Semester 2 2017/2018

DESIGN OF REINFORCED CONCRETE RETAINING WALL

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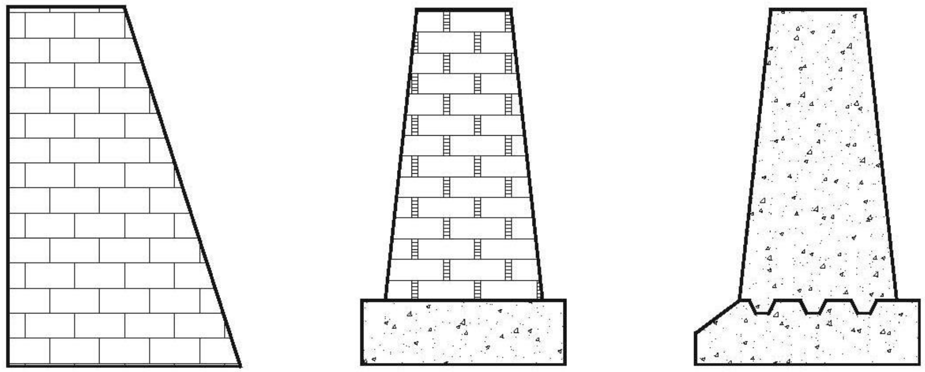
Introduction

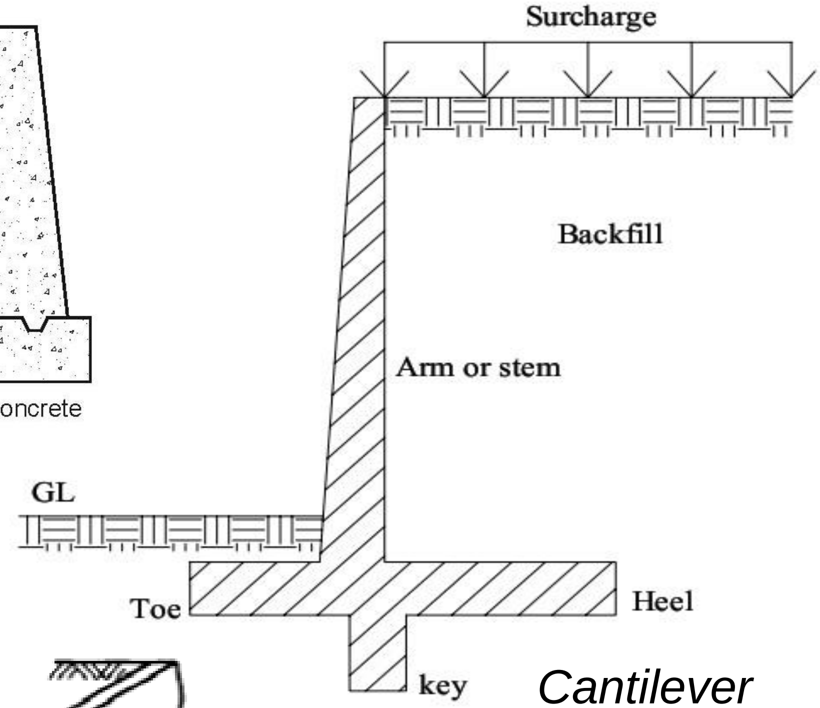
- Retaining walls are usually built to hold back soil mass.
- Retaining walls are structures that are constructed to retail soil or any such materials which are unable to stand vertically by themselves.
- They are also provided to maintain the grounds at two different levels.
- Types of retaining wall:
  - Gravity wall
  - Cantilever wall
  - Counterfort wall
  - Buttress wall
  - Piling wall (CBP)
  - Anchored wall

