

## **Module 6 : Design of Retaining Structures**

### **Lecture 29 : Braced cuts [ Section 29.1 : Introduction ]**

#### **Objectives**

**In this section you will learn the following**

- Introduction

## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.1 : Introduction ]

#### Introduction

Deep excavations with vertical sides require lateral supports to prevent cave in of the earth and to protect the adjacent areas against ground subsidence and lateral movement of the subsoil. When excavations are shallow and ample space is available, the sides of the excavation can be sloped at a safe angle to ensure stability. However, in deep excavation, especially in built up areas there may not be adequate space for providing safe slopes. Moreover it becomes uneconomical to provide safe slope because of large quantities of earth involved.

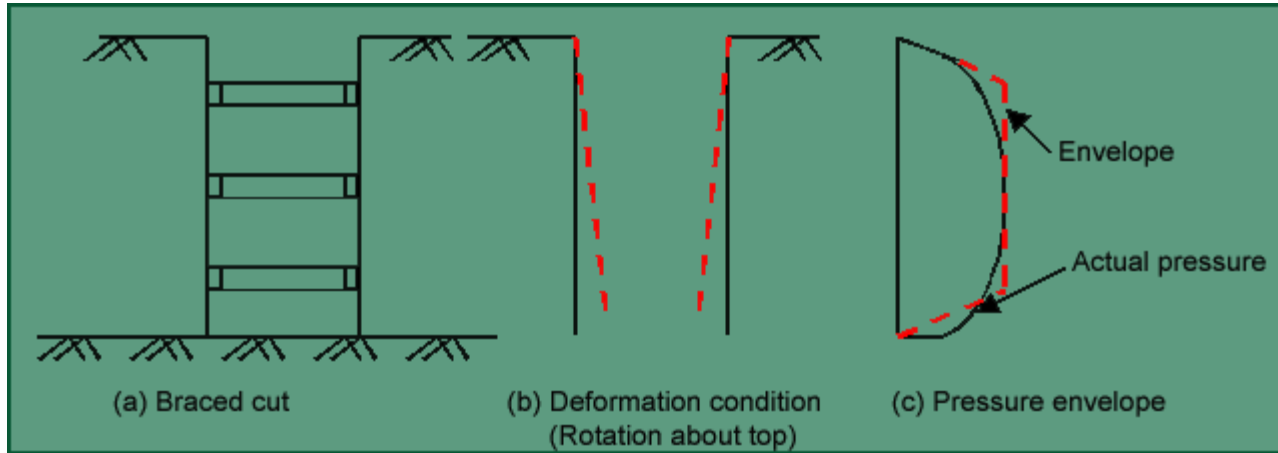


Fig-6.28 Braced cuts

## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.1 : Introduction ]

Excavations which are laterally supported are Braced cuts (Fig-6.6.1-a). The vertical sides of the excavations are supported by a sheeting and bracing system. It consists of relatively flexible sheeting placed against excavations walls. The lateral thrust on the sheeting is resisted by the horizontal members in compression (struts). Known as Bracing system. Bracing is provided as the excavation proceeds and the face of the sheeting becomes exposed. So, various types of the Bracing systems is adopted to make the excavation stable When no plenty space is available for excavation in a natural slopes. Sheet piling is used primarily as a bulkhead to hold or restrict the lateral movement behind it. Some typical uses of Braced Excavation are

- Laying underground pipeline
- Construction of bridge abutment.
- Construction of basement.
- Metro railway construction.
- Construction of subway tunnel.

A Gravity Retaining wall is a Permanent Structure, used, when an excavation is permanent. But when excavation is temporary i.e. excavation for buildings or subway, the excavation is filled with a structure which then permanently retain surrounding soil/earth. If the temporary Excavation is made in sand, the walls of the excavation must be supported during construction of the building by a system of bracing.

## **Module 6 : Design of Retaining Structures**

### **Lecture 29 : Braced cuts [ Section 29.1 : Introduction ]**

#### **Recap**

**In this section you have learnt the following.**

- Introduction

## **Module 6 : Design of Retaining Structures**

### **Lecture 29 : Braced cuts [ Section 29.2 : Different types of the Sheeting and Bracing systems ]**

#### **Objectives**

**In this section you will learn the following**

- Vertical Timber Sheeting
- Steel Sheet Piles
- Soldier Beams
- Tie Backs

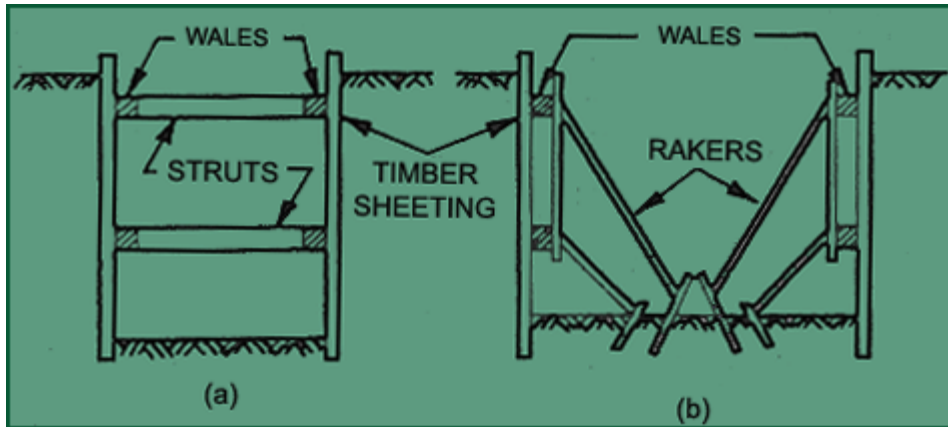
## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.2 : Different types of the Sheet piling and Bracing systems ]

The following types of sheet piling and bracing system for braced cuts are commonly used:

- **Vertical Timber Sheet piling**

In this method, vertical timber sheet piling consisting of the planks about 8 to 10 cm. thick are driven around the boundary of the proposed excavation to a depth below the base of the excavation. The soil between the sheet piling is excavated. The sheet piling is held in place by a system of Wales and struts. The Wales are the horizontal beams running parallel to the excavation wall. The Wales are supported by the horizontal struts which extend from the side of the excavations.



**Fig –6.29 Vertical timber sheet piling**

However, if the excavations are relatively wide, it becomes economical to support the Wales by inclined struts, known as rakers (fig-6.6.2b). For inclined struts to be successful, it is essential that the soil in the base of the excavation is strong enough to provide adequate reaction.

