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Certification of the supervisor:

I certify that the engineering project title (retaining wall) was done under me

Supervision at the water resource engineering department, college of engineering

Salahaddin university_ Erbil

In the partial fulfillment of the requirement for the degree of bachelor of science

in water resource engineering

Supervisor:

Signature:

Name: Mr. Rushdi khalis

Date:

Chapter one:

1.1introduction of retaining walls:

A retaining wall is a structure designed to sustain the earth behind it. It retains a steep faced slope of an earth mass against rupture of slopes faced slopes in cuts and fills and against sliding down. The retained material exerts a push on structures and this tends to overturn and slide it. Besides the self-weight, the main predominant force for analysis and design of the retaining wall is lateral earth pressure. The lateral earth pressure behind the wall depends on the angle of internal friction and the cohesive strength of the retained material, as well as the direction and magnitude of movement of the stems. Its distribution is typically triangular, least at the top of the wall and increasing towards the bottom. The earth pressure could push the wall forward or overturn it if not properly addressed. Retaining walls are encountered and constructed in various fields of engineering such as roads, harbors, dams, subways, railroads, tunnels, and military fortifications.

Figure 1.1 retaining wall supports a building side slope

Retaining walls are built can be used to define property boundaries and provide privacy or security., and Retaining walls provide support and stability for structures built on sloped or uneven ground. They can be used to enhance the visual appeal of a landscape by creating terraced gardens or defining different levels of a yard.

Retaining walls are structural members used to provide stability for soil or other materials and prevent them from assuming their natural slope, in this sense, the retaining wall maintains unequal levels of earth on it is two faces.

When compared to the use of a conventional cut or fill slope, the use of a retaining wall generally results in more developable land, as shown in Figures 1.1 and 1.2.

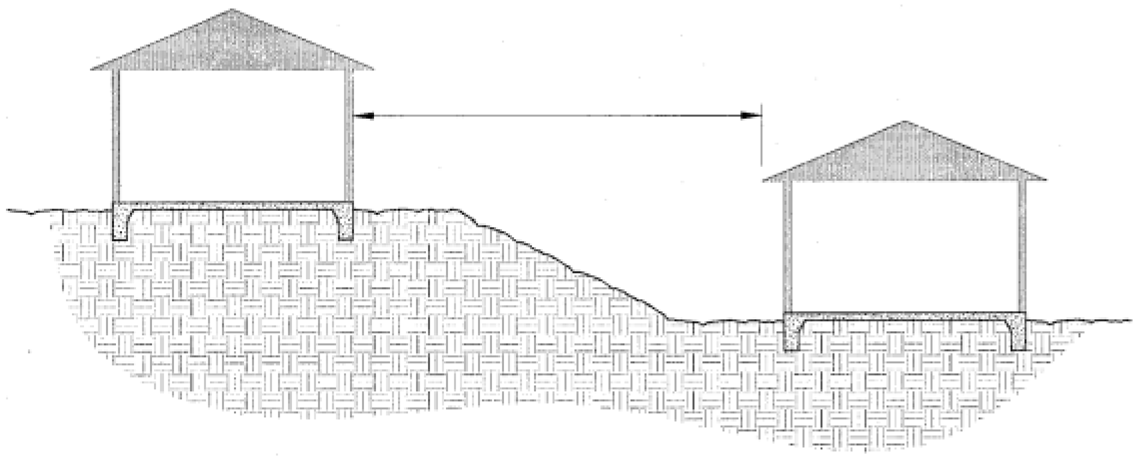

Figure 1.2 Section showing a slope between two structures that are at different elevations with respect to each other.

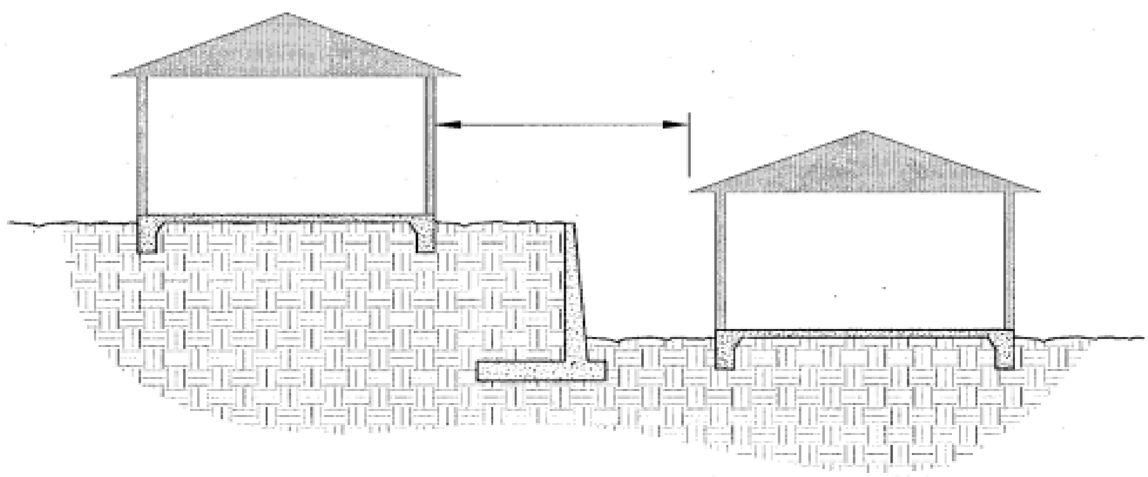

Figure 1.3 Section showing the use of a cantilever retaining wall between two structures rather than a slope (Figure 1.2) to allow the structures, such as those of a residential tract development, to be spaced closer together resulting in more developable land.

1.2 The purpose of retaining wall:

A retaining wall is a structure designed to hold back soil or withstand land pressure.

It is a structure that is designed to retain the shape of a landscape, hence its name. Lateral earth pressure that requires a retaining wall could be from backfill, soil pressure, soil erosion, liquid pressure, and even sand. Any sort of granular materials behind the retaining structure can cause this pressure.

Figure 1.4 Retaining wall

1.3 the most common material used for retaining wall:

1. Concrete: Durable and versatile, concrete retaining walls can be poured on-site or precast and offer various design options.

2. Timber: Wood retaining walls are popular for their natural look and ease of installation, though they may require more maintenance.

3. Gabion: Gabion walls are constructed using wire mesh baskets filled with rocks or stones, providing both strength and aesthetics.

4. Stone: Natural stone retaining walls offer a classic appearance and can be dry-stacked or mortared for stability.

5. Brick: Brick retaining walls provide a timeless aesthetic and are often used for decorative purposes in addition to functionality.

6. steel and plastic interlocking sheets

7. Anchors into the soil or rock mass (soil nailing)

1.4 Common Problems with retaining walls

The biggest problem with retaining walls is poor **drainage**, which in turn means saturated soil wet soil adds extra weight and can put additional strain on the wall, the single biggest enemy of retaining walls is water, saturated soil put pressure on retaining walls, if saturated soil is freezes, expansion forces can be significant, wall may move as a single unit, leaning away from the hill or may crack and break apart,

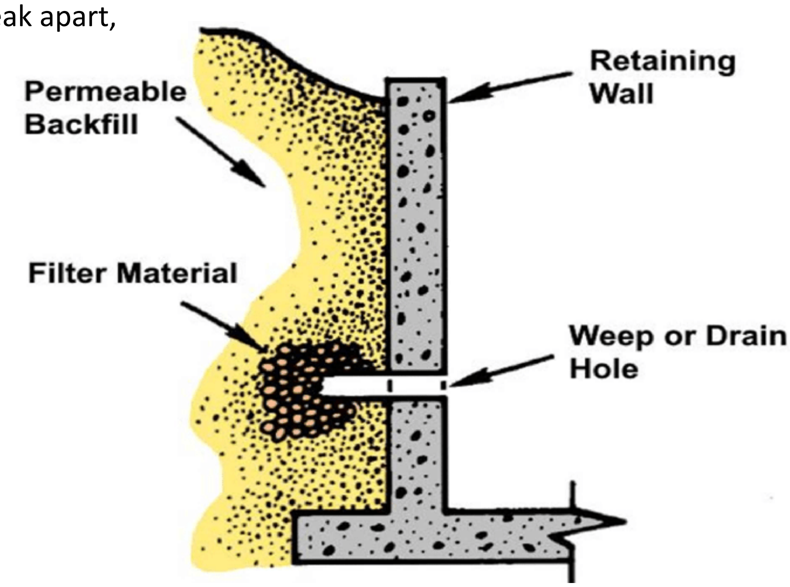

Figure 1.5 weep/drainage holes in retaining walls

Vegetation growth: Plant roots can penetrate retaining walls, causing damage and compromising structural integrity.

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Figure 1.6 Vegetation growth caused to fail of retaining wall

Poor maintenance: Neglecting routine inspections, repairs, and maintenance can exacerbate existing issues and lead to deterioration over time

Figure 1.7 retaining wall maintenance properly over time to prevent the fail

1.5 Retaining wall applications:

Erosion Control: Retaining walls help prevent soil erosion by holding back soil on slopes or hillsides.

Figure 1.8 retaining wall for protection rock and soil falls

Landscaping: They are used to create terraces or multi-level gardens, making sloped landscapes more usable and aesthetically pleasing.

Figure 1.9 Retaining wall landscape

Water Management: They are used in drainage systems to control the flow of water and prevent flooding or water damage.

