GABION VIS-À-VIS CONVENTIONAL RETAINING WALLS

FINAL YEAR PROJECT UG 2016

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This is to certify that the

Final Year Project Titled

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ABSTRACT

Soil is a complex material and one of the complexities associated with the soil mass is exertion of lateral earth pressure. Due to this pressure, lateral displacements along the slopes can occur which will further destabilize the slope and can have very dire impacts on construction projects like roads, dams or bridges. There are number of existing techniques engineered to retain soil mass. Retaining walls are the most commonly and extensively used techniques. There are some limitations or challenges faced while constructing conventional retaining structures. Like once we surpass a certain height, Performance of conventional structures drops significantly. To counter this problem, Economy of the project must be compromised. Apart from that it has some serious Environmental impacts because of the extensive concreting and structure will be Un-Sustainable and Un-Economical.

Because of severe impacts of concreting, World is moving towards Energy Efficient Structures. Mechanically Stabilized Earth Structures (**MSE**) or Hybrid Structures and Gabion Retaining Walls are modern solutions. There is no concreting involved in construction procedure of these retaining walls so there are no Environmental impacts. But there are some challenges as well regarding the implementation techniques and Design of the gabion walls. This research is aiming towards the comparative analysis of Gabion Retaining Walls and Conventional Retaining Walls along with Design optimization of Gabion Retaining Walls to overcome the shortcomings associated with the Design Constraints of Gabion retaining walls to further enhance the functionality and Performance of Gabion retaining structures.

Keywords: Retaining Walls, Gabion Retaining Walls, Environment Friendly Retaining Walls, Conventional Retaining Walls, Excel VBA, Design Sheets, Analysis Sheets, Automated Design Sheets, Programming.

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List of Abbreviations
SBC-Soil Bearing capacity
FOS-Factor of Safety
BOQ-Bill of Quantities
VBA-Visual Basic Applications

CHAPTER 1

INTRODUCTION

1.1 Background

As the load of the structure is, ultimately, transferred to ground so it is important to know the Soil conditions of Site. You need to ask some questions before you can begin construction process like: “What is the type of soil?”, “What is the saturation level?”, “Is the soil Stable or not?”. Therefore, Soil plays an important role in the stability of any structure. So, for the stability of the soil, it is important to know the associated properties. As if the soil is stable so is out structure. It is pertinent to know the properties of the soil. On the contrary, there are number of factors which can lead to De-stabilization of the soil and ultimately De-stabilization of the existing structure which has detrimental effects not only on financial ground but sometimes it can cause loss of human life.

So, to overcome this problem, Stabilization of soil is the prime concern of any site Engineer. Soil Stabilization is generally referred to “Slope Stability”. There are number of techniques used for slope stability. But most used techniques are “Retaining Structures”. These structures are further classified into different types which will be discussed later. Apart from that, there are other techniques like Soil Nailing, Rock Bolting, Vegetation etc. But our interest for this research will be the construction and impacts of retaining structures and how it can be made efficient.

There are further division among Retaining structures i.e. Conventional Retaining structures and Modern or Environmentally Friendly retaining structures but the main concept behind the retaining structures is same which is the comparison of structural resistive force and retention material exertive force. If the Resistive force is greater than the Exertive force, then our structure is stable and vice versa.

Conventional Retaining Structures are constructed using concrete, steel etc. e.g. Cantilever Retaining Walls, Gravity Retaining Walls etc. These walls have Environmental impacts as concrete is being used while Gabion Retaining Walls, which are Environmentally friendly, do not use concrete or any other such material.

1.2 Problem Statement

As the world is moving towards Green buildings or Environmentally Friendly Structures, Massive Concreting is required for the construction of Conventional Retaining Structures. As we know that Concrete has high heat of Hydration and Emits Carbon Dioxide which has negative impacts on Environments. On the Contrary, Gabion Retaining Structures are entirely Concrete free, so it is an acceptable alternative. But there is no definite research regarding the comparison among these two types of Retaining walls to give us the definite answer regarding Economy, sustainability or Structure stability of these structures.

So, this study aims to perform comparison of Gabions with Conventional retaining Walls regarding Performance, Economy and Sustainability along with Design optimization of Gabion retaining wall.

1.3 Objectives

There are two main objectives of this study. These are:

- Comparative analysis based on
    - Stability
    - Economy
    - Sustainability
- Design Optimization of Gabion Retaining Walls

1.4 Over-view of Chapters

Chapter 2 elaborates the literature view which has been done to carry out this research. First and foremost is to understand the behavior of soil and how it will behave under loading condition. Understanding of properties associated with siding and how these properties effects the sliding. Research papers, books or techniques which have been reviewed and consulted will be mentioned in references.

Chapter 3 deals with the theoretical background of the techniques used for the retention. It explains the theory and concept behind Cantilever Retaining Walls, Gravity Retaining Walls and gabion Retaining Walls. It also points out the limitation associated with the Conventional Retaining Walls and Environmental impacts associated with these retaining structures and why the need of Environment friendly structure arises. Apart from that, it individually explains all these structures as well.

Chapter 4 deals with explanation of the methodology which has been used in our study which includes Performance base analysis for which an Excel Sheet is designed which will give us the Internal and External Stability of the Structure. After that, Economic Analysis is performed out to check the financial requirements of these walls and last but not the least, Environmental Impact Assessment Report is made. Different Software's are used, like GEO-5 and TEKLA TEDD, to counter check the results.

Chapter 5 consists of Results and Discussions.

Chapter 6 contains Conclusion of the study.

CHAPTER 2

LITERATURE REVIEW

Retention of soil and other earth materials in sloppy territories has always been one of the main concerns of Geotechnical Engineers. These structures have been used since classical times for the improvement of the functionality, efficiency and aesthetics of various properties. Numerous studies have been done to analyze which material could serve this purpose. Depending on the materials and design techniques, various types of retaining walls were introduced. Some of them prove to be superior based on their stability and performance, while some are relatively cost effective. The performance and stability of latter can be enhanced by design improvements. One of these types is Gabion retaining walls which are combination of rectangular or square baskets of galvanized steel wire mesh filled with stones.

Conventional retaining structures constitute the following:

- Gravity Wall
- Cantilever Wall
- Counterfort Cantilever Wall etc.

There are many studies conducted regarding the stability and performance of these conventional retaining walls. The main factor that is to be considered while analyzing the stability of any retaining structure is Earth Pressure. Many theories were presented to quantify the coefficients to calculate the earth pressures. Two main theories are mentioned below:[1]

1) Rankine's Earth Pressure Theory
2) Coulomb's Earth Pressure Theory

Both theories differ from each other based on their assumptions. With the help of these theories, the pressure to be countered can be easily calculated. By performance-based analysis means to evaluate Factor of Safety for the Sliding, Overturning and Bearing Capacity.[2]

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[1] Principles of Geotechnical Engineering 7th ed. by B. M. Das. (Chapter:13)

[2] Principles of Foundation Engineering 8th ed. by B. M. Das (Chapter 13)

Whether the wall is rigid or semi rigid, there external stabilities could be checked using these approaches of calculating factors of safety. As discussed earlier, rigid or conventional retaining walls are relatively more stable than semi rigid retaining walls. The main type of stability to be compared is their Internal Stability. Cantilever walls are internally stabilized by providing reinforcement to counter moments in each part. The design standard commonly followed for this purpose is ACI-318. For Gabion Walls, the internal stability is dependent upon Gabion to Gabion friction, joint tensile strength, resistance of each basket layer to overturning, resistance to subsidence of foundation and stager of the gabion layers. If these factors are taken into consideration while designing Gabion Walls, their internal stability could surely be improved while ensuring their cost effectiveness at the same time.

Gabion retaining walls are also subjected to following constructability failures:[3]

- Corrosion of wire mesh
- Bulging of baskets
- Erosion of stones
- Backfill cracks
- Foundation soil erosion

Solutions to above mentioned problems are also presented to make them prone to such failures.

The feasibility of gabion walls over conventional walls is assessed on the following advantages:[4]

- Economical
- Flexibility
- Permeability
- Durability
- Sustainability

Studies suggest that if proper design improvements are made in the gabion structures, they prove to be efficient and economical than other retaining walls.

A few comparisons between these walls are made to assess effectiveness of each type. Various software and design sheets are developed for the analysis and design of these walls. Excel sheets are used widely because of availability of MS Excel in wide range.

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[3] "Failures of Gabion Walls" published by Ganesh Chikute and Ishwar Sonar in September 2019.

[4] "Engineering feasibility of Gabion Structures over Reinforced Concrete Structures" published by Saleem Yousuf Shah, Zahoor ul Islam and Shakeel Ahmed in October 2018

To make these sheets simpler and user friendly, Visual Basic Applications in the backend of the Excel could be used. As far as the cost analysis is concerned, the quick way is to use Revit software.

One of the important advantages of using Gabion walls over other walls is that they are environment friendly. Any massive structure made from concrete results into Carbon emissions that could further pose ecological imbalance. Reinforced Wall construction uses fine aggregates that adds dust to the atmosphere. Thus, any type of concrete structure causes unfit environmental issues during their construction. In contrast, Gabion walls are sustainable and do not pose such environmental issues.[5]

Thus, if a detailed comparison is made between Gabion Walls and conventional retaining walls, Gabion walls should prove to be more stable, economical and sustainable than other wall types.

"Engineering feasibility of Gabion Structures over Reinforced Concrete Structures" published by Saleem Yousuf Shah, Zahoor ul Islam and Shakeel Ahmed in October 2018

CHAPTER 3

THEORETICAL BACKGROUND

3.1 RETAINING WALLS

Retaining walls are the structure that are designed to retain the earth material and to resist lateral pressure. The lateral pressure of soil can be due to different causes such as the pressure of earth mass or pore water pressure. There are various types of retaining walls based on the purpose they serve. Their function can be as to provided change in elevation of ground that is more that natural slope existing in ground, to stabilize the slope and to provide resistance against land sliding. They can also provide the resistance against the erosion and sloughing.

3.1.1 Lateral Earth Pressure on Retaining Walls

Lateral earth pressure is the major force that acts on retaining wall, it results in sliding, bending, and overturning of wall. It is caused by the retained backfill in the horizontal plane. The purpose of retaining wall is to hold back the soil mass behind it, so as a reaction it must apply equal and opposite forces to stabilize the forces caused by retained soil mass. The vertical effective pressure (σ_v) and horizontal effective pressure (σ_h) are considered in analysis of plane strain condition. Craig, (1992) had defined the lateral earth pressure that it is the stress that exist between retained earth mass and adjacent retaining wall in horizontal plane. The ratio of vertical effective pressure (σ_v) and horizontal effective pressure (σ_h) is defined as the coefficient of lateral pressure, K. This coefficient is used to calculate the lateral earth pressure by considering three cases as coefficient of pressure at rest, coefficient of pressure at active pressure and passive coefficient of pressure. Case 1 is defined as wall is at rest, active defines that wall rotate away from retained earth and passive defines that wall rotate towards the retained earth mass about it bottom. The lateral earth pressure acts on face of retaining wall in horizontal plane and tends to generate moment that rotate the wall in outward direction. The objective of understanding concept of lateral earth pressure is to design the retaining wall that must be capable resisting this pressure and failures induced by these stresses in their entire design life.

3.1.1.1 Rankine's and coulomb's theory of lateral earth pressure

Lateral earth pressure of retained earth mass is calculated by using theories of lateral earth pressure. To obtain the accurate magnitude of strains and stresses that exist in earth mass a complete analysis of equilibrium equations, stress and strain relationships, and boundary conditions is required. Practically it is difficult to know all the boundary condition for solving differential equations in analysis of lateral earth pressure. That is why we cannot have the solution of lateral pressure with sufficient degree of precision, so geotechnical engineer seeks the help of theories to find the magnitude of lateral pressure.

The lateral earth pressure can be calculated by two most widely accepted theories, the Rankine's theory of active earth pressure (1857) and Coulomb theory of lateral earth pressure (1776). Both theories gave the numerical relations for calculating earth pressure as listed in Table 3.1 and Table 3.2. There are five considerations in the use of these theories. First consideration is that in backfill the soil has granular and cohesionless particles, there is very negligible amount if fine grain soil. Second consideration is that the soil is same throughout (Homogenous). Thirdly the soil has same properties of stress and strain in all direction (isotropic soil.). The fourth consideration is that wall extends to in-finite depth and retained earth mass is undisturbed. The last consideration is the retained earth mass is well drained, so we can neglect pore water pressure. These theories are considered for calculating lateral earth pressure of soil.

The theory of Rankine's earth pressure was presented by William Rankine. This theory is used to calculate lateral pressure on wall considering cases of rest, passive and active pressure by using numerical relations based on soil properties. Behind the frictionless wall it considers an element of soil mass. The rotational movement of wall about its base produce the active and passive pressure in wedge of soil considered between frictionless wall and failure plane. Active earth pressure occur when wall rotates away from retained soil about its base point. As wall moves away from the retained earth mass so the magnitude of principal stress will decrease gradually until it reaches to limiting strength(tensile) value of soil. Passive earth pressure of soil occurs when the wall rotates toward retained soil about its base point. Due to this moment the value of effective stress σ_h increases to maximum. The way in which wall yields has a great influence on pressure distribution of earth pressure. Sufficient deformation occurs to reaching the active and passive pressure. The lateral strain should exist at top of wall and the point about which the wall rotates must be its base. The strain at top of wall gets zero if the wall rotates about top. Pressure at rest condition applies at zero value of lateral strain. The numerical relations for Rankine's theory are listed in the Table 3.1.

Table 3.1: Formulae of Rankine Theory of Earth Pressure, where z = depth, Ø = soil friction angle

State	Lateral Earth Pressure Coefficient	Pressure
Active	$Ka = \frac{\cos\beta - \sqrt{(\cos\beta^2 - \cos\text{Ø}^2)}}{\cos\beta + \sqrt{\cos\beta^2 - \cos\text{Ø}^2}}$	$P_a = K_a \gamma z \cos\beta$
Passive	$Kp = \frac{\cos\beta + \sqrt{(\cos\beta^2 - \cos\text{Ø}^2)}}{\cos\beta - \sqrt{\cos\beta^2 - \cos\text{Ø}^2}}$	$P_p = K_p \gamma z \cos\beta$
At-rest	k_O can be calculated by experiment of triaxial test	$P_o = K_0 \gamma' z$

The Coulomb's theory of lateral earth pressure was presented by Charles Augustin Coulomb in 1776. He was first to consider the concept of analyzing the earth pressure for retaining walls. His theory has similarity to Rankine's theory with some difference of assumptions. The theory of Coulomb does not consider the wall at rest case. One of the assumptions of Rankine's theory was to consider wall as frictionless whereas Coulomb consider wall friction into account by direct shear test. Coulomb's theory will give same results as Rankine if the wall friction is zero. The limit equilibrium theory is used to calculate the value of active earth coefficient and passive earth coefficient, Kp. Coulomb considers that the failure surface of wall is a plane. There many possible failure planes, each plane must be considered and analyzed. The theory of Coulomb' earth pressure gives generally overestimated passive pressure and underestimated active pressure. The numerical relation for Coulomb's theory for listed in the Table 3.2.

Table 3.2: Formulae of Coulomb Theory of Earth pressure, where δ= wall friction angle, Ø = soil friction angle and H= height of the wall

State	Lateral Earth Pressure Coefficient	Pressure
Active	$Ka = (\frac{\sin(\alpha - \emptyset)/\sin\alpha}{(\sqrt{\sin(\alpha+\delta)} + \sqrt{\frac{\sin(\emptyset+\delta)\sin(\emptyset-\beta)}{\sin(\alpha-\beta)}}})^2$	$P_a = \frac{1}{2}K_a\gamma H^2$
Passive	$Kp = (\frac{\sin(\alpha - \emptyset)/\sin\alpha}{(\sqrt{\sin(\alpha+\delta)} - \sqrt{\frac{\sin(\emptyset+\delta)\sin(\emptyset-\beta)}{\sin(\alpha-\beta)}}})^2$	$P_p = \frac{1}{2}K_p\gamma H^2$

3.2 CONVENTIONAL RETAINING WALLS

Following are the types of conventional retaining wall with respect to shape and the mode of resisting earth pressure.

- Gravity Retaining Wall
- Cantilever Retaining Wall
- Counterfort Retaining Wall

3.2.1 Gravity Retaining Wall

Gravity retaining walls are retaining structure that rely on their weight in resisting lateral earth pressure of retained earth mass. They are constructed with variety of materials including masonry stones, precast concrete blocks, in situ concrete etc. Gravity retaining walls must be designed sufficient weight to counteract the stresses due to lateral pressure acting on the wall. Dead load, live load and as well pore water pressure can induce stresses in soil. To improve stability the wall can be batter (batter is angle with respect to vertical) slightly towards the retained earth mass. The design and the construction of gravity retaining walls is simple this add to their advantage but due to that fact that they rely on their mass to resist lateral earth pressure makes them uneconomical for higher heights. Moreover, due to mass concreting there is a significant environmental impact in form of carbon emissions and heat of hydration. Therefore, gravity retaining walls has height limitations, as increase in height of wall will require more mass to resist the large retained earth against sliding and overturning.

Increase in weight of wall will cause the bearing capacity failure and increased settlements.

3.2.1.1 Design of gravity retaining wall

The design of gravity walls include two major steps, in first step the approximated dimensions of the retaining wall are estimated based on relation given in the literature this is called proportioning. The second stem is to counter check those estimated dimension by applying the stability checks as following

3.2.1.1.1 Proportioning the gravity retaining wall

Proportioning is the estimation of initial dimension of gravity retaining wall based on few relations with respect to the height of construction. The depth of the stem at top should be greater than 0.3m. The depth of base slab can be taken as 0.12 H to0.17 H, where H is height of cantilever wall. The length dimensions of base slab ranges in proportion to height of wall as 0.5 H to 0.7 H. The toe of base slab must be project as 0.12 H to 0.17 H. After assuming initial dimensions, the design is revised by applying different stability and design checks.

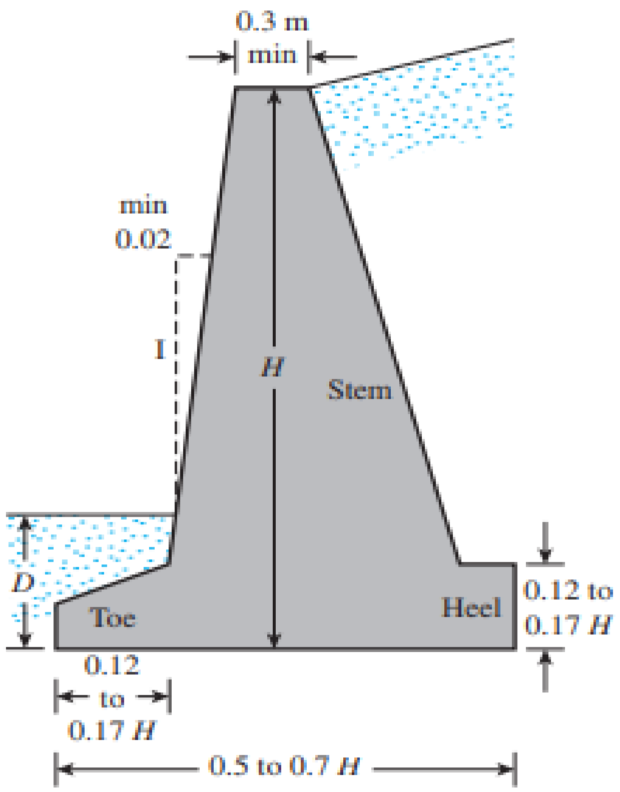


Figure 3.1: Typical proportioning of Gravity Wall

3.2.1.2 Stability analysis

Stability of gravity retaining wall can be analyzed in various ways.

3.2.1.2.1 Sliding

Gravity retaining wall can fail in sliding if the sliding forces (Horizontal forces) exceeds the resisting forces (forces contributing to hold retaining wall against sliding), this results the wall to slide forward along ground surface. If the wall is constructed with masonry blocks, then the sliding can occur between blocks relative to each other.

