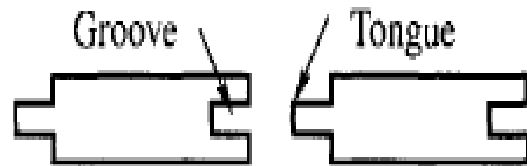


CHAPTER-X-ANALYSIS AND DESIGN OF SHEET **PILE WALL**

INTRODUCTION

- ❖ Sheet pile walls are retaining walls constructed to retain earth, water or any other fill material.
- ❖ Sheet piles may be of timber, reinforced concrete or steel. Timber piling is used for short spans and to resist light lateral loads. They are mostly used for temporary structures such as braced sheeting in cuts.
- ❖ If used in permanent structures above the water level, they require preservative treatment and even then, their span of life is relatively short.
- ❖ Timber piles are not suitable for driving in soils consisting of stones as the stones would dislodge the joints.
- ❖ Timber sheet piles are joined to each other by tongue-and-groove joints as indicated in Fig.

- ❖ Reinforced concrete sheet piles are precast concrete members, usually with a tongue-and groove joint. Typical section of piles are shown in Fig.
- ❖ These piles are relatively heavy and bulky.
- ❖ They displace large volumes of solid during driving.
- ❖ This large volume displacement of soil tends to increase the driving resistance.
- ❖ Steel sheet piles are available in the market in several shapes. Some of the typical pile sections are shown in Fig.



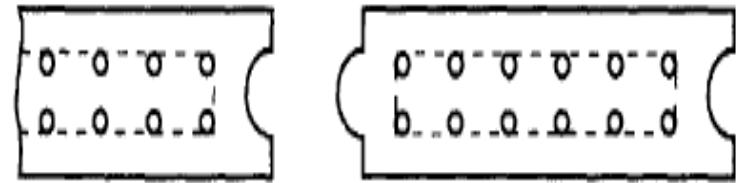
Timber pile wall section



(a) Straight sheet piling



(b) Shallow arch-web piling



Reinforced concrete Sheet pile wall section



(c) Arch-web piling



(d) Z-pile

Sheet pile sections

SHEET PILE WALLS ARE GENERALLY USED FOR THE FOLLOWING:

1. Water front structures, for example, in building wharfs, quays, and piers
2. Building diversion dams, such as cofferdams
3. River bank protection
4. Retaining the sides of cuts made in earth

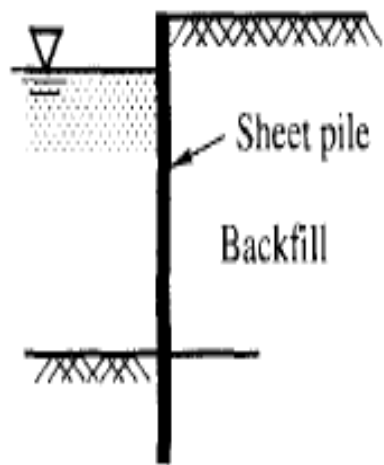
Steel piles possess several advantages over the other types.

Some of the important advantages are:

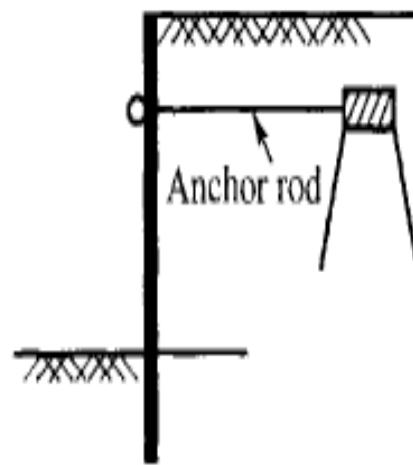
1. They are resistant to high driving stresses as developed in hard or rocky material
2. They are lighter in section
3. They may be used several times
4. They can be used either below or above water and possess longer life
5. Suitable joints which do not deform during driving can be provided to have a continuous wall
6. The pile length can be increased either by welding or bolting

Steel sheet piles may conveniently be used in several civil engineering works. They may be used as:

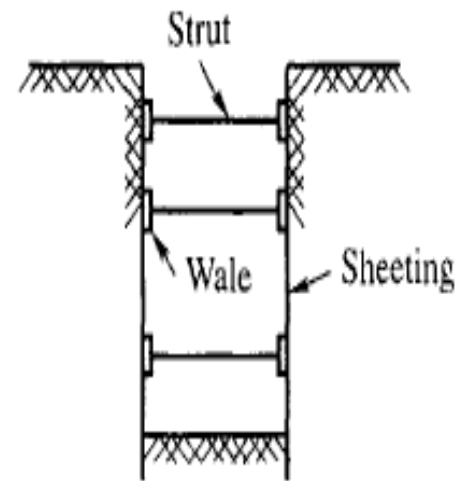
1. Cantilever sheet piles
2. Anchored bulkheads
3. Braced sheeting in cuts
4. Single cell cofferdams
5. Cellular cofferdams, circular type
6. Cellular cofferdams (diaphragm)



