

CHAPTER-V

ANALYSIS AND DESIGN OF RETAINING WALL

Introduction

In general, retaining walls can be divided into two major categories:

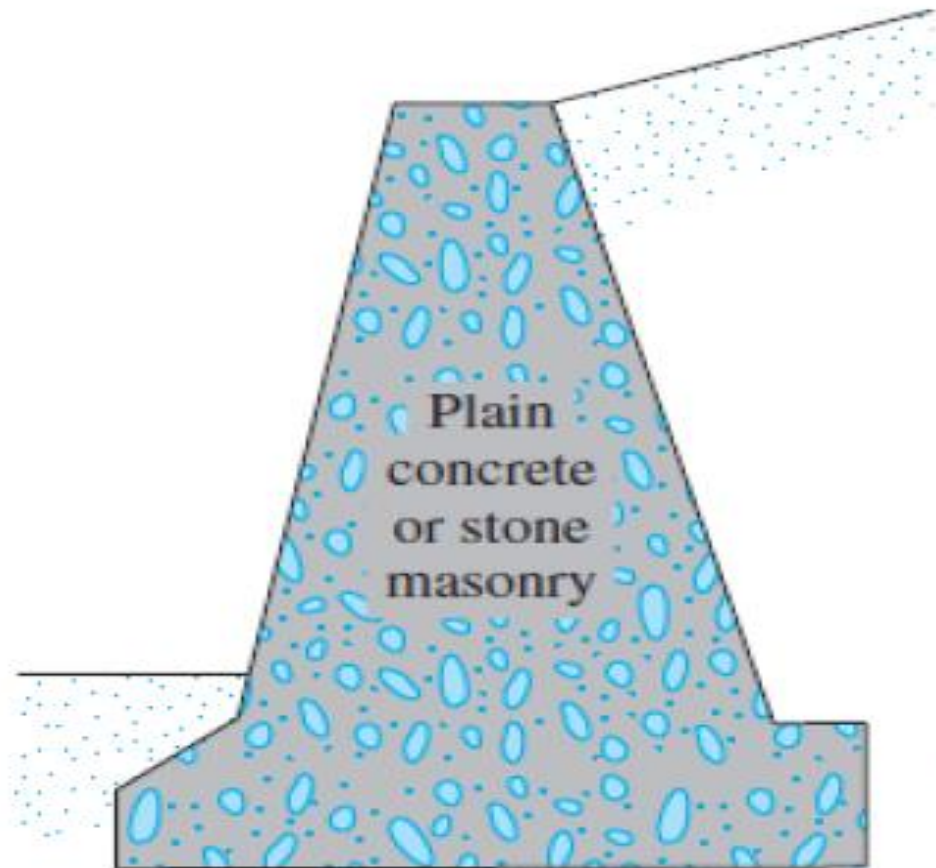
- (a) conventional retaining walls and
- (b) mechanically stabilized earth walls

Conventional retaining walls can generally be classified into four varieties:

- (1) Gravity retaining walls
- (2) Semi-gravity retaining walls
- (3) Cantilever retaining walls
- (4) Counterfort retaining walls

(1) Gravity retaining walls

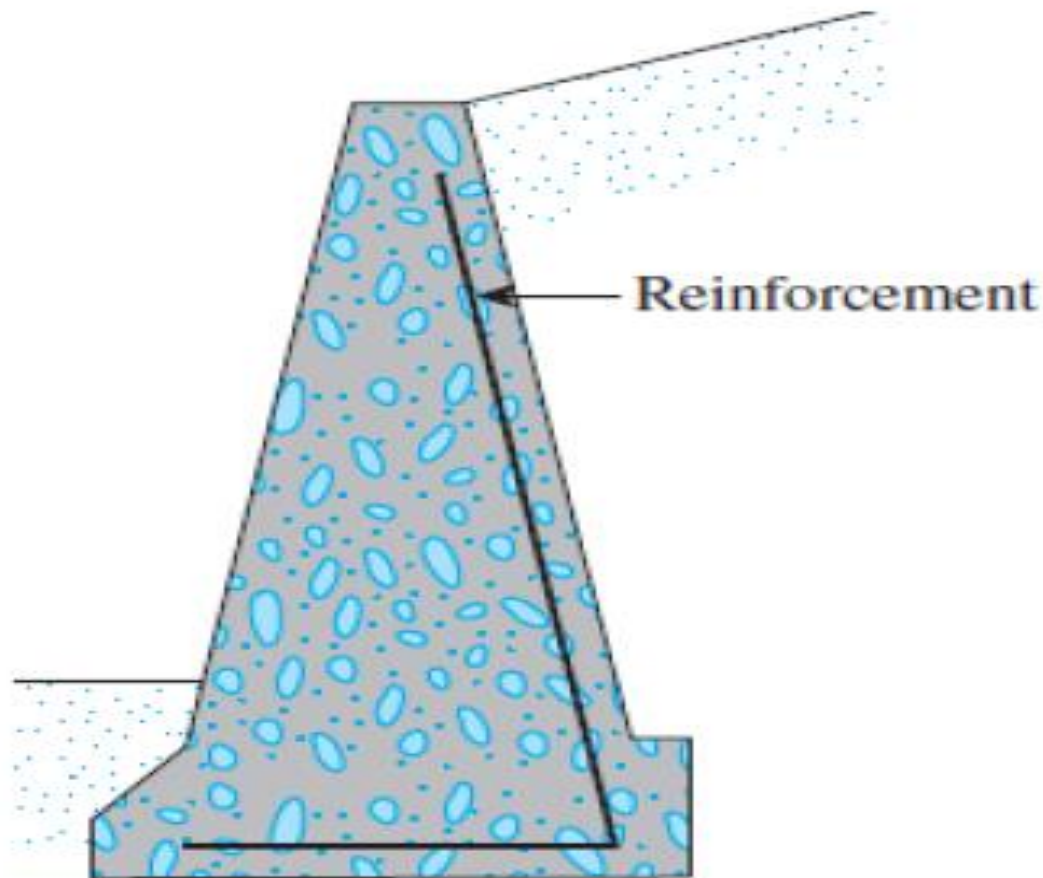
Gravity retaining walls (Figure a) are constructed with plain concrete or stone masonry. They depend for stability on their own weight and any soil resting on the masonry. This type of construction is not economical for high walls.



(a) Gravity wall

(2) Semi-gravity retaining walls

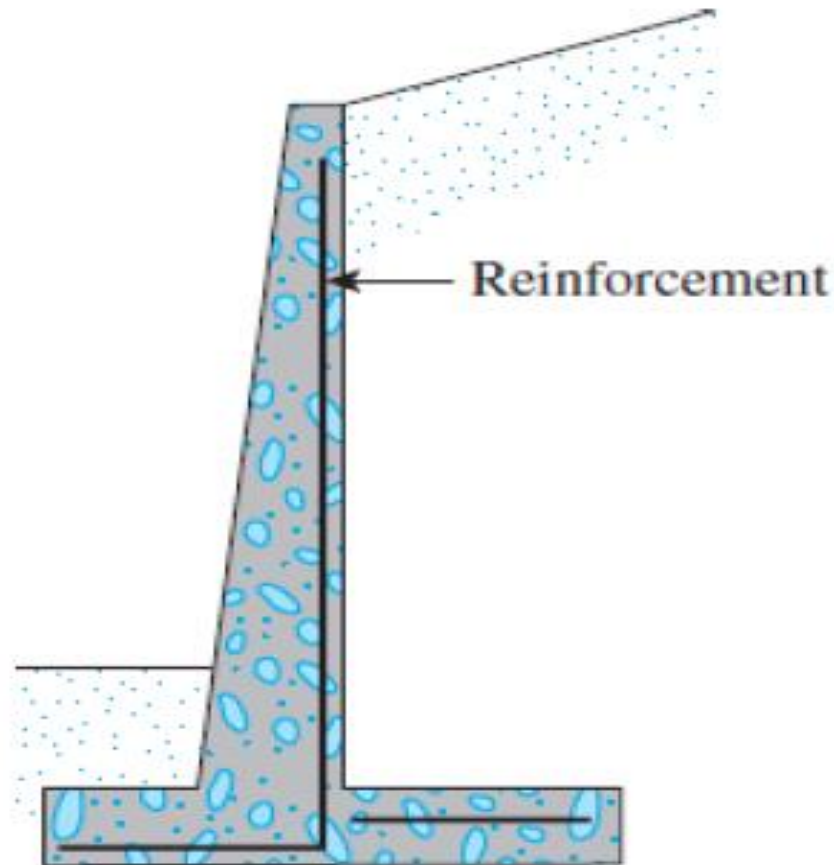
In many cases, a small amount of steel may be used for the construction of gravity walls, thereby minimizing the size of wall sections. Such walls are generally referred to as semi-gravity walls (Figure b).



(b) Semigravity wall

(3) Cantilever retaining walls

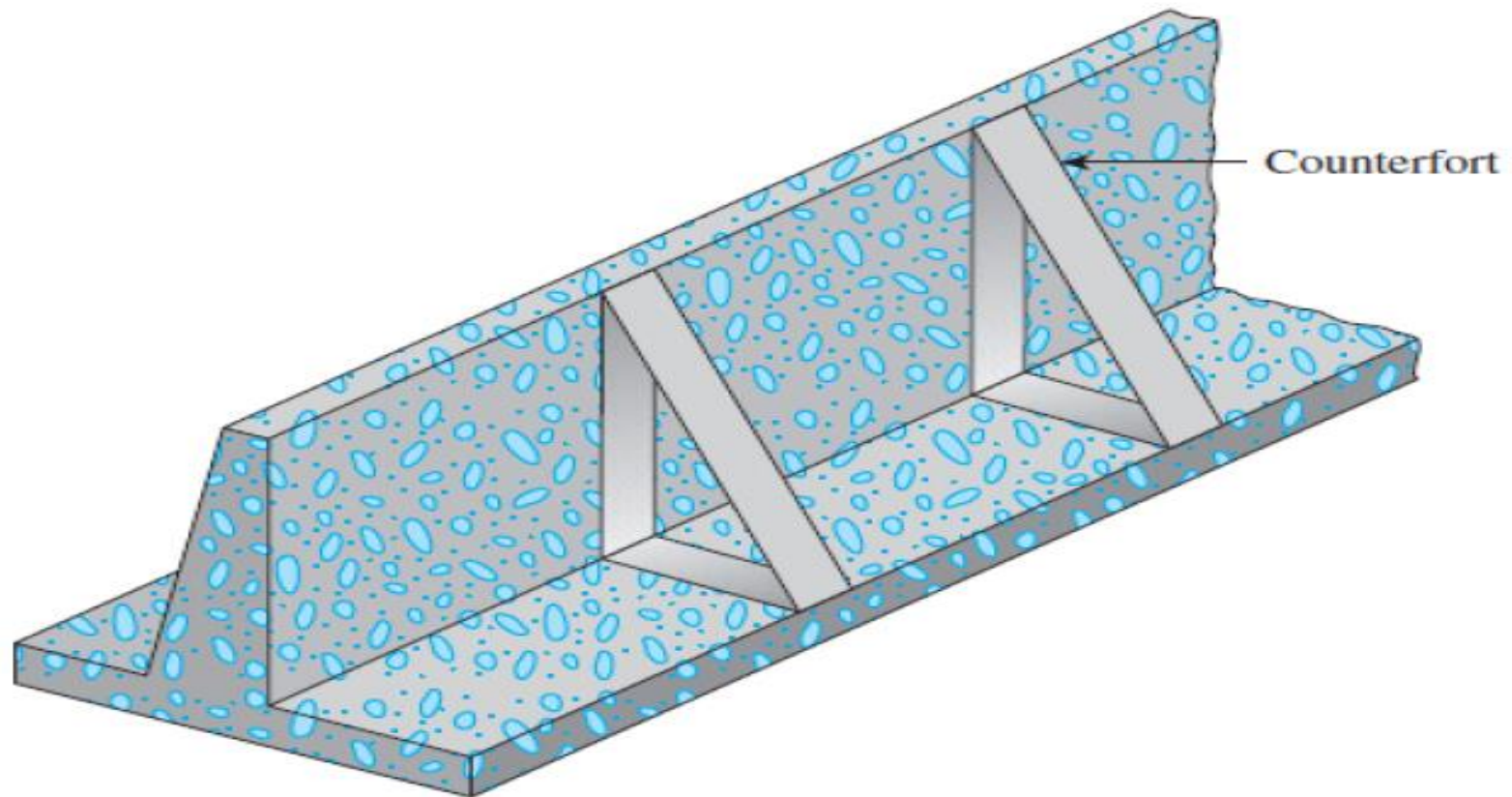
Cantilever retaining walls (Figure c) are made of reinforced concrete that consists of a thin stem and a base slab. This type of wall is economical to a height of about 8 m (25 ft).