The factor of safety for sliding can defined as the ratio of forces resisting the sliding of gravity retaining wall to forces causing the sliding. Generally, value of factor of the safety for sliding can be given as 1.5. The numerical form can be expressed as

$$F.S = \frac{\sum F_R}{\sum F_D}$$

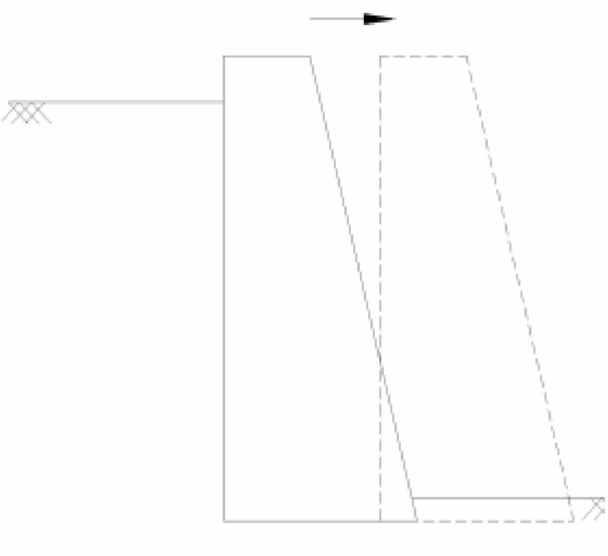


Figure 3.2: Sliding Failure of Gravity Wall

The forces resisting sliding includes the friction between underlain soil and base of structure, passive pressure, and weight of the wall. Whereas the sliding is caused by horizontal force of lateral earth pressure.

3.2.1.2.2 Overturning

Overturning of gravity retaining wall can result due the moment caused by lateral earth pressure forces, wall rotates about its toe. This occur when the moment occurred by lateral forces exceeds the moment caused by weight of gravity retaining wall. If wall is constructed with individual blocks than they can overturn relative to each other.

The factor of safety for overturning can defined as ratio of moment resisting the wall to overturn about toe to moment rotating wall about the toe. Practically value of the factor of safety for overturning is ranges from 2 to 3 (B.M Das). Numerically it can be expressed as.

$$F.S = \frac{\sum M_r}{\sum M_D}$$

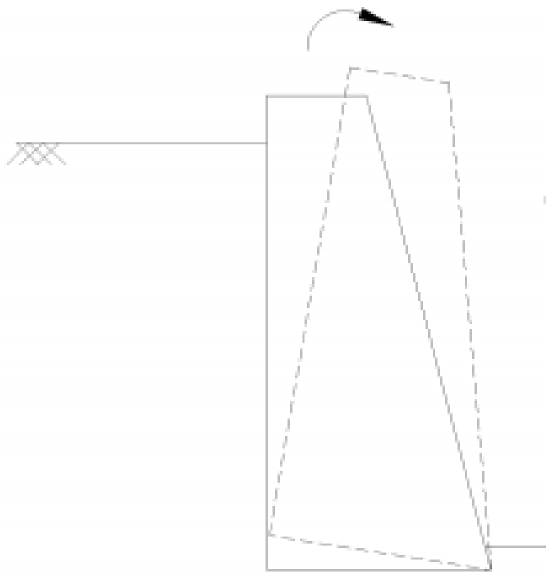


Figure 3.3: Overturning Failure of the Gravity Retaining Wall

The resisting moment is contributed by the weight of gravity retaining wall whereas the moment overturning wall about its toe is caused by the lateral earth pressure forces.

3.2.1.2.3 Bearing capacity:

The bearing capacity failure occur when bearing pressure exerted by weight of the wall exceeds the bearing capacity of underlain soil. Soil must have adequate bearing strength to counter the bearing pressure exerted by the wall. The factor of safety for bearing capacity can be defined as ratio of the ultimate bearing capacity of soil to bearing pressure exerted by the gravity retaining wall. Practically the value of factor of safety for bearing the capacity is taken as 3 (B.M Das). Mathematically it can be resented as

$$F.S = \frac{q_u}{q_{max}}$$

Where,

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

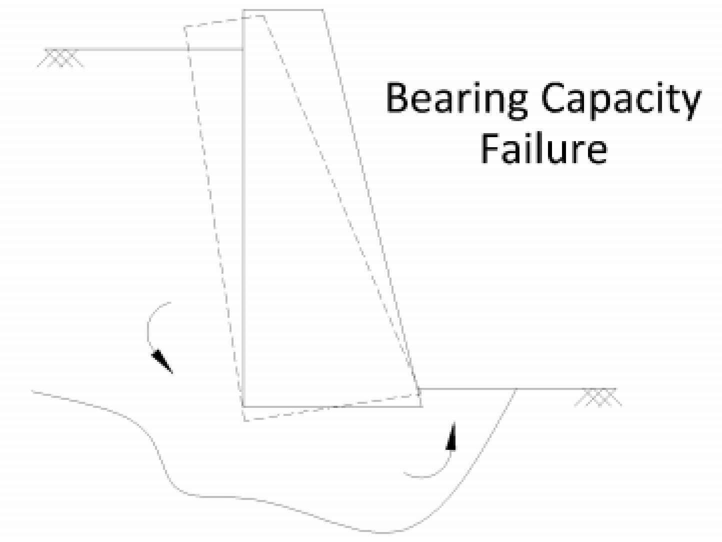


Figure 3.4: Bearing Capacity Failure of Gravity Retaining Wall

3.2.1.2.4 Stability against tension

This is the failure caused when eccentricity ‘e’ is greater than B/6 factor. The pressure at heel of the wall becomes negative this induced the tensile stress at heel. This can cause instability as the soil is weak in tension. Pressure at heel can be expressed as.

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

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

If value of the eccentricity becomes greater than B/6, than design should be revised.

3.2.2 Cantilever Retaining Wall

Cantilever retaining wall is constructed with reinforced concrete and they resist lateral earth pressure by principle of leverage. The structure of cantilever retaining wall consist of vertical stem and a base in shape of inverted T. The stem of cantilever retaining wall behaves as cantilever beam against lateral pressure. The heel slab of cantilever retaining wall behave as cantilever against the overburden soil pressure whereas the toe slab behaves as cantilever against upward soil pressure. These cantilever actions add to the strength of cantilever retaining wall that reduces it's mass unlike gravity retaining walls. Due to reduced mass they are economical up to the height of 8m. The bending behavior of it's cantilever structures enable the cantilever wall to resist the lateral earth pressure as well vertical pressure. When they are constructed at higher heights the mass of retained earth increases, this cause large overturning moments. The wall can fail by overturning actions as the factor of safety decrease with increase in height.

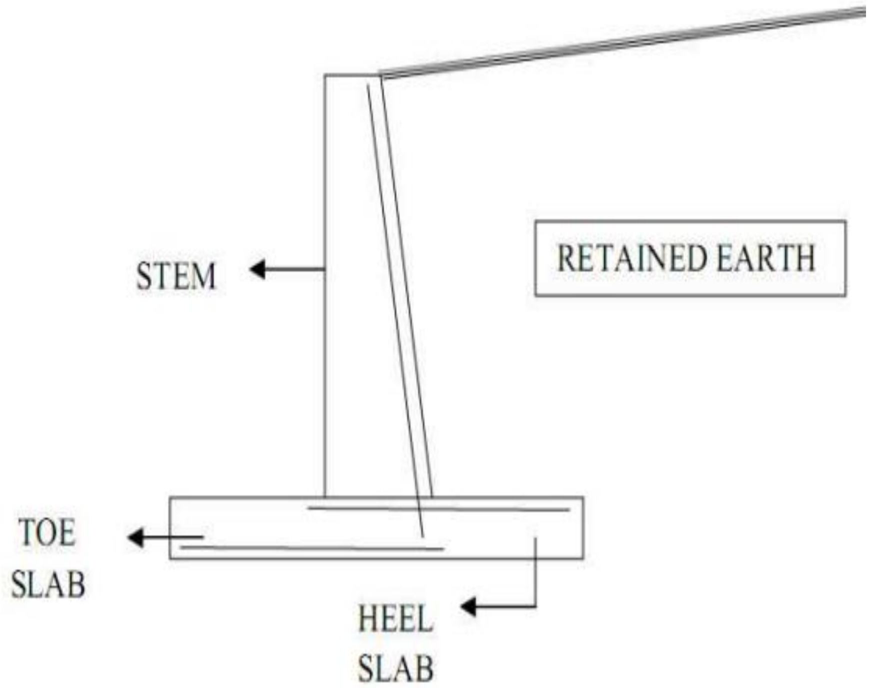


Figure 3.5: Cantilever Retaining Wall

Cantilever retaining wall gets advantage due to the cantilever arms, as it gives sliding resistance by increasing surface area of base structure. The bending of cantilever arm due to weight of above soil help in resisting the overturning moment. These advantages add up to enable the construction of cantilever retaining wall at height greater than gravity retaining wall. Unlike gravity retaining wall it requires more excavation to project the cantilever arm at greater length. This can cause problem if there is restriction on right of way or presence of any utility line. Like gravity retaining wall after some height cantilever retaining wall becomes uneconomical and stability problem arises due to increased moments.

3.2.2.1 Design of cantilever retaining wall

The design of cantilever retaining wall involves three major steps. The first step is called proportioning which involves the assumption of dimensions as given in literature. The second step is to check the structure for the stability which include sliding, overturning, and bending. Third steps include the design of reinforcement, and individual components including base, stem, and toe against factored loads. These design steps are based on ACI code 318-14.

3.2.2.1.1 Proportioning the retaining wall

In this step initial dimensions of the cantilever retaining wall are assumed called proportioning. These dimensions are taken from literature based on experience and empirical relations. The thickness of stem at top should be greater than 0.3m. The depth of base slab can be taken as 0.1 H, where H, is height of cantilever retaining wall. The length of base slab ranges in proportion to height of wall as 0.5 H to 0.7 H. After assuming initial dimensions, the design is revised by applying different stability and design checks.

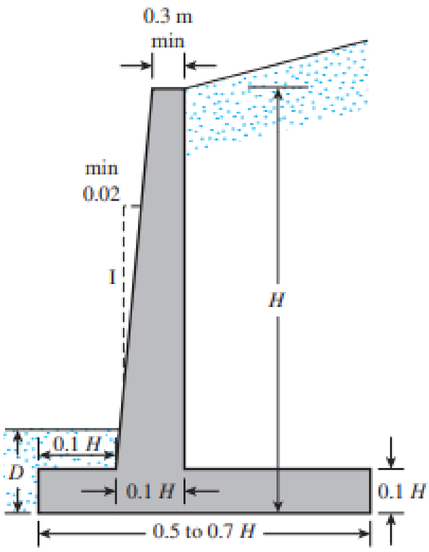


Figure 3.6: Approximate Dimensions of Cantilever Retaining Wall

3.2.2.1.2 Design of stem for shear

The design of stem in cantilever retaining wall include two factors. In the first step thickness of stem is designed for shear, the shear force V_n acting on stem of cantilever wall is equal to lateral forces acting on it. The nominal shear stress is multiplied with factor 1.6 to get ultimate shear stress V_u . According to the recommendation of ACI code 318-14, the ultimate shear stress should less than allowable shear strength V_{allow}.

$$V_n = \frac{1}{2} K_a \gamma \frac{H^2}{2}$$

$$V_u = 1.6\, V_n$$

The design will be safe when ultimate shear V_u stress is less than the allowable shear stress.

$$V_{allow} = \emptyset\, V_c$$

$$V_c = 0.17\sqrt{f_c}\, b_w d$$

Check: $V_u < V_{allow}$

If the ultimate shear stress is greater than allowable shear stress, then the thickness of stem must be increased.

The second step is to consider bending moment, that is equal to

$$M = \frac{1}{2} K_a \gamma \frac{H^3}{6}$$

Using this bending moment, the area of required steel is calculated in according to ACI code 318-14.

3.2.2.1.3 Design of heel slab

The design of heel slab is as cantilever, at heel the weight of soil and slab acts downward. Whereas there is an upward pressure due to reaction. Top reinforcement is provided at face of heel slab after calculating net pressure that will be in downward direction.

3.2.2.1.4 Design of toe slab

In design of toe slab of cantilever retaining wall, the weight of soil above toe is neglected. Due to this the net pressure at toe will act upward as soil reaction. At toe slab the bottom reinforcement is placed and the thickness of slab at toe and heel is same after calculating the maximum bending moment.

3.2.2.1.5 Depth of foundation.

The depth of foundation is considered as the soil must able to bear the applied bearing pressure. Rankine give the relation for minimum depth of foundation as

$$D = \frac{q_O}{\gamma} {K_a}^2$$

Where bearing capacity of the soil is given by q_O. The induced pressure must be less or equal to it.

3.2.2.1.6 Stability analysis of cantilever retaining wall

The final step after completing the design of cantilever retaining wall is to analyze it as following checks.

3.2.2.1.7 Sliding

Cantilever retaining wall can fail in sliding if the sliding forces (Horizontal forces) exceeds the resisting forces (forces contributing to hold retaining wall against sliding), this results the wall to slide forward along ground surface. It is defined as the ratio of forces resisting the sliding to forces driving wall to slide forward. Mathematical representation of this factor of safety for sliding is given as

$$F.S_{sliding} = \frac{\sum F_R}{\sum F_D}$$

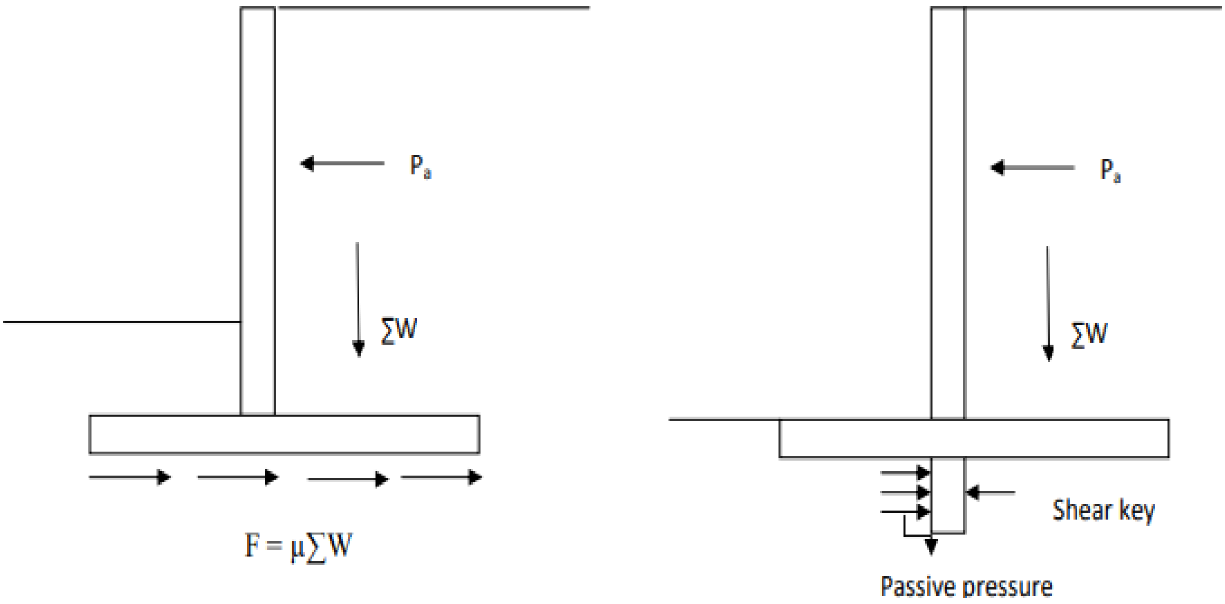


Figure 3.7: Sliding of Cantilever Retaining Wall without Shear Key and with Shear Key

Where F_R is the resistive force and F_D is the force causing the sliding of the wall. The driving force is due to horizontal component of the active earth pressure. Practically minimum value of factor of the safety for sliding is given as 1.5. If the value of factor of safety comes out to be less than 1.5 than design of wall should be revised. It can be increased by enlarging the width of base slab or constructing a shear key at certain depth below the base slab. This will add a passive force against sliding the wall. Increasing the base surface area will increase the friction.

3.2.2.1.8 Overturning

Overturning of cantilever retaining wall can result due the moment caused by lateral earth pressure forces, wall rotates about its toe. This occur when the moment occurred by lateral forces exceeds the moment caused by weight of gravity retaining wall. The factor of safety for overturning can be defined as ratio of moment resisting the wall to overturn about toe to moment rotating wall about the toe. Numerically it can be expressed as.

$$F.S_{overturning} = \frac{\sum M_r}{\sum M_D}$$

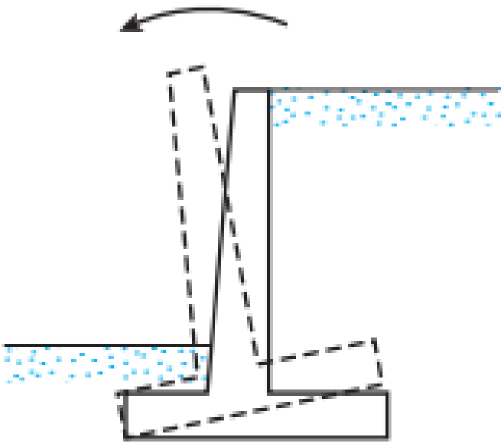


Figure 3.8: Overturning of Cantilever Retaining Wall

Practically the value of factor of safety for overturning is ranges from 2 to 3. The overturning is caused by the moment of lateral earth pressure about the toe of wall. The resistive moment is contributed by the weight of all components of wall.

3.2.2.1.9 Bearing capacity

The factor of safety for bearing capacity can defined as the ratio of the ultimate bearing capacity of soil to bearing pressure exerted by the cantilever retaining wall. The bearing capacity failure occur when the bearing pressure exerted by weight of wall exceeds the bearing capacity of underlain soil. Soil must have adequate bearing strength to resist the bearing pressure exerted by the wall. Practically the value of factor of safety for bearing capacity is taken as 3 (B.M Das). Mathematically it can be resented as

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

The pressure distribution below the base at toe and heel is represented by q_{max} and q_{min} respectively as

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

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

To avoid the bearing capacity failure the q_{max} should be less than bearing capacity of soil. Moreover, the value of q_{min} should not be negative, so the value of eccentricity should be greater than B/6 factor.

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

If above condition does not satisfy than the design should be revised. The pressure at heel of the wall becomes negative this induced the tensile stress at heel. This can cause instability as the soil is weak in tension.

3.2.2.1.10 Bending failure

In structure of the cantilever retaining wall there are three different components which includes cantilever toe slab stem, and heel slab. The stem behave as cantilever against the lateral earth pressure and the bending will occur as cantilever. The heel is reinforced at top face as the net pressure in heel slab act downwards causing it to bend as like cantilever and the tensile face will form upward. At toe slab reinforcement is placed at bottom face of slab as the net pressure act upward in form of soil reaction.

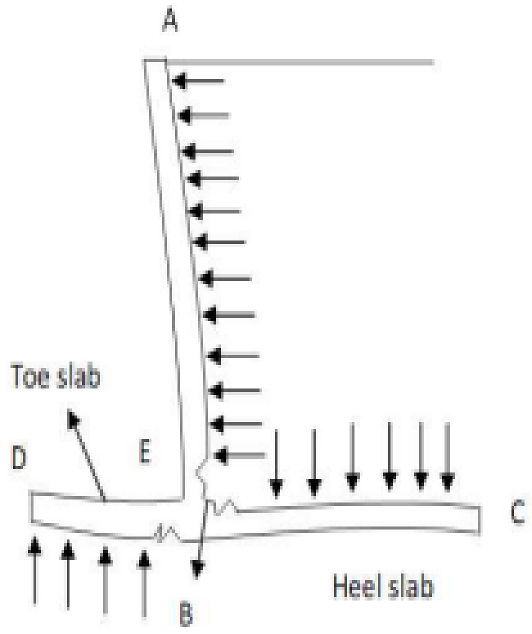


Figure 3.9: Bending Failure of Cantilever Retaining Wall

Due to bending action of all components the point of intersection between slab and vertical stem becomes critical. If there is no proper reinforcement than cracks may originates will cause failure of the wall. Moreover, to resist the compressive stresses caused by bending the thickness of base slab must be sufficient.

3.2.3 Counterfort Retaining Wall

The design of counterfort retaining wall is same as the cantilever retaining wall except they include buttresses or webs at regular spacing along the length of wall. These buttresses or webs are called counterforts. In other words, the counterfort retaining walls are the cantilever retaining wall with monolithic joint with concrete buttresses at backside of wall. These buttresses are joined with top of stem and with base slab. These buttresses decrease the bending and shear stresses by behaving as tension stiffeners. Due to increase in height of the cantilever retaining wall the bending moment become so large that they can affect the stability of retraining wall. That is why the buttresses are added at regular spacing with connection to stem and base slab. By adding the counterfort, the construction height increases from 8 tom 12m. Another advantage of adding counterfort is that they increase the weight of wall due to which there will be resistance against sliding and overturning of the wall.

