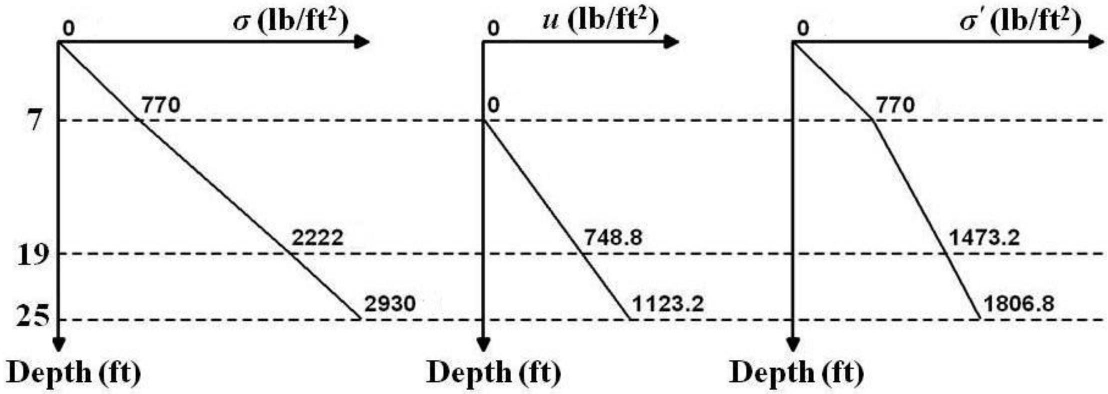
Chapter 9

9.1

Point	lb/ft^2		
	σ	u	σ'
A	**0**	**0**	**0**
B	(7)(110) = **770**	**0**	**770**
C	770 + (12)(121) = **2222**	(62.4)(12) = **748.8**	**1473.2**
D	2222 + (6)(118) = **2930**	748.8 + (62.4)(6) = **1123.2**	**1806.8**

The plot is given below.



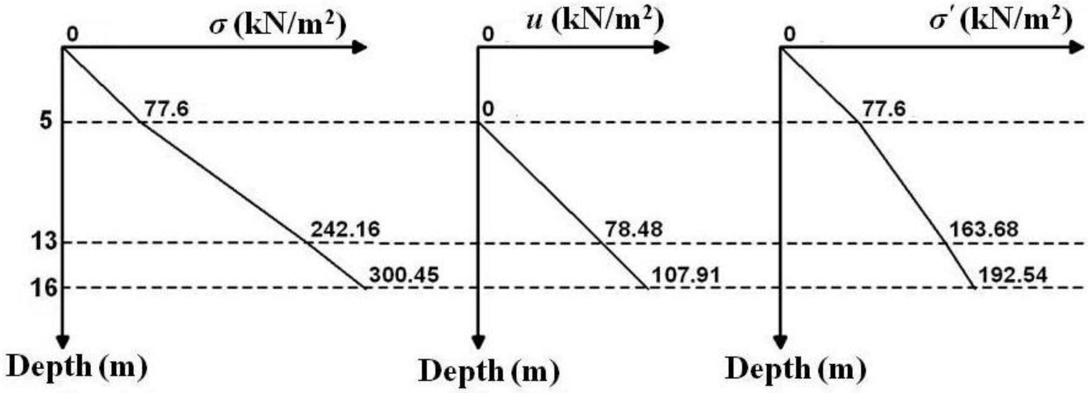
9.2 $$\gamma_{d\,(\text{layer 1})} = \frac{G_s\gamma_w}{1+e} = \frac{(2.69)(9.81)}{1+0.7} = 15.52 \text{ kN/m}^3$$

$$\gamma_{\text{sat(layer 2)}} = \frac{\gamma_w(G_s+e)}{1+e} = \frac{(9.81)(2.7+0.55)}{1+0.55} = 20.57 \text{ kN/m}^3$$

$$\gamma_{\text{sat(layer 3)}} = \frac{\gamma_w(G_s+e)}{1+e} = \frac{(9.81)\left(\frac{1.2}{0.38}+1.2\right)}{1+1.2} = 19.43 \text{ kN/m}^3$$