(c) Cantilever wall

(4) Counterfort retaining walls

Counterfort retaining walls (Figure d) are similar to cantilever walls. At regular intervals, however, they have thin vertical concrete slabs known as counterforts that tie the wall and the base slab together. The purpose of the counterforts is to reduce the shear and the bending moments.

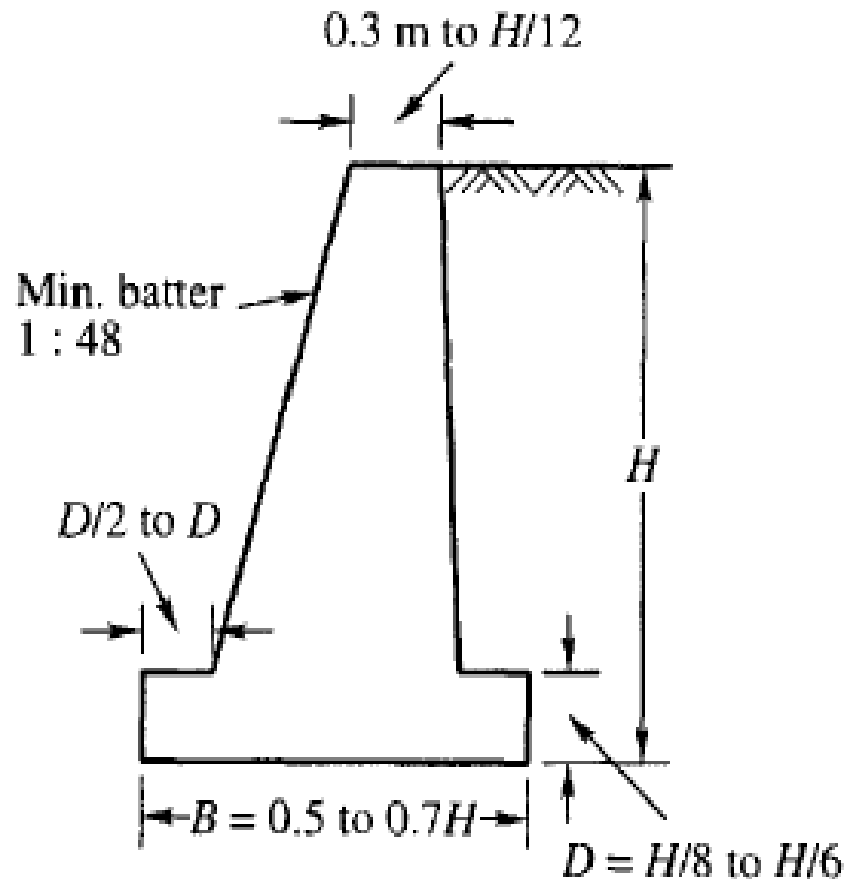


(d) Counterfort wall

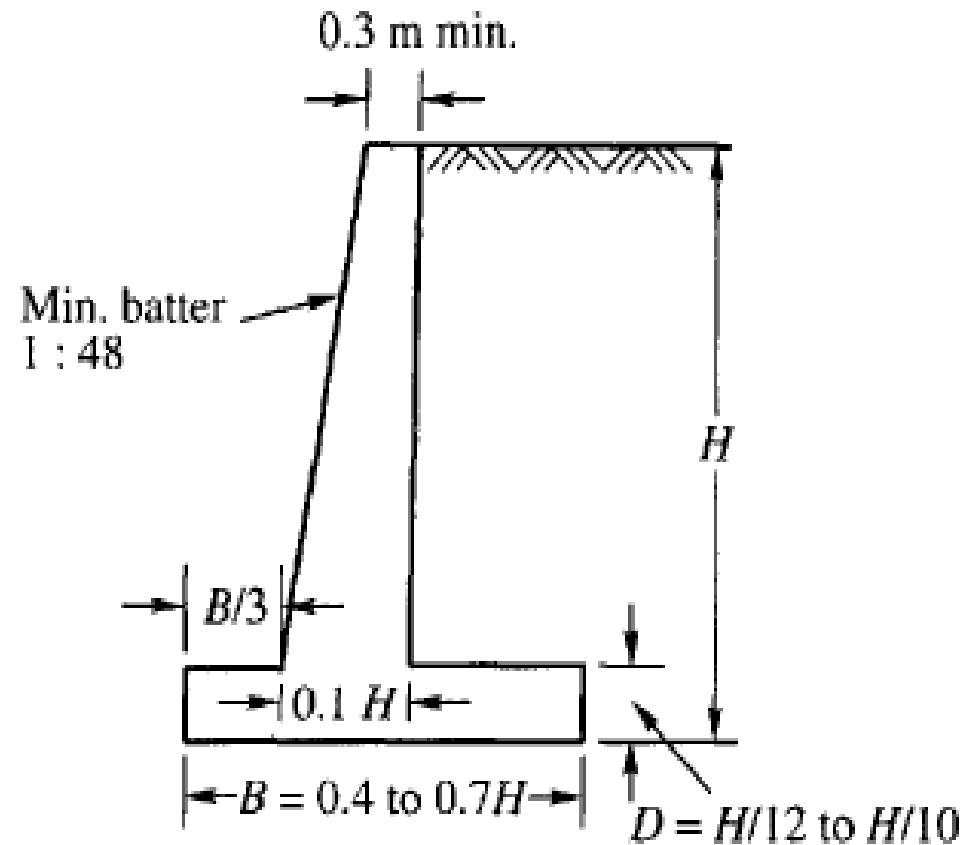
To design retaining walls properly, an engineer must know the basic parameters –the unit weight, angle of friction, and cohesion– of the soil retained behind the wall and the soil below the base slab. Knowing the properties of the soil behind the wall enables the engineer to determine the lateral pressure distribution that has to be designed for.

PROPORTIONING OF RETAINING WALLS

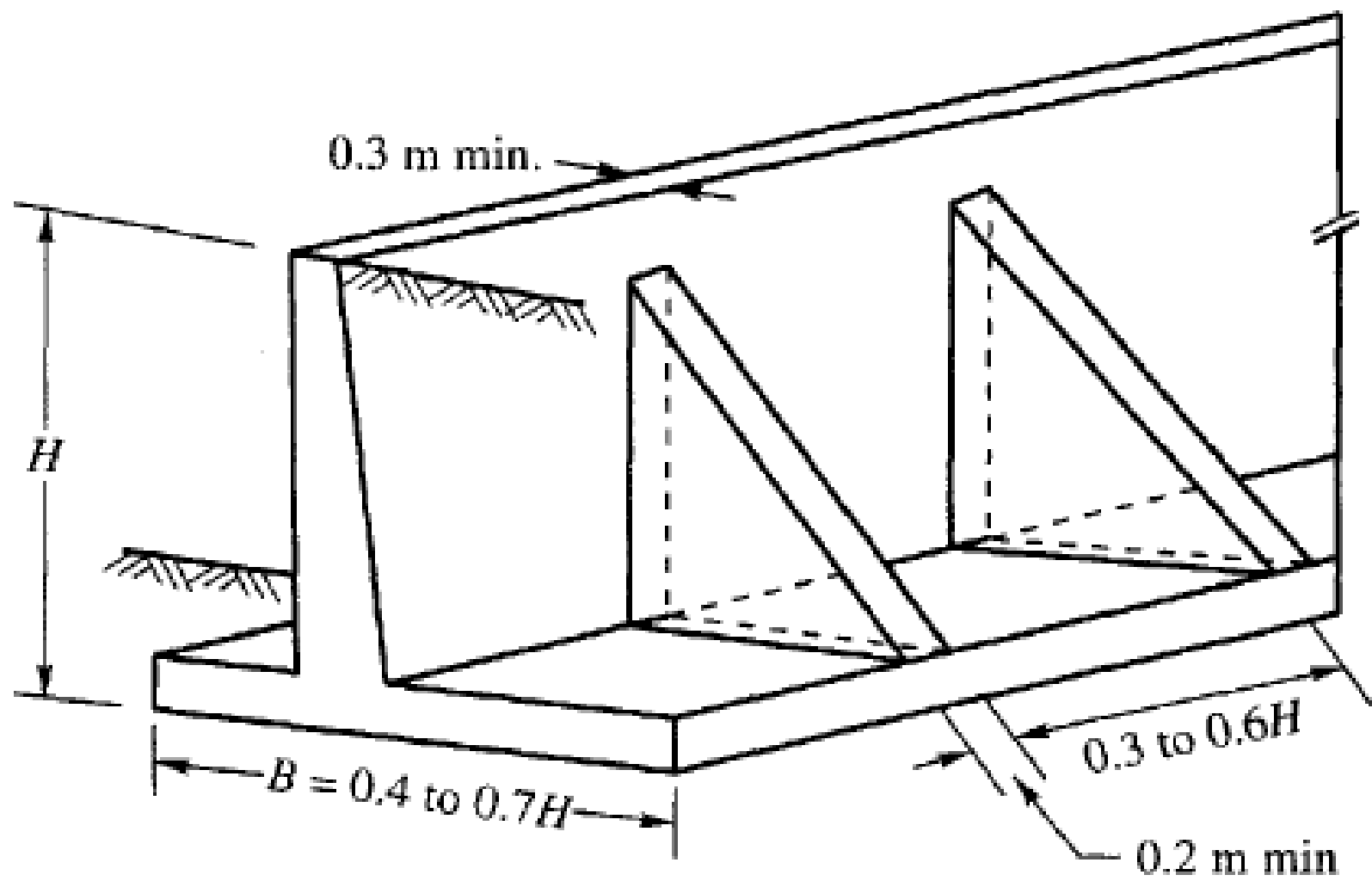
The common dimensions used for the various types of retaining walls are given below.