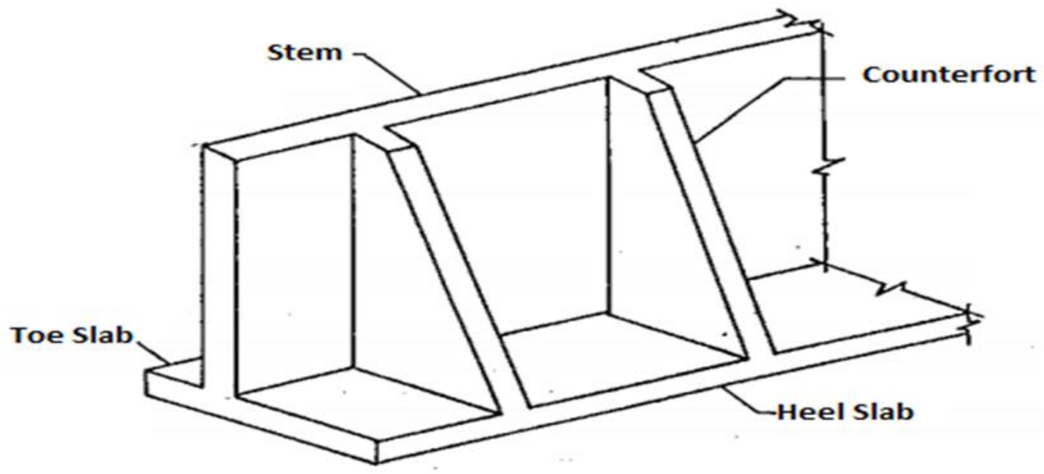


Figure 3.10: Counterfort Retaining Wall

The construction of counterforts divides the stem into two portions and stabilizes them by providing support. The function of counterforts is like vertical beams of T section. By providing sufficient reinforcement a monolithic connection is constructed at base slab and stem. Due to increase in height of the wall increases the mass of retained earth also increases this can lead to massive bending moment. These moments can be countered by adding counterforts at spacing of 0.3 H to 0.5 H, where 'H' is donated as the height of wall. The minimum thickness of counterforts must be 0.3 m .

3.3 Gabion Retaining Wall

Gabion retaining wall has function similar as the gravity retaining wall, they also rely on their weight to counter lateral earth pressure of retained earth mass. It is constructed with individual wire mesh boxes called gabions. These gabion baskets are filled with boulders and wires of gabions are made up of steel wire coated with PVC. Heavy galvanized steel wire is used to form double twisted hexagonal wire net. The individual gabions act as construction blocks and these blocks filled with boulders. They are stacked over each other to form layers and are properly connected with each other with steel lacing wire to form monolithic construction blocks. To reach the desired height multiple layers of gabions are stacked over each other. They may arrange in different way, in form of stepped or battered to increase stability. The gabions are internally divided by cell or diaphragms.

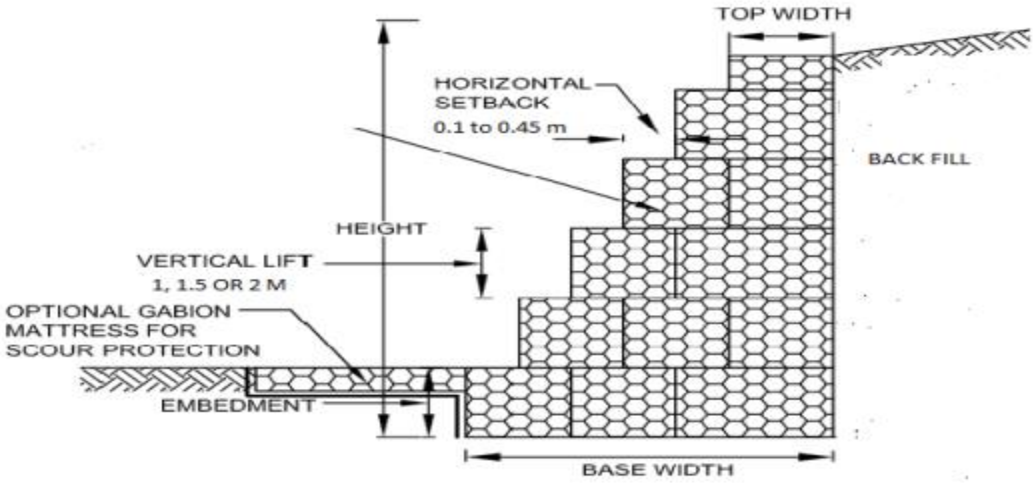


Figure 3.11: Gabion Retaining Wall

Gabion retaining wall have some advantages over conventional retaining walls. They provide drainage of water unlike other retaining wall that reduces the pore water pressure. They can counter the differential settlement due to flexible nature. Moreover, they add to advantage of speedy construction and variety of material that can be used in the baskets.

3.3.1 Design of Gabion Retaining Wall

The gabion retaining walls are analyzed similar as the gravity retaining wall. Both retaining wall rely on their weight to counteract against earth pressure. Individual layers and boxes are tied up to form a composite wall. The first step in design is to assume trial dimension of gabion retaining wall using proportioning mentioned in literature for the required height of wall. After calculating the resultants of all forces applied on the wall. In second step the wall is analyzed for both internal stability and external stability. If it does not satisfy stability checks then wall dimension will be revised and subjected for stability analysis again.

3.3.1.1 Configuration of gabion wall face

Gabion retaining wall can be constructed as either as front face steeped or with smooth face. If gabion wall is constructed with steps in front face, then it must be battered with angle of 6-10 degrees towards retained material. The height of riser in steps are up to height of 3 feet and the horizontal setbacks are of 1 to 1.5 feet. To increase the stability against sliding and overturning the wall cross section can be increased. To accommodate the tilting of wall by 6-10-degree angle towards backfill the foundation needs to be well compacted.

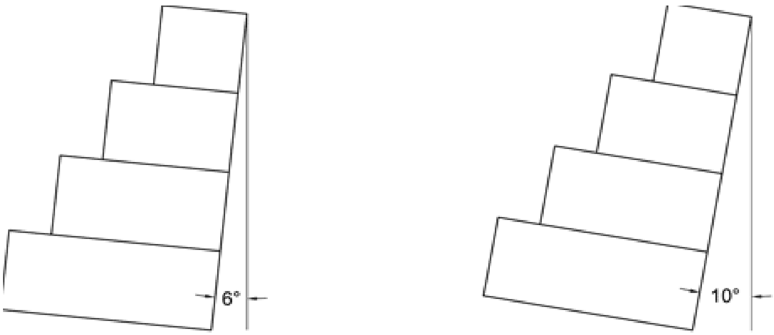


Figure 3.12: Gabion wall is battered 6 to 10 Degree

The base of gabion wall is designed with respect to total construction height of wall. As height of gabion wall increases the base width must increase to make wall stable against moments. The proportioning mentioned in the literature suggest that the base must ranges from value 0.5 H to 0.7 H, where H, is donated as height of the retaining wall.

3.3.1.2 Design specification of gabion box

ASTM-975 gives the complete design specification of gabion boxes including the material characteristics of steel wire, boxes dimensions and specification of lacing wires. The dimensions of mesh size are also given by ASTM -975. The gabions boxes are fabricated in factory by using mechanical woven technique. Different wires are used in connection of gabion baskets such as selvedge wire, lacing wire, fasteners, and stiffener. The opening size of net form by wire is called mesh size. According to standards provided by ASTM the mesh size for gabion boxes must be 8 by 10 with owning of 3.25in by 4.5in. The detail characteristics are provided as in Table 3.3.

Table 3.3: Characteristic of Mesh Wire (ASTM-975)

Characteristics	Gabion	
	Metallic Coated	PVC Coated
Mesh Type	8 * 10	
Mesh Opening	3.25 by 4.5 in	3.25 by 4.5 in
Mesh Wire	0.12 in	0.106 in
Selvedge Wire	0.15 in	0.134 in
Lacing Wire	0.087 in	0.087 in

Fasteners	0.118 in	0.118 in
Stiffeners:		
• Using Lacing Wire	0.087 in	0.087 in
• Preformed	0.15 in	0.134 in
PVC Coating Thickness:		
• Nominal	N/A	0.02 in
• Minimum	N/A	0.015 in

ASTM provides the standard for coating the gabion wire against corrosion. According to this standard there are four types of coating that can be provided on gabion wire. First is the zinc coated wire, in which the wire is coated with zinc before twisting it into mesh. Second way is to add more resistance against corrosion by adding 5% aluminum in zinc coating. Third type is to add PVC coating over zinc coating, this will help to add variety of colors to wire. The last type is instead of using zinc coated the wire should be coated with aluminum, as aluminum give better protection against the rust due to sacrificial rusting. ASTM provide the size dimensions of boxes as in Table 3.4.

Table 3.4: Sizes of Gabion Box (ASTM-975)

Length ft	Width ft	Height ft	Number of Cells Each	Volume yd ^3
6.0	3.0	3.0	2.0	2.0
9.0	3.0	3.0	3.0	3.0
12.0	3.0	3.0	4.0	4.0
6.0	3.0	1.5	2.0	1.0
9.0	3.0	1.5	3.0	1.5
12.0	3.0	1.5	4.0	2.0
6.0	3.0	1.5	2.0	0.67
9.0	3.0	1.0	3.0	1.0
12.0	3.0	1.0	4.0	1.33

According to the standards of ASTM and EN the quality of gabion wire and coating must be tested as per standards shared by ASTM. The test for tensile strength of gabion wire is performed as per EN-10223-3 or ASTM A641 in which the test is performed on a wire cut of length 1.2 m and the value of tensile strength must be in range of 350-500 MPa. ASTM also provide test specification for minimum weight of coating as mentioned in wire characteristic table. According to the standards the quality of PVC coating is checked for thickness by choosing a random sample of wire. Using the micrometer, the difference in diameter of coated wire and uncoated wire is calculated that will give the thickness of PVC coating. The strength parameters for wire is given as in Table 3.5.

Table 3.4: Required strength of Connections (ASTM-A975-97, 2004)

Test Description	Gabions Metallic Coated	Gabion PVC Coated
	lbf/ft	lbf/ft
Parallel to twist	3500	2900
Perpendicular to twist	1800	1400
Connection to selvedges	1400	1200
Panel to panel connection using lacing wire	1400	1200
Punch Test	lbf	lbf
	6000	5300

3.3.2 Stability Analysis of Gabion Retaining Wall

The stability analysis of gabion retaining wall consist of external stability analysis and internal stability analysis. In external analysis the stability checks are applied on composite wall. Whereas in internal stability analysis the analysis checks are applied on individual gabion boxes, to check their relative stability in sliding and overturning.

3.3.2.1 External stability analysis

3.3.2.1.1 Sliding

Gabion wall can fail in sliding if the sliding forces (Horizontal forces) exceeds the resisting forces (forces contributing to hold retaining wall against sliding), this results the wall to slide forward along ground surface.

The factor of safety for sliding can defined as the ratio of forces resisting the sliding of gravity retaining wall to forces causing the sliding. Generally, the value of factor of the safety against sliding can be given as 1.5. The numerical form can be expressed as

$$F.S = \frac{\sum F_R}{\sum F_D}$$

The forces resisting sliding includes the friction between underlain soil and base of structure, passive pressure, and weight of the wall. Whereas the sliding is caused by horizontal force of lateral earth pressure.

3.3.2.1.2 Overturning

Overturning of gabion retaining wall can result due the moment caused by lateral earth pressure forces, wall rotates about its toe. This occur when the moment occurred by the lateral forces exceeds the moment caused by weight of gabion retaining wall. If wall is constructed with individual blocks than they can overturn relative to each other.

The factor of safety for overturning can defined as ratio of moment resisting the wall to overturn about toe to moment rotating wall about the toe. Practically the value of factor of the safety for overturning is ranges from 2 to 3 (B.M Das). Numerically it can be expressed as.

$$F.S = \frac{\sum M_r}{\sum M_D}$$

The resisting moment is contributed by weight of gabion retaining wall whereas the moment overturning wall about it’s toe is caused by the lateral pressure forces.

3.3.2.1.3 Bearing capacity:

The bearing capacity failure occur when bearing pressure exerted by weight of the wall exceeds bearing capacity of underlain soil. Soil must have adequate bearing strength to resist the bearing pressure exerted by wall. The factor of the safety for bearing capacity can defined as the ratio of the ultimate bearing capacity of soil to bearing pressure exerted by the gabion retaining wall. Practically value of the factor of safety for bearing capacity is taken as 3 (B.M Das). Mathematically it can be resented as

$$F.S = \frac{q_u}{q_{max}}$$

Where

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

3.3.2.1.4 Stability against tension

This is the failure caused when eccentricity ‘e’ is greater than B/6 factor. The pressure at heel of the wall becomes negative this induced the tensile stress at heel. This can cause instability as the soil is weak in tension. Pressure at heel can be expressed as.

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

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

The value of eccentricity should not be greater than B/6, than design should be revised.

3.3.2.2 Internal stability analysis

The gabion retaining walls are constructed with individual baskets, that are tied to each other to form a layer. That is why the stability of gabion boxes relative to each other must be checked.

3.3.2.2.1 Sliding

The concept of internal sliding analysis is same as external analysis, the horizontal component of each layer is compared with the lateral pressure acting on that layer. The factor of the safety is calculated as the ratio of forces resisting the sliding of layer to forces driving the layer to slide.

$$F.S_{sliding} = \frac{\sum F_R}{\sum F_D}$$

Where F_R are forces resisting the sliding and F_D are forces causing layer to slide.

3.3.2.2.2 Overturning

This analysis concept is same as external stability check, but the overturning of individual layer is checked relative to each other. The overturning moments for each layer are calculated about toe of that layer. The ratio of moment resisting the overturning to the moment causing the layer to overturn about it toe is calculated and gives the factor of safety for internal overturning analysis.

$$F.S_{overturning} = \frac{\sum M_r}{\sum M_D}$$

CHAPTER 4

METHODOLOGY

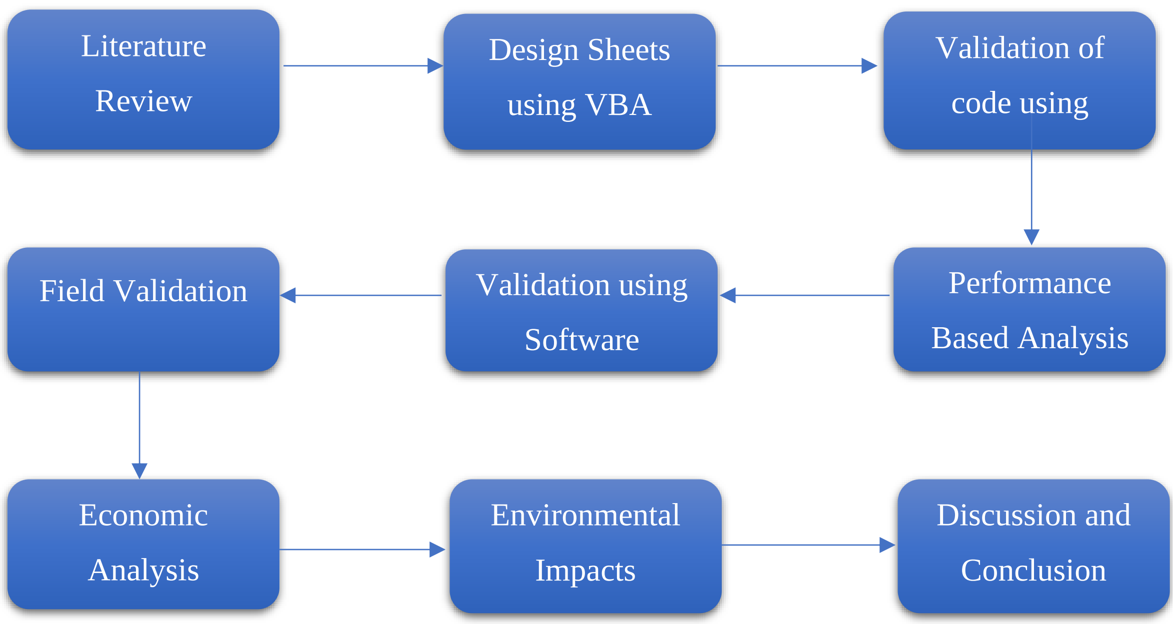
4.1 General

This chapter will deal with the framework/methodology used to solve the problem encountered. After the extensive literature review, the next most important step is to get a thorough idea about the theoretical background of Gabions and Conventional retaining structures. In a broader view, the problem statement can be divided into 3 major categories and these are

- Technical Aspect
- Economical Aspect
- Environmental Aspect

After the thorough understanding of theoretical background, a code is written using the language, Visual Basics for Application (VBA) on excel. Once the code is done, the next step involves checking the accuracy and efficiency of that code. For that, a structure model was built on "GEO-5" and "Tekla Tedd" and the analysis were run. Factors of the safety in Excel and Factors of safety on software was in the acceptable range. This check proves the accuracy and efficiency of the program. The next step was to check the Economical Aspects and compare the construction cost. Last but not the least, was the Environmental Impacts of selected retaining walls and to find a More Stable, More Economical and More Energy Efficient structure. Methodology for this project is shown below.

Flow Chart for Methodology



4.2 Development of Automated Excel Sheets using VBA

Automated Excel Design-Analysis Sheets were developed using Visual Basic Applications (VBA) after an extensive literature review. The code is attached in annexures.

4.2.1 Gabion Retaining Wall Code

There were different inputs for different types of wall especially for Gabion walls the inputs are totally different because the theory behind the stability of the Gabion wall is based upon the stacking of Gabion Baskets on one another and these individual Gabion Baskets acts as a combined single unit to resist the lateral Earth Pressure, moments and Bearing pressure. There are basically two types of stability checks involves in Gabion walls

- External Factor of Stability

  Is same as the rest of retaining structures i.e. Moment check, Bearing Check and Sliding Check.
- Internal Factor of Stability

  Is especially related to Gabion Retaining Walls i.e. Layer-to-Layer Over-turning and Sliding Checks.

For Bearing Check in External Factor of Safety, the offsets at front and back side of the wall should be provided to elapse the pressure distribution curve and hence, increase the Factor of the Safety for Bearing Capacity of soil. Apart from the site and soil conditions, the main inputs for code was Height, Offsets and Size of Gabion and Gabion Baskets.

To counter the complex equations for the stability checks, Visual Basics for Applications also known as VBA is used. It is a programming language used for Excel and other Microsoft office programs. It is basically writing a script you want Excel to execute and once the script is executed, Excel perform the function which it is intended to. Like in this project, calculation of factors of safety. It also plots the Cross-Section of the Gabion Wall; the figure will be attached below. The figure depicts the offsets, Gabion basket size, and height of Wall.

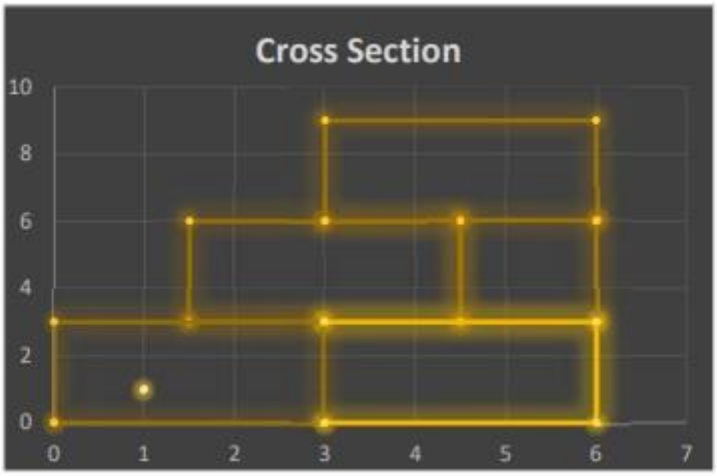


Figure 4.1: X-section view of Gabion Retaining wall from Excel VBA

4.2.2 Gravity Retaining Wall code

The VBA code for Gravity retaining wall was developed after a detailed comprehension and understanding the Visual Basic (VB) language. The code developed for design and analysis of Gravity wall is attached in the annexures.

4.2.2.1 Input Parameters

4.2.2.1.1 Geometrical Inputs

The input parameters are Surcharge Pressure, Surcharge Angle, Height of the wall above the ground, Thickness of Stem Top, Depth of foundation, Heel Projection, Toe Projection, Stem bottom thickness, Base slab width and Base slab thickness. For each input cell, the "Data Validation" function is used to aid the user about the acceptable ranges of the input parameters. A dialog box containing acceptable ranges of each input appears when the user selects the respective cell.

