OPTIMUM DESIGN OF RETAINING WALL FOR EARTH RETAINING STRUCTURES OF DIFFERENT HEIGHT

By

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

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TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohd Nur Shafiq Bin Ismail

ABSTRACT

Retaining walls are usually classified as geotechnical structures. Retaining wall can be either earth retaining wall or water retaining wall. For earth retaining wall, it is generally used to provide lateral support for an earth fill, embankment, or some other material and to support vertical loads. One primary purpose for these walls is to maintain a difference in elevation of the ground surface on each side of the wall. The earth whose ground surface is at the higher elevation is commonly called the backfill, and the wall is said to retain this backfill. The main objective to be achieved by this project is to investigate the optimum height of different types of retaining wall. As the problems regarding the slope failure and land sliding is becoming more significant in the Peninsular Malaysia, the study on how to minimize or even to eliminate the risks of these problems are crucial. The optimum height of different types of retaining wall should be determined and the design needs to be optimized to provide the best rectification possible. In order to determine the optimum height of different types of retaining walls such as cantilever wall, counter-fort and buttress wall, macros on Excel spreadsheet programs to be develop. Based on the most critical parameters such as soil properties, surcharge pressure, and etc the optimum height can be obtained and then the design is to be optimized.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious, the Most Merciful. Praise to Him the Almighty that in His will and given strength, author managed to complete this final year project. Here, author would like to take this opportunity to express his appreciation to those who had assisted him in completing his final year project successfully.

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CHAPTER 1.0
INTRODUCTION

1.1 Background of Study

Retaining wall is a generic structure that is employed to restrain a vertical-faced or near-vertical-faced mass of earth. The earth behind the wall may be either the natural embankment or the backfill material placed adjacent to the retaining wall. Retaining walls must resist the lateral pressure of the earth, which tends to cause the structure to slide or overturn. Retaining walls are commonly used to level or retain slopes and give them a more vertical character.

Generally, the more restricted or congested the site, the greater the need for retaining walls to provide usable space for landscape purposes. Functional retaining walls are constructed for purely structural needs. For example, they can be used to level, retain, or terrace a sloping area; to maintain an existing grade around a tree or some other landscape feature you're trying to save; to allow a more abrupt change in grade than you can achieve with graded slopes; and to support a level area such as a patio or driveway. Outdoor steps are modified human-scale retaining walls. Like outdoor steps, some retaining walls serve a purely functional purpose, and you may not be able to incorporate aesthetic considerations such as form, texture, color, shape, scale, and proportion.

Other retaining walls are used for visual effect in the landscape, and generally have several common characteristics. For example, they feature an informal shape and irregular placement of wall materials. They're less significant in size but more pronounced in visual character than functional retaining walls. They complement other landscape elements such as plants, paving and mulches. They're more compatible with human activity and can be adapted to many uses. They can be used as a bench wall, as a base for a fence, or an accent element in the landscape. And the materials used to build decorative retaining walls -- native stone, timbers and colored concrete bricks and blocks -- are chosen to provide the desired visual effect in the landscape. The higher the retained slope, the more structural stability is required. Many times, critical structural requirements necessitate engineering a design that considers the length of slope, site-soil characteristics, and the wall material use, construction space available and height of the wall.

Retaining wall is one of the geotechnical structures and it is generally defined as a vertical structure that holds back earth or prevents retained material from assuming its natural slope. Wall structures are commonly used to support earth, coal, ore piles, and water. In addition to that, a retaining wall has many uses such as wall for roadside embankments, to separate older roads from highways, a house retaining wall for the garage; a retaining wall helps keep river banks from eroding and retaining wall to keep earth from stairwells and driveways. Most retaining structures are vertical or nearly so. Retaining walls may be classified according to how they produce stability:

1. Mechanically reinforced earth – also sometimes called a gravity wall
2. Gravity walls – either reinforced earth, masonry or concrete
3. Cantilever walls – concrete or sheet-pile
4. Anchored walls – sheet-pile and certain configurations of reinforced earth

The design of a retaining wall must account for all the applied loads. The load that presents the greatest problem and is of primary concern is the lateral earth pressure induced by the retained soil. The comprehensive earth pressure theories are evolving from the original Coulomb's and Rankine's theories.

1.2 Problem Statement

1.2.1 Problem Identification

Slope failure and land sliding is a common problem in the Peninsular Malaysia. Land sliding is defined as rapid slipping of a mass of earth or rock from a higher elevation to a lower level under the influence of gravity and water lubrication. More specifically, rockslides are the rapid downhill movement of large masses of rock with little or no hydraulic flow, similar to an avalanche. Water-saturated soil or clay on a slope may slide downhill over a period of several hours. Earth flows of this type are usually not serious threats to life because of their slow movement, yet they can cause blockage of roads and do extensive damage to property. Mudflows are more spectacular streams of mud that pour down canyons in mountainous regions during major rainstorms where there is little vegetation to protect hillsides from erosion. The runoff from the storm and mud becomes thin slurry that funnels down the canyons until it thickens and stops.