Point	kN/m^2		
	σ	u	σ'
A	**0**	**0**	**0**
B	(5)(15.52) = **77.6**	**0**	**77.6**
C	77.6 + (8)(20.57) = **242.16**	(9.81)(8) = **78.48**	**163.68**
D	242.16 + (3)(19.43) = **300.45**	78.48 + (9.81)(3) = **107.9**	**192.54**

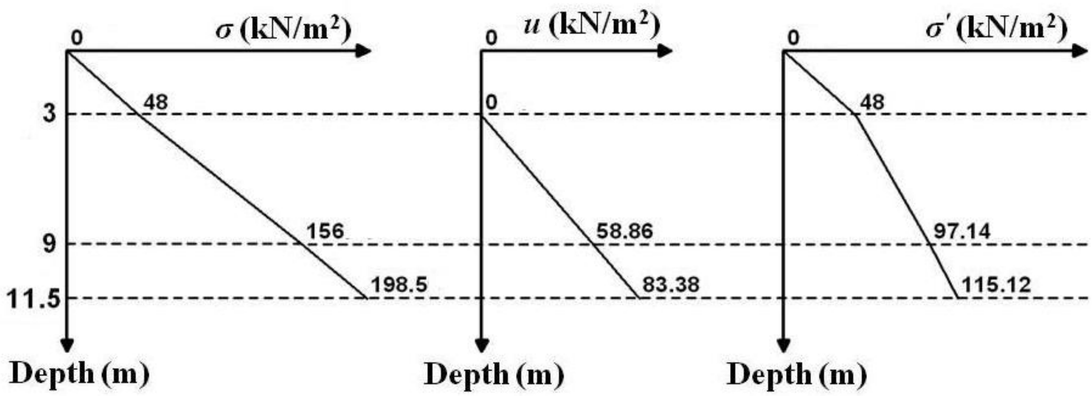
The plot is shown below.



9.3

Point	kN/m^2		
	σ	u	σ'
A	**0**	**0**	**0**
B	(3)(16) = **48**	**0**	**48**
C	48 + (6)(18) = **156**	(9.81)(6) = **58.86**	**97.14**
D	156 + (2.5)(17) = **198.5**	58.86 + (9.81)(2.5) = **83.38**	**115.12**

The plot is shown below.



9.4 a. Water table drops 2 m within layer 2. Assuming dry condition for 2 m:

$$\gamma_{d\,(\text{layer 2})} = \frac{G_s \gamma_w}{1+e} = \frac{(2.7)(9.81)}{1+0.55} = 17.08 \text{ kN/m}^3$$

σ'(at point C) = (5)(15.52) + (2)(17.08) + (6)(20.57) – (6)(9.81)

= 176.32 kN/m^2

Increase in σ': 176.32 – 163.68 = **12.64 kN/m^2**

b. Water table rises to the surface. Layer 1 is saturated.

$$\gamma_{\text{sat(layer1)}} = \frac{\gamma_w(G_s + e)}{1+e} = \frac{(9.81)(2.69+0.7)}{1+0.7} = 19.56\,\text{kN/m}^3$$

σ'(at point C) = (5)(19.56) + (8)(20.57) – (13)(9.81) = 134.83 kN/m^2

Decrease in σ': 163.68 – 134.83 = **28.85 kN/m^2**

c. Water level rises 3 m above ground. All layers are saturated

σ'(at point C) = (3)(9.81) + (5)(19.56) + (8)(20.57) – (16)(9.81)

= 134.83 kN/m^2

Decrease in σ': 163.68 – 134.83 = **28.85 kN/m^2** (same as Part b)