Figure 1.10 Gabion River stream and coastal erosion control.

highway retaining wall: constructed to support and stabilize the embankments or cut slopes along highways and roads.

Figure 1.11 highway Retaining wall

culvert (sewer) walls: The culvert retaining wall serves to support the embankment or roadway while also providing structural stability to the culvert, and crucial role in ensuring the safe and efficient conveyance of water under transportation infrastructure.

Figure 1.12 culvert retaining wall

Tunnel portals approaches: is built along the sides of a tunnel to support the surrounding soil or rock and prevent collapses or instability.

Figure 1.13 tunnel portal retaining wall

1.6 lateral earth pressure:

The lateral Earth pressure due to earth pressure is the major force acting on the retaining wall, we provide a retaining wall to prevent soil from the sudden collapse of soil mass like a landslide. Retaining wall should be designed to support appropriate lateral pressure, such as surcharge water pressure and earthquake loading.

1.7 Type of earth pressure

Two types of earth pressure should be considered during the process of designing retaining wall.

i. active earth pressure (pa)

Active earth pressure refers to the lateral pressure exerted by soil against a retaining structure when the soil is in a state of movement away from the structure. It typically occurs when the soil is allowed to freely expand or move away from the structure, causing it to exert pressure against the retaining wall or structure. This pressure is influenced by factors such as soil properties, wall geometry, and the relative movement between the soil and the structure.

Active earth pressure can be reduced by:

1. reducing coefficient of active earth pressure (increase more compaction for the soil which increase the soil friction angle (Ø))
2. Providing proper drainage: Improving drainage behind the retaining wall can reduce the build-up of hydrostatic pressure, which contributes to active earth pressure.
3. The sloped face behind retaining wall helps to distribute the lateral pressure exerted by the soil more evenly along the height of the wall, minimizing the risk of wall failure due to excessive pressure.
4. Modifying the slope(decreasing) of the soil behind the retaining structure can reduce the lateral pressure exerted on the structure.

ii. Passive earth pressure

Passive earth pressure refers to the lateral pressure exerted by soil against a retaining structure when the soil is being pushed towards the structure. It occurs when the soil is prevented from moving away from the structure, causing it to exert pressure against the structure in the opposite direction. Passive earth pressure is typically lower than active earth pressure and is commonly observed in situations where the soil is being retained by a wall or a similar structure. Understanding passive earth pressure is important in the design of retaining walls and other structures to ensure stability and structural integrity.

1.8 design consideration:

The Four Primary Concerns for the Design of Nearly any Retaining Wall are:

1. That it has an acceptable Factor of Safety with respect to overturning.

2. That it has an acceptable Factor of Safety with respect to sliding.

3. That the allowable soil bearing pressures are not exceeded.

4. That the stresses within the components (stem and footing) are within code allowable limits to adequately resist imposed vertical and lateral loads. It is equally important that it is constructed according to the design.

for calculate the pressure at any point of the retaining wall this information should be known exactly

- height of the water table
- type of wall
- material used in the construction of wall
- nature and type of soil

Chapter two

2.1 Type of Retaining Wall:

1. Gravity Retaining Wall
2. Crib Retaining Wall
3. Gabion Retaining Walls
4. Cantilever Retaining Wall
5. Counter-fort / Buttressed Retaining Wall
6. Anchored Retaining Wall
7. Sheet Piled Retaining Wall

2.1.1 Gravity retaining walls

Gravity retaining walls use the gravitational force of their own weight to resist the lateral earth pressure from the soil behind them, which prevents toppling and sliding. They are the simplest and earliest recorded type of retaining wall.

Built of concrete, masonry, brick, blocks or mass cast-in-situ concrete, these hard-wearing structures rely on their large weight to resist toppling and sliding caused by the lateral earth pressure from the soil behind them.

Gravity retaining walls are typically designed to be wider at their base, with sloped faces, enabling them to resist the higher lateral earth pressures at depth. As such, this type of retaining wall is easy to build and suitable for retained heights of up to about 3m.

Despite their advantages, gravity retaining walls are not suitable for retained heights above 3m. If built any higher, the retaining structures tend to take up too much space and can end up being too heavy for the ground below, leading to bearing capacity failure. Ultimately, this can result in the wall failing to retain soil.

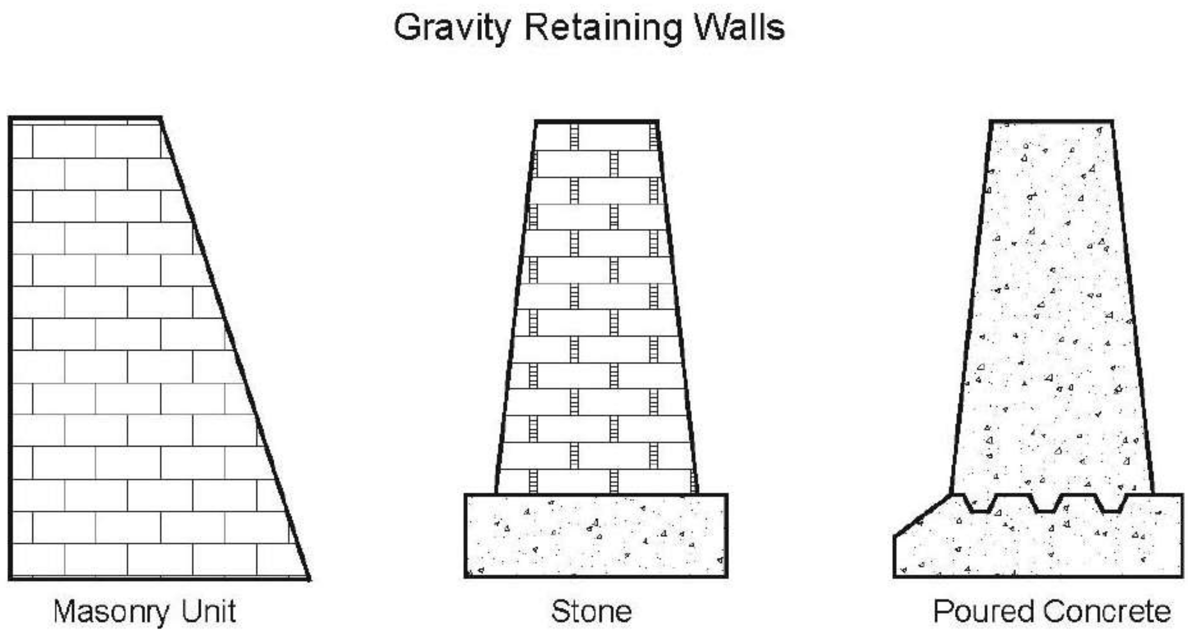


Fig.2.1 Materials used for gravity retaining wall construction

advantages:

- easy to construct
- can be built quickly.
- They are also durable and require minimal maintenance.

Disadvantages:

- Gravity retaining walls are not suitable for high walls
- may require additional reinforcement if the soil is unstable.

2.1.2 Sheet pile wall:

are retaining walls constructed to retain earth, water or any other filling materials. Sheet piles are sections of sheet materials with interlocking edges that are driven into the ground to provide earth retention and excavation support. Sheet piles are most commonly made of steel, but can also be formed of timber or reinforced concrete.

These walls are thinner in section compared to masonry walls. Sheet pile walls are generally used for following: 1. Water front structures, i.e. in building wharfs, quays and piers.

2. Building diversion dams, such as cofferdams 3. River bank protection 4. Retaining the sides of cuts made in earth Sheet pile walls can be of timber, reinforced concrete or steel.

Sheet pile wall advantages are:

- It is light in weight, making lifting and handling easy.
- It is reusable and recyclable.
- The length and design of the pile are easily adjustable.
- Joints are designed to withstand the high pressure necessary for them to be placed in place.
- They can be used for temporary and permanent structures.
- The work is neat, clean, and creates no spoil arisings. The supervision of work on-site can be reduced, and minimal storage space is required.

Sheet pile wall disadvantages are:

- Installation of sheet piles is difficult in soils with boulders or cobbles. In such cases, the desired wall depths may not be reached.
- Settlements in adjacent properties may take place due to installation vibrations
- Steel sheet piles are a relatively expensive material, and installation requires specialized equipment and personnel, further increasing the cost.
- Corrugated steel sheet piles require regular maintenance to maintain their integrity and prevent corrosion, which can add to the overall cost.

Figure 2.2 sheet pile retaining wall

Cantilever retaining wall

Cantilever retaining wall are usually of reinforced concrete and work on the principles of leverage. It has much thinner stem and utilize the weight of the backfill soil to provide most of the resistance to sliding and overturning. Cantilever retaining wall is the most common type of earth-retaining structure.
The stem and base slab are two components of the cantilever retaining wall. Cantilever retaining walls are often built of concrete that has been prepared on-site by forming formwork. As a cantilever retaining wall, a precast retaining wall is employed.
Part of the base slab is put below the backfill material in this retaining wall. The heel is the vertical part, while the toe is the other vertical part. A cantilever retaining wall is normally very cost-effective up to 10 meters.
Compared to a gravity retaining wall, this retaining wall uses less concrete. However, it is meticulously built to account for various aspects in its ideal state. The cantilever retaining wall design includes sliding, uplift pressure, and soil bearing pressure.

