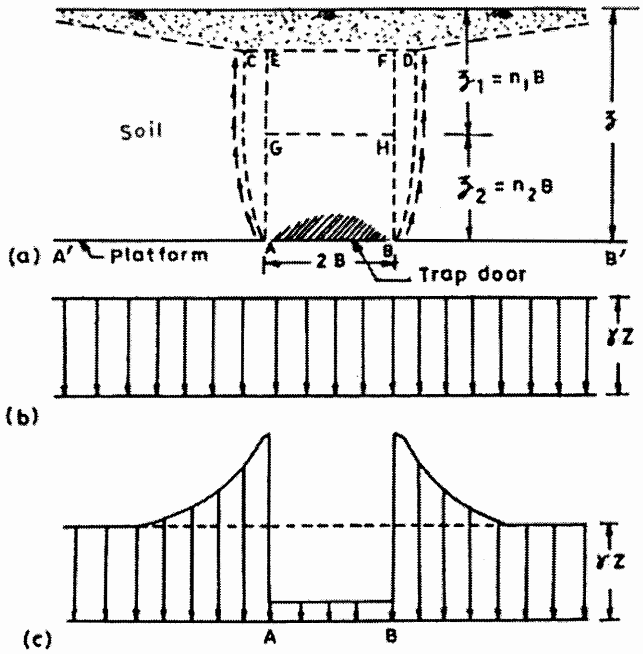
Chapter : 4 Arching in Soils and Braced Cuts

4.1.Arching in soils

In supported soil moss, when certain port of the soil moss yields, then the soil adjoining the yielding part also gets displaced from its original position. The deformation of the parted soil is resisted by mobilization of shearing resistance along the zones of contact between the yielding and non-yielding portions of the soil As the direction of mobilization of shear strength is opposed to the direction of deformation of the yielding soil, there is a reduction in pressure on the yielding part of the support and a consequent increase in the pressure of the adjoining stationary parts. This phenomenon of the transfer of pressure from the yielding part of a soil mass to the non-yielding part of the mass is referred to as **arching**.



Terzaghi's Trap Door Experiment

Arching in soil can be demonstrated from trap door experiment of Terzaghi a.s shown above. It is clear tha.t if certain mass of soil tends to move downward (the sol mass withing AE and BF in the figure) there is resistance (shearing resistance) in the upward direction offered by adjacent soil which get mobilized along the boundaries AC and BD.

The pressure which was earlier acting on the trap door AB, is now transferred from the yielding mass onto the sides. This transfer of pressure onto the stationary adjoining mass is called arching.

The two essential components of arching effect to exists are relative movement within soil and shear strength available for mobilisation.

Theories of Soil Arching

Terzaghi (1942) classified the available theories of arching into three main groups. Theories under the first group considered conditions of equilibrium of sand immediately above the yielding strip without satisfying compatibility conditions at greater distances from the strip. Theories under the second group are based on the unjustifiable assumption that the entire mass of sand above the yielding strip is in a state of plastic equilibrium. The theories under the third group assume vertical sliding surfaces passing through the outer edges of the yielding strip and the pressure on the yielding strip is taken as the difference between the weight of sand above the strip and full frictional resistance along the vertical sections.

The values of vertical pressure on a strip, obtained by different theories are, however, different. It is difficult to say conclusively which theory is better: However theories under the third group (assuming vertical sliding surface) are simplest. Cain's theory (1961) is one of them which falls in this category.

CAIN'S THEORY

Cain's theory makes the following assumptions:

(a) The soil is homogeneous, isotropic and semi-infinite.

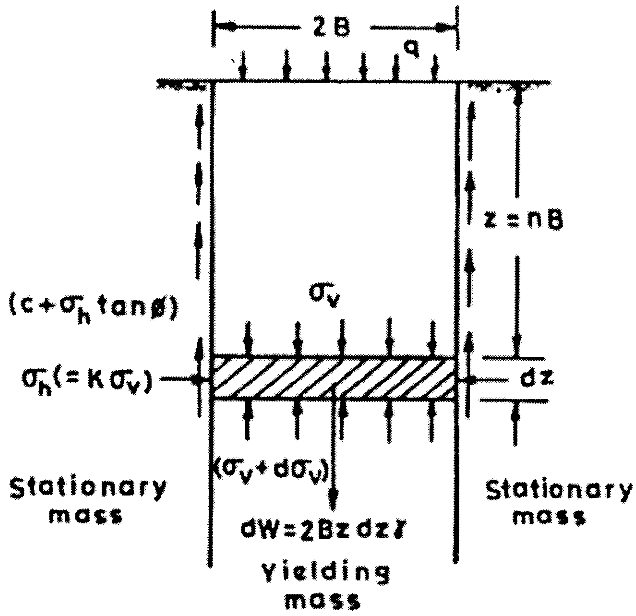
(b) The shearing resistance of the soil is governed by the equation,
$s = c + \sigma \tan \phi$.

