SECTION –B

UNIT-II

BRACED CUTS

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TYPES OF VERTICAL CUTS

- Shallow cuts
- Deep cuts
- Open cuts
- Closed cuts
- Temporary cuts
- Permanent cuts

In shallow cuts depth of excavation is less than 6 m. The bracings of this type of cut generally standard

In deep cuts depth of excavation is more than 6 m and the design of suitable bracings (supporting system) is necessary to safe guard the cut or trench against collapse

DEPTH OF UNSUPPORTED VERTICAL CUT

The critical height (H_c) of vertical cut without supports is two times Z_o

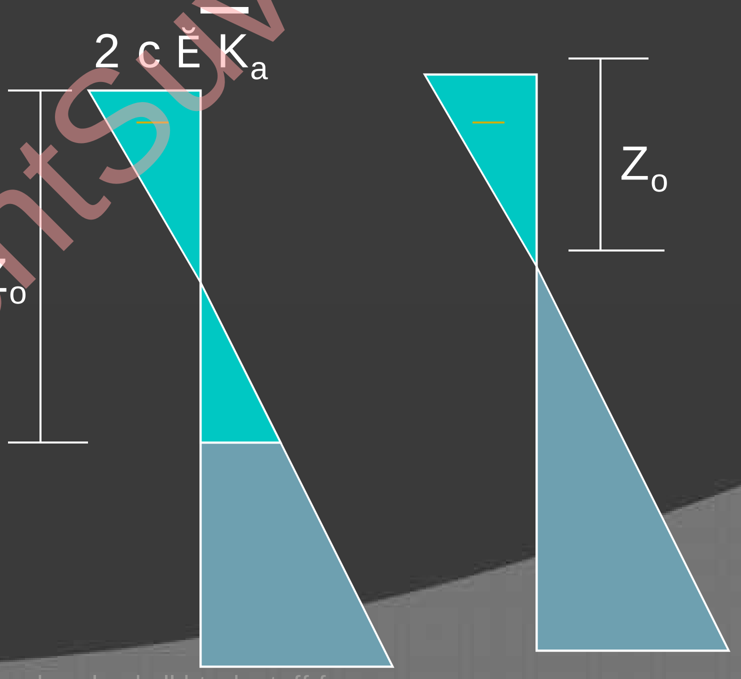
$H_c = 2\,Zo$ where,

$$Z_o = \frac{2c}{¥\sqrt{K_a}}$$

Where, Z_o is point of zero pressure

Hence,

$$H_c = \frac{4c}{¥\sqrt{K_a}}$$



WHAT IS BRACED CUT?

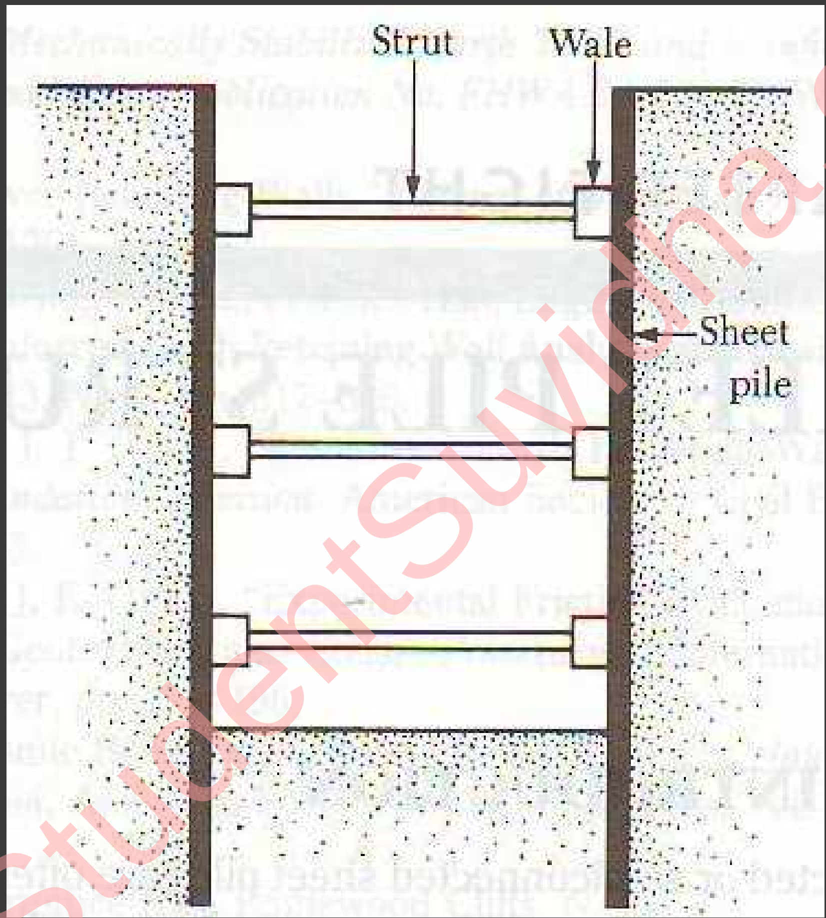
An excavation supported by suitable bracing system are called braced cut.

These excavation support systems are used to,

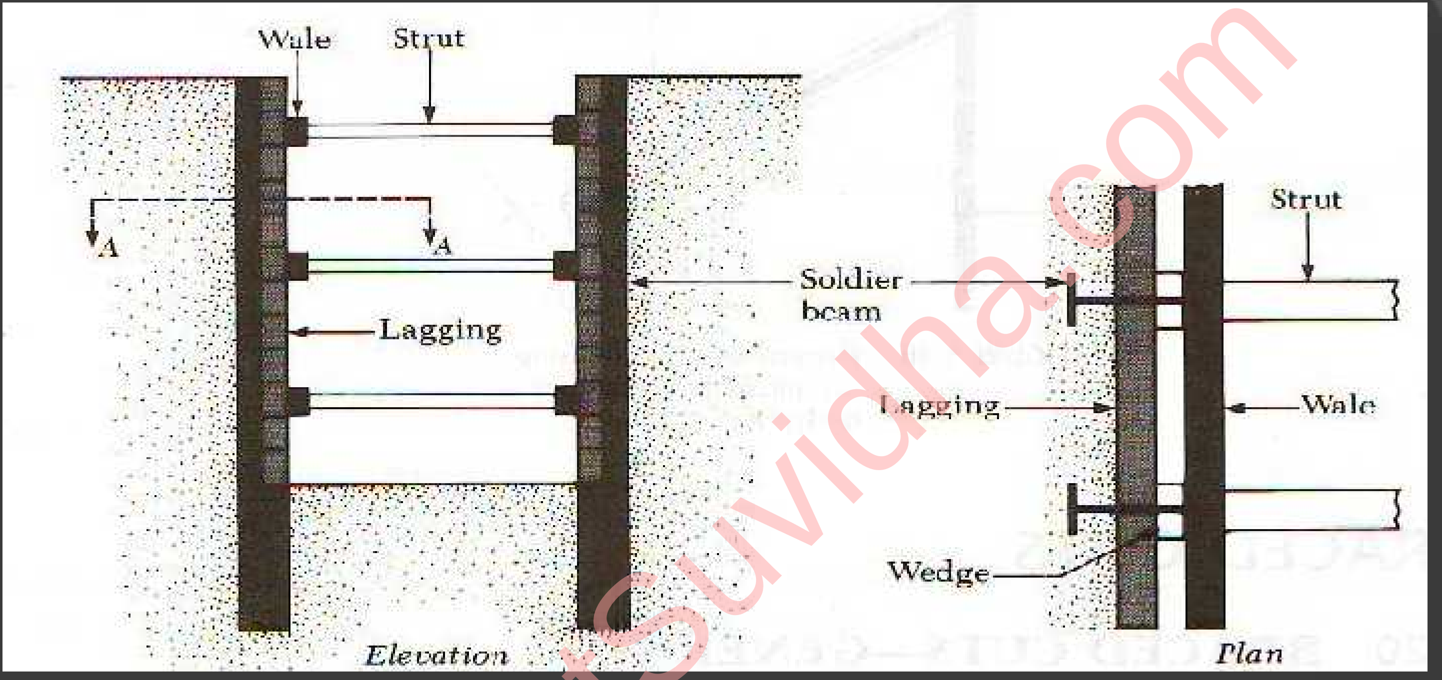
- minimize the excavation area,
- keep the sides of deep excavations stable, and
- ensure that movements of soil will not cause damage to neighboring structures or to utilities in the surrounding ground.

Design of braced excavation means selection of wales, struts, sheet piles and soldier beams to support the excavation without any collapse by estimating the lateral earth pressure to which the braced cuts will be subjected to.

CROSS SECTION OF BRACED CUT



Type I use of soldier beams



soldier beam is driven into the ground before excavation and is a vertical steel or timber beam.

Laggings, which are horizontal timber planks, are placed between soldier beams as the excavation proceeds.

When the excavation reaches the desired depth, wales and struts (horizontal steel beams) are installed. The struts are horizontal compression members.

Type II use of sheet piles

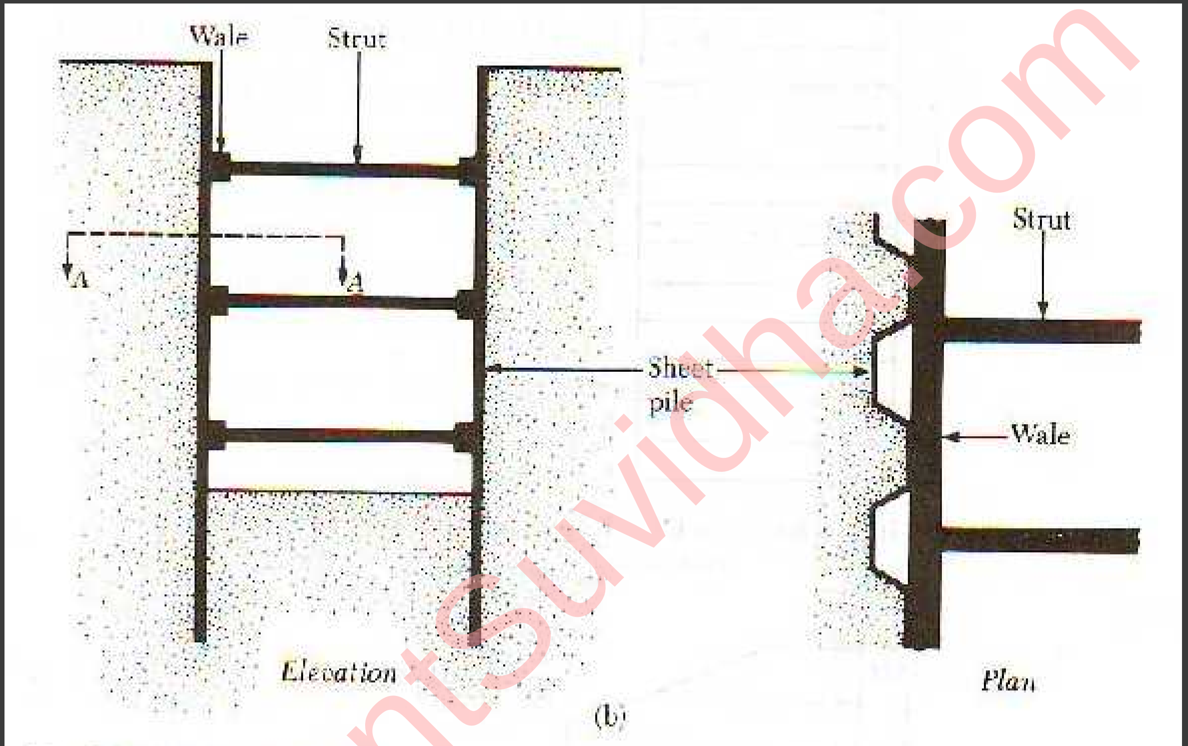


FIGURE 8.49 (Continued)

interlocking sheet piles are driven in to the soil before excavation.

