Module 6 : Design of Retaining Structures

Lecture 27 : Cantilever sheet pile walls [Section 27.1: Introduction]

Objectives

In this section you will learn the following

- Introduction

Module 6 : Design of Retaining Structures

Lecture 27 : Cantilever sheet pile walls [Section 27.1: Introduction]

Types

- With concentrated load.
- Supporting earth/backfill.

Assumptions.

- Wall is smooth and vertical and earth pressure theories applicable to rigid retaining walls only.
- The pivot point should be at a depth xo from ground level and not at the sheet pile wall.
- All equilibrium equations are applicable to sheet pile wall.
- Sum over vertical moments is not required for design of sheet pile wall because weight of sheet pile wall is considered as negligible.

Recap

In this section you have learnt the following.

- Introduction

Objectives

In this section you will learn the following

- Cantilever sheet pile with concentrated load
- Some problem by assuming parabolic variation

Cantilever sheet pile with concentrated load.

Cantilever sheet piling walls depend on the passive resisting capacity of the soil below the depth of excavation to prevent overturning. The depth of sheet piling walls below the bottom of the excavation is determined by using the difference between the passive and active pressures acting on the wall. The theoretical depth of pile penetration below the depth of excavation is obtained by equating horizontal forces and by taking moments about an assumed bottom of piling. The theoretical depth of penetration represents the point of rotation of the piling. Additional penetration is needed to obtain some fixity for the piling. Computed piling depths are generally increased 20% to 40% to obtain some fixity and to prevent lateral movement at the bottom of the piling.

Sum of the Horizontal moments is,

1. $\sum F_H = 0$,

$$P_1 = H + P_2$$

H is the horizontal force at tip of pile.

Sum of the moments about point 'O',

2. $\sum M_0 = 0$,

$$P_1 s + P_2 \left(\frac{2}{3}\right)(d - x_0) - H(h + x_0) = 0$$

P_1 & P_2 are the total earth pressure forces, and h is the height of the sheet pile above ground level.

Intensity of earth pressure is, $p_1 = \gamma x_1(k_p - k_a)$

$$P_1 s = \left\{\frac{1}{2}p_1 x_1(x_0 - \frac{2}{3}x_1) + \frac{1}{2}\frac{2}{3}p_1(x_0 - x_1)^2\right\}b$$