(c) The sliding surfaces are vertical and pass through the outer edges of the yielding strip. The actual surfaces of sliding may resemble logarithmic spirals (*AC* and *BD* of Fig. 13.1) such that the depression of the surface at top is wider than the support.

(d) Full shearing resistance is mobilised on the vertical sliding surfaces.

(e) The ratio of vertical to the horizontal pressure is constant, say *K*.

(f) The problem is two-dimensional.



Forces acting on an elemental strip

The general equation developed by Cain's theory is

$$\sigma_v = qe^{-K\tan\phi\, z/B} - \frac{B}{K\tan\phi}(\gamma - c/B)(1 - e^{K\tan\phi\, z/B})$$

The above equation can be used for three different cases

(a) $q = 0, c > 0$

$$\sigma_v = \frac{B}{K\tan\phi}(\gamma - c/B)(1 - e^{-K\tan\phi\, z/B})$$

(b) $q > 0, c = 0$

$$\sigma_v = \frac{B\gamma}{K\tan\phi}(1 - e^{-k\tan\phi z/B}) + qe^{-K\tan\phi\, z/B}$$

(c) $q = 0, c = 0$

$$\sigma_v = \frac{B\gamma}{K\tan\phi}(1 - e^{-K\tan\phi\, z/B})$$

4.2. Braced excavations

Shallow excavations can be made without supporting the surrounding material if there is adequate space to establish slopes at which the material can stand. The steepest slopes that can be used in a given locality are best determined by experience. Many building sites extend to the edges of the property lines. Under these circumstances, the sides of the excavation have to be made vertical and must usually be supported by bracings.

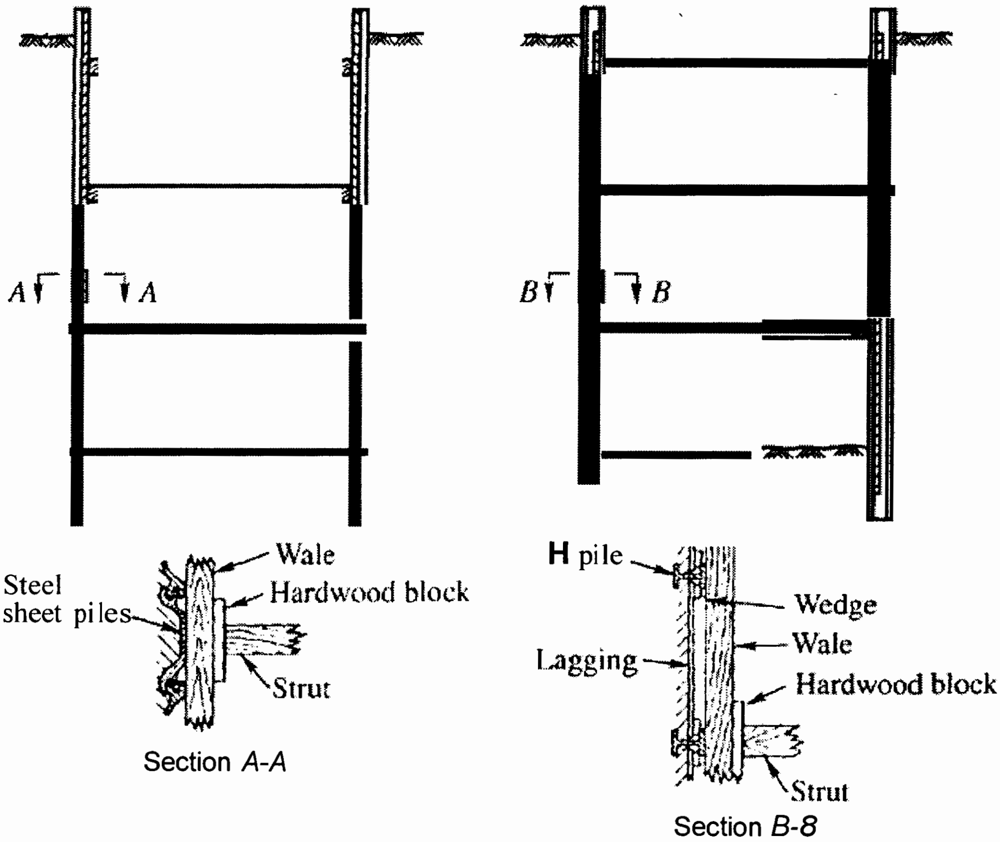


Figure:2 Bracing system

Common methods of bracing the sides are shown in Fig. 2 The practice is to drive vertical timber planks known as sheeting along the sides ofthe excavation. The sheeting is held in place by means of horizontal beams called wales that in turn are commonly supported by horizontal struts extending from side to side of the excavation. The struts are usually of timber for widths not exceeding about 2m. For greater widths metal pipes called trench braces are commonly used.