Wales and struts are inserted immediately after excavation reaches the appropriate depth.

DIFFERENT TYPES OF SHEETING AND BRACING SYSTEMS

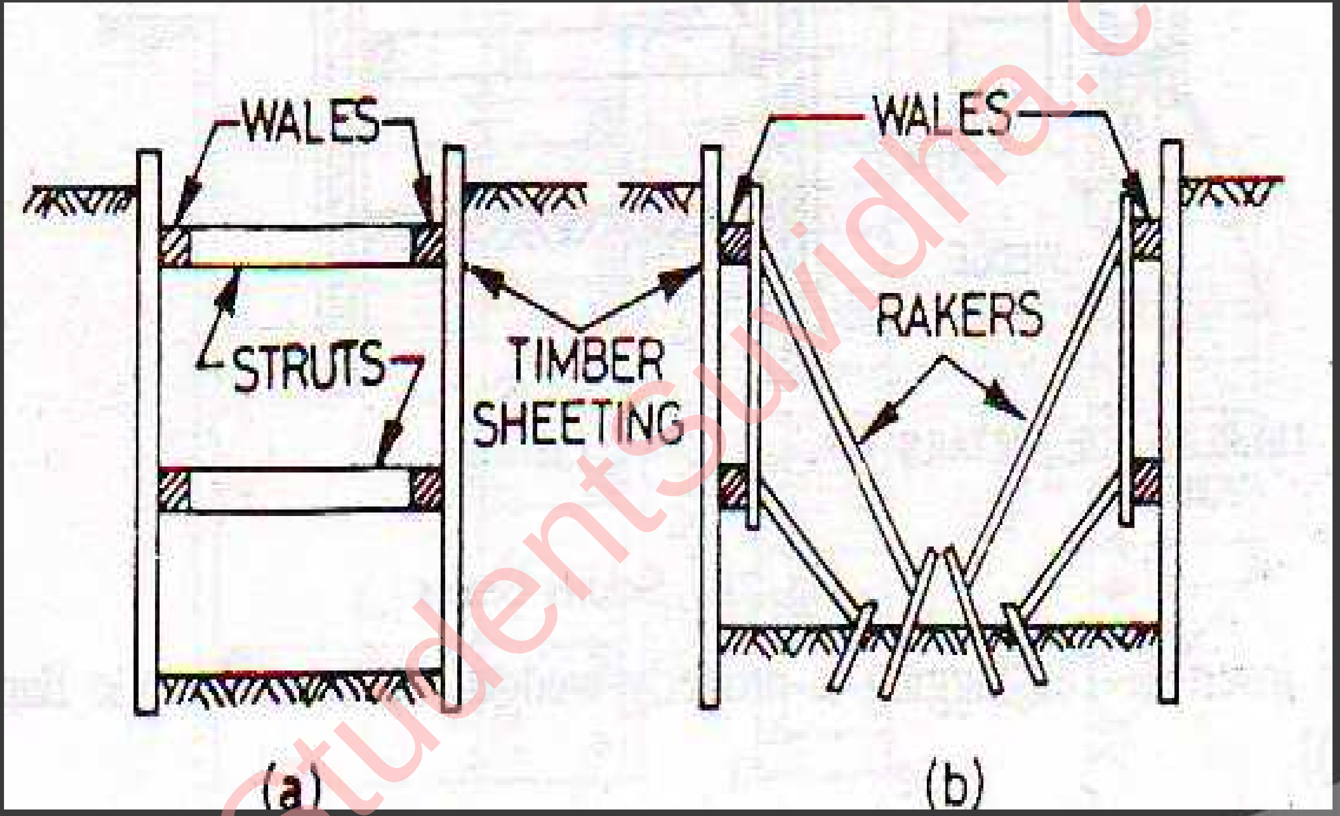
The following types of sheeting and bracing systems for cuts are commonly used.

Vertical Timber Sheeting: Vertical timber sheeting consisting of planks about 8 to 10 cm thick are driven around the boundary of the proposed excavation to some depth below the base of the excavation. The soil between the sheeting is then excavated. The sheeting is held in place by a system of wales and struts. The wales are horizontal beams running parallel to the excavation wall. The wales are supported by horizontal struts which extend from side to side of the excavation. However, if the excavations are relatively wide, it becomes economical to support the wales by inclined struts, known as rakers. For inclined struts to be successful, it is essential that the soil at the base of the excavation be strong enough to provide adequate reaction.

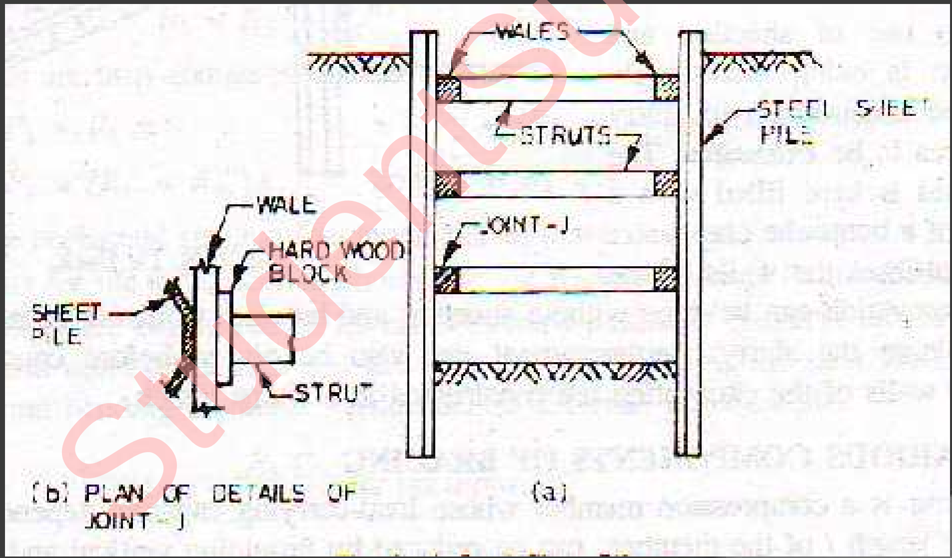
If the soil can be temporarily support itself an excavation of limited depth without an external support, the timber sheeting can be installed in the open or in a partially completed excavation.

Vertical timber sheetings are economical up to a depth of 4 to 6 m.

VERTICAL TIMBER SHEETING



Steel Sheet Pile: In this method, the steel sheet piles are driven along the sides of the proposed excavation. As the soil is excavated from the enclosure, wales and struts are placed. The wales are made of steel. The struts may be of steel or wood. As the excavation progresses, another set of wales and struts is inserted. The process is continued till the excavation is complete. It is recommended that the sheet piles should be driven several meters below the bottom of excavation to prevent local heaves. If the width of a deep excavation is large, inclined bracing may be used.



Soldier Beams: Soldier beams are H-piles which are driven at a spacing of 1.5 to 2.5 m around the boundary of the proposed excavation. As the excavation proceeds, horizontal timber planks called laggings are placed between the soldier beams. When the excavation advances to a suitable depth, wales and struts are inserted. The lagging is properly wedged between the pile flanges or behind the back flange.

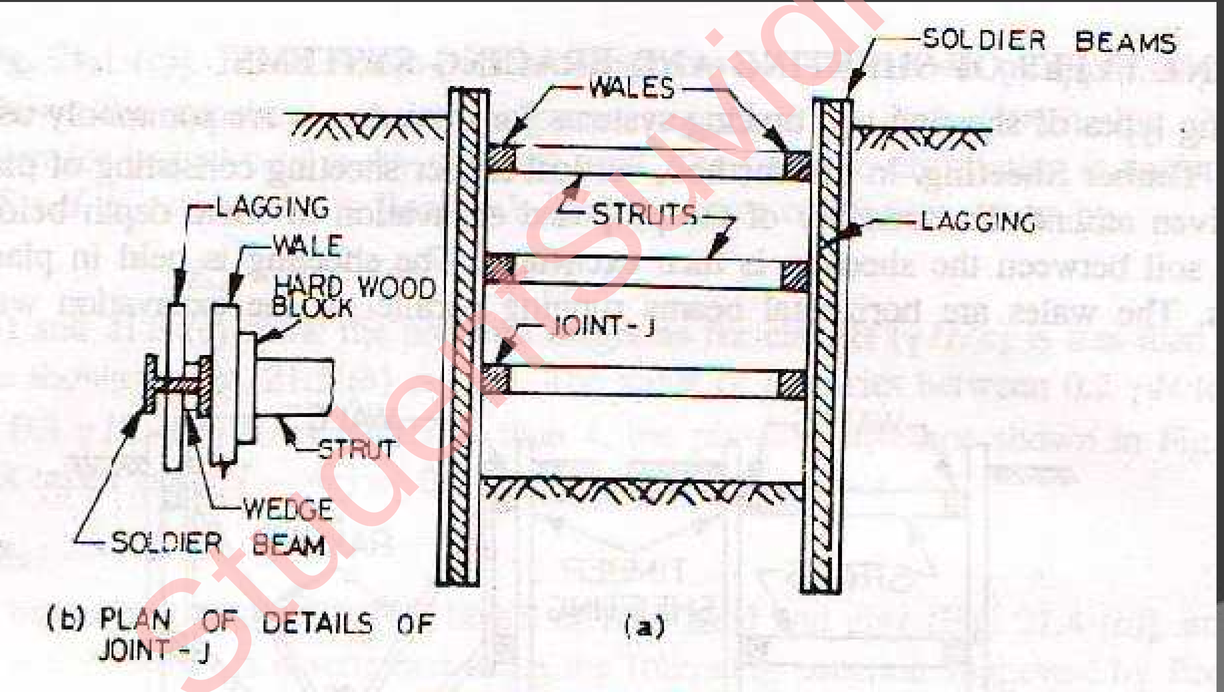


Fig. 21.7. Soldier Beams.

Tie Backs: In this method, no bracing in the form of struts or inclined rakers is provided. Therefore, there is no hindrance to the construction activity to be carried out inside the excavated area. The tie back is a rod or a cable connected to the sheeting or lagging on one side and anchored into soil (or rock) outside the excavation area. Inclined holes are drilled into the soil (or rock), and the hole is concreted. An enlargement or a bell is usually formed at the end of the hole. Each tie back is generally prestressed the depth of excavation is increased further to cope with the increased tension.

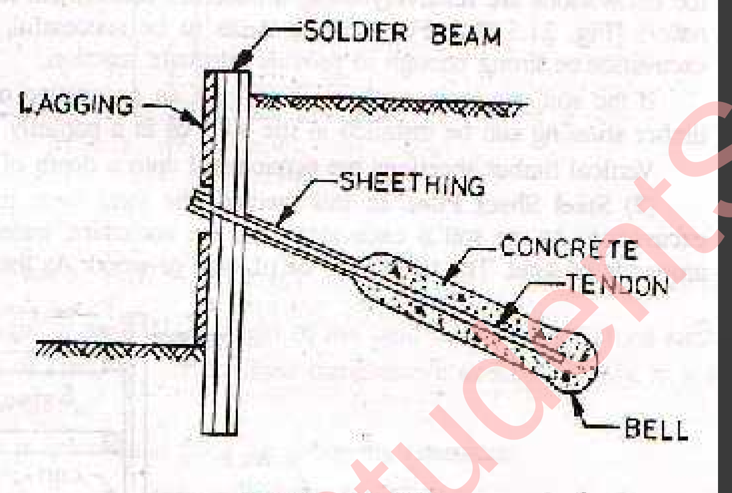


Fig. 21.8. Tie Back.

