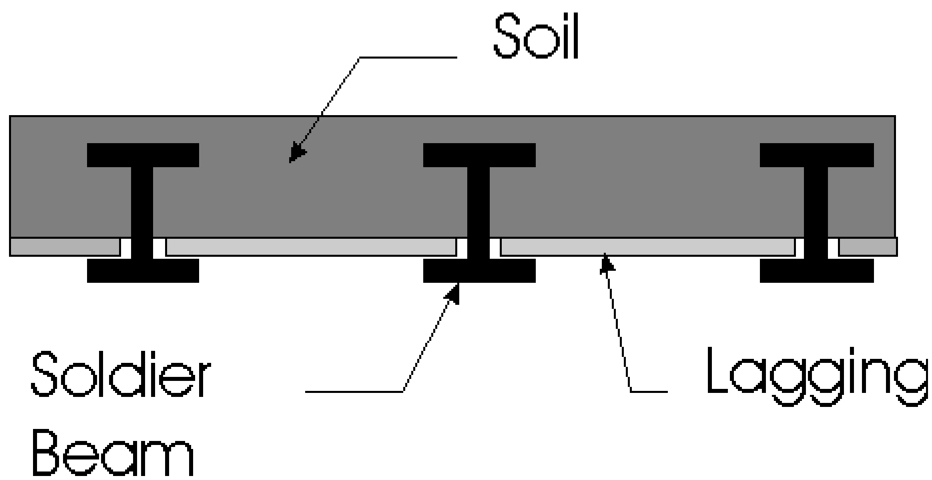
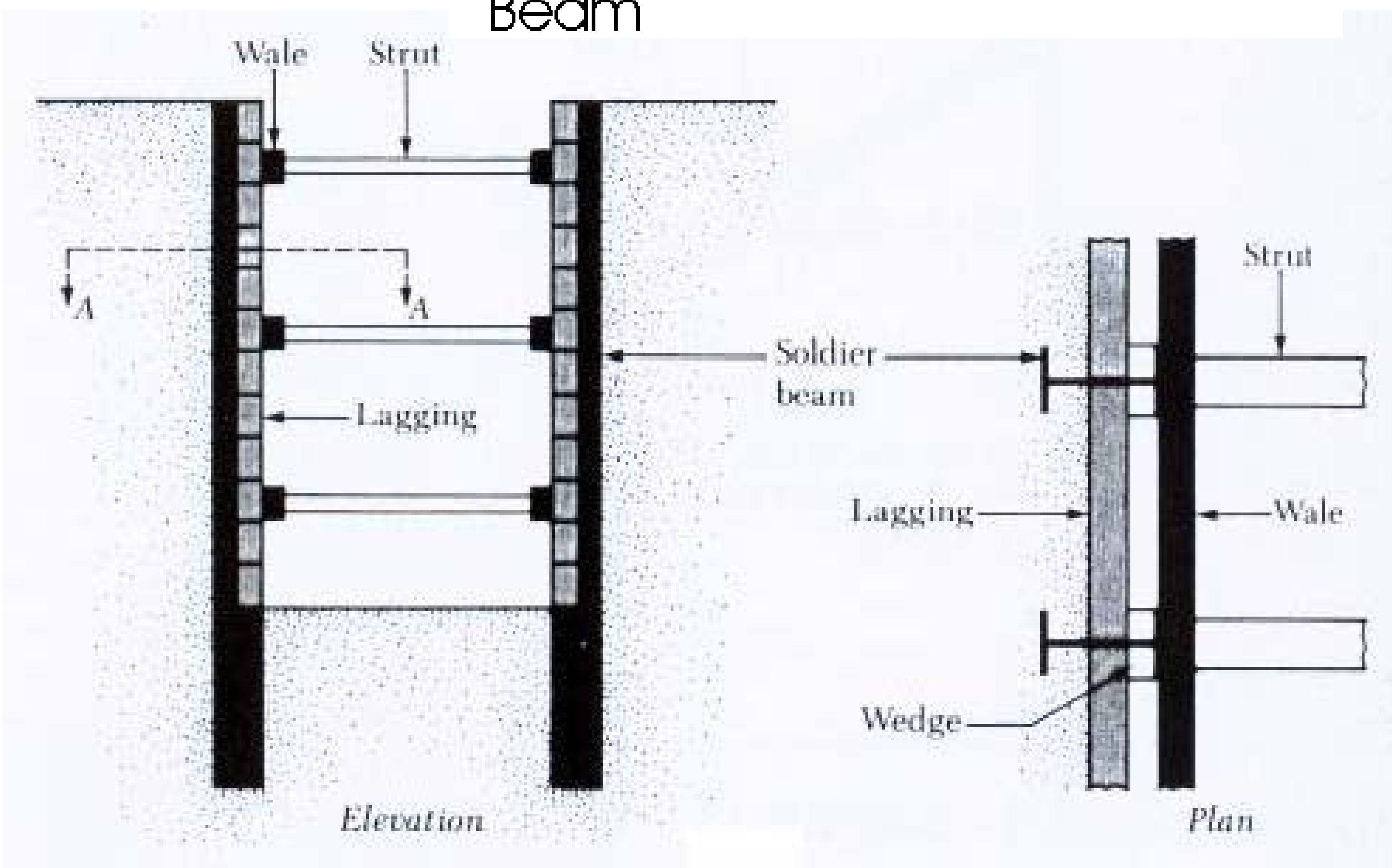
BRACED CUT AND COFFER DAM

BRACED CUTS

- Deep excavations with vertical sides require lateral supports to prevent cave-in of the earth and to protect the adjacent areas against subsidence and lateral movement of the subsoil.
- Excavations which are laterally supported are called braced cuts.
- Two types of braced cut commonly used in construction work.
  - **Soldier beam**
  - **Sheeting**
- **Soldier beam :-** is driven in to the ground before excavation and is a vertical steel or timber beam.
- **Laggings** are timber planks placed horizontally between the soldier piles to retain the soil behind the excavated area


Soil
Soldier
Beam
Lagging

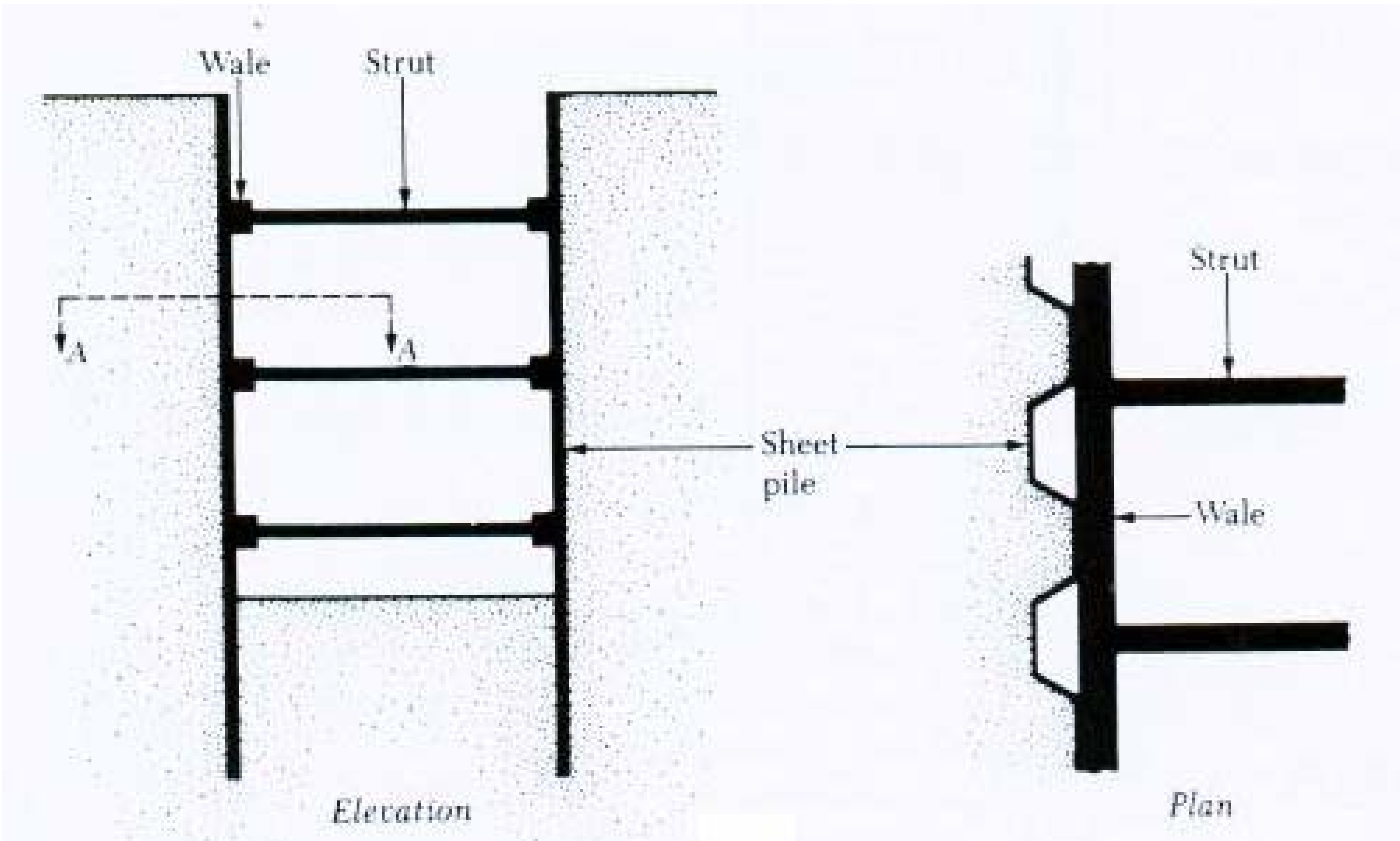

Wale
Strut
A
A
Soldier
beam
Lagging
Strut
Lagging
Wale
Wedge
Elevation
Plan

- For narrow excavations, When the excavation reaches the desired depth, wales and struts (horizontal steel beams) are installed.
- Struts are horizontal compression members