(a) Gravity wall



(b) Cantilever wall



(c) Counterfort wall

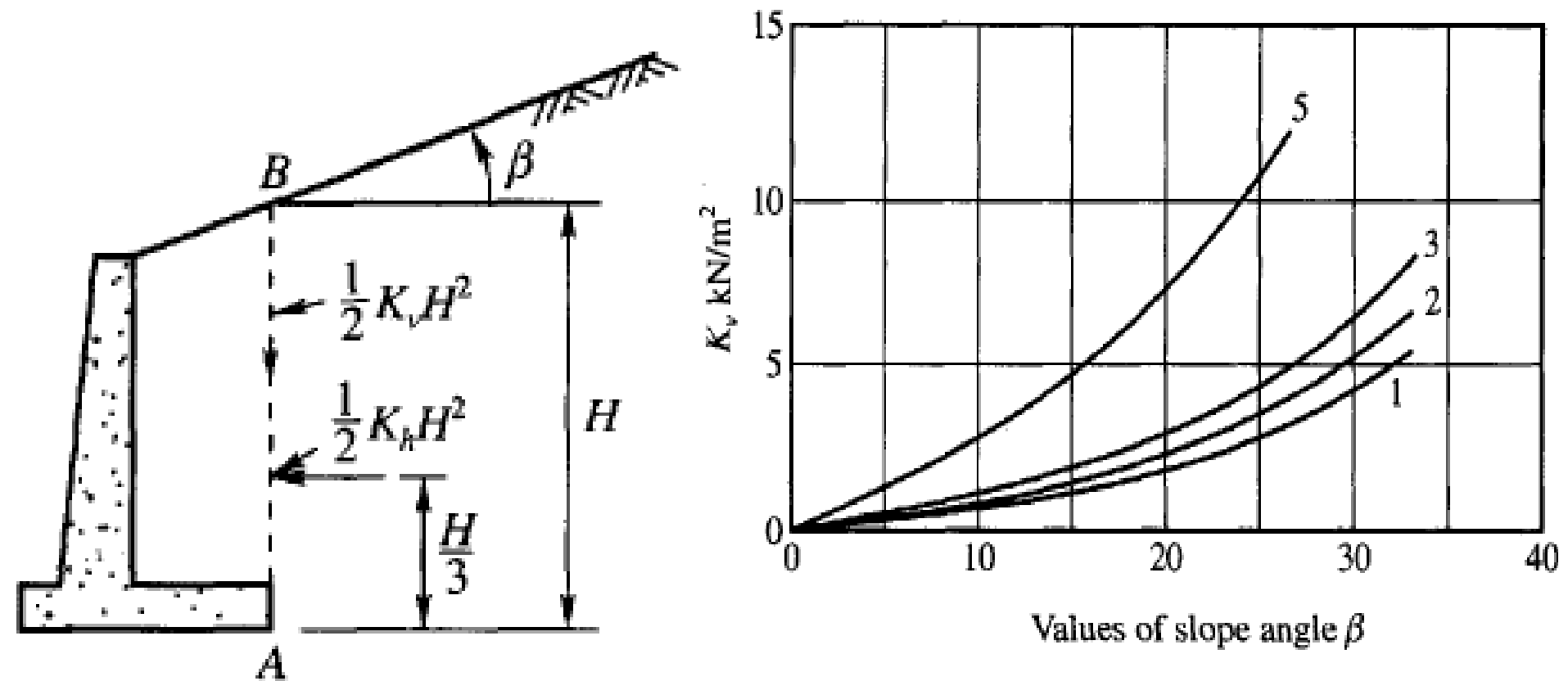
TYPES OF BACKFILL FOR RETAINING WALLS

<u>Type</u>	<u>Backfill material</u>
1	Coarse-grained soil without admixture of fine soil particles, very permeable (clean sand or gravel)
2	Coarse-grained soil of low permeability due to admixture of particles of silt size
3	Residual soil with stones fine silty sand, and granular materials with conspicuous clay content
4	Very soft or soft clay, organic silts or silty clays
5	Medium or stiff clay

EARTH PRESSURE CHARTS FOR RETAINING WALLS

Charts have been developed for estimating lateral earth pressures on retaining walls based on certain assumed soil properties of the backfill materials.

Chart for estimating pressure of backfill against retaining walls supporting backfills with a plane surface.



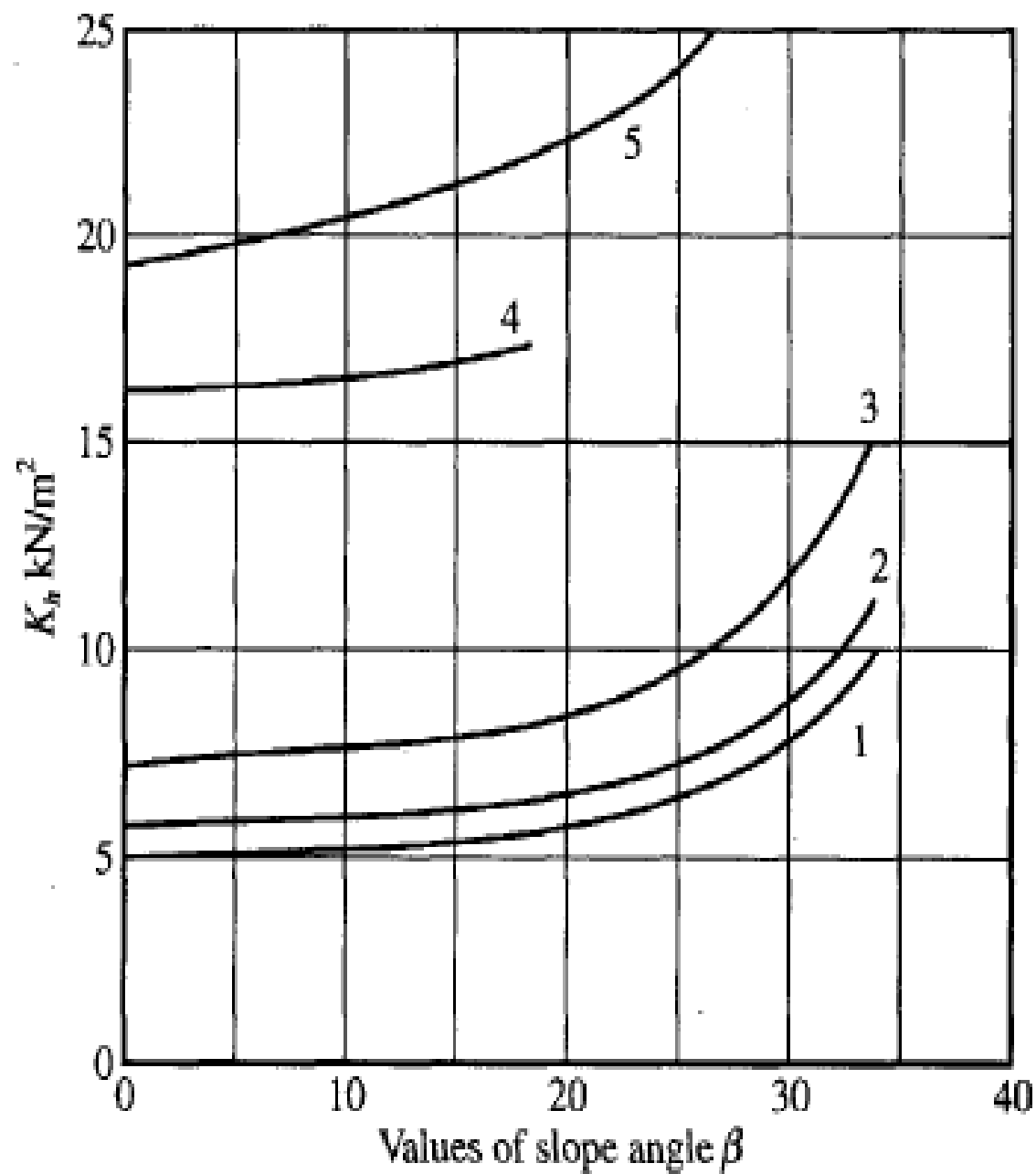
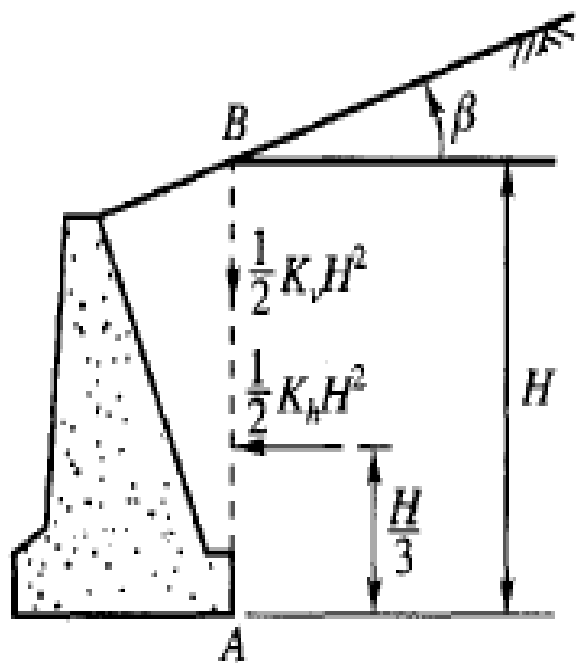
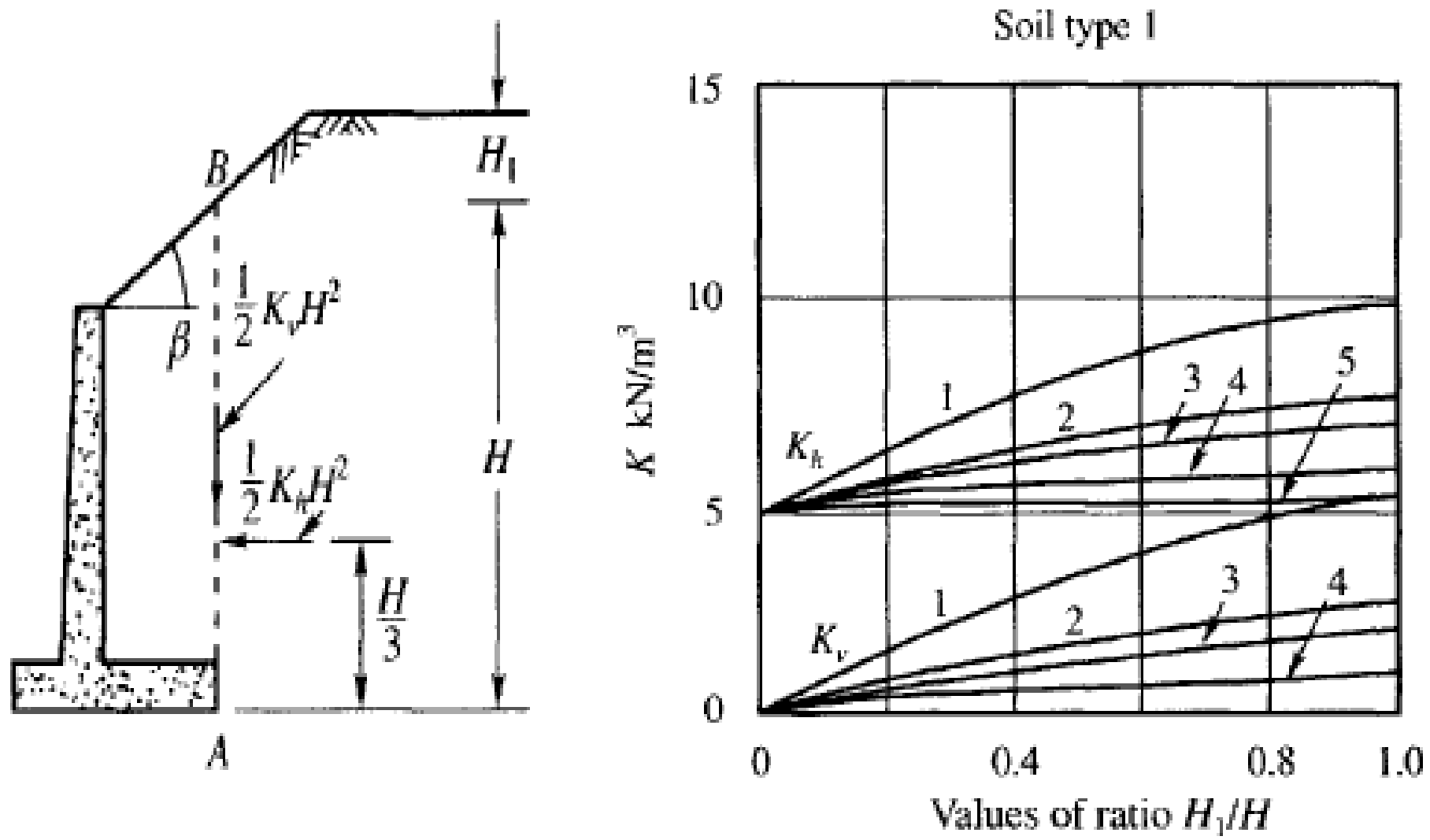
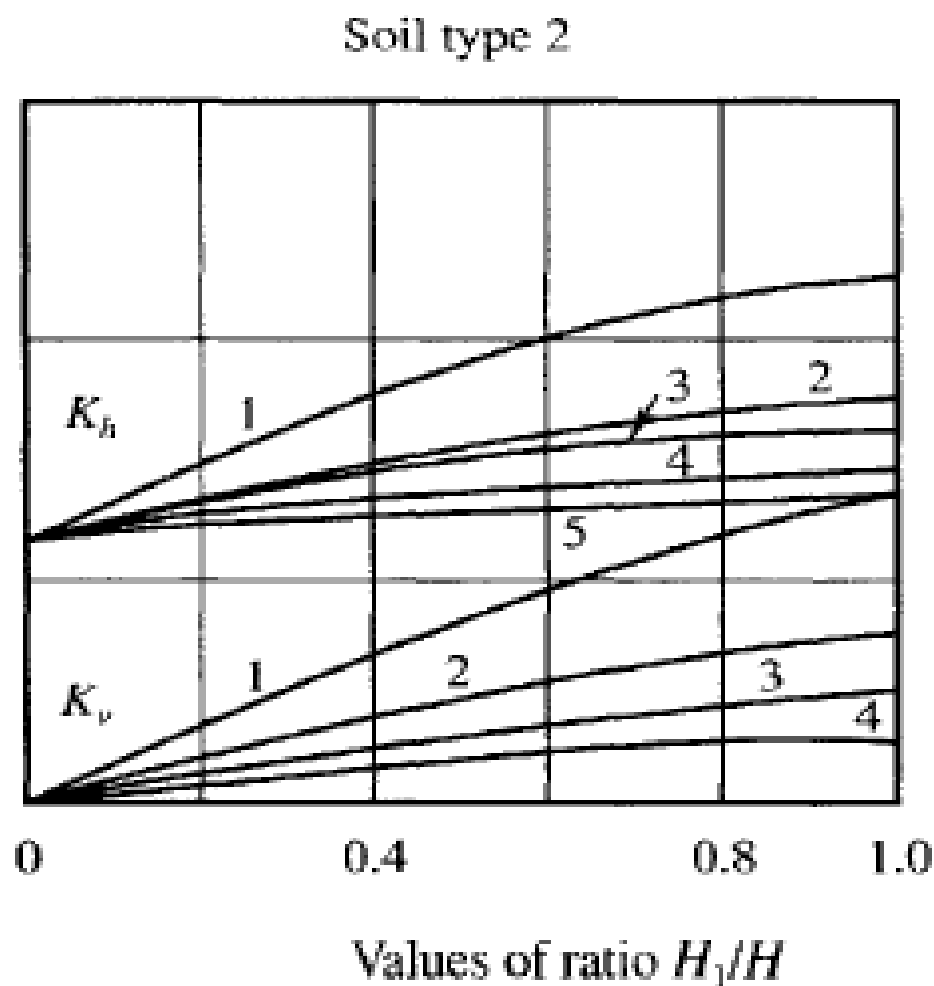
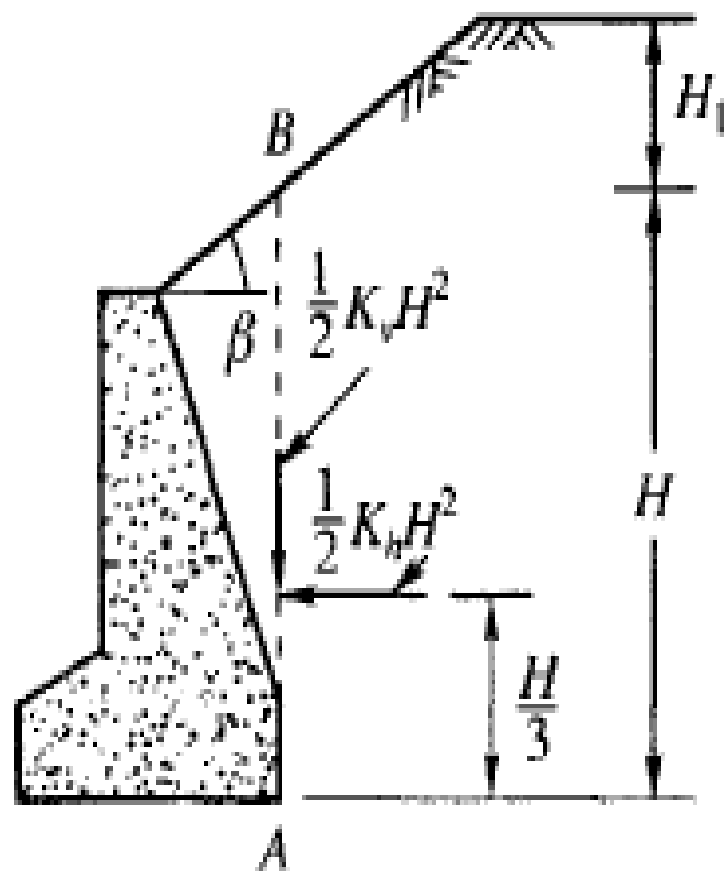
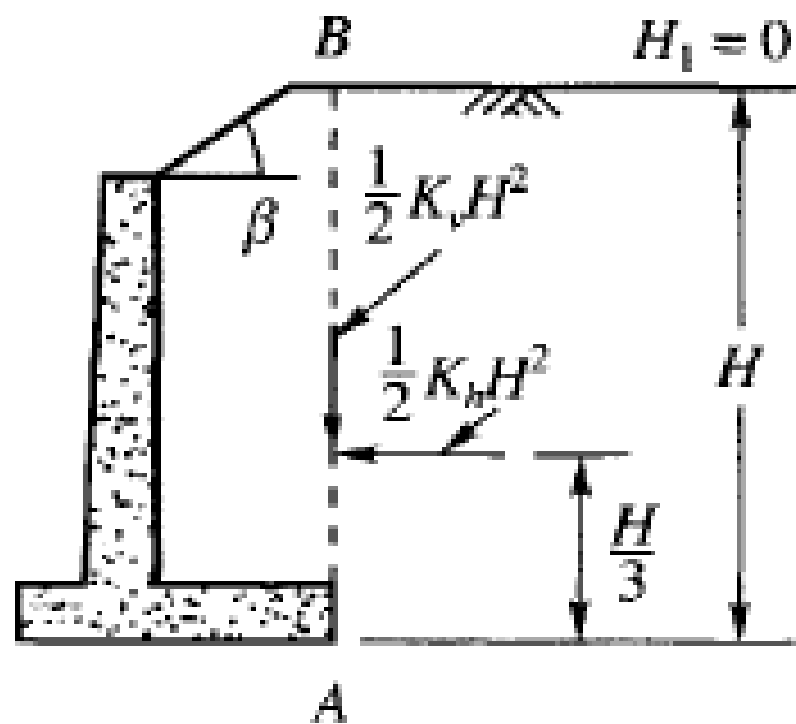


