

Module 6 : Design of Retaining Structures

Lecture 28 : Anchored sheet pile walls [Section 28.1 : Introduction]

Objectives

In this section you will learn the following

- Introduction

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Lecture 28 : Anchored sheet pile walls [Section 28.1 : Introduction]

Introduction

Anchored sheet pile walls are held above the driven depth by anchors provided at suitable level. The anchors provide forces for the stability of the sheet pile, in addition to the lateral passive resistance of the soil into which the sheet piles are driven.

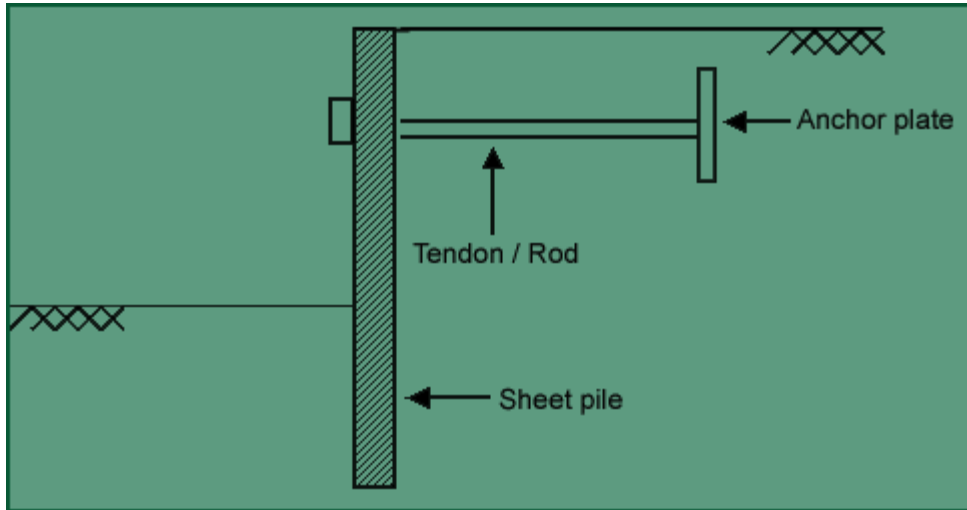


Fig. 6.17 Anchored sheet pile wall

It includes an anchor or tieback at or near the head of the wall. More than one set of anchors or tiebacks can be used. It increases wall stability and enables taller walls to be built and sustained almost a necessity with vinyl, aluminium and fiberglass sheet piles. It is not exclusive to sheet piling; also used with other types of in situ wall systems. In case of cantilever sheet pile walls if the deflection at top point of the sheet pile wall is very large, then settlement of soil takes place at top just behind the sheet pile wall. So, to reduce the excessive deflections the anchors are provided. The different types of anchored sheet pile walls are shown in figure.

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Lecture 28 : Anchored sheet pile walls [Section 28.1 : Introduction]