- **Sheeting**:- in this case, interlocking sheet piles are driven into the soil before excavation . Wales and struts are inserted immediately after excavation reaches the appropriate depth.

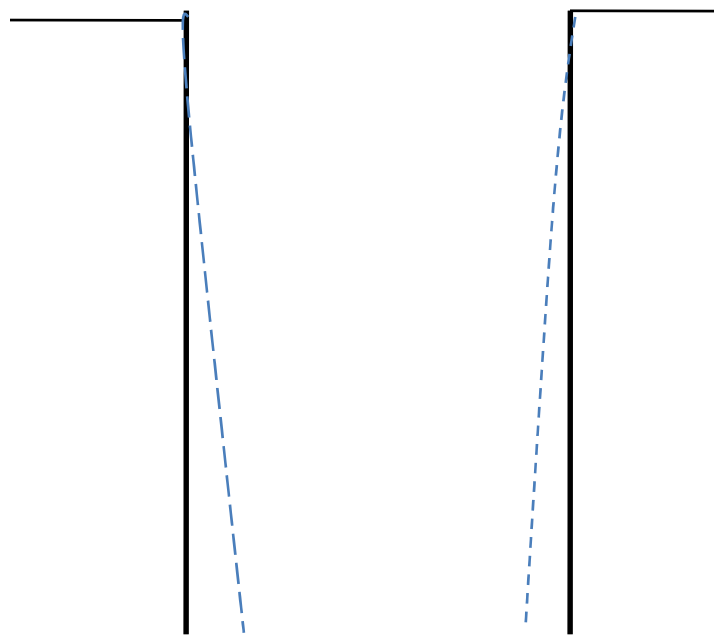
- To design braced excavations (i.e., to select wales, strut, sheet piles and soldier beams), the engineer must estimate the lateral pressure to which the braced cuts will be subjected.

Two examples of soldier beams and lagging method used for retaining walls

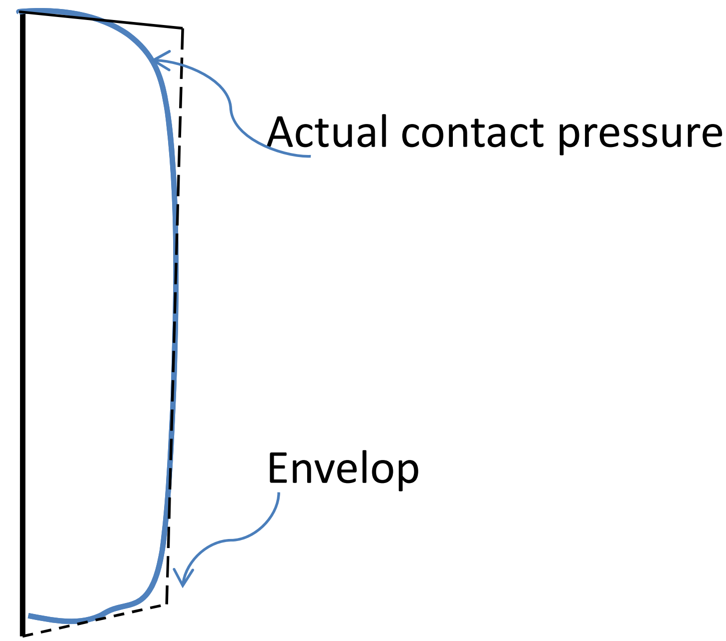

Wale
Strut
A
A
Sheet
pile
Elevation
Strut
Wale
Plan

• Lateral earth pressure in braced cuts.

- Rankine’s and Coulomb’s theories of earth pressure cannot be used for the pressure in braced cuts, as those theories are applicable to rigid retaining walls rotating at base.
- In contrast to retaining walls, braced cuts show a different type of wall yielding. In this case, deformation of the wall gradually increases with the depth of excavation.
- The variation of the amount of deformation depends on several factors , such as the type of soil, depth of excavation and the workmanship.
- The total lateral earth force , P, imposed on a wall may be evaluated theoretically by using Terzaghi's general wedge theory.



Deformation condition



Pressure envelop

- **Pressure Envelop for Braced Cut Design**
- After observation of several braced cuts, Peck (1969) suggested using design pressure envelops (apparent pressure envelop)

Cuts in Sand

$$p_a = 0.65\gamma H K_a$$

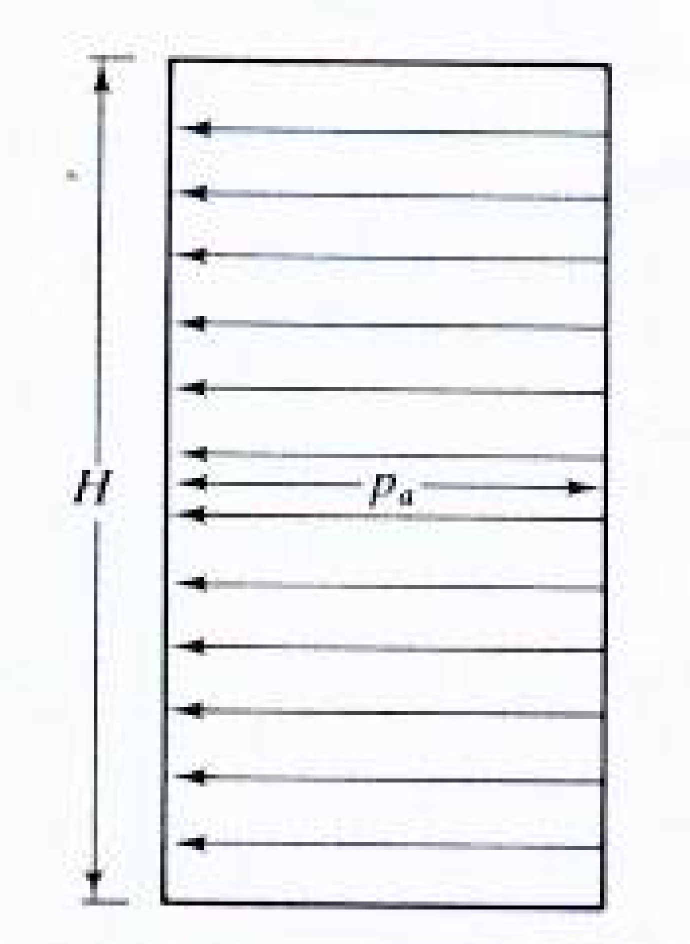
Where:

γ = unit weight

H = height of the cut

K_a = Rankine active pressure coefficient

$= \tan^2(45-\phi/2)$



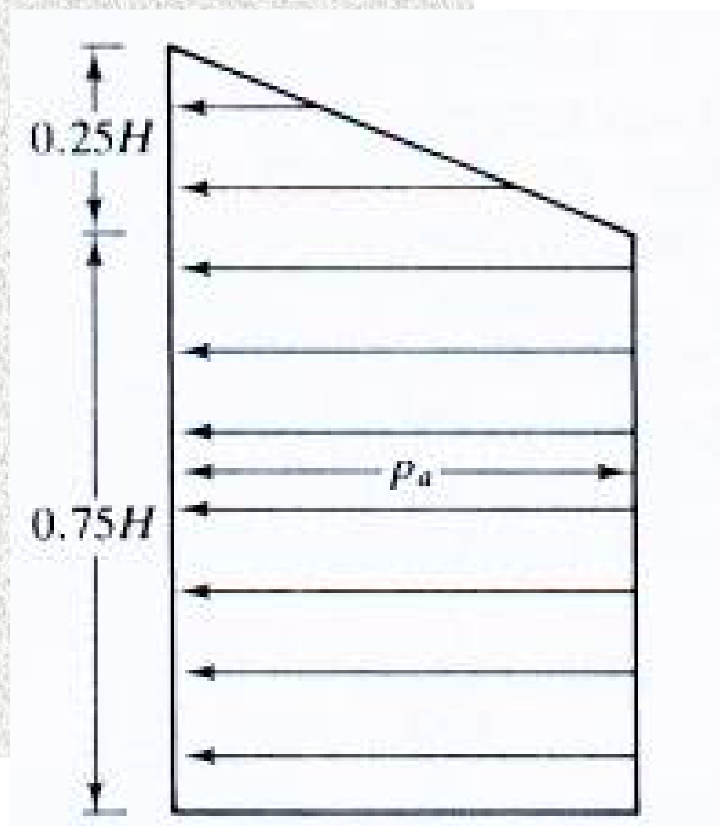
- **Cuts in Soft and Medium Clay ϕ =0 and** $\frac{\gamma H}{c} > 4$