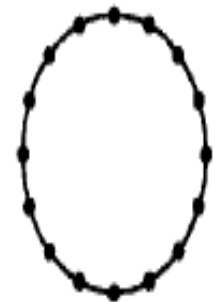
(a) Cantilever sheet piles



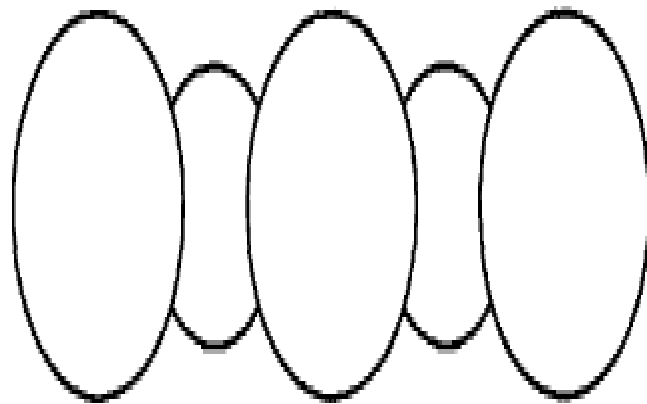
(b) Anchored bulk head



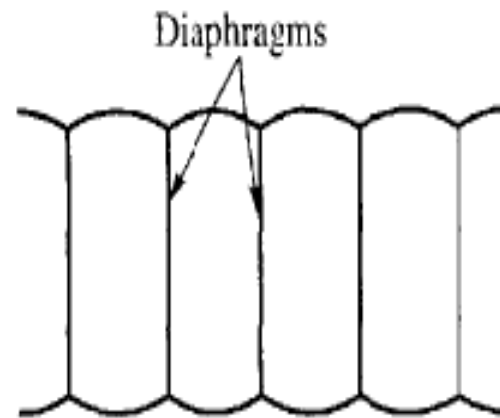
(c) Braced sheeting in cuts



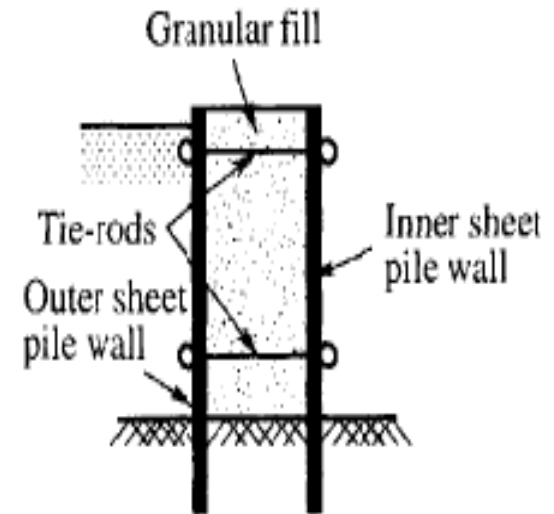
(d) Single cell cofferdam



(e) Cellular cofferdam



(f) Cellular cofferdam,
diaphragm type

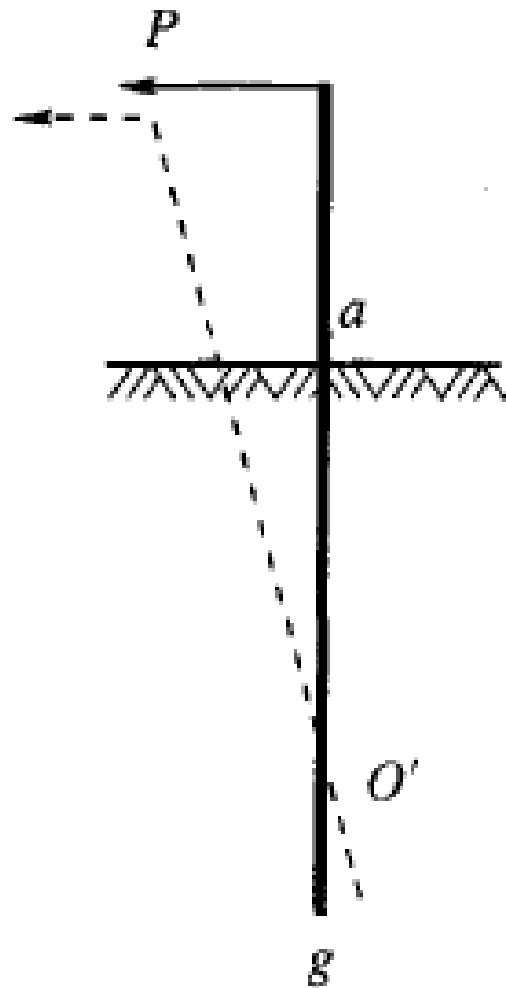


(g) Double sheet pile walls

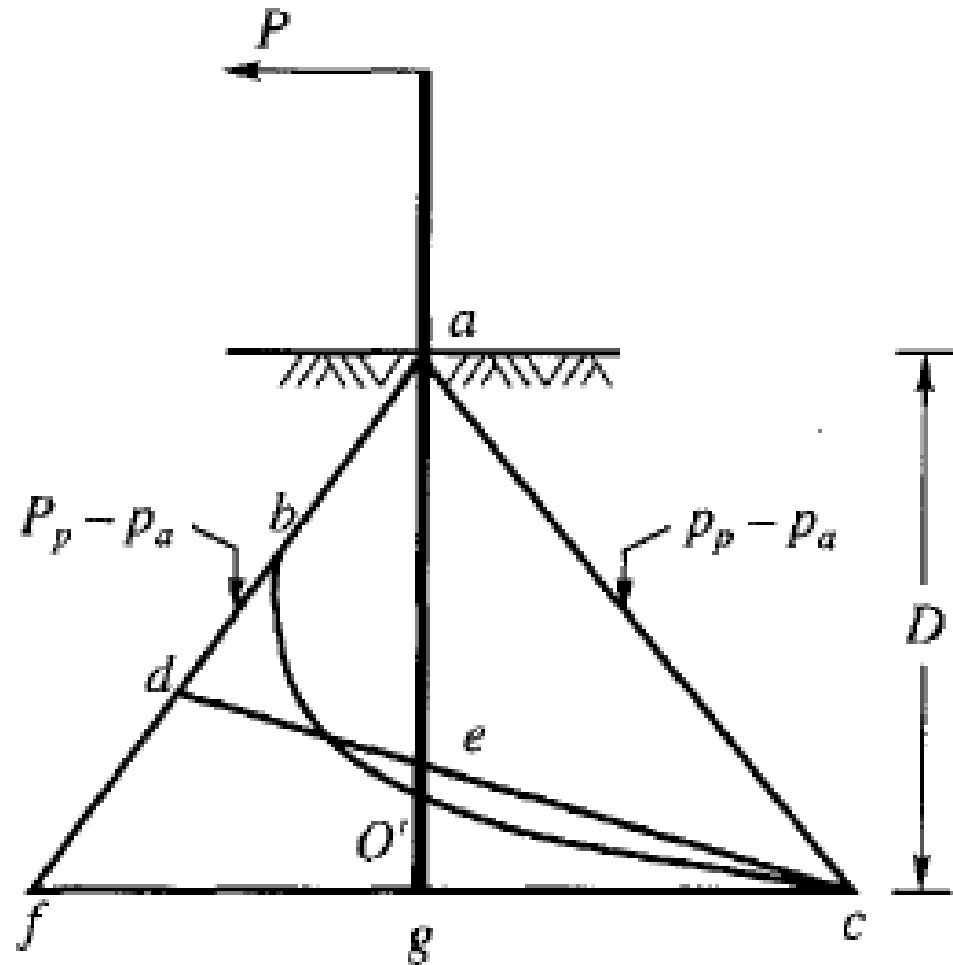
FREE CANTILEVER SHEET PILE WALLS

- ❖ When the height of earth to be retained by sheet piling is small, the piling acts as a cantilever.
- ❖ The forces acting on sheet pile walls include:
 1. The active earth pressure on the back of the wall which tries to push the wall away from the backfill.
 2. The passive pressure in front of the wall below the dredge line. The passive pressure resists the movements of the wall.

Example illustrating earth pressure on cantilever sheet piling



(a)



(b)

- ❖ The active and passive pressure distributions on the wall are assumed hydrostatic.
- ❖ In the design of the wall, although the Coulomb approach considering wall friction tends to be more realistic, the Rankine approach *is normally used*.
- ❖ The pressure due to water may be neglected if the water levels on both sides of the wall are the same.
- ❖ If the difference in level is considerable, the effect of the difference on the pressure will have to be considered.
- ❖ Effective unit weights of soil should be considered in computing the active and passive pressures.

DEPTH OF EMBEDMENT OF CANTILEVER WALLS IN SANDY SOILS

Case 1: With Water Table at Great Depth

- ❖ The active pressure acting on the back of the wall tries to move the wall away from the backfill.