Introduction

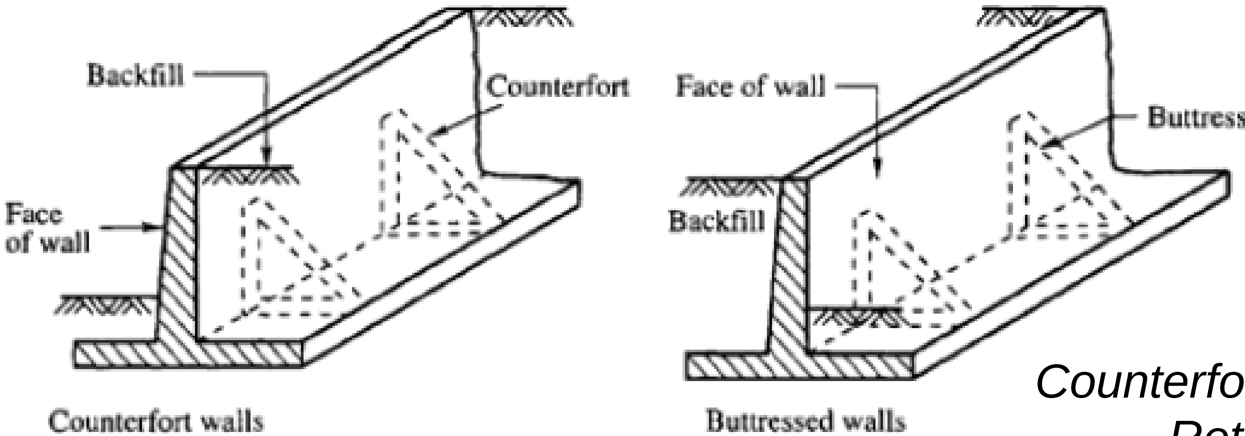
Introduction



Gravity Retaining Wall



Cantilever Retaining Wall



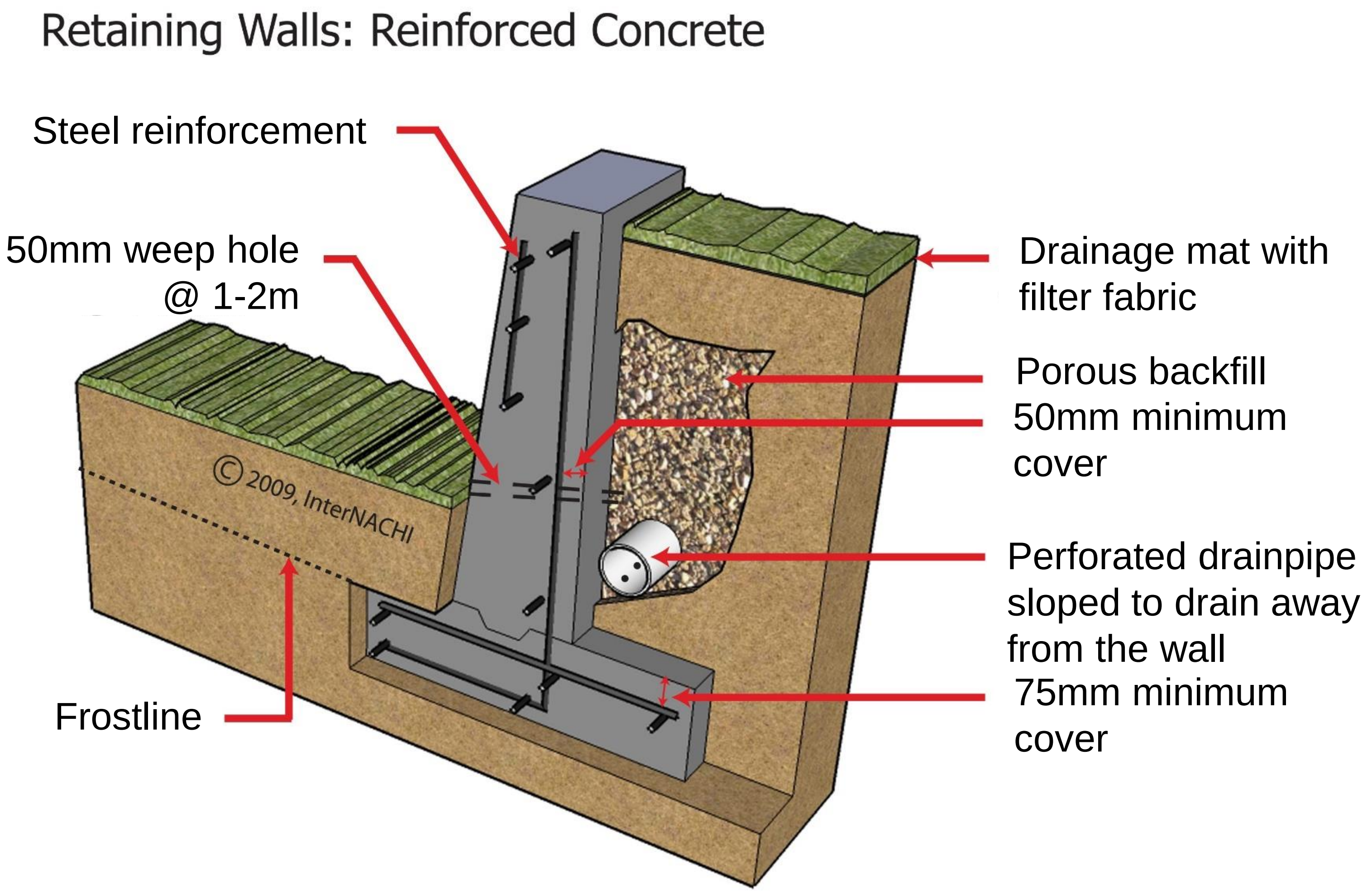
Counterfort and Buttressed Retaining Wall

Introduction

No.	Type	Descriptions
1	Gravity wall	Stability is provided by the weight of the concrete in the wall.
2	Cantilever wall	Wall acts as a vertical cantilever. Stability is provided by the weight of structure and earth on an inner base or the weight of the structure only when the base is constructed externally.
3	Counterfort and buttress wall	The slab is supported on the three sides by the base and counterfort or buttress. Stability is provided by the weight of the structure in the case of buttress and by the weight of structure and earth on the base in the counterfort wall.