4.2.2.1.2 Characteristics of the Backfill

The input parameters related to Backfill are Cohesion, Unit weight, Friction Angle.

4.2.2.1.3 Characteristics of the Foundation soil

Soil Bearing Capacity (SBC) is to be provided as an input.

4.2.2.1.4 Characteristics of Concrete and Base soil

The software takes concrete properties as its Unit Weight. The cohesion of the base soil and friction between base soil and base slab is also to be provided.

4.2.2.2 VBA Macro

At the backend of the Excel workbook, the function named as "**Sub Gravity ()"** is developed. This function has some variables in which the values of the Input Parameters provided by the user are meant to be stored. The macro has various If-Else conditions that help in decision making depending on the variety of the data. The code comprises of various parts which are devoted to the calculations of the required parameters for design and analysis.

4.2.2.2.1 Dimensions Proportioning

The code is developed in such a way that if the user desires to obtain the general dimensions according to the standards, it would calculate those desired dimensions automatically. The only input parameters required for this purpose are "Height above the ground" and "Top width of the Stem" e.g.

$$\text{Base width} = 0.6(\text{Height})$$

However, if all of the dimensions are given as input the further calculations will be according to those given dimensions.

4.2.2.2.2 Coding for Cross-Section of the wall:

An automated cross-section of the wall was to be obtained which could change its dimensions depending on the Input dimensions. The technique used for this purpose is the use of Chart and Coordinate system in Excel. The code is written in such a way that the input values of the dimensions work as coordinates for the line chart and eventually it makes the desired model.

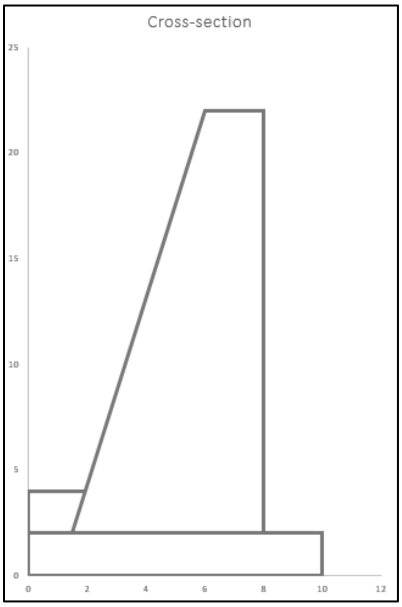


Figure 4.2: X-section view of Gravity Retaining wall from Excel VBA

4.2.2.2.3 Code for Analysis

The major part of the macro is the calculations for the analysis of the wall according to literature.[6] The Coefficient of Active Earth Pressure, Surcharge pressure, Vertical forces, Moments and Lever Arm are calculated according to the given parameters by incorporating the standard formulas in the code. The obtained values are further used in the calculation of two types of factor of safety (FOS) i.e. $FOS_{overturning}$, $FOS_{sliding}$ and Bearing Capacity check.

The code returns the calculated FOSs as output and gives “OK” or “Fail” result by comparing the calculated values with the standard values.

4.2.2.3 Output and Report Generation

The values of FOSs are the final output of all the calculations according to the provided data. These also depict whether the calculated FOSs are safe or not.

The macro is assigned to the “Generate Report” button in the very end of the sheet which if clicked, generates a PDF report of the Inputs and Results.

[6] Principles of Foundation Engineering 8th ed. by B. M. Das (Chapter 13)

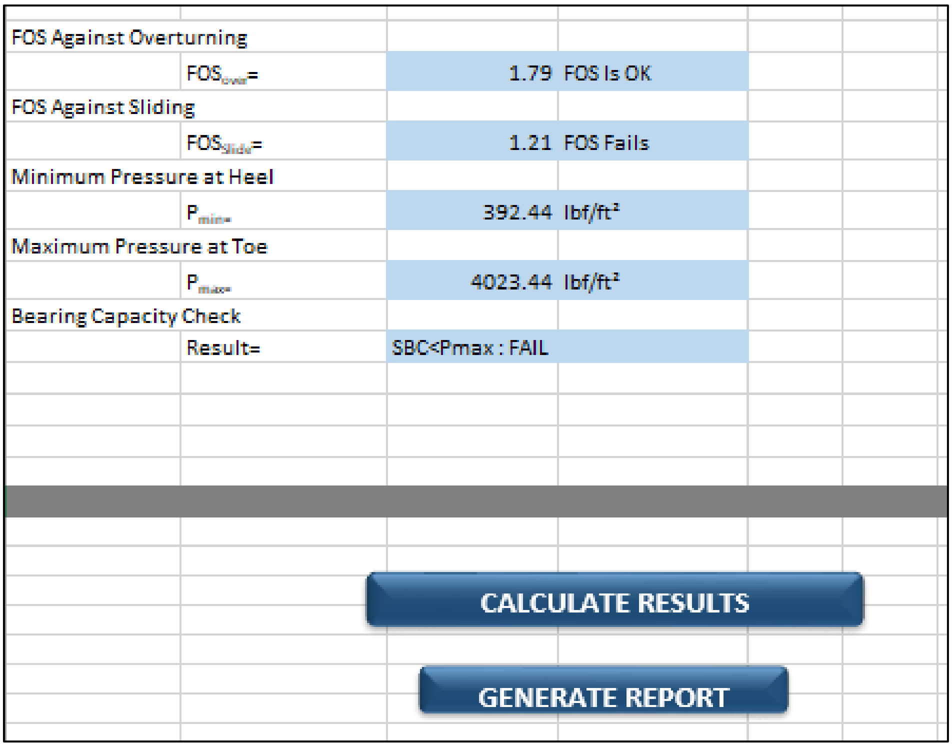


Figure 4.3: Gravity wall sheet Outputs

4.2.3 Cantilever Retaining Wall code

The VBA code for Cantilever wall was developed after a detailed comprehension and understanding the Visual Basic (VB) language. The code developed for design and analysis of the Gravity wall is attached in the annexures.

4.2.3.1 Input Parameters

4.2.3.1.1 Geometrical Inputs

The geometrical input parameters for Cantilever retaining wall are Surcharge Pressure, Surcharge Angle, Height of the wall above the ground, Thickness of Stem Top, Depth of foundation, Heel Projection, Toe Projection, Stem bottom thickness, Base slab width and Base slab thickness. For each input cell, the "Data Validation" function is used to aid the user about the acceptable ranges of the input parameters. A dialog box containing acceptable ranges of each input appears when the user selects the respective cell.

4.2.3.1.2 Characteristics of the Backfill

The input parameters related to Backfill are Cohesion, Unit weight, Friction Angle.

4.2.3.1.3 Characteristics of the Foundation soil

Soil Bearing Capacity (SBC) is to be provided as an input.

4.2.3.1.4 Characteristics of Concrete and Base soil

The software takes concrete properties as its Unit Weight. The cohesion of the base soil and friction between base soil and base slab is also to be provided.

4.2.3.1.5 Steel Strength

The design sheet takes the Grade of the steel as an input to do the analysis related to reinforcement

4.2.3.1.6 Area of steel

The area of the steel provided is to be given by the user so that the calculated area of steel can be compared with it to check reinforcement requirements.

4.2.3.2 VBA Macro

At the backend of the Excel workbook, the function named as "**Sub Cantilever ()"** is developed. This function has some variables in which the values of the Input Parameters provided by the user are meant to be stored. The macro has various If-Else conditions that help in decision making depending on the variety of the data. The code comprises of various parts which are devoted to the calculations of the required parameters for design and analysis.

4.2.3.2.1 Dimensions Proportioning

The code is developed in such a way that if the user desires to obtain the general dimensions according to the standards, it would calculate those desired dimensions automatically. The only input parameters required for this purpose are "Height above the ground" and "Top width of the Stem" e.g.

$$\text{Base width} = 0.5(\text{Height})$$

However, if all of the dimensions are given as input the further calculations will be according to those given dimensions.

4.2.3.2.2 Coding for Cross-Section of the wall:

An automated cross-section of the wall was to be obtained which could change its dimensions depending on the Input dimensions. The technique used for this purpose is the use of Chart and Coordinate system in Excel. The code is written in such a way that the input values of the dimensions work as coordinates for the line chart and eventually it makes the desired model.

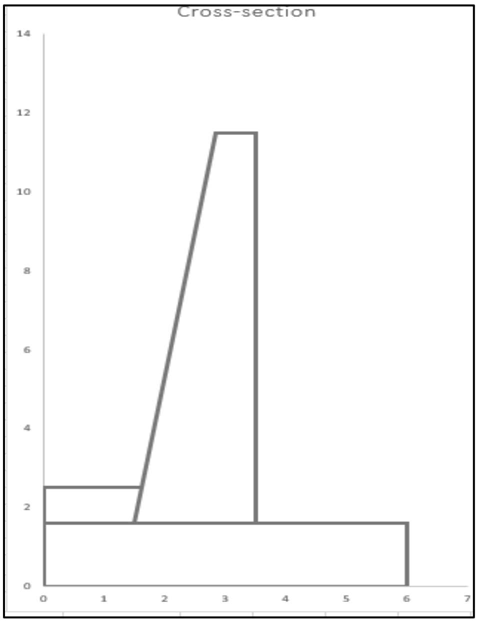


Figure 4.4: X-section view of Cantilever Retaining wall from Excel VBA

4.2.3.2.3 Code for Analysis

One of the two major parts of the macro is the calculations for the analysis of the wall according to literature.[7] The Coefficient of Active Earth Pressure, Surcharge pressure, Vertical forces, Moments and Lever Arm are calculated according to the given parameters by incorporating the standard formulas in the code. The obtained values are further used in the calculation of two types of factor of safety (FOS) i.e. $FOS_{overturning}$, $FOS_{sliding}$ and Bearing Capacity check.

The code returns the calculated FOSs as output and gives "OK" or "Fail" result by comparing the calculated values with the standard values.

The second main part is the **Steel Design.** In this part, the design procedure followed is according to ACI-318-14. This approach was followed to design the following reinforcement:

- Stem Reinforcement
- Heel Reinforcement

[7] Principles of Foundation Engineering 8th ed. by B. M. Das (Chapter 13)

- Toe Reinforcement

The results given by the code comprises of Area of steel required for these three parts of a Cantilever wall.

4.2.3.3 Output and Report Generation

The values of FOSs and Area of steel required are the final output of all the calculations according to the provided data. These also depict whether the calculated reinforcement and FOSs are safe or not. There is a drop-down list from which the user can select the reinforcement spacing and diameters of the bars provided. The selected spacing and diameter automatically gets converted into Area of steel provided for the respective part.

The “Area of the steel required” is compared with the “Area of the steel provided” and remarks about the check are provided as “Steel OK” or “Revise Steel”

The macro is assigned to the “Generate Report” button in the very end of the sheet which if clicked, generates a PDF report of the Inputs and Results.

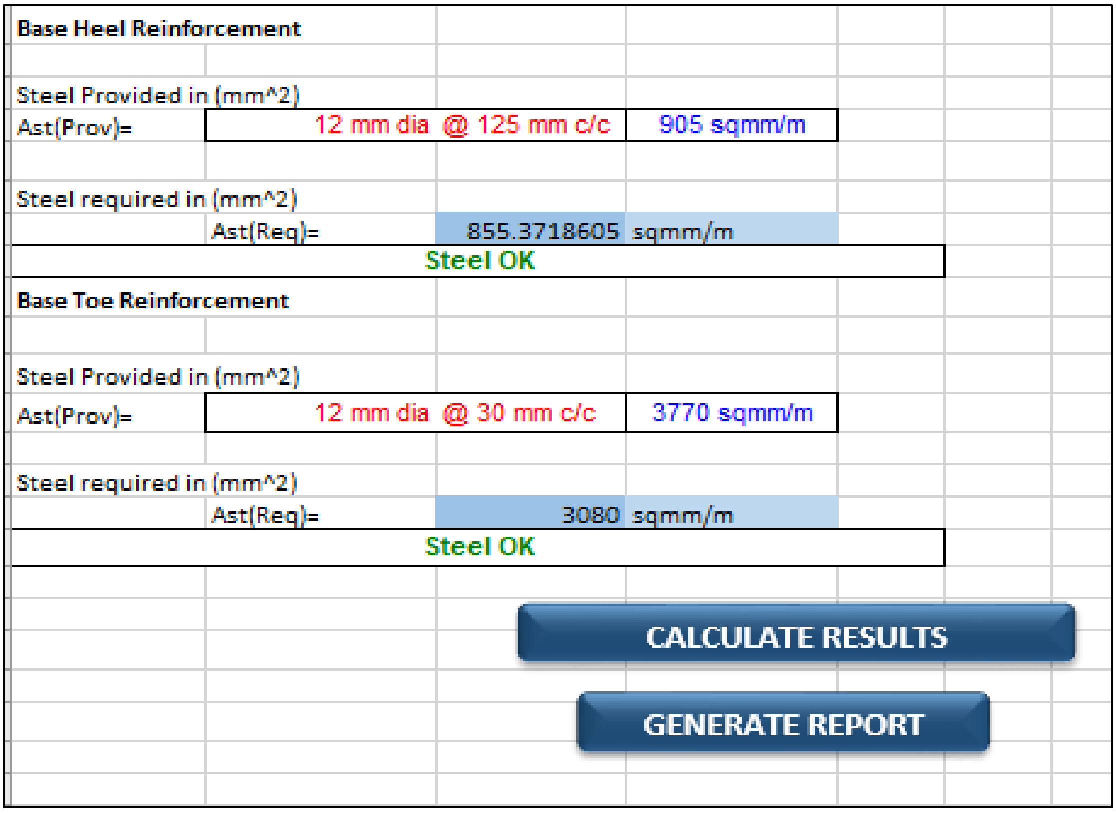


Figure 4.5: Cantilever wall sheet Outputs

4.3 Validation of code using Software

4.3.1 Gabion Wall code validation

After the code has been written, the next step is to check does the code run. If it runs then what is the accuracy of results obtained. For that, the random data is used to perform stability checks and results concluded from the Design sheets was then compare with the software results. The FEM software like GEO-5 and Tekla Tedds were used. Comparison of these two results lies within the acceptable deviation. So, the program developed on Excel using VBA works fine. Same parameters were used for Excel and Software and the Cross Section obtained is attached below.

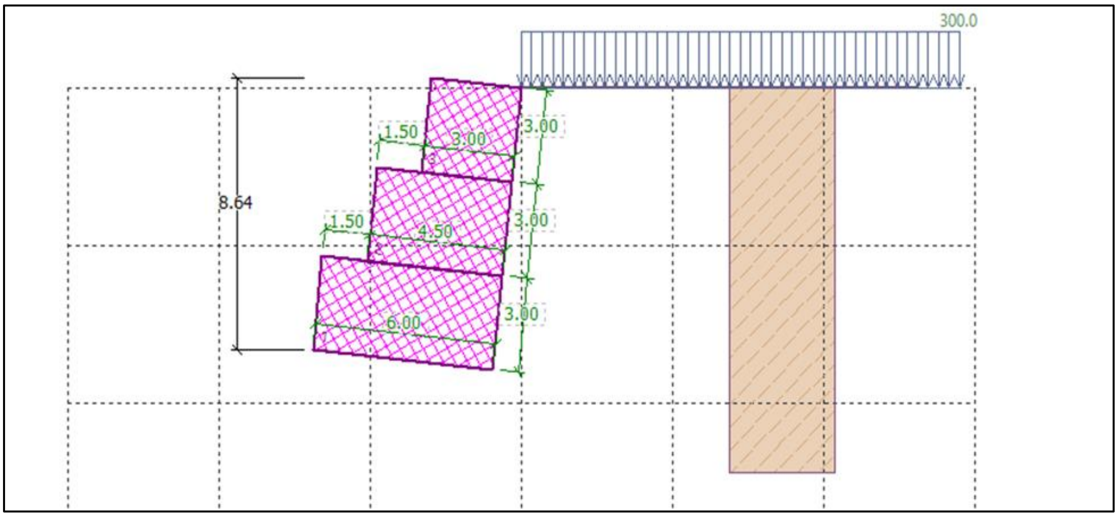


Figure 4.6: X-section view of Gabion Retaining wall from GEO-5

4.3.2 Gravity Wall code validation

The next step after the development of code in VBA Excel was to check the validity of its Results and outcomes by comparing it with that of any FEM software. For this purpose, GEO 5 software was used and the results were validated by putting the same inputs in both Gravity wall design-analysis sheet and GEO 5. The cross-section obtained by sheet and software appeared to be same and the values of results proved to be accurate up to one decimal place.

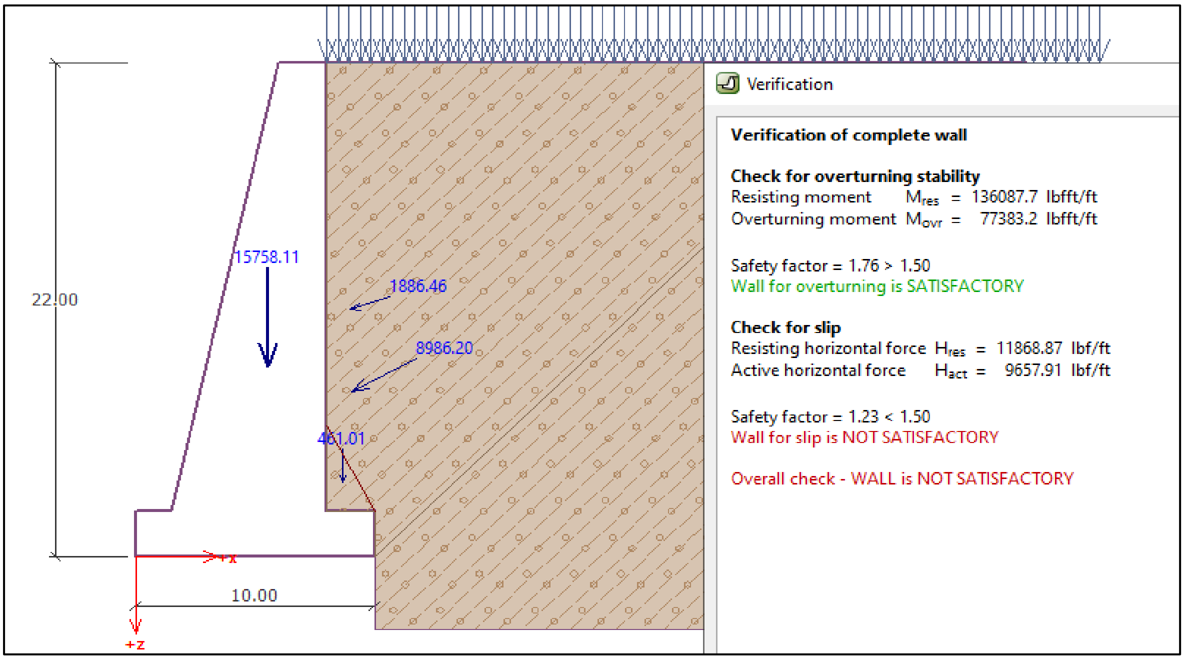


Figure 4.7: X-section view of Gravity Retaining wall from GEO-5

4.3.3 Cantilever Wall code validation

The next step after the development of code in VBA Excel was to check the validity of its Results and outcomes by comparing it with that of any FEM software. For this purpose, GEO 5 software was used and the results were validated by putting the same inputs in both Cantilever wall design-analysis sheet and GEO 5. The cross-section obtained by sheet and software appeared to be same and the values of results proved to be accurate up to one decimal place.