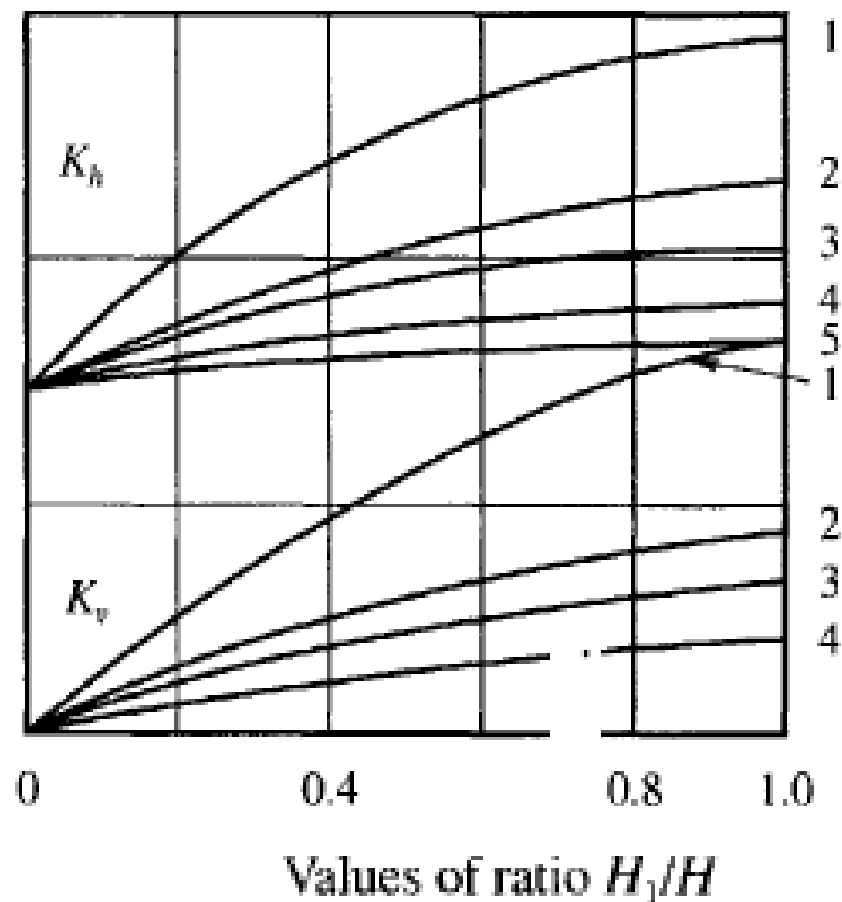
Chart for estimating pressure of backfill against retaining walls supporting backfills with a surface that slopes upward from the crest of the wall for limited distance and then becomes horizontal.