$$= \frac{\gamma(k_p - k_a)bx_1x_0}{6}(2x_0 - x_1) \qquad \text{--------(A)}$$

$$P_2 = \frac{b}{2}p_2(x_1 - x_0) = P_1 - H$$

$$= \frac{b}{2}p_1 x_0 - H$$

$$= \frac{1}{2}\gamma(k_p - k_a)bx_0x_1 - H \qquad \text{--------(B)}$$

k_a and k_p are active and passive earth pressure coefficients

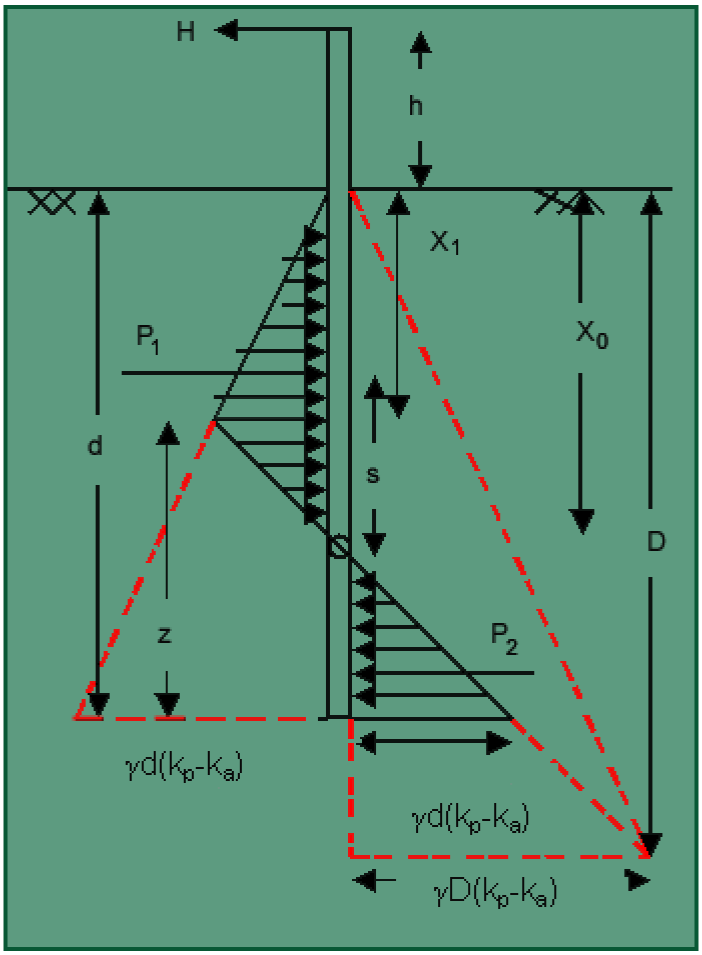

Fig 6.13 Earth pressure diagram for sheet pile with concentrated load.

After solving (A) & (B) , $x_0 = \dfrac{2H(2d+3h)}{b\gamma(k_p - k_a)(2dx_1 - x_1^2) - 2H}$ -------(C)

'b' is the width of the sheet pile.

$$\frac{p_2}{d - x_0} = \frac{p_1}{x_0 - x_1}$$

$$p_2 = \frac{\gamma(k_p - k_a)x_1(d - x_0)}{x_0 - x_1} \qquad \text{--------(D)}$$

from (B) & (D) , $x_0\left[-2b\gamma(k_p - k_a)dx_1 + \gamma(k_p - k_a)x_1^2 + 2\frac{H}{b}\right] + x_1\left[\gamma(k_p - k_a)d^2 - 2\frac{H}{b}\right] = 0$ --------(E)

from (C) & (E), $x_1 = \dfrac{2H(2d+3H)}{b\gamma(k_p - k_a)d^2 - 2H}$ --------(F)

from (F) & (C), $x_0 = \dfrac{2d^5 + 3hd^4 - 8ad^3 - 12ahd^2 + 8a^2d + 12a^2h}{3d^4 + 6hd^3 - 12ad^2 - 36ahd - 18ah^2 - 4a^2}$

where, $a = \dfrac{H}{\gamma b(k_p - k_a)}$

Factor of safety at limiting condition, $p_2 = \gamma d(k_p - k_a)$

The sheet pile is stable when, $p_2 \le \gamma d(k_p - k_a)$ and by providing $D > d_{min}$

Determination of driving depth:

$p_2 = \gamma d(k_p - k_a)$ from limiting condition.

1. $\sum F_H = -H + \frac{1}{2}\gamma d(k_p - k_a)db - \frac{1}{2}2\gamma d(k_p - k_a)zb = 0$
2. $\sum M_F = H(h+d) - \frac{1}{2}\gamma d(k_p - k_a)db\frac{d}{3} + \frac{1}{2}2\gamma d(k_p - k_a)zb\frac{z}{3} = 0$

$$z = \frac{\gamma d^2(k_p - k_a)b - 2H}{2\gamma d(k_p - k_a)b} \qquad \text{-------(G)}$$

by substituting (G) in (2),

$$d^4 - \frac{8H}{\gamma(k_p - k_a)b}d^2 - \frac{12Hhd}{\gamma(k_p - k_a)b} - \left[\frac{2H}{\gamma(k_p - k_a)b}\right]^2 = 0$$

Solve for value of d and then find D by approximately, D=1.2d

Some problem by assuming parabolic variation:

In this case the variation of earth pressure distribution is assumed as parabolic variation as shown below,

Coefficient resistance, $R_c = ax$ (linearly varying with depth)