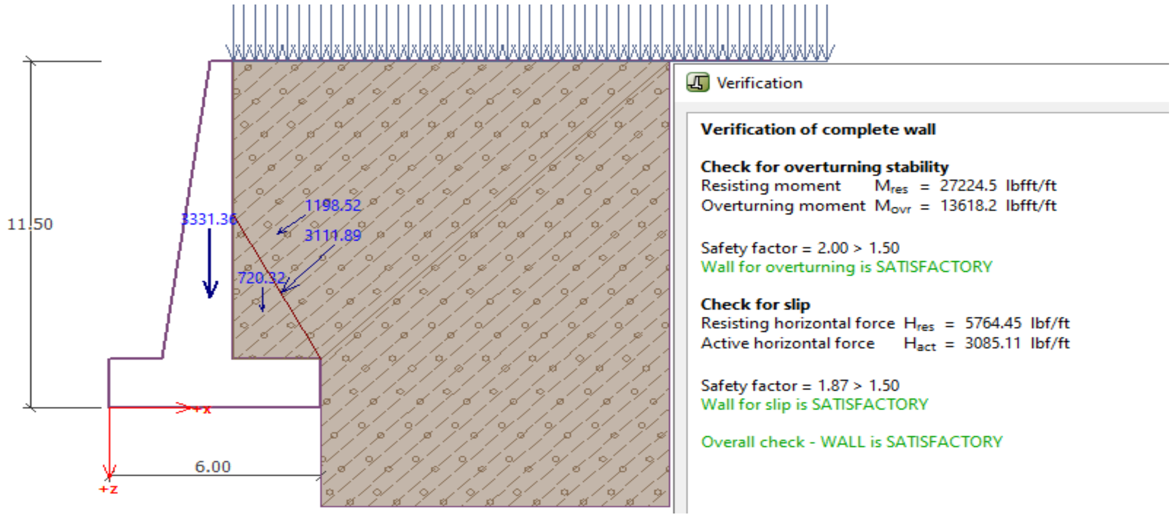


Figure 4.8: X-section view of Cantilever Retaining wall from GEO-5

4.4 Performance Based Analysis

This step of methodology involves stability analysis of all the retaining structure by using Excel Program and calculate Internal and External (if have) factors of safety. Here, we will discuss in detail the performance-based Analysis of all three walls and how the program is performing this analysis on Excel then, to counter check the results, same parameters are used to run the stability analysis on software for the validation of results.

4.4.1 Analysis of Gabion Retaining Wall

Analysis for Gabion Walls was a bit complex and extensive because of the Internal Factors of Safety. We will discuss in detail how the analysis was run and what is the Algorithm for the VBA Excel Program.

4.4.1.1 External Stability Analysis

There are three main checks involves in the stability analysis of any structure and these are

- Safety for Sliding
- Safety for Overturning Moment
- Safety for Bearing Capacity.

For this project, All the analysis based on Rankine Theory of Lateral Pressure and Coulomb's Theory of the Earth Pressure. So, the first step in Stability Analysis is to calculate Lateral Pressure caused by Retained Soil. The formula for the Lateral Pressure discussed above in "Theoretical Background".

Once the Lateral Earth Pressure has calculated, next step is to calculate the horizontal component of this Pressure as it acts parallel to the Backfill Slope. If the Backfill slope angle is "0" then this lateral Earth pressure will be the force causing sliding. The summation of forces resisting this active force can be calculated by calculating the sum of Gabion weight at base of wall and comparing it with the active sliding force. As the base is not embedded in the soil so the no resisting force caused by the soil will be incorporated in the equation.

For Overturning Moment check, the main difference between Gabion and Conventional Retaining Walls is, in Conventional Retaining structure the whole structure act as a single unit to resist the Overturning Moment but in case of Gabion Walls, the whole wall is divided into layers and each layer acts on it on to resist the Overturning Moment and has different weight and different Moment Arm from the Toe of wall. As the Gabion Baskets are rectangular in shape, So, the total weight of any layer is

$$Weigth\ of\ 1\ layer = No.of\ Gabion\ baskets\ X\ Area\ of\ One\ \ X\ Gabion\ Density$$

Once, the weight of Gabion for one layer is calculated, next step is to determine the Moment Arm. As the Moment is determined at toe of the wall, So, the Moment arm for each layer is different due to the staggering technique which is used to eliminate the formation of Failure Plane. The formula for moment arm is as follows.

$$Moment\ Arm = \frac{Base\ width\ of\ that\ layer}{2} + Offset\ from\ the\ front(\ N-1\ )$$

N = Layer Number

$\frac{Base\ width\ of\ that\ layer}{2}$ = Centroid of the Shape (For Rectangular shape only)

Code runs in such a manner to ensure that the calculation starts from the base and moves upward. So, a Loop is used to ensure that the value of "N" is updated each time the height increases.

For Example, if the Basket Height is 3ft and total wall height to be build is 9ft then the number of layers is 9/3 = 3. So, for the first layer there is no offset but when the calculation for weight and Moment Arm moves to the second layer the value of "N" becomes "2" but there is one offset so "N-1" ensures that one offset is added into the centroid of the layer to calculate the moment arm. As the weight is acting perpendicular to the base so there is no horizontal component.

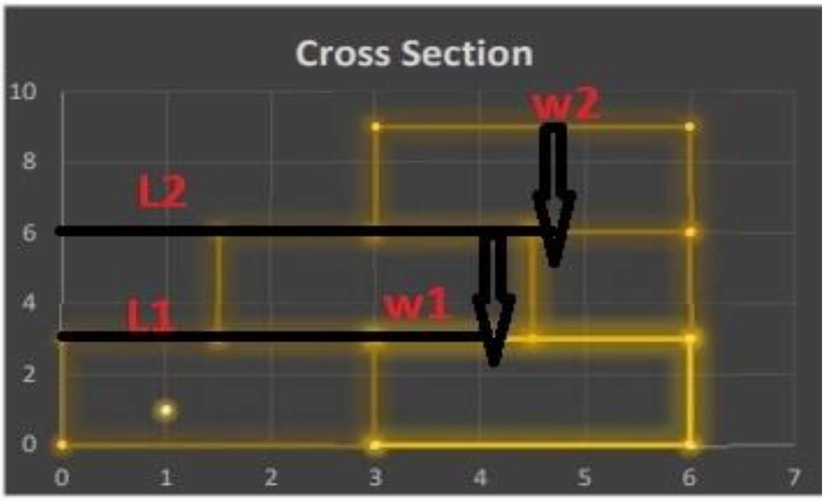


Figure 4.9: Calculation of Resisting Moment

Horizontal component of Lateral Earth Pressure causes the Overturning moment and the vertical component tries to cancel out this Overturning Moment. So, at the end, if the value of Overturning Moment exceeds the Resisting Moment then the Wall fails otherwise it sustains.

The last and most important step is to check for the Bearing capacity failure. Calculation for this safety factor is easy. Weight of the wall should be less than bearing capacity of the soil, which is calculated by the field engineer and provided in Geotechnical Investigation. The entire weight of the wall is equal to Area of the total number of gabion Baskets times the Gabion Density.

This is the Performance based analysis for External Factors of Safety for Gabion walls.

4.4.1.2 Internal Stability

This analysis is specifically related to the Gabion Walls. As the Gabion Wall is constructed by stacking Gabion Baskets. And second layer of Gabion Baskets is paced on top of the first layer. So, it is quite possible that the upper layer can slide down or Overturn and this way the whole structure fails. So, to check the Internal stability of Gabion walls, two similar checks are used

- Sliding of Gabion Layers
- Overturning of Gabion Layers

According to ASTM, Gabion Baskets should be bind together with steel wire. So, the sliding of Gabion Baskets is controlled. But this is not an effective technique.

In this project, the sliding of each layer is checked against the active lateral pressure. For that purpose, the lateral Earth Pressure diagram is used to determine the lateral earth pressure to that layer and the horizontal component of the weight is compared against that earth pressure to ensure the stability against sliding of the Gabion layer.

For Overturning Check, the analysis starts from the base and ends at the top of the second last layer. The toe of each layer is taken as a reference and rest of the phenomena is same as that for External Stability analysis. The only difference is, once the check was applied for a layer, this layer was eliminated from the next iteration, in this way the stability of each layer can be calculated. The code for these stability analyses is attached.

4.4.2 Analysis of Gravity Retaining Wall

The analysis of the Gravity retaining wall was carried out with the help of developed Excel sheet. The code written in the backend of the design and analysis sheet developed in such a way to make it conform to the standard analysis method as mentioned in the literature.[8] Coulomb lateral Earth Pressure Theory is used to calculate the Active lateral Earth Pressure.

Gravity walls are rigid structures that retain the soil mass with the help of their weight only. So, as such no internal stability checks are required. However, to check their External stability following safeties are generally ensured:

[8] Principles of Foundation Engineering 8th ed. by B. M. Das (Chapter 13)

- Safety against Overturning
- Safety against Sliding
- Bearing Capacity check

In this research, these three checks were applied to the Gravity wall that is to be designed for a specific site. The soil parameters, height to be retained, right-of-way and other such factors required for the analysis were taken from a Research Paper[9]. The wall was oriented such that its rear face is vertical, and the voids filled with a gravel backfill. A continuous drainage is provided along the joint of its base slab and stem to mitigate the hydrostatic forces at the wall's back face.

4.4.2.1 Varying Heights

Although the height to be retained was 9 feet in the research paper, two additional heights i.e. 18 ft and 27 ft were also used in analysis. The corresponding dimensions of base slab width, thickness and other dimensions were determined itself by the design sheets. The purpose of opting three different heights was to analyze the optimum height at which the wall proves to be safest.

4.4.2.2 Safety against overturning

Gravity wall at each height was check for its safety against overturning due to active pressure of soil at its back. This was done in the design and analysis sheets. As mentioned earlier that the code calculates the $FOS_{overturning}$ based on the formula:

$$FOS_{overturning} = \frac{Mr}{Mo}$$

whereas,

Mr = Sum of overturning moment at toe

Mo= Sum of resisting moment at toe

The results obtained were $FOS_{overturning}$ for the Gravity wall at three different heights.

4.4.2.3 Safety against sliding

The wall at each height was checked for its capability of resisting the sliding forces. The formula used in the code was:

[9] LANE (Design Manual), LANE Enterprises, INC.

$$\text{FOS}_{\text{sliding}} = \frac{\mu Rv}{Rh}$$

whereas,

Rv = Vectorial summation of vertical forces

Rh= Vectorial summation of horizontal forces

μ = coefficient of friction

The results obtained were $\text{FOS}_{\text{sliding}}$ for the Gravity wall at three different heights.

4.4.2.4 Bearing Capacity Check

Bearing capacity was checked at each wall height to confirm whether it is safe for the P_{max} imposed by the wall's heel. The code calculated the P_{max} as:

$$P_{max} = \frac{Rv}{B}\left(1 + \frac{6e}{B}\right)$$

whereas.

Rv = Vectorial summation of vertical forces

B = Base slab width

e = Eccentricity

The soil's BC was compared with the P_{max} for each height.

4.4.3 Analysis of Cantilever Retaining Wall

The analysis of the Cantilever retaining wall was carried out with the help of developed Excel sheet. The code written in the backend of the design and analysis sheet developed in such a way to make it conform to the standard analysis method as mentioned in the literature.[10] Coulomb lateral Earth Pressure Theory is used to calculate the Active lateral Earth Pressure. Moreover, the reinforcement design approach followed was same as specified in ACI-318.

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[10] Principles of Foundation Engineering 8th ed. by B. M. Das (Chapter 13)

Cantilever retaining wall is a reinforced concrete structure that retain the soil mass by the principle of leverage. It has a thinner stem as compared to Gravity walls. Their stability is divided into two parts:

- External Stability
- Internal Stability

4.4.3.1 External Stability

The external stability of these structures is defined by checking them against three potential failures:

- Overturning
- Sliding
- Bearing Capacity

A cantilever wall is said to be safe if it is safe against these three checks.

In this research, these three checks were applied to the Cantilever wall that is to be constructed at a specific site. The soil parameters, height to be retained, right-of-way and other such factors required for the analysis were taken from a Research Paper[11]. The wall was oriented such that its rear face is vertical and the voids filled with a gravel backfill. A continuous drainage is provided along the joint of its base slab and stem to mitigate the hydrostatic forces at the wall's back face.

4.4.3.1.1 Varying Heights

Although the height to be retained was 9 feet in the research paper, two additional heights i.e. 18 ft and 27 ft were also used in the analysis. The corresponding dimensions of base slab width, thickness and other dimensions were determined itself by the design sheets. The purpose of opting three different heights was to analyze the optimum height at which the wall proves to be safest.

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[11] LANE (Design Manual), LANE Enterprises, INC.

$$\text{FOS}_{\text{overturning}} = \frac{Mr}{Mo}$$

whereas,

Mr = Sum of overturning moment at toe

Mo= Sum of resisting moment at toe

The results obtained were $\text{FOS}_{\text{overturning}}$ for the Cantilever wall at three different heights.

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The wall at each height was checked for its capability of resisting the sliding forces. The formula used in the code was:

$$\text{FOS}_{\text{sliding}} = \frac{\mu Rv}{Rh}$$

whereas,

Rv = Vectorial summation of vertical forces

Rh= Vectorial summation of horizontal forces

μ = coefficient of friction

The results obtained were $\text{FOS}_{\text{sliding}}$ for the Cantilever wall at three different heights.

4.4.3.1.4 Bearing Capacity Check

Bearing capacity was checked at each wall height to confirm whether it is safe for the P_{max} imposed by the wall's heel. The code calculated the P_{max} as:

$$P_{max} = \frac{Rv}{B}\left(1 + \frac{6e}{B}\right)$$

whereas.

Rv = Vectorial summation of vertical forces

B = Base slab width

e = Eccentricity

The soil's BC was compared with the P_{max} for each height.

4.4.3.2 Internal Stability

This stability was ensured by designing the optimum steel or reinforcement required for each component of Cantilever wall for its safety against flexure. The aim was to determine the Area of the steel for each section i.e. Stem, Toe and Heel. After the determination of ultimate moments at each section, these areas were calculated.

$A_{steel} = \rho\, b\, d$

whereas,

$$\rho = \frac{0.85\, fc'}{fy}\left(1 - \sqrt{1 - \frac{2Ru}{0.85(fc')}}\right)$$

b = section width

d = the section effective depth

The calculated area of steel then compared with provided area of steel.

4.5 Validation of analysis using Software

4.5.1 Validation of Gabion wall analysis

Once the perform base analysis is performed on Excel VBA, the next step is to check the results from software to ensure the accuracy of these results and for that purpose, GEO-5 and Tekla Tedd are used. Factors of Safety calculated by using the Gabion walls model in software checks out for the factors calculated using Excel Program. After that the impact on factor of safety is checked by increasing the height of wall and compare these factors with Conventional Retaining walls to check the efficiency of Gabion Retaining Walls.

The next step is to apply this program in real life and check the stability factors for an existing structure and ensure that the program is accurate. The soil and site parameters are obtained from an international research paper and Stability Analysis is performed. Results were in acceptable range. These results are attached in annexures.

4.5.2 Validation of Gravity wall analysis

After the complete Performance based analysis of the wall at different heights, the next step was to verify the results using any FEM software. GEO 5 was used to validate whether the calculated results are accurate. The models for gravity wall were constructed in the GEO 5. The same input parameters were used in the software as were used in the Excel sheets.

The results given by the **Design- Analysis sheet** and **GEO 5** came out to be almost similar (Upto one decimal place) for each height.

4.5.3 Validation of Cantilever wall analysis

Cantilever wall analysis by Design-Analysis sheet was validated by **GEO5** software. The procedure adopted for this purpose was just as the Gravity wall validation. The results for external stability i.e. FOSs were compared with those computed by GEO5 and they were accurate up to one decimal place.

4.6 Economic Analysis

As the goal of an engineer is to construct a stable and economical structure. So, the economy of these walls will determine the effectiveness and efficiency of these retaining structures.

4.6.1 Gabion Wall Economic Analysis

In case of Gabion walls, components included in the Bill of Quantity (BOQ) are as follows

Table 4.1: BOQ components of Gabion Wall

BOQ Components for Gabion Walls	
Steel Wire mesh for Gabions	lbs.
Rockfill in Gabion Baskets	cft
Filter Layer of Granular Material	cft

Filter layer is provided at the back of Gabion walls to ensure that there is no movement of soil particles across the gabion structure because this will cause slope failure and can increase the weight of the wall which in return can exceeds the bearing capacity of the soil and can leads to a bearing capacity failure.

The next step is to check the effect on economy when the height of wall is increased. This is especially important to compare the economical aspect of Gabion and Conventional Retaining walls.

Total cost of the Gabion wall is calculated by determining the total number of Gabion baskets used and the total weight of the Gabion Fill consumed while constructing the Gabion wall. The filter design cost is constant for a thickness. These components for BOQ are selected after an extensive literature review and the cost of Gabion baskets are used after consulting the manufacturing industry of Gabion baskets.

Units for each component is mentioned in table.

4.6.2 Gravity Wall Economic Analysis

After the Performance-Based analysis, the next task was to analyze the Gravity wall economically. For Economic Analysis, the Bill of Quantity was generated in the Design-Analysis Excel sheet. For BOQ, a simple code was written to calculate the Quantities from the dimensions of the wall. The quantities were further used to calculate final costs of each material. The prices/unit were taken from MRS, June 2020 (Rawalpindi).

BOQs are attached in the annexures.

BOQ's Elements

The elements i.e. materials and services required for wall to be constructed are included in the BOQ so that the cost of these major materials could be calculated.

Table 4.2: BOQ's Elements for Gravity Retaining Wall

BOQ Components	**Units**
Concrete Class A3	cft
Structural Excavation	100 cft
Common Backfill	100 cft
Granular Subbase	100 cft
Foundation Slab Concrete (1:4:8)	100 cft
Erecting and Removing Formwork	ft

Concrete Class A3 is used for the construction of Gravity walls and has compressive strength of around **4000 psi**. Compacted Common Backfill is provided at back face of the wall. Granular sub-base and Slab concrete (1:4:8) are for the foundation slab. Other than these materials there are related services which are primarily required for the construction of Gravity walls so they cannot be neglected while doing the cost estimation.

4.6.3 Cantilever Wall Economic Analysis

After the Performance-Based analysis, the next task was to analyze the Cantilever wall economically. For Economic Analysis, the Bill of Quantity was generated in the Design-Analysis Excel sheet. For BOQ, a simple code was written to calculate the Quantities from the dimensions of the wall. The quantities were further used to calculate final costs of each material. The prices/unit were taken from MRS, June 2020 (Rawalpindi).

BOQs are attached in the annexures.

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Table 4.3: BOQ's Elements for Cantilever Retaining Wall

BOQ Components	Units
Concrete	cft
Steel	cwt
Structural Excavation	100 cft
Common Backfill	100 cft
Granular Subbase	100 cft
Foundation Slab Concrete (1:4:8)	100 cft
Erecting and Removing Formwork	ft

The Grade of the steel varies from **15-30 MPa** in the drop-down list from which the user can select it depending on his requirements.

4.7 Environmental Impact

Sustainability and Energy Efficient structure are the need of the hour. Because of the environmental impacts of concrete due to its Carbon Print and Heat of Hydration and massive concrete can leads to increase in the temperature. The world is moving toward the energy efficient structures and Gabion walls are Energy efficient. As we know that for the construction of Cantilever and Gravity walls, massive concreting is required and if we increase the height of the structure, the amount of concrete required also increases. So, it is cardinal to find an alternative solution which involves minimum or no concrete at all. Gabion Retaining Walls solely depends upon the self-weight of the Gabions filled in gabion Baskets and joined together through a steel wire to resist the lateral earth pressure while on the other hand, Gravity and Cantilever retaining walls retained the soil material due to the concreting and Steel (in case if Cantilever). Data for the impact of Concrete on the environment is attached.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Cantilever Retaining Walls

5.1.1 External Stability

5.1.1.1 Excel Sheets

Excel sheets were compiled using Excel VBA to design Cantilever Wall. The input parameters includes variables of backfill material Foundation soil properties properties of concrete and the loading conditions.

Results

Factors of safety are obtained from design sheets of cantilever wall using excel design sheets. Following is the figure of FOS of Cantiliver Wall of 9ft.

FOS Against Overturning		
	FOS_{over}=	2.133783743 FOS Is OK
FOS Against Sliding		
	FOS_{Slide}=	1.774217764 FOS Is OK
Minimum Pressure at Heel		
	$P_{min=}$	-70.96549465 lbf/ft²
Maximum Pressure at Toe		
	$P_{max=}$	2154.315495 lbf/ft²
Bearing Capacity Check		
	Result=	SBC>Pmax : OK
Factor of Safety Check		
	Result=	FOS Is OK

Figure 5.1: Excel VBA External Stability Factors

The FOS obtained through Cantilever wall using mentioned input parameters are greater than 1.5. Thus the designed Cantiliver wall is analytically stable**.**Similarly, Safety Factors were calculated for heights of 18 and 27 feets.

5.1.1.2 GEO5 Analysis

GEO5 is one of the major programs for geotechnical analysis. There are various programs that are working in that software package and running on same environment. Each of the program is specialized to work for a specific geotechnical field. Several programs included in Geo5 work on analytical and finite element method. Structures can be designed and checked quickly and efficiently by analytical methods of computation. By using Geo5 the design can be transformed into FEM application and structure can be analyzed by FEM.