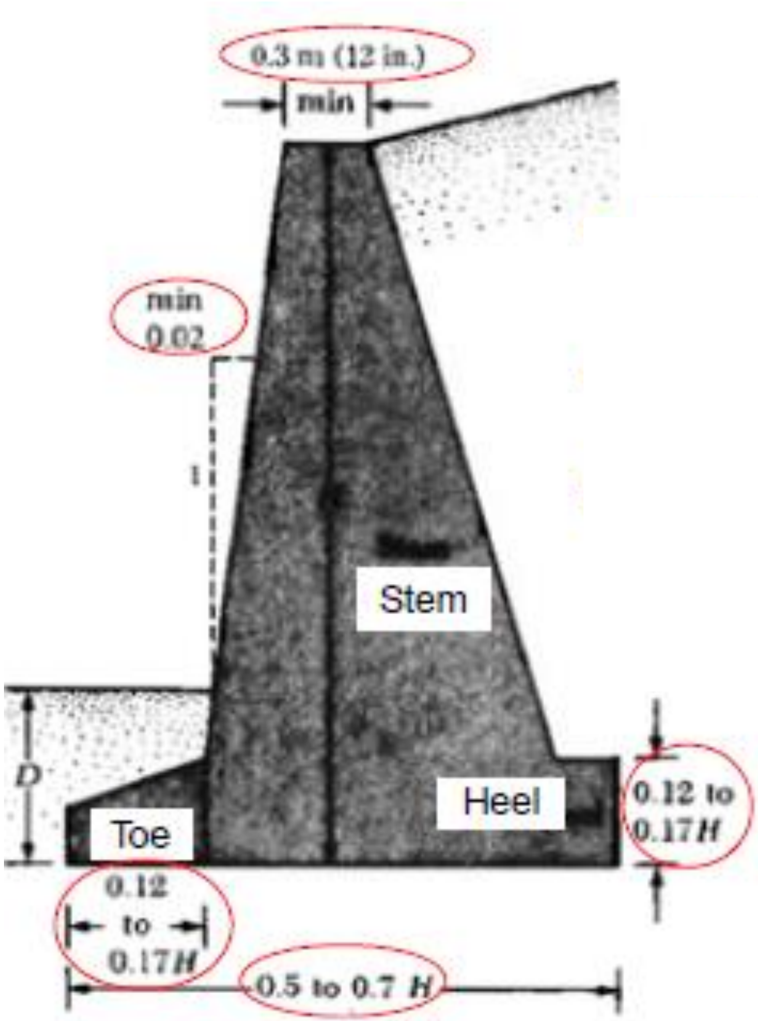
Design Consideration

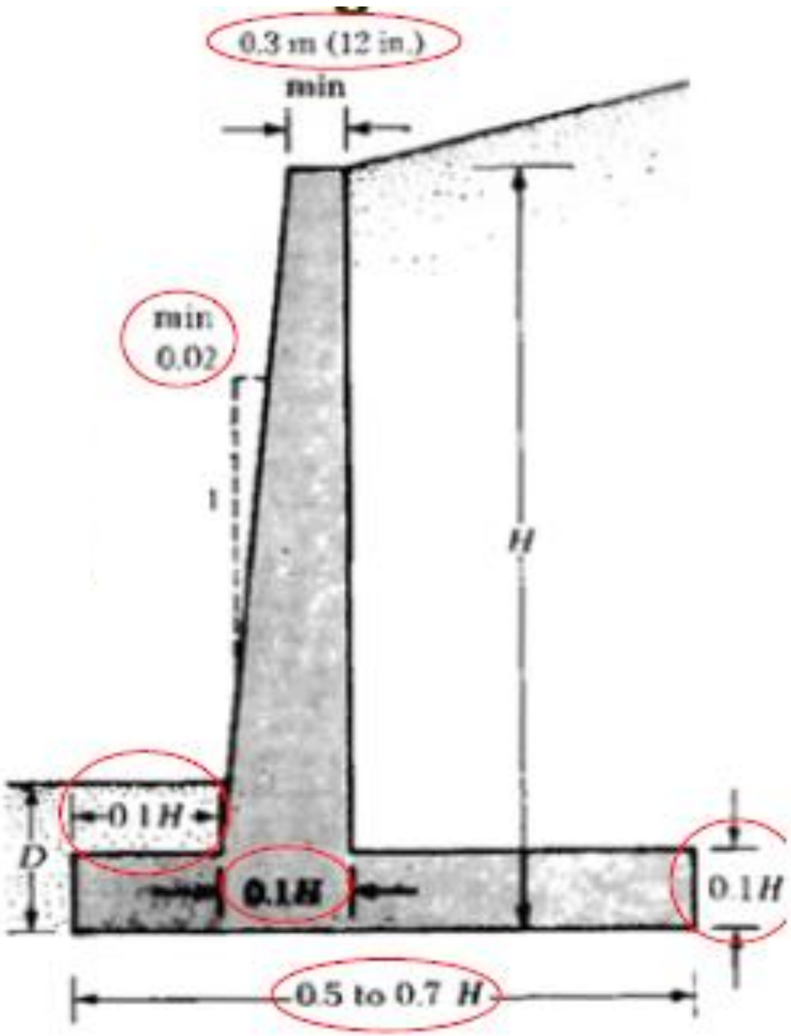
- Component:



Design Consideration

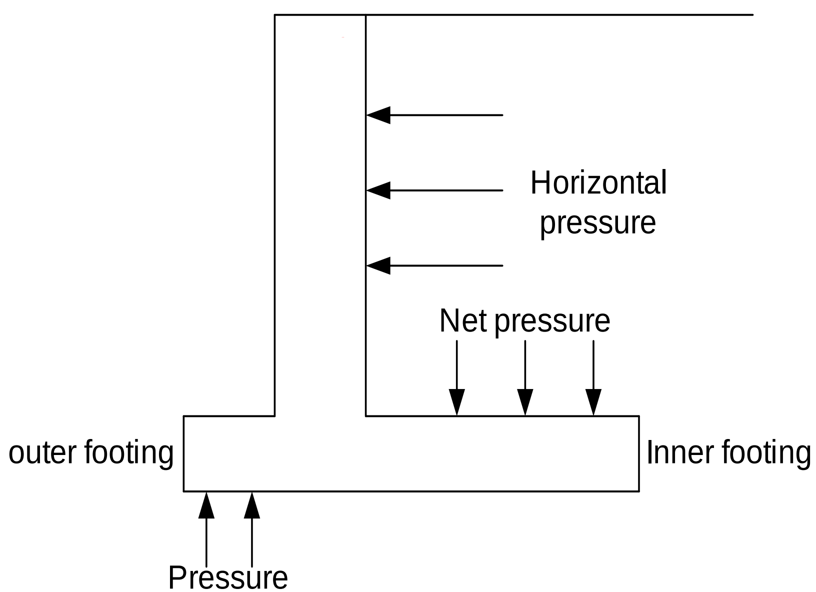
- Typical size:

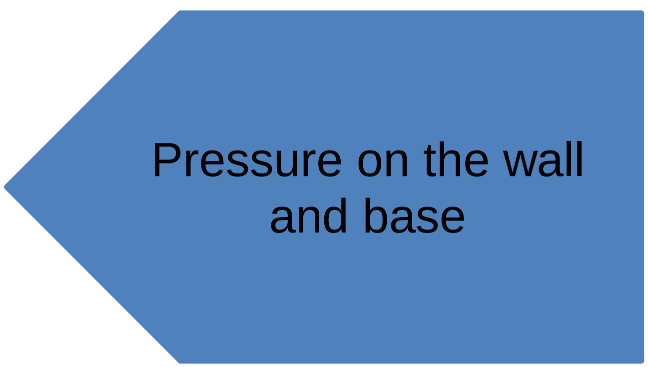




Design Consideration

- Design procedure (cantilever retaining wall):
  - Assume a breath for the base is 0.75 of the wall height. The preliminary thickness for the wall and base section can be assumed.
  - Calculate the horizontal pressure on the wall. Then, considering all forces, check stability against overturning and the vertical pressure under the base of the wall.