Uses of braced cut:

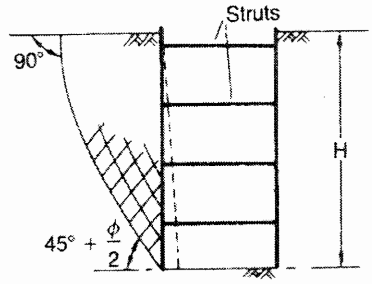
- for deep, narrow excavations
- pipelines
- service cuts

Steps followed in sheet piling:

i. drive in piling
ii. excavate first ponion
iii. install wales and top struts
iv. excavate next portion
v. install next wales and struts
vi. excavate next portion
vii. install next wales and struts
viii. excavate last portion

4.3.Earth pressure against bracings in cuts

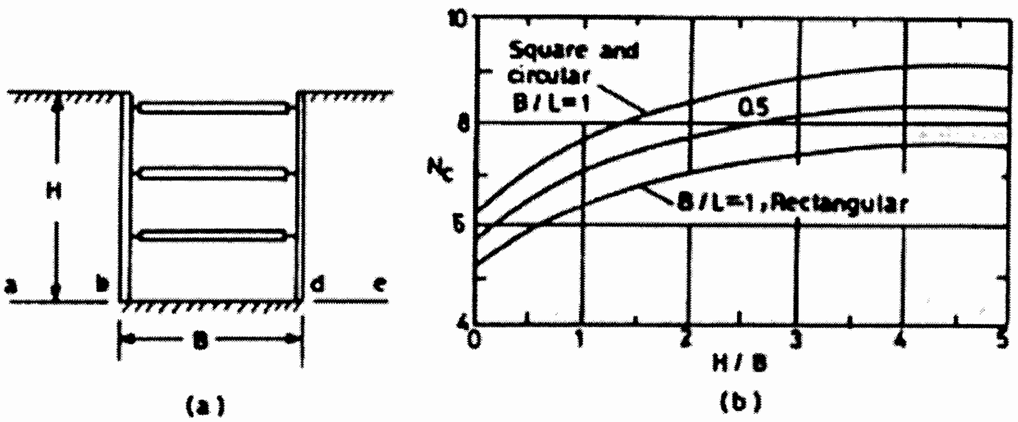
In cuts, when the first row of strut is placed, the depth of excavation is so small that for all practical problems, the original state of the stress is unaltered I.e. a.t rest condition. Thus the first row of struts is in position before any yielding of soil mass can take place. As the excavation proceeds to the level of the second row of struts, the horizontal yielding of the soil near the ground surface is prevented by the rigidity of the first set of struts. However the lateral pressure of the soil outside the cut acts on the sheet piles, resulting in their inward yield by rotating about a line at the level of the uppermost row of struts. Thus the placement of second row of struts is preceded by the horizontal yield as shown in the figure. As the depth of cutting increases, the yielding also increases.



From this discussion, it is clear that the yielding at the top of the strut level is insignificant to produce Rankine active condition. The soil at the bottom portion is only in the plastic condition to produce the Rankine active condition. Hence, the Rankine theory cannot be applied in the analysis of braced cut.

4.4.Heave of the bottom of cut in soft clays

The bottom of the cuts in soft clays are likely to foil by heaving. as the weight of the blocks of clay adjoining the cut tend to displace the underlying soft clay towards the excavation. The surcharge at the level **ab** and **de** in figure below is equal to the weight of clay above these levels. These strips **ab** and **de** act as footings.



Thus if the bearing capacity of the clay at the base is exceeded, the bottom of the cut fails by heaving. As the ultimate bearing capacity of day for .ϕ_u=0 condition is equill to $c_u N_c$, the safety factor against the heaving is given by;

$$F=\frac{c_u N_c}{\gamma H} \qquad F_s=\frac{5.7c_u}{\gamma H}$$

This tendency of the bottom of cut to heave reduces if the depth of sheet pile extends below the bottom of the cut This is because of the higher stiffness of the sheet pile and this depends upon the location of the hard soil below the depth of cutting;

4.5. Strut load

The bracing for a cut are composed of several components and if failure of one unit occurs then the failure of whole system occurs. The important member of bracing is strut and the estimation of the strut load is important. If a strut fails by overstressing then the load carried by this strut is shared by remaining struts which consequently fails by overloading. Thus the size of strut should be so selected that it can take maximum estimated load on any strut, which type of design is known as conservative design. The load taken by strut is the function of;

- The deformation condition
- The forces with which the wedges are driven
- The time-elapse between the excavation of cut and the installation of supports.