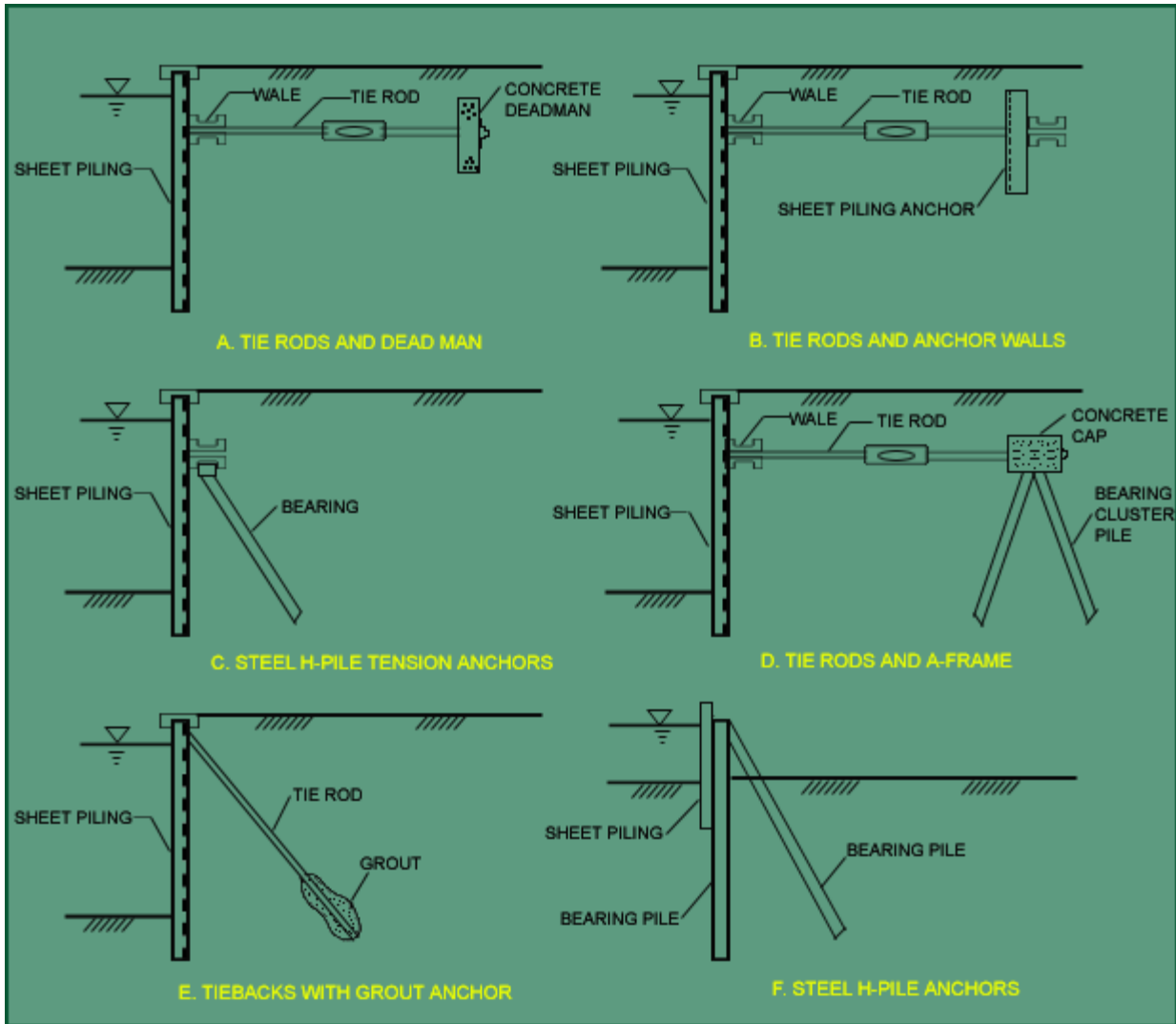


Fig. 6.18 Different types of anchored sheet pile walls

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Lecture 28 : Anchored sheet pile walls [Section 28.1 : Introduction]

Recap

In this section you have learnt the following.

- Introduction

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Lecture 28 : Anchored sheet pile walls [Section 28.2 : Different types of anchored sheet pile walls]

Objectives

In this section you will learn the following

- Free earth support piles
- Fixed earth support piles
- Comparison between fixed earth method and free earth method

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Lecture 28 : Anchored sheet pile walls [Section 28.2 : Different types of anchored sheet pile walls]

There are types of anchored sheet pile walls

1. Free earth support piles,
2. Fixed earth support piles.

Free earth support piles

An anchored sheet pile is said to have free earth support when the depth of embedment is small and pile rotates at its bottom tip. Thus, there is no point of inflection in the pile. It is assumed that

- The base of the pile is relatively free to move, so passive resistance is mobilized on one face only.
- The lateral pressure increases linearly with depth.
- Wall friction is negligible.

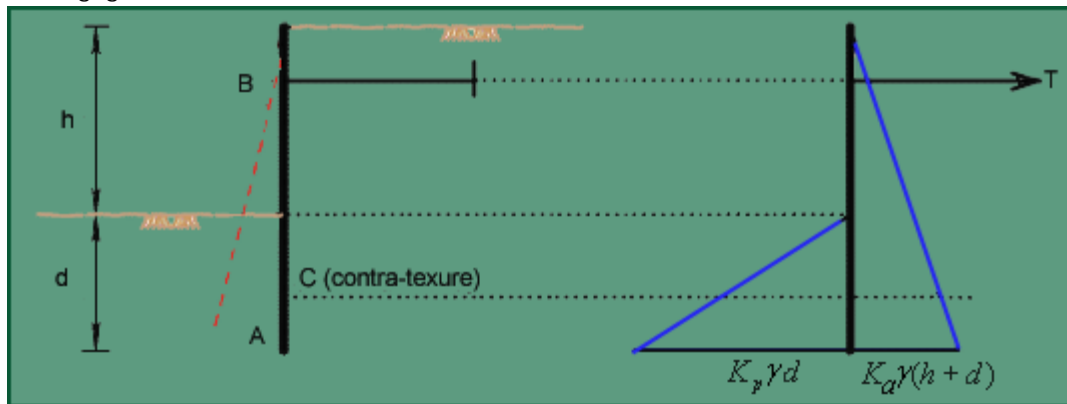


Fig. 6.19 Free earth support

Fixed earth support piles

An anchored sheet pile is said to have fixed earth support when the depth of embedment is large and the bottom tip of the pile is fixed against rotation. Thus, there is change in curvature of pile, hence inflection point occurs. It is assumed that

- The base of the pile is relatively fixed, so that there is a point of contra-flexure above the toe of the pile.
- Passive resistance is mobilized on both faces (similar to cantilever pile).
- The lateral pressure increases linearly with depth.
- No wall friction

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Lecture 28 : Anchored sheet pile walls [Section 28.2 : Different types of anchored sheet pile walls]