Advantages of cantilever retaining wall:

- Cantilever walls offer an unobstructed open excavation.
- Cantilever walls do not require installation of tiebacks below adjacent properties.
- Cantilever walls offer a simpler staged construction procedure.

disadvantages of cantilever retaining wall:

- Maximum excavation for cantilever walls is rather limited, typically to 6m.
- It is generally not recommended to use cantilever walls next to adjacent buildings.
- Control of lateral wall displacements depends on the mobilization of passive earth resistance.
- For deeper cantilever excavations the wall stiffness may need to be considerably increased. This can limit the available space within the excavation.

Figure 2.3 cantilever retaining wall

2.1.3 buttress retaining wall

A buttress retaining wall is an enhanced structural solution for holding back soil on sloped terrains. It consists of a vertical wall that's reinforced with support elements, known as buttresses, which extend at right angles or are inclined from the face of the wall. This design significantly strengthens the wall and helps to counteract the lateral earth pressure. The buttresses distribute the load more evenly, allowing the wall to be thinner and more economical than a plain retaining wall. Typically made of concrete, the buttress retaining wall is suitable for sites with heavy loads and poor soil conditions

Figure 2. Buttress Retaining Wall

2.1.4 Counterfort retaining wall:

Counterfort retaining wall is those retaining wall which withstands all the lateral forces by its flexural action rather than its weight. So, such wall has a broad base foundation, vertical stem reinforced with bar and supported by thin transverse slabs called Counterfort placed at regular intervals.

Counterfort are used for heigh walls with heigh greater than 8 to12 m, The are also used in the situation where there is high lateral pressure , where the back fill soil are heavy surcharged , the counterfort tie the base slab and wall stem together and the act as tension bracing which strengthen the connection between wall and base slab , the counterfort help to reduce bending moment and shear forces induced by the soil pressure to the retaining wall , moreover ,it also serves to increase the self-weight of the retaining wall which adda stability to the retaining wall .

advantages of counterfort retaining wall

- These walls are more economical to tie the vertical wall with the heel slab by counterforts.
- To support vertical walls, this wall acts as a tension member.
- This wall reduces the bending moment and supports the hell slab.
- By weight of the earth and by self-weight, stability is maintained.
- From 8m to 12m, this wall height ranges.
- These walls are more widely used because it is hidden beneath the retained materials.
- For more efficient space in front of the wall, these walls have a clean and uncluttered face.
-

disadvantages of counterfort retaining wall

- they can be expensive to build.
- Retaining walls require careful planning and engineering to ensure they are strong enough to hold back the soil.
- counterfort retaining walls is that they can be difficult to maintain

Figure 2. Counter Retaining Wall

2.1.5 crib retaining wall:

A crib retaining wall is a gravity retaining structure, usually employed for soil stabilization and erosion control. It consists of interlocking boxes made from precast concrete or timber, forming a crib-like framework. This framework is then filled with granular material such as gravel, soil, or rocks, which adds weight to the structure and enhances its stability. The openings in the wall allow for natural drainage, reducing hydrostatic pressure behind the wall. Crib retaining walls are favored for their flexibility and ease of installation, making them suitable for applications such as landscaping, slope stabilization, and support of embankments.

advantage of crib retaining wall

- Has a soft natural appearance that blends into the surrounding environment.
- Depending on the materials used, crib walls can be environmentally friendly options, especially if constructed with sustainable or recycled materials.
- surface and/or deep drainage systems will be provided to keep the backfill materials free from groundwater pressures
- Crib walls are relatively simple to construct, requiring fewer specialized skills and equipment compared to some other types of retaining walls.
- Compared to other retaining wall options, crib walls can be more cost-effective to build, especially for larger retaining projects.
- Durable, with very little maintenance requirements.

Disadvantage of crib retaining wall

- Compared to other retaining wall options, crib walls can be more cost-effective to build, especially for larger retaining projects.
- Crib walls are typically not suitable for very tall retaining wall applications.
- Construction of crib walls often requires significant site preparation and excavation, adding to the overall cost and time of the project.

Figure 2. Crib Retaining Wall

2.1.6 Gabion Retaining wall:

Gabion retaining wall systems are one of the oldest forms of gravity wall. Gabion walls are manufactured by factory fabricating a galvanized hexagonal wire mesh of varying diameters into box cages. These box cages are site filled with stones, cobbles, rocks, and gravel in a pattern as per design. A gabion basket is built from heavily galvanized steel wires which form a porous structure.

They are used in areas where the foundation conditions are not favorable for adopting any other retaining structures. The concept of a gabion wall is to increase the shear capacity of rock by providing the box cages. They can accommodate substantial ground movements without failures. Gabion boxes are free-draining structures that can reduce hydro-static pressure drastically.

The main purpose of a gabion wall is to stabilize the soil on coasts, river banks, roads, highways, and slopes.

In addition, gabion walls are used to build temporary flood walls, river training, and for river lining. There are several upsides to building a gabion wall on your project site or private property.

Advantage of gabion retaining wall

- using the material made by excavations the costs of acquisition and transport are significantly reduced
- gabion walls are permeable and are not damaged by passing water
- Efficiency of gabion walls can increase in time, since the vegetation fills voids and strengthens the wall structure
- Soil movements don't negatively influence gabion walls, which is an advantage in regard to stiffer structures (reinforced concrete walls)
- Easy to install.
- Simple to assemble, disassemble and reuse.

Disadvantage of gabion retaining wall

- The entire wall must be disassembled to reach the damaged area if the rocks shift or become worn down inside the metal baskets as a result of heavy water and wave activity.
- Gabion walls can require regular maintenance, such as checking for erosion, debris buildup, and ensuring the wire mesh remains intact.
- Gabions are not ideal for very high walls or structures. They are best suited for projects with a height of up to 3 meters (10 feet).

Figure 2.7 Gabion Retaining Wall

Chapter Three:

Type of failure

Sliding failure:

Sliding failure in a retaining wall structure occurs when the lateral forces exerted against the wall exceed the wall's resistance to horizontal movement, causing it to slide along its base or foundation. This type of failure can be critical, leading to substantial structural damage or collapse if not addressed promptly.

Retaining walls are designed to hold back soil, water, or other materials, and they are subjected to various forces, primarily the lateral earth pressure from the retained material. This pressure can increase due to several factors, such as increased moisture content in the soil, additional loads on the soil surface (like vehicles or buildings), seismic activity, or poor compaction during construction.

When the lateral forces exceed the frictional resistance between the base of the wall and its underlying foundation or soil, the wall begins to slide. The critical element in resisting sliding is the frictional force generated by the weight of the retaining wall pressing down on its base. The greater the friction, the more resistance to sliding. Sliding can also be resisted through additional anchoring, such as tiebacks or geosynthetic reinforcement, and by designing a wider base to increase stability.

Check for Sliding along the base

A slide results if the shear stress along some potential slip surface becomes equal to the shear strength. One possible slip surface is shown in below Figure

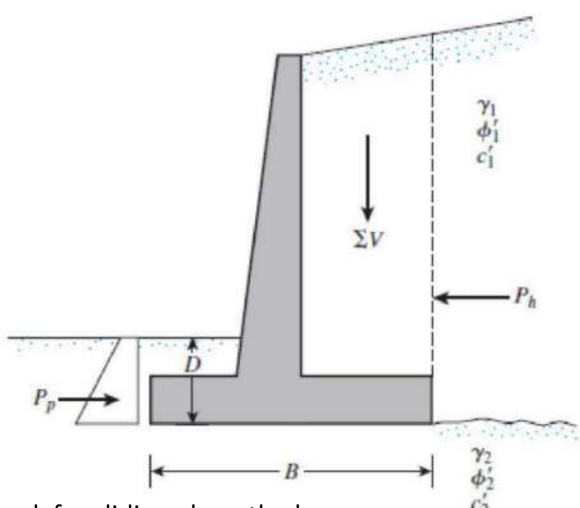


Figure 3.4: Check for sliding along the base.

The factor of safety against sliding may be expressed by the equation:

$F.S_{Sliding} = \frac{\sum F_R}{\sum F_d} \geq 1.75$

Where:

$F_R =$ Sum of the horizontal resisting forces.

$F_d =$ Sum of the horizontal driving forces.

$\sum F_R = (\sum V) * tan\delta' + BC'_a + P_P$

$\sum F_d = P_a * cos\beta$

Where:

P_P = The passive horizontal force.

$\sum V$ = Sum of the vertical forces.

$\delta' =$ The angle of friction between the soil and the base slab and may be $= \frac{2}{3}\emptyset$

$C'_a =$ Adhesion between the soil and the base slab.

$P_a =$ The active horizontal force.

$\beta =$ The angle of backfill slop.

$F.S_{Sliding} = \frac{(\sum V)*tan\delta' + BC'_a + P_P}{P_a * cos\beta}$

If the desired value of $F.S_{Sliding}$ is not achieved, several alternatives may be investigated as illustrated in Figure 3.5.

1. Increase the width of the base slab (i.e., the heel of the footing).
2. Use a key to the base slab.
3. Use a dead-man anchor at the stem of the retaining wall.

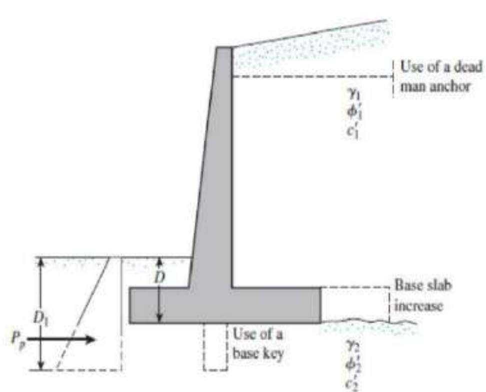


Figure 3.5: Alternatives for increasing the factor of safety with respect to sliding.