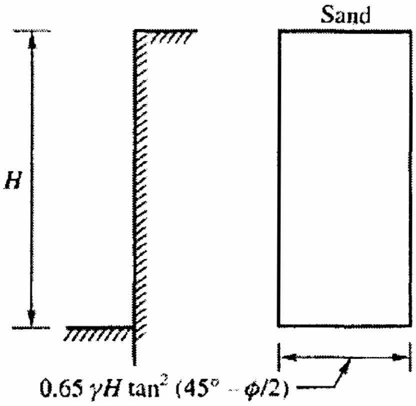
For simplification the forces of the strut is calculated using the procedure given by Terzaghi and Peck as follows:

- It is assumed that the load on each strut is equal to the total earth pressure acting on the sheeting over a rectangular area extending horizontally half the distance to the next vertical row of struts on either side and also vertically half the distance between the horizontal sets of struts.
- The earth pressure is assumed to be uniformly distributed over the rectangular area.
- For purposes of calculations, the bottom of the cut is assumed to be a strut.

Due to the continuity of the sheeting and the assumption regarding the pressure near the bottom of the cut, the computed earth pressure diagram and real distribution may differ significantly. Also, in cohesionless soil, the earth pressure at the ground surface must be zero. So, the pressure diagram is worked out from the measured strut load which is known as apparent earth pressure diagram.

4.6. Deep cuts in sand

Measurement from different cities of world by different researchers it is recommended to use Rankine solution taking the maximum pressure of $.65K\gamma H$ for the entire pressure diagram for deep cuts in sand as shown below in the figure.



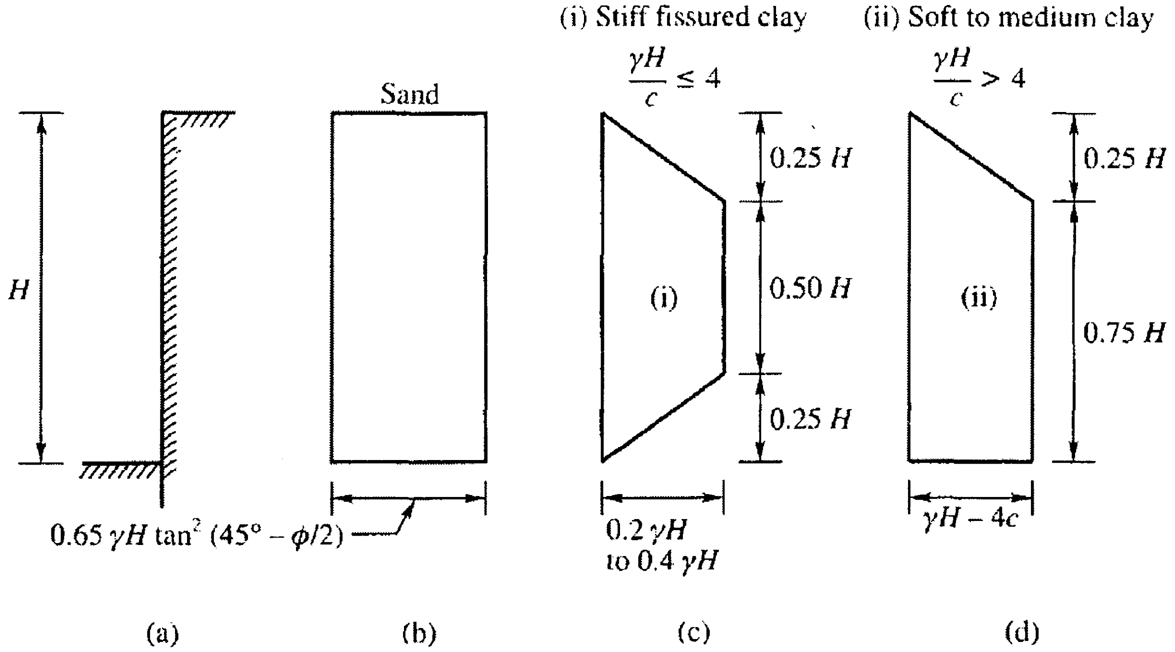
4.7. Deep cut in saturated, soft to medium days

From measurements of strut loads in cuts in medium to soft clays in different cities of world with excavation made rapidly, the condition ϕ_u=0 applies to a clay soil and only undrained shear strength c_u is used in the analysis. If there is no possibility of failure by bottom heave, failure by buckling of struts remains the principal type of failure to be possible.

From experience, when $\gamma H/c_u$, is less than 6, movements of bracing system and heave of tile clay are small. If $\gamma H/c_u$, approaches about 8, the movements of even well-designed bracing system becomes very large. At. $\gamma H/c_u$, exceeding 8, the bracing is likely to collapse because of large inward movements of clay outside the embedded portion of the sheet piles and excessive upward heave of clay beneath the excavation.

For the case of clay soil when the magnitude of $\gamma H/c_u \leq 4$,the apparent pressure diagram shown **if** figure (c) is used and the magnitude of peak earth pressure is taken as average of $0.3\gamma H$.