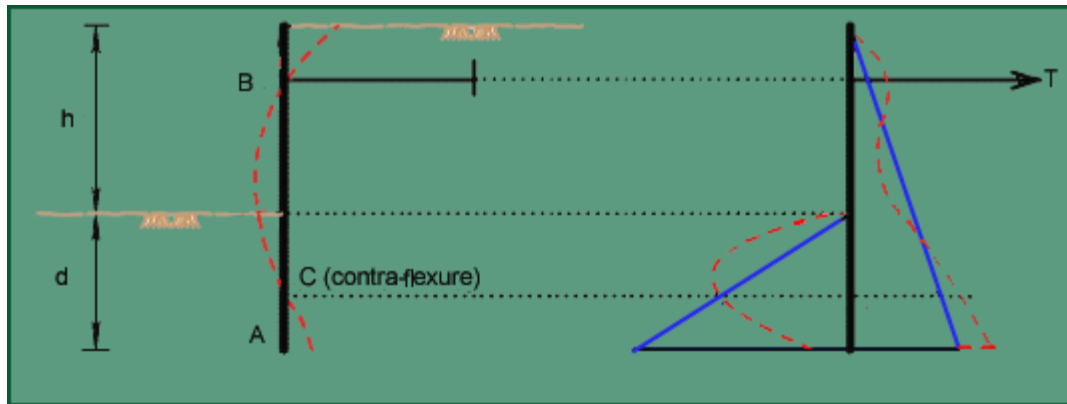


Fig. 6.20 Fixed earth support

Comparison between fixed earth method and free earth method

- The free earth support method gives a pressure distribution that would apply when the wall is on the point of failure by rotation about the anchor.
- The fixed earth support method is unlikely to represent the true loading at any stage.
- Both methods tend to over-estimate the bending moment in the pile.
- The free earth support method is simpler.
- In the fixed earth support, depth provided is more, moment through out the section reduces, so thinner section is to be provided.
- In the free earth support, depth provided is less, moment through out the section is more than fixed earth support, so thicker section is to be provided.

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Lecture 28 : Anchored sheet pile walls [Section 28.2 : Different types of anchored sheet pile walls]

Recap

In this section you have learnt the following.

- Free earth support piles
- Fixed earth support piles
- Comparison between fixed earth method and free earth method

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Lecture 28 : Anchored sheet pile walls [Section 28.3 : Design of sheet pile wall by free earth support]

Objectives

In this section you will learn the following

- Cohesionless soil
- Cohesive soils

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Lecture 28 : Anchored sheet pile walls [Section 28.3 : Design of sheet pile wall by free earth support]

Design of sheet pile wall by free earth support

The figure shows the condition for the free earth support. The deflection of the bulk head is somewhat similar to that of a vertical elastic beam whose lower end B is simply supported and the other end is fixed as shown in fig. 6.5.6. The forces acting on the sheet pile are :

- Active pressure due to soil behind pile,
- Passive pressure due to soil in front of the pile,
- The tension in the anchor rod.

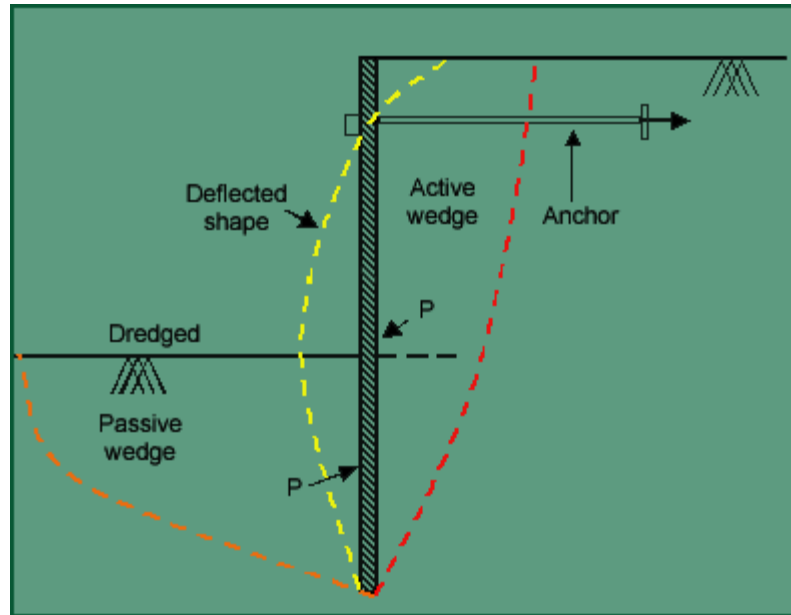


Fig. 6.21 Conditions for free earth support of an anchored sheet pile wall

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Lecture 28 : Anchored sheet pile walls [Section 28.3 : Design of sheet pile wall by free earth support]

- Cohesionless soil

The forces acting on the wall are shown in the fig. Assuming that the material above and below dredged level in cohesionless.