The pressure p_a is the larger of

$$p_a = \gamma H\left[1 - \left(\frac{4c}{\gamma H}\right)\right]$$

or

$$p_a = 0.3\gamma H$$



where:

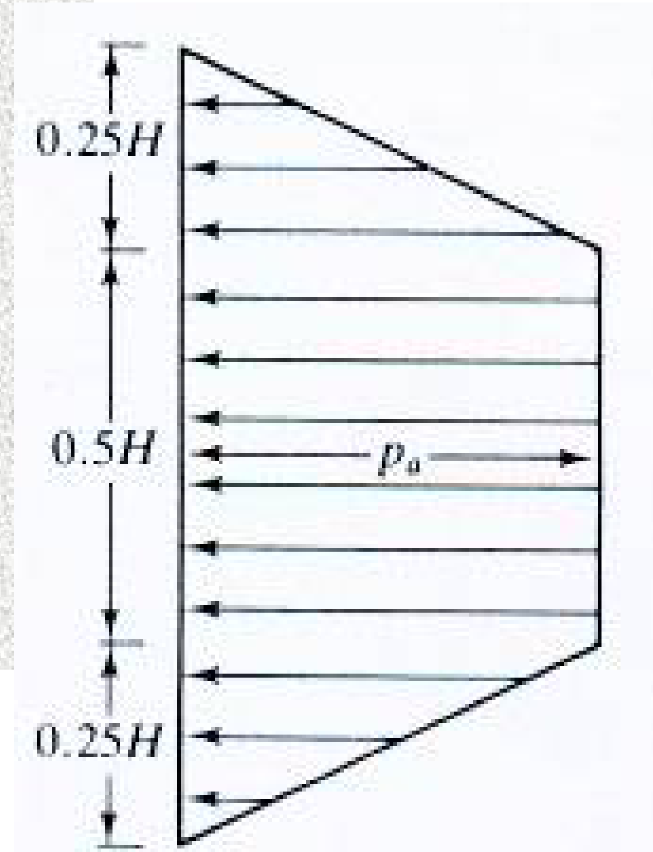
γ = unit weight of clay

c = undrained cohesion (ϕ=0)

Cuts in Stiff Clay $\phi = 0$ and $\frac{\gamma H}{c} \leq 4$

$p_a = 0.2\gamma H$ to $0.4\gamma H$

with an average of $0.3\ \gamma\ H$

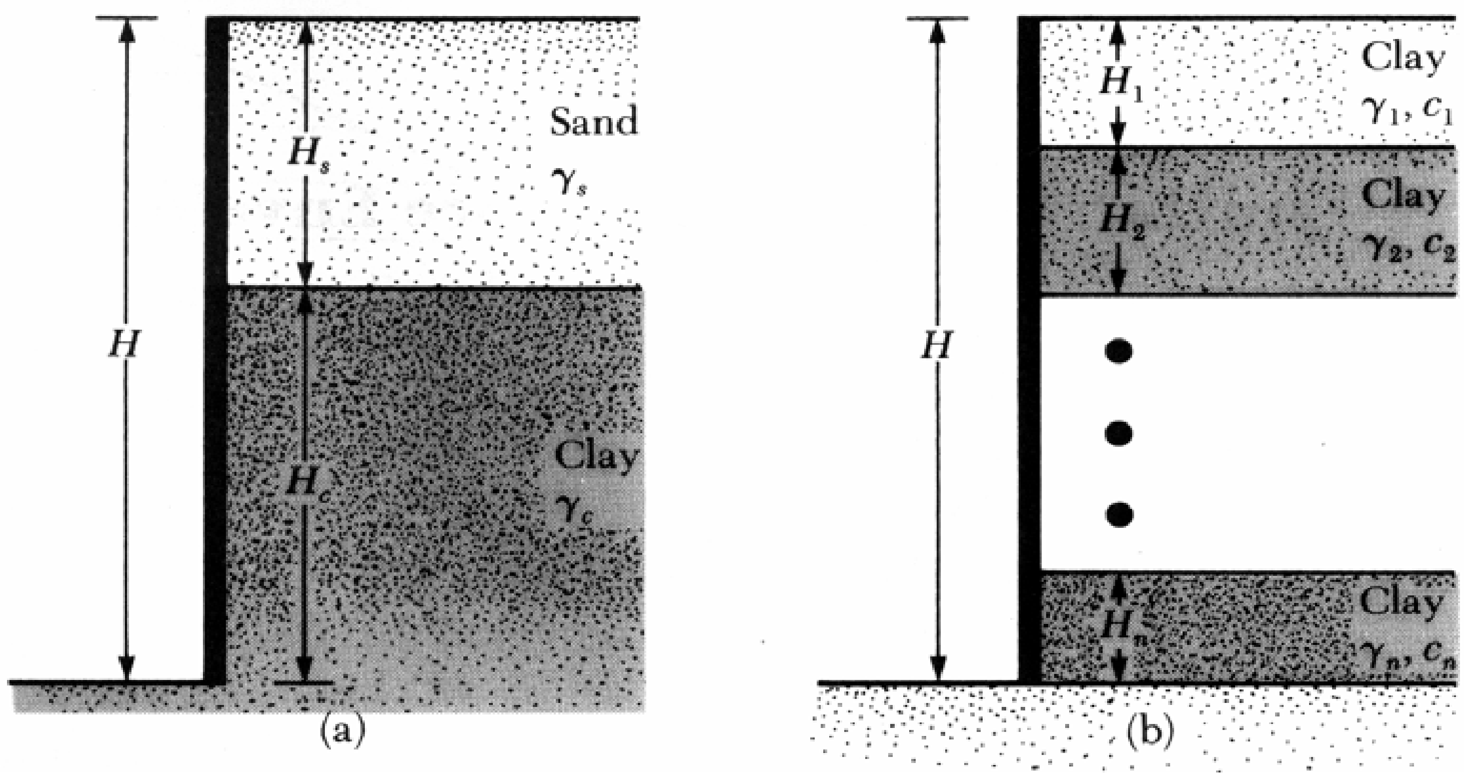


Limitations:

1. The pressure envelopes are sometimes referred to as apparent pressure envelopes. The actual pressure distribution is a function of the construction sequence and the relative flexibility of the wall.
2. They apply to excavations having depths greater than about 20 ft (≈6m)
3. They are based on the assumption that the water table is below the bottom of the cut
4. Sand is assumed to be drained with zero pore water pressure
5. Clay is assumed to be undrained and pore water pressure is not considered

Cuts in Layered Soil

- Sometimes, layers of both sand and clay are encountered when a braced cut is being constructed.
- In this case Peck proposed that an equivalent value of cohesion (ϕ=0 concept) should be determined in the following manner



- Case a

$$c_{av} = \frac{1}{2H}\left[\gamma_s . K_s . H_s^2 . \tan\phi_s + (H - H_s) . n' . q_u\right]$$

$$\gamma_{av} = \frac{1}{H}\left[\gamma_s . H_s + (H - H_s)\gamma_c\right]$$

Where:

H = total height of the cut

γ_s = unit weight of sand

H_s = thickness of sand layer

K_s = a lateral earth pressure coefficient for the sand layer (≈1)

γ_{av} = average unit weight

ϕ_s = friction angle of sand

q_u = unconfined compression strength of clay

n' = a coefficient of progressive failure (ranging from 0.5 to 1.0; average value 0.75)

γ_c = saturated unit weight of clay layer

Once the average values of cohesion and unit weight are determined, the pressure envelopes in clay can be used to design the cuts

Case b.

$$c_{av} = \frac{1}{H}\left[c_1.H_1 + c_2.H_2 + \ldots + c_n.H_n\right]$$

$$\gamma_{av} = \frac{1}{H}\left[\gamma_1.H_1 + \gamma_2.H_2 + \gamma_3.H_3 + \ldots + \gamma_n.H_n\right]$$