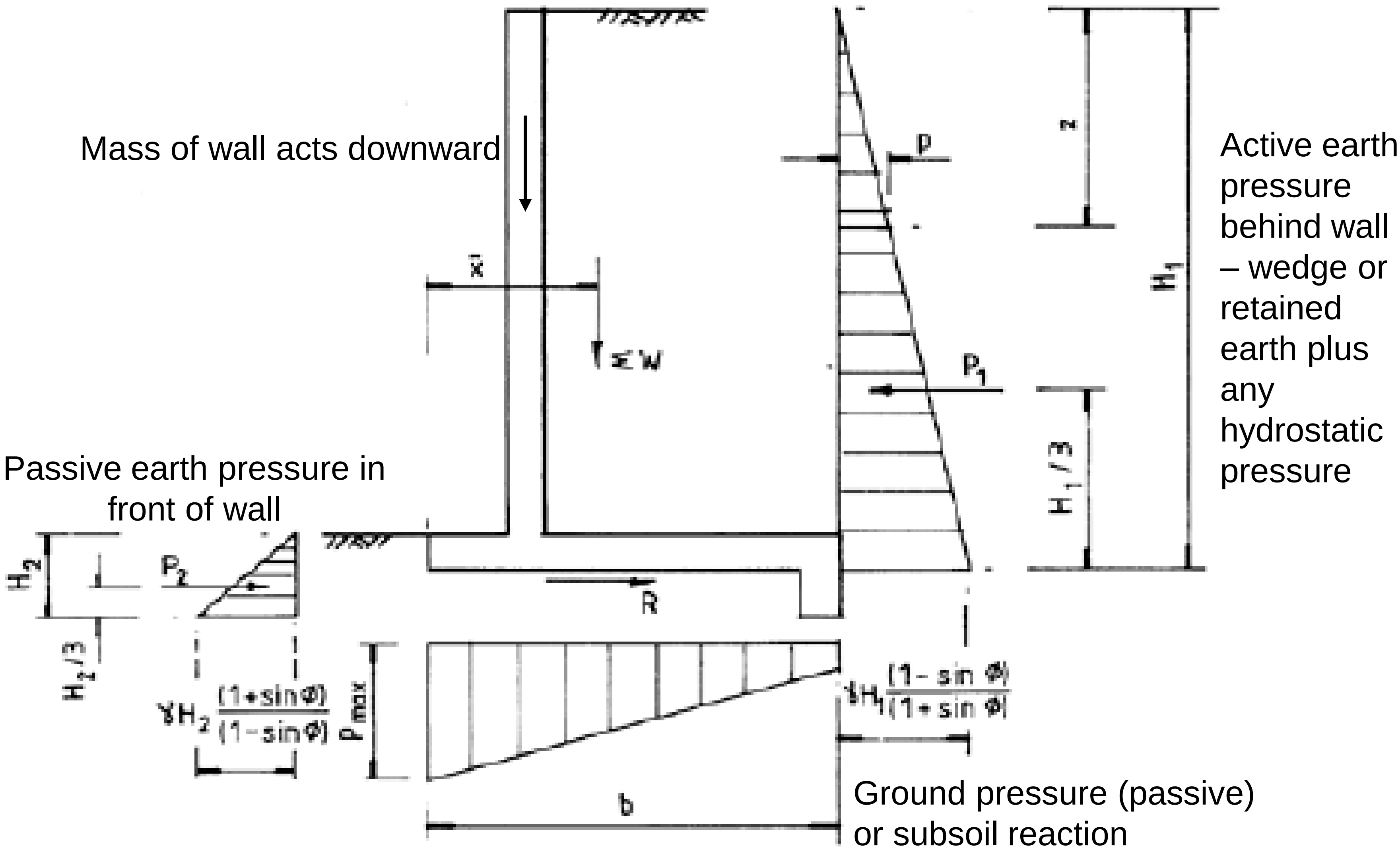
Design Consideration

- Calculate and check the resistance to sliding. Use γ_f = 1.4 to the horizontal loads for the overturning and sliding check. The maximum vertical pressure is calculated using service load and should not exceed safe bearing pressure.
- Reinforced concrete design for the wall is conducted by using the ultimate load. For the wall and earth pressure, use γ_f = 1.4.
- Surcharge if present may be classed as either dead or imposed load depending on its nature.
- For the wall, calculate shear force and moments caused by the horizontal earth pressure.
- Design the vertical moment steel for the inner face and check the shear stresses.

Design Consideration

- Minimum secondary steel is provided in the horizontal direction for the inner face and both vertically and horizontally for the outer face.
- The net moment due to earth pressure on the top and bottom faces of the inner footing causes tension in the top and reinforcement is designed for this position.
- The moment due to earth pressure causes tension in the bottom face of the outer footing.

Earth Pressure



Earth Pressure

- Active soil pressure:
  - Two cases known as cohesionless soil such as sand and cohesive soil such as clay.
  - The active soil pressure is due to the level of backfill.
  - If there is a surcharge of w kN/m^2 on the soil behind the wall, this is equivalent to an additional soil depth of

$$z = \frac{w}{\gamma}$$

where:

w is surcharge in kN/m^2

γ is the density of soil in kN/m^3

Earth Pressure

- For cohesionless soil (c = 0), the pressure at any depth, z is given by:

$$\rho = \gamma z \frac{1-\sin\varphi}{1+\sin\varphi}$$

where: γ is the density of soil and φ is the friction angle. Meanwhile, the force on the wall of height H1 is:

$$P_1 = 0.5\gamma H_1^{\,2} \frac{1-\sin\varphi}{1+\sin\varphi}$$

- For cohesive soil ($\varphi = 0$), the pressure at any depth, z is given by:

$$\rho = (\gamma z) - 2c$$

This expression gives negative value near top of the wall. In practice, a value for the active soil pressure is < $0.25\gamma z$.

Earth Pressure

- Vertical pressure under the base:
  - The vertical pressure under the base in calculated for the service load.
  - For a cantilever wall, 1m length of wall with based width *b* is consider; then the area and modulus of section area:

$$A = b \times 1\,\mathrm{m} = b\ \mathrm{m}^2 \quad ; \quad Z = b^2 / 6\ \mathrm{m}^3$$

  - The sum of the moment of all vertical forces about the center of the base and active pressure on the wall is:

$$\sum M = \sum W\,(x - b/2) - P_1(H_1/3)$$

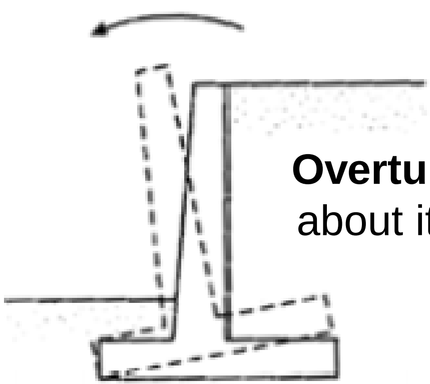
  - The passive earth pressure in front of the base has been neglected. The maximum pressure is:

$$P_{max} = \frac{\sum W}{A} \pm \frac{\sum M}{Z}$$

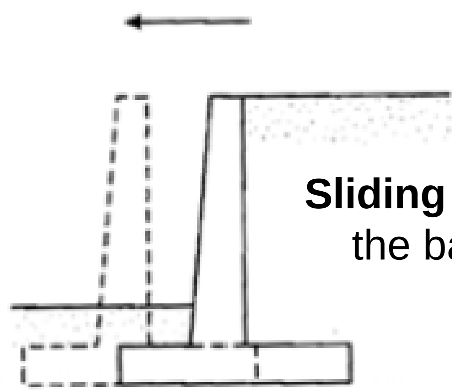
This should not exceed the safe bearing pressure on the soil

Stability

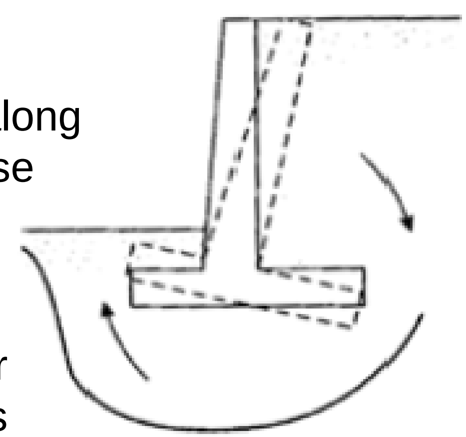
- Wall stability
  - The vertical loads are made up of the weight of the wall and base, and the weight of the backfill on the base. Front fill on the outer base can be neglected.
  - Surcharge would need to be included if present.
  - The critical condition for overturning is when a maximum horizontal force acts with minimum vertical load.