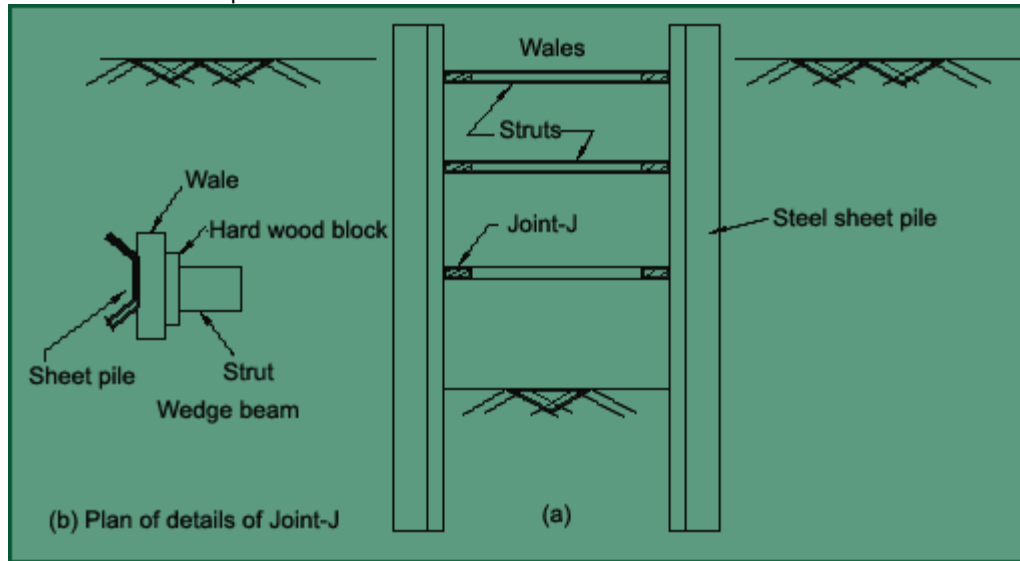
If the soil can temporarily support itself an excavation of limited depth without an external support, the timber sheet piling can be installed in the open or in a partially completed excavation. Vertical timber sheet piling is economical up to a depth of 4 to 6 meter.

## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.2 : Different types of the Sheet piling and Bracing systems ]

#### ■ Steel Sheet Piles

Piles, or sheeting, driven in close contact to form a continuous interlocking wall which resists the lateral pressure of water or earth. In this method, the steel sheet pile is driven around the boundary of the proposed excavations. A continuous line of pile is driven in advance of excavation. As the soil is excavated from the enclosure Wales and struts are placed.



**Fig- 6.30 Steel sheet Piles**

The Wales are made of the steel. The lateral thrust from the sides is resisted by horizontal members called the struts are placed across the excavation And wedged against the Wales. The struts may be of the steel or wood. As the Excavations 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. Figure shows the details of the joint J.

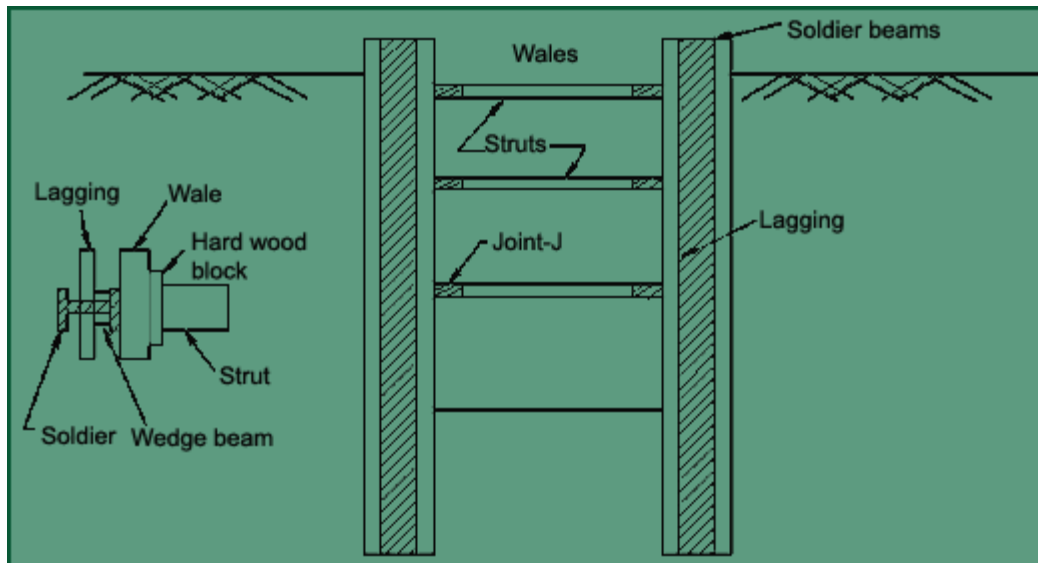
The upper strut is placed when the excavation is shallow and little lateral yield of soil has occurred to change appreciably the original state of stress. As excavation proceeds downward the lower part of the face is freely to yield inward before it could be restrained by the next strut. The inward yield of soil increase with an increase in the depth of excavation. Thus problem is analogous to a retaining wall tilting about its top. The sheeting tilts about its tops.

## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.2 : Different types of the Sheet piling and Bracing systems ]

- **Soldier Beams**

Soldier beams are H-piles which are driven at suitable spacing of 1.5 to 2.5 m. around the boundary of the proposed excavation



**Fig-6.31 Soldier Beam**

As the excavation proceeds, horizontal timber planks called lagging are placed between the soldier beams. When the excavation advances to the suitable depth, Wales and the struts are inserted. The lagging is properly wedged between piles flanges or behind their back flange.



## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.2 : Different types of the Sheet piling and Bracing systems ]

#### ■ Tie Backs

In this method, no bracing in the form of struts or inclined rakes 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 sheet piling or lagging on one side and anchored into the soil or rock out side of the excavation area (Fig-6.6.5). Inclined holes are drilled in to the soil Or Rock, and the tensile reinforcement (tendon) is then inserted and the hole is concreted. An enlargement or bell is usually formed at the end of the hole. Each tie back is generally prestressed before the depth of excavation is increased further to cope with the increased tension.