In case the value of $\gamma H/c_u > 4$, the apparent pressure diagram of figure (d) is used.



Figures - Apparent pressure diagram for calculating loads in struts of braced cuts: (a) sketch of wall of cut. (b) diagram for cuts in drv or moist sand. (c) diagram for clays if $\gamma H/c_u \leq 4$ (d) diagram for clays if $\gamma H/c_u > 4$. where c is the average undrained shearing strength of the soil (Peck. 19691

Example

A long trench is excavated in medium dense sand for the foundation of a multistorey building. The sides of the trench are supported with sheet pile walls fixed in place by struts and wales as shown in Fig. The soil properties are:

$\gamma = 18.5$ kN/m^3, $c = 0$ and $\phi = 38°$

Determine: (a) The pressure distribution on the walls with respect to depth.

(b) Strut loads. The struts are placed horizontally at distances $L = 4$ m center to center.

(c) The maximum bending moment for determining the pile wall section.

(d) The maximum bending moments for determining the section of the wales.

Solution

(a) For a braced cut in sand use the apparent pressure envelope given in equation for p_a is

$$p_a = 0.65\,\gamma H\,K_A = 0.65 \times 18.5 \times 8 \tan^2(45 - 38/2) = 23 \text{ kN/m}^2$$

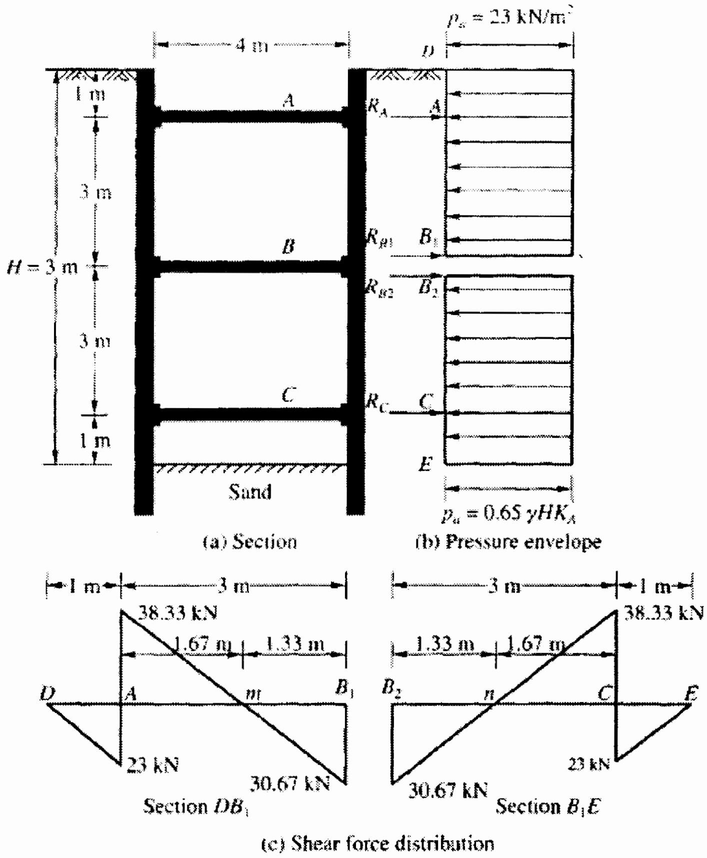


Figure - EX 20.17

(b) Strut loads

The reactions at the ends of struts A, B and C are represented by R_A, R_B and R_c respectively

For reaction R_A, take moments about B

$$R_A \times 3 = 4 \times 23 \times \frac{4}{2} \text{ or } R_A = \frac{184}{3} = 61.33 \text{ kN}$$

$R_{B1} = 23 \times 4 - 61.33 = 30.67$ kN

Due to the symmetry of the load distribution,

$R_{B1} = R_{B2} = 30.67$ kN, and $R_A = R_C = 61.33$ kN.

Now the strut loads are (for $L = 4$ m)

Strut A, $P_A = 61.33 \times 4 \approx 245$ kN

Strut B, $P_B = (R_{B1} + R_{B2}) \times 4 = 61.34 \times 4 \approx 245$ kN

Strut C, $P_C = 245$ kN

(c) Moment of the pile wall section

To determine moments at different points it is necessary to draw a diagram showing the shear force distribution.

Consider sections DB_1 and B_2E of the wall in Fig. Ex. 20.17(b). The distribution of the shear forces are shown in Fig. 20.17(c) along with the points of zero shear.