Prestressed concrete is a method for overcoming the concrete's natural weakness in tension

Having been stressed before use

Methods of increasing the load bearing capacity of concrete by applying increased tension on steel tendons or bars inside a beam. ...

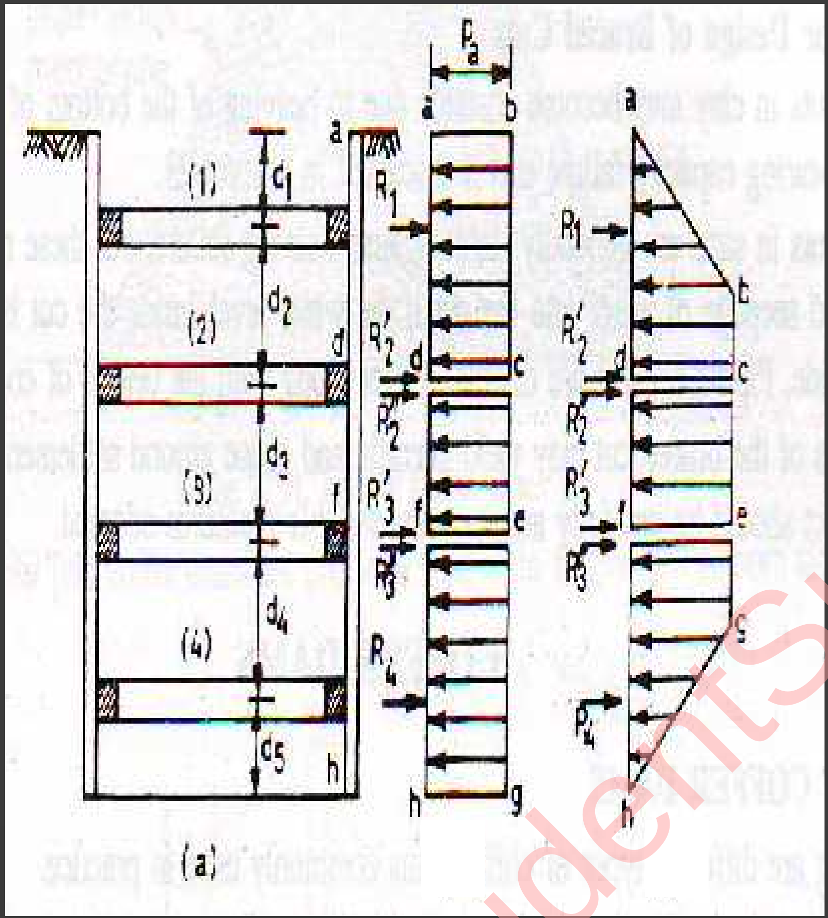
Use of Slurry Trenches: An alternative to use of sheeting and bracing system, which is being increasingly used these days, is the construction of slurry trenches around the area to be excavated and is kept filled with heavy, viscous slurry of a bentonite clay-water mixture. The slurry stabilizes the walls of the trench, and thus the excavation can be done without sheeting and bracing. Concrete is then placed through a tremie. Concrete displaces the slurry. Reinforcement can also be placed before concreting, if required. Generally, the exterior walls of the excavation are constructed in a slurry trench.

Design of Various Components of Bracing

Struts: The strut is a compression member whose load-carrying capacity depends upon slenderness ratio, l/r. The effective length 'l' of the member can be reduced by providing vertical and horizontal supports at intermediate points. The load carried by a strut can be determined from the pressure envelope. The struts should have a minimum vertical spacing of about 2.5 m. In the case of braced cuts in clayey soils, the depth of the first strut below the ground surface should be less than the depth of tensile crack (Zc), which is equal to ,

$$Z_C = \frac{2c}{\gamma}$$

While calculating the load carried by various struts, it is generally assumed that the sheet piles (or soldier beams) are hinged at all the strut levels expect for the top and bottom struts.



For sand For clay

The reaction R_1 per unit length is determined by taking moments of the forces acting on span a d at d, and equating them to zero. Once R_1 has been determined, the reaction component R_2' is determined from the equilibrium equation in the horizontal for the span a d.

The reaction components R_2'' and R_3' are determined considering span df as hinged at d and f.

Thus reaction at d, $R_2 = R_2' + R_2''$

The reaction R_4 is determined by taking moments about f of the forces acting on fh. The reaction component R_3'' is determined from the equilibrium equation for horizontal forces acting on fh. The analysis is similar to that of the top strut. Thus reaction at f,

$$R_3 = R_3' + R_3''$$

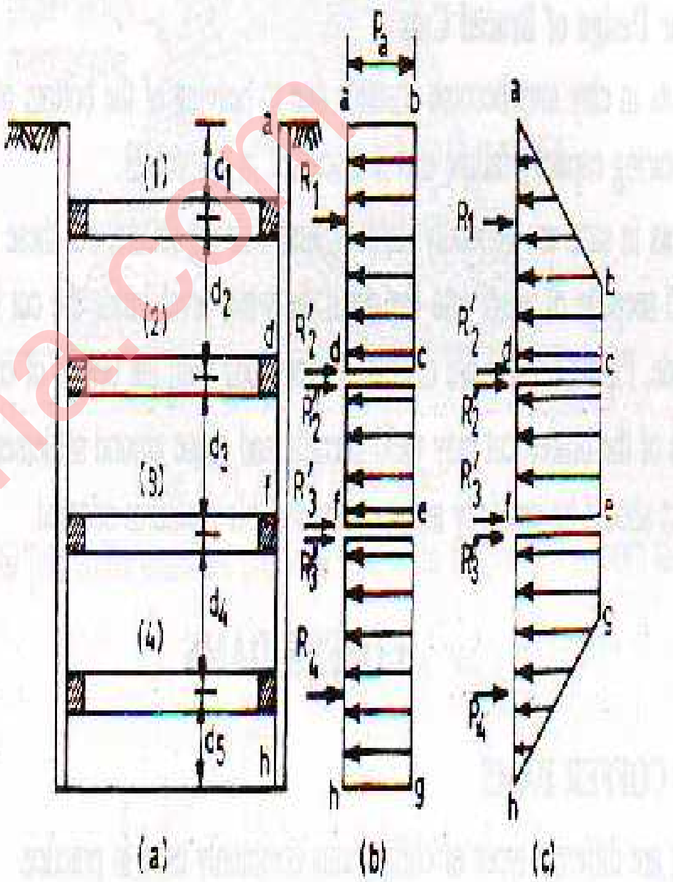
The strut loads are then computed as under.

$$P_1 = R_1 \times s \qquad P_2 = (R_2' + R_2'')s \qquad \text{...(21.6)}$$

$$P_3 = (R_3' + R_3'')s \quad \text{and } P_4 = R_4 \times s$$

where s is the horizontal spacing (perpendicular to plane of paper) of struts.

Proper sections for the struts can be chosen for the respective loads found above.



(*b*) **Wales.** Wales are considered as horizontal beams pinned at the strut levels. The maximum bending moment will depend upon the span *s* and the loads on the struts. As the strut loads are different at various levels, the maximum bending moments would also be different. For example,

$$M_{max} = \frac{R_1 s^2}{8}, \text{ for the top wale} \qquad \text{...[21.7(a)]}$$

and

$$M_{max} = \frac{R_2 s^2}{8}, \text{ for the second wale} \qquad \text{...[21.7(b)]}$$

Once the maximum bending moments have been computed, the section modulus (*S*) is computed as

$$S = \frac{M_{max}}{\sigma_{all}} \qquad \text{...(21.7)}$$

where σ_{all} = allowable bending stress.

Sheet piles

Sheet piles act as vertical plates supported at strut levels. The maximum bending moments in various sections such as ad, df and f h are determined.

Once the maximum bending moments have been computed, the section modulus of the sheet pile can be computed and the section chosen.

Other Criteria for Design of Braced Cuts

Braced cuts in clay may become unstable due to heaving of the bottom of the excavation. This is a type of bearing capacity failure and is discussed.

Braced cuts is sand are generally stable against heaving failure but these may become unstable to upward seepage of water into the cut if the water level inside the cut is substantially lower than that outside.

Piping failures is also one of the concern to be taken care of.

The walls of the braced cut may yield laterally and cause ground settlement in the surrounding area.

This effect should be carefully assessed and suitable measures adopted.

MODES OF FAILURE OF BRACED CUT

- Failure of soil by bottom heave (applicable to clay)
- Failure of soil due to piping (applicable to sand)
- Failure by buckling of struts

When ¥ H / c_u is less than 6, movement of bracing system and heave of clay are small.

When, ¥ H / c_u approaches about 8, the movement of a well designed bracing system becomes very large.

When, ¥ H / c_u exceeding 8, the bracing is likely to collapse because of large inward movement of clay outside the embedded portion/s of the sheet piles and excessive upward heave of clay beneath the excavation.

In this case, design of simple braced system will not serve the purpose.

BOTTOM HEAVING OF A CUT IN CLAY

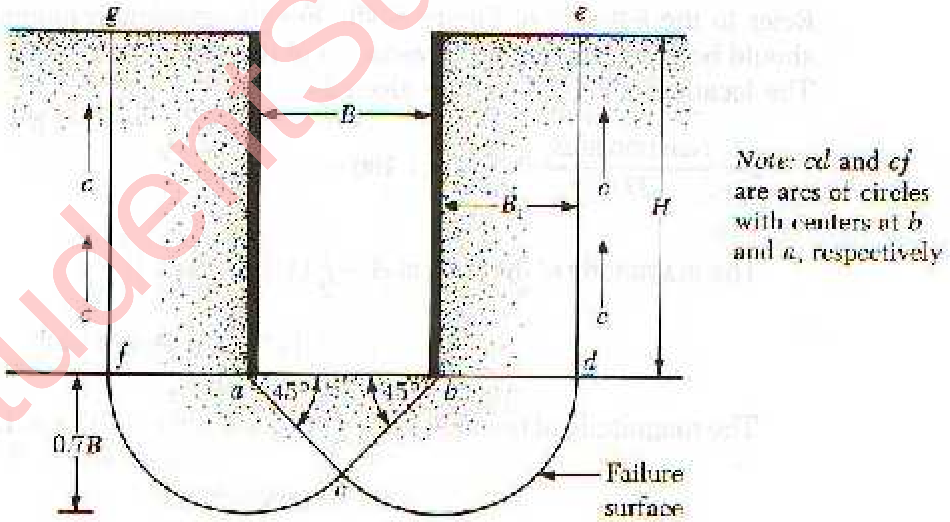
Braced cuts in clay may become unstable as a result of heaving of the bottom of the excavation. Terzaghi (1943) analyzed the factor of safety of braced excavations against bottom heave. The failure surface for such a case is shown in Figure 8.59. The vertical load (per unit length of the cut) at the bottom of the cut along line *bd* and *af* is