Where:

c_1, c_2,…,c_n = undrained cohesion in layers 1,2,..,n

H_1, H_2,…,H_n = thickness of layers 1, 2, …, n

γ_1, γ_2, … γ_n = unit weight of layers 1, 2, … , n

- DESIGN OF VARIOUS COMPONENTS OF A BRACED CUT

Struts

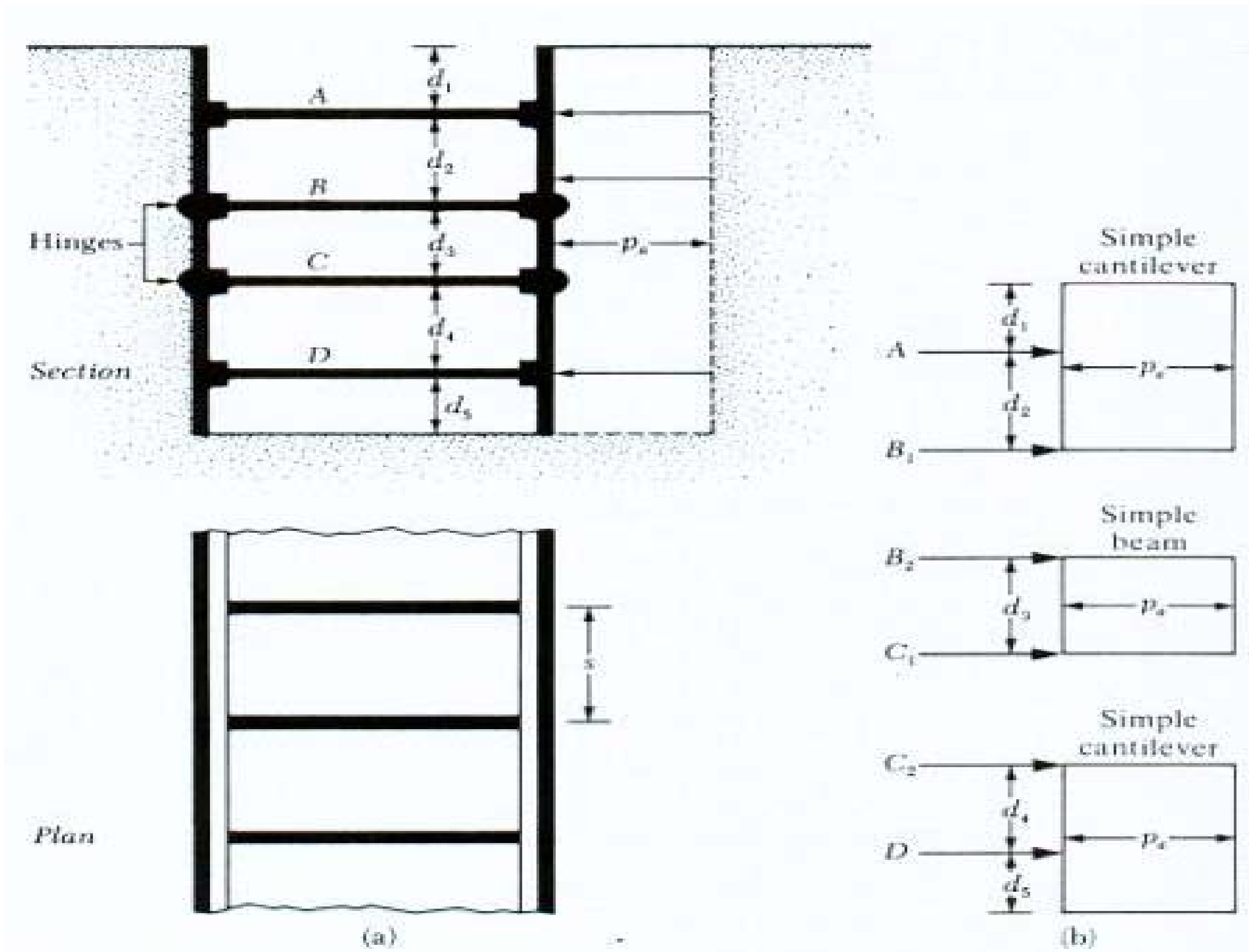
- Should have a minimum vertical spacing of about 9 ft (2.75 m) or more.
- Actually horizontal columns subject to bending
- The load carrying capacity of columns depends on the slenderness ratio.
- The slenderness ratio can be reduced by providing vertical and horizontal supports at intermediate points
- For wide cuts, splicing the struts may be necessary.
- For braced cuts in clayey soils, the depth of the first strut below the ground surface should be less than the depth of tensile crack, z_c

$$z_c = \frac{2c}{\sqrt{k_a}\gamma}$$

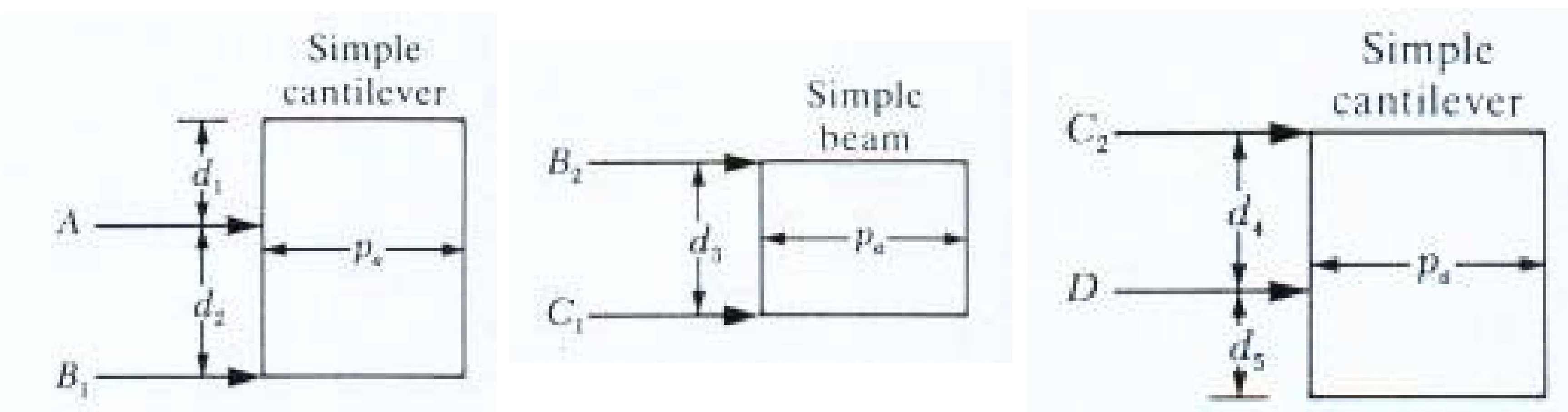
Struts

General Procedures:

1. Draw the pressure envelope for the braced cut



2. Determine the reactions for the two simple cantilever beams (top and bottom) and all the simple beams between. In the following figure, these reactions are A, B_1, B_2, C_1, C_2 and D



3. The strut loads may be calculated as follows:

$P_A = (A)(s)$

$P_B = (B_1+B_2)(s)$

$P_C = (C_1+C_2)(s)$

$P_D = (D)(s)$

where:

P_A, P_B, P_C, P_D = loads to be taken by the individual struts at level A, B, C and D, respectively

A, B_1, B_2, C_1, C_2, D = reactions calculated in step 2

s = horizontal spacing of the struts

4. Knowing the strut loads at each level and intermediate bracing conditions allows selection of the proper sections from the steel construction manual.

Sheet Piles

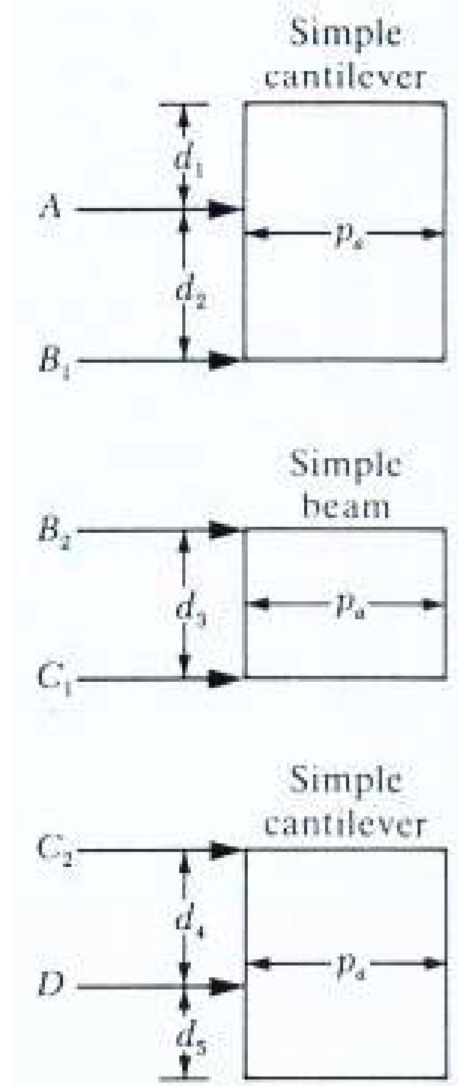
General Procedures:

1. Determine the maximum bending moment
2. Determine the maximum value of the maximum bending moments (M_{max}) obtained in step 1.
3. Obtain the required section modulus of the sheet piles

$$S = \frac{M_{\max}}{\sigma_{all}}$$

$$where\ \sigma_{all} = \ allowable\ flexural\ stress\ of\ the\ sheet\ pile\ materia$$

4. Choose the sheet pile having a section modulus greater than or equal to the required section modulus



- **Wales**
- Wales may be treated as continuous horizontal members if they are spliced properly.
- Conservatively, they may also be treated as though they are pinned at the struts.
- The maximum moment for the wales (assuming that they are pinned at the struts) and section modulus are

$$At \quad level \quad A, \quad M_{max} = \frac{(A)(s^2)}{8}$$

$$At \quad level \quad B, \quad M_{max} = \frac{(B_1 + B_2)(s^2)}{8}$$

$$At \quad level \quad A, \quad M_{max} = \frac{(C_1 + C_2)(s^2)}{8}$$

$$At \quad level \quad A, \quad M_{max} = \frac{(D)(s^2)}{8}$$

then

$$S = \frac{M_{max}}{\sigma_{all}}$$

Where A, B_1, B_2, C_1, C_2, and D are the reactions under the struts per unit length of the wall

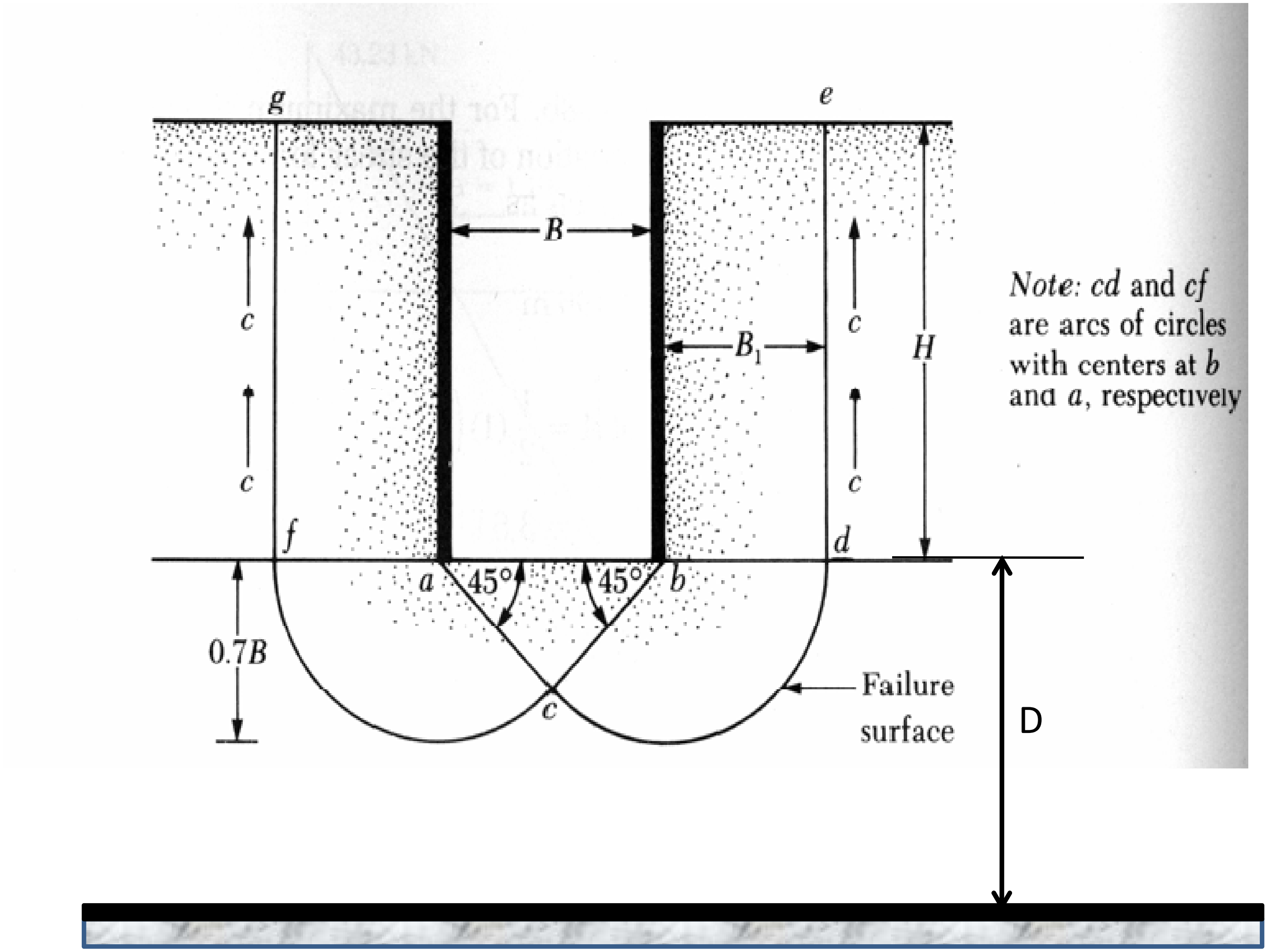
- Heave of the bottom of a cut in Clay
- Braced cuts in clay may become unstable as a result of heaving of the bottom of the excavation.
- Terzaghi analyzed the factor of safety of braced excavations against bottom heave
- The vertical load per unit length of the cut at the bottom of the cut along line bd and af is

$$Q = \gamma H B_1 - cH$$

where $B_1 = 0.7B$

c = cohesion

- 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 is



Hard Stratum (ROCK)

$Q_{ult}.\ cN_cB_1 = 5.7cB_1$

- Factor of safety against bottom heave ≥ 1.5

When D > 0.7 B

$$FS = \frac{Q_{ult}}{Q} = \frac{5.7cB_1}{\gamma HB_1 - cH} = \frac{1}{H}\left(\frac{5.7c}{\gamma - \frac{c}{0.7B}}\right)$$

when D ≤0.7B

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

- If factor of safety is less than 1.5, the sheet pile is driven deeper. Usually the depth, d is kept less than or equal to B/2.
- In that case, the force P, per unit length of the buried sheet pile may be expressed as follows

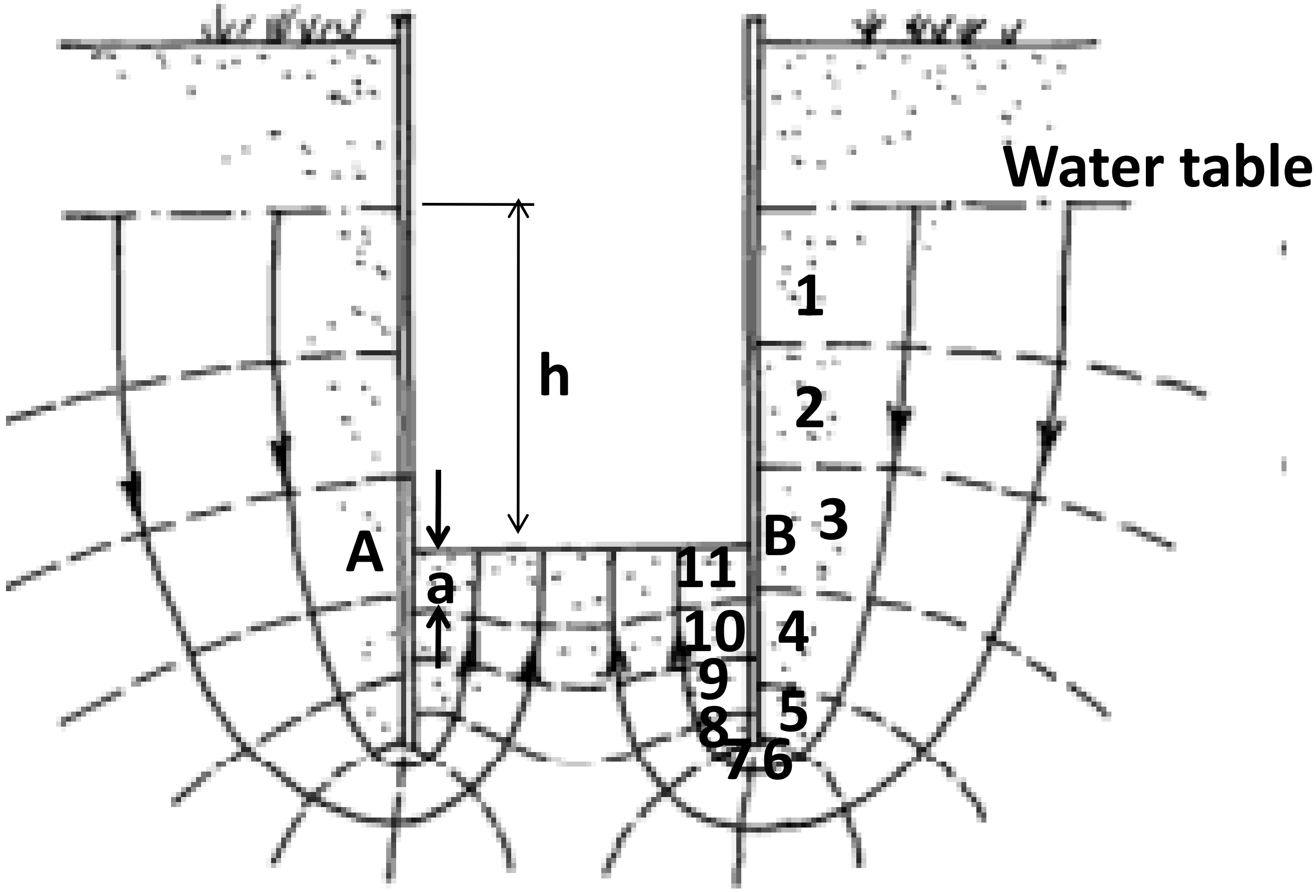
$$P = 0.7(\gamma Hb - 1.4cH - \pi cB) \quad for\ d > 0.47B$$