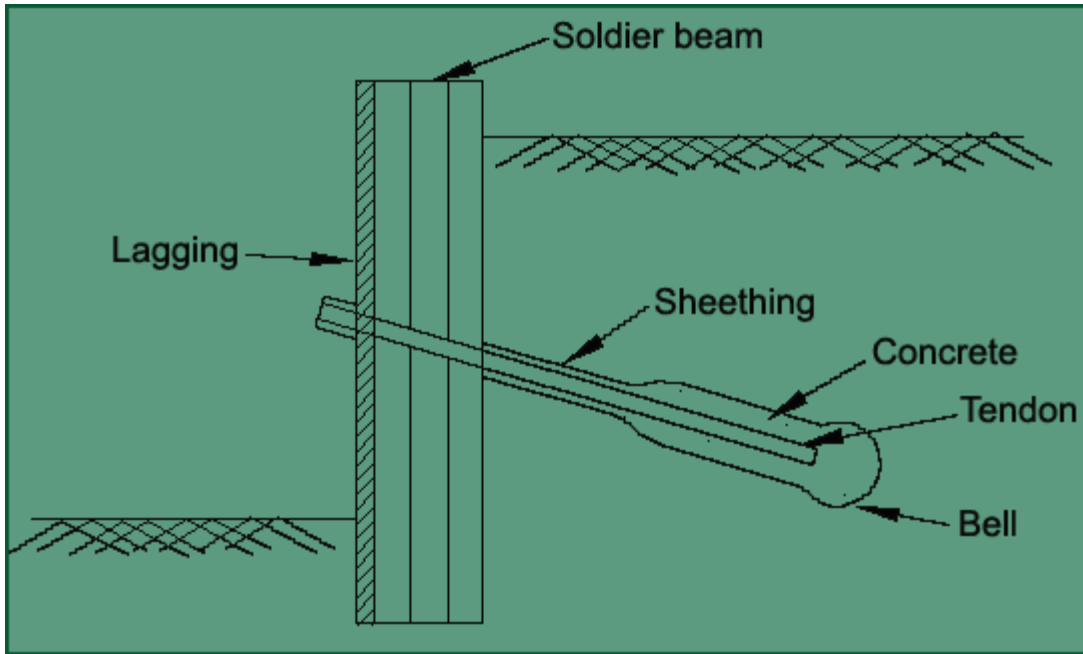


Fig-6.32 Tie Back

#### Use of slurry Trenches

An alternative to use of sheet piling and bracing system, which is being increasingly used these days, is the construction of slurry trenches around the area to be excavated. The trench is excavated and is kept filled with a heavy, viscous slurry bentonite of the clay water mixture. The slurry stabilizes the wall of the trenches, and thus the excavation can be done without sheet piling 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 are constructed in a slurry trench.

## **Module 6 : Design of Retaining Structures**

### **Lecture 29 : Braced cuts [ Section 29.2 : Different types of the Sheeting and Bracing systems ]**

#### **Recap**

**In this section you have learnt the following.**

- Vertical Timber Sheeting
- Steel Sheet Piles
- Soldier Beams
- Tie Backs

## **Module 6 : Design of Retaining Structures**

### **Lecture 29 : Braced cuts [ Section 29.3 : Lateral earth Pressure on Sheetings ]**

#### **Objectives**

**In this section you will learn the following**

- Lateral earth Pressure on Sheetings
- Non uniform soils

## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.3 : Lateral earth Pressure on Sheetings ]

#### Lateral earth Pressure on Sheetings

Rankine's and coulomb earth pressure theory can not be used for the computation of the lateral earth pressure on sheetings, as those theories are applicable to rigid retaining walls rotating about the base. The sheeting and bracing system is somewhat flexible and rotation takes place at the top of the wall. Sheetings are placed against the walls of the excavation when these are shallow. The upper strut is placed when the excavation is shallow and the lateral yield of the soil has occurred. As the excavation proceeds downwards, the lower part of the face is free yield inward before the next strut is placed. The inward yield of the soil increases with an increase in the depth of excavation. Thus the sheeting tilts about its top. The method of earth pressure of calculation has been developed by **Terzaghi** based on the observations of actual loads in struts in full scale excavations in sand in BERLIN and in soft clay in CHICAGO. Pressure distributions against the sheeting have been approximated on the assumptions that each strut support the sheeting area. The effect of various factors is not fully understood. However, the results of the field studies can be used as a basis for developing earth pressure diagram required for the design of the bracing system. The pressure diagram recommended for design represent an envelope which encompass the actual pressure distribution diagram obtained from the field tests. These design pressure diagram are also known as apparent pressure diagram.

Fig. shows the apparent pressure diagram suggested by the **Peck (1969)** . Fig. Gives the pressure diagram for braced cut in dry or moist sand. The pressure diagram is uniform with a pressure (  $P_a$  ) equal to  $1.6(P_a)$  or  $(0.65 \cdot \gamma \cdot H \cdot K_a)$ .

Where  $K_a$  is Rankine's earth pressure coefficient, given by  $K_a = \tan^2(45 - \phi/2)$ .

And  $P_a$  = Total normal active pressure on a wall of height H determined by coulomb theory .

The resultant active earth pressure diagram is 28% greater than the coulomb active pressure for dense sand & 44% greater than for loose sand. Since, the sheeting can not resist, in general, the vertical shear forces, the friction and adhesion on them are assumed to be Zero.

Fig shows the pressure diagram for the clay.

## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.3 : Lateral earth Pressure on Sheetings ]