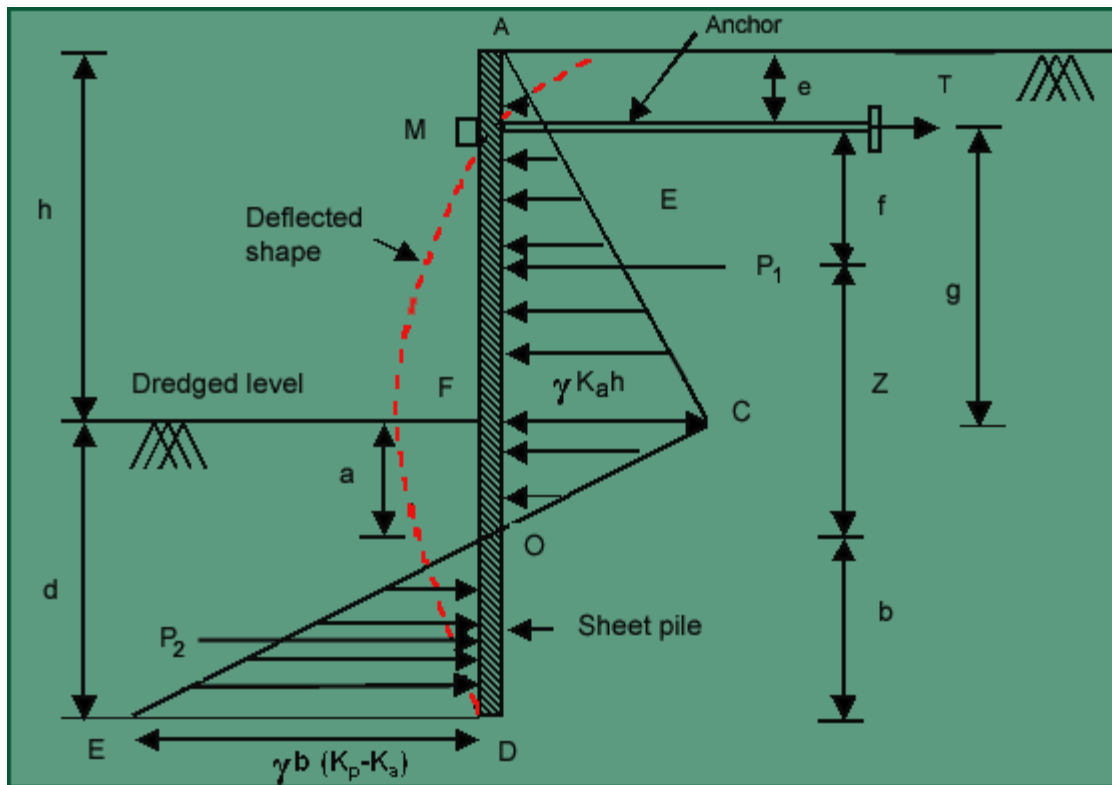


Fig. 6.22 Forces acting on sheet pile in free earth support case (cohesionless soil)

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Lecture 28 : Anchored sheet pile walls [Section 28.3 : Design of sheet pile wall by free earth support]

From horizontal equilibrium,

$$T + P_2 - P_1 = 0 \text{ Where,}$$

T is the tensile force in the anchor,

P_2 is the resultant earth pressure acting below the dredged level for b height of the wall,

P_1 is the resultant earth pressure acting for (h+a) height of the wall.

The depth a to the point of zero pressure can be determined by equating the earth pressure on both the side of the sheet pile.

$$\gamma K_a (h+a) = \gamma K_p a$$

$$a = \frac{hK_a}{(K_p - K_a)}$$

$$\text{Therefore, } P_2 = \frac{1}{2} [\gamma (K_p - K_a) b] b = \frac{1}{2} \gamma (K_p - K_a) b^2$$

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Lecture 28 : Anchored sheet pile walls [Section 28.3 : Design of sheet pile wall by free earth support]

Taking moments of all forces about anchor point M,

$$P_1 (a + h - e - Z_1) - P_2 (h - e + a + 2b/3) = 0$$

Where,

a is the distance of the zero earth pressure point below dredged level,

h is height of the sheet pile above the dredged level,

e is the distance of the anchor from the top level of sheet pile, generally taken as 1 to 1.5m,

Z_1 is the distance between point of application of force P_1 and O point.

Substituting the value of P_2 in the above equation,

$$P_1 (a + h - e - Z_1) - \gamma (K_p - K_a) b (b/2) (h - e + a + 2b/3) = 0$$

The above equation can be written as,

$$b^3 (K_p - K_a) (\gamma/3) + b^2 (K_p - K_a) (\gamma/2) (g+a) - P_1 f = 0$$

$$\text{or } b^3 + 1.5b^2 (g+a) - \frac{3P_1 f}{\gamma (K_p - K_a)} = 0$$

where, $f = a + h - e - Z_1$ and $g = h - e$.

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Lecture 28 : Anchored sheet pile walls [Section 28.3 : Design of sheet pile wall by free earth support]

The above equation can be solved for b. Then, d is determined as,

$$d = b + a.$$

The actual depth D is taken equal to 1.2 to 1.4 times d.

The force in the anchor rod can be calculated as,

$$T = P_2 - P_1,$$

The values of P_1 and P_2 are determined from the pressure diagrams.

■ Cohesive soils

Consider the case, the sheet pile is driven in clay ($\phi = 0$), but has the backfill of cohesionless soil as shown in fig. The earth pressure distribution above the dredged line is same as that in case of cohesionless soil. However the pressure below the dredge line at any point at a distance of z from dredged level is given as,

$$p_2 = (K_p \gamma z + 2c\sqrt{K_a}) - [K_a(z+h)\gamma - 2c\sqrt{K_a}]$$

For $\phi = 0$, $K_a = K_p = 1.0$.

Therefore, $p_2 = 2c + 2c - \gamma h = 4c - \gamma h$

Where,

h is the height of the sheet pile above the dredged level,

c is the cohesion and γ is the unit weight of the soil.