Overturning failure:

Overturning is one of the commonly observed causes for retaining wall failures.

Overturning failure is rotation of wall about its toe due to exceeding of moment caused

due to overturning forces to resisting forces.

Overturning failure occurs when the moments (rotational forces) generated by the lateral pressure behind a retaining wall exceed the resisting moments created by the wall's weight and other stabilizing factors. This imbalance leads to a rotational movement that causes the wall to tip or overturn, potentially leading to structural failure or collapse.

Check for overturning (Rotation):

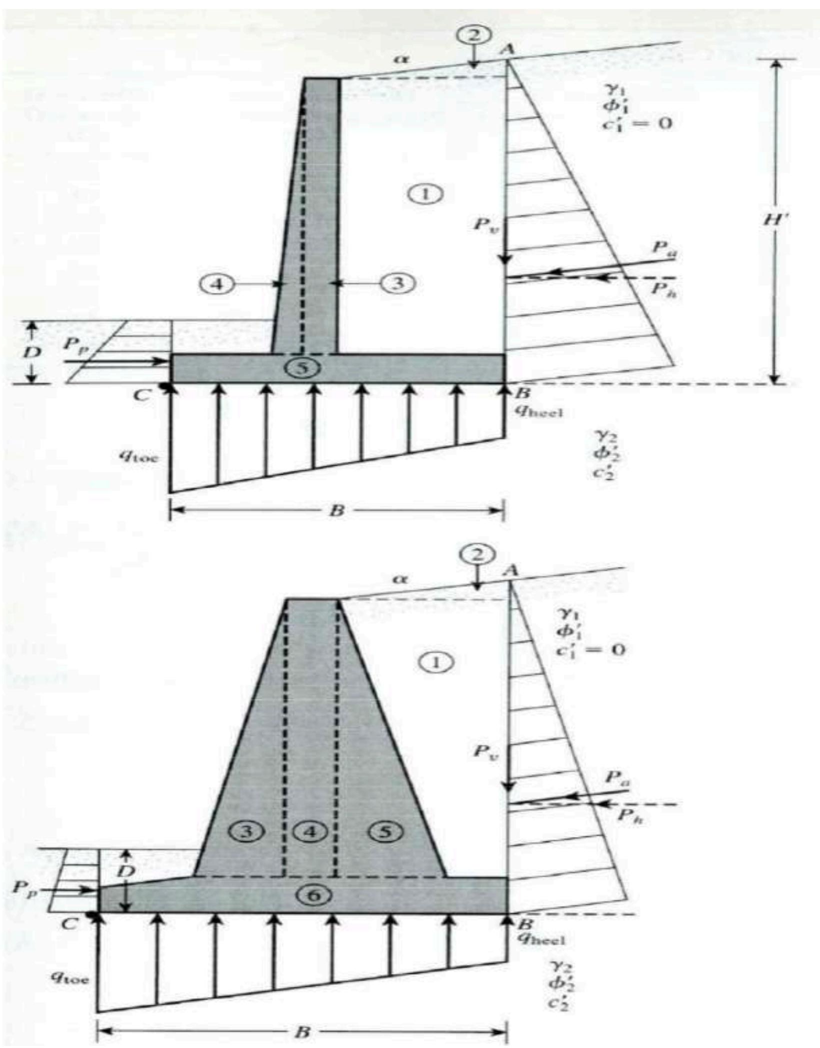


Figure 3.7 Check for overturning, assuming that the Rankine pressure is valid

The factor of safety against overturning about the toe-that is, about point C

$$F.S_{overturning} = \frac{\sum M_R}{\sum M_O}$$

Where:

$\sum M_O =$ sum of the moments of forces tending to overturn about point C

$\sum M_R =$ sum of the moments of forces tending to resist overturning about point C

The overturning moment is

$$\sum M_O = P_h(\frac{H'}{3})$$

Where $P_h = P_a * cos\alpha$

For calculation of the resisting moment, $\sum M_R$

Note that the force P_v=also contributes to the resisting moment.

P_v is the vertical component of the active force P_a

The moment of the force P_v about C is

$$M_v = P_v\, B = P_a\, sin\alpha\, B$$

Where:

B = width of the base slab

Once $\sum M_R$ is known, the factor of safety can be calculated as

$$F.S_{overturning} = \frac{M_1+M_2+M_3+M_4+M_5+M_6+M_v}{P_a * cos\alpha(\frac{H'}{3})} \geq 2$$

Section	Area	Weight/unit length of wall	Moment Arm measured from C	Moment about C
1	A_1	$W_1 = \gamma_1 * A_1$	X_1	M_1
2	A_2	$W_2 = \gamma_2 * A_2$	X_2	M_2
3	A_3	$W_3 = \gamma_C * A_3$	X_3	M_3
4	A_4	$W_4 = \gamma_C * A_4$	X_4	M_4
5	A_5	$W_5 = \gamma_C * A_5$	X_5	M_5
		P_v	B	M_v
		$\sum V$		$\sum M_R$

$\gamma_1 = unit\ weight\ of\ backfill$ & $\gamma_C = unit\ weight\ of\ concrete$

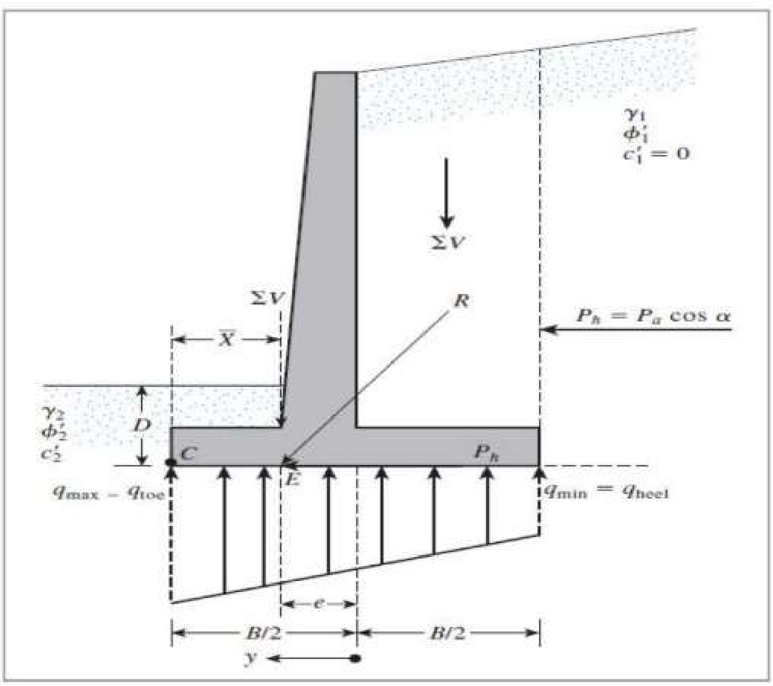
Bearing capacity failure

Bearing capacity failure in retaining wall structures is a critical structural failure that occurs when the soil or foundation supporting the wall is unable to withstand the loads exerted by the retaining wall and the materials it retains. This type of failure typically involves a loss of stability in the ground or foundation, leading to significant movement, tilting, or collapse of the retaining wall.

Check for Bearing capacity failure

The vertical pressure transmitted to the soil by the base slab of the retaining wall should be checked against the ultimate bearing capacity of the soil. The nature of variation of the vertical pressure transmitted by the base slab into the

soil is shown in Figure 3.6. Note that toe and heel are the maximum and the minimum pressures occurring at the ends of the toe and heel sections, respectively. The magnitudes of and can be determined in the following manner:



$q_{max} = \frac{\Sigma V}{area}\left(1 + \frac{6e}{B}\right)$ and $q_{min} = \frac{\Sigma V}{area}\left(1 - \frac{6e}{B}\right)$

Area =B. (1)

$q_{max} = \frac{\Sigma V}{B}\left(1 + \frac{6e}{B}\right)$

$q_{min} = \frac{\Sigma V}{B}\left(1 - \frac{6e}{B}\right)$

Where:

$$\sum V = Alegbraic\ sum\ of\ all\ the\ vertical\ forces\ includes\ the\ weight\ of\ the\ soil\ .$$

B= width of the wall base

e= the eccentricity of the resultant force on the base

$X = \frac{\sum M_{net}}{\sum v}$

$e = \frac{B}{2} - X$

$\sum M_R = P_P \times l_p + \sum W \times l_w$

$\sum M_O = P_a \times l_a$

$F.S_{Bearing\ capacity} = \frac{q_u}{q_{max}} \geq 3$

- Three different cases arise depending upon the value of (e)
    1. $e < \frac{B}{6}$
    2. $e = \frac{B}{6}$ in this case the maximum pressure can be computed as

       $q_{max} = \frac{2 \sum V}{B}$ and $q_{min} = 0$

$e > \frac{B}{6}$ in this case tension is suppose to have developed as shown. since soil is consider incapable

Of resisting Any tension, the pressure is taken to be redistributed along intact of width 3B`, where b`

Is the distance of the line of action of $\sum V$ from the toe. q_{max} is then given by:

$q_{max} = \frac{3 \sum V}{B`}$ and $q_{min} = O$

$$B' = \frac{B}{2} - e$$

Chapter Four:

