{6 \times 0.411}{4}\right) = 190.2 \text{ kN/m}^2 \text{ (toe)}$$

$$= 45.13 \text{ kN/m}^2 \text{ (heel)}$$

The ultimate bearing capacity of the soil can be determined from Eq. (8.22)

$$q_u = c_2' N_c F_{cd} F_{ci} + q N_q F_{qd} F_{qi} + \frac{1}{2} \gamma_2 B' N_\gamma F_{\gamma d} F_{\gamma i}$$

For $\phi_2' = 20°$ (see Table 3.3), $N_c = 14.83$, $N_q = 6.4$, and $N_\gamma = 5.39$. Also,

$$q = \gamma_2 D = (19)(1.5) = 28.5 \text{ kN/m}^2$$

$$B' = B - 2e = 4 - 2(0.411) = 3.178 \text{ m}$$

$$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c \tan\phi_2'} = 1.148 - \frac{1 - 1.148}{(14.83)(\tan 20)} = 1.175$$

$$F_{qd} = 1 + 2\tan\phi_2'(1 - \sin\phi_2')^2\left(\frac{D}{B'}\right) = 1 + 0.315\left(\frac{1.5}{3.178}\right) = 1.148$$

$$F_{\gamma d} = 1$$

$$F_{ci} = F_{qi} = \left(1 - \frac{\psi°}{90°}\right)^2$$

and

$$\psi = \tan^{-1}\left(\frac{P_a \cos\alpha}{\Sigma V}\right) = \tan^{-1}\left(\frac{160.43}{470.71}\right) = 18.82°$$

So

$$F_{ci} = F_{qi} = \left(1 - \frac{18.82}{90}\right)^2 = 0.626$$

and

$$F_{\gamma i} = \left(1 - \frac{\psi}{\phi_2'}\right)^2 = \left(1 - \frac{18.82}{20}\right)^2 \approx 0$$

Hence,

$$q_u = (40)(14.83)(1.175)(0.626) + (28.5)(6.4)(1.148)(0.626) + \tfrac{1}{2}(19)(5.93)(3.178)(1)(0)$$

$$= 436.33 + 131.08 + 0 = 567.41 \text{ kN/m}^2$$

and

$$\text{FS}_{\text{(bearing capacity)}} = \frac{q_u}{q_{\text{toe}}} = \frac{567.41}{190.2} = \mathbf{2.98}$$

Note: $\text{FS}_{\text{(bearing capacity)}}$ is less than 3. Some repropertioning will be needed.