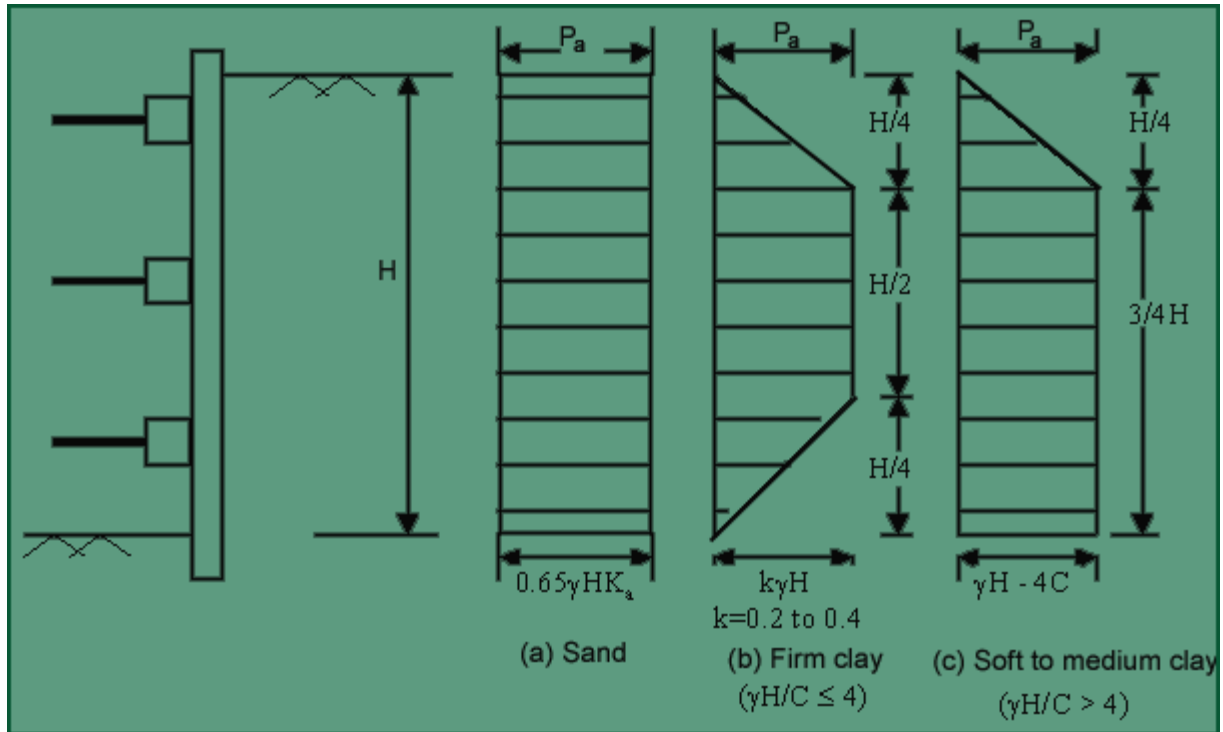


Fig-6.33. Apparent Pressure Diagram

$$N = \text{stability no.} = \frac{\gamma H}{C}$$

If  $\frac{\gamma H}{C} < 4.0$  The pressure envelop shown in Fig (a) is used.

The value of the  $P_a$  varies between  $0.2 \cdot \gamma \cdot H$  to  $0.4 \cdot \gamma \cdot H$ . Average value will be taken ( $0.3 \cdot \gamma \cdot H$ ).

If  $\frac{\gamma H}{C} > 4.0$ , the pressure envelop shown in Fig (b) is used. The Pressure  $P_a$  is taken as ( $\gamma \cdot H - 4 \cdot C$ ) or ( $0.3 \cdot \gamma \cdot H$ ).

$$\text{or } P_a = K_a \cdot \gamma \cdot H = \left[ 1 - m \times \frac{4C}{\gamma H} \right] \quad (m \text{ depends on } N. \quad N < 4.0 \text{ } m = 0.6 \text{ to } 0.8 \text{ \& } N > 4.0 \text{ } m = 1.0)$$

## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.3 : Lateral earth Pressure on Sheetings ]

#### Non uniform soils

When the braced cuts passes through the no. of clay layers of both sand and clay, an equivalent value of cohesion  $C_e$  &  $\gamma_e$  is determined using the following equations( **Peck 1943** ):

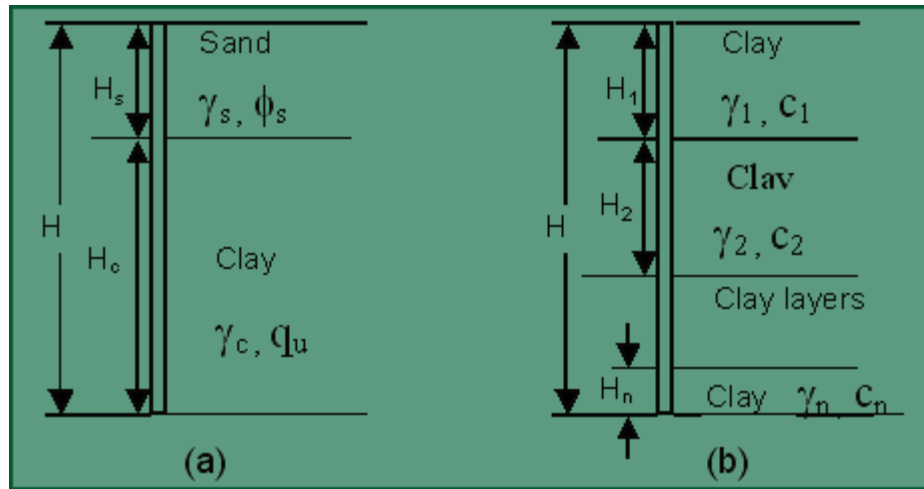


Fig- 6.34 Stratified soil

$$C_e = \frac{1}{H} [C_1.H_1 + C_2.H_2 + \dots + C_n.H_n]$$

Where  $C_1, C_2, \dots, C_n$  are undrained cohesion of layers 1,2,...,n and  $H_1, H_2, \dots, H_n$  are the thickness of layers.

$$\gamma_e = \frac{1}{H} [\gamma_1.H_1 + \gamma_2.H_2 + \dots + \gamma_n.H_n]$$

## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.3 : Lateral earth Pressure on Sheetings ]

When braced cut passes through layers of both sand and clay(fig-), an equivalent value of cohesion  $C_e$  (assume  $\Phi = 0$ ) is determined using the peck(1943) eq. :

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

Where H= Total height of the cut,  $\gamma_s$  = Unit weight of the sand,  $H_s$  = Height of the sand layer,  $K_s$  = a lateral earth pressure coefficient (  $K_s = 1$  ).  $\Phi_s$  = angle of friction of sand,  $q_u$  = Unconfined compressive strength of clay,  $n'$  = a coefficient of progressive failure (average value 0.75).

The equivalent unit weight of the layer is determined from the equation:

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

Where  $\gamma_c$  = Saturated unit weight of clay layer.

Now N value is calculated by  $N = \frac{\gamma_e . H}{C_e}$

## **Module 6 : Design of Retaining Structures**

### **Lecture 29 : Braced cuts [ Section 29.3 : Lateral earth Pressure on Sheetings ]**

#### **Recap**

**In this section you have learnt the following.**

- Lateral earth Pressure on Sheetings
- Non uniform soils



## **Module 6 : Design of Retaining Structures**

### **Lecture 29 : Braced cuts [ Section 29.4 : Failure Analysis Of Bracing Systems ]**

#### **Objectives**

**In this section you will learn the following**

- Bottom heave
- Clay bursting

## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.4 : Failure Analysis Of Bracing Systems ]

#### Stability considerations :

There are various methods by which a braced cut can be expected to attain failure. Before carrying out a braced excavation the stability criteria are first judged and adequate steps are taken up to ensure the stability. Building of struts or walls nor wales cannot prevent these phenomenon. These aspects are described in the subsequent sections.