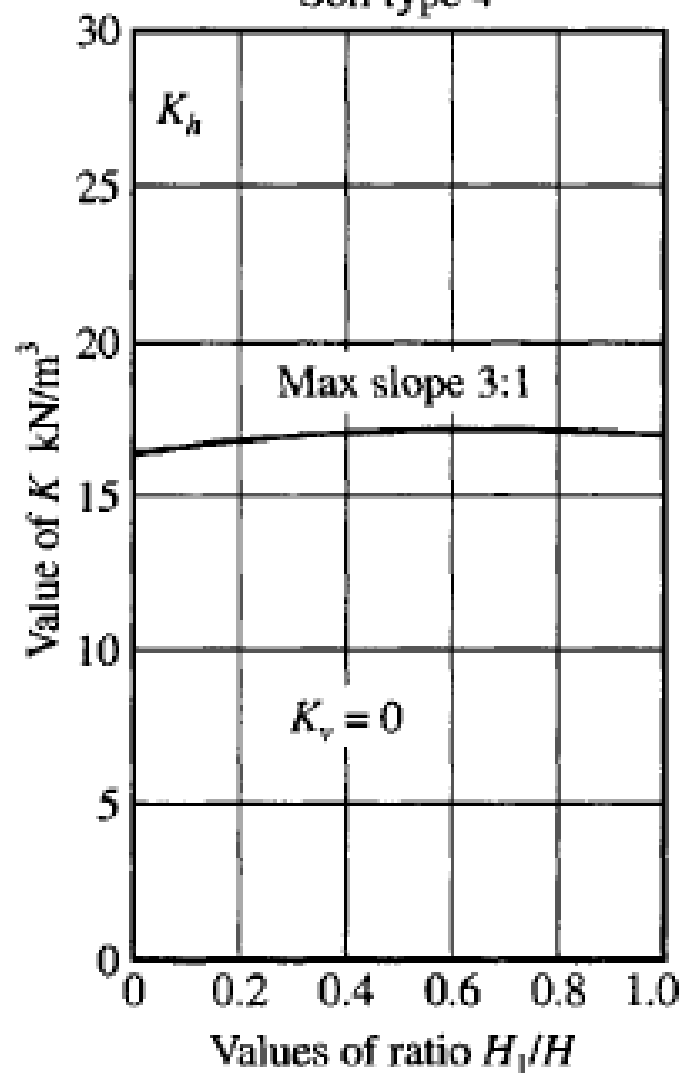




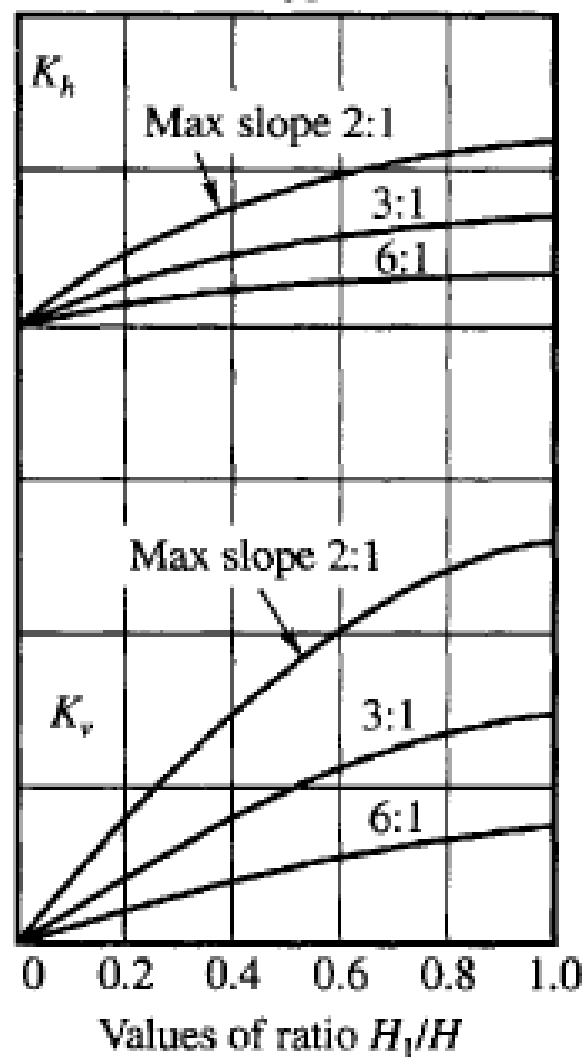
Soil type 3



Soil type 4



Soil type 5

**Note:**

Numerals on curves indicate the following slopes

No.	Slope
1	1.5:1
2	1.75:1
3	2:1
4	3:1
5	6:1

$$P_v = \frac{1}{2} K_v H^2$$

Values of K_h and K_v are plotted against slope angle β and the ratio H_1/H

STABILITY OF RETAINING WALLS

The stability of retaining walls should be checked for the following conditions:

1. Check for sliding
2. Check for overturning
3. Check for bearing capacity failure
4. Check for base shear failure

The minimum factors of safety for the stability of the wall are:

1. Factor of safety against sliding = 1.5
2. Factor of safety against overturning = 2.0
3. Factor of safety against bearing capacity failure = 3.0

Stability Analysis

Consider a cantilever wall with a sloping backfill for the purpose of analysis. The same principle holds for the other types of walls.

Fig. gives a cantilever wall with all the forces acting on the wall and the base, where

P_a = active earth pressure acting at a height $H/3$ over the base on section AB

P_h = $P_a \cos \beta$

P_v = $P_a \sin \beta$

β = slope angle of the backfill

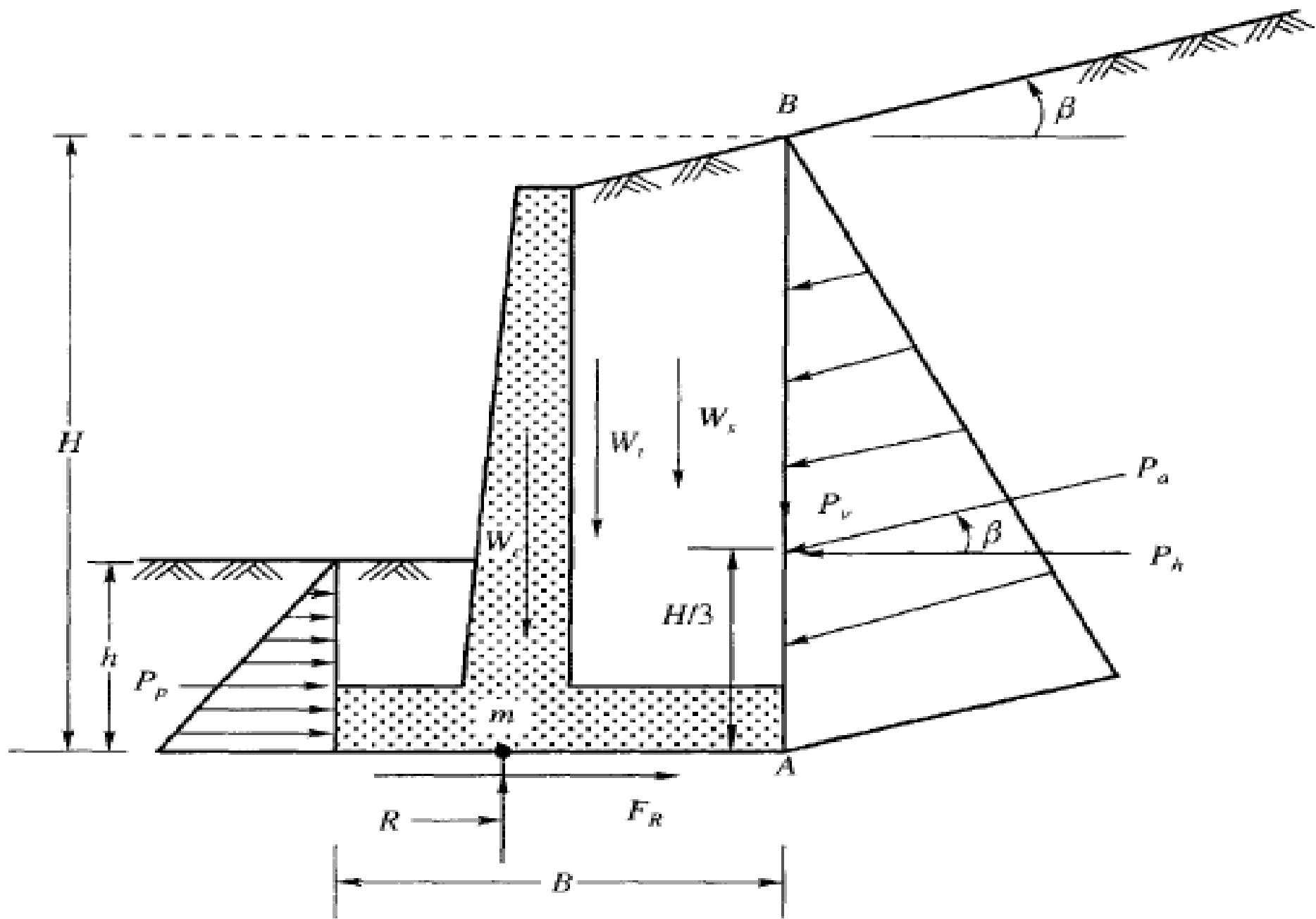
W_s = weight of soil

W_c = weight of wall including base

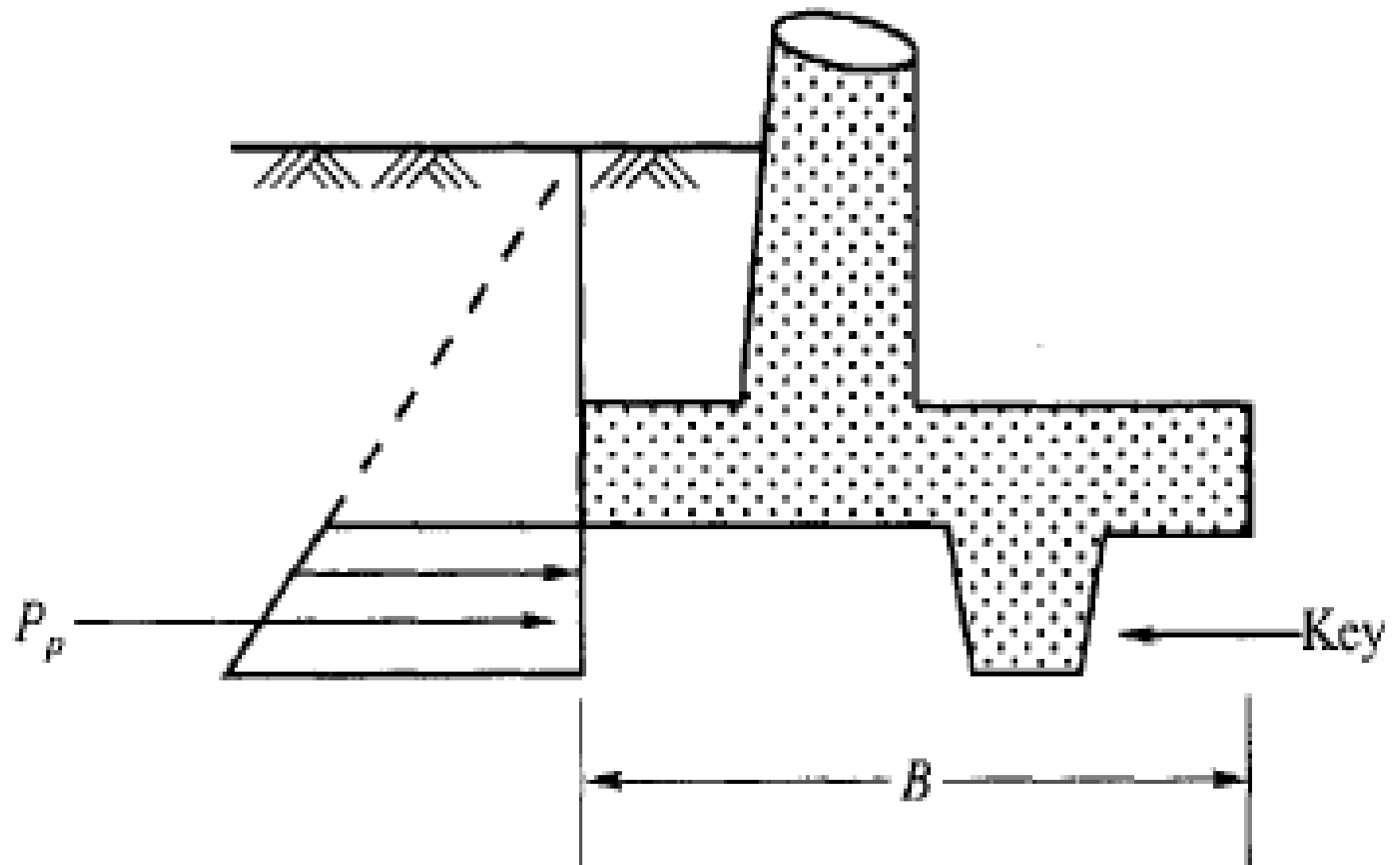
W_t = the resultant of W_s and W_c

P_p = passive earth pressure at the toe side of the wall.

F_R = base sliding resistance



(a) Forces acting on the wall



(b) Provision of key to increase sliding resistance

Check for Sliding

The force that moves the wall = horizontal force P_h

The force that resists the movement is

$$F_R = c_a B + R \tan \delta + P_p$$

$$R = \text{total vertical force} = W_s + W_c + P_v,$$

$$\delta = \text{angle of wall friction}$$

$$c_a = \text{unit adhesion}$$

If the bottom of the base slab is rough, as in the case of concrete poured directly on soil, the coefficient of friction is equal to $\tan \phi$, ϕ being the angle of internal friction of the soil.