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Lecture 28 : Anchored sheet pile walls [Section 28.3 : Design of sheet pile wall by free earth support]

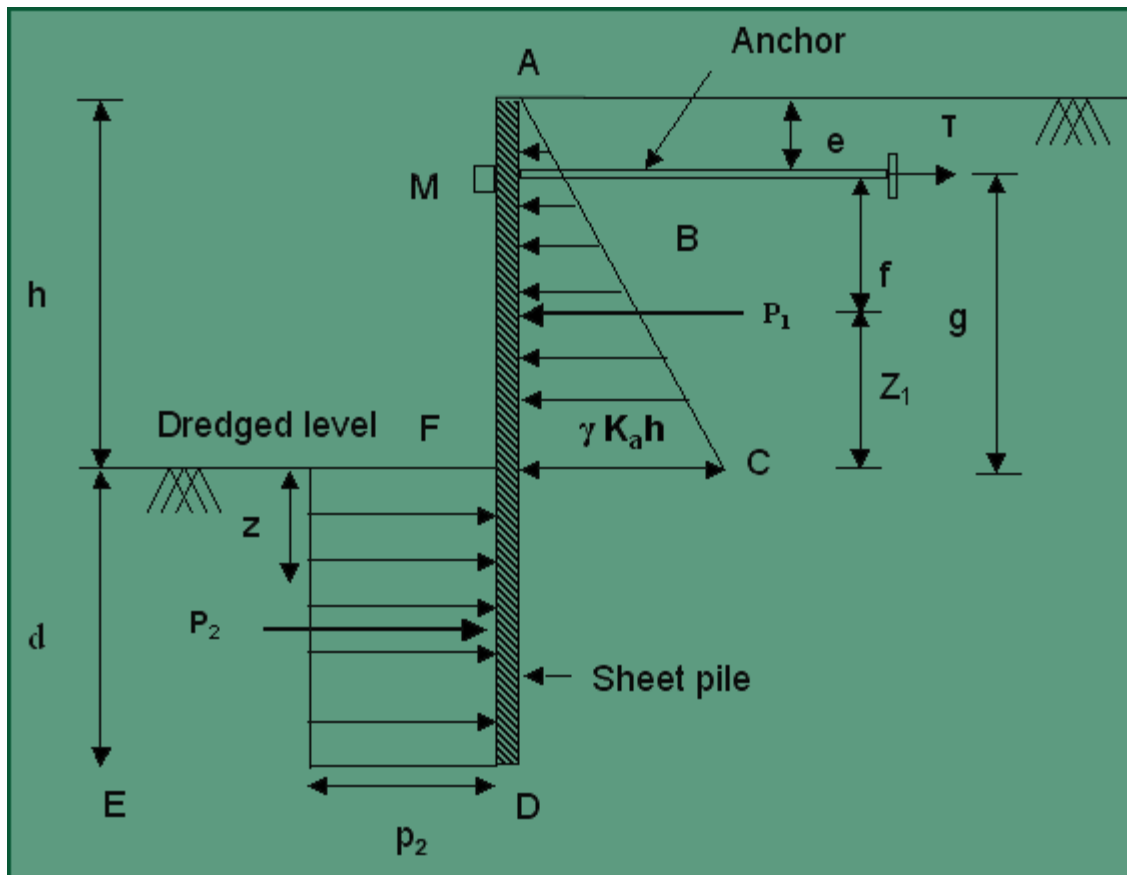


Fig. 6.23 Forces acting on sheet pile in free earth support case (cohesive soil)

From the horizontal equilibrium of the forces,

$$T + P_2 - P_1 = 0 \text{ or } P_1 - P_2 d = T$$

Where, T is the tensile force in the anchor,

P_2 is the resultant earth pressure acting below the dredged level,

P_1 is the resultant earth pressure acting above the dredged level.

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Lecture 28 : Anchored sheet pile walls [Section 28.3 : Design of sheet pile wall by free earth support]

Taking moments of all the forces about M,

$$P_1 f - p_2 d (g + d/2) = 0$$

Substituting the value of $p_2 = 4c - \gamma h$ in the above equation,

$$P_1 f - (4c - \gamma h) d (g + d/2) = 0$$

$$\text{or } d^2 + 2gd - \frac{2P_1 f}{4c - \gamma h} = 0$$

where,

g is the distance of the tendon above dredged level,

f is the distance between the point of application of P_1 force and tendon (M) = g - Z_1 .

The above equation can be solved for d.

The actual depth provided is 20 to 40% more than d.

The force in the anchor rod can be calculated as,

$$T + P_2 - P_1$$

The values of P_1 and P_2 are determined from the pressure diagrams.

The wall becomes unstable when p_2 becomes zero.

$$4c - \gamma h = 0, \text{ or } \frac{c}{\gamma h} = \frac{1}{4} = 0.25$$

In the above equation, $\frac{c}{\gamma h}$ is the stability number. Therefore the wall becomes unstable when stability number = 0.25.

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Lecture 28 : Anchored sheet pile walls [Section 28.3 : Design of sheet pile wall by free earth support]

Recap

In this section you have learnt the following.