and

$$P = 1.5d\left(\gamma H - \frac{1.4cH}{B} - \pi c\right) \quad for\ d < 0.47B$$

- 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 ground water level.
- In case dewatering is needed, the factor of safety against piping should be checked.
- Piping may be occur when a high hydraulic gradient is created by water flowing into the excavation.



Water table
h
A
a
B
1
2
3
4
5
6
7
8
9
10
11

- 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.

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

where a = length of the flow element at A (or B)

N_d = number of drops (For the Figure shown N_d = 11)

- The factor of safety against piping may be expressed as

$$FS = \frac{i_{cr}}{i_{\max(exit)}} \geq 1.5$$

- where i_{cr}= critical hydraulic gradient

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

COFFERDAMS

- A cofferdam is a temporary structure.
- It is normally constructed to divert water in a river or to keep away water from an enclosed area in order to construct a permanent structure such as a bridge pier.
- When construction must take place below the water level, a cofferdam is built to give workers a dry work environment.
- The word "cofferdam" comes from "coffer" meaning box, in other words a dam in the shape of a box.

- A cofferdam involves the interaction of the structure, soil, and water. The loads imposed include the hydrostatic forces of the water, as well as the dynamic forces due to currents and waves.

- The loads imposed on the cofferdam structure by construction equipment and operations must be considered, both during installation of the cofferdam and during construction of the structure itself

- Types of cofferdam:
  - ❖Single wall
  - ❖Braced
  - ❖Earth-Type
  - ❖Double-Walled Sheet Pile
  - ❖Cellular

❑Single wall Cofferdams

- ➢Formed from a single wall of sheet piling
- ➢Driven into the ground to form a box around the excavation site
- ➢Interior is dewatered
- ➢Primarily used for bridge piers in shallow water .

❑Braced Cofferdams

- ➢Formed from a single wall of sheet piling
- ➢Driven into the ground to form a box around the excavation site
- ➢The "box" is then braced on the inside
- ➢Interior is dewatered
- ➢Primarily used for bridge piers in shallow water .

❑ Earth-Type Cofferdams

- Simplest Type of Cofferdam
- Consists of an earth bank with a clay core or vertically driven sheet piling in the middle.
- Used for low-level waters with low velocity
- The construction occupies more time and space
- Easily scoured by water rising over the top

❑Double-Walled Cofferdam

- Two-parallel rows of steel sheet piles driven into the ground
- Tied together with anchors and wales then filled with granular material such as sand, gravel or broken rock

Double wall Sheet pile Cofferdam

❑Cellular Cofferdam

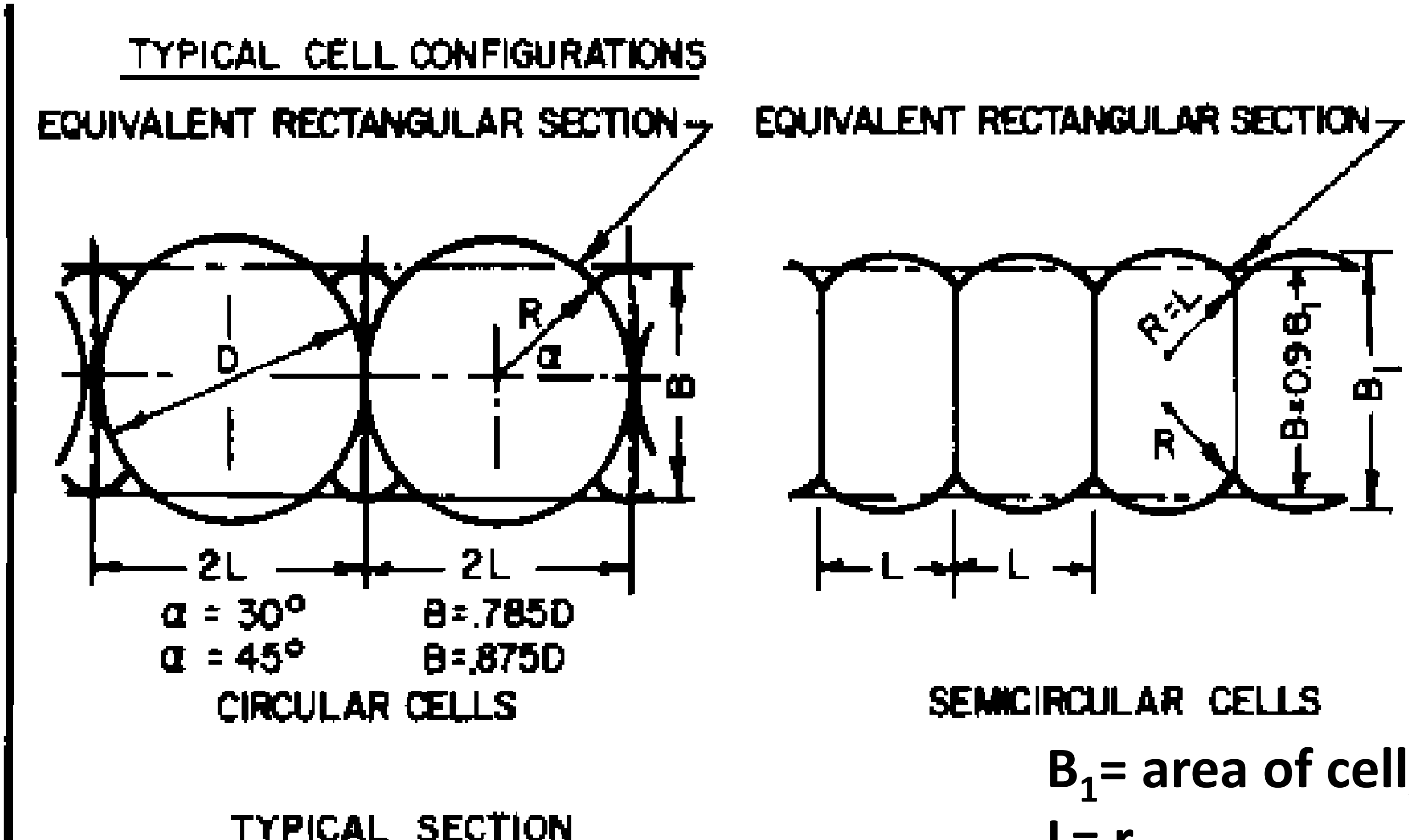
- constructed by driving sheet piles of special shapes to form a series of cells.
- Cells are interconnected to form a watertight wall.
- Cells are filled with soil to provide stabilizing force against lateral pressure.
- No Internal bracing (which would obstruct the work area)
- Basically, there are two types of cellular cofferdams that are commonly used.
  - ❖**Diaphragm type**
  - ❖**Circular type**

i. Diaphragm type

- Consists of circular arcs on the inner and outer sides which are connected by straight diaphragm walls.
- Connections between the curved parts and the diaphragms are made by means of specially fabricated element.
- Cofferdam is thus made from inter-connected steel sheet piles.
- Cells are filled with coarse-grained soils which increase the weight of the cofferdam and its stability. The leakage through the cofferdam is also reduced

ii. Circular type

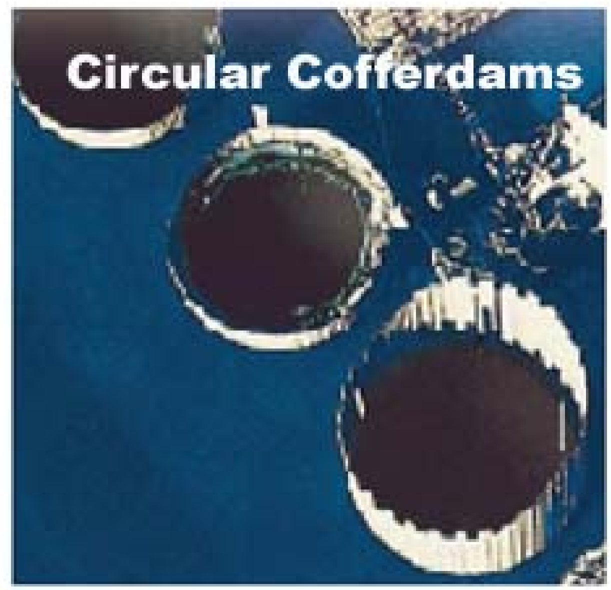
- Consists of a set of large diameter main circular cells interconnected by arcs of smaller cells.
- Usually intersect the circles at a point 30^0 or 45^0 with longitudinal axis of the cofferdam
- Walls of the connecting cells are perpendicular to the main circular cells of large diameters
- Circular-type cellular cofferdams are self-sustaining, and therefore independent of the adjacent circular cells.
- Each cell can be filled independently.