The factor of safety against sliding is

$$F_s = \frac{F_R}{P_h} \geq 1.5$$

In case $F_s < 1.5$, additional factor of safety can be provided by constructing one or two keys at the base level shown in Fig. The passive pressure P in front of the wall should not be relied upon unless it is certain that the soil will always remain firm and undisturbed.

CHECK FOR OVERTURNING

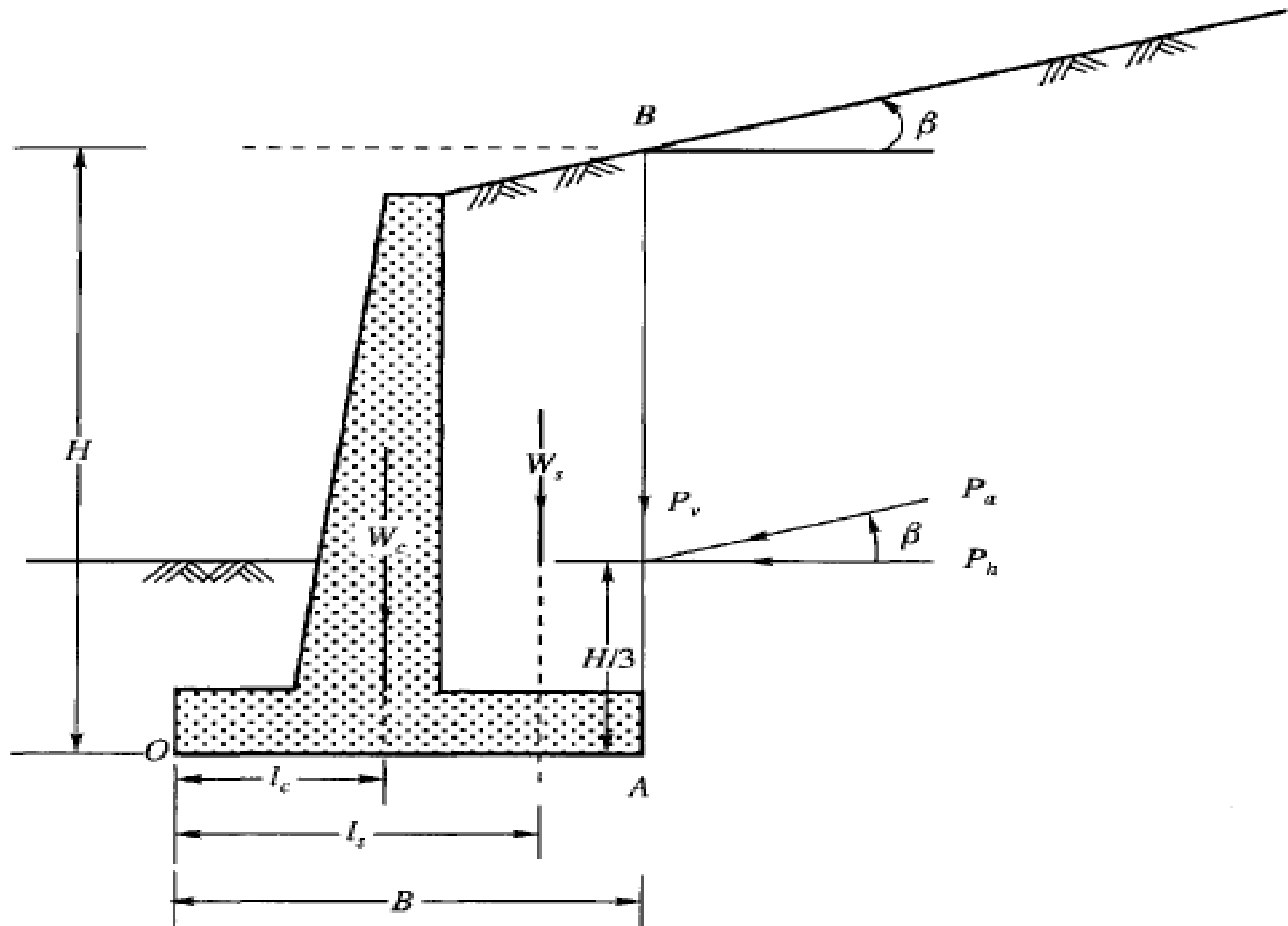
The forces acting on the wall are shown in Fig. The overturning and stabilizing moments may be calculated by taking moments about point O.

The factor of safety against overturning is therefore

$$F_o = \frac{\text{Sum of moments that resist overturning}}{\text{Sum of overturning moments}} = \frac{M_R}{M_o}$$

$$F_o = \frac{W_c l_c + W_s l_s + P_v B}{P_h (H/3)}$$

where F_o should not be less than 2.0.



Check for Bearing Capacity Failure

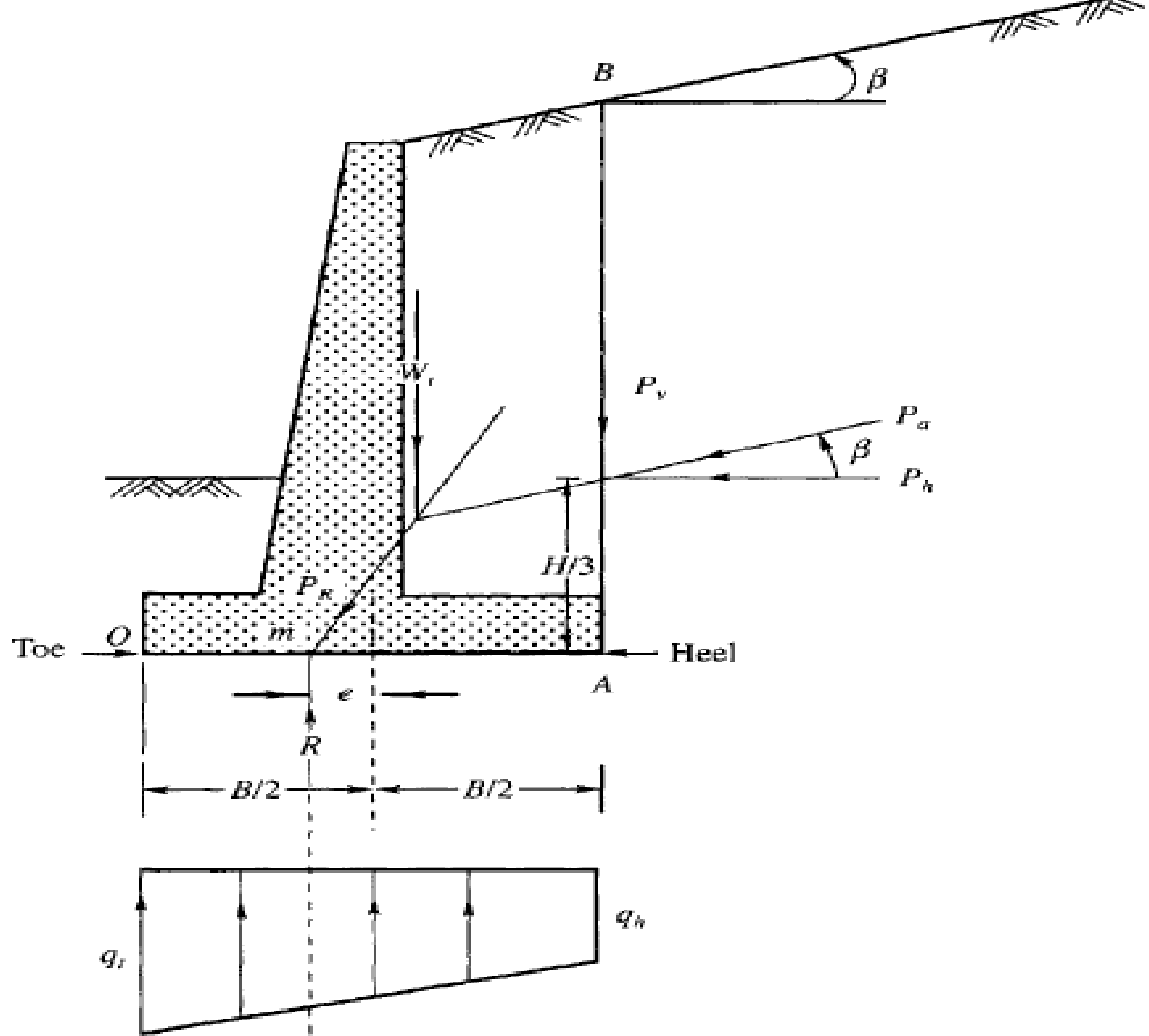
In Fig. W_c is the resultant of W_s and W_c . P_R is the resultant of P_a and W_f and P_R meets the base at m . R is the resultant of all the vertical forces acting at m with an eccentricity e .

Fig. shows the pressure distribution at the base with a maximum q_t at the toe and a minimum q_h at the heel.

An expression for e may be written as

$$e = \frac{B}{2} - \frac{(M_R - M_o)}{\Sigma V}$$

where $R = \Sigma V$ = sum of all vertical forces



The values of q_t and q_h may be calculated by making use of the equations

$$q_t = \frac{R}{B} \left[1 + \frac{6e}{B} \right] = q_a \left[1 + \frac{6e}{B} \right]$$

$$q_h = q_a \left[1 - \frac{6e}{B} \right]$$

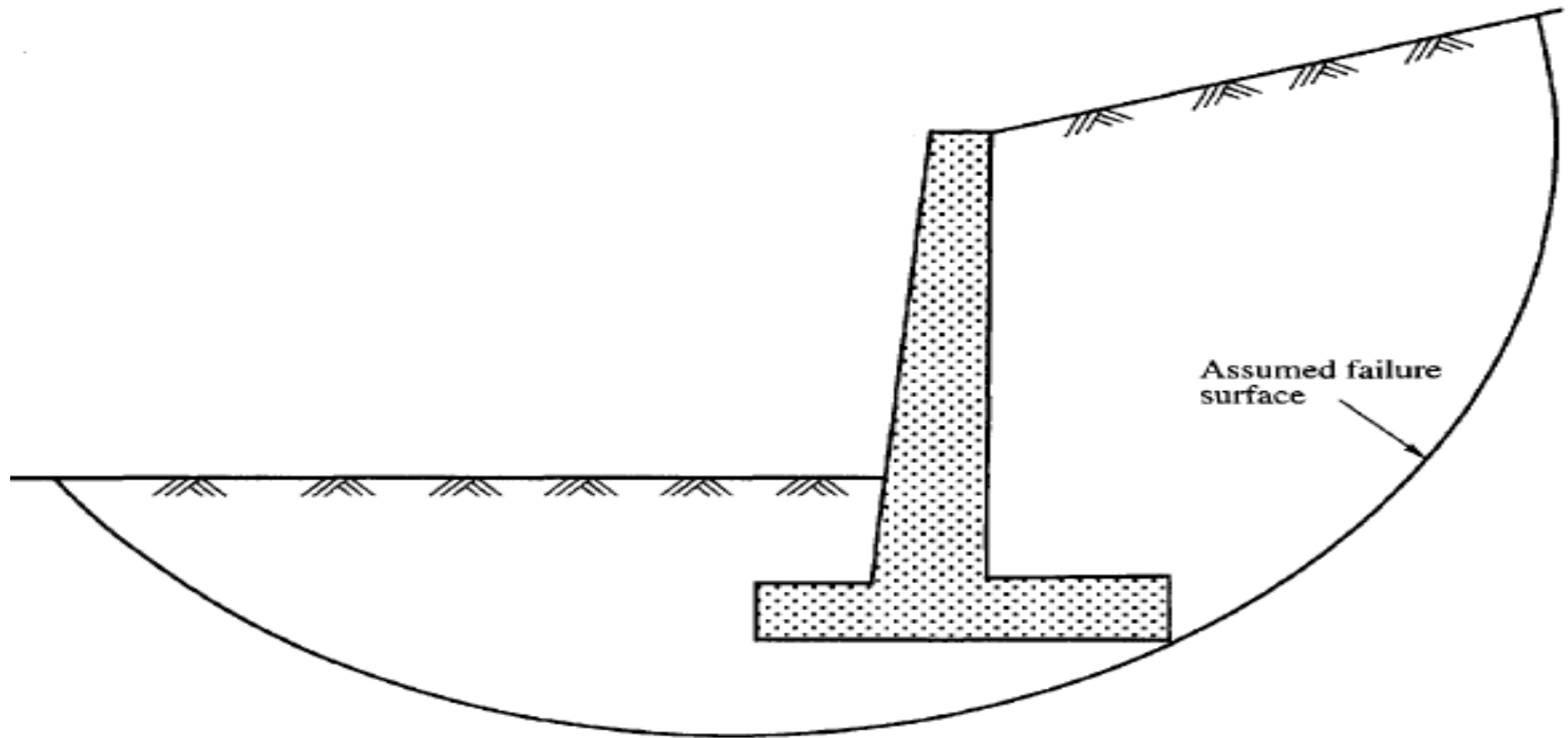
where, $q_a = R/B$ = allowable bearing pressure.