- ❖ If the depth of embedment is adequate the wall rotates about a point O' *situated above the bottom of* the wall as shown in Fig. (a).
- ❖ The types of pressure that act on the wall when rotation is likely to take place about O' *are:*
 1. Active earth pressure at the back of wall from the surface of the backfill down to the point of rotation, O' . *The pressure is designated as P_{al} .*

2. Passive earth pressure in front of the wall from the point of rotation O' to the dredge line. This pressure is designated as $PP1$.
3. Active earth pressure in front of the wall from the point of rotation to the bottom of the wall. This pressure is designated as $Pa2$.
4. Passive earth pressure at the back of wall from the point of rotation O' to the bottom of the wall. This pressure is designated as $Pp2$

The various notations used are:

D = minimum depth of embedment with a factor of safety equal to 1

K_A = Rankine active earth pressure coefficient

K_p = Rankine passive earth pressure coefficient

K = $K_p - K_A$

$\bar{p}_a$ = effective active earth pressure acting against the sheet pile at the dredge line
 $= \gamma H K_A$

$\bar{p}_p$ = effective passive earth pressure at the base of the pile wall and acting towards the backfill $= \gamma D_o K$

$\bar{p}'_p$ = effective passive earth pressure at the base of the sheet pile wall acting against the backfill side of the wall $= p''_p + \gamma K D_o$

$\bar{p}''_p$ = effective passive earth pressure at level of $O = \gamma y_0 K + \gamma H K_p$

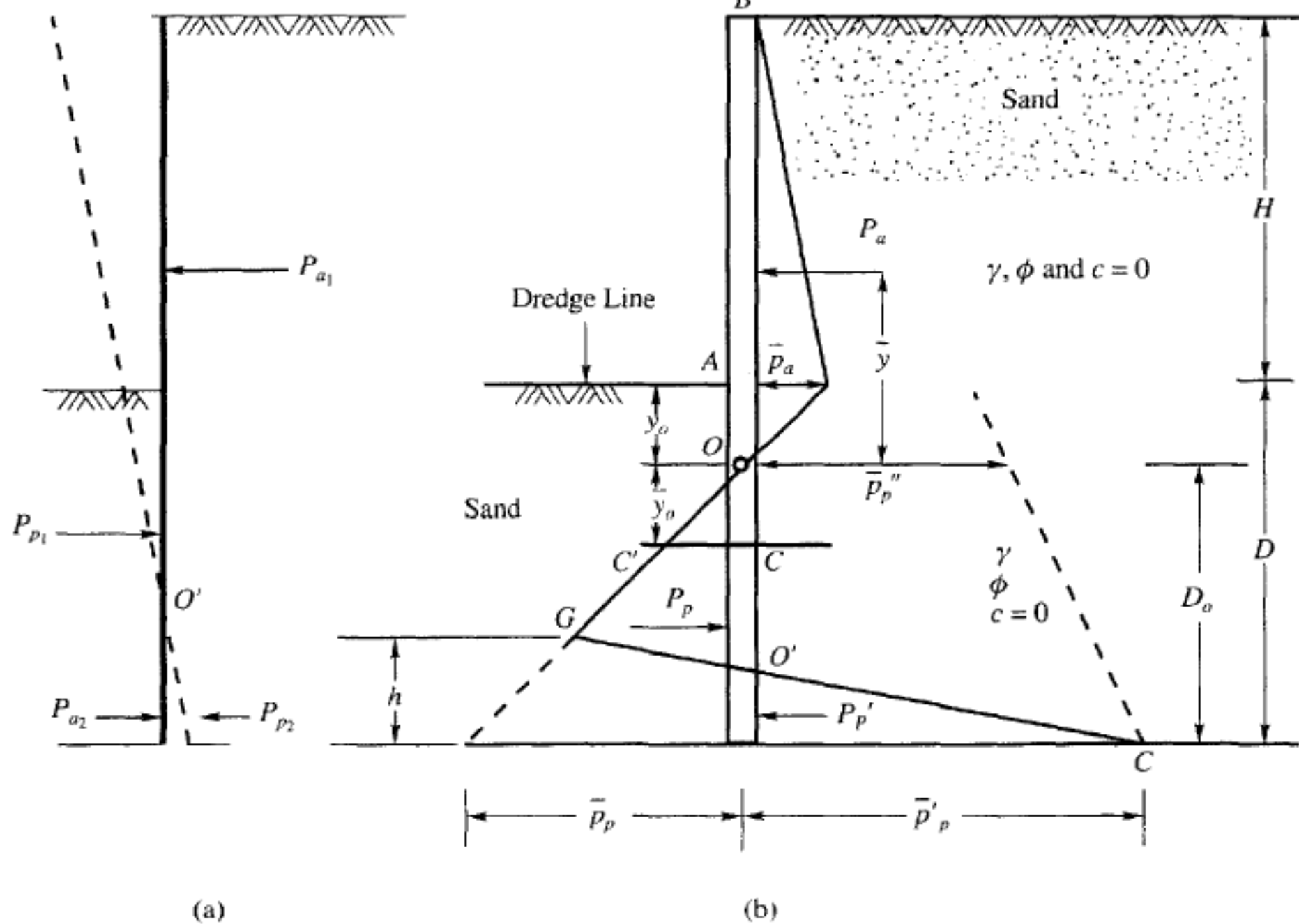
γ = effective unit weight of the soil assumed the same below and above dredge line