According to terzaghi, $a = \dfrac{\gamma(k_p - k_a)}{y_0}$

$$\frac{y}{y_0} = \frac{x_0}{x_0 - x}$$

Earth pressure at any depth, $p = ax\dfrac{y_0}{x_0}(x - x_0) = a\dfrac{y_0}{x_0}(x^2 - x_0 x)$

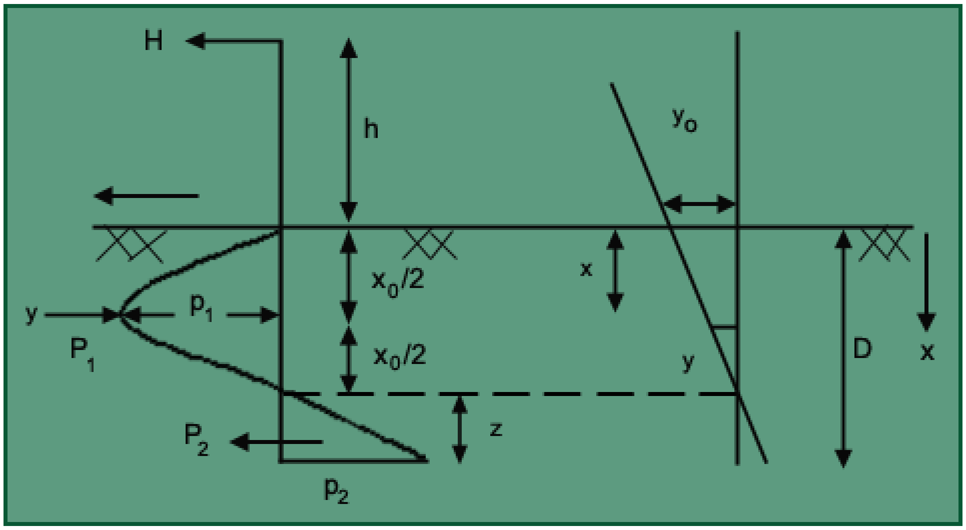

Fig 6.14 Earth pressure diagram with assumed parabolic variation.

1) $\sum F_H = 0,$ $\quad H + \sum_{i=1}^{2} P_i = 0$

$$\sum_{i=1}^{2} P_i = b\int_0^d p\,dx = ba\frac{y_0}{x_0}\int_0^d (x^2 - x_0 x)dx$$

$$H + a\frac{y_0}{x_0}b\left(\frac{d^3}{3} - x_0\frac{d^2}{2}\right) = 0 \qquad \text{-------- (1)}$$

2) $\sum M_A = 0, \qquad Hh - b\int_0^d px\,dx = 0$

$$Hh = \frac{a}{12}\frac{y_0}{x_0}b(3d^4 - 4x_0 d^3) \qquad \text{--------(2)}$$

from (1) & (2), $x_0 = (\frac{d}{2})\frac{3d+4h}{2d+3h} \qquad \& \qquad y_0 = \frac{6H}{ad^4}(3d+4h)$

$$p = \frac{6Hx}{d^4 b}\left[2x(2d+3h) - d(3d+4h)\right]$$

Boundary conditions,

1. $x=0, p=0$
2. $x= x_0, p=0$
3. $x= x_0/2$, $p_1 = -\frac{3}{4}\frac{H}{db}\frac{(3d+4h)^2}{3d+3h}$
4. $x=d$, $p_2 = \frac{6H}{d^2 b}(d+2h)$

After solving using boundary conditions the driving depth is, $d^3 - \frac{18Hd}{\gamma b(k_p - k_a)} - \frac{24Hh}{\gamma b(k_p - k_a)} = 0$

And then D=1.2d.

Recap

In this section you have learnt the following.

- Cantilever sheet pile with concentrated load
- Some problem by assuming parabolic variation

Module 6 : Design of Retaining Structures

Lecture 27 : Cantilever sheet pile walls [Section 27.3 : Cantilever sheet pile in granular soil]

Objectives

In this section you will learn the following

- Cantilever sheet pile in granular soil

Cantilever sheet pile in granular soil

The pile tends to point O deflecting away from the backfill. Above the point of rotation, the sheet pile wall deflects away from the backfill, thus generating active conditions on the back of the wall. At the same time, between the dredge line (point e) and the point of rotation (point O), as the wall tends to move towards the soil in front of the wall, passive conditions are generated in this side. However, below the point of rotation, the active and passive conditions generated on the two sides are reversed. The earth pressure diagrams are shown below.