#### 1. Bottom heave

Consider a excavation pit as shown in the figure and the rectangular soil mass adjacent to it. If this soil mass is considered as a foundation with the failure surfaces as shown the heaving of soil will occur at the bottom of the pit due to release of overburden pressure at that point. The pit has to be safeguarded against this heaving.

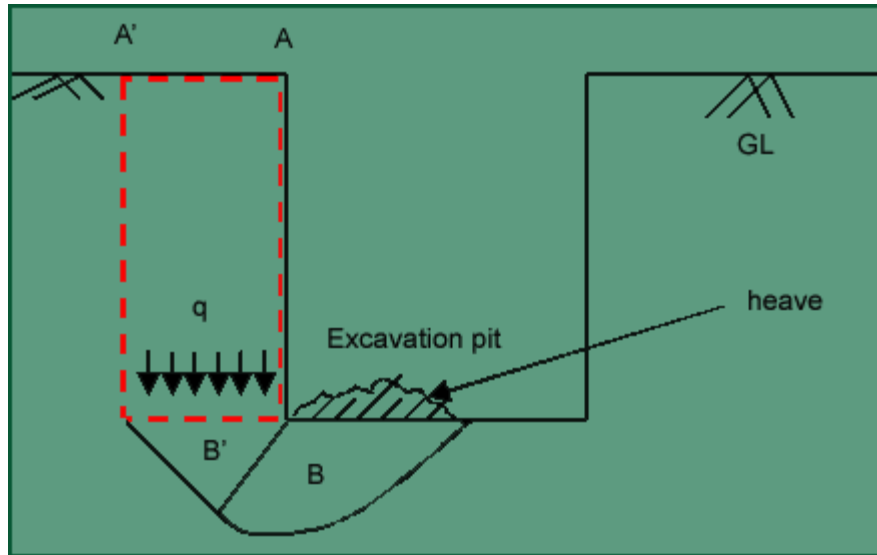


Fig.6.35 Bottom heave

## 2. Clay bursting

This occurs when a impermeable layer (clay) lies over a permeable layer (sand). At level 1-1, when there is no excavation, full overburden pressure exists. When excavation occurs, at level BC some overburden pressure is released. At the same level 1-1, upward water pressure exists due to presence of sand layer. When no excavation occurs the total overburden pressure is greater than the upthrust, but the layer of soil below the excavation pit may not have sufficient depth to resist the uplift force. Hence if the uplift force the excavation level becomes more, the clay layer bursts open.

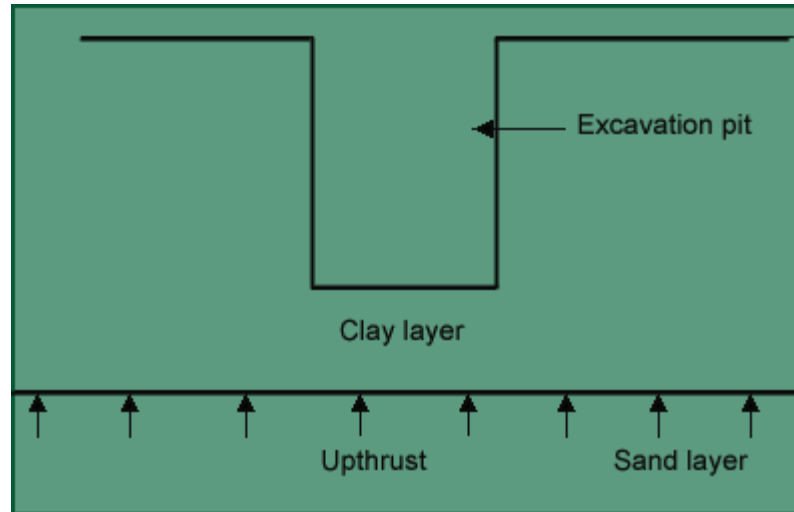


Fig . 6.36 Clay Bursting

## **Module 6 : Design of Retaining Structures**

### **Lecture 29 : Braced cuts [ Section 29.4 : Failure Analysis Of Bracing Systems ]**

Once the stability against bottom heave and clay bursting are achieved, the next step is to ensure the structural stability of the braced excavation. These include the following:

- **Yielding of supports**

Due to earth pressure on both sides of the excavation pit, compressive stresses are generated on the struts. When this force increases beyond safety the struts may yield.

- **Excessive ground movements**

Braced excavation is carried out in places where there is scarcity of place in the surrounding to make a stable inclined slope. Now during excavation as the earth is being removed the pit, the pressure of the foundations of the adjacent buildings tend to create pressure on the soil mass leading to the movement of the surrounding soil into the pit and thereby the surrounding structures are distressed. The above phenomenon is more critical for a small structure in the vicinity than a large one.

## **Module 6 : Design of Retaining Structures**

### **Lecture 29 : Braced cuts [ Section 29.4 : Failure Analysis Of Bracing Systems ]**

#### **Recap**

**In this section you have learnt the following.**

- Bottom heave
- Clay bursting

## **Module 6 : Design of Retaining Structures**

### **Lecture 29 : Braced cuts [ Section 29.5 : Stability checks for designing a braced excavation: ]**

#### **Objectives**

**In this section you will learn the following**

- Stability against bottom heave
- Stability against piping failure or clay bursting
- Piping failure

Stability checks for designing a braced excavation

- Stability against bottom heave

The analysis is a total stress analysis since the time of dissipation of pore water pressure is very less unless there is sandy deposit. Consider a stratified soil deposit in which braced excavation was carried out as shown in the figure.