$$Q = \gamma H B_1 - cH \tag{8.115}$$

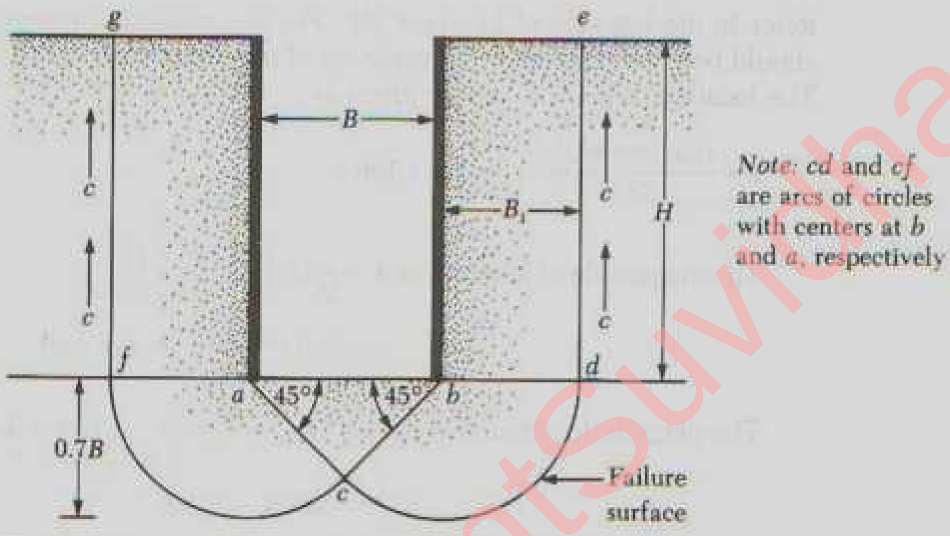
where $B_1 = 0.7B$
c = cohesion ($\phi = 0$ concept)

This load Q may be treated as a load per unit length on a continuous foundation at the level of *bd* (and *af*) and having a width of $B_1 = 0.7B$. Based on Terzaghi's bearing capacity theory, the net ultimate load-carrying capacity per unit length of this foundation (Chapter 3) is

$$Q_u = cN_cB_1 = 5.7cB_1$$



▼ FIGURE 8.59 Factor of safety against bottom heave



▼ FIGURE 8.59 Factor of safety against bottom heave

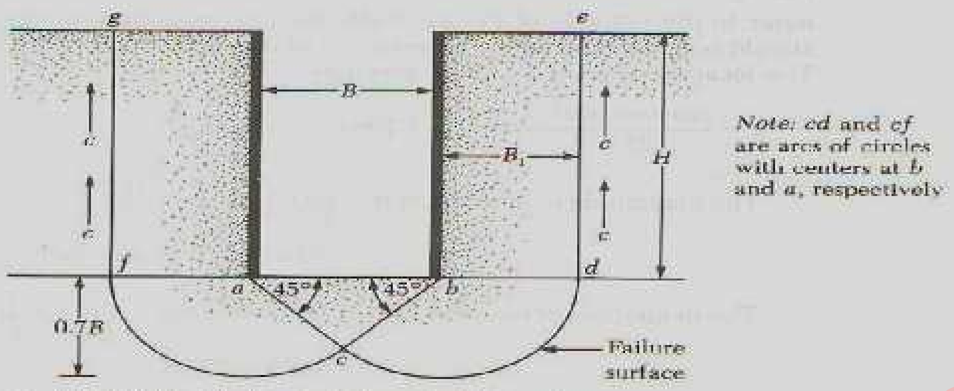


FIGURE 8.59 Factor of safety against bottom heave

Hence from Eq. (8.115), the factor of safety against bottom heave is

$$FS = \frac{Q_u}{Q} = \frac{5.7cB_1}{\gamma HB_1 - cH} = \frac{1}{H}\left(\frac{5.7c}{\gamma - \dfrac{c}{0.7B}}\right) \tag{8.116}$$

This factor of safety is based on the assumption that the clay layer is homogeneous, at least to a depth of $0.7B$ below the bottom of the cut. However, a *hard layer of rock or rocklike material at a depth of* $D < 0.7B$ will modify the failure surface to some extent. In such a case, the factor of safety becomes

$$FS = \frac{1}{H}\left(\frac{5.7c}{\gamma - c/D}\right) \tag{8.117}$$

Bjerrum and Eide (1956) also studied the problem of bottom heave for braced cuts in clay. For the factor of safety, they proposed:

$$FS = \frac{cN_c}{\gamma H} \tag{8.118}$$

The bearing capacity factor, N_c, varies with the ratios H/B and L/B (where L = length of the cut). For infinitely long cuts ($B/L = 0$), $N_c = 5.14$ at $H/B = 0$ and increases to $N_c = 7.6$ at $H/B = 4$. Beyond that — that is, for $H/B > 4$ — the value of N_c remains constant. For cuts square in plan ($B/L = 1$), $N_c = 6.3$ at $H/B = 0$, and $N_c = 9$ for $H/B \geq 4$. In general, for any H/B,

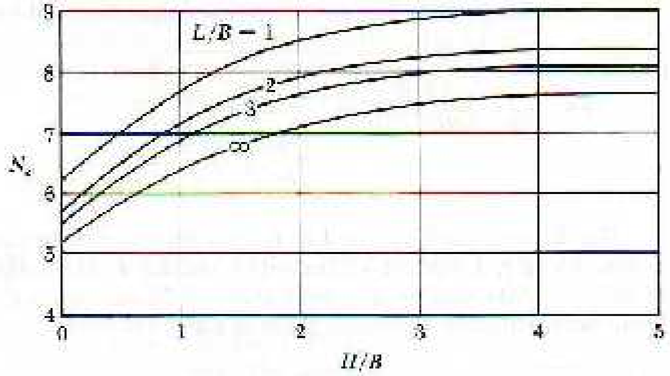
$$N_{c(\text{rectangle})} = N_{c(\text{square})}\left(0.84 + 0.16\frac{B}{L}\right) \tag{8.119}$$

Figure 8.60 shows the variation of the value of N_c for $L/B = 1, 2, 3$, and ∞.

When Eqs. (8.118) and (8.119) are combined, the factor of safety against heave becomes

$$FS = \frac{cN_{c(\text{square})}\left(0.84 + 0.16\frac{B}{L}\right)}{\gamma H} \tag{8.120}$$

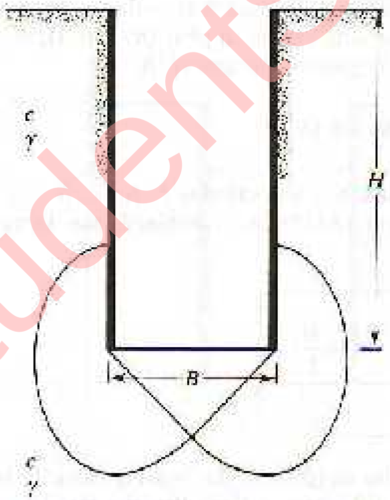
Equation (8.120) and the variation of the bearing capacity factor, N_c, as shown in Figure 8.60 are based on the assumptions that the clay layer below the bottom of the cut is homogeneous and that the magnitude of the undrained cohesion in



▼ FIGURE 8.60 Variation of N_c with L/B and H/B [based on Bjerrum and Eide's equation, Eq. (8.119)]

the soil that contains the failure surface is equal to c (Figure 8.61). However, if a stronger clay layer is encountered at a shallow depth, as shown in Figure 8.62a, the failure surface below the cut will be controlled by the undrained cohesions c_1 and c_2. For this type of condition, the factor of safety is

$$FS = \frac{c_1[N_{c(strip)}F_s]F_d}{\gamma H} \quad (8.121)$$



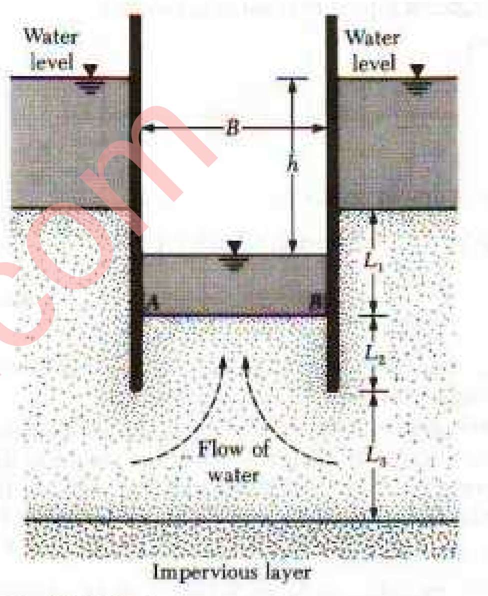
▼ FIGURE 8.61 Derivation of Eq. (8.120)

STABILITY OF THE BOTTOM OF A CUT IN SAND

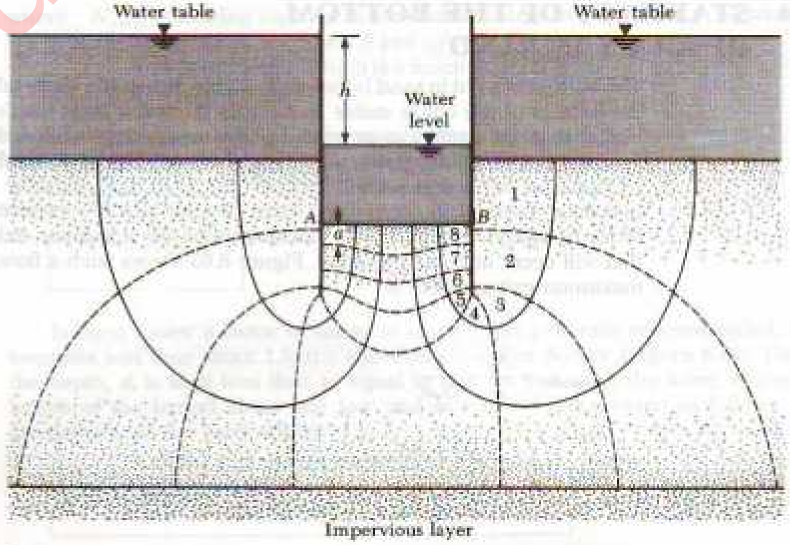
The bottom of a cut in sand is generally stable. When the water table is encountered, the bottom of the cut is stable as long as the water level inside the excavation is higher than the groundwater level. In case dewatering is needed (Figure 8.64), the factor of safety against piping should be checked. [*Piping* is another term for failure by heave, as defined in Section 1.11; see Eq. (1.51)]. Piping may occur when a high hydraulic gradient is created by water flowing into the excavation. To check the factor of safety, draw flow nets and determine the maximum exit gradient [$i_{max(exit)}$] that will occur at points *A* and *B*. Figure 8.65 shows such a flow net, for which the maximum exit gradient is

$$i_{max(exit)} = \frac{\frac{h}{N_d}}{a} = \frac{h}{N_d a}$$

where a = length of the flow element at *A* (or *B*)
N_d = number of drops (*note:* in Figure 8.65, $N_d = 8$ — also see Section 1.9)



▼ FIGURE 8.64



▼ FIGURE 8.65 Determining the factor of safety against piping by drawing flow net