The moments at different points may be determined as follows

$$M_A = \frac{1}{2} \times 1 \times 23 = 11.5 \text{ kN-m}$$

$$M_C = \frac{1}{2} \times 1 \times 23 = 11.5 \text{ kN-m}$$

$$M_m = \frac{1}{2} \times 1.33 \times 30.67 = 20.4 \text{ kN-m}$$

$$M_n = \frac{1}{2} \times 1.33 \times 30.67 = 20.4 \text{ kN-m}$$

The maximum moment M_{max} = 20.4 kN-m. A suitable section of sheet pile can be determined as per standard practice.

(d) Maximum moment for wales

The bending moment equation for wales is

$$M_{max} = \frac{RL^2}{8}$$

where R = maximum strut load = 245 kN

L = spacing of struts = 4 m

$$M_{max} = \frac{245 \times 4^2}{8} = 490 \text{ kN-m}$$

A suitable section for the wales can be determined as per standard practice.

Example 20.18

Fig. Ex. 20.18a gives the section of a long braced cut. The sides are supported by steel sheet pile walls with struts and wales. The soil excavated at the site is stiff clay with the following properties

c = 800 lb/ft^2, $\phi = 0$, γ = 115 lb/ft^3

Determine: (a) The earth pressure distribution envelope.

(b) Strut loads.

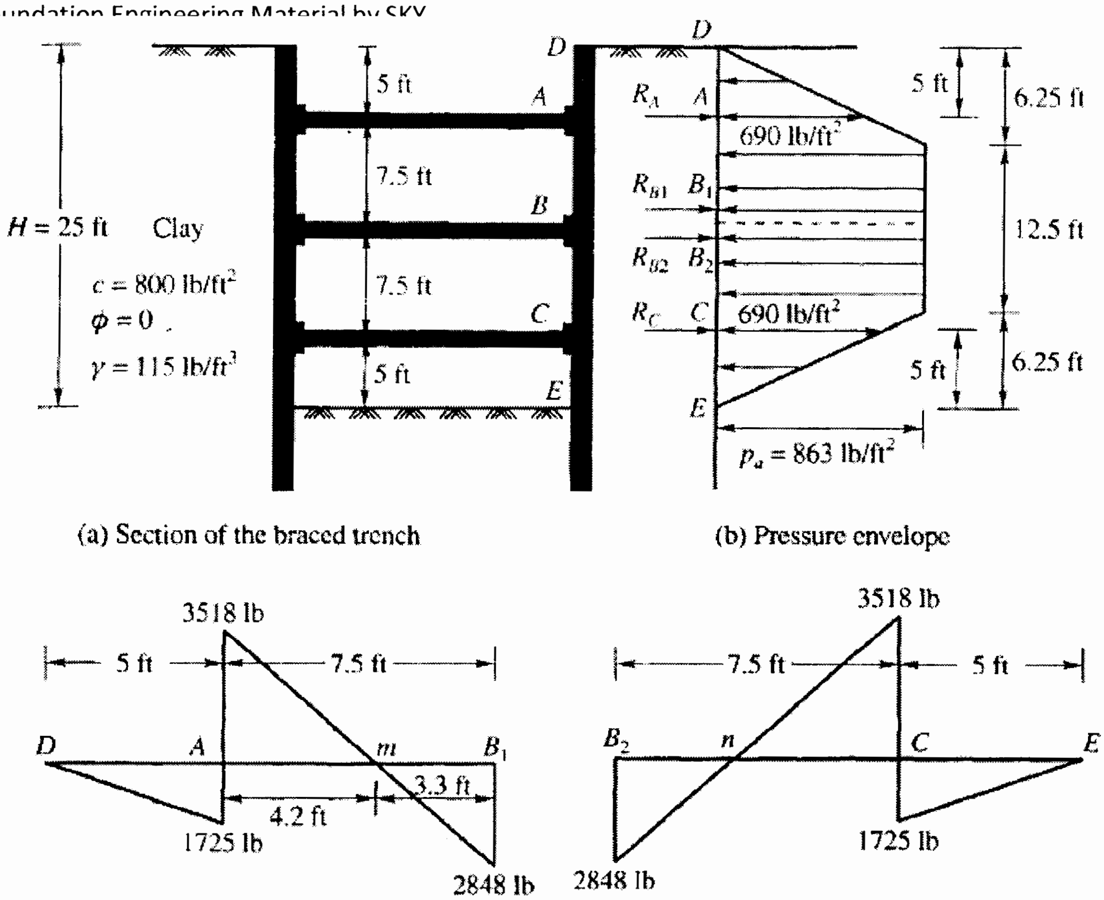
(c) The maximum moment of the sheet pile section.

The struts are placed 12 ft apart center to center horizontally.

Solution

(a) The stability number N_s

$$N_s = \frac{\gamma H}{c} = \frac{115 \times 25}{800} = 3.6 < 4$$



(a) Section of the braced trench

(b) Pressure envelope

(c) Shear force diagram

Figure Ex. 20.18

The soil is stiff fissured clay. As such the pressure envelope shown in Fig. 20.28(c) is applicable. Assume $p_a = 0.3\,\gamma H$

$p_a = 0.3 \times 115 \times 25 = 863$ lb/ft²

The pressure envelope is drawn as shown in Fig. Ex. 20.18(b).