Overturning about its toe



Sliding along the base



Bearing capacity failure of supporting base

*Excessive settlement may occur if weak soil layer is located below the foundation within 1.5 times foundation width

Stability

- To guard against failure by overturning, it is usual to apply conservative factors of safety to the force and loads.
- If the centre of gravity of these loads is x from the toe of the wall, the stabilizing moment is ΣWx with partial safety factor is $\gamma_f = 0.9$.
- The overturning moment due to the active earth pressure is $1.1P_1\ (H_1/3)$ with adverse partial safety factor $\gamma_f = 1.1$.
- The unfavourable effects of the variable surcharge loading are multiplied by the partial safety factor of $\gamma_f = 1.5$.
- The stabilizing moment from passive earth pressure has been neglected.
- For the wall to satisfy the requirement of stability:

$$\sum Wx \geq \gamma_f P_1 \left(\frac{H_1}{3} \right)$$

Stability

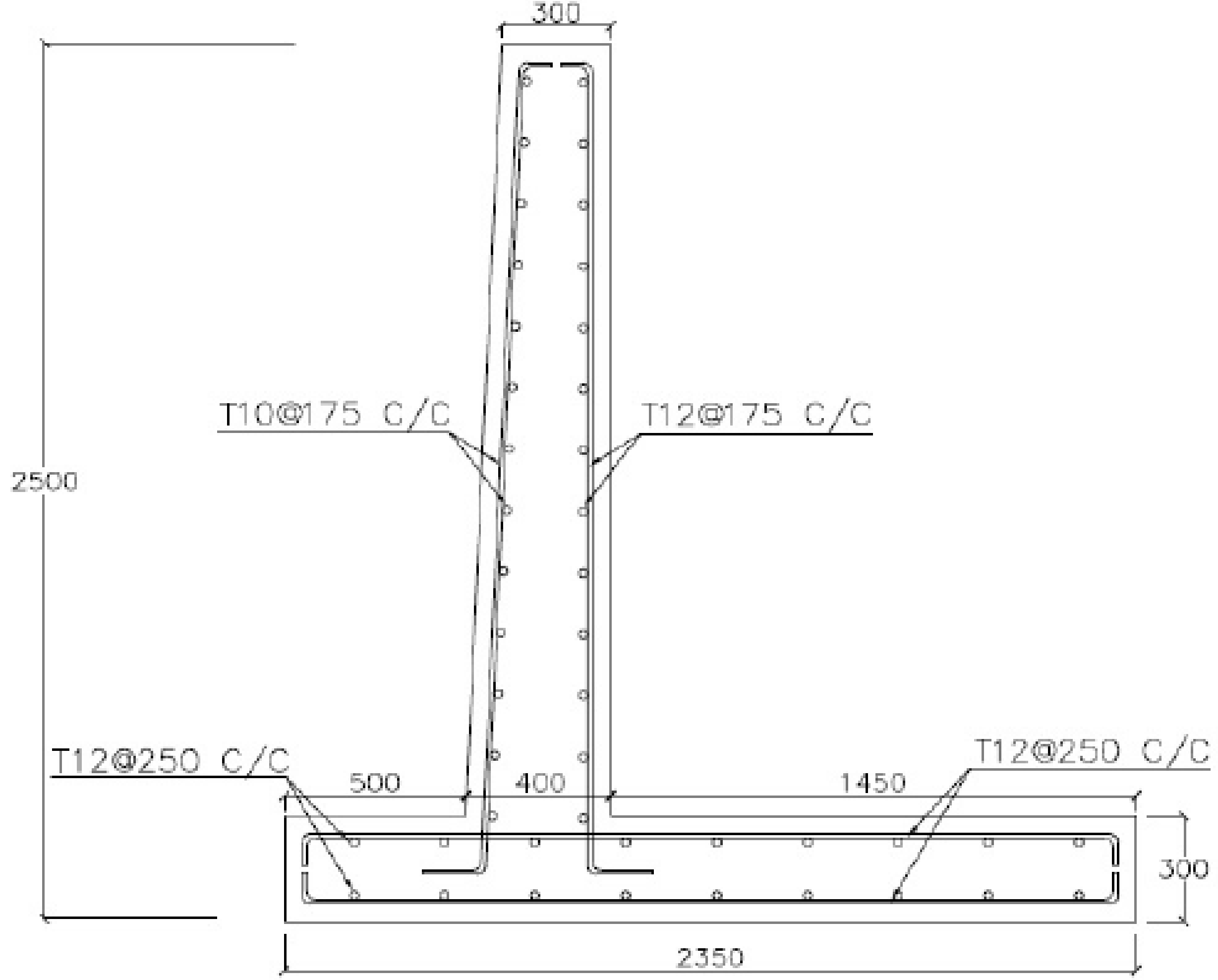
- Resistance to sliding
  - Cohesionless soil: The friction *R* between the base and the soil is $\mu\Sigma M$ where μ is the coefficient of friction between the base and the soil ($\mu = tan\phi$). The passive earth force against the front of the wall from a depth H_2 soil is:

$$P_2 = 0.5\gamma H_2{}^2 \frac{1+\sin\varphi}{1-\sin\varphi}$$

  - Cohesive soils: The adhesion *R* between the base and the soil is β_b where β is the adhesion in kN/m^2. The passive earth pressure is $P_2 = 0.5\gamma H_2{}^2 + 2cH_2$.
  - A nib can be added to increase the resistance to sliding through passive earth pressure.
  - For the wall to be safe against sliding, $1.0\mu G_k \geq \gamma_f H_k$ where H_k is the horizontal active earth pressure on wall