Methodology

Calculate forces

1. Coefficient of Active and passive Earth pressure

Because the backfill is horizontal, the Rankine equation can be written as:

$K_a = \frac{1-sin\emptyset}{1+sin\emptyset}$ or $\tan^2(45 - \frac{\emptyset}{2})$

$K_a = \frac{1-sin30}{1+sin30}$

$K_p = \frac{1}{K_a}$

$K_a = coefficient\ of\ active\ earth\ pressure$

$K_p = coefficient\ of\ passive\ earth\ pressure$

$\emptyset = soil\ friction\ angle$

2. For active pressure:

$\sigma_1 = K_a * (\gamma_s * h_1)$

$P_1 = \frac{1}{2} * \sigma_1 * h_1$

$\sigma_1 = lateral\ earth\ pressure$

$P_1 = lateral\ earth\ pressure$

3. Surcharge pressure

$\sigma_2 = K_a * q$

$P_2 = \sigma_2 * h_2$

$\sigma_2 =$

$P_2 = lateral\ earth\ pressure$

4. Passive pressure

$\sigma_3 = K_p * (\gamma_s * h_2)$

$P_3 = \frac{1}{2} * \sigma_3 * h_2$

$\sigma_3 =$

$P_3 = lateral\ earth\ pressure$

Stability Forces

W = $\sum(\gamma * Volume)$

R$\nu = \sum \nu$

W = Weight of soil or concrete

$\gamma = density\ of\ soil\ or\ concrete$

$Volume = volume\ of\ soil\ or\ concrete\ for\ one\ meter$

Rν = sum of weights

1. **Check overturning**

F.S.O = $\frac{\sum M_R}{\sum M_O} \geq 1.5$

$\sum M_R = sum\ of$ resisting moment

$\sum M_O = sum\ of$ overturning moment

2. **Check sliding**

F.S.S = $\frac{\sum \text{R}\nu * \tan(\delta) + C'_a B + P_p}{\sum P_a}$

C'$_a$ = $\frac{2}{3}\ C'$

$\sum R_\nu$ = Sum of the vertical forces.

$\delta' =$ The angle of friction between the soil and the base slab and may be $= \frac{2}{3}$Ø

$C'_a =$ Adhesion between the soil and the base slab $= \frac{2}{3}\ C'$

P_P = The passive horizontal force.

$\sum P_a = sum\ of$ The active horizontal force.

$\beta =$ The angle of backfill slop.

3. **Check for Bearing capacity failure**

$q_{max} = \frac{\sum v}{B}\ (1 + \frac{6e}{B}) < q_{all}$

$q_{min} = \frac{\sum v}{B}\ (1 - \frac{6e}{B}) > 0$

$M_{net} = \sum M_R - \sum M_O$

$X = \frac{\sum M_{net}}{\sum v}$

$e = \frac{B}{2} - X$

$\frac{B}{6} \geq e$

$\sum V = Alegbraic\ sum\ of\ all\ the\ vertical\ forces\ includes\ the\ weight\ of\ the\ soil\ .$

B= width of the wall base

e= the eccentricity of the resultant force on the base

Analysis

At stem

$P_1 = q * k * h$

$Arm_{P_1} = \frac{1}{2} * h$

$P_2 = k * \gamma * h * \frac{1}{2}\ h$

$Arm_{P_2} = \frac{1}{3} * h$

$Moment = P_1 * Arm_{P_1} + P_2 * Arm_{P_2}$

$Shear\ force = P_1 + P_2$

$P_1 = lateral\ earth\ pressure\ for\ surcharge$

$P_2 = lateral\ earth\ pressure\ for\ active\ pressure$

At toe

$q_1 = \frac{(q_{toe} - q_{heel}) * X_1}{B} + q_{heel}$

$Shear\ force = O.W * L_1 - \frac{q_{toe} + q_1}{2} * L_1$

$O.W = \gamma_{concrete} * h$

$Moment = O.W * \frac{{L_1}^2}{2} - q_1 * \frac{{L_1}^2}{2} - (q_{toe} - q_1) * \frac{L_1}{2} * \frac{2}{3} * L_1$

At heel

$q_2 = \frac{(q_{toe} - q_{heel}) * X_2}{B} + q_{heel}$

$Shear\ force = O.W * L_1 - \frac{q_{heel} + q_1}{2} * L_1$

$O.W = \gamma_{concrete} * h_{concrete} + \gamma_{soil} * h_{soil} + surcharge$

$Moment = O.W * \frac{{L_2}^2}{2} - q_2 * \frac{{L_2}^2}{2} - (q_2 - q_{heel}) * \frac{L_2}{2} * \frac{2}{3} * L_2$

Design of section

For stem

$Vu = 1.6 * shear\ force\ in\ steam$

$\emptyset Vc = \frac{\emptyset}{6}\sqrt{f'c}bd$

If $Vu < \emptyset Vc$ → safe.

Design of flexture

$M_u = 1.6 * Moment\ in\ steam$

$R = \frac{M_u * 10^6}{\emptyset b d^2}$

$m = \frac{fy}{0.85 fc}$

$\rho = \frac{1}{m}(1 - \sqrt{1 - \frac{2Rm}{fy}})$

$A_s = \rho b d$

$A_{s\,min} = \rho_{min} b h$

$A_s > A_{s\,min}$

Longitudinal

For $A_{s\,min}$

if use $fy \geq 420$ then use 0.0012

if use $fy < 420$ then use 0.0015

if bar size $\leq No\ 16$

if $>$ No 16 & fy any then use 0.0015

Horizontal or transverse bars $A_{s\,min} = 0.0025$

For horizontal → $A_{s\,min} = 0.0025bh$

For toe

Check shear

$Vu = 1.6 * \ shear\ force\ in\ toe$

$\emptyset Vc = \frac{\emptyset}{6}\sqrt{f'c}bd$

If $Vu < \emptyset Vc$ → safe.

Design of flexture

$M_u = 1.6 * Moment\ in\ toe$

$R = \frac{M_u * 10^6}{\emptyset b d^2}$

$m = \frac{fy}{0.85 fc}$

$\rho = \frac{1}{m}(1 - \sqrt{1 - \frac{2Rm}{fy}})$

$A_s = \rho bd$

$A_{s\,min} = \rho_{min} bh$

$A_s > A_{s\,min}$

$A_b = \frac{\pi}{4} d^2$

$No. of\ bars = \frac{A_s}{A_b}$

$spacing = \frac{1000}{No\ bars}$

For Shrinkage

$A_{s\,min} = \rho_{min} bh$

For Heel

Check shear

$Vu = 1.6 * shear\ force\ in\ Heel$

$\emptyset Vc = \frac{\emptyset}{6}\sqrt{f'c}bd$

If $Vu < \emptyset Vc$ → safe.

Design of flexture

$M_u = 1.6 * Moment\ in\ toe$

$R = \frac{M_u * 10^6}{\emptyset bd^2}$

$m = \frac{fy}{0.85fc}$

$\rho = \frac{1}{m}(1 - \sqrt{1 - \frac{2Rm}{fy}})$

$A_s = \rho bd$

$A_{s\,min} = \rho_{min} bh$

$A_b = \frac{\pi}{4} d^2$

$No.of\ bars = \frac{A_s}{A_b}$

$spacing = \frac{1000}{No\ bars}$

For Shrinkage

$A_{s\ min} = \rho_{min} bh$

$A_b = \frac{\pi}{4} d^2$

$No.of\ bars = \frac{A_s}{A_b}$

$spacing = \frac{1000}{No\ bars}$

Chapter Five:

Example

Design of cantilever wall to retain a bank of earth 5m Hight above ground level the bottom of base is 1m below ground level. the soil has density of 1.8 t/m^3 and angle of friction of 30^o. The surface of the bank is horizontal and is subjected to surcharge of 1.5 t/m^2. The allowable pressure on soil is 1.5 kg/cm^2.

take $Fc'=200\ kg/cm^2$, $fy= 3600\ kg/cm^2$.

Solution:

According to the Rankine method showed in figure (666) & our design retaining wall showed in figure (666) below.