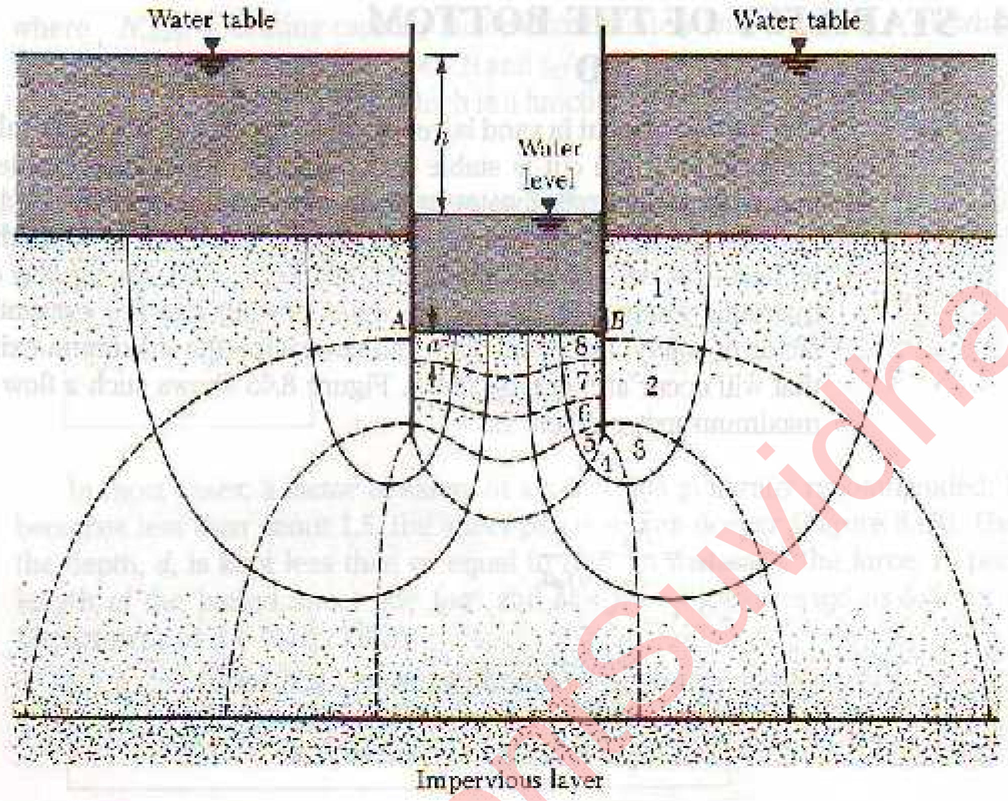


FIGURE 8.65 Determining the factor of safety against piping by drawing flow net

The factor of safety against piping may be expressed as

$$FS = \frac{i_{cr}}{i_{max(exit)}} \tag{8.126}$$

where i_{cr} = critical hydraulic gradient

The relationship for i_{cr} was given in Chapter 1 as

$$i_{cr} = \frac{G_s - 1}{e + 1}$$

The magnitude of i_{cr} varies between 0.9 and 1.1 in most soils, with an average of about 1. A factor of safety of about 1.5 is desirable.

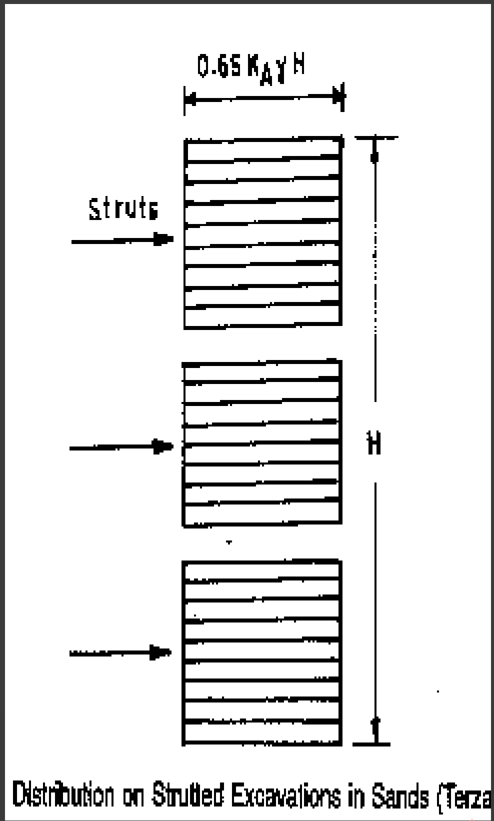
The maximum exit gradient for sheeted excavations in sands with $L_3 = \infty$ can also be evaluated theoretically (Harr, 1962). (Only the results of these mathematical derivations will be presented here. For further details, refer to the original work.) To calculate the maximum exit gradient, refer to Figures 8.66 and 8.67 and perform the following steps.

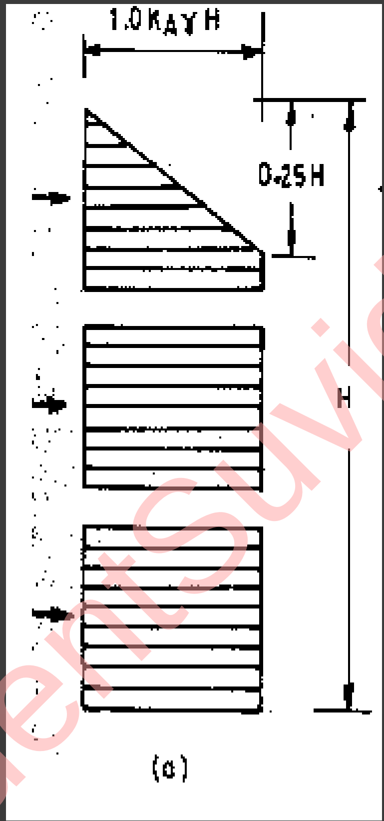
1. Determine the modulus, m, from Figure 8.66 by obtaining $2L_2/B$ (or $B/2L_2$) and $2L_1/B$.
2. With the known modulus and $2L_1/B$, refer to Figure 8.67 and determine $L_2 i_{exit(max)}/h$. Because L_2 and h will be known, $i_{exit(max)}$ can be calculated.
3. The factor of safety against piping can be evaluated by using Eq. (8.126).

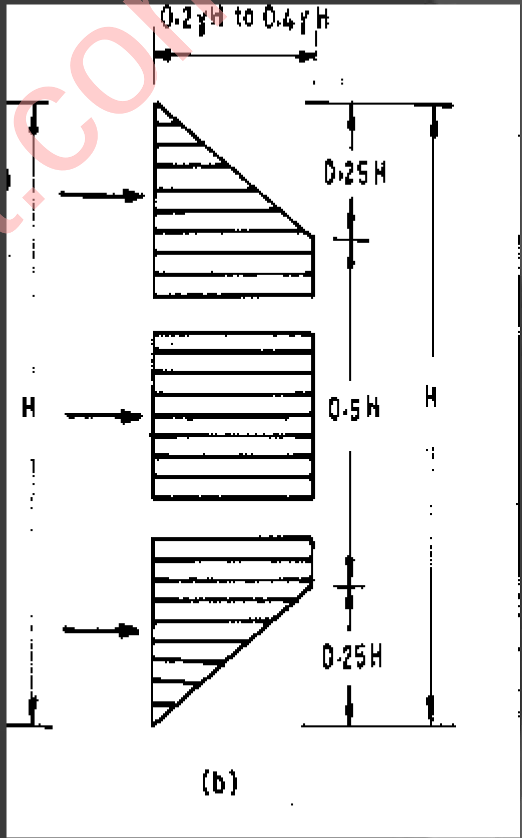
Marsland (1958) presented the results of model tests conducted to study the influence of seepage on the stability of sheeted excavations in sand. They were summarized by the U.S. Department of the Navy (1971) in *NAVFAC DM-7* and are given in Figure 8.68a, b, and c. Note that Figure 8.68b is for the case of determining the sheet pile penetration (L_2) needed for the required factor of safety against piping when the sand layer extends to a great depth below the excavation. However, Figure 8.68c represents the case in which an impervious layer lies at depth $L_2 + L_3$ below the bottom of the excavation.

Design of Braced Sheeting in Cuts

EARTH PRESSURE DISTRIBUTION BEHIND SHEETING







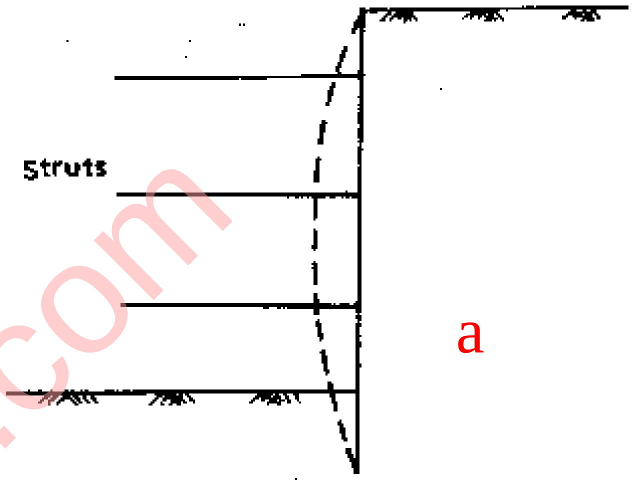
FOR DRY OR MOIST SAND FOR SOFT TO MEDIUM CLAY FOR STIFF CLAY

Design of Braced Sheeting in Cuts

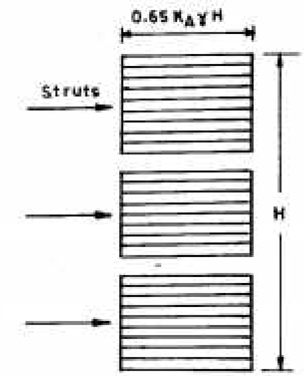
Sheet piles are used to retain the sides of the cuts in sands and clays. The sheet piles are kept in position by wales and struts. The first brace location should not exceed the depth of the potential tension cracks.

$$h_0 = \frac{2c}{\gamma}\tan\left(45 + \frac{\phi}{2}\right)$$

Since the formation of cracks will increase the lateral pressure against the sheeting and if the cracks are filled with water, the pressure will be increased even more. The sheeting of a cut is flexible and is restrained against deflection at the first series of struts. The deflection, therefore, is likely to be as shown in Fig. (a). The pressure distribution on sheet pile walls to retain sandy soil and clay soil are shown in Figs. (b) and (c) respectively.