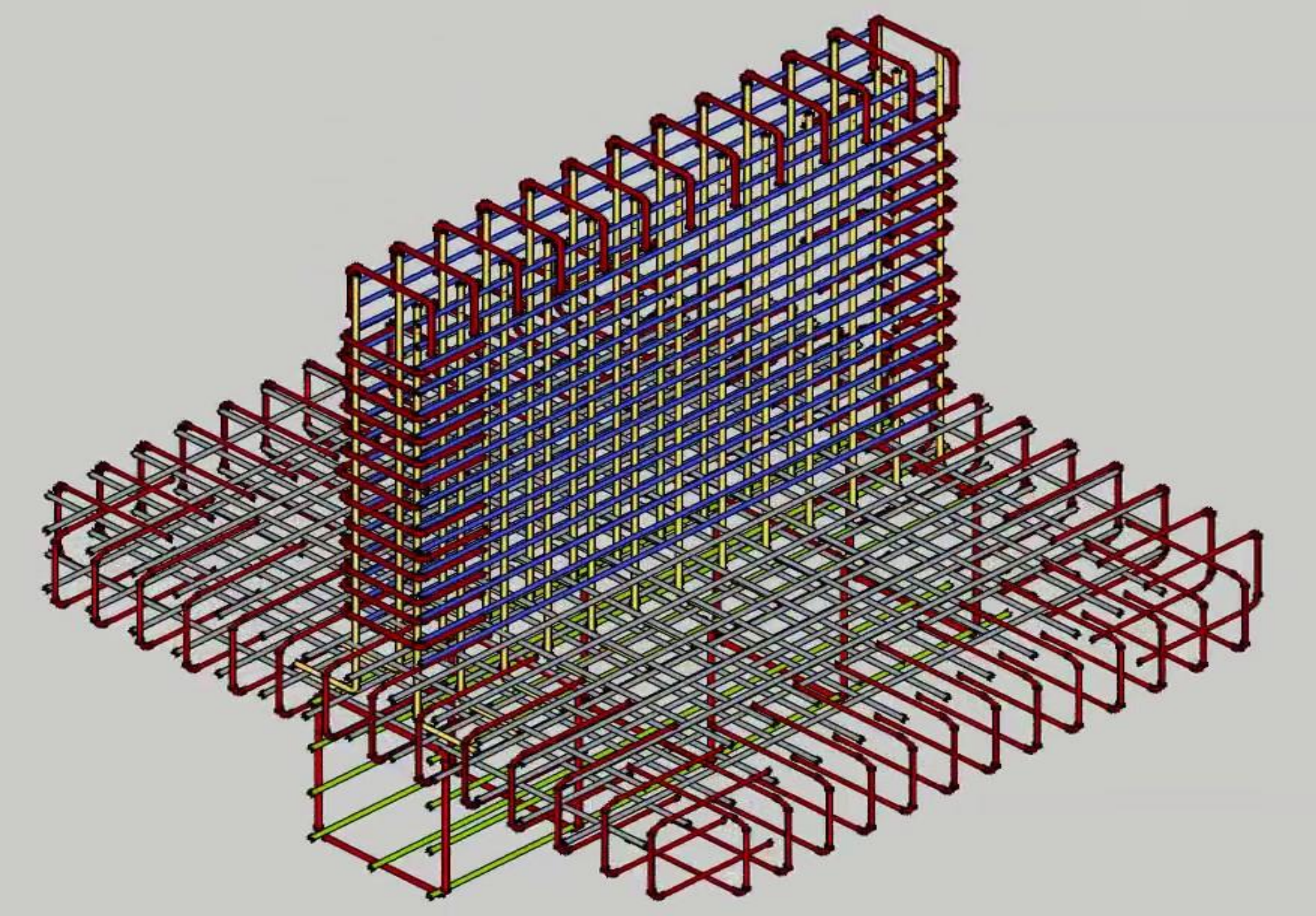
Detailing

- Reinforcement arrangement:



Detailing

- Reinforcement arrangement:



Example 5.1:

Cantilever Retaining Wall

Example 5.1

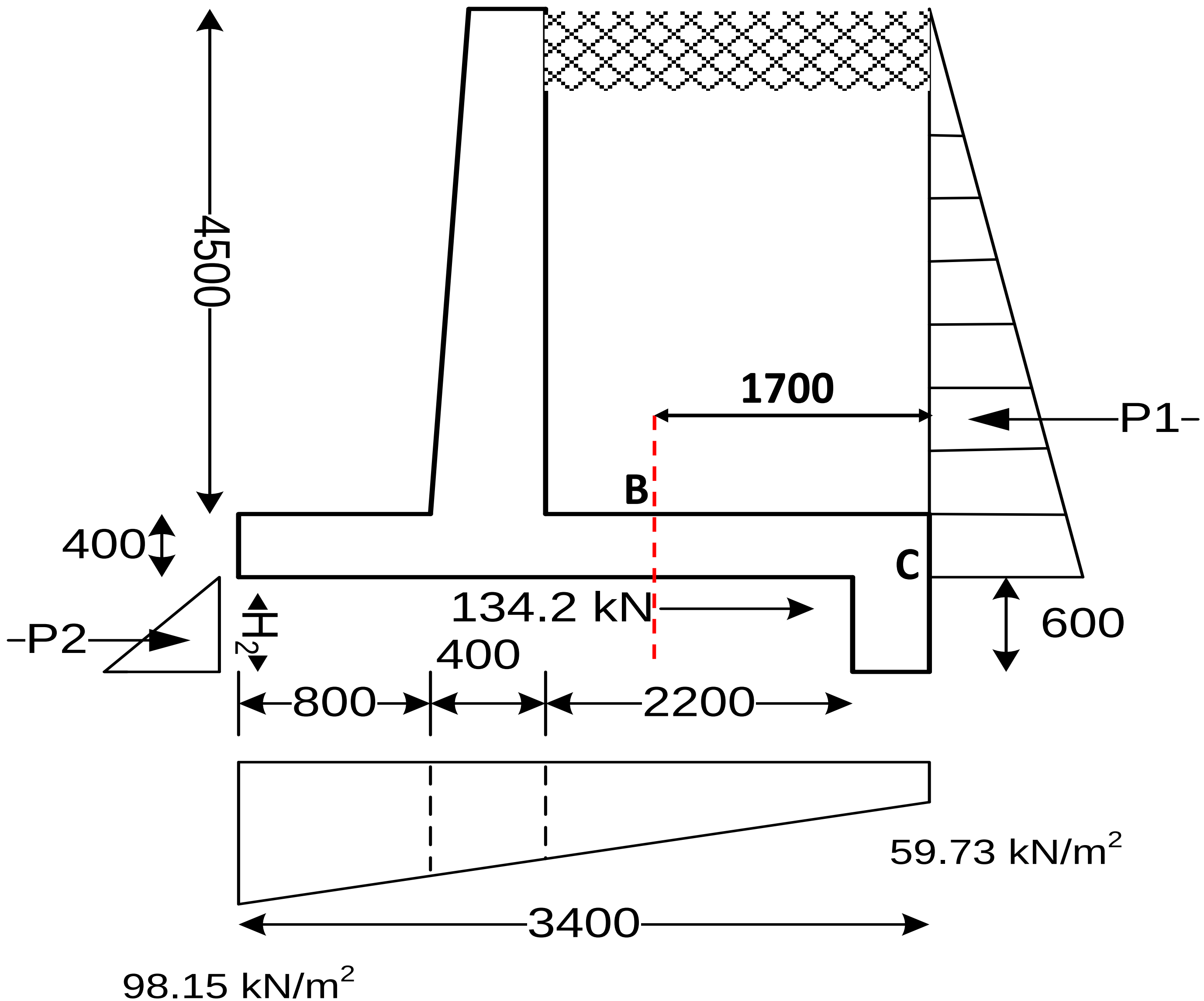
- Cantilever retaining walls as in Figure 1 support a bank of earth 4.5m height. The soil behind the wall is well-drained sand with the following properties:

  - Density, γ_{soil} = 2000 kg/m^3 = 20 kN/m^3
  - Angle of internal friction, ϕ = 30^o

  The material under the wall has a safe bearing pressure of 110 kN/m^2. The coefficient of friction between the base and the soil is 0.45.