y_0 = depth of point O below dredge line where the active and passive pressures are equal

$\bar{y}$ = height of point of application of the total active pressure P_a above point O

h = height of point G above the base of the wall

D_o = height of point O above the base of the wall



Pressure distribution on a cantilever wall.

Expression for y_0

At point O , the passive pressure acting towards the right should equal the active pressure acting towards the left, that is

$$\gamma_0 K_p = \gamma(H + y_0)K_A$$

Therefore, $\gamma_0(K_p - K_A) = \gamma HK_A$

$$y_0 = \frac{\gamma HK_A}{\gamma(K_p - K_A)} = \frac{\bar{p}_a}{\gamma K}$$

Expression for h

For static equilibrium, the sum of all the forces in the horizontal direction must equal zero. That is

$$P_a - \frac{1}{2} \bar{p}_p (D - y_0) + \frac{1}{2} (\bar{p}_p + \bar{p}'_p)h = 0$$

Solving for h ,

$$h = \frac{\bar{p}_p (D - y_0) - 2P_a}{\bar{p}_p + \bar{p}'_p}$$

Taking moments of all the forces about the bottom of the pile, and equating to zero

$$P_a(D_0 + \bar{p}) - \frac{1}{2} \bar{p}_p \times D_0 \times \frac{D_0}{3} + \frac{1}{2}(\bar{p}_p + \bar{p}'_p) \times h \times \frac{h}{3} = 0$$

$$\text{or } 6P_a(D_0 + \bar{y}) - \bar{p}_p D_0^2 + (\bar{p}_p + \bar{p}'_p) h^2 = 0$$

Therefore,

$$\bar{p}_p = \gamma K D_0$$

$$\bar{p}'_p = \bar{p}''_p + \gamma K D_0$$

Substituting in Eq. for $\bar{p}_p$, $\bar{p}'_p$ and h and simplifying,

$$D_0^4 + C_1 D_0^3 + C_2 D_0^2 + C_3 D_0 + C_4 = 0$$

where,

$$C_1 = \frac{\bar{p}_p''}{\gamma K}$$

$$C_2 = -\frac{8P_a}{\gamma K}$$

$$C_3 = -\frac{6P_a}{(\gamma K)^2} (2\bar{y}\gamma K + \bar{p}_p'')$$

$$C_4 = -\frac{6P_a\bar{y}\bar{p}_p'' + 4P_a^2}{(\gamma K)^2}$$

The solution of Eq. (20.4) gives the depth D_0 . The method of trial and error is generally adopted to solve this equation. The minimum depth of embedment D with a factor of safety equal to 1 is therefore

$$D = D_0 + y_0$$

A minimum factor of safety of 1.5 to 2 may be obtained by increasing the minimum depth D by 20 to 40 percent.

Maximum Bending Moment

The maximum moment on section AB in Fig. 20.6(b) occurs at the point of zero shear. This point occurs below point O in the figure. Let this point be represented by point C at a depth $\bar{y}_0$ below point O . The net pressure (passive) of the triangle OCC' must balance the net active pressure P_a acting above the dredge line. The equation for P_a is

$$P_a = \frac{1}{2} \bar{y}_0^2 \gamma (K_p - K_A) = \frac{1}{2} \bar{y}_0^2 \gamma K$$

$$\text{or } \bar{y}_0 = \sqrt{\frac{2P_a}{\gamma K}}$$

where γ = effective unit weight of the soil. If the water table lies above point O , γ will be equal to γ_b , the submerged unit weight of the soil.

Once the point of zero shear is known, the magnitude of the maximum bending moment may be obtained as

$$M_{\max} = P_a (\bar{y} + \bar{y}_o) - \frac{1}{3} \frac{1}{2} \bar{y}_o^2 \gamma K \quad \bar{y}_o = P_a (\bar{y} + \bar{y}_o) - \frac{1}{6} \bar{y}_o^3 \gamma K$$

The section modulus Z_s of the sheet pile may be obtained from the equation

$$Z_s = \frac{M_{\max}}{f_b}$$

where, f_b = allowable flexural stress of the sheet pile.