The ultimate bearing capacity q_u may be determined by taking into account the eccentricity. It must be ensured that

$$q_t \leq \frac{q_u}{F_s} = \frac{q_u}{3}$$

BASE FAILURE OF FOUNDATION

If the base soil consists of medium to soft clay, a circular slip surface failure may develop as shown in Fig. Such stability problems may be analyzed either by the method of slices or any other method.

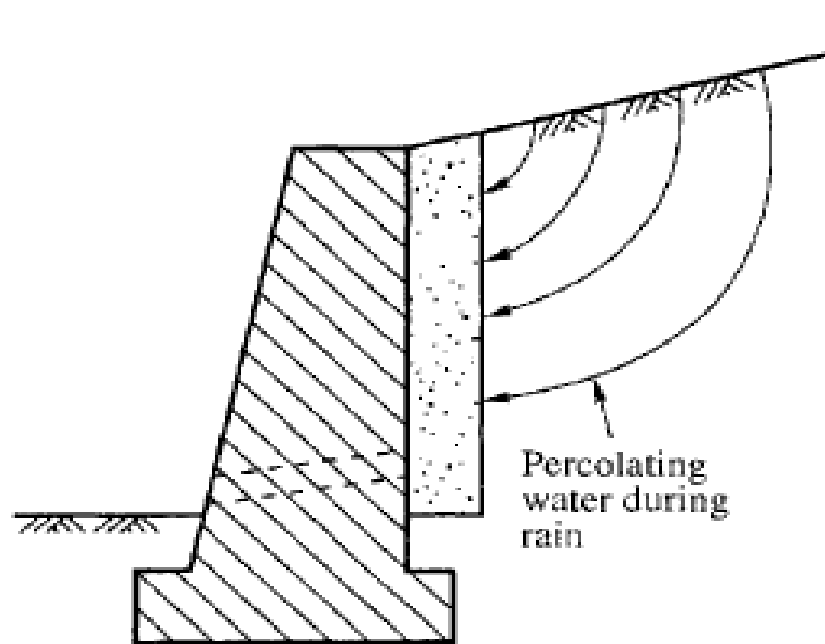


Stability against base slip surface shear failure

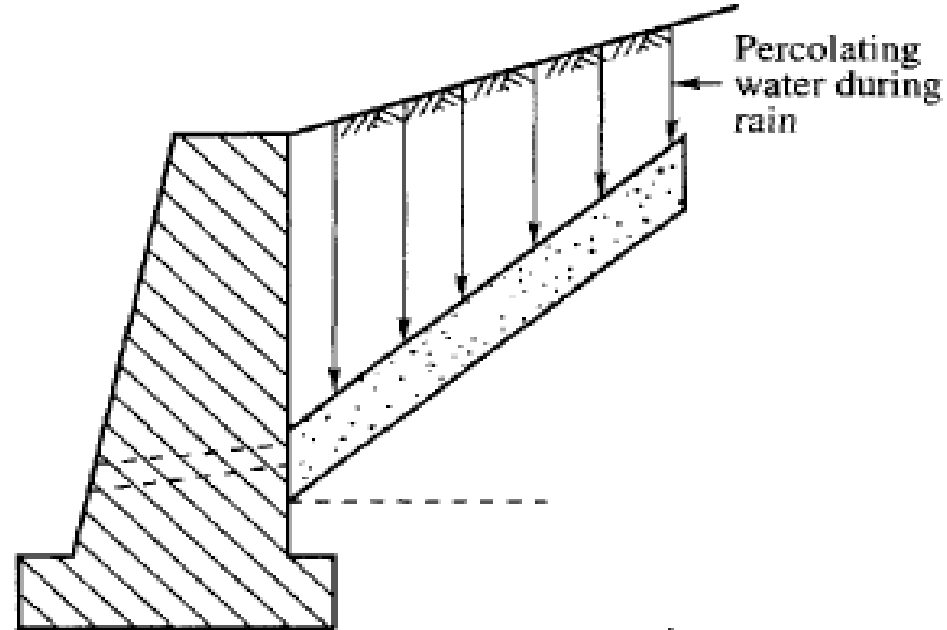
DRAINAGE PROVISION FOR RETAINING WALLS

The saturation of the backfill of a retaining wall is always accompanied by a substantial hydrostatic pressure on the back of the wall. Saturation of the soil increases the earth pressure by increasing the unit weight. It is therefore essential to eliminate or reduce pore pressure by providing suitable drainage.

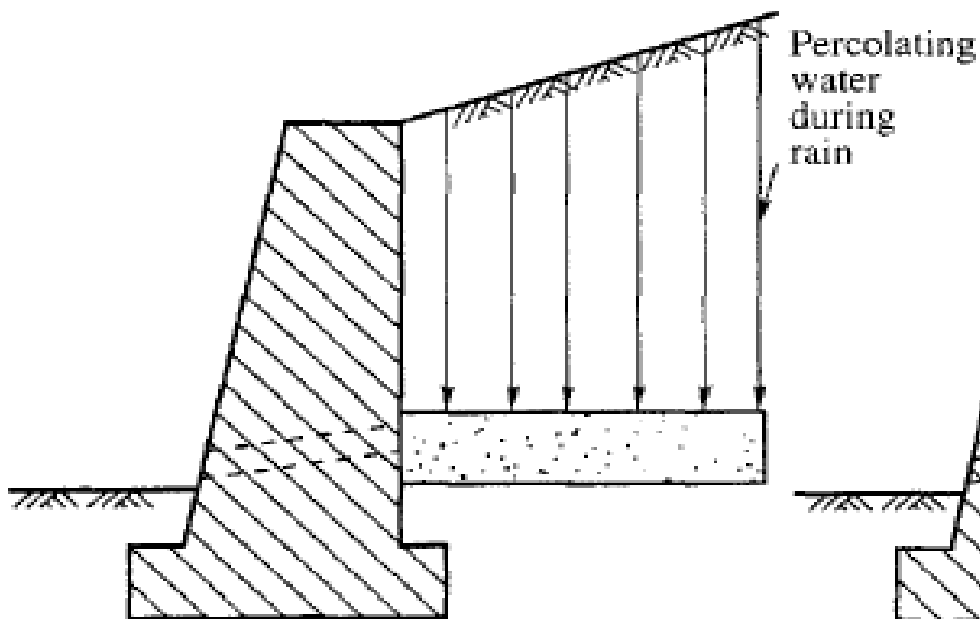
Four types of drainage are given in Fig. The drains collect the water that enters the backfill and this may be disposed of through outlets in the wall called weep holes. The graded filter material should be properly designed to prevent clogging by fine materials. The present practice is to use geotextiles or geogrids.



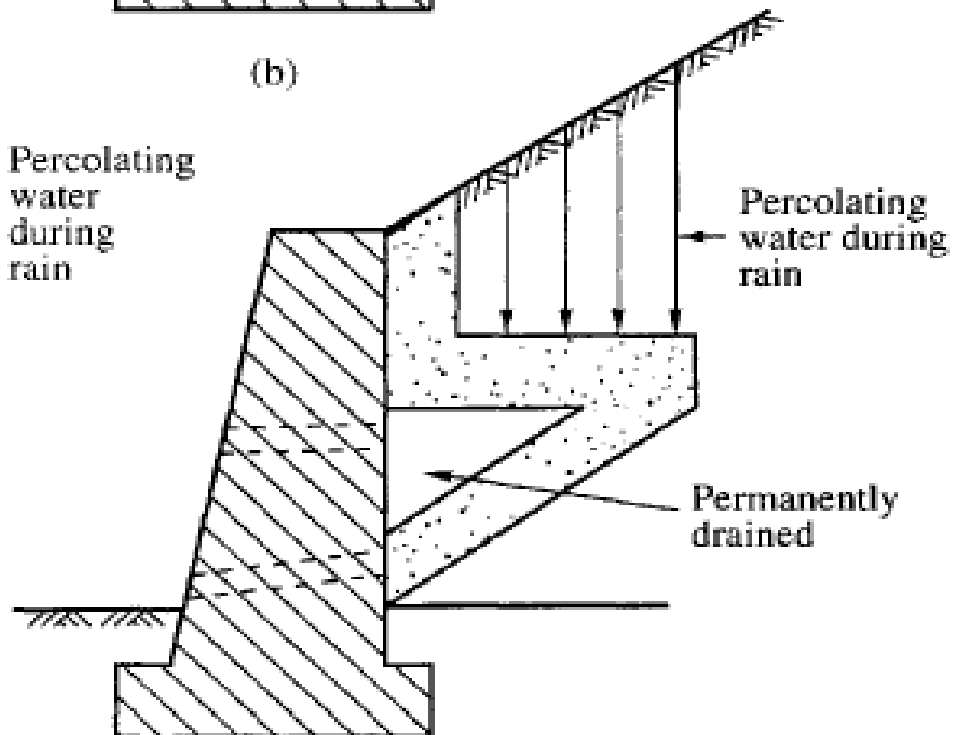
(a)



(b)