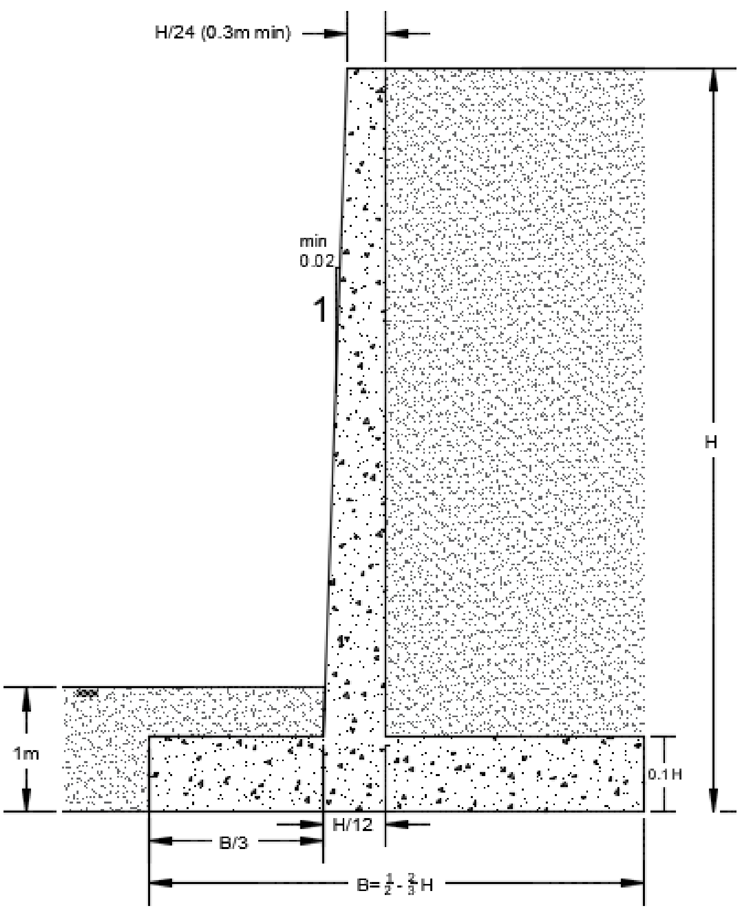


Figure (666): Rankine Method

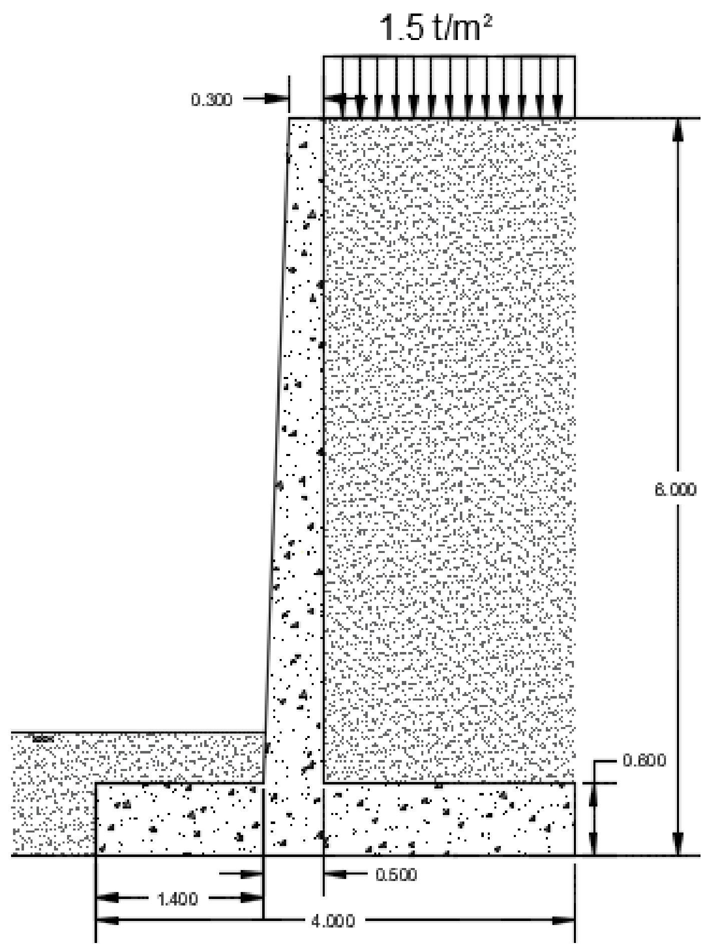


Figure (666): Retaining Wall

Calculate forces

coefficient of Active and passive Earth pressure coefficient

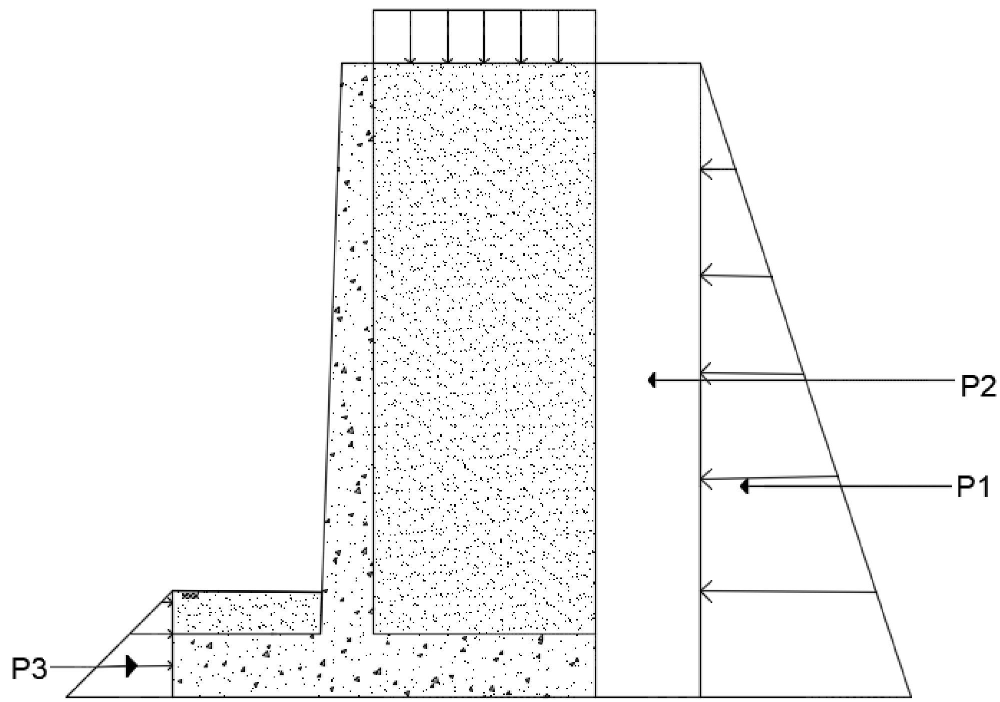
Because the backfill is horizontal, the Rankine equation can be written as:

Ka = $\frac{1-sin\emptyset}{1+sin\emptyset}$ or $\tan^2(45 - \frac{\emptyset}{2})$

Ka = $\frac{1-sin30}{1+sin30} = \frac{1}{3}$

$K_p = \frac{1}{K_a}$

$K_p = \frac{1}{\frac{1}{3}} = 3$



For active pressure:

σ_1 = Ka * $(\gamma_s * h_1)$

$\sigma_1 = \frac{1}{3}$ * (1.8 * 6) = 3.6 ton/m^2

$P_1 = \frac{1}{2} * \sigma_1 * h_1$

$P_1 = \frac{1}{2}$ * 3.6 * 6 = 10.8 ton

Surcharge pressure

$\sigma_2 = K_a * q$

$\sigma_2 = \frac{1}{3}$ * 1.5 = 0.5 ton/m^2

$P_2 = \sigma_2 * h_2$

P_2 = 0.5 * 6 = 3 ton

Passive pressure

$\sigma_3 = K_p * (\gamma_s * h_2)$

σ_3 = 3 * (1.8 * 1) = 5.4 ton/m^2

$P_3 = \frac{1}{2} * \sigma_3 * h_2$

$P_3 = \frac{1}{2}$ * 5.4 * 1 = 2.7 ton

Stability Forces

W = $\sum(\gamma * Volume)$

$W_1 = \frac{1}{2} * 0.2 * 5.4 * 1 * 2.5 = 1.35\ ton$

$W_2 = 0.3 * 5.4 * 1 * 2.5 = 4.05\ ton$

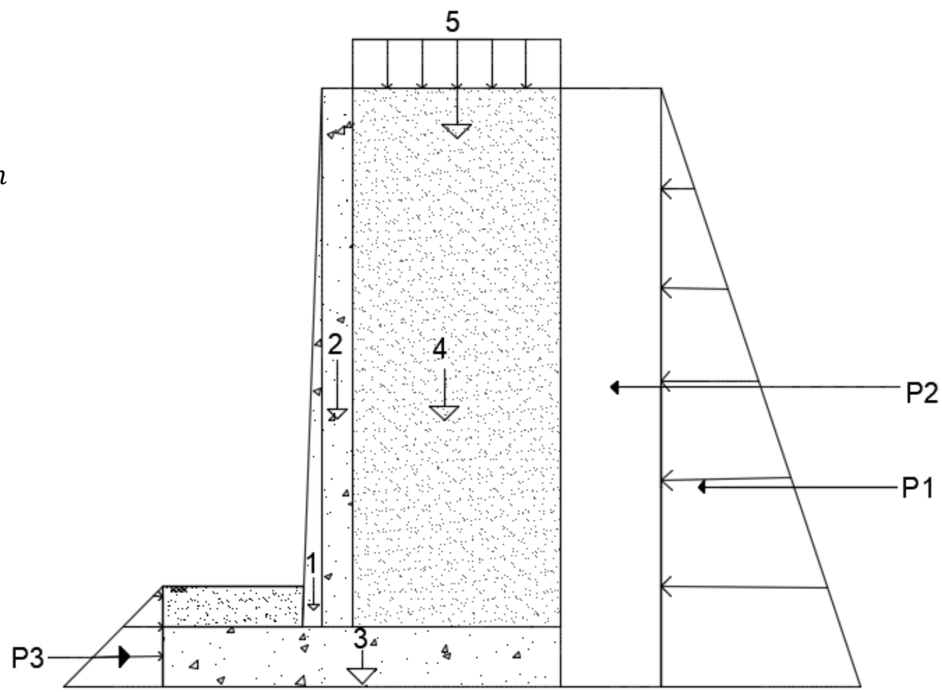
$W_3 = 4 * 0.6 * 1 * 2.5 = 6\ ton$

$W_4 = 2.1 * 5.4 * 1 * 1.8 = 20.412\ ton$

$W_5 = 2.1 * 1.5 * 1 = 3.15\ ton$

The sum of these weight:

$R\nu = \sum \nu = 34.962$ ton



Check overturning

$$F.S.O = \frac{\sum M_R}{\sum M_O} \geq 1.5$$

The resisting moment and the overturning moment are shown in the following tables.