B_1= area of cell/ L

L= r

Cellular Cofferdams



❑Cell Fill

- The material used for the cell fill should have the following properties

1. The fill should be free-drainage granular soil with little fine particles
2. It should possess high angle of friction
3. The fill should be as dense as possible
4. It should possess large resistance to scour and leakage. Well graded soil are most suitable

- **Advantages of Cofferdam**
- Performing work over water has always been more difficult and costly than performing the same work on land.
- And when the work is performed below water, the difficulties and cost difference can increase geometrically with the depth at which the work is performed.
- Below some of the advantages of cofferdams are listed:
  - Allow excavation and construction of structures in otherwise poor environment
  - Provides safe environment to work
  - Steel sheet piles are easily installed and removed
  - Materials can typically be reused on other projects

- Dimension of cofferdam
- The height of a cofferdam is fixed on the basis of the maximum level in the river where it is constructed.
- Cellular cofferdams are economical up to a total height (H) of 15 to 18m
- Its diameter is based on the safety requirements.
- Diameter (D) of the main cells is chosen depending upon the height (H) of the cofferdam.
  - The diameter (D)of the main cells is given by

$$D = 1.0H \text{ to } 1.2H$$

  - The diameter of the connecting cells (D1) is given by

$$D_1 = 0.60\,D$$

- The design of a cofferdam begins with a tentative proportion which subsequently analyzed for stability and other safety requirements .

- The design is usually made on the basis of a section one meter long with a uniform average width B which is used in the design calculations

- An approximate value of the average width may be obtained by equating the equivalent rectangular area to the actual area of the cofferdam between center to center.
  - Let B = average width
  - L = distance center of cell
  - Then $B = \dfrac{Area\, of\ main\ cell + Area\, of\ connecting\, cell}{L}$

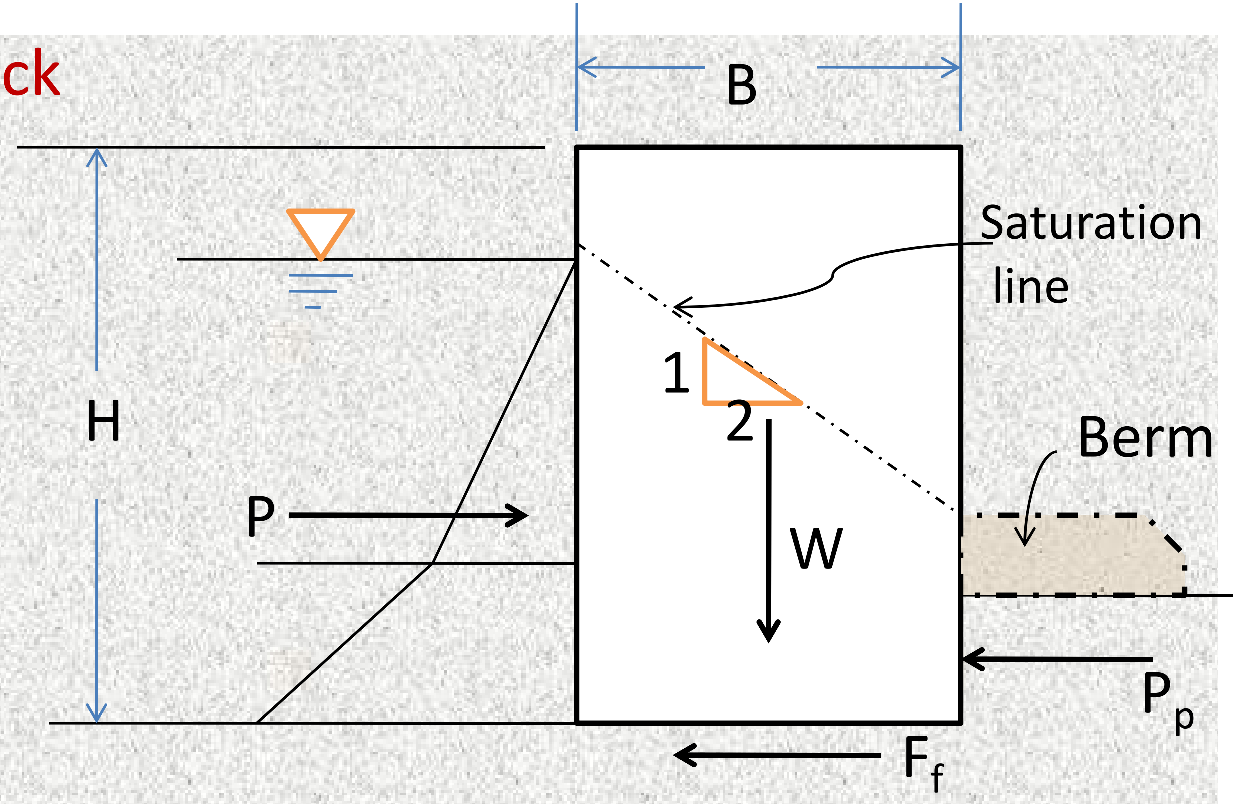
- The average width B of cells ranges from 0.785D to 0.875D .

• Stability of cellular cofferdam

- ➢ The tentative dimensions that are initially assumed are to be checked for their safety requirements.
- ➢ The preliminary dimensions assumed for cofferdams should satisfy the following stability requirements.

    1. Resistance to sliding
    2. Resistance to overturning
    3. Resistance to shear along a vertical plane (or cell shear)
    4. Resistance to bursting

- Cofferdams on Rock
- <u>Sliding stability</u>



- P =The lateral pressure due to water and submerged soil.
-   = Pa +Pw
- F_f = frictional resisting force = W$\tan\phi$
- W = effective weight of the fill material= submerged weight below saturation line + total weight above saturation line
- P_p = Passive pressure (soil +berm).

  If no berm , Pp due to soil only

- The factor of safety against sliding, Fs

$$F_s = \frac{P_p + F_f}{P} \geq 1.25$$

- Overturning stability
- Neglecting the passive resistance of the berm, the factor of safety against overturning is given by

$$Fs = \frac{\text{Resisting moment}}{\text{Overturning moment}} = \frac{We}{P\bar{y}} = \frac{\gamma HBe}{P\bar{y}} \geq 2.0$$

- where $\bar{y}$ = point of application of P above the base

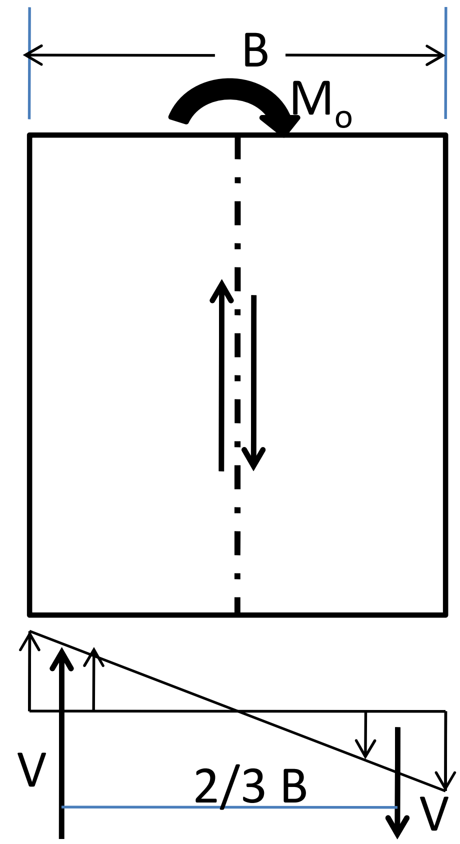
  e = Eccentricity
- When $M_o = M_r$,

$$e = \frac{P\bar{y}}{\gamma HB} \leq \frac{B}{6}$$

- Cell shear stability
- Overturning moments on a cell develops shear stresses on a vertical plane through the center line of the cell. For stability the shearing resistance along this plane (which is the sum of soil shear resistance and resistance in the interlocks) must be equal to or greater than the shear due to overturning effects.
- Overturning moment due to the overturning shear force developed at the base is

$$M_o = \frac{2}{3} BV$$

$$V = 1.5 \frac{M_o}{B}$$



- For stability the shearing resistance developed must be greater than V.
- The shearing resistance is equal to the sum of the shearing resistance of soil (S_1) and the resistance due to interlock (S_2) obtained as follows