9.5 a. $$\gamma_{d\text{(sand)}} = \frac{G_s\gamma_w}{1+e} = \frac{(2.66)(9.81)}{1+0.61} = 16.2\,\text{kN/m}^3$$

$$\gamma_{\text{sat(sand)}} = \frac{(G_s+e)\gamma_w}{1+e} = \frac{(2.67+0.48)(9.81)}{1+0.48} = 20.88\,\text{kN/m}^3$$

Point	kN/m^2 σ	u	σ'
A	**0**	**0**	**0**
B	(16.2)(4) = **64.8**	**0**	**64.8**
C	64.8 + (20.88)(5) = **169.2**	(9.81)(5) = **49.05**	**120.15**

b. Let the height of rise be h. Portions of the top sand layer will be saturated.

$$\gamma_{\text{sat(top sand)}} = \frac{(G_s + e)\gamma_w}{1+e} = \frac{(2.66+0.61)(9.81)}{1+0.61} = 19.92\ \text{kN/m}^3$$

So, at any time, the stresses at C are:

$\sigma = (4 - h)(16.2) + (h)(19.92) + (5)(20.88) = 169.2 + 3.72h$

$u = (5 + h)(9.81) = 49.05 + 9.81h$

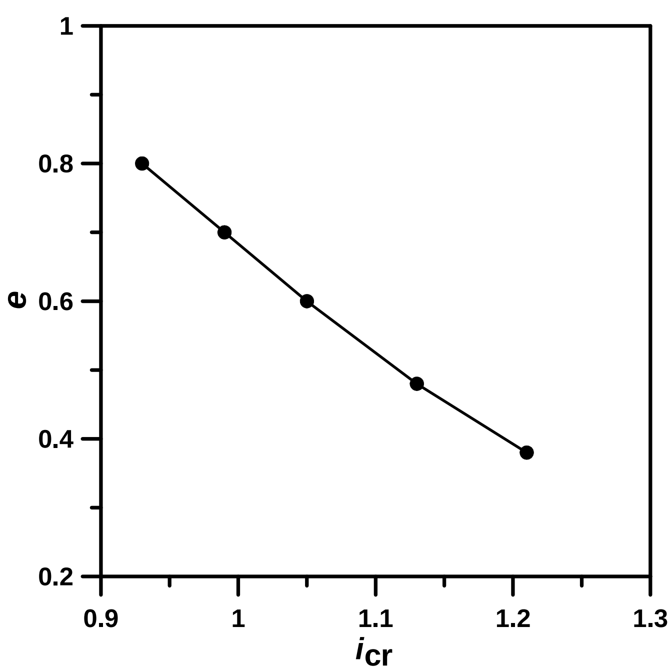
$\sigma' = (169.2 + 3.72h) - (49.05 + 9.81h) = 120.15 - 6.09h$

New σ' at C: $111 = 120.15 - 6.09h$; $h =$ **1.5 m**

9.6 $$i_{\text{cr}} = \frac{\gamma'}{\gamma_w} = \frac{G_s - 1}{1+e} = \frac{2.68-1}{1+e} = \frac{1.68}{1+e}$$

e	i_{cr}
0.38	1.21
0.48	1.13
0.6	1.05
0.7	0.99
0.8	0.93

The plot is shown below.



9.7 $\gamma_{\text{sat(clay)}} = \dfrac{(1+w)G_s\gamma_w}{1+wG_s} = \dfrac{(1+0.29)(2.68)(9.81)}{1+(0.29)(2.68)} = 19.08\text{ kN/m}^3$

Let the depth of the excavation be H.

So, $(10 - H)(19.08) - (6)(9.81) = 0 = \sigma'$.