Table (777): The resisting moments.

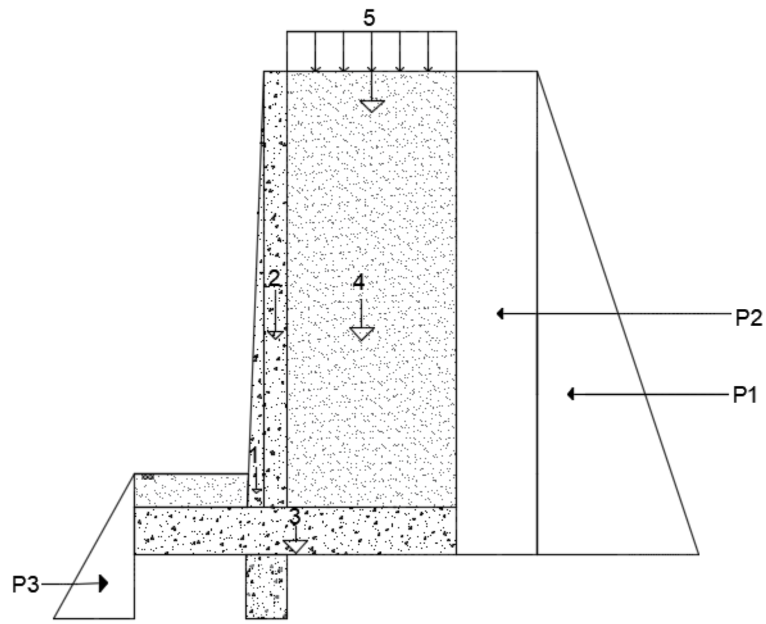
Force (ton)	Arm (m)	Moment around toe (ton. m)
W_1 = 1.35	1.533	2.07
W_2 = 4.05	1.75	7.0875
W_3 = 6	2	12
W_4 = 20.412	2.95	60.215
W_5 = 3.15	2.95	9.293
		$\sum$ 90.67

Table (777): the overturning moments.

Force (ton)	Arm (m)	Moment around toe (ton. m)
P_1 = 10.8	2	21.6
P_2 = 3	3	9
		30.6

F.S.O = $\frac{90.67}{30.6} = 2.96 \geq 1.5$ .... ok it's safe.

Check sliding



F.S.S = $\frac{\sum R\nu * \tan(\delta) + C'_a B + P_p}{\sum P_a}$

C'$_a$ = $\frac{2}{3}\ C' = \frac{2}{3} * 0 = 0$

$\delta = \frac{2}{3}\ \emptyset = \frac{2}{3} * 30 = 20^o$

F.S.S = $\frac{34.962 * \tan(20) + 0 + 2.7}{13.8} = 1.12\ \leq 1.5$ unsafe.

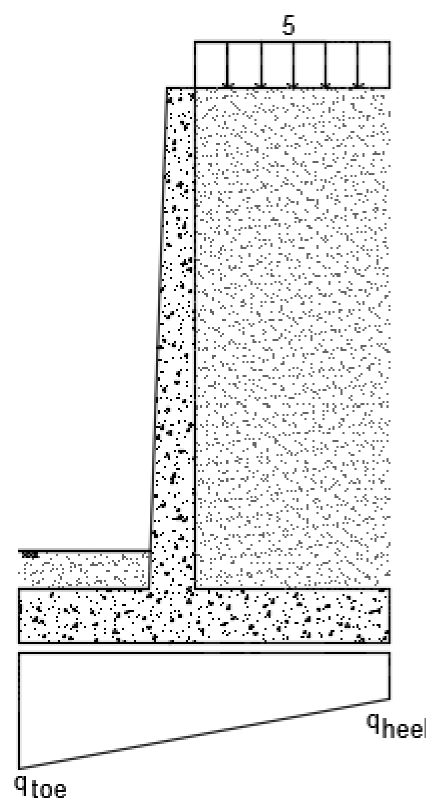
Try a toy key 0.8m deep.

σ_3 = 3 * (1.8 * 1.8) = 9.72 ton/m^2

P$_3$ = $\frac{1}{2}$ * 9.72 * 1.8 = 8.75 ton

F.S.S = $\frac{34.962 * \tan(20) + 0 + 8.75}{13.8} = 1.56\ \geq 1.5$ .... ok it's safe.

Checking for bearing capacity of the soil:



$q_{max} = \frac{\sum \nu}{B}\ (1 + \frac{6e}{B}) < q_{all}$

$q_{min} = \frac{\sum \nu}{B}\ (1 - \frac{6e}{B}) > 0$

$M_{net} = \sum M_R - \sum M_O$ = 90.67 − 30.6 = 60.07 ton. m

$X = \frac{\sum M_{net}}{\sum \nu} = \frac{60.07}{34.962}$ = 1.72m

e = $\frac{B}{2} - X = \frac{4}{2} - 1.72$ = 0.28m

$\frac{B}{6} = 0.667\ \geq e = 0.28$ ok

$q_{max} = \frac{\sum 34.962}{4}\ (1 + \frac{6*0.28}{4})$ = 12.42 < q_{all} = ??? .... ok it's safe.

$q_{min} = \frac{\sum 34.962}{4}\ (1 - \frac{6*0.28}{4})$ = 5.06 > 0 .... ok it's safe.

Analysis

At stem

$P_1 = q * k * h$

$P_1 = \frac{1}{3} * 1.5 * 5.4 = 2.7\ ton$

$Arm = \frac{1}{2} * h = \frac{1}{2} * 5.4 = 2.7m$

$P_2 = k * \gamma * h * \frac{1}{2}\ h$

$P_2 = \frac{1}{3} * 1.8 * 5.4 * \frac{1}{2} * \ 5.4 = 8.75\ ton$

$Arm = \frac{1}{3} * h = \frac{1}{3} * 5.4 = 1.8m$

$Moment = 2.7 * 2.7 + 8.75 * 1.8\ = 23.04\ ton.m$

$Shear\ force = P_1 + \ P_2 = 2.7 + 8.75 = 11.45\ ton$

At toe

$q_1 = \frac{(q_{toe} - q_{heel}) * X_1}{B} + \ q_{heel}$

$q_1 = \frac{(12.42 - 5.06) * 2.6}{4} + \ 5.06 = 9.85\ t/m^2$

$Shear\ force = O.W * L_1 - \frac{q_{toe} + q_1}{2} * \ L_1$

$O.W = \gamma_{concrete} * h = 2.5 * 0.6 = 1.5\ t/m^2$

$Shear\ force = 1.5 * 1.4 - \frac{12.42 + 9.85}{2} * \ 1.4 = 13.5\ ton$

$Moment = O.W * \frac{{L_1}^2}{2} - q_1 * \frac{{L_1}^2}{2} - (q_{toe} - \ q_1) * \frac{L_1}{2} * \frac{2}{3} * L_1$

$Moment = 1.5 * \frac{1.4^2}{2} - 9.85 * \frac{1.4^2}{2} - (12.42 - \ 9.85) * \frac{1.4}{2} * \frac{2}{3} * 1.4 = 9.86\ ton.m \rightarrow at\ bottom$

At heel

$$q_2 = \frac{(q_{toe} - q_{heel}) * X_2}{B} + q_{heel}$$

$$q_2 = \frac{(12.42 - 5.06) * 2.1}{4} + 5.06 = 8.92\ t/m^2$$

$$Shear\ force = O.W * L_1 - \frac{q_{heel} + q_1}{2} * L_1$$

$$O.W = \gamma_{concrete} * h_{concrete} + \gamma_{soil} * h_{soil} + surcharge$$

$$O.W = 2.5 * 0.6 + 5.4 * 1.8 + 1.5 = 12.72\ t/m^2$$

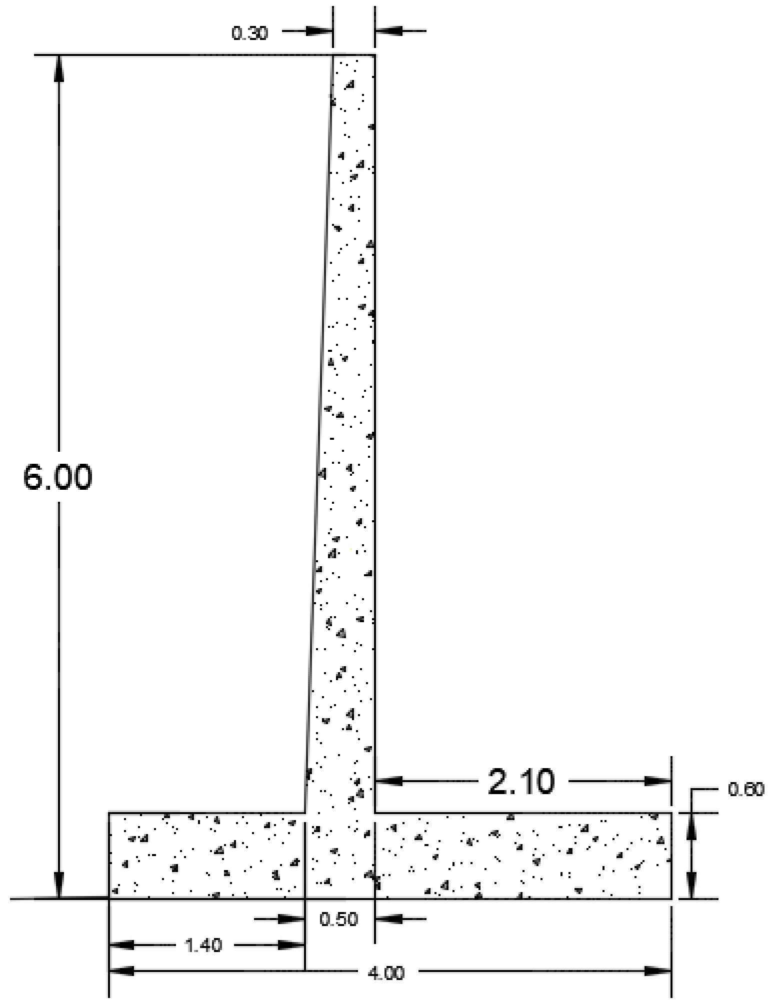
$$Shear\ force = 12.72 * 2.1 - \frac{5.06 + 8.92}{2} * 2.1 = 12.03\ ton$$