  Design the wall using grade 30 concrete and grade 500 reinforcement.

Example 5.1


4500
1700
P1
B
400
C
134.2 kN
600
P2
H_2
400
800
2200
59.73 kN/m²
3400
98.15 kN/m²

Example 5.1

- Check wall stability

Earth pressure, $\rho = \gamma z \dfrac{1-\sin\varphi}{1+\sin\varphi} = 20(4.9)\dfrac{1-\sin 30}{1+\sin 30}$

$$= 32.34 \text{kN/m}^2$$

For 1m length of wall,

Horizontal load $= 0.5(32.34)(4.9) = 79.23\text{kN}$

- Maximum soil pressure

The base properties area $= 3.4 \times 1\text{m (width)} = 3.4\ \text{m}^2$

Modulus $= 3.4^2/6 = 1.93\text{m}^3$

Maximum soil pressure at toe is:

$$P_{max} = \frac{\Sigma W}{A} + \frac{\Sigma M}{Z} = \frac{271.4}{3.4} + \frac{129.41 - 91.22}{1.93} = 99.6\text{kN/m}^2$$

$99.6\text{kN/m}^2 < 110\text{kN/m}^2$ (OK)

Example 5.1

Load	Horizontal load (kN)	Distance from C (m)	Moment about C (kNm)
Active pressure	79.23	1/3(4.9) = 1.63	-129.41
	Vertical load (kN)	**Distance from B (m)**	**Moment about B (kNm)**
Wall	0.5 (0.3+0.4)4.5 x 25 = 39.4	- 0.7	- 27.58
Footing	0.4 x 3.4 x 25 = 34	0	0
Backfill	2.2 x 4.5 x 20 = 198	0.6	118.8
Total	**271.4**		**91.22**

Example 5.1

- Check stability and overturning

The stability moment about the toe A of the wall for a partial safety factor $\gamma_f = 1.0$ is:

$$91.22 + (271.4 \times 1.7) = 552.6 \text{ kNm}$$

The overturning moment for a partial safety factor $\gamma_f = 1.4$ is:

$$1.4 \times 129.41 = 181.2 \text{ kNm}$$

The stability of the wall is adequate

Example 5.1

- Check resistance to sliding

The forces resisting sliding are the friction under the base and the passive resistance for a depth of earth:

$$\text{Passive force,} \quad P_2 = 0.5\gamma H_2{}^2 \frac{1+\sin\varphi}{1-\sin\varphi}$$

$$= 0.5(20)(0.6)^2(3) = 10.8$$

Friction force = 0.45 x 271.4 = 122.13kN

Total friction force = 10.8 + 122.13 = 132.9kN

Sliding force = 79.23 x 1.4 = 110.9kN

The resistance to sliding is satisfactory

Example 5.1

- Wall reinforcement:

Pressure at the base of the wall,

$$\rho = \gamma z \frac{1 - \sin\varphi}{1 + \sin\varphi} = 20(4.5)(0.33) = 29.7\text{kN/m}^2$$

Shear force $= 1.35[0.5(29.7)(4.5)] = 90.2\text{kN}$

Moment $= 90.2\left[\frac{1}{3}(4.5) + \frac{1}{2}(0.4)\right] = 153.34\text{kNm}$

Use C_{nom} = 40mm; $Ø_{bar}$ = 20mm

$$d = 400 - 3 - 0.5(20) = 360mm$$

$$\frac{M}{bd^2} = \frac{153.34 \times 10^6}{1000(360^2)} = 1.18 < 1.27$$

Use Z = 0.95d

$$A_s = \frac{M}{0.86 f_{yk} z} = \frac{153.34 \times 10^6}{0.87(500)(0.95 \times 360)} = 1031\text{mm}^2/\text{m}$$

Use H20-250 (A_s = 1260mm^2/m)

Example 5.1

- Inner footing reinforcement:

Shear force,

$$= 1.35\left[198 + 34\left(\frac{2.2}{3.4}\right) - (60 \times 2.2) - (0.5 \times 2.2 \times 25.6)\right]$$

$$= 1.35[198 + 21.1 - 131.4 - 31.1] = 79.56\text{kN}$$

Moment,

$$= 1.35[(198 + 21.1 - 132)(1.1 + 0.2) - 31.1(0.733 + 0.2)]$$

$$= 117.5\text{kNm}$$

$$\frac{M}{bd^2} = \frac{117.5 \times 10^6}{1000(360^2)} = 0.90 < 1.27$$ ➡ Use Z=0.95d

$$A_s = \frac{M}{0.86 f_{yk} z} = \frac{117.5 \times 10^6}{0.87(500)(0.95 \times 360)} = 790\text{mm}^2/\text{m}$$

Use H20-300 (A_s = 1050mm^2/m)

Example 5.1

- Outer footing reinforcement:

Shear force,

$$= 1.35\left[(90.3 \times 0.8) + (0.5 \times 0.8 \times 9.3) - 34\left(\frac{0.8}{3.4} \right) \right]$$

$$= 1.35[\,72.2 + 3.72 - 7.7\,] = 92.10\text{kN}$$

Moment,

$$= 1.35[\,(72.2 - 7.2)(0.4 + 0.2) + 3.72(2/3(0.8) + 0.2)\,]$$

$$= 68.4\text{kNm}$$

$$\frac{M}{bd^2} = \frac{68.4 \times 10^6}{1000(360^2)} = 0.52 < 1.27$$ → Use Z=0.95d

$$A_s = \frac{M}{0.86 f_{yk} z} = \frac{68.4 \times 10^6}{0.87(500)(0.95 \times 360)} = 457\text{mm}^2/\text{m}$$

Use H16-300 (A_s = 670mm^2/m)

Example 5.2:

Cantilever Retaining Wall
(Include Surcharge Loading)