$H \approx$ **6.91 m**

9.8 Consider the stability of point A in terms of heaving.

$\gamma_{\text{sat(clay)}} = \dfrac{(1925)(9.81)}{1000} = 18.88\text{ kN/m}^3$

$\sigma_A = (10 - 5.75)(18.88) = 80.24\text{ kN/m}^2$

$u_A = (6)(9.81) = 58.86\text{ kN/m}^2$

For heaving to occur, $\sigma' = 0$; or $\sigma = u$

Therefore, factor of safety = $\dfrac{\sigma_A}{u_A} = \dfrac{80.24}{58.86} = \mathbf{1.36}$

9.9 Let the maximum permissible depth of cut be H.

$\sigma_A = (10 - H)(18.88)$

$u_A = (6)(9.81) = 58.86\text{ kN/m}^2$

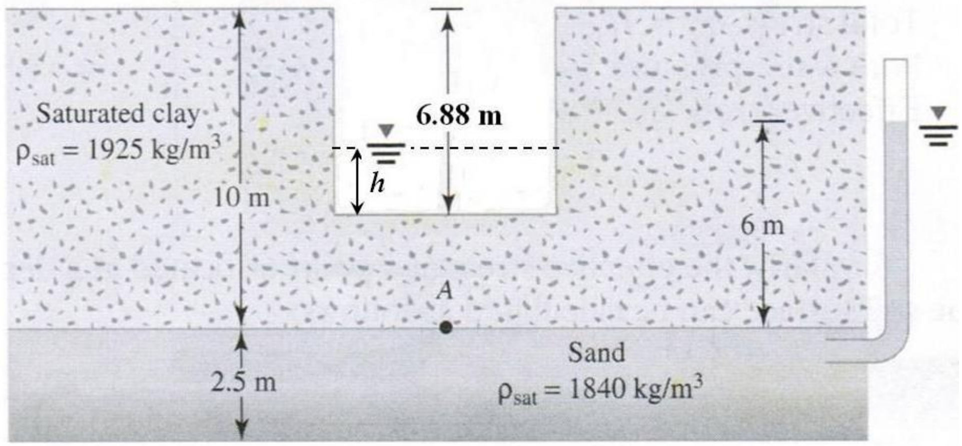
For heaving to occur, $\sigma' = 0$; or $\sigma_A - u_A = 0$

$(10 - H)(18.88) - 58.86 = 0$; $H =$ **6.88 m**

9.10 Let the height of water inside the cut be h (see figure on following page)

$\sigma_A = (10 - 6.88)(18.88) + (h)(9.81) = 58.9 + 9.81h$

$u_A = (6)(9.81) = 58.86\text{ kN/m}^2$



Factor of safety: $\dfrac{\sigma_A}{u_A} = \dfrac{58.9 + 9.81h}{58.86} = 1.5$

h = **3.0 m**

9.11 a. $i = \dfrac{h}{H_2} = \dfrac{1.5}{2.5} = 0.6$

$q = kiA = (0.21)(0.6)(0.62 \times 100^2 \text{ cm}^2) =$ **781.2 cm³/sec**

b. $i_{cr} = \dfrac{\gamma'}{\gamma} = \dfrac{G_s - 1}{1+e} = \dfrac{2.66-1}{1+0.49} = 1.11$

Since $i < i_{cr}$, **no boiling**.

c. $i = i_{cr} = \dfrac{h}{H_2}; \quad 1.11 = \dfrac{h}{2.5}$

h = **2.77 m**

9.12 a. $i = \dfrac{h}{H_2} = \dfrac{1.5}{4.5} = 0.33$

$q = kiA = (0.31)(0.33)(6.2) =$ **0.634 ft³/min**

b. Refer to Figure 9.4 (a). Since C is located at the middle of the soil layer,

$z = H_2/2 = 4.5/2 = 2.25$ ft

Eq. (9.7): $\sigma'_c = z\gamma' - iz\gamma_w =$ (2.25)(119-62.4) – (0.33)(2.25)(62.4) = **81 lb/ft²**