Geo5 was used to validate the design of cantilever wall. Factors of safety against slipping and overturning were determined and compared Excel sheet results. Keeping the loading conditions constant factors of safety were determined using various heights of walls.

Details of analytical design of Centiliter wall of height =9ft is given as

5.1.1.2.1 Overturning and Slipping

Model of cantilever wall was made as it is shown in the figure. For overturning factor of safety, resisting and overturning moment were calculated. FoS came out to be 2.0. As overturning factor of safety e is greater than 1.5. The design of wall for overturning is satisfactory.

To determine Factors of Safety against sliding, resisting horizontal forces and active horizontal force were determined and divided. As FOS is greater than 1.5. So wall is safe under this loading condition.

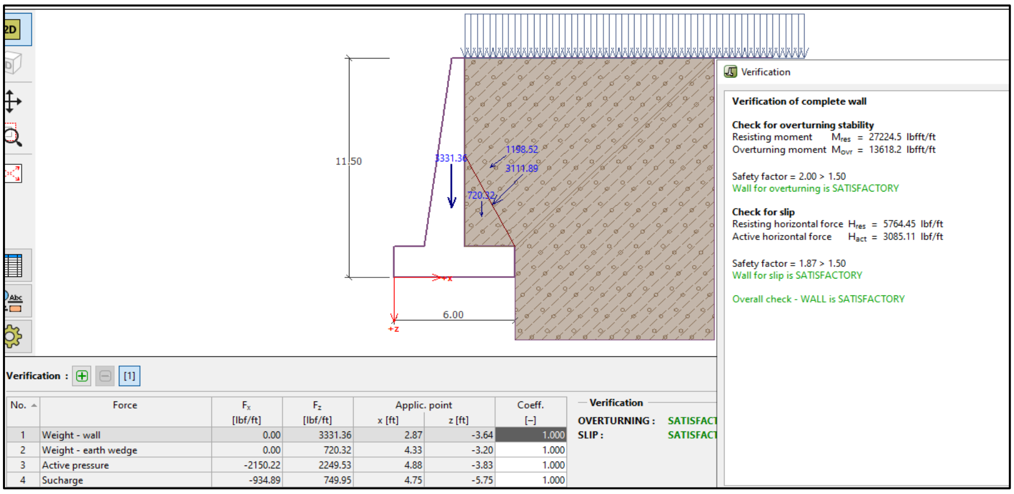


Figure 5.2: GEO-5 Cantilever External Factors of Safety

5.1.1.2.2 Bearing Capacity

Standard procedure was adopted to determine if Soil is safe enough to carry the loading pressure exerted by wall. Maximum vertical stress exerted at the footing bottom was determined and was divided by bearing capacity of soil below foundation to determine Factor of Safety against bearing.

Value of Safety factor is 2.18 which is greater than threshold of 1.5. So the design is satisfactory.

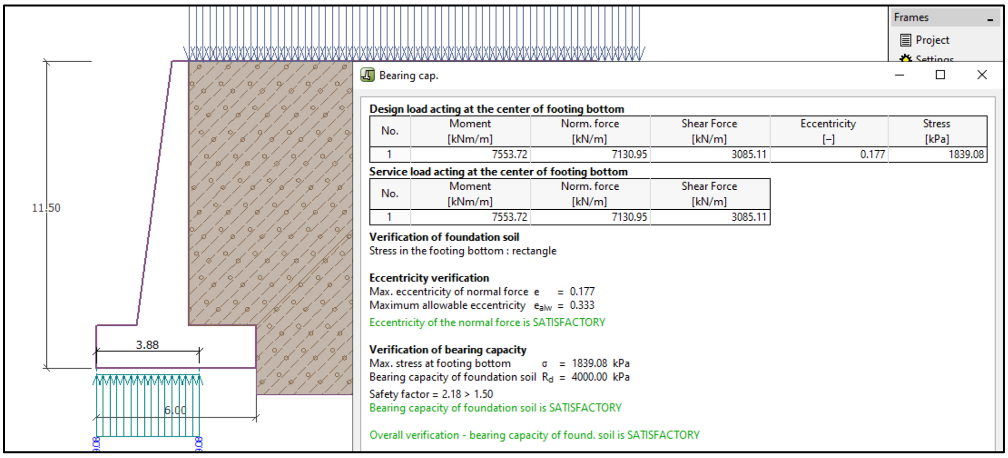


Figure 5.3: Cantilever Bearing Capacity Check from Geo-5

Similarly, same procedure was repeated to determine safety factors for Cantilever Wall of 18Ft and 27ft height.

Followings are factors of safety obtained

Table 5.1: Factors of Safety for different height of Cantilever Retaining Wall

	EXCEL			**GEO5**		
	H=9ft	**H=18ft**	**H=27ft**	**H=9ft**	**H=18ft**	**H=27ft**
FOS for Overturning	2.13	1.84	1.32	2.05	1.78	1.26
FOS for Sliding	1.77	1.19	0.81	1.83	1.23	0.76
Bearing Capacity	1.95	1.21	0.38	2.18	1.32	0.33

5.1.2 Internal Stability

In order to access Internal Stability of Cantilever Wall.**ACI-318-14 Design Approach** is used for determination of area of steel calculation.

Following are kinds of reinforcement that are required in Cantilever wall.

1. Design of Stem Reinforcement
2. Design of Heel Reinforcement
3. Design of Toe Reinforcement

Then A_s required was compared with A_s provided. These check were provided to optimise the material requirement i.e steel.Reinforcement checks were used to determine if Steel provided at base heel and toe is adequate to insure internal stability of wall.

5.2 Gravity Retaining Wall

5.2.1 Excel Sheet Analysis

Excel sheets were compiled using Excel VBA to design Gravity Wall. **The parameters include variables of backfill material Foundation soil properties properties of concrete and the loading conditions.**

Results

Followings are the factors of the safety that are obtained from design sheets of Gravity wall using Excel sheets.

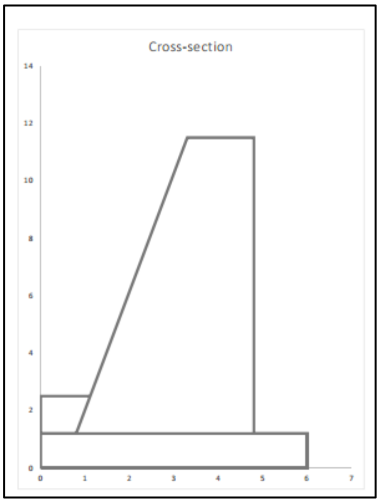
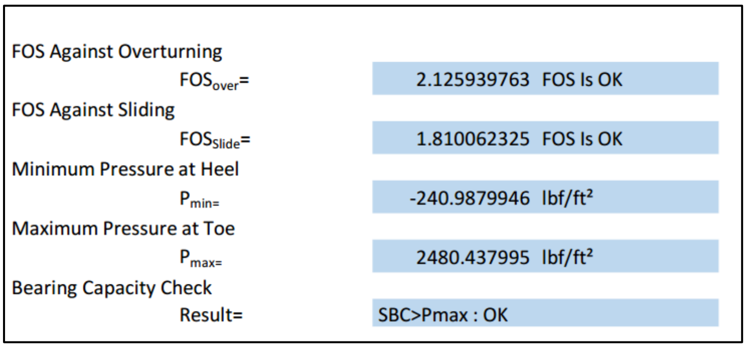
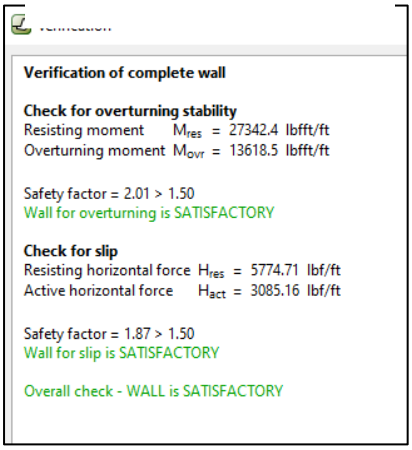


Figure 5.6: Gravity Wall Excel Model



FOS Against Overturning		
FOS_{over}=	2.125939763	FOS Is OK
FOS Against Sliding		
FOS_{Slide}=	1.810062325	FOS Is OK
Minimum Pressure at Heel		
$P_{min=}$	-240.9879946	lbf/ft²
Maximum Pressure at Toe		
$P_{max=}$	2480.437995	lbf/ft²
Bearing Capacity Check		
Result=	SBC>Pmax : OK	

Figure 5.5: Factors of Safety for different height of Gravity Retaining Wall



Verification of complete wall

Check for overturning stability
Resisting moment M_{res} = 27342.4 lbfft/ft
Overturning moment M_{ovr} = 13618.5 lbfft/ft

Safety factor = 2.01 > 1.50
Wall for overturning is SATISFACTORY

Check for slip
Resisting horizontal force H_{res} = 5774.71 lbf/ft
Active horizontal force H_{act} = 3085.16 lbf/ft

Safety factor = 1.87 > 1.50
Wall for slip is SATISFACTORY

Overall check - WALL is SATISFACTORY

Figure 5.4: Verification from GEO 5

The FOS obtained through Gravity wall using mentioned input parameters are greater than 1.5. So the designed Gravity wall is analytically stable.

5.2.2 GEO 5 Analysis

Details of analytical design of Gravity wall of height =9ft is given as

5.2.2.1 Overturning and Slipping

. Firstly, resisting and overturning moment were calculated and Safety factor came out to be 2.01. As, overturning factor of the safety is greater than threshold of 1.5. The design of wall for overturning is satisfactory.

To determine Factors of the Safety against sliding, resisting horizontal forces and active horizontal force were determined and divided.

Safety factor for sliding is greater than 1.5. So wall is safe under this loading condition.

5.2.2.2 Bearing Capacity

Safety of soil to carry the loading pressure exerted by wall is determined by using loading conditions, soil capacity and weight of the wall. Maximum vertical stress exerted at the footing bottom was determined and was divided by bearing capacity of soil below foundation to determine Factor of Safety against bearing.

Value of Safety factor is 2.13 which is greater than threshold of 1.5. So, the design is satisfactory.

Similarly, same procedure was repeated to determine safety factors for Gravity Wall of 27ft height.

Followings are factors of safety obtained:

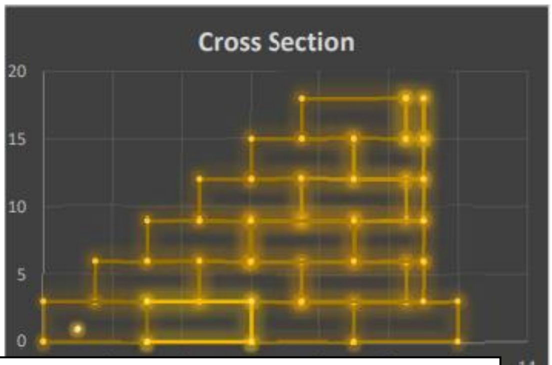
Table 5.2: Factors for Safety For different height of Gravity Wall

	EXCEL			GEO5		
	H=9ft	**H=18ft**	**H=27ft**	**H=9ft**	**H=18ft**	**H=27ft**
FOS for Overturning	2.08	1.83	1.32	2.01	1.76	1.25
FOS for Sliding	1.81	1.19	0.83	1.87	1.23	0.76
FOS for Bearing Capacity	1.96	1.00	0.33	2.13	1.05	0.30

5.3 Gabion Retaining Wall

Gabion retaining wall was our main concern and therefore we designed extensive VBA sheets and provided appropriate number of checks to optimize the design of these Walls.

For Optimization, we considered Staggering Gabion Baskets and Steps on both sides which can be seen within the VBA cross section.



5.3.1 Excel Sheets Results:

Excel sheet results interface can be seen by figure. Geotechnical report is providing both internal and external Safety Factors. Furthermore, coloring pattern was used to improve graphics and to decrease possibility of errors. Green, Yellow and Red Color were used to show the nature of Safety Factors with

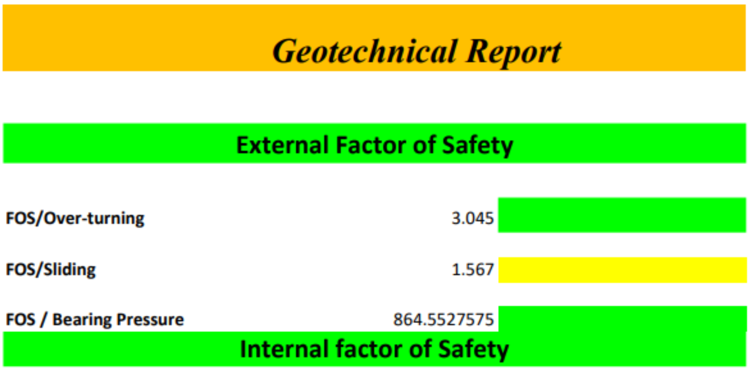


Figure 5.7- Output of EXCEL VBA Sheets for 9ft wall (Gabion)

Green showing satisfactory results while Red represents that Safety factor isn't Satisfactory

In the figure, It can be seen that most of FOSs are satisfactory and are represented by green color. In case of External Factor of Safety for Sliding, Yellow color is shown. Yellow color shows that FOS is not very much satisfactory and is close to Cutoff boundary of FOS i.e 1.5.

Following are the results obtained using different heights:

Table 5.3: Excel VBA Factors of Safety for Gabion Wall

	EXCEL		
	H=9ft	**H=18ft**	**H=27ft**
FOS for Overturning	3.04	3.42	3.18
FOS for Sliding	1.56	1.72	1.59
FOS for Bearing Capacity	3.90	3.02	2.13

5.3.2 Geo5 Analysis

Details of analytical design of Gabion wall of height =9ft is given as

Figure 5.8: GEO-5 FOS for Gabion Walls

5.3.2.1 Overturning and Slipping

Model of Gravity wall was made as it is shown in the figure. For overturning factor of safety, resisting and overturning moment were calculated. Safety factor came out to be

3.20. As overturning factor of the safety is greater than threshold of 1.5. The design of wall for overturning is satisfactory. To determine Factors of Safety for sliding, resisting horizontal forces and active horizontal force were determined and divided. safety factor for sliding is greater than 1.5. So, is safe under this loading condition.

5.3.2.2 Check for Bearing Capacity

Standard procedure was adopted to determine if Soil is safe enough to carry the loading pressure exerted by wall. Value of Safety factor is 3.43 which is greater than threshold of 1.5.

Table 5.4: Factors of Safety of Gabion for Different Height from GEO-5

GEO5			
Height	**9ft**	**18ft**	**27ft**
FOS for Overturning	3.2	3.43	3.28
FOS for Sliding	1.63	1.88	1.67
FOS for Bearing Capacity	3.43	2.35	1.62

5.3.3 Tekla Tedds Analysis

The gabion retaining wall is modeled by considering the gabion basket of combination $3 \times 3 \times 6$ (feet). Where the height of gabion basket is 3 feet, width of gabion basket is 3 feet and length is 6 feet. In Tekla Tedds software we considered three model for three different heights of 9, 18 and 27 feet. The geometry of gabion retaining wall for 9 feet height is shown as Figure 5.9.

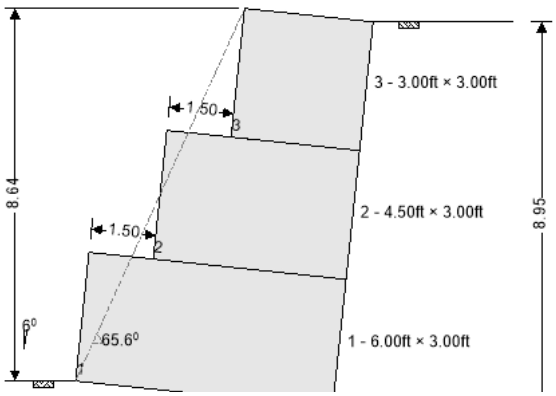


Figure 5.9-Geometry of Gabion Retaining Wall using Tekla Tedds

The Tekla Tedds software applies three checks of external stability as overturning, sliding, and bearing capacity. Software generates complete analysis report that includes detailed computation of factor of safety for each stability checks. In the end the summary of results in the form of analysis table is shown. The software computation of external analysis for gabion wall of 9 feet height is shown in Figure 5.9. As shown in calculation that the wall satisfies all the checks for external stability analysis. The factor of safety for overturning, sliding, and bearing capacity exceeds the minimum required FOS as per standards.

Summary of Results of Tekla Report:

Table 5.5: Factors of Safety of Gabion for different heights from Tekla Tedds

Tekla Ted (Gabion)			
Height	**9ft**	**18ft**	**27ft**
FOS for Overturning	2.97	3.34	2.85
FOS for Sliding	1.62	1.75	1.6
FOS for Bearing Capacity	3.85	2.71	1.66

5.3.3.1 Internal Stability

The Tekla Tedds software analyzes gabion retaining wall for internal stability analysis by using check of overturning and sliding. The gabion retaining walls are constructed with individual baskets that are tied to each other to form a layer. That is why the stability of gabion boxes relative to each other must be checked. The Tekla Tedd carry out internal stability analysis for sliding by comparing the horizontal component of weight for each layer with the lateral pressure acting on that layer. The factor of safety is calculated as the ratio of forces resisting the sliding of layer to forces driving the layer to slide. In the analysis of overturning for internal stability the overturning moments for each layer are calculated about toe of that layer. The ratio of moment resisting the overturning to the moment causing the layer to overturn about its toe is calculated and gives the factor of safety for internal overturning analysis. Calculations for factor of safety of 9 feet gabion retaining wall are shown in Figure 5.10.

Overturning stability - take moments about the toe	
Overturning moment	$M_o = F_{soil\_h} \times d_{h,soil} + F_{surch\_h} \times d_{h,surch}$ = **1.8** kips_ft/ft
Restoring moment	$M_R = F_{gabion\_v} \times X_g + F_{soil\_v} \times b_{v,soil} + F_{surch\_v} \times b_{v,surch}$ = **5.9** kips_ft/ft
Factor of safety	$FoS_M = M_R / M_o$ = **3.283**
Allowable factor of safety	FoS_{M_allow} = **2.000**
	PASS - Design FOS for overturning exceeds min allowable FOS for overturning
Sliding stability - ignore any passive pressure in front of the structure	
Total horizontal force	$T = F_{soil\_h} + F_{surch\_h}$ = **0.9** kips/ft
Total vertical force	$N = F_{gabion\_v} + F_{soil\_v} + F_{surch\_v}$ = **2.2** kips/ft
Sliding force	$F_f = T \times \cos(\varepsilon) - N \times \sin(\varepsilon)$ = **0.7** kips/ft
Sliding resistance	$F_R = (T \times \sin(\varepsilon) + N \times \cos(\varepsilon)) \times \tan(\delta_{bg})$ = **1.6** kips/ft
Factor of safety	$FoS_S = F_R / F_f$ = **2.306**
Allowable factor of safety	FoS_{S_allow} = **1.500**
	PASS - Design FOS for sliding exceeds min allowable FOS for sliding

Figure 5.10-Check for Sliding and Overturning between courses 1 and 2

Overturning stability - take moments about the toe	
Overturning moment	$M_o = F_{soil\_h} \times d_{h,soil} + F_{surch\_h} \times d_{h,surch}$ = **0.3** kips_ft/ft
Restoring moment	$M_R = F_{gabion\_v} \times X_g + F_{soil\_v} \times b_{v,soil} + F_{surch\_v} \times b_{v,surch}$ = **1.4** kips_ft/ft
Factor of safety	$FoS_M = M_R / M_o$ = **4.186**
Allowable factor of safety	FoS_{M_allow} = **2.000**
	PASS - Design FOS for overturning exceeds min allowable FOS for overturning
Sliding stability - ignore any passive pressure in front of the structure	
Total horizontal force	$T = F_{soil\_h} + F_{surch\_h}$ = **0.3** kips/ft
Total vertical force	$N = F_{gabion\_v} + F_{soil\_v} + F_{surch\_v}$ = **0.9** kips/ft
Sliding force	$F_f = T \times \cos(\varepsilon) - N \times \sin(\varepsilon)$ = **0.2** kips/ft
Sliding resistance	$F_R = (T \times \sin(\varepsilon) + N \times \cos(\varepsilon)) \times \tan(\delta_{bg})$ = **0.6** kips/ft
Factor of safety	$FoS_S = F_R / F_f$ = **2.625**
Allowable factor of safety	FoS_{S_allow} = **1.500**
	PASS - Design FOS for sliding exceeds min allowable FOS for sliding

Figure 5.11-Check for Sliding and Overturning between courses 2 and 3

The Figure 5.11 shows the computation for internal stability checks between layer 1 and layer 2 of gabion retaining wall modelled for height of 9 feet. As shown in calculations for overturning the magnitude of resisting moment exceeds the value of moment causing overturning of layers. That is is why factor of the safety for overturning is greater than minimum allowable FOS (2). Moreover, in calculation of sliding the forcing resisting the sliding between layer1 and layer 2 exceeds the magnitude of force driving the layer to slide. The factor of safety for sliding turns out to be 2.3016 that is greater than minimum allowable FOS. Hence, we can say that the layer1 and 2 are internally stable against sliding and overturning relative to each other. Similarly, as shown in Figure 5.11 the layer 2 and 3 also satisfies the criterion of internal stability analysis. Tekla Tedds generate the summary of results in form of table. The results for internal stability analysis for gabion retaining wall of height 9 feet are shown in Figure 5.12.