Case 2: With Water Table Within the Backfill

In this case the soil above the water table has an effective unit weight γ and a saturated unit weight γ_{sat} below the water table. The submerged unit weight is

$$\gamma_b = (\gamma_{\text{sat}} - \gamma_w)$$

The active pressure at the water table is

$$\bar{p}_1 = \gamma h_1 K_A$$

and $\bar{p}_a$ at the dredge line is

$$\bar{p}_a = \gamma h_1 K_A + \gamma_b h_2 K_A = (\gamma h_1 + \gamma_b h_2) K_A$$

The other expressions are

$$\bar{p}_p = \gamma_b D_o K$$

$$\bar{p}'_p = \bar{p}''_p + \gamma_b D_o K$$

$$\bar{p}''_p = \gamma_b y_o K + (\gamma h_1 + \gamma_b h_2) K_p$$

$$y_o = \frac{\bar{p}_a}{\gamma_b K}$$

$$P_a = \frac{1}{2} \bar{p}_p (D - y_o) - \frac{1}{2} (\bar{p}_p + \bar{p}'_p) h$$

$$h = \frac{\bar{p}_p (D - y_o) - 2P_a}{\bar{p}_p + \bar{p}'_p}$$

The fourth degree equation in terms of D_o is

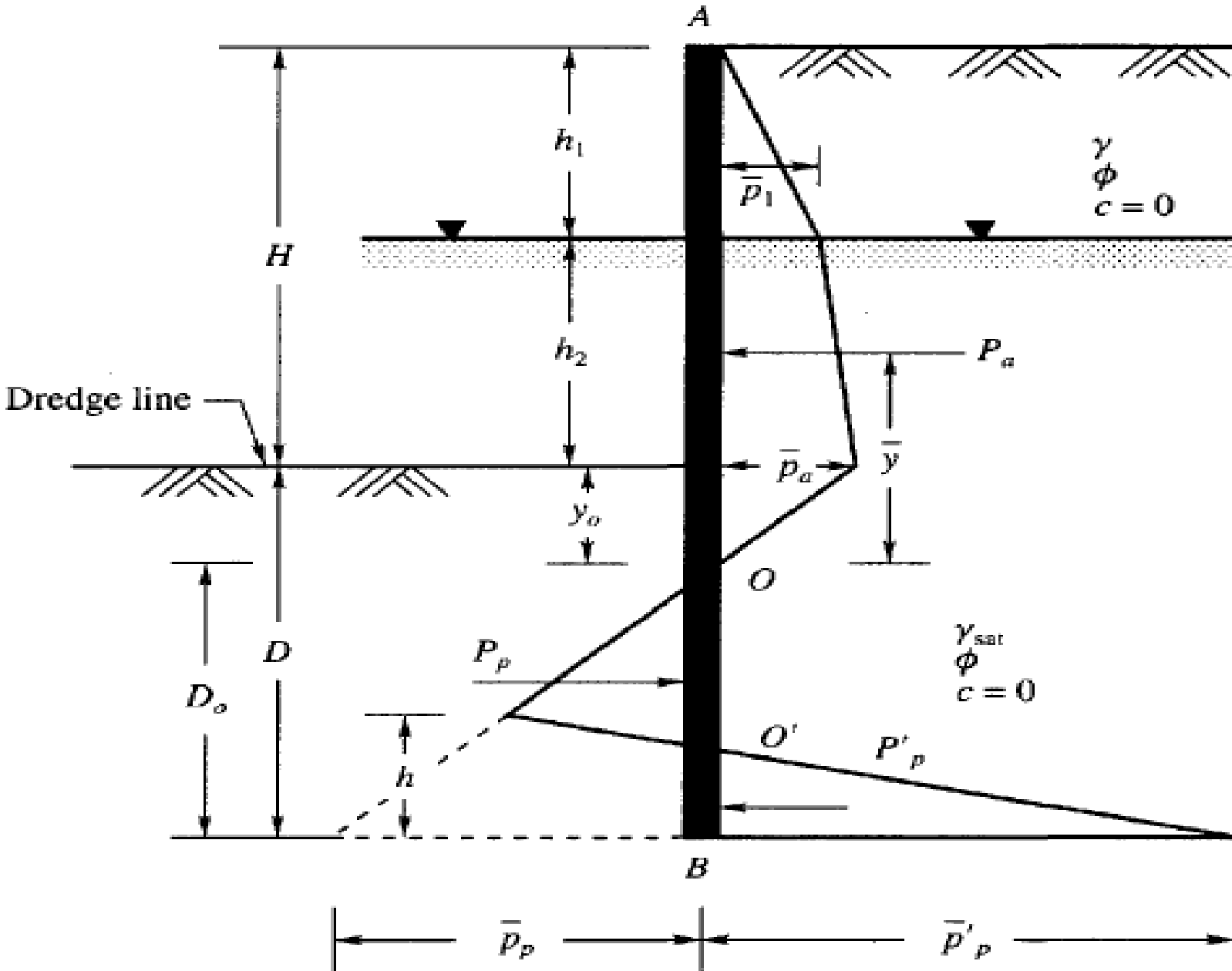
$$D_o^4 + C_1 D_o^3 + C_2 D_o^2 + C_3 D_o + C_4 = 0$$

where, $C_1 = \frac{\bar{p}_p''}{\gamma_b K}$

$$C_2 = -\frac{8P_a}{\gamma_b K}$$

$$C_3 = -\frac{6P_a}{(\gamma_b K)^2} (2\bar{y} \gamma_b K + \bar{p}_p'')$$

$$C_4 = -\frac{6P_a \bar{y} \bar{p}_p'' + 4P_a^2}{(\gamma_b K)^2}$$



Pressure distribution on a cantilever wall with a water table in the backfill

Case 3: When the Cantilever is Free Standing with No Backfill

The cantilever is subjected to a line load of P per unit length of wall. The expressions can be developed on the same lines explained earlier for cantilever walls with backfill. The various expressions are