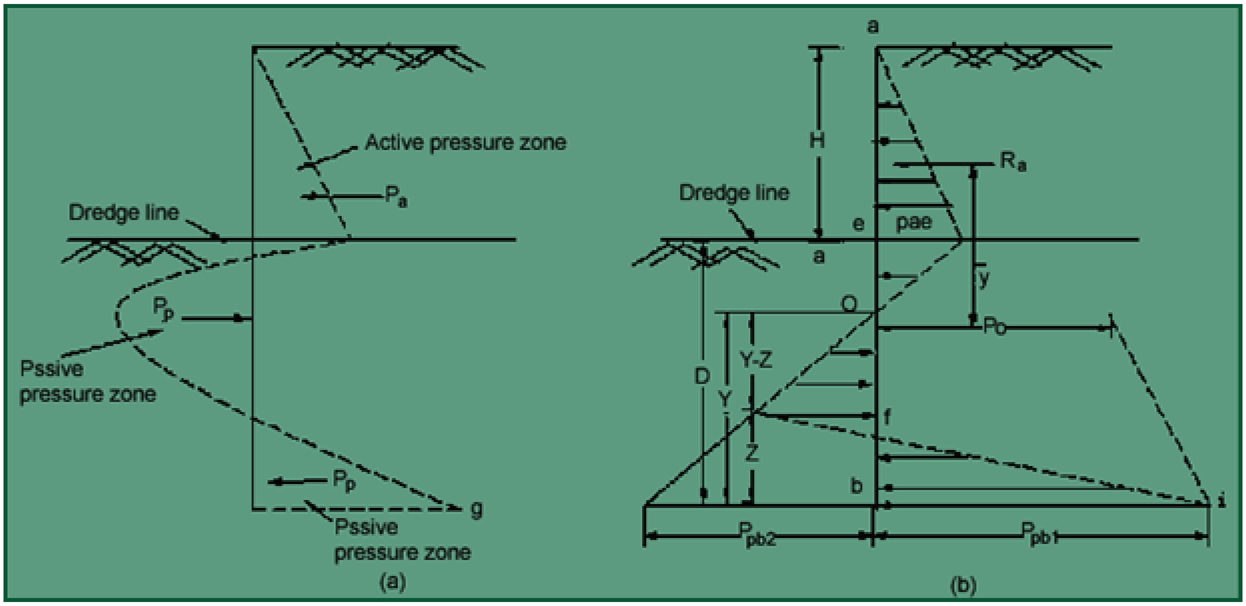

Fig 6.15 Probable and assumed Earth pressure diagram.

The point of rotation located at distance a below the dredge line has zero earth pressure. The magnitude of earth pressure at locations e,O and b can be worked out,

$$p_{Ae} = K_a \gamma H$$

The magnitude of a is given by the equation, $p_{Ae} = (K_p - K_a)\gamma a$

or $$a = \frac{p_{Ae}}{(K_p - K_a)\lambda}$$

$$p_{po} = K_p\gamma(H + a) - K_A\gamma a$$
$$= (K_p - K_A)\gamma a + K_p\gamma H$$
$$p_{pb_1} = p_{po} + (K_p - K_A)\gamma y$$
$$= (K_p - K_A)\gamma D + K_p\gamma H$$
$$p_{pb_2} = (K_p - K_A)\gamma y$$

Let R_a be the result of all forces above point O, acting at a distance 'y' above O. the distance is worked out by satisfying horizontal equilibrium equation,

$$R_a + (p_{pb_1} + p_{pb_2})\frac{Z}{2} - p_{pb2}\frac{y}{2} = 0$$

$$Z = \frac{p_{pb_2}y - 2R_a}{p_{pb1} + p_{pb_2}}$$

Thus taking moments about base of the pile and satisfying the moment equilibrium,

$$R_a(y + \bar{y}) + \frac{Z}{3}(p_{pb_1} + p_{pb_2})\frac{Z}{2} - p_{pb_2}\frac{y}{2}\frac{y}{3} = 0$$
$$6R_a(y + \bar{y}) + Z^2(p_{pb_2} + p_{pb_1}) - p_{pb_2}y^2 = 0$$

The value of 'y' can be found and then the value of D=a+y.