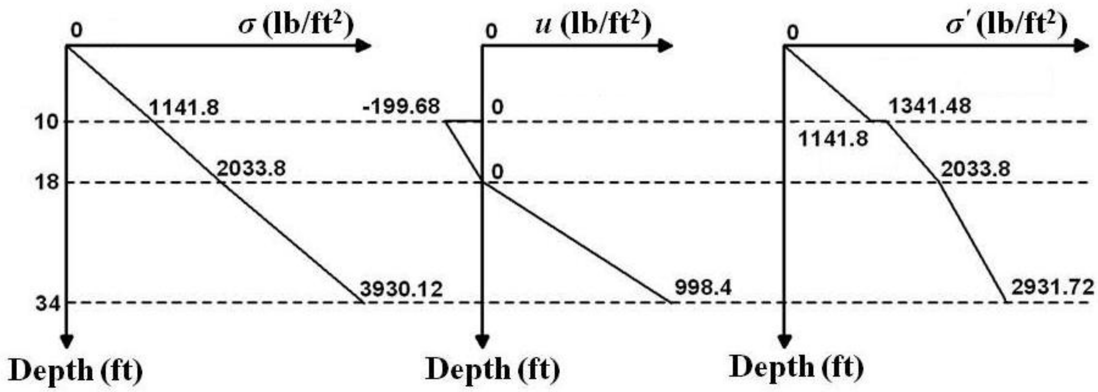
9.13 $$\gamma_{d\,(\text{sand})} = \frac{G_s\gamma_w}{1+e} = \frac{(2.69)(62.4)}{1+0.47} = 114.18\ \text{lb/ft}^3$$

$$\gamma_{\text{sat(clay: capillary zone)}} = \frac{\gamma_w(G_s + Se)}{1+e} = \frac{(62.4)[2.73+(0.4)(0.68)]}{1+0.68} = 111.5\ \text{lb/ft}^3$$

$$\gamma_{\text{sat(clay)}} = \frac{\gamma_w(G_s+e)}{1+e} = \frac{(62.4)(2.7+0.89)}{1+0.89} = 118.52\ \text{lb/ft}^3$$

Depth (ft)	lb/ft² σ	u	σ'
0	**0**	**0**	**0**
10	(114.18)(10) = **1141.8**	**0**	**1141.8**
		(–0.4)(62.4)(8) = **–199.68**	**1341.48**
10+8=18	1141.8+ (111.5)(8) = **2033.8**	**0**	**2033.8**
10+8+16=34	2033.8 + (118.52)(16) = **3930.12**	(16)(62.4) = **998.4**	**2931.72**

The plot is given below.



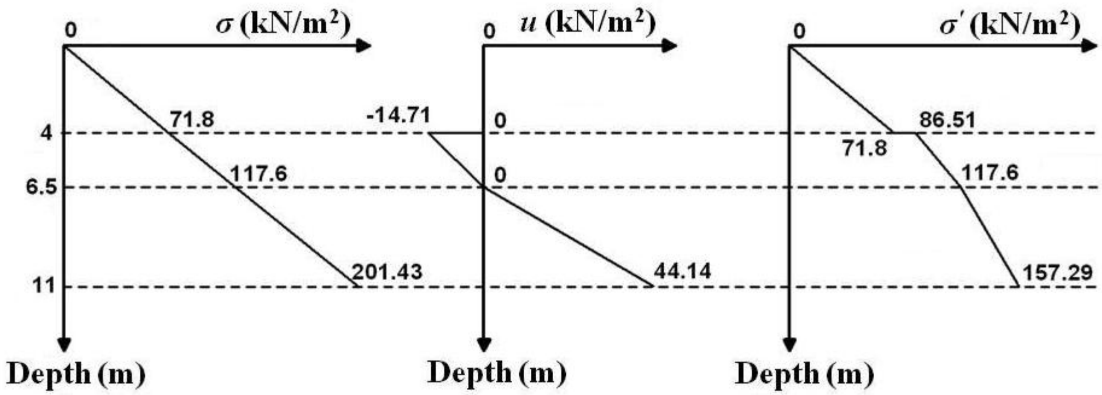
9.14 $\gamma_{d\,(\text{sand})} = \dfrac{(2.69)(9.81)}{1+0.47} = 17.95\ \text{kN/m}^3$

$$\gamma_{\text{sat(clay: capillary zone)}} = \frac{(9.81)[2.73+(0.6)(0.68)]}{1+0.68} = 18.32\ \text{kN/m}^3$$

$$\gamma_{\text{sat(clay)}} = \frac{(9.81)(2.7+0.89)}{1+0.89} = 18.63\ \text{kN/m}^3$$