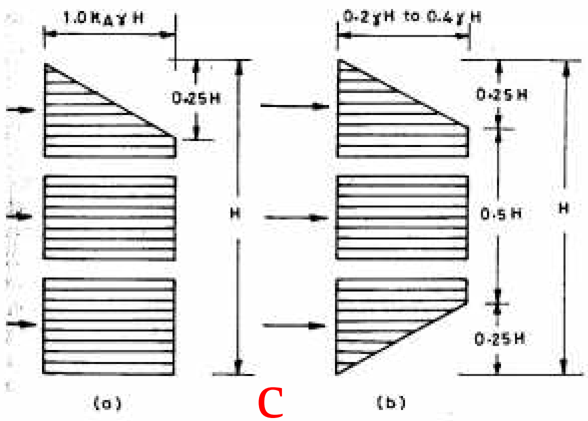


a



b

Pressure Distribution on Strutted Excavations in Sands (Terzaghi and Peck, 196



c

Design

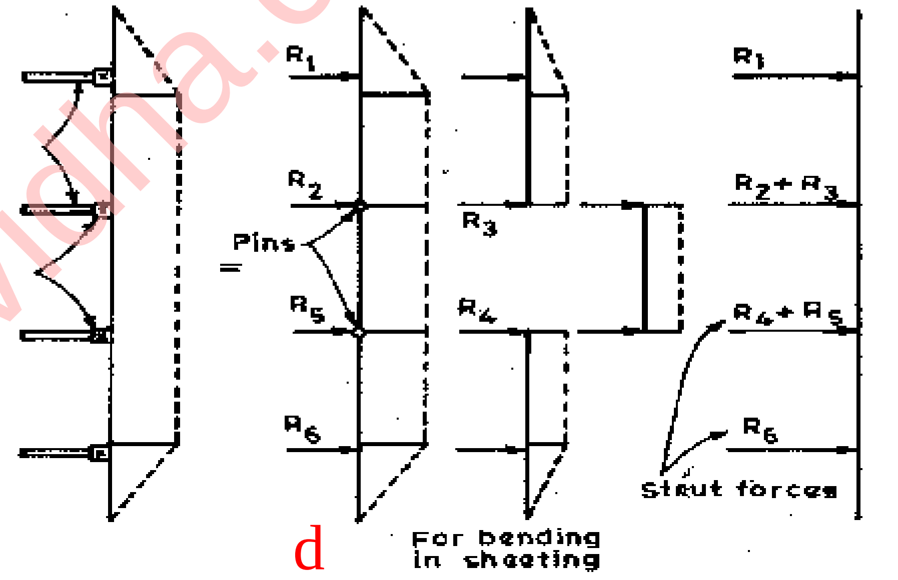
1. The sheet pile is considered as continuous beam supported on wales either cantilevered at top, fixed, partially fixed, hinged, or cantilevered at the bottom depending upon the amount of penetration below the excavation line.

2. Bending moment and shearing force diagram are then obtained using moment distribution method.

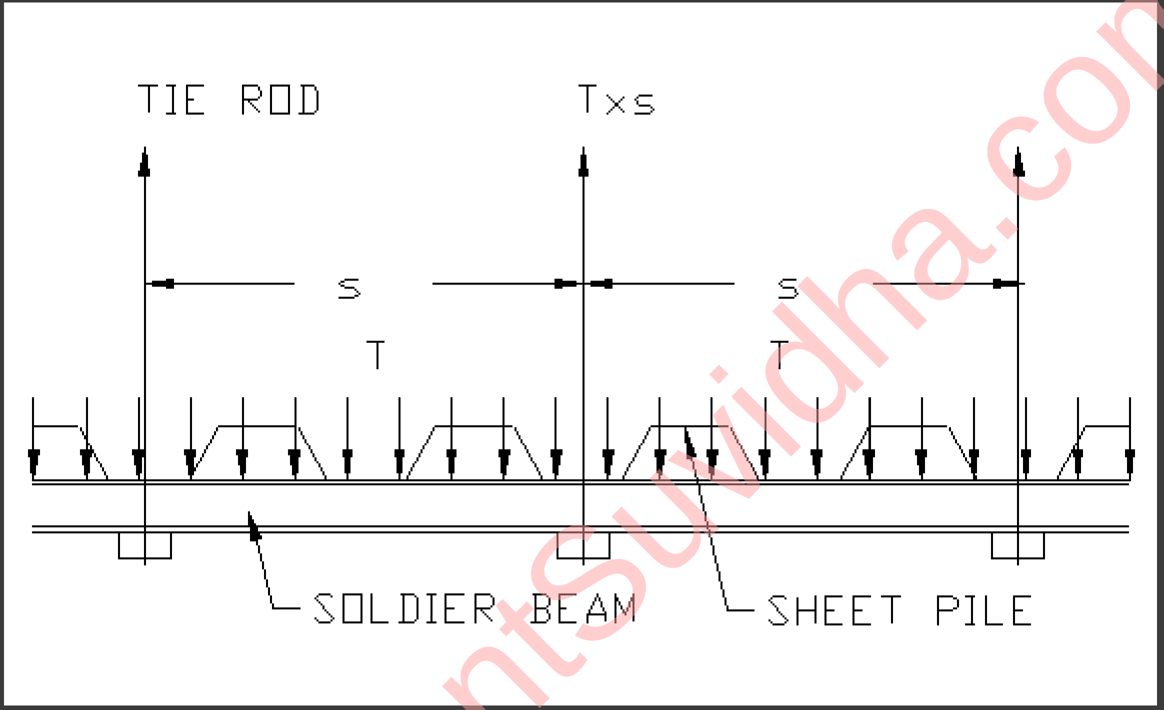
3. Section of the sheet pile is then designed in the conventional way for the maximum bending moment.

   A fast way of designing sheeting is to assume conditions as shown in Fig. (d). The top is treated as a cantilever beam including the first two struts. The remaining spans between struts are considered as simple beams with a hinge or cantilever at the bottom.

   Struts are designed as columns subjected to an axial force. The wales as continuous members or simply supported members pinned at the struts.



d



Cross section of sheeting and bracing systems

Deflection pattern of braced cuts

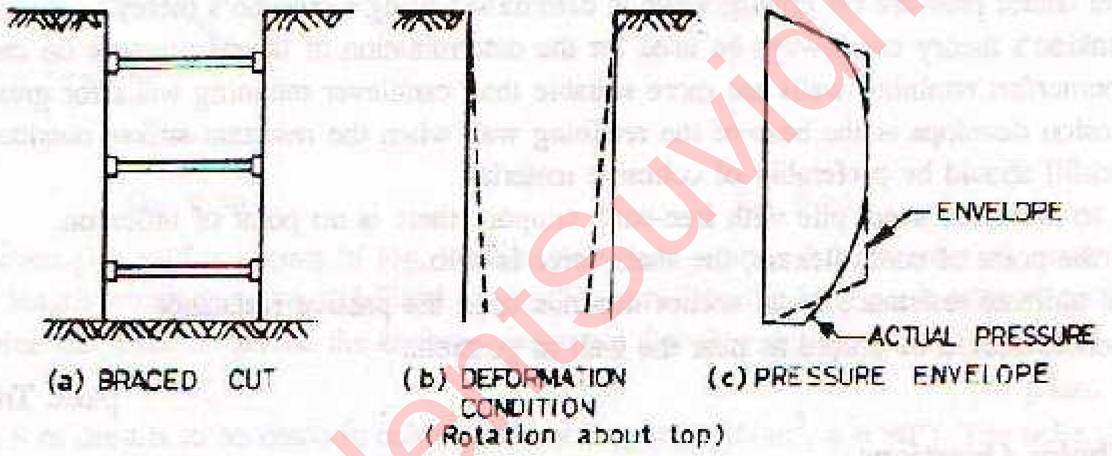


Fig. 21.1. Braced Cut.

Deflection pattern of braced cuts

Deep excavations in soil are often required, for example, for the construction of basements. The sides of the excavation should be properly supported to ensure safety of excavation and construction. Sheet piles are used against the sides which are joined by a set of wales running across them. The earth pressure acting on sheeting is resisted by horizontal struts (Figs. 16.2 and 17.30a), or by inclined struts (Fig. 17.34), or by the tie back braces (Fig. 17.30b). The struts and braces must be designed for the forces which act upon them.

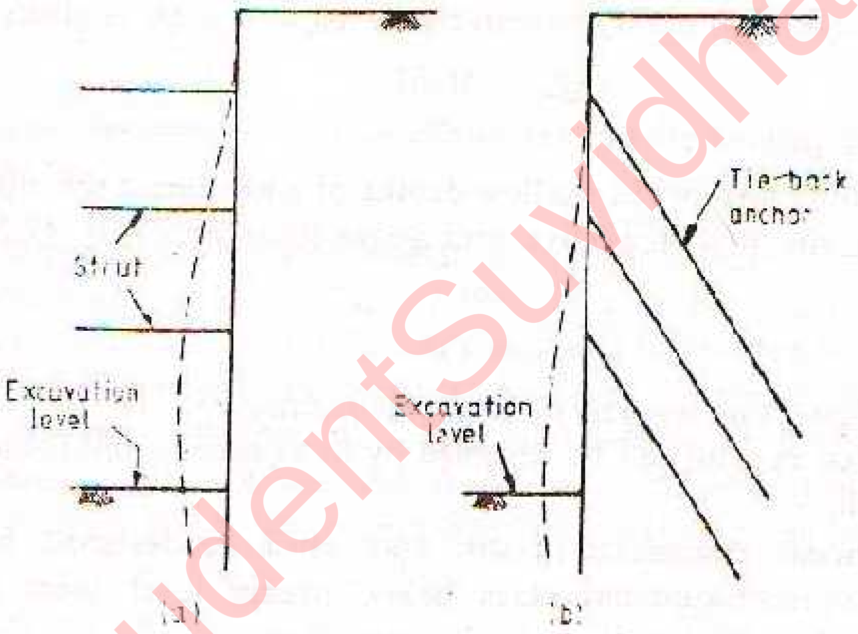


Fig. 17.30 Deflection pattern of braced cuts

Figure 17.30 shows typical deflection pattern of braced cuts. As a result of restricted deformation near the braces at the top active earth pressure distribution behind the sheeting cannot be assumed. Based on a number of experiments and measurements of earth pressure in braced cuts for actual excavations investigators have proposed earth pressure distribution diagrams which will be discussed here.

EARTH PRESSURE DISTRIBUTION

- In sand
- In clay

EARTH PRESSURE DISTRIBUTION IN SAND

Figure 17.31 shows the various recommendations for earth pressure distribution behind sheeting. In these diagrams H is the height of excavation. K_a is the coefficient of active earth pressure distribution with wall friction angle as zero ($\delta = 0°$).

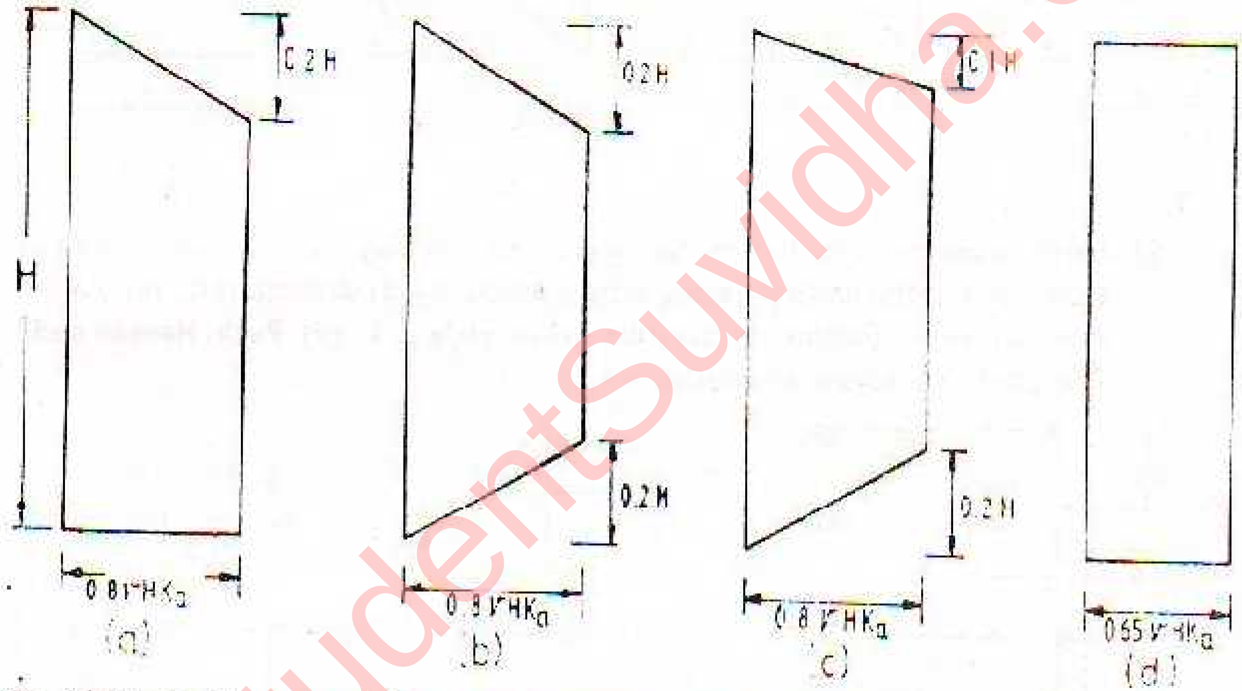


Fig. 17.31 Earth pressure distribution in sand for braced cuts due to: (a) Terzaghi and Peck—for loose sand, (b) Terzaghi and Peck—for dense sand, (c) Tschebotarioff, and (d) Peck, Hanson, and Thornburn—for moist and dry sands

EARTH PRESSURE DISTRIBUTION IN CLAY

17.3.2 Recommendations for Earth Pressure Distribution in Clay

Figure 17.32 shows the different recommendations in case of clay. In the diagrams, c is the average undrained cohesion of soil over the depth of excavation. γ is the average total density.