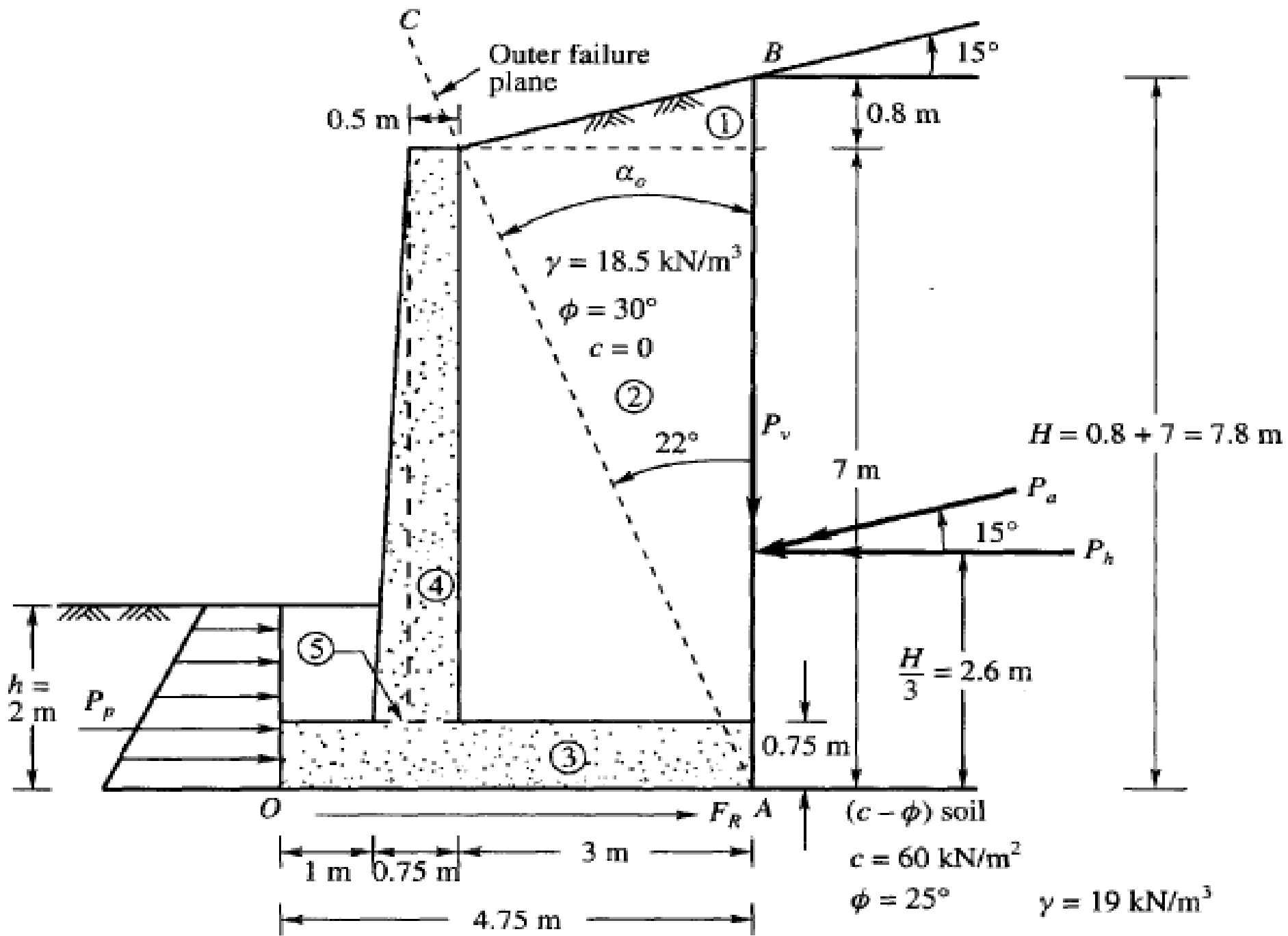
(c)



(d)

Example

Figure shows a section of a cantilever wall with dimensions and forces acting thereon. Check the stability of the wall with respect to (a) overturning, (b) sliding, and (c) bearing capacity.



Solution

Check for Rankine's condition

$$\alpha_o = \frac{90 - \phi}{2} - \frac{\varepsilon - \beta}{2}$$

$$\text{where } \sin \varepsilon = \frac{\sin \beta}{\sin \phi} = \frac{\sin 15^\circ}{\sin 30^\circ} = 0.5176$$

$$\text{or } \varepsilon \approx 31^\circ$$

$$\alpha_o = \frac{90 - 30}{2} - \frac{31 - 15}{2} = 22^\circ$$

The outer failure line AC is drawn making an angle 22° with the vertical AB . Since this line does not cut the wall Rankine's condition is valid in this case.

Rankine active pressure

Height of wall = $AB = H = 7.8$ m

$$P_a = \frac{1}{2} \gamma H^2 K_A$$

where $K_A = \tan^2(45^\circ - \phi / 2) = \frac{1}{3}$

substituting

$$P_a = \frac{1}{2} \times 18.5 \times (7.8)^2 \times \frac{1}{3} = 187.6 \text{ kN / m of wall}$$

$$P_h = P_a \cos \beta = 187.6 \cos 15^\circ = 181.2 \text{ kN / m}$$

$$P_v = P_a \sin \beta = 187.6 \sin 15^\circ = 48.6 \text{ kN / m}$$

CHECK FOR OVERTURNING

The forces acting on the wall in Fig are shown. The overturning and stabilizing moments may be calculated by taking moments about point O.

The whole section is divided into 5 parts as shown in the figure. Let these forces be represented by $W_1, W_2, \dots, W_5$ and the corresponding lever arms as $l_1, l_2, \dots, l_5$. ***Assume the weight of concrete $\gamma_c = 24 \text{ kN/m}^3$.***

The equation for the resisting moment is

$$M_R = w_1 l_1 + w_2 l_2 + \dots + w_5 l_5$$

The overturning moment is

$$M_o = P_h \frac{H}{3}$$

The details of calculations are tabulated below.

Section No.	Area (m ²)	Unit weight kN/m ³	Weight kN/m	Lever arm(m)	Moment kN-m
1	1.20	18.5	22.2	3.75	83.25
2	18.75	18.5	346.9	3.25	1127.40
3	3.56	24.0	85.4	2.38	203.25
4	3.13	24.0	75.1	1.50	112.65
5	0.78	24.0	18.7	1.17	21.88
			$P_v = 48.6$	4.75	230.85
			$\Sigma_v = 596.9$		$\Sigma_M = 1,779.3 = M_R$

$$M_O = 181.2 \times 2.6 = 471.12 \text{ kN-m}$$

$$F_s = \frac{M_R}{M_O} = \frac{1,779.3}{471.12} = 3.78 > 2.0 \quad \text{-- OK.}$$

CHECK FOR SLIDING

The force that resists the movement as per is

$$F_R = c_a B + R \tan \delta + P_p$$

where B = width = 4.75 m

$$c_a = \alpha c_u, \alpha = \text{adhesion factor} = 0.55$$

$$R = \text{total vertical force } \Sigma_v = 596.9 \text{ kN}$$

For the foundation soil:

$$\delta = \text{angle of wall friction} \approx \phi = 25^\circ$$

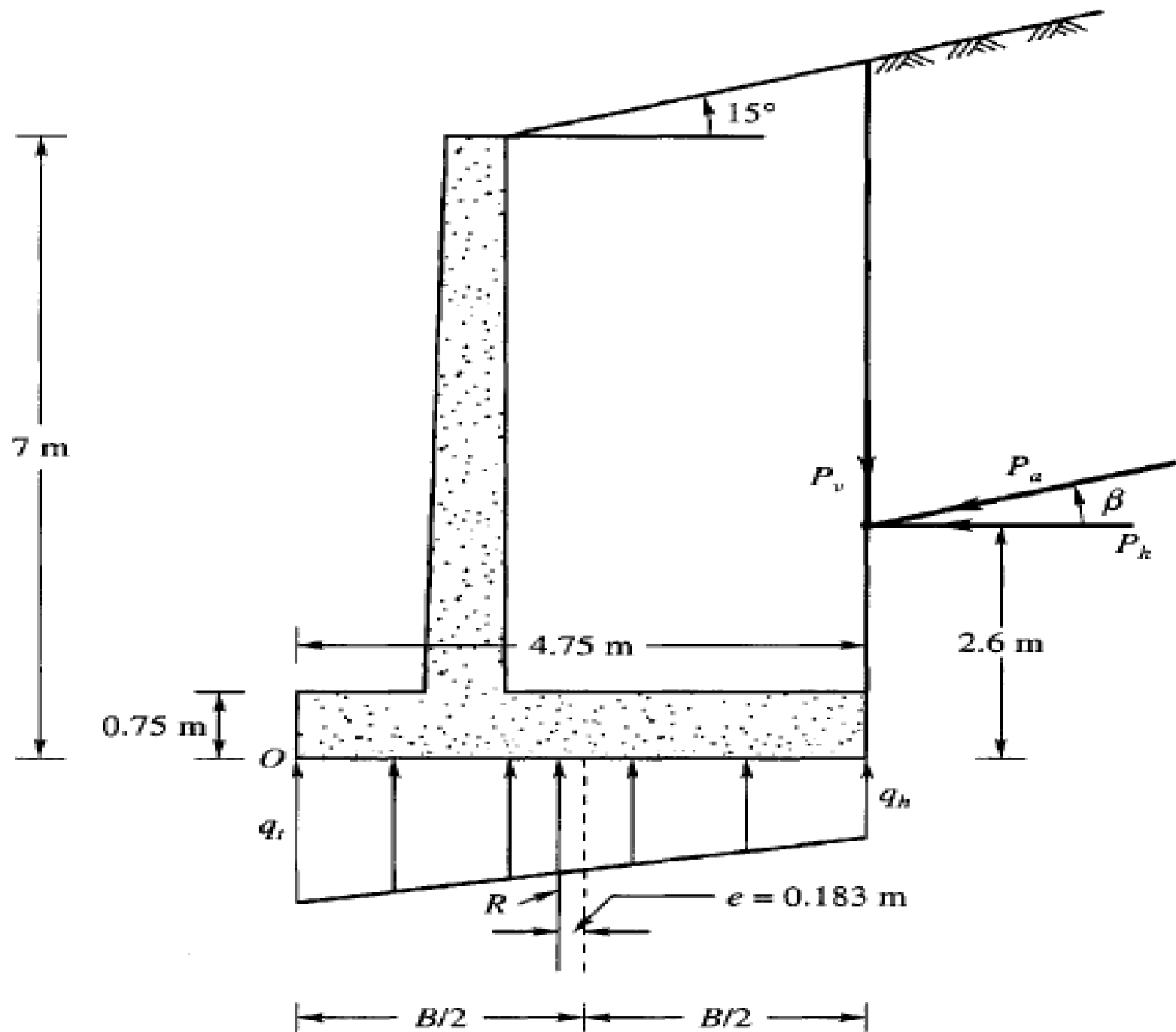
$$P_p = \frac{1}{2} \gamma h^2 K_p + 2ch\sqrt{K_p}$$

where $h = 2$ m, $\gamma = 19$ kN/m³, $c = 60$ kN/m²

$$K_p = \tan^2 (45^\circ + \phi/2) = \tan^2 (45^\circ + 25/2) = 2.46$$

substituting

$$P_p = \frac{1}{2} \times 19 \times 2^2 \times 2.46 + 2 \times 60 \times 2 \times \sqrt{2.46} = 470 \text{ kN/m}$$



$$F_R = 60 \times 4.75 + 596.9 \tan 25^\circ + 470 = 285 + 278 + 470 = 1033 \text{ kN/m}$$

$$P_h = 181.2 \text{ kN/m}$$

$$F_s = \frac{F_R}{P_h} = \frac{1033}{181.2} = 5.7 > 1.5 \quad \text{-- OK.}$$

Normally the passive earth pressure P_p is not considered in the analysis. By neglecting P_p , the factor of safety is

$$F_s = \frac{1033 - 470}{181.2} = \frac{563}{181.2} = 3.1 > 1.5 \quad \text{-- OK}$$

Check for bearing capacity failure (Fig.b)

From Eq. (b and c), the pressures at the toe and heel of the retaining wall may be written as

$$q_t = \frac{R}{B} \left[1 + \frac{6e}{B} \right]$$

$$q_h = \frac{R}{B} \left[1 - \frac{6e}{B} \right]$$

where e = eccentricity of the total load R ($= \Sigma V$) acting on the base. eccentricity e may be calculated.

$$e = \frac{B}{2} - \frac{(M_R - M_O)}{R} = \frac{4.75}{2} - \frac{(1,779.3 - 471.12)}{596.9} = 0.183 \text{ m}$$

$$\text{Now } q_t = \frac{596.9}{4.75} \left[1 + \frac{6 \times 0.183}{4.75} \right] = 154.7 \text{ kN/m}^2$$

$$q_h = \frac{596.9}{4.75} \left[1 - \frac{6 \times 0.183}{4.75} \right] = 96.6 \text{ kN/m}^2$$

The ultimate bearing capacity q_u may be determined . It has to be ensured that

$$q_t \leq \frac{q_u}{F_s}$$

where $F_s = 3$