Depth (m)	kN/m^2 σ	u	σ'
0	**0**	**0**	**0**
4	(17.95)(4) = **71.8**	**0**	**71.8**
		(–0.6)(9.81)(2.5) = **–14.71**	**86.51**
4+2.5=6.5	71.8 + (18.32)(2.5) = **117.6**	**0**	**117.6**
4+2.5+4.5=11	117.6 + (18.63)(4.5) = **201.43**	(4.5)(9.81) = **44.14**	**157.29**

The plot is given.



9.15 From Eq. (9.22), $FS = \dfrac{D\gamma'}{C_o\gamma_w(H_1 - H_2)}$

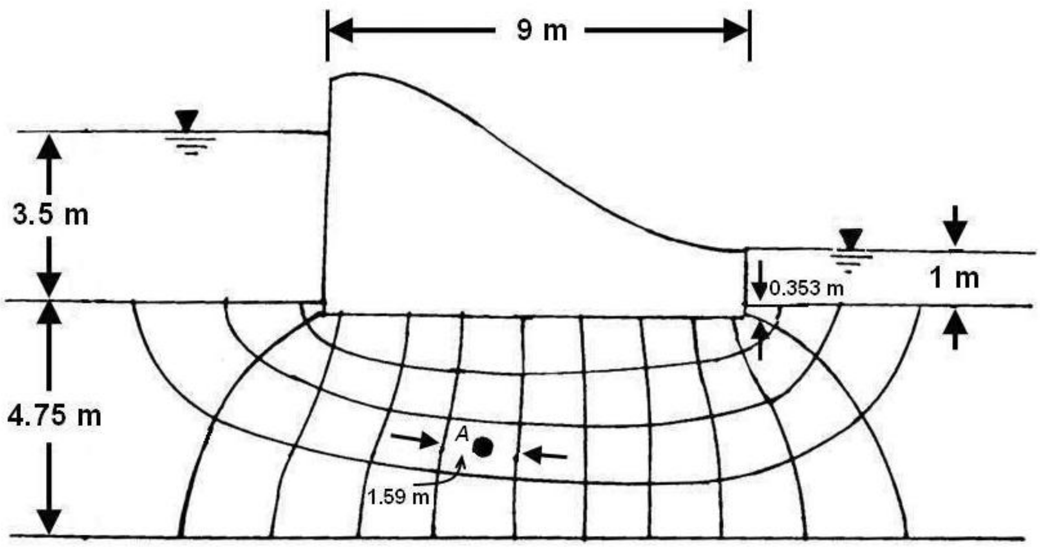
$D = 4.5$ m; $\gamma' = 17 - 9.81 = 7.19$ kN/m^3; $H_1 - H_2 = 7 - 3 = 4$ m;

$D/T = 4.5/12 = 0.375$. From Table 9.1, $C_o = 0.354$ (by linear interpolation).