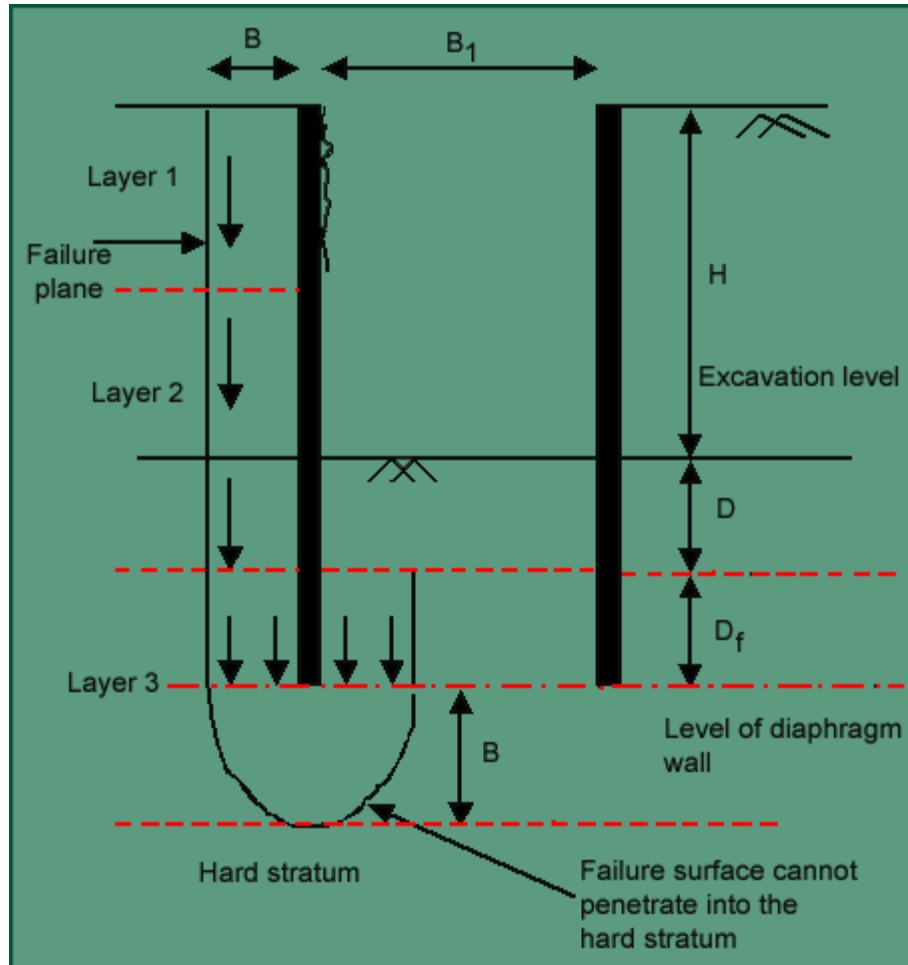


Fig. 6.37 Excavation with diaphragm walls showing bottom heave

## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.5 : Stability checks for designing a braced excavation: ]

First the stability is to be checked at the excavation level as follows:

$q_u = c_u$ .  $N_c$  is the force that resists the heave which is brought about by the weight of soil of magnitude  $\gamma H$ .

The stability factor is calculated as  $S = \gamma H / c_u$ .

If,  $S < 6$  ----- stable, where  $N_c$  is taken as 6.

$S > 6$  ----- unstable.

$S = 6$  ----- limiting condition.

If instability criteria occurs the idea is to increase the depth of the diaphragm wall in order to take advantage of the layers of higher strength lying below. The failure plane as shown cannot penetrate through the hard stratum and is tangent to the same. This is shown in the fig. 6.7.3.

$$\text{Factor of safety against bottom heave} = \frac{c_u N_c + \gamma D_f + \gamma (c_u H / D_1)}{\gamma (H + D + D_f)}$$

F.O.S should be more than **2** for bottom heave.

The depth  $D_1$  is calculated as follows:

- $D_1 = D$ , since failure surface cannot penetrate the hard stratum.
- $D_1 = 0.7B$ , which is obtained from bearing capacity analysis.
- $D_1$  is taken as least of the above two values.



The factor of safety for clay bursting should be more than 1.3.

## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.5 : Stability checks for designing a braced excavation: ]

#### Piping failure

For piping failure, the factor of safety =  $i / i_c$  . where,  $i$  is the exit gradient and  $i_c$  is the critical gradient. Factor of safety for piping failure should be more than 1.3.

#### Piping in sand

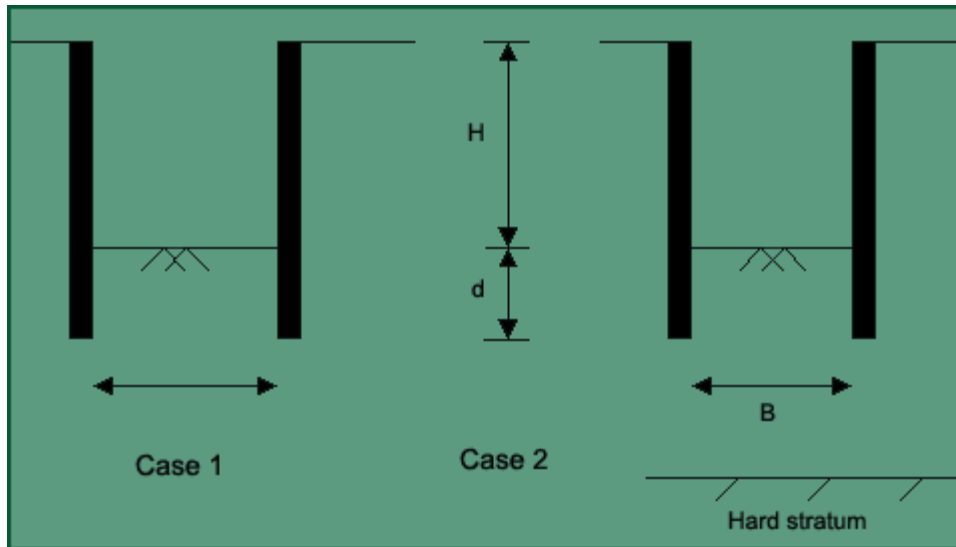


Fig.6.39 Piping in sand

## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.5 : Stability checks for designing a braced excavation: ]

Table 2

Case 1 ( sand upto infinite depth)

B / H	F.O.S = 1.5		F.O.S = 2.0	
	d / H		d / H	
	Loose sand	Dense sand	Loose sand	Dense sand
0.5	1.2	1.05	1.75	1.7
1.0	1.1	0.85	1.50	1.3
2.0	0.9	0.65	1.20	0.9
3.0	0.8	0.50	1.05	0.75
4.0	0.75	0.50	1.04	1.07

Case 2 ( sand upto finite depth)