- Cohesionless soil
- Cohesive soils

Module 6 : Design of Retaining Structures

Lecture 28 : Anchored sheet pile walls [Section 28.4 : Design of sheet pile wall by fixed earth support]

Objectives

In this section you will learn the following

- Design of sheet pile wall by fixed earth support

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Lecture 28 : Anchored sheet pile walls [Section 28.4 : Design of sheet pile wall by fixed earth support]

Design of sheet pile wall by fixed earth support

Figure shows the deflected shape of an anchored sheet pile with fixed earth support. The elastic line changes its curvature at the inflection point I. the soil into which the soil is driven exerts a large restraint on the lower part of the pile and causes the change in the curvature. The distance of the inflection point below dredged level (i) can be related to the internal friction angle (ϕ) as given in table 1.

Table 1 Relation between Distance of the inflection point below dredged level (i) and Friction angle (ϕ)

Friction angle (ϕ)	20 0	25 0	30 0	40 0
Distance of the inflection point below dredged level (i)	0.25h	0.15h	0.08h	-0.007h

Where, h is the height of the sheet pile wall above the dredged level.

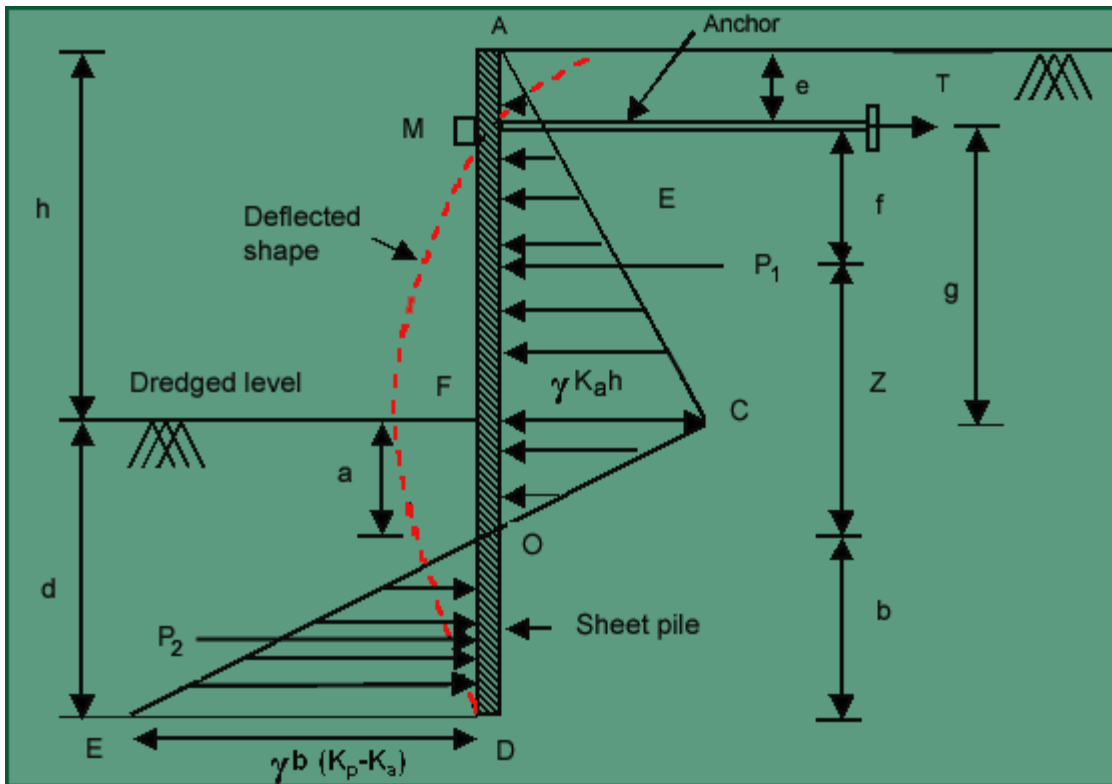


Fig. 6.24 Forces acting on sheet pile in fixed earth support case

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Lecture 28 : Anchored sheet pile walls [Section 28.4 : Design of sheet pile wall by fixed earth support]

As exact analysis of the anchored sheet pile with fixed earth support is complicated, an approximate method known as equivalent beam method is generally used. It is assumed that the sheet pile is a beam which is simply supported at anchor point M and fixed at the lower end K. Figure shows the bending moment diagram. The bending moment is zero at the inflection point I. The beam is divided into two parts as shown in figure. The following procedure is used for the analysis:

(a) For beam AI:

- determine the pressure p_1 at the dredged level,
- determine the distance l of the inflection point from table 1.
- determine the distance a i.e. the point of zero earth pressure ,

$$a = \frac{hK_a}{(K_p - K_a)}$$

- determine the pressure p_0 at the point of inflection as

$$p_0 = \frac{p_1}{a}(a-i)$$

- determine the reaction R_I for the beam IB by taking moments about point M of the anchor.