Action	Resistance	Force	FoS	Allowable FoS	Status
Overturning, sliding and bearing at base level					
Overturning (kips_ft/ft)	14.9	5.0	2.970	2.000	PASS
Sliding (kips/ft)	2.1	1.3	1.620	1.500	PASS
Bearing (ksi)	4.0	1.0	3.853	2.000	PASS
Eccentricity (ft)	Reaction acts within the middle third of base				PASS
Overturning and sliding between courses 1 and 2					
Overturning (kips_ft/ft)	5.9	1.8	3.283	2.000	PASS
Sliding (kips/ft)	1.6	0.7	2.306	1.500	PASS
Overturning and sliding between courses 2 and 3					
Overturning (kips_ft/ft)	1.4	0.3	4.186	2.000	PASS
Sliding (kips/ft)	0.6	0.2	2.625	1.500	PASS

Figure 5.12-Summary of Results for Stability Analysis of Gabion Retaining Wall using Tekla Tedds

5.4 Graphical Illustration of Results and Discussion

5.4.1 Discussion on Analysis

Following graph compares Safety factors of Cantilever Wall which are obtained for excel sheets and Geo5 software. This analysis was performed to validate the results. Following results can be extracted from the graph.

- Safety factors are similar for excel and Geo5 which validates the analysis.
- Safety factors decrease with increasing height.
- Height is Critical for Bearing Pressure
- ALL of factors are below threshold of 1.5 after 20ft height.

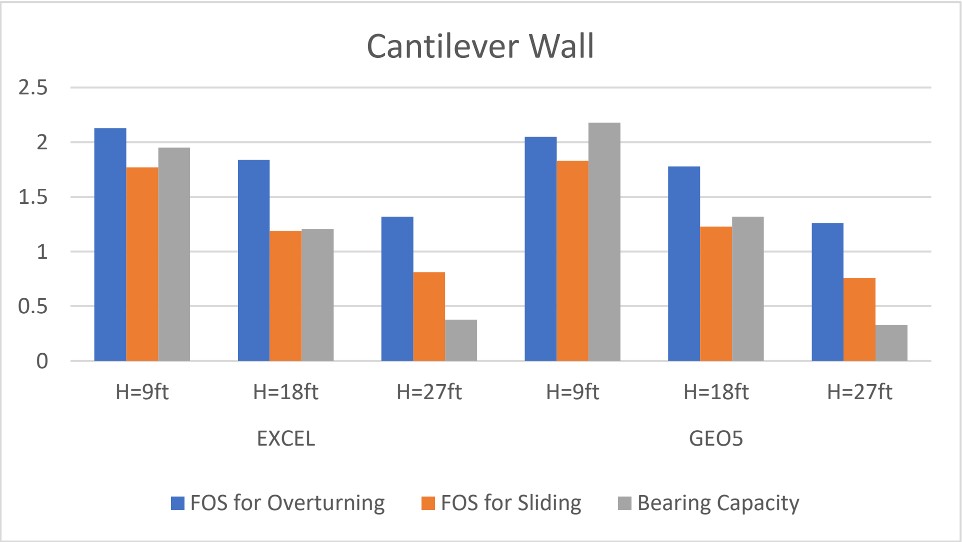


Figure 5.13: Histogram of Cantilever Factors of Safety

Following graph compares Safety factors of Gravity Wall This analysis was performed to validate the results.

Following results can be extracted from the graph.

- Safety factors are similar for excel and Geo5 which validates the analysis.
- Safety factors decrease with increasing height.
- ALL of factors are below threshold of 1.5 after 20ft height.
- Bearing Capacity factor is more sensitive to height

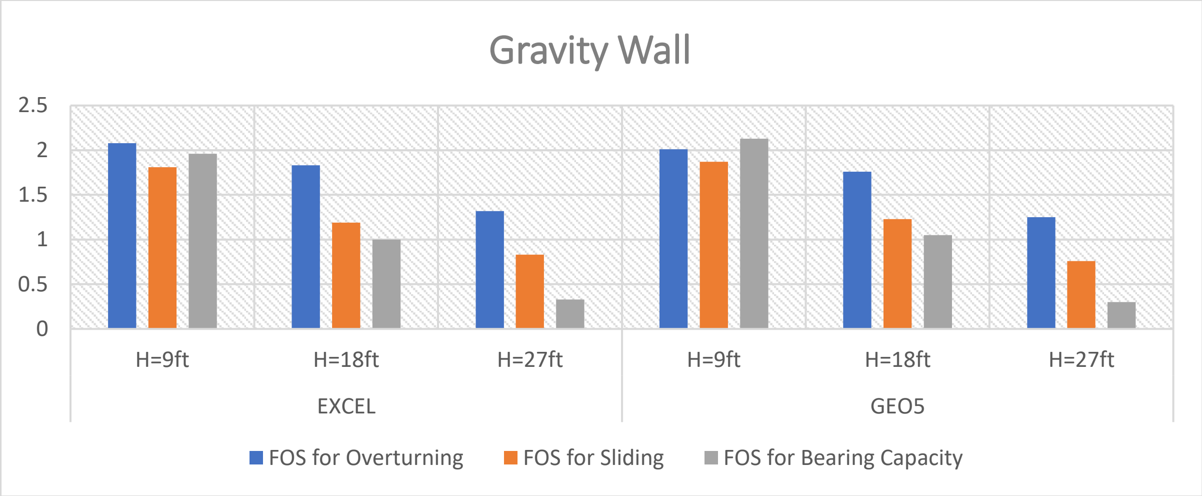


Figure 5.14: Histogram of Gravity wall factors of Safety

Following graph compares Safety factors of Gabion Wall. This analysis was performed to validate the results. Following results can be extracted from the graph.

- Safety factors are similar for excel and Geo5 which validates the analysis.
- Safety factors decrease with increasing height.
- ALL of Safety factors are below threshold of 1.5 after 20ft height.
- Bearing Capacity factor is more sensitive to height
- Safety factor for Sliding and Overturning don’t change significantly with increasing height

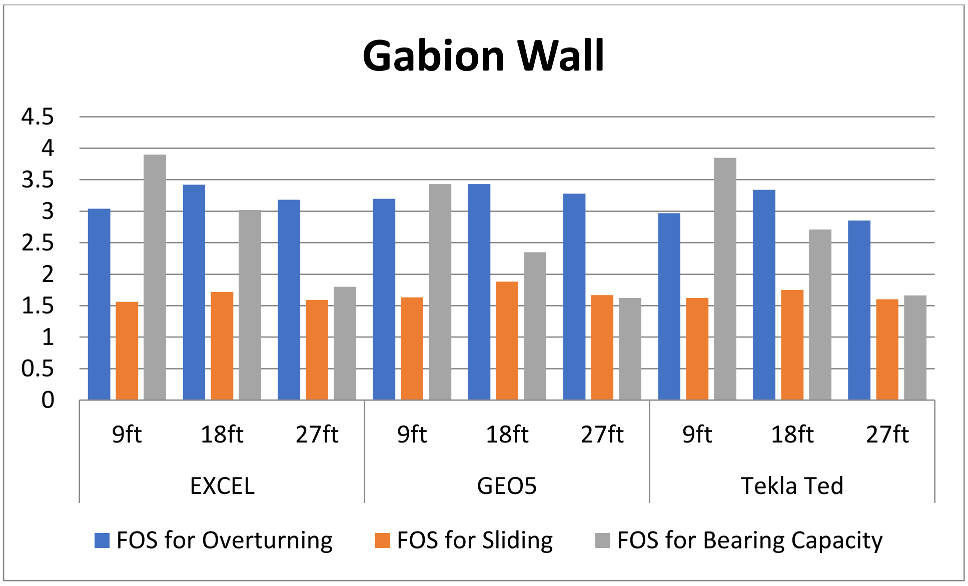


Figure 5.15: Histogram of gabion Wall Factors of Safety

Overturning Safety factor is significantly high for Gabion as compared to conventional Structure.The decrease in FoS against overturning is lesser for Gabion. This makes Gabion more suitable for larger heights.

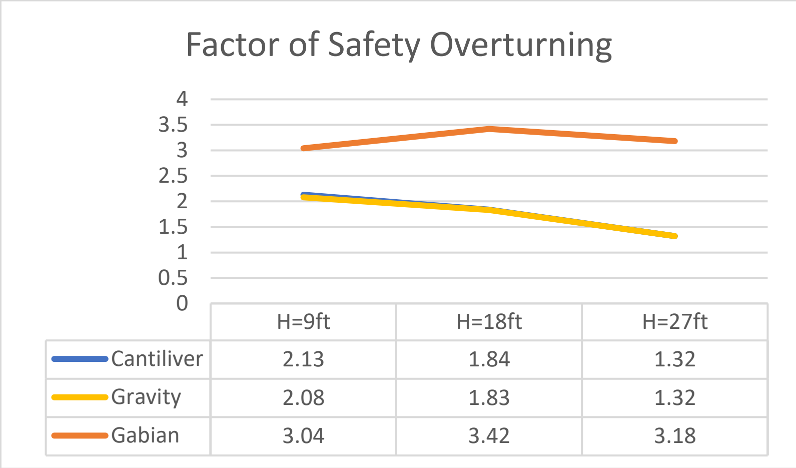


Figure 5.16: Overturning FOS comparison of Gabion V Conventional walls

Following are the key points regarding Factors of Safety against Sliding.

- Safety factor of Sliding is less for Gabion for low height but it maintains its value with increasing heights. FoS for Sliding of Gabion is higher for higher heights as compared to other walls
- The decrease in FoS (with increasing height) against sliding is lesser for Gabion as compared to Conventional ones. As it can be seen in graph that Slope of Safety factor for cantilever and gravity is steep.

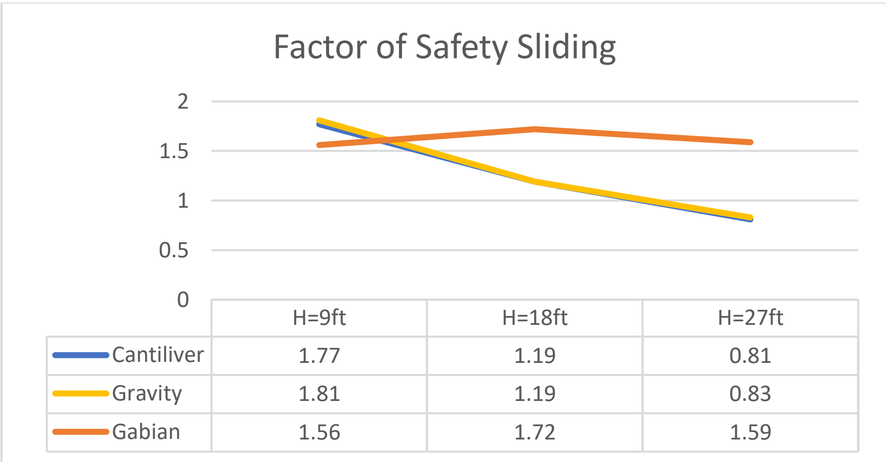


Figure 5.17: Sliding FOS comparison of Gabion Vs. Conventional walls

Following is comparison of safety factors of bearing Capacity.

- FOS against Bearing for Gabion walls is greater than 1.5(which is threshold value). For conventional walls, this is not the case.

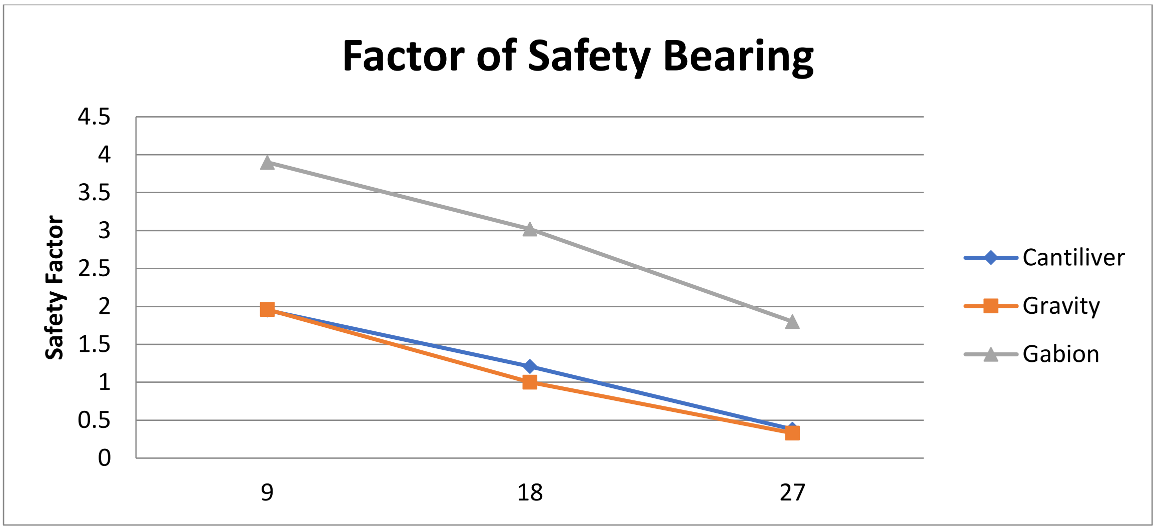


Figure 5.18: bearing FOS comparison of Gabion V Conventional walls

5.4.2 Cost Comparison Report:

Below is the list of all the elements that are included in Cost estimates of cantilever wall.

Table 5.6: Components for BOQ for Gabions and Conventional walls

Cantilever Wall	Gravity Wall	Gabion Wall
Concrete	Concrete	Weight of wire mesh of gabion baskets
Steel Erecting and Removing Formwork	Structural Excavation	Rockfill in gabion baskets
Common Backfill	Common Backfill	Filter layer
Granular Sub-base	Foundation Slab PCC	
Structural Excavation	Granular Sub-base	
Foundation Slab PCC	Erecting and Removing Formwork	

MRS RAWALPINDI 2019 schedule of rates were used to determine total capital cost on each wall. Cost was determined by multiplying rates of each item with respective quantity. Composite rates were used to accommodate labor cost as well. Cost estimate was done for each at number of different heights. Cost had direct relation with height as it can be seen in table below

Table 5.7: Cost Comparision of Gabion and Conventional Walls

Height	Cantilever	Gravity	Gabion
9ft	34503	22527	16435
18ft	114789	62240	55247
27ft	322688	105957	103650

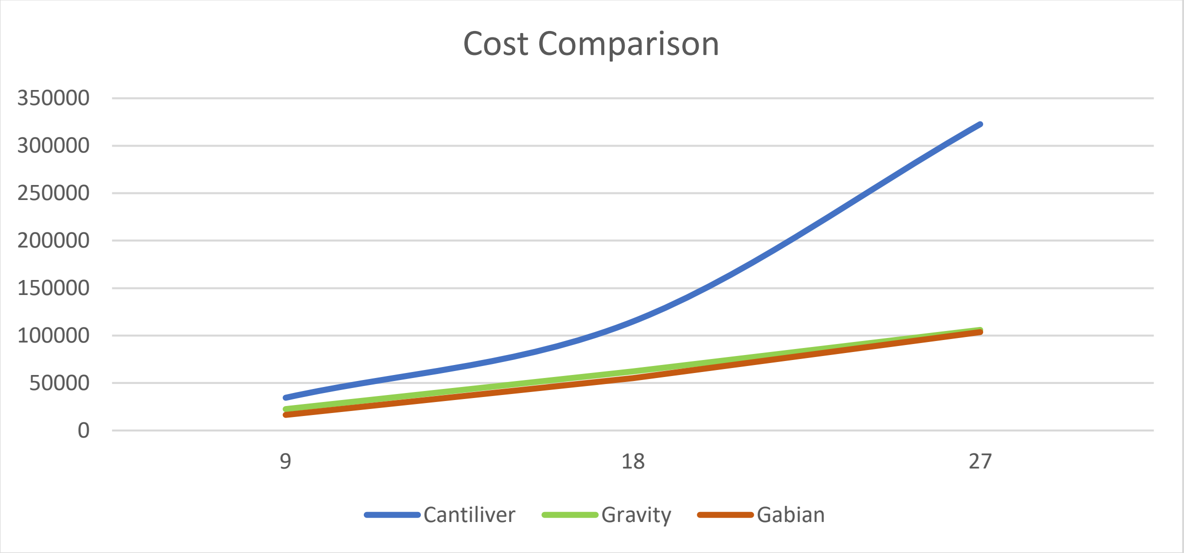


Figure 5.19: Cost comparison of Gabion V Conventional walls

Following are the salient feathers of the Cost Comparison Graph.

- Both Gabion and Gravity wall have similar Costs while Cantilever wall have significantly higher cost than former.
- Cost of Wall increased with increase in height. The slope of increase in cost in less steep for Gabion and Gravity as compared to Cantilever Wall.

5.4.3 Environmental Impacts

Climate Change is quite a defining issue of our time. Concrete is one of main contributor to Global Warming. Carbon Emission due to cement manufacturing within cement kiln is approximately 6.23kg/ft3.Heat of Hydration generated through 1 ft^3 of cement is around 30,582KJ. It was assumed that Concrete Mix Design is same for all Walls. Volume of steel is ignored in case of Cantilever due to complexity and its small value. Length of all walls is 30ft long as an assumption.