B / H	F.O.S = 1.5		F.O.S = 2.0	
	d / H		d / H	
	$H_1 / H=1$	$H_1 / H=2$	$H_1 / H=1$	$H_1 / H=2$
0.5	0.70	1.10	0.80	1.50
1.0	0.55	0.80	0.75	1.10
2.0	0.40	0.65	0.50	0.45
3.0	0.35	0.45	0.50	0.55
4.0	0.35	0.45	0.50	0.55

## **Module 6 : Design of Retaining Structures**

### **Lecture 29 : Braced cuts [ Section 29.3 : Lateral earth Pressure on Sheetings ]**

#### **Recap**

**In this section you have learnt the following.**

- Stability against bottom heave
- Stability against piping failure or clay bursting
- Piping failure

## **Module 6 : Design of Retaining Structures**

### **Lecture 29 : Braced cuts [ Section 29.6 : Design of the structural members ]**

#### **Objectives**

**In this section you will learn the following**

- Design of struts
- Design of diaphragm walls
- Design of wales
- Excessive ground movement

## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.6 : Design of the structural members ]

#### Design of the structural members

##### ■ Design of struts:

The struts are the structural members whose function is to transfer the earth pressure coming on the diaphragm walls due to the earth pressure from the surrounding soil. For calculation of the struts loads, Peck (1969) proposed apparent earth pressure diagrams to be used for the designing of the bracing systems. The diagrams are given in figure.

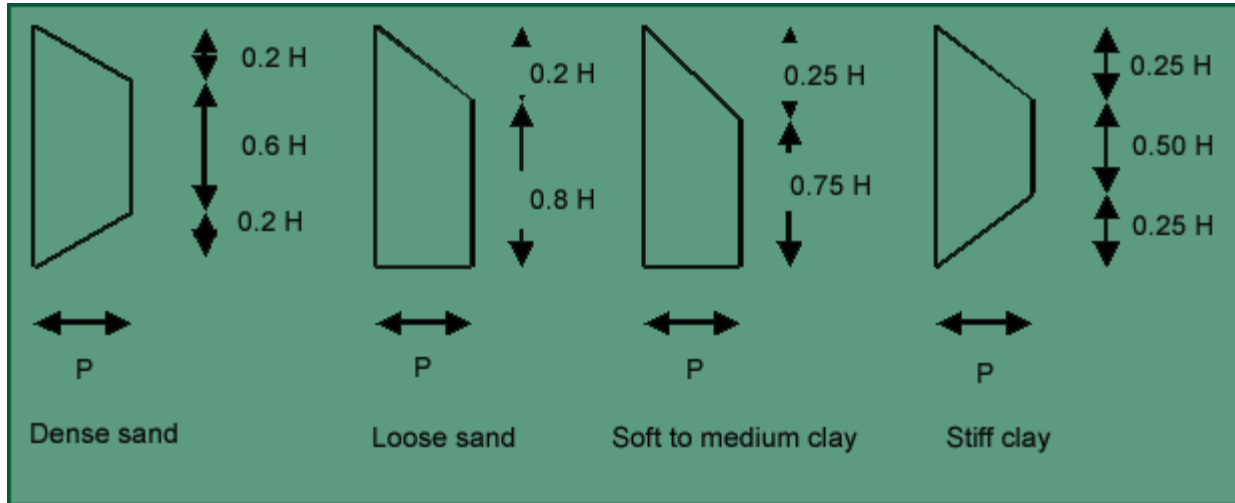


Fig 6.40. Apparent earth pressure diagrams (Peck, 1969)

For sands,  $p = 0.65 k_A \gamma H$ , where,  $k_A = (1 - \sin \phi) / (1 + \sin \phi)$

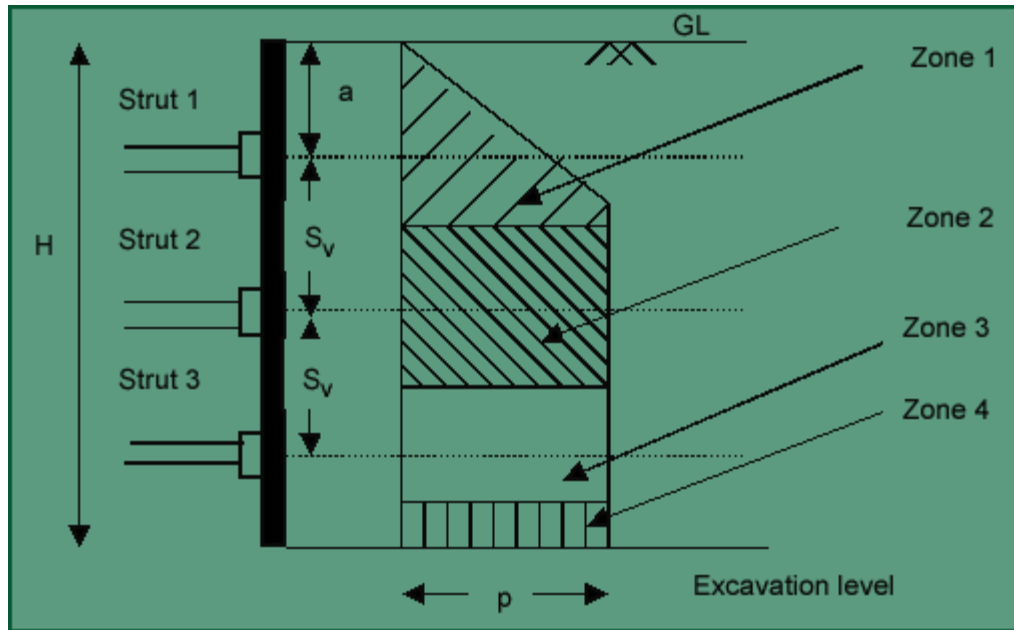
H = height of the vertical cut.

For clays,  $p = \gamma H (1 - 4mc_u / \gamma H)$ ,

where, m = coefficient depending on the stability of the wall

For  $S < 4$ ,  $m = 0.6 - 0.8$ .

For  $S > 4$ ,  $m = 1.0$ . {  $S = \gamma H / c_u$  }



**Fig. 6.41 Apparent earth pressure acting on diaphragm wall**

The apparent earth pressure acting on diaphragm wall is chosen as per the type of soil existing in the field. For each strut we get an effective zone over which the earth pressure acts. Usually the earth pressure zones extend from centerline of one strut to that of the other, which implies that each strut takes the earth pressure on either halves upto half the vertical spacing ( $S_v$ ). As shown zones 1,2,3 apply pressure on the struts 1,2,3. For zone 4, it is assumed that the soil in that portion does not apply pressure and it is taken up by the underlying soil.