$$h = \frac{\gamma K D^2 - 2P}{2\gamma DK}$$

where $K = (K_p - K_a)$

The fourth degree equation in D is

$$D^4 + C_1 D^2 + C_2 D + C_3 = 0$$

where $C_1 = -\frac{8P}{\gamma K}$

$$C_2 = -\frac{12PH}{\gamma K}$$

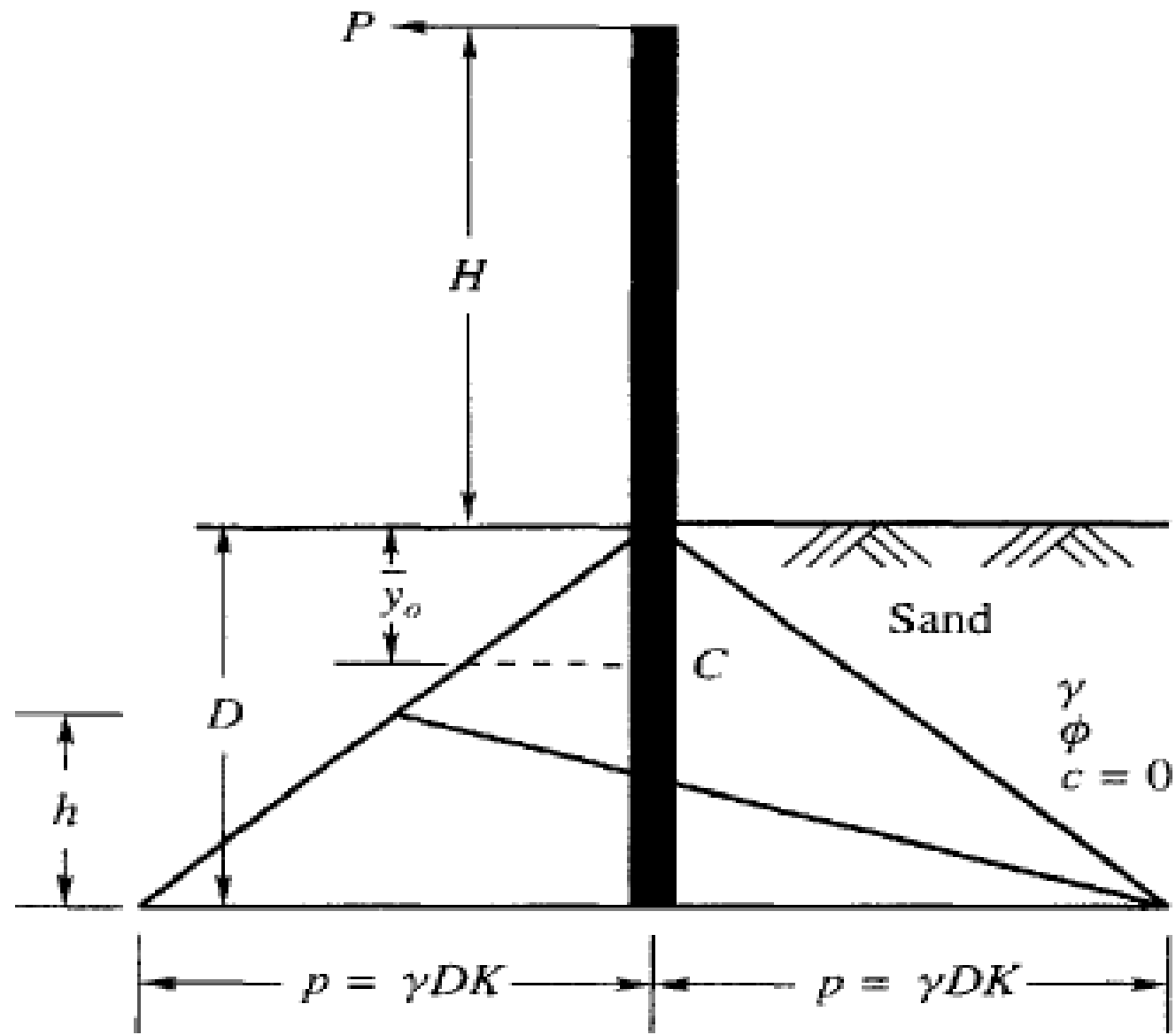
$$C_3 = -\frac{4P^2}{(\gamma K)^2}$$

Equation (20.11) gives the theoretical depth D which should be increased by 20 to 40 percent. Point C in Fig. 20.9 is the point of zero shear. Therefore,

$$M_{\max} = P(H + \bar{y}_o) - \frac{\gamma \bar{y}_o^3 K}{6}$$

$$\bar{y}_o = \sqrt{\frac{2P}{\gamma K}}$$

where γ = effective unit weight of the soil



Free standing cantilever with no backfill

Example

Determine the depth of embedment for the sheet-piling shown in Fig. Ex. 20.1a by rigorous analysis. Determine also the minimum section modulus. Assume an allowable flexural stress $f_b = 175 \text{ MN/m}^2$. The soil has an effective unit weight of 17 kN/m^3 and angle of internal friction of 30° .