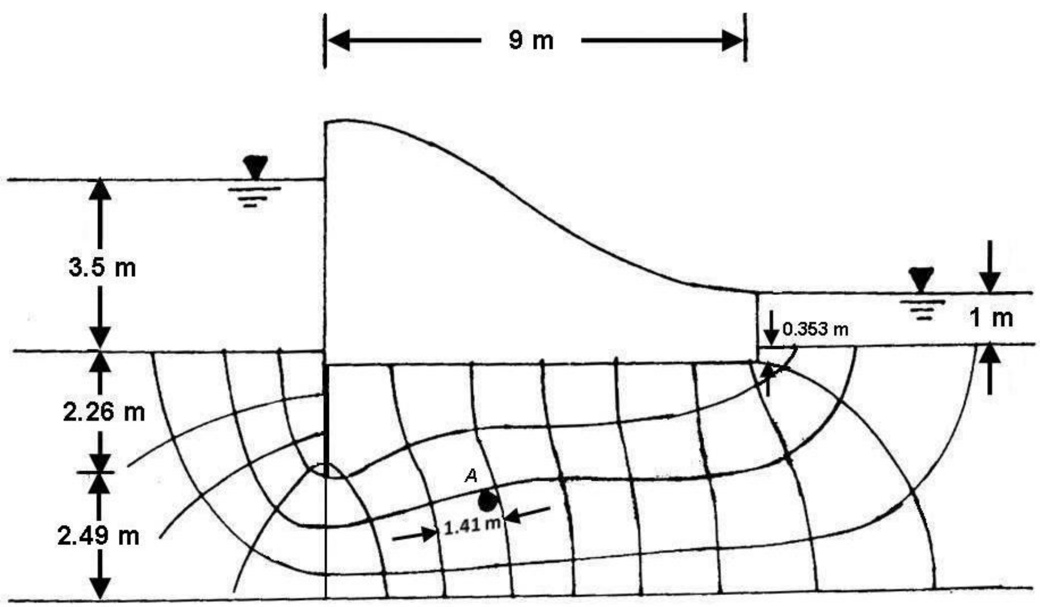
$$FS = \frac{(4.5)(7.19)}{(0.354)(9.81)(4)} = \mathbf{2.33}$$

9.C.1 a. The flow nets for both cases are given below:

Case 1



Case 2



b. Determination of $\frac{q}{k}$:

From Eq. (8.21): $q = kH\frac{N_f}{N_d}$

Case 1: $N_f = 4$, $N_d = 11$, $H = 3.5 - 1 = 2.5$ m

$$\frac{q}{k} = (2.5)\left(\frac{4}{11}\right) = \mathbf{0.909\,m}$$

Case 2: $N_f = 3.5$, $N_d = 13$, $H = 2.5$ m

$$\frac{q}{k} = (2.5)\left(\frac{3.5}{13}\right) = \mathbf{0.673\,m}$$

c. $FS = \frac{i_{\mathrm{cr}}}{i_{\mathrm{exit}}}$

$$i_{\mathrm{cr}} = \frac{G_s - 1}{1+e} = \frac{2.66-1}{1.55} = 1.071$$

Case 1: Refer to the flow net and Eq. (9.24a):

$$i_{\mathrm{exit}} = \frac{H}{N_d\, l} = \frac{2.5}{(11)(0.353)} = 0.643$$

$$FS = \frac{1.071}{0.643} \approx \mathbf{1.67}$$

Case 2: Refer to the flow net and Eq. (9.24a):

$$i_{\mathrm{exit}} = \frac{H}{N_d\, l} = \frac{2.5}{(13)(0.353)} = 0.545$$

$$FS = \frac{1.071}{0.545} \approx \mathbf{1.97}$$

d. From Eq. (9.18), seepage force per unit volume is $\gamma_w i$

Case 1: Refer to the flow net. At *A*,

$$i = \frac{\Delta H}{l} = \frac{(2.5/11)}{1.59} = 0.143$$

Seepage force = $\gamma_w i$ = (9.81)(0.143) = **1.4 kN/m³**

Case 2: Refer to the flow net. At *A*,

$$i = \frac{\Delta H}{l} = \frac{(2.5/13)}{1.41} = 0.136$$

Seepage force = $\gamma_w i$ = (9.81)(0.136) = **1.33 kN/m³**

Installation of the sheet pile cut-off wall reduced the exit gradient and increased the factor of safety against heaving. Accordingly, at any point *A*, the seepage force also decreased due to a drop in the hydraulic gradient.