(b) Strut loads

Taking moments about the strut head B_1 (B)

$$R_A \times 7.5 = \frac{1}{2} 863 \times 6.25\left(\frac{6.25}{3} + 6.25\right) + 863 \times \frac{(6.25)^2}{2}$$

$= 22.47 \times 10^3 + 16.85 \times 10^3 = 39.32 \times 10^3$

$R_A = 5243$ lb/ft

$$R_{B1} = \frac{1}{2} \times 863 \times 6.25 + 863 \times 6.25 - 5243 = 2848 \text{ lb/ft}$$

Due to symmetry

$R_A = R_C = 5243$ lb/ft

$R_{B2} = R_{B1} = 2848$ lb/ft

Strut loads are:

$P_A = 5243 \times 12 = 62{,}916$ lb = 62.92 kips

$P_B = 2 \times 2848 \times 12 = 68{,}352$ lb = 68.35 kips

$P_C = 62.92$ kips

(c) Moments

The shear force diagram is shown in Fig. 20.18c for sections DB_1 and B_2 E

Moment at $A = \frac{1}{2} \times 5 \times 690 \times \frac{5}{3} = 2{,}875$ lb-ft/ft of wall

Moment at $m = 2848 \times 3.3 - 863 \times 3.3 \times \frac{3.3}{2} = 4699$ lb-ft/ft

Because of symmetrical loading

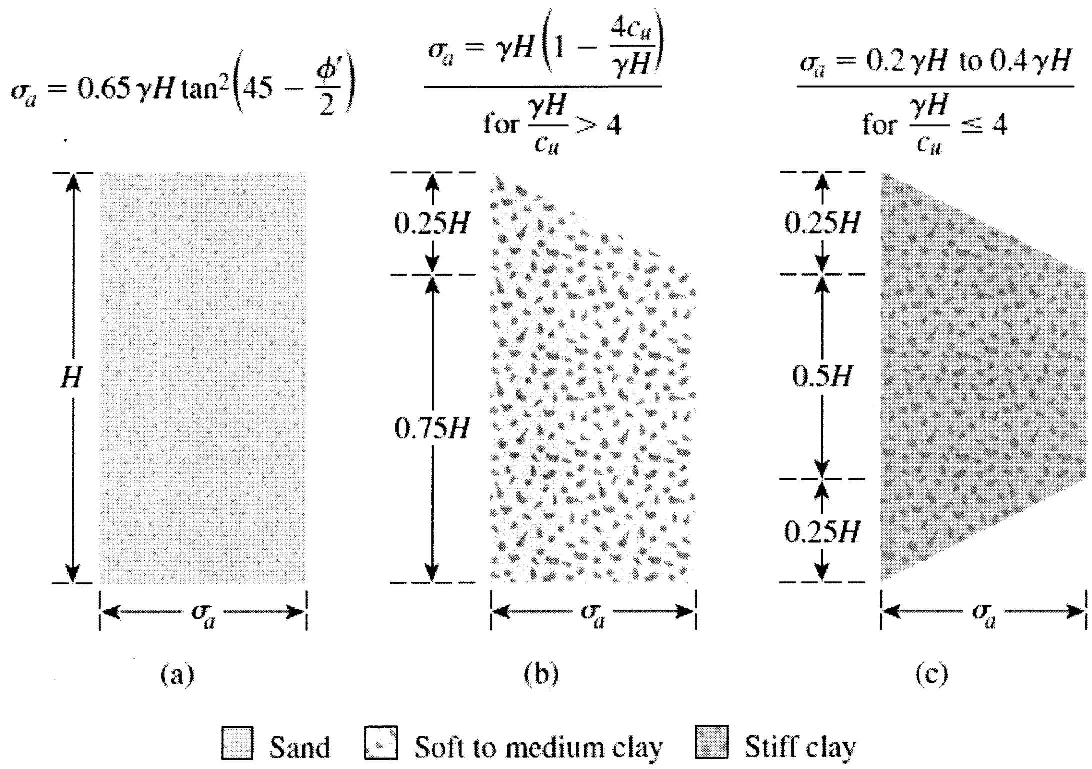
Moment at A = Moment at C = 2875 lb-ft/ft of wall