Solution

$$\text{For } \phi = 30^\circ, K_A = \tan^2 (45^\circ - \phi/2) = \tan^2 30 = \frac{1}{3}$$

$$K_p = \frac{1}{K_A} = 3, \quad K = K_p - K_A = 3 - \frac{1}{3} = 2.67.$$

The pressure distribution along the sheet pile is assumed as shown in Fig.

$$\bar{p}_a = \gamma H K_A = 17 \times 6 \times \frac{1}{3} = 34 \text{ kN/m}^2$$

$$y_0 = \frac{\bar{p}_a}{\gamma(K_p - K_A)} = \frac{34}{17 \times 2.67} = 0.75 \text{ m.}$$

$$P_a = \frac{1}{2} \bar{p}_a H + \frac{1}{2} \bar{p}_a y_0 = \frac{1}{2} \times 34 \times 6 + \frac{1}{2} \times 34 \times 0.75$$

$$= 102 + 12.75 = 114.75 \text{ kN/meter length of wall or say } 115 \text{ kN/m.}$$

$$\bar{p}_p = \gamma D(K_p - K_A) - \bar{p}_a = 17 \times D \times 2.67 - 34 = 45.4D - 34$$

$$\bar{p}'_p = \gamma HK_p + \gamma D(K_p - K_A) = 17 \times 6 \times 3 + 17 \times D \times 2.67 = 306 + 45.4D$$

$$\bar{p}''_p = \gamma HK_p + \gamma y_0(K_p - K_A) = 17 \times 6 \times 3 + 17 \times 0.75 \times 2.67 = 340 \text{ kN/m}^2$$

To find $\bar{y}$

$$P_a \bar{y} = \frac{1}{2} \bar{p}_a H \left(\frac{H}{3} + y_0 \right) + \frac{1}{2} \bar{p}_a y_0 \left(\frac{2}{3} y_0 \right)$$

$$= \frac{1}{2} \times 34 \times 6 \times (2 + 0.75) + \frac{1}{2} \times 34 \times 0.75 \times \frac{2}{3} \times 0.75 = 286.9$$

$$\text{Therefore, } \bar{y} = \frac{286.9}{P_a} = \frac{286.9}{115} = 2.50 \text{ m.}$$

Now D_0 can be found from Eq. (20.4), namely

$$D_0^4 + C_1 D_0^3 + C_2 D_0^2 + C_3 D_0 + C_4 = 0$$

$$C_1 = \frac{\bar{p}_p''}{\gamma K} = \frac{340}{17 \times 2.67} = 7.49, \quad C_2 = -\frac{8P_a}{\gamma K} = -\frac{8 \times 115}{17 \times 2.67} = -20.3$$

$$C_3 = -\frac{6P_a}{(\gamma K)^2} (2\bar{y} \gamma K + \bar{p}_p'') = -\frac{6 \times 115}{(17 \times 2.67)^2} (2 \times 2.50 \times 17 \times 2.67 + 340) = -189.9$$

$$C_4 = -\frac{6 P_a \bar{y} \bar{p}_p'' + 4 P_a^2}{(\gamma K)^2} = -\frac{6 \times 115 \times 2.50 \times 340 + 4 \times (115)^2}{(17 \times 2.67)^2} = -310.4$$

Substituting for C_1 , C_2 , C_3 and C_4 , and simplifying we have

$$D_0^4 + 7.49 D_0^3 - 20.3 D_0^2 - 189.9 D_0 - 310.4 = 0$$

This equation when solved by the method of trial and error gives

$$D_0 \approx 5.3 \text{ m}$$

Depth of Embedment

$$D = D_0 + y_0 = 5.3 + 0.75 = 6.05 \text{ m}$$

Increasing D by 40%, we have

$$D \text{ (design)} = 1.4 \times 6.05 = 8.47 \text{ m or say } 8.5 \text{ m.}$$

(c) Section modulus

(The point of zero shear)

$$\bar{y}_o = \sqrt{\frac{2P_a}{\gamma K}} = \sqrt{\frac{2 \times 115}{17 \times 2.67}} = 2.25 \text{ m}$$

$$M_{\max} = P_a (\bar{y} + \bar{y}_o) - \frac{1}{6} \bar{y}_o^3 \gamma K$$

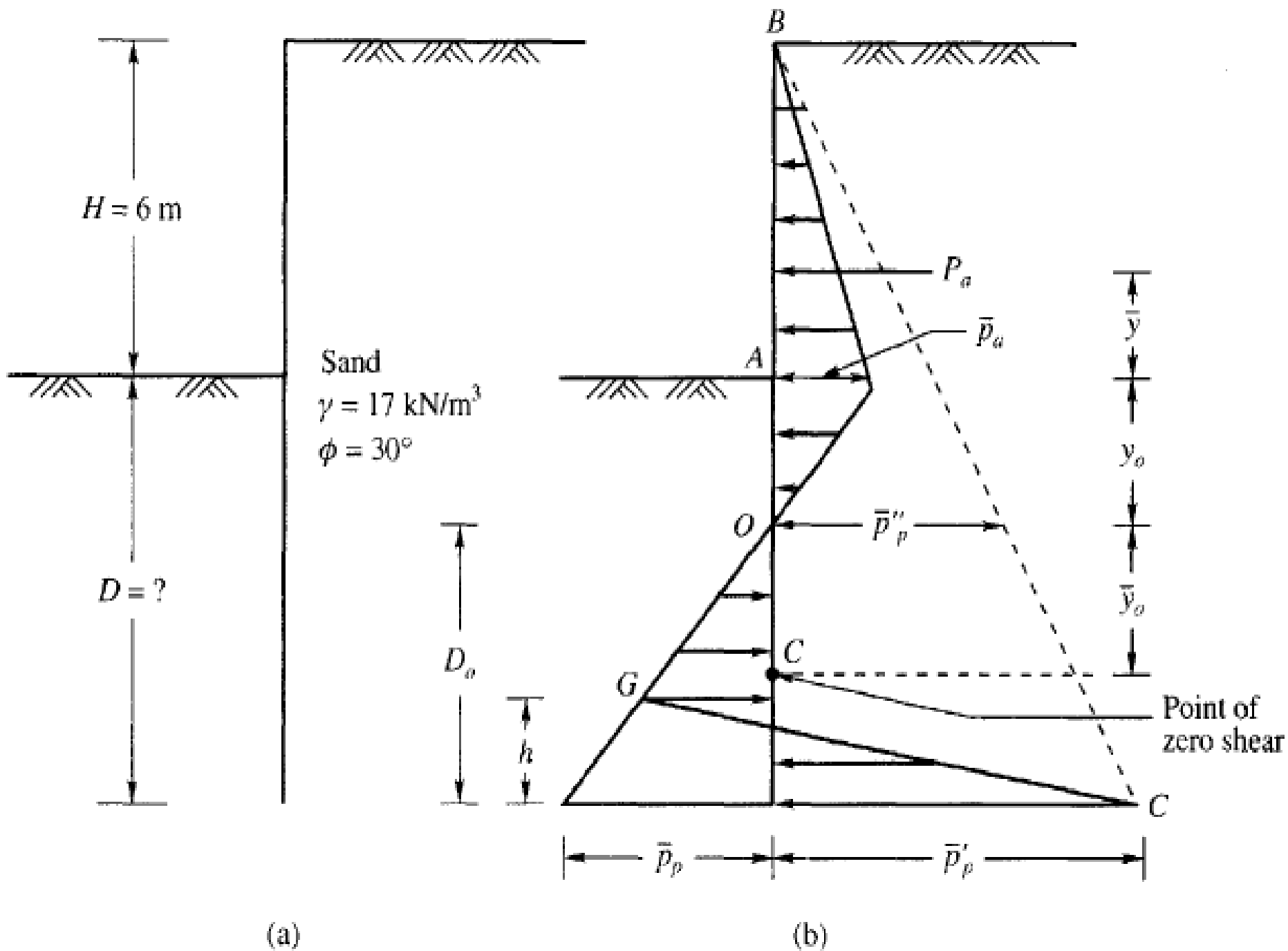
$$= 115(2.50 + 2.25) - \frac{1}{6}(2.25)^3 \times 17 \times 2.67$$