Braced excavations in clay may become unstable due to the heave of bottom. To ensure the stability of braced systems $\gamma H/c_b$ must be kept less than 6, where c_b is the undrained shear strength of soil below base or excavation level. Figure 17.32d can be used for $\gamma H/c$ value as large as 10 to 12, but $\gamma H/c_b$ must be less than 6.

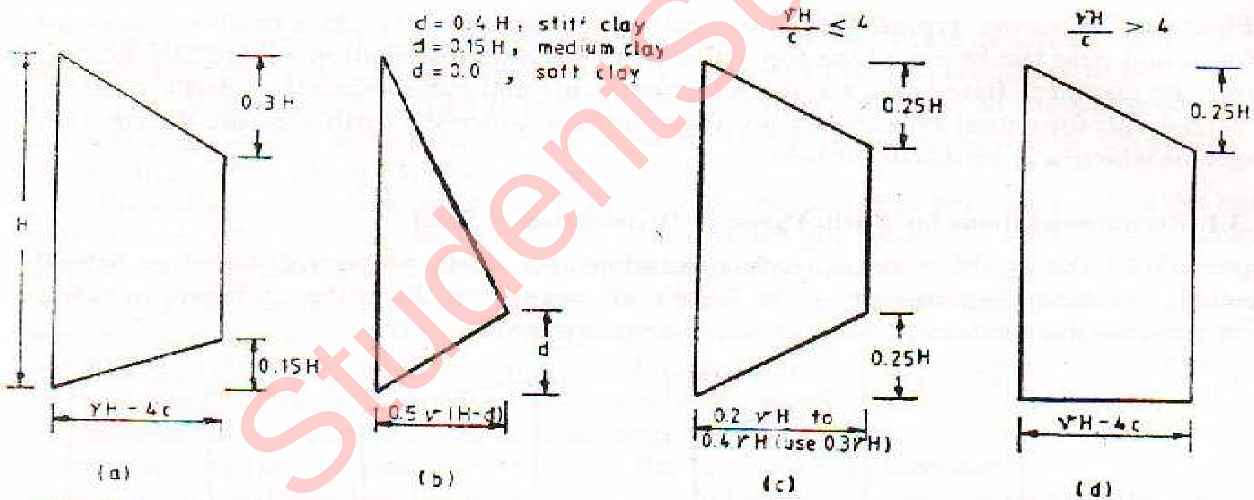


Fig. 17.32 Earth pressure distribution for braced cuts in clay: (a) for plastic clay by Peck, (b) neutral earth pressure ratio method by Tschebotarioff, (c) Peck, Hanson, and Thornburn's diagram when $\gamma H/c \leq 4$, (d) Peck, Hanson and Thornburn's diagram when $\gamma H/c > 4$.

EARTH PRESSURE DISTRIBUTION IN CLAY

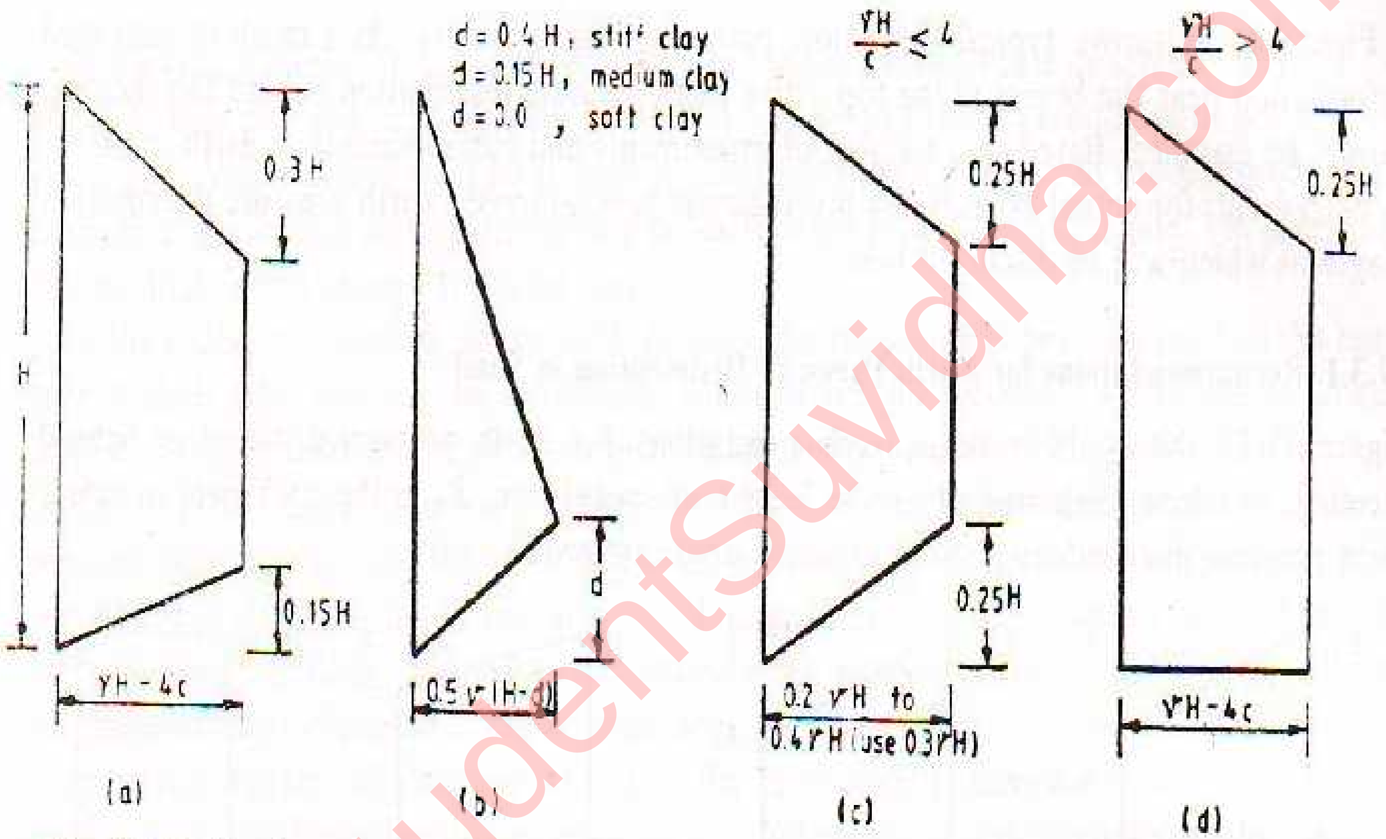


Fig. 17.32 Earth pressure distribution for braced cuts in clay: (a) for plastic clay by Peck, (b) neutral earth pressure ratio method by Tschebotarioff, (c) Peck, Hanson, and Thornburn's diagram when $\gamma H/c \leq 4$, (d) Peck, Hanson and Thornburn's diagram when $\gamma H/c > 4$

LOADS ON BRACES

Tributary area method

Equivalent beam method

17.3.3 Loads on Braces

Figure 17.33 explains the two methods of analysis for loads in horizontal struts. In tributary area method (Fig. 17.33a) the load on a strut is equal to the load resulting from pressure distribution over the tributary area for that strut. For example, strut load P_B in Fig. 17.33a is the total load on tributary area 1-2-3-4. In the equivalent beam method of analysis (Fig. 17.33b) the entire depth is split into segments of simply supported beam and the reactions can then be determined by standard procedures. In both the methods of analysis, P_S is the soil reaction in the embedded portion of sheet piles or soldier piles.

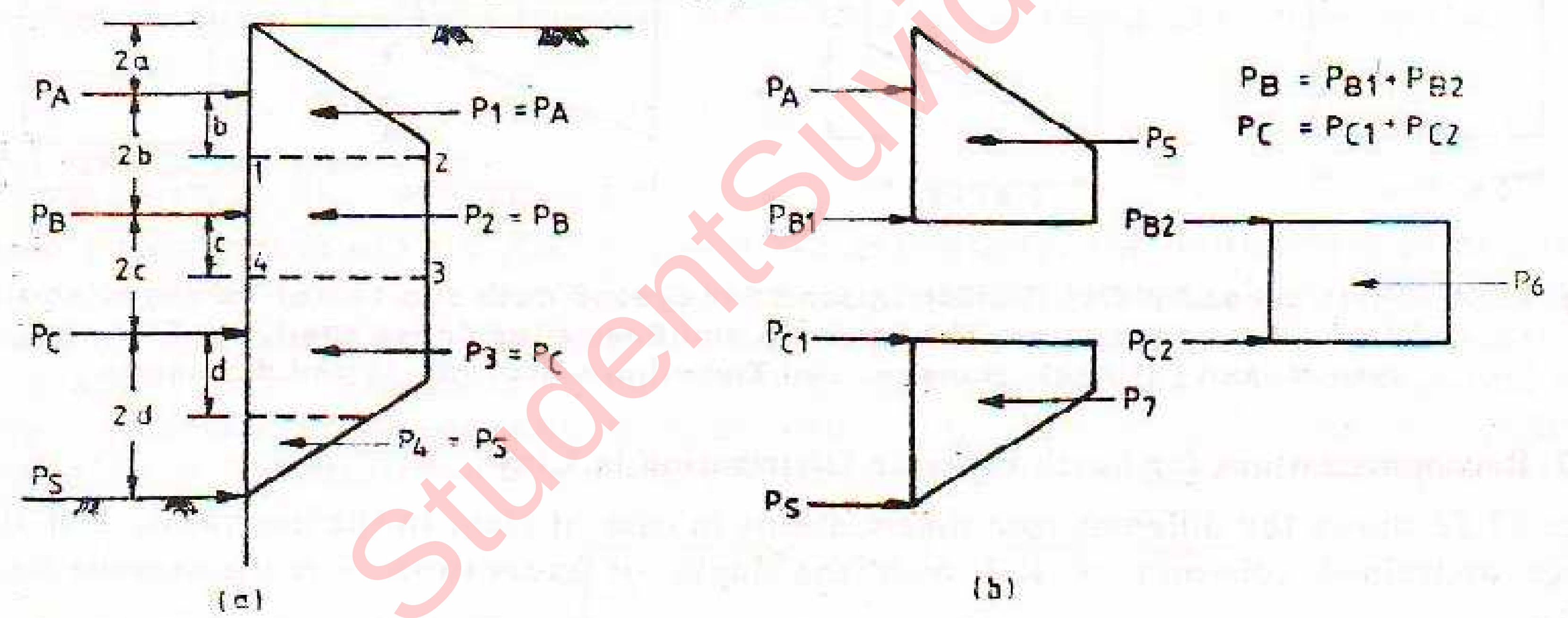


Fig. 17.33 Loads on horizontal struts (a) tributary area method, (b) equivalent beam method