Each strut load is calculated by multiplying the effective area of action of earth pressure with the apparent earth pressure ( $p$ ). Usually the vertical spacing of the struts are taken between 3-4 m. The highest strut load is taken up for choosing the section of the struts and same section is provided throughout.

## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.6 : Design of the structural members ]

- **Design of diaphragm walls:**

For design of the diaphragm walls the wall is assumed to lie as a beam and the pressure distribution acting on it as shown in the figure

**Fig 6.42 Load on Diaphragm wall**

From the pressure distribution the exact moment and forces acting on the struts and the wall can be calculated. However, for all practical purposes, the maximum bending moment acting on the wall ( $M_{\max}$ ) =  $wl^2 / 10$ , where  $l = S_v$ . Accordingly the section of the diaphragm wall is chosen based on the moment acting on it.

- **Design of wales:**

The wales are structural members which transfers the load from the diaphragm walls to the struts thereby acting as beams. The design of struts is done as simply supported beams as shown in fig. 6.7.9. Maximum moment on wales =  $(p \cdot S_v) \cdot S_H^2 / 8$ .



## Module 6 : Design of Retaining Structures

### Lecture 29 : Braced cuts [ Section 29.6 : Design of the structural members ]

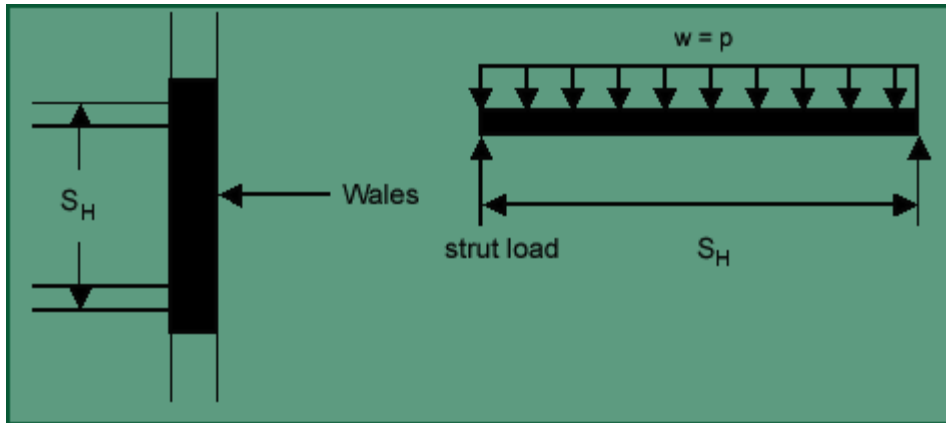


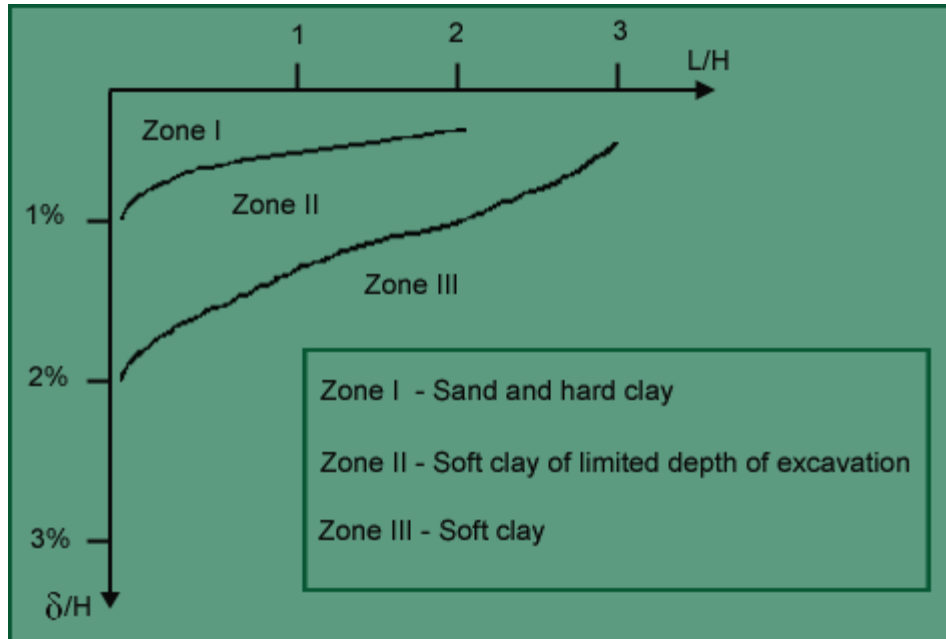
Fig. 6.43 Plan of struts and wales along with loading arrangement

#### Excessive ground movement

The various structural members are constructed to minimize ground movements in the vicinity. However, wall cannot be infinitely rigid. Irrespective of placing of struts, diaphragm wall movement cannot be prevented. After some excavation is done, before a strut is placed there is a certain movement of the wall. Also, between subsequent placing of struts certain movement of wall occurs. As a result, the ground movement occurs locally.

If the joints are subjected to such movements excessive forces may generate leading to the distress of the structure. Therefore whatever ground movement occurs, it has to be limited to a minimum value. Total ground movement is the sum total of the ground movement and the bottom heaving. The idea of providing structural members is to minimize ground movements. More rigid the structure, lesser is the ground movement.

Peck (1969) proposed a graph which indicated the ground movements and their extent for a excavation site and site conditions as shown in figure



**Fig 6.44. Amount and extent of ground settlement (Peck, 1969)**

Before conducting any excavation, depending on site and soil conditions, we can estimate the maximum settlement and extent of settlement that is going to occur when a excavation is carried out at that site. It is to be noted that Peck's analysis was based on experiments done over sheet pile walls. Therefore, if the rigidity of the structural members can be increased the settlement values can be minimized and whatever settlement we could have got for a sheet pile wall in zone III can be found to fall in zone II due to a more rigid structure. Hence after finding out the extent of settlement it has to be judged whether any surrounding structure falls within that range.

## **Module 6 : Design of Retaining Structures**

### **Lecture 29 : Braced cuts [ Section 29.6 : Design of the structural members ]**

#### **Recap**

**In this section you have learnt the following.**

- Design of struts
- Design of diaphragm walls
- Design of wales
- Excessive ground movement