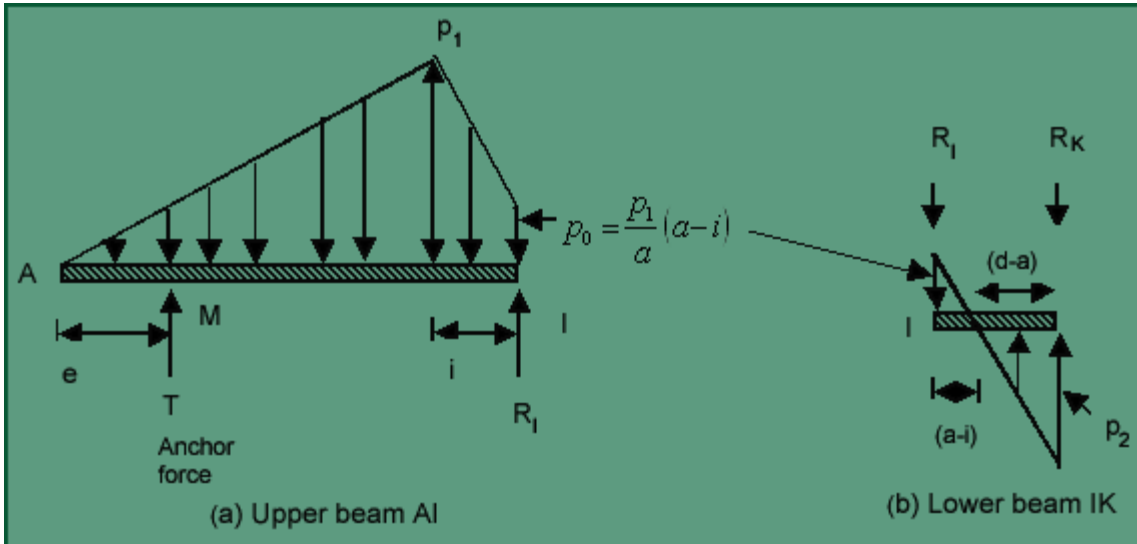


Fig. 6.25 Equivalent beam method

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Lecture 28 : Anchored sheet pile walls [Section 28.4 : Design of sheet pile wall by fixed earth support]

(b) For beam IK :

- determine pressure p_2 as

$$p_2 = \gamma(K_p - K_a)(d - a) \quad \text{or} \quad p_2 = \frac{P_0}{(a - i)}(d - a)$$

- determine distance (d-a) by taking moments of the forces in beam IK about K. the reaction R_I of the lower beam is equal and opposite to the upper beam.

calculate depth d from equation in step . The provided depth (D) of sheet pile is 20% higher than d.

$$D = 1.2 d$$

- determine the tension T in the anchor by considering equilibrium of IA beam,

$$T = P_1 - R_I$$

Where, P_1 is the total forces due to pressure on IB.

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Lecture 28 : Anchored sheet pile walls [Section 28.4 : Design of sheet pile wall by fixed earth support]

Recap

In this section you have learnt the following.

- Design of sheet pile wall by fixed earth support

Module 6 : Design of Retaining Structures

Lecture 28 : Anchored sheet pile walls [Section 28.5 : Moment reduction for anchored wall]

Objectives

In this section you will learn the following

- Moment reduction for anchored wall

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Lecture 28 : Anchored sheet pile walls [Section 28.5 : Moment reduction for anchored wall]

Moment reduction for anchored wall

Rowe (1952) demonstrated that the Free Earth method overestimates the maximum bending moment in anchored walls with horizontal tie rods. The sheet piles are relatively flexible and these deflect considerably. Their flexibility causes a redistribution of the lateral earth pressure. The net effect is that the maximum bending moment is considerably reduced below the value obtained for the free earth supports. It is used to take into consideration the flexibility of the pile and its effect on relieving the actual bending moment the wall experiences. The reduced bending moment for design (M_{design}) is given by

$$M_{\text{design}} = M_{\text{max}} R_m$$

where

M_{max} = maximum bending moment predicted by the Free Earth method,

R_m = reduction factor depending on wall geometry, wall flexibility, and foundation soil characteristics.

- Moment reduction factor for granular foundation soils. When the soil below the dredge line is granular, the magnitude of the reduction factor R_m is a function of a flexibility number given by

$$\rho = \frac{H^4}{EI}$$

where, H = total length of the sheet piling (ft),

E = modulus of elasticity of the pile material (psi),

I = moment of inertia (in 4) per foot of wall.

Curves of R_m are given in fig. for "loose" and "dense" foundation material and several system geometries.

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Lecture 28 : Anchored sheet pile walls [Section 28.5 : Moment reduction for anchored wall]

- Moment reduction factor for cohesive foundation soils. Moment reduction factors for piles in homogeneous cohesive soils also depend on the stability number (S_n) given by

$$S_n = 1.25 \left(\frac{c}{p_v} \right)$$

where, c = cohesive strength of the soil,

p_v = effective vertical soil pressure on the retained side of the wall at the elevation of the dredge line .The curves for R_m are given for various combinations of system parameters in Figure