$$Moment = O.W * \frac{{L_2}^2}{2} - q_2 * \frac{{L_2}^2}{2} - (q_2 - q_{heel}) * \frac{L_2}{2} * \frac{2}{3} * L_2$$

$$Moment = 12.72 * \frac{2.1^2}{2} - 5.06 * \frac{2.1^2}{2} - (8.92 - 5.06) * \frac{2.1}{2} * \frac{2}{3} * 2.1 = 11.22\ ton.m \rightarrow at\ top$$

Design of section

For stem



$Vu = 1.6 * 11.45 = 18.32\ ton$

$\emptyset Vc = \frac{\emptyset}{6}\sqrt{f'c}bd$

$\emptyset Vc = \frac{0.75}{6}\sqrt{20} * 1000 * 430 = 24.04\ ton$

$Vu\ (18.32) < \emptyset Vc\ (24.04)$ → safe.

Design of flexture

$M_u = 1.6 * 23 = 36.8\ ton.m$

$R = \frac{M_u*10^6}{\emptyset bd^2}$

$R = \frac{36.8*10^6}{0.9*1000*430^2} = 2.2\ MPa$

$m = \frac{fy}{0.85fc} = \frac{360}{0.85*20}$=21.18

$\rho = \frac{1}{m}(1 - \sqrt{1 - \frac{2Rm}{fy}})$

$\rho = \frac{1}{21.18}\left(1 - \sqrt{1 - \frac{2*2.2*21.18}{360}}\right) = 6.6 * 10^{-3}$

$A_s = \rho bd = 6.6 * 10^{-3} * 1000 * 430 = 2840mm^2/m$

$A_{s\ min} = \rho_{min}bh = 0.0015 * 1000 * 500 = 750mm^2/m$

$A_s(2840mm^2/m) > \ A_{s\ min}(750mm^2/m)$

Use Ø25 , $A_b = \frac{\pi}{4}d^2 = \frac{\pi}{4}25^2 = 491mm^2$

$No.of\ bars = \frac{A_s}{A_b} = \frac{2840}{491} \approx 5.8$

Use 6Ø25 → at right

$spacing$=$\frac{1000}{No\ bars} = \frac{1000}{6} = 166.66\ mm = 160\ mm$

Use 6Ø25@160$mm\ c/c$

Longitudinal

For $A_{s\ min}$

if use $fy \geq 420$ then use 0.0012

if use $fy < 420$ then use 0.0015

if bar size $\leq No\ 16$

if > No 16 & fy any then use 0.0015

Horizontal or transverse bars $A_{s\ min} = 0.0025$

For horizontal → $A_{s\ min} = 0.0025bh = 0.0025 * 1000 * 500 = 1250\ mm^2/m$

$For\ one\ side = \frac{1250}{2} = 625\ mm^2/m$

Use Ø12 , $A_b = \frac{\pi}{4}d^2 = \frac{\pi}{4}12^2 = 113mm^2$

$No. of\ bars = \frac{A_s}{A_b} = \frac{625}{113} \approx 5.5$

Use 6Ø12

$spacing = \frac{1000}{No\ bars} = \frac{1000}{6} = 166.66\ mm = 160\ mm$

Use 6Ø12@160$mm\ c/c$

For toe

Check shear

$Vu = 1.6 * 13.72 = 21.95\ ton$

$\emptyset Vc = \frac{\emptyset}{6}\sqrt{f'c}bd$

$\emptyset Vc = \frac{0.75}{6}\sqrt{20} * 1000 * 530 = 29.63\ ton$

$Vu\ (21.95) < \emptyset Vc\ (29.63)$ → safe.

Design of flexture

$M_u = 1.6 * 10 = 16\ ton.m$

$R = \frac{M_u * 10^6}{\emptyset bd^2}$

$R = \frac{16*10^6}{0.9*1000*530^2} = 0.63\ MPa$

$m = \frac{fy}{0.85fc} = \frac{360}{0.85*20}$=21.18

$\rho = \frac{1}{m}(1 - \sqrt{1 - \frac{2Rm}{fy}})$

$\rho = \frac{1}{21.18}\left(1 - \sqrt{1 - \frac{2*0.63*21.18}{360}}\right) = 1.8 * 10^{-3}$

$A_s = \rho bd = 1.8 * 10^{-3} * 1000 * 530 = 954\ mm^2/m$

$A_{s\,min} = \rho_{min} bh = 0.002 * 1000 * 600 = 1200 mm^2/m$

$A_s(954\ mm^2/m) < A_{s\,min}(1200\ mm^2/m)$ use $A_{s\,min}(1200\ mm^2/m)$

Use Ø16 , $A_b = \frac{\pi}{4}d^2 = \frac{\pi}{4}16^2 = 201\ mm^2$

$No.of\ bars = \frac{A_s}{A_b} = \frac{1200}{201} \approx 5.97$

Use 6Ø16 → at Bottom

$spacing = \frac{1000}{No\ bars} = \frac{1000}{6} = 166.66\ mm = 160\ mm$

Use Ø16@160 $mm\ c/c$

For Shrinkage

$A_{s\,min} = \rho_{min} bh$

$A_{s\,min} = 0.002 * 1000 * 600 = 1200 mm^2/m$

Use Ø16 , $A_b = \frac{\pi}{4}d^2 = \frac{\pi}{4}16^2 = 201\ mm^2$

$No.of\ bars = \frac{A_s}{A_b} = \frac{1200}{201} \approx 5.97$

Use 6Ø16

$spacing = \frac{1000}{No\ bars} = \frac{1000}{6} = 166.66\ mm = 160\ mm$

Use Ø16@160 $mm\ c/c$

For Heel

Check shear

$Vu = 1.6 * 12.03 = 19.25\ ton$

$\emptyset Vc = \frac{\emptyset}{6}\sqrt{f'c}bd$

$\emptyset Vc = \frac{0.75}{6}\sqrt{20} * 1000 * 530 = 29.63\ ton$

$Vu\ (19.25) < \emptyset Vc\ (29.63)$ → safe.

Design of flexture

$M_u = 1.6 * 11.22 = 17.95\ ton.m$

$R = \frac{M_u * 10^6}{\emptyset bd^2}$

$R = \frac{17.95*10^6}{0.9*1000*530^2} = 0.71\ MPa$

$m = \frac{fy}{0.85fc} = \frac{360}{0.85*20}$=21.18

$\rho = \frac{1}{m}(1 - \sqrt{1 - \frac{2Rm}{fy}})$

$\rho = \frac{1}{21.18}\left(1 - \sqrt{1 - \frac{2*0.71*21.18}{360}}\right) = 2 * 10^{-3}$

$A_s = \rho bd = 2 * 10^{-3} * 1000 * 530 = 1068\ mm^2/m$

$A_{s\ min} = \rho_{min} bh = 0.0015 * 1000 * 600 = 1200mm^2/m$

$A_s(1068\ mm^2/m) < A_{s\ min}(1200\ mm^2/m)$ use $A_{s\ min}(1200\ mm^2/m)$

Use Ø16 , $A_b = \frac{\pi}{4}d^2 = \frac{\pi}{4}16^2 = 201\ mm^2$

$No.of\ bars = \frac{A_s}{A_b} = \frac{1200}{201} \approx 5.97$

Use 6Ø16 → at Bottom

$spacing = \frac{1000}{No\ bars} = \frac{1000}{6} = 166.66\ mm = 160\ mm$

Use Ø16@160 $mm\ c/c$

For Shrinkage

$A_{s\ min} = \rho_{min} bh$

$A_{s\ min} = 0.002 * 1000 * 600 = 1200mm^2/m$

Use Ø16 , $A_b = \frac{\pi}{4}d^2 = \frac{\pi}{4}16^2 = 201\ mm^2$

$No.of\ bars = \frac{A_s}{A_b} = \frac{1200}{201} \approx 5.97$

Use 6Ø16

$spacing = \frac{1000}{No\ bars} = \frac{1000}{6} = 166.66\ mm = 160\ mm$

Use Ø16@160 $mm\ c/c$