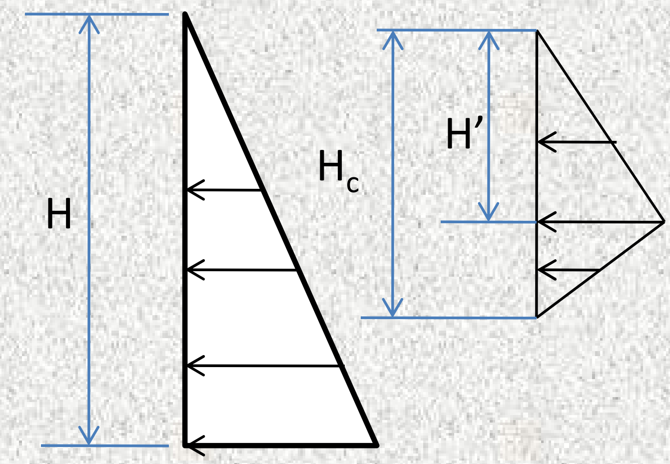
$$S_1 = \frac{1}{2}\gamma H^2 k \tan\phi$$

$$where \qquad k = \frac{\cos^2\phi}{2 - \cos^2\phi}$$

- The resistance S_2 is equal to the interlock tension T multiplied by coefficient of friction(f)

$$S_2 = f\,T$$

- If a sheet pile rests on a rock bed or is embedded in soil, a restraining force preventing the lateral movement of the cell is developed at the base.



- This effect causes the maximum pressure to be developed at a depth $H' = \frac{3}{4} H_c$, where H_c is the height of cell above the point of fixity or embedment. Thus

$$T = \frac{1}{2}\gamma H\left(\frac{3}{4}H_c\right)K_a$$

$$Therefore\ , \quad S_2 = \frac{3}{8}\gamma H H_c k_a f$$

where γ =effective unit weight of fill material

K_a = coefficient of active earth pressure

- The coefficient of interlock friction f is generally taken as 0.30
- The factor of safety against vertical shear is give by

$$F_s = \frac{S_1 + S_2}{V} \geq 1.25$$

- Resistance to bursting
- The cell should be stable against bursting pressure.
- The critical sections are in the interlock points.
- The bursting pressure is the maximum hoop-tension developed in the interlock at a depth H' (H'=0.75Hc) from the surface of fill.

The max. active pressure, $P_a = k_a \gamma H'$

Bursting pressure , $T = P_a r + \gamma_w H_w$

where r = radius of cell

H_w = depth of water above the point of maximum pressure.

- The computed maximum interlock tension T, should not exceed the maximum stress specified by the manufacturers of steel sheet piles.

- Cofferdams on deep layers of sand or clay
- The principle of analyses of cofferdams founded on deep layers sand or clay is the same as that applied to cofferdams on rock.
- In addition, the following requirements must be satisfied.

i. The sheet pile in sand must be driven to such a depth that a bearing capacity at that level is greater than the vertical force acting on the pile. A minimum factor of safety of 1.50 is generally recommended.

The maximum vertical force per unit length (Q) developed is equal to the frictional resistance between the fill and the pile is given by

$$Q = \frac{1}{2}\gamma H^2 k_a \tan\delta$$

where H = height of cell above top of stratum

K_a = coefficient of active earth pressure

δ = angle of wall friction between fill and pile

γ = unit weight of cell fill

Factor of safety , $F_s = Q_{ult}/Q$

where Q_{ult} = ultimate bearing capacity

ii. If the cofferdam is embedded in clay, the ultimate bearing capacity is give by

$Q_{ult} = 5.7cB$, where c = unit cohesion

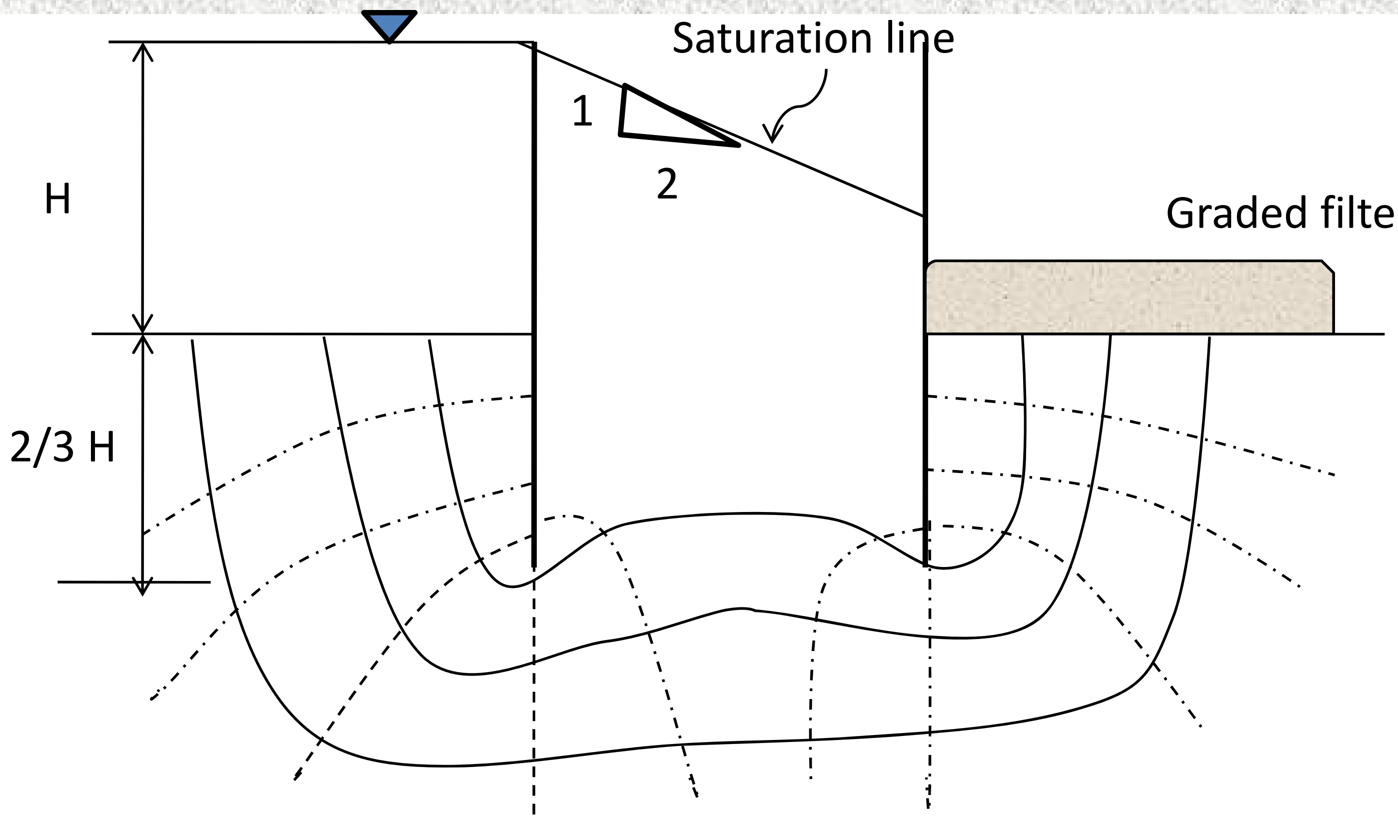
The factor of safety is given by

$$F_s = \frac{Q_{ult}}{Fill\ load} = \frac{5.7cB}{\gamma HB} = \frac{5.7c}{\gamma H} \geq 1.5$$

$$or \quad H = \frac{5.7c}{\gamma F_s}$$

iii. If the cofferdam is embedded in soft to medium clay, it should safe against tilting caused by unequal settlement. The tilting can be estimated from the compressibility characteristics of the soil.

iv. Cellular cofferdams to be founded on sand bed should be designed to prevent boiling (piping) at the toe due to seepage of water.



- If the seepage pressure is equal to or greater than the submerged unit weight , boiling (piping) conditions may be developed.
- The danger of boiling can be eliminated by the use of loaded filter.
- As an alternative, the sheet piling may be driven to a great depth in order to eliminate the boiling condition
- The depth of the sheet piling below the bed level required for this purpose is approximately equal to 2/3H , where H is the height of the sheet pile above the bed.