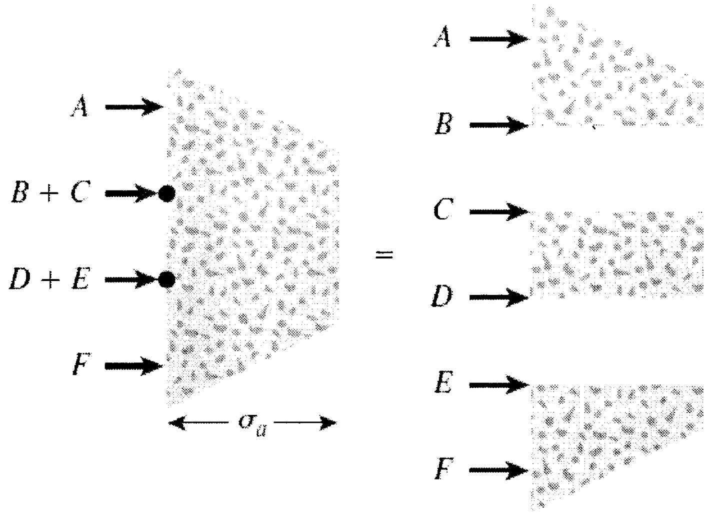
Moment at m = Moment at n = 4699 lb-ft/ft of wall

Hence, the maximum moment = 4699 lb-ft/ft of wall.

The section modulus and the required sheet pile section can be determined in the usual way.

Example from B M Das.





Example

A 7-m-deep braced cut in sand is shown in Figure 14.13. In the plan, the struts are placed at s = 2 m center to center. Using Peck's empirical pressure diagram, calculate the design strut loads.

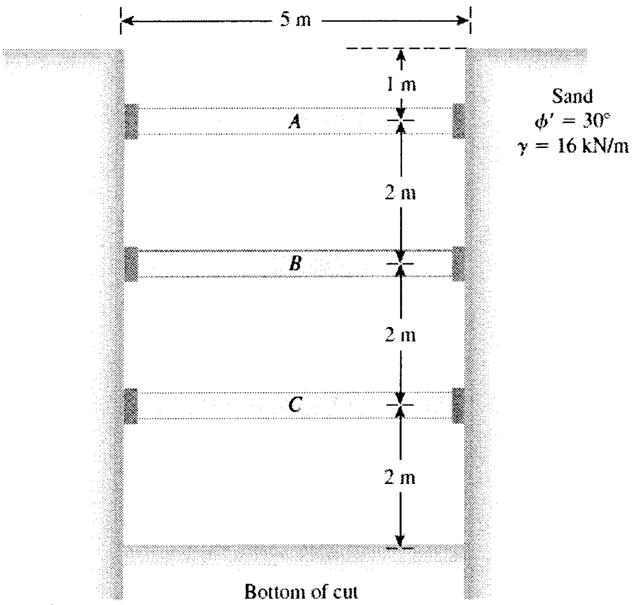


Figure 14.13 Braced cut in sand

Solution

Refer to Figure 14.11a. For the lateral earth pressure diagram,

$$\sigma_a = 0.65\gamma H \tan^2\left(45 - \frac{\phi'}{2}\right) = (0.65)(16)(7)\tan^2\left(45 - \frac{30}{2}\right) = 24.27\text{kN/m}^2$$

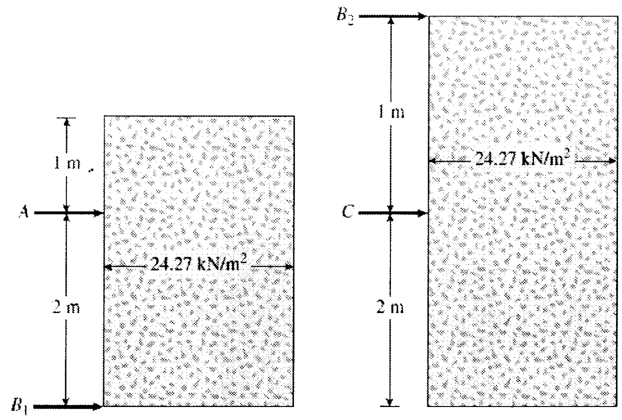


Figure 14.14 Calculation of strut loads from pressure envelope

Assume that the sheeting is hinged at strut level B. Now refer to the diagram in Figure 14.14 We need to find reactions at A, B_1, B_2, and C. Taking the moment about B_1, we have

$$2A = (24.27)(3)\left(\frac{3}{2}\right); \quad A = 54.61\,\text{kN/m}$$

Hence,

$$B_1 = (24.27)(3) - 54.61 = 18.2\text{ kN/m}$$

Again, taking the moment about B_2, we have

$$2C = (24.27)(4)\left(\frac{4}{2}\right)$$

$$C = 97.08\,\text{kN/m}$$

So,

$$B_2 = (24.27)(4) - 97.08 = 0$$

The strut loads are as follows:

At level A: $(A)(s) = (54.61)(2) = \mathbf{109.22\ kN}$

At level B: $(B_1 + B_2)(s) = (18.2 + 0)(2) = \mathbf{36.4\ kN}$

At level C: $(C)(s) = (97.08)(2) = \mathbf{194.16\ kN}$