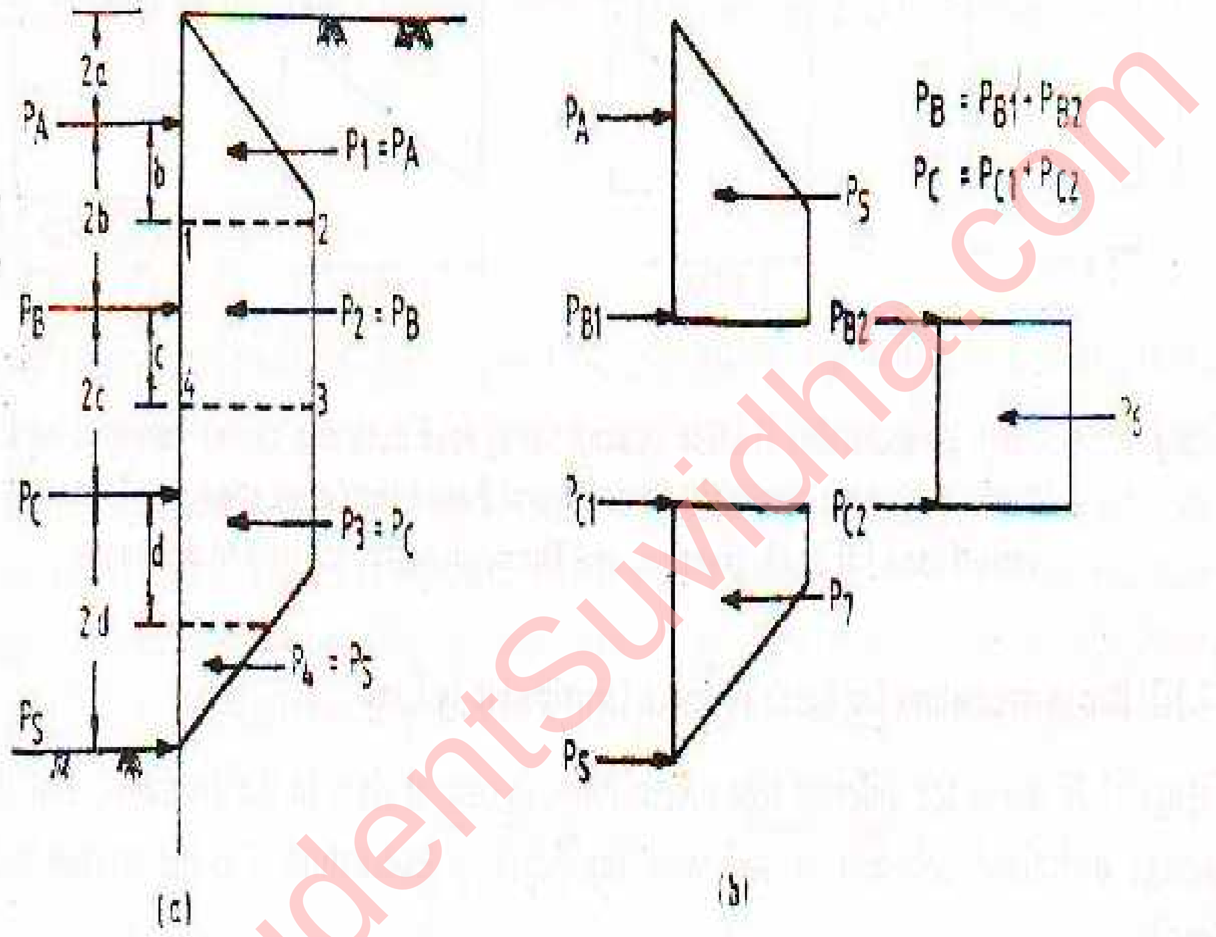
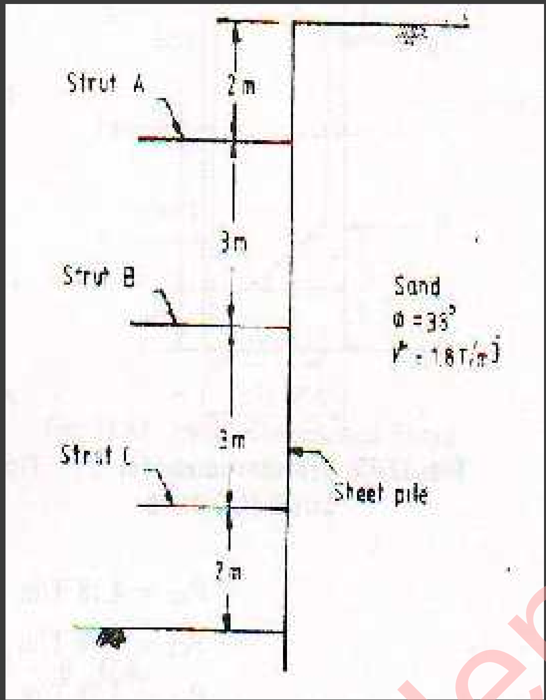


Fig. 17.33 Loads on horizontal struts (a) tributary area method, (b) equivalent beam method



For the cut shown in figure determine, the strut loads per meter run of excavation by,

1. Tributary area method
2. Equivalent beam method

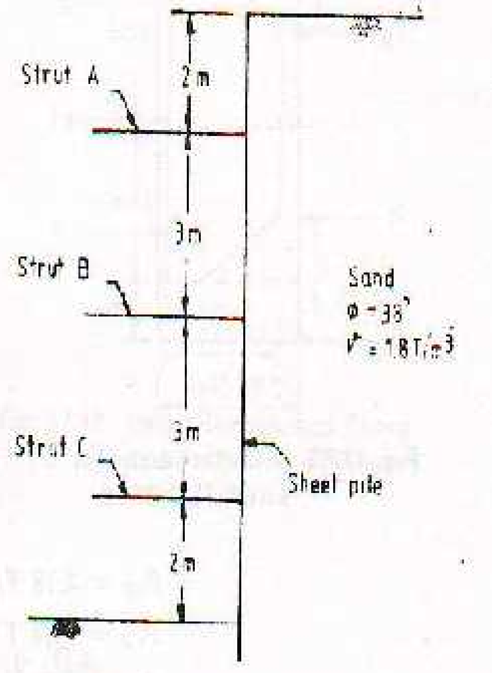


Fig. 17.38 Q 17.16

Solution by tributary area method using Peck, Hanson and Thornburn's diagram

$$K_a = 0.238$$

The uniform pressure over the depth of sheet pile is

$$= 0.65 \times 1.8 \times 10 \times 0.238 = 2.785\ \text{T/m}^2$$

The diagram for analysis of strut loads is shown in Fig. 17.39 from which,

$$P_A = 2.785 \times 3.5 = 9.75\ \text{T/m}$$

$$P_B = 2.785 \times 3 = 8.36\ \text{T/m}$$

$$P_C = 2.785 \times 2.5 = 6.96\ \text{T/m}$$

$$P_S = 2.785 \times 1 = 2.785\ \text{T/m}$$

Depending on the spacing of struts along the length of excavation the load per strut can be computed as,

Load per strut = load on strut per unit length × spacing of struts

Solution by equivalent beam method using Peck, Hanson and Thornburn's diagram

Figure 17.40 gives the

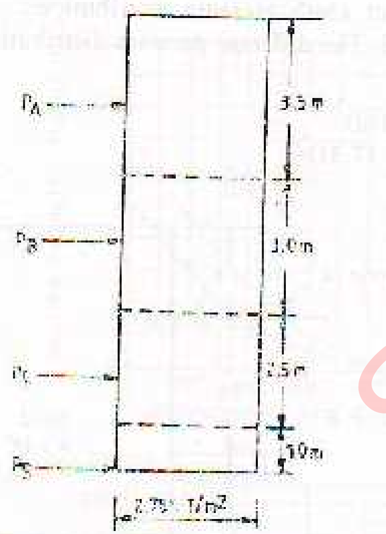


Fig. 17.39 Tributary areas for struts in Q 17.16

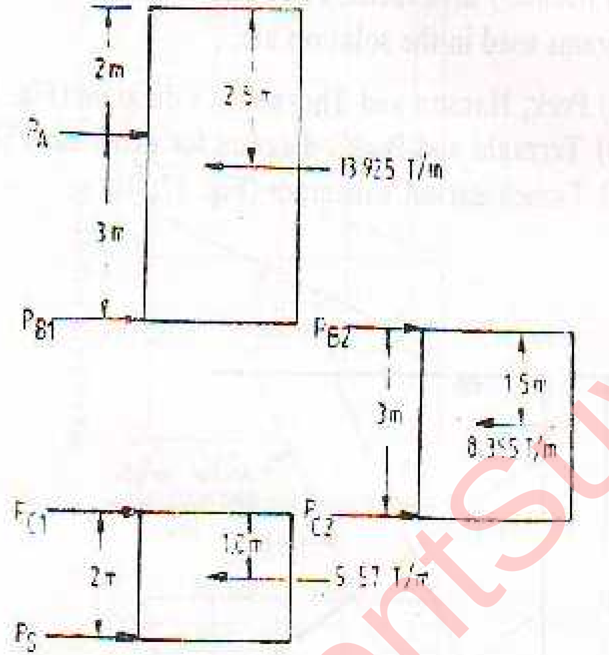


Fig. 17.40 Equivalent beams for struts in Q 17.16

Solution by equivalent beam method using Peck, Hanson and Thornburn's diagram

Figure 17.40 gives the analysis for strut loads using equivalent beam method. From analysis it can be shown that,

$$P_A = 11.6 \text{ T/m}$$
$$P_{B1} = 2.32 \text{ T/m}$$
$$P_{B2} = 4.18 \text{ T/m}$$
$$P_{C2} = 4.18 \text{ T/m}$$
$$P_{C1} = 2.78 \text{ T/m}$$
$$P_S = 2.78 \text{ T/m}$$
$$P_B = 2.32 + 4.18 = 6.5 \text{ T/m}$$
$$P_C = 4.18 + 2.78 = 6.96 \text{ T/m}$$

The other pressure diagrams can also be analysed in the same manner. Table 17.3 gives the results of all analyses.

Table 17.3 Results of Analyses for Q 17.16

(All values in T/m)

Force	Tributary area method			Equivalent beam method		
	Peck, Hanson, Thornburn diagram	Terzaghi, Peck, diagram	Tschebotarioff diagram	Peck, Hanson, Thornburn diagram	Terzaghi, Peck diagram	Tschebotarioff diagram
P_A	9.75	8.58	10.29	11.6	9.34	11.62
P_B	8.36	10.29	10.29	6.5	9.52	8.95
P_C	6.96	7.72	7.72	6.96	7.43	7.43
P_S	2.78	0.86	0.86	2.78	1.14	1.14