The computed D can be multiplied by factor 1.2 or 1.4.

Recap

In this section you have learnt the following.

- Cantilever sheet pile in granular soil

Objectives

In this section you will learn the following

- Cantilever sheet pile in cohesive soil.

Cantilever sheet pile in cohesive soil.

Cantilever sheet pile in cohesive soil: the analysis of cantilever sheet pile wall in cohesive soil is carried out in a manner almost similar to that in granular soils. However, certain phenomenon such as consolidated of clay in passive pressure zones, formation of tension cracks in the active zone may need additional consideration. Further, the clay may shrink and lose contact with the wall. To account for this, the benefit of wall adhesion is usually neglected in design.

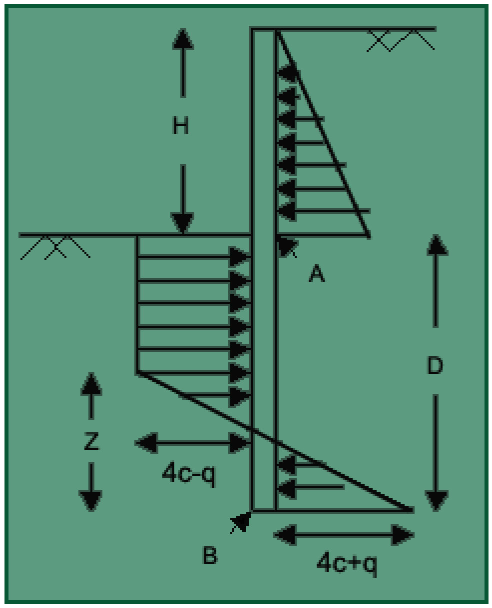

Fig 6.16 Earth pressure diagram in purely cohesive soil

The active earth pressure in purely cohesive soil is given by,

$$p_A = qK_A - 2c\sqrt{K_A}$$

where q is the effective vertical depth at any depth. For pure cohesive soil the frictional angle is zero then k_a = k_p =0, then the above equation becomes,

$$p_A = q - 2c$$

Likewise, it can be shown that , $p_p = q + 2c$

The net pressure at A is, $\left(p_p - p_A\right)_e = (0 + 2c) - (q - 2c) = 4c - q$ acting to the right.

Similarly, at the base of the wall, i.e. point B, the net pressure is given by,

$$\begin{aligned}(p_p - p_A)_b &= (q + \gamma D + 2c) - (\gamma\gamma \ - 2c) \\ &= 4c + q\end{aligned}$$

acting to the left.

Summing the pressure areas and satisfying the condition of stability, $\sum F_H = 0$,

$$R_a + \frac{Z}{2}(4c - q + 4c + q) - D(4c - q) = 0$$

$$Z = \frac{D(4c - q) - R_a}{4c} \qquad \text{or} \qquad R_a + \frac{Z}{2}(8c) - D(4c - q) = 0$$

where R_a is the resultant active earth pressure above the dredge line acting at ‘y' above the dredge line.

Further, some of the moments of forces about base are,

$$R_a(y + D) - \frac{D^2}{2}(4c - q) + \frac{Z}{3}\frac{Z}{2}(4c - q + 4c + q) = 0$$

substituting the value of Z from above equation and simplified the driving depth is determined.

$$D^2(4c - q) - 2DR_a - \frac{R_a(12cy + R_a)}{2c + q} = 0$$

Driving depth =1.2-1.4 D.

Recap

In this section you have learnt the following.

- Cantilever sheet pile in cohesive soil.