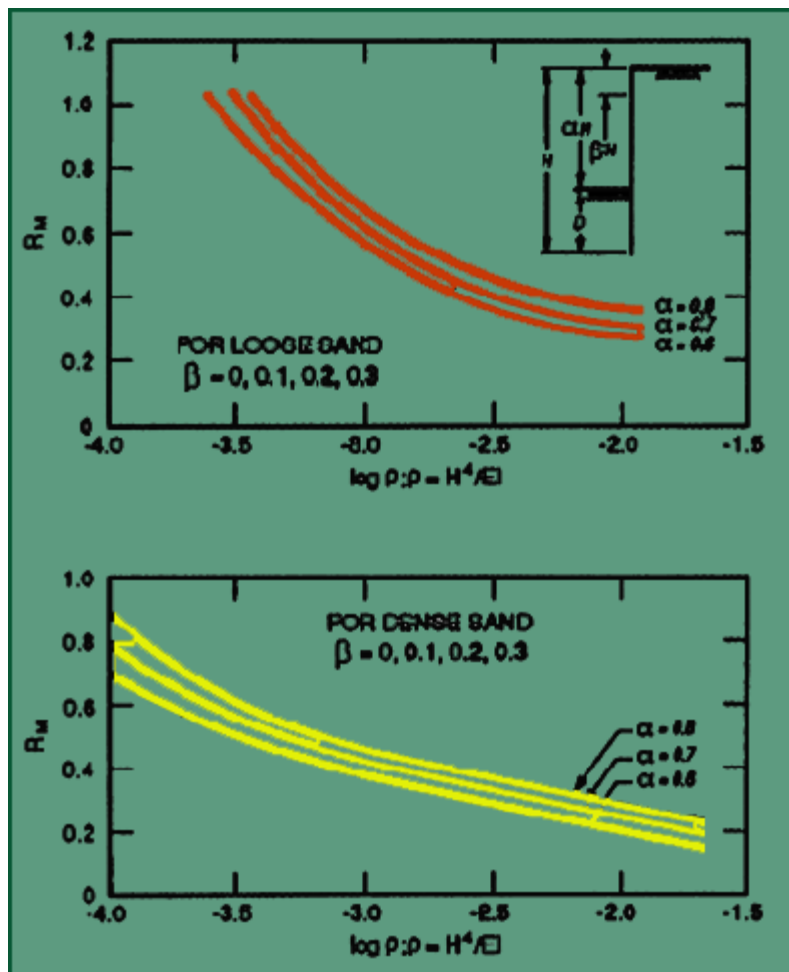


Fig. 6.26 Rowe's moment reduction coefficients for sand (after Bowles, 1982)

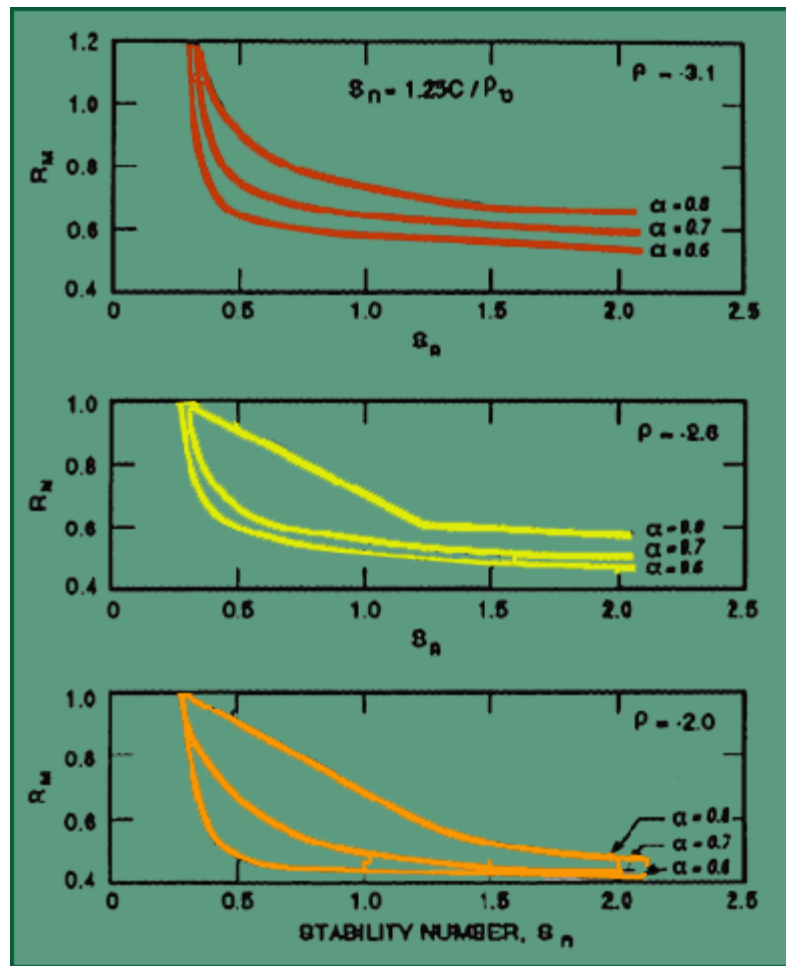


Fig. 6.27 Rowe's moment reduction coefficients for clays (after Bowles, 1982)

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Lecture 28 : Anchored sheet pile walls [Section 28.5 : Moment reduction for anchored wall]

Recap

In this section you have learnt the following.

- Moment reduction for anchored wall