As Cement is not used in Gabion Walls. Carbon emission and heat of hydration is none for this case. Estimates of Environmental Impacts of Cantilever and Gravity wall are attached below:

Table 5.8: Environmental Impact Analysis of Conventional Retaining Walls

Gravity wall				
	Cross-sectional Area	Volume(l=30ft.say)	carbon emission(kg)	heat of hydration (KJ)
Unit Value			6.23kg/ft3	30582KJ/ft3
9 ft. wall				
Stem Slab	28.325	849.75	6640	32592767
Base Slab	7.2	216		
18ft wall				
Stem Slab	85	2550	19624.5	96333300
Base Slab	20	600		
27ft wall				
Stem Slab	150	4500	34763.4	170647560
Base Slab	36	1080		

Cantilever wall				
	Cross Sectional Area	Volume	carbon emission(kg)	heat of Hydration(KJ)
Unit Value		say 30 ft. length	6.23 kg/ft3	30582KJ/ft3
9ft				
Stem Slab	13.167	395.01	2627 kg	12896735 KJ
Base Slab	0.89	26.7		
18ft				
Stem Slab	31.825	954.75	6295 kg	30902805 KJ
Base Slab	1.858	55.74		
27ft				
Stem Slab	76.85	2305.5	14988 kg	73575338 KJ
Base Slab	3.3446	100.338		

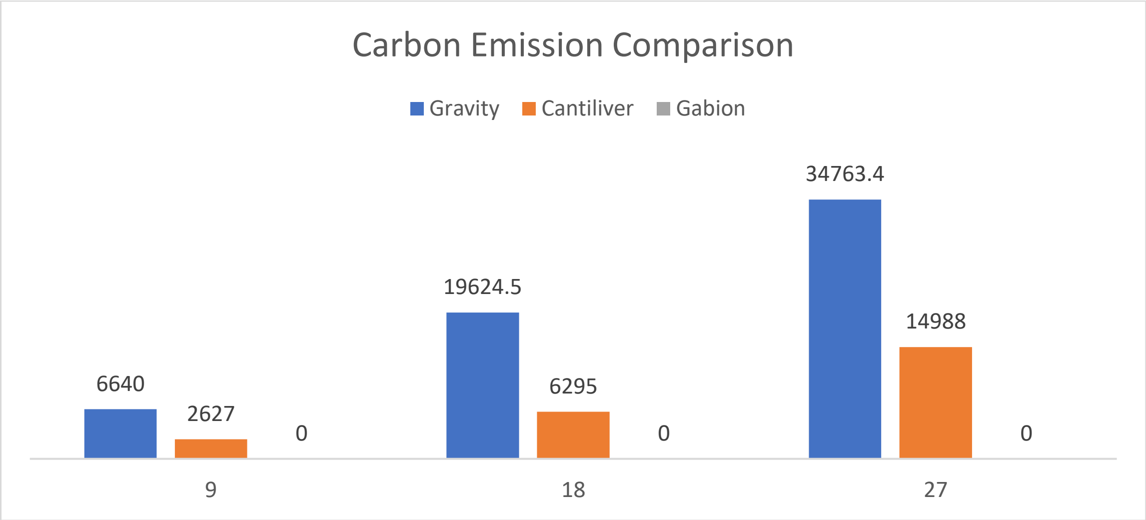


Figure 5.20: Carbon Emission comparison of Gabion Vs Conventional walls

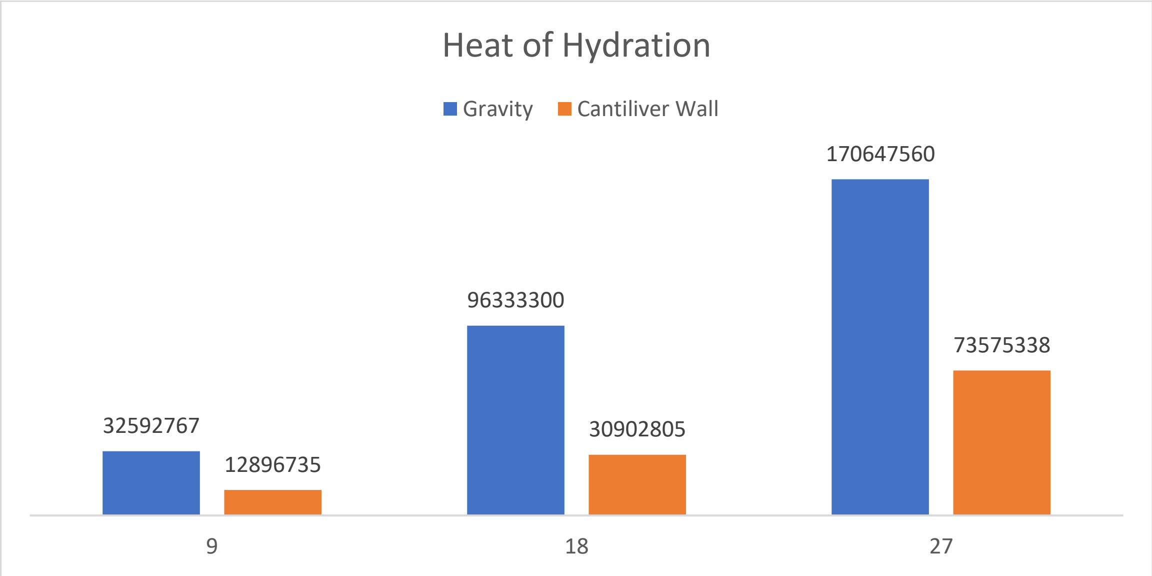


Figure 5.21: Heat of Hydration comparison of Gabion Vs Conventional walls

These graphs show environmental impact of Cantilever and Gravity wall. Following are few points related to environmental aspects of Retaining Structures.

- Carbon Emission and Heat of Hydration increased with height.
- Carbon Emission for Gravity Wall is more than that of Cantilever Wall.
- Gabion Wall has no carbon Emission and Heat of Hydration. That is why Gabions are environment friendly and most suited for larger heights.

CHAPTER 6

CONCLUSION

After an elaborative explanation of Result and Discussions section, it is quite evident that Gabion walls are way better than Conventional Retaining Structures I.e. Cantilever Retaining Walls and Gravity Retaining Walls. There were three factors used for comparative analysis and these are:

- Stability
- Economy
- Sustainability

As far as stability is concerned, As discussed in previous sections, Gabion has very high factors of Safety. And these safety factors initially increase like Overturning and Sliding Factors of safety. On the contrary, safety factors for Conventional Structures decreases and, sometimes, exceeds the allowable limits for the Same height.

Economy plays a pivotal role in Construction Industry. Gabion Walls are comparatively cheap to construct and easy to maintain as compared to Conventional Retaining Walls. The entire theory of Gabion Walls rest on Gabion Stones which are readily available and cheap as compared to concrete and steel, So, this is a clear edge to Gabion walls.

World is moving towards Environmentally Friendly Structures, so, Constructing Gabions instead of Conventional Retaining Walls also have very positive Environmental Impacts as there is No Concrete being used So there will not be any heat of hydration due to concrete.

6.1 Prospective Application

As we have developed EXCEL VBA code which can further be improved into Excel VB and the Design-Analysis sheets for Gabion and Conventional Retaining walls can be made efficient by involving other Stability checks like Dynamic Loading Conditions, Comparison with other Retaining walls and collecting a large data set so a detailed analysis within Gabion walls can be performed to check the effect of different Gabion Stones and Different arrangement on Factors of Safety for Gabion Walls.

6.2 Recommendations

- Gabion-MSE hybrid structure
- Soil Reinforced Gabion Walls
- Design Optimization of Gabion Retaining Walls

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APPENDICES

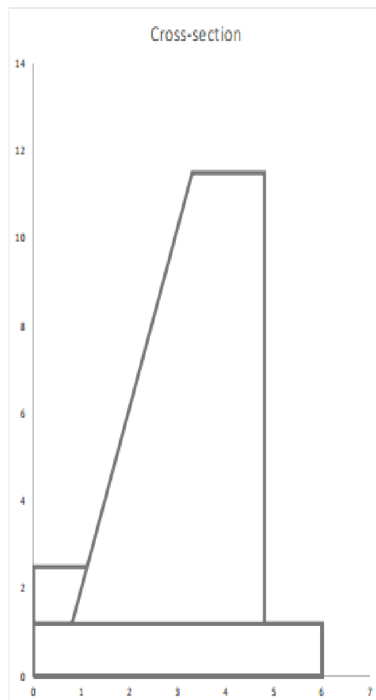
Design-Analysis Sheet : Gravity Wall

DESIGN AND ANALYSIS OF GRAVITY RETAINING WALL

Project Name:	XYZ Project
Date:	3/21/2020

Select Units	US Unit (ft)
Enter the value of Surcharge Pressure q=	300 lbf/ft²
Enter the value of Surcharge Angle α=	0 °
Enter height of the Wall above the ground h=	9 ft
Enter the Thickness of Stem Top (200mm-400mm) Tw=	1.5 ft
Enter the Depth of the foundation (opt) Df=	2.5 ft
Enter the value of Heel projection (opt) hp=	1.2 ft
Enter the value of Toe Projection(opt) tp=	0.8 ft
Enter the Stem bottom thickness (opt) StBw=	4 ft

Enter the total width of the base slab (opt) Bw=	6 ft
Enter the value of Base Slab thickness (opt) bt=	1.2 ft



Characteristics of the Backfill

Enter the Cohesion Parameter c=	0 lbf/ft²
Enter the Unit Weight of the backfill γ =	120 lbf/ft³
Enter the Friction Angle of the soil φ' =	35 °

Characteristics of the Foundation Soil

Enter the Soil Bearing Capacity SBC=	4000 lbf/ft²

Characteristics of the concrete

Enter the unit weight of the Concrete γ concrete =	150 lbf/ft³
Enter the Angle of friction between the base and the foundation soil φ'2 =	18 °
Enter the Cohesion of the base soil c2=	900 lbf/ft²

FOS Against Overturning		
FOS_{over}=	2.125939763	FOS Is OK
FOS Against Sliding		
FOS_{Slide}=	1.810062325	FOS Is OK
Minimum Pressure at Heel		
P_{min}=	-240.9879946	lbf/ft²
Maximum Pressure at Toe		
P_{max}=	2480.437995	lbf/ft²
Bearing Capacity Check		
Result=	SBC>Pmax : OK	

FOS Is OK

CALCULATE RESULTS

GENERATE REPORT

Design-Analysis Sheet : Cantilever Wall

DESIGN AND ANALYSIS OF CANTILEVER RETAINING WALL

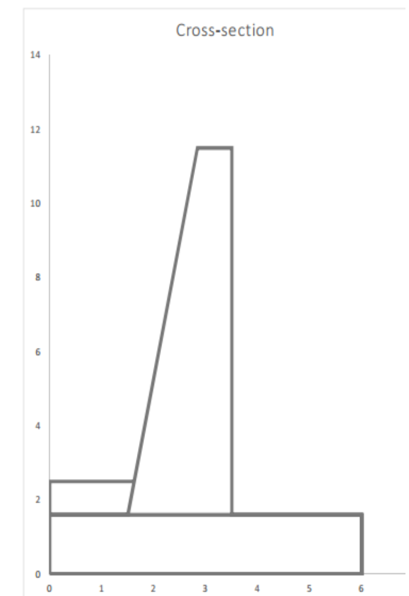
Project Name: FYP

Date: 3/21/2020

Select Units: US Unit (ft)

Enter the value of Surcharge Pressure		
q=	300	lbf/ft²
Enter the value of Surcharge Angle		
α=	0	°
Enter height of the Wall above the ground		
h1=	9	ft
Enter the Thickness of Stem Top (200mm-400mm)		
Tw=	0.66	ft
Enter the Depth of the foundation (opt)		
Df=	2.5	ft
Enter the value of Heel projection (opt)		
hp=	2.5	ft
Enter the value of Toe Projection(opt)		
tp=	1.5	ft
Enter the Stem bottom thickness (opt)		
StBw=	2	ft

Enter the total width of the base slab (opt)		
Bw=	6	ft
Enter the value of Base Slab thickness (opt)		
bt=	1.6	ft



Characteristics of the Backfill

Enter the Cohesion Parameter		
c=	0	lbf/ft²
Enter the Unit Weight of the backfill		
γ =	120	lbf/ft³
Enter the Friction Angle of the soil		
φ' =	35	°

Characteristics of the Foundation Soil

Enter the Soil Bearing Capacity		
SBC=	4000	lbf/ft²

Characteristics of the concrete

Enter the unit weight of the Concrete		
γ concrete =	150	lbf/ft³
Enter the Angle of friction between the base and the foundation soil		
φ'2 =	18	°
Enter the Cohesion of the base soil		
c2=	900	lbf/ft²

FOS Against Overturning	
FOS_{over}=	2.133783743 FOS Is OK
FOS Against Sliding	
FOS_{Slide}=	1.774217764 FOS Is OK
Minimum Pressure at Heel	
P_{min}=	-70.96549465 lbf/ft²
Maximum Pressure at Toe	
P_{max}=	2154.315495 lbf/ft²
Bearing Capacity Check	
Result=	SBC>Pmax : OK
Factor of Safety Check	
Result=	FOS Is OK

Steel Design and Check

Concrete and Steel Strength

i)	Grade of concrete	30 MPa
ii)	Grade of steel	500 MPa

Stem Reinforcement

Steel Provided in (mm^2)

Main Bars	8 mm dia @ 50 mm c/c	1005 sqmm/m
Distribution Bars	8 mm dia @ 500 mm c/c	995 sqmm
Shrinkage Bars	12 mm dia @ 45 mm c/c	2513 sqmm/m

Steel required in (mm^2)

Ast(Req)=		
Main Bars	884.321627 sqmm/m	Steel OK
Distribution Bars	810.7778591 sqmm	Steel OK
Shrinkage Bars	2446.568156 sqmm/m	Steel OK

Steel required in (mm^2)

Ast(Req)=		
Main Bars	884.321627	sqmm/m

Steel OK

Distribution Bars	810.7778591	sqmm

Steel OK

Shrinkage Bars	2446.568156	sqmm/m

Steel OK

Base Heel Reinforcement

Steel Provided in (mm^2)

Ast(Prov)=	12 mm dia @ 125 mm c/c	905 sqmm/m

Steel required in (mm^2)

Ast(Req)=	855.3718605	sqmm/m

Steel OK

Base Toe Reinforcement

Steel Provided in (mm^2)

Ast(Prov)=	12 mm dia @ 30 mm c/c	3770 sqmm/m

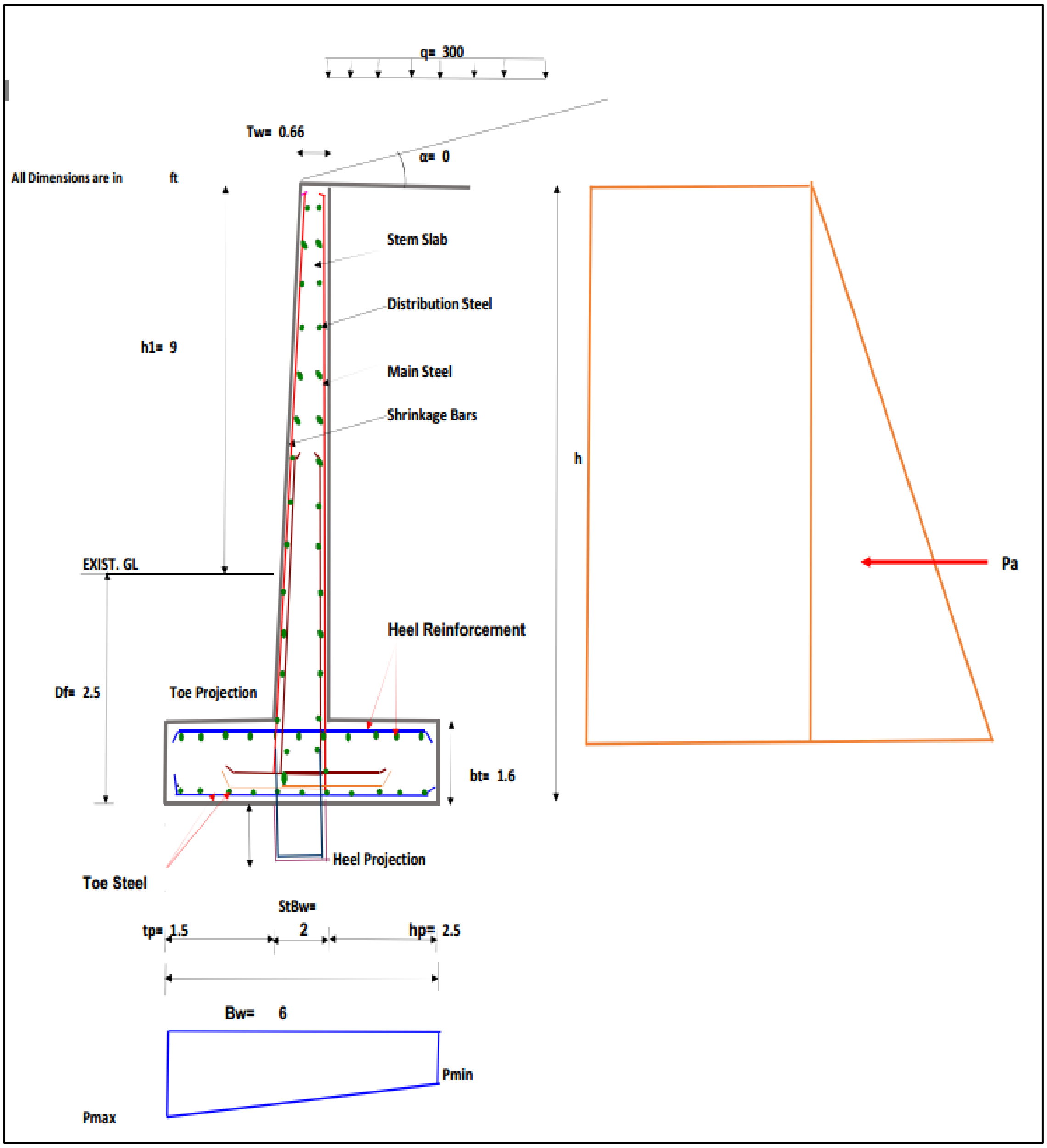
Steel required in (mm^2)

Ast(Req)=	3080	sqmm/m

Steel OK

CALCULATE RESULTS

GENERATE REPORT


q= 300
Tw= 0.66
α= 0
All Dimensions are in ft
Stem Slab
Distribution Steel
h1= 9
Main Steel
Shrinkage Bars
h
EXIST. GL
Pa
Heel Reinforcement
Df= 2.5
Toe Projection
bt= 1.6
Heel Projection
Toe Steel
StBw=
tp= 1.5
2
hp= 2.5
Bw= 6
Pmin
Pmax

Design-Analysis Sheet: Gabion Wall

Geotechnical Report

Project Name	
Location	
Date	6/9/2020

Inputs
Geo-Technical Data

Wall height	9
Base of Wall	6
Surcharge Value	300
Back Slope Angle	0
Back-Face Angle	-6
Wall Friciton Angle	0
Soil Fricition Angle	35
Gabion Fill Density	100
Soil Density	120
Soil Bearing Pressure	4000
Gabion Basket Length	3
Gabion Basket Width	3
No of Baskets Used	5

Geotechnical Report

External Factor of Safety

FOS/Over-turning	3.045
FOS/Sliding	1.567
FOS / Bearing Pressure	864.5527575

Internal factor of Safety

Over-Turning	**Sliding**

BOQ:

Gravity (H = 9ft)

Quantity and Cost Estimation (BOQ)
Gravity Wall

Project Name: FYP

Date: 3/21/2020

Concrete Class A3

	Cross Sec. Area (sft)	Volume/ft	Price (Rs.)/cft	Cost/rft
Stem Slab	28.325	28.325	475.2	13460
Base Slab	7.2	7.2	380.65	2740

Structural Excavation

Area (sft)	Volume/ft (x 100 cft)	Price (Rs.)/100cft	Cost/rft
15	0.15	16223	2433.45

Common Backfill

Area (sft)	Volume/ft (x 100 cft)	Price (Rs.)/100cft	Cost/rft
12.36	0.1236	3023	373.6428

Granular Sub Base

Area (sft)	Volume/ft (x 100 cft)	Price (Rs.)/100cft	Cost/rft
6	0.06	5432	325.92

Foundation Slab Concrete (1:4:8)

Area (sft)	Volume/ft (x 100 cft)	Price (Rs.)/100cft	Cost/rft
6	0.06	23780	1426.8

Erecting and Removing Formwork

Area (sft)	Volume/ft	Price (Rs.)/sft	Cost/rft
22	-	80.35	1767.7

Total Cost Incurred Per Running Foot=	**Rs 22,527.51**

BOQ:

Cantilever (H = 9ft)

Quantity and Cost Estimation (BOQ) Cantilever Wall

Project Name: FYP

Date: 3/21/2020

Concrete				
	Cross Sec. Area (sft)	**Volume/ft**	**Price (Rs.)/cft**	**Cost/rft**
Stem Slab	13.167	13.167	455.2	5993
Base Slab	0.891891	0.891890875	353.65	315
Steel				
	Area of Steel (sqft)	**Volume/ft**	**Density (lb/ft^3)**	**Weight (lb)/ft**
Stem Slab	0.443611	0.443610978	493.18	218.78006
Base Slab	0.300115	0.30011509	493.18	148.01076
Structural Excavation				
	Area (sft)	**Volume/ft**	**Price (Rs.)/100cft**	**Cost/rft**
	4.572056	0.045720556	16223	741.72458
Common Backfill				
	Area (sft)	**Volume/ft**	**Price (Rs.)/100cft**	**Cost/rft**
	2.299406	0.022994062	3023	69.511048
Granular Sub Base				
	Area (sft)	**Volume/ft**	**Price (Rs.)/100cft**	**Cost/rft**
	1.828822	0.018288222	5432	99.341624
Foundation Slab Concrete (1:4:8)				
	Area (sft)	**Volume/ft**	**Price (Rs.)/100cft**	**Cost/rft**
	1.828822	0.018288222	23780	434.89393
Erecting and Removing Formwork				
	Area (sft)	**Volume/ft**	**Price (Rs.)/sft**	**Cost/rft**

Total Cost Incurred Per Running Foot= Rs 34,503.84

BOQ:

Gabion Wall (H=9ft)

Cost of Gabion Wall Components				
COMPONENT NAME	UNITS	PRICE/UNIT	QUANTITY	TOTAL AMOUNT
Steel wire mesh for Gabion	*lbs*	78	182	14185
Rock Fill in Gabion	*Cft*	40	45	1800
Filter Layer of Granular Material	*Cft*	50	9	450
			Total Amount	***16435***