Example 5.2

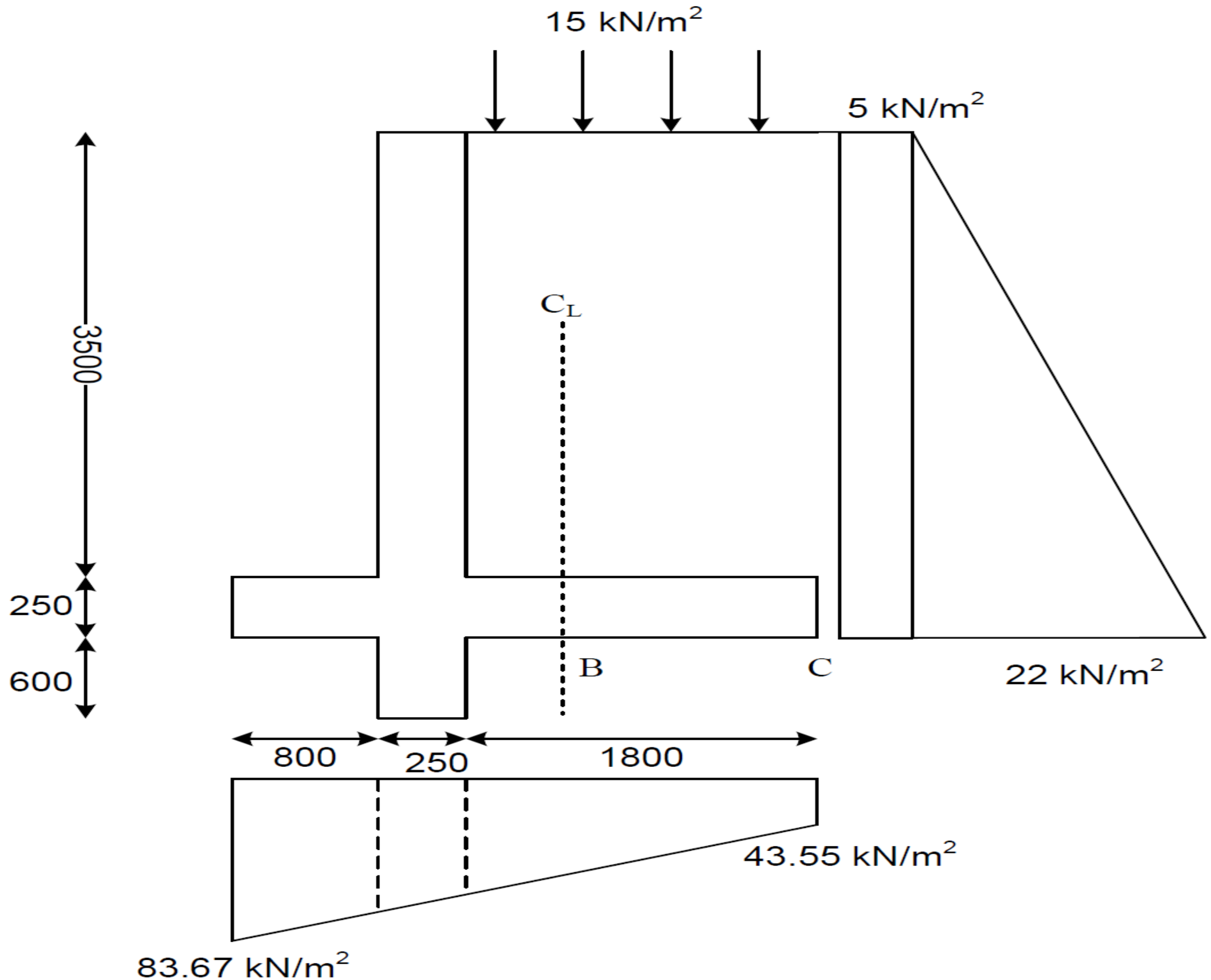
- Design a cantilever retaining wall to support a bank of earth 3.5m height. The top surface is horizontal behind the wall but it is subjected to a dead load surcharge in 15 kN/m^2. The soil behind the wall is well-drained sand with the following properties:

  - Density, γ_{soil} = 1800 kg/m^3 = 18 kN/m^3
  - Angle of internal friction, φ = 30^o

  The material under the wall has a safe bearing pressure of 100 kN/m^2. The coefficient of friction between the base and the soil is 0.50.

  Design the wall using grade C30 concrete and grade 500 reinforcement.

Example 5.2



15 kN/m²
5 kN/m²
3500
250
600
C_L
B
C
22 kN/m²
800
250
1800
43.55 kN/m²
83.67 kN/m²

Example 5.2

- Check wall stability

Consider 1m length of the wall. The surcharge is equivalent to an additional height of $15kN/m^2/18kNm^3$ = 0.85.

Therefore, total height of the soil = 3.5 + 0.25 + 0.85 = 4.6m

Earth pressure,

$$\rho = \gamma z \frac{1-\sin\varphi}{1+\sin\varphi} = 20(z)\frac{1-\sin 30}{1+\sin 30}$$

$$= 17.6(z)(0.333) = 5.87z\text{kN/m}^2$$

At z= 0.85m, ρ= $5kN/m^2$

At z = 4.6m, ρ=$27kN/m^2$

- Maximum soil pressure

The base properties area $= 2.85 \times 1\text{m (width)} = 2.85\ \text{m}^2$

Modulus$= 2.85^2/6 = 1.35\text{m}^3$

Example 5.2

Load	Horizontal load (kN)	Distance from C (m)	Moment about C (kNm)
Active pressure	5 x 3.75 = 18.75 0.5 x 22 x 3.75 = 41.25	1.875 1.25	-35.08 -51.56
Total	59.98		-86.64
	Vertical load (kN)	**Distance from B (m)**	**Moment about B (kNm)**
Wall	4.1 x 0.25 x 25 = 25.6	-0.5	-12.8
Footing	2.85 x 0.25 x 25 = 17.81	0	0
Backfill	1.8 x 3.5 x 17.6 = 110.88	0.525	58.21
Surcharge	15 x 1.8 = 27	0.525	14.18
Total	**181.29**		**59.59**

Example 5.2

Maximum soil pressure at service load:

$$P_{max} = \frac{\Sigma W}{A} + \frac{\Sigma M}{Z} = \frac{181.29}{2.85} + \frac{86.67 - 59.59}{1.35} = 83.76\text{kN/m}^2$$

$$83.76\text{kN/m}^2 < 110\text{kN/m}^2 \quad \text{(OK)}$$

- Check stability and overturning

  The stability moment about the toe A of the wall for a partial safety factor $\gamma_f = 0.9$ is:

  59.59 + [181.29 x (2.85/2)] = 317.9 x 0.9 = 286.11 kNm

  The overturning moment for a partial safety factor $\gamma_f = 1.1$ is:

  1.1 x 86.64 = 95.3 kNm 1

  The stability of the wall is adequate

Example 5.1

- Check resistance to sliding

The forces resisting sliding are the friction under the base and the passive resistance for a depth of earth of 850 mm to the top of the base.

Passive force, $P_2 = 0.5\gamma H_2{}^2 \frac{1+\sin\varphi}{1-\sin\varphi}$

$$= 0.5(18)(0.85)^2(3) = 19.51$$

Friction force = 0.45 x 181.29 = 81.58kN

Total friction force = 19.51 + 81.85 = 101.36kN

Sliding force = 1.4 x 59.98 = 83.97kN

The resistance to sliding is satisfactory