$$= 546.3 - 86.2 = 460 \text{ kN-m/m}$$

From Eq. (20.8)

Section modulus

$$Z_s = \frac{M_{\max}}{f_b} = \frac{460}{175 \times 10^3} = 26.25 \times 10^{-2} \text{ m}^3/\text{m of wall}$$

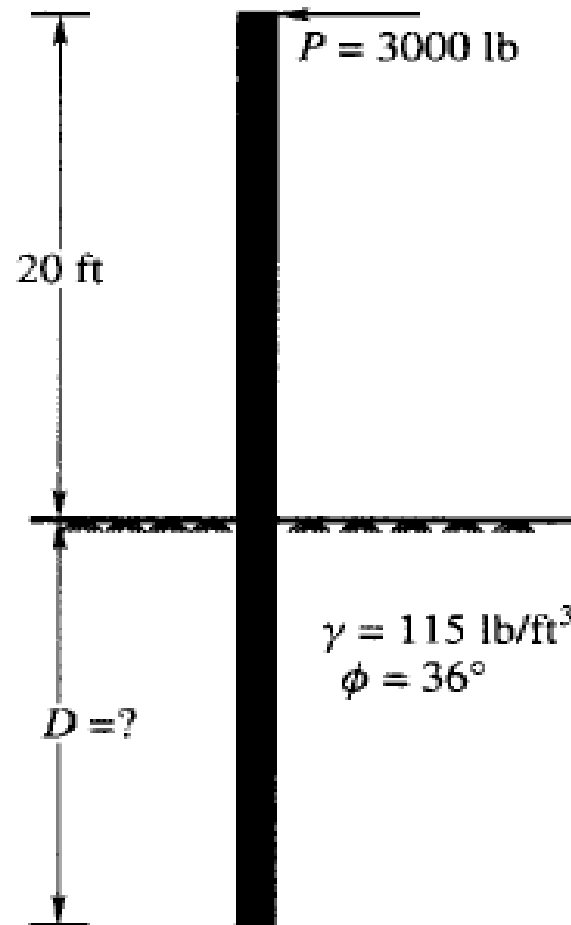


Example

Fig. shows a free standing cantilever sheet pile with no backfill driven into homogeneous sand. The following data are available:

$$H = 20 \text{ ft}, P = 3000 \text{ lb/ft of wall}, \gamma = 115 \text{ lb/ft}^3, \phi = 36^\circ.$$

Determine: (a) the depth of penetration, D , and (b) the maximum bending moment $M_{\max}$.



Solution

$$K_p = \tan^2 45^\circ + \frac{\phi}{2} = \tan^2 45^\circ + \frac{36}{2} = 3.85$$

$$K_A = \frac{1}{K_p} = \frac{1}{3.85} = 0.26$$

$$K = K_p - K_A = 3.85 - 0.26 = 3.59$$

The equation for D is (Eq 20.11)

$$D^4 + C_1 D^2 + C_2 D + C_3 = 0$$

$$\text{where } C_1 = -\frac{8P}{\gamma K} = -\frac{8 \times 3000}{115 \times 3.59} = -58.133$$

$$C_2 = -\frac{12PH}{\gamma K} = -\frac{12 \times 3000 \times 20}{115 \times 3.59} = -1744$$

$$C_3 = -\frac{4P^2}{(\gamma K)^2} = -\frac{4 \times 3000^2}{(115 \times 3.59)^2} = -211.2$$

Substituting and simplifying, we have

$$D^4 - 58.133 D^2 - 1744 D - 211.2 = 0$$

From the above equation $D \approx 13.5$ ft.

From Eq. (20.6)

$$\bar{y}_0 = \sqrt{\frac{2P_a}{\gamma K}} = \sqrt{\frac{2P}{\gamma K}} = \sqrt{\frac{2 \times 3000}{115 \times 3.59}} = 3.81 \text{ ft}$$

$$M_{\max} = P_a (H + \bar{y}_0) - \frac{\gamma \bar{y}_0^3 K}{6}$$

$$= 3000(20 + 3.81) - \frac{115 \times (3.81)^3 \times 3.59}{6}$$

$$= 71,430 - 3,806 = 67,624 \text{ lb-ft/ft of wall}$$

$$M_{\max} = 67,624 \text{ lb-ft/ft of wall}$$