One of the ways to rectify this problem is by applying the earth retaining structures or the retaining walls. A very details analysis and study need to be conducted in order to determine the best type of retaining walls to be applied. Then the optimum height of different types of retaining walls for the most critical parameters (properties of soil, surcharge pressure, etc) is to be determined.

1.2.2 Significant of the Project

At the end of this project, the spreadsheet data that have been developed should be enough to function as a guideline during the selection of retaining wall to be used. The Excel spreadsheet program should contain enough data for choosing the most suitable plus economical retaining wall to be constructed. This data should indicate the constructed retaining wall will be at optimum height which the design has been optimized.

1.3 Objectives and Scope of Study

The main objective of this project is to investigate the optimum height of different types of retaining walls by developing a spreadsheet on Microsoft Excel. As this is a new project to be carried out, it aims to transfer different types of retaining walls calculation procedures which is very long, tedious and time consuming into spreadsheets using the Microsoft Excel Spreadsheet Design Program.

CHAPTER 2.0

LITERATURE REVIEW AND/OR THEORY

2.1 Lateral Earth Pressure

Lateral earth pressure represents pressures that are "to the side" (horizontal) rather than vertical. Calculating lateral earth pressure is necessary in order to design structures such as:

- Retaining Walls
- Bridge Abutments
- Bulkheads
- Temporary Earth Support Systems
- Basement Walls

2.1.1 Categories of Lateral Earth Pressure

There are three categories of lateral earth pressure and each depends upon the movement experienced by the vertical wall on which the pressure is acting. The three categories are:

- At rest earth pressure
- Active earth pressure
- Passive earth pressure

At rest pressure develops when the wall experiences no lateral movement. This typically occurs when the wall is restrained from movement such as a basement wall that is supported at the bottom by a slab and at the top by a floor framing system prior to placing soil backfill against the wall.

The active pressure develops when the wall is free to move outward such as a typical retaining wall and the soil mass stretches sufficiently to mobilize its shear strength.

On the other hand, if the wall moves into the soil, then the soil mass is compressed sufficiently to mobilize its shear strength and the passive pressure develops. This situation might occur along the section of wall that is below grade and on the opposite side of the wall from the higher section. Some engineers use the passive pressure that develops along this buried face as additional restraint to lateral movement.

In order to develop the full active pressure or the full passive pressure, the wall has to move. If the wall does not move a sufficient amount, then the full pressure will not develop. If the full active pressure does not develop behind a wall, then the pressure will be higher than the expected active pressure. Likewise, significant movement is necessary to mobilize the full passive pressure.

Thus the intensity of the active / passive horizontal pressure, which is a function of the applicable earth pressure coefficient, depends on wall movement as the movement controls the degree of shear strength mobilized in the surrounding soil.

2.1.2 Lateral Earth Pressure Coefficients

Retaining walls support slopes of earth masses. Design and construction of retaining walls require a thorough knowledge of the lateral forces that act between the retaining walls and the soil masses being retained. These lateral forces are caused by lateral earth pressure. There are various earth pressure theories such as:

i) At – rest lateral earth pressure
ii) Rankine lateral earth pressure
iii) Coulomb lateral earth pressure

2.1.2.1 At – Rest Lateral Earth Pressure

Depending upon whether the soil is loose sand, dense sand, normally consolidated clay or over consolidated clay, there are published relationships that depend upon the soil's engineering values for calculating the at rest earth pressure coefficient. One common earth pressure coefficient for the "at rest" condition used with granular soil is:

$$K_0 = 1 - \sin(\varphi) \quad \ldots\ldots.(1.0)$$

where: K_0 is the "at rest" earth pressure coefficient and φ is the soil friction value.

2.1.2.2 Rankine's Lateral Earth Pressure

Rankine's theory, developed in 1857, predicts active and passive earth pressure. It is an analytically derived theory based on the assumption that the pressure resultant is parallel to the backfill surface (of a retaining wall), the soil is cohesionless, the wall is frictionless, the soil-wall interface is vertical, and the rupture surface that the soil mass moves on is planar.

The Rankine's theory of active pressure are applied when a retaining wall is allowed to move away from the soil mass gradually hence decreasing the horizontal principle stress. The state of plastic equilibrium and failure of the soil can be represented by a Mohr's circle.

In Rankine's theory of passive pressure, it discuss how the soil behave when the wall is gradually pushed into the soil mass instead of the wall being allowed to move away from the soil mass. In this condition, the effective principle stress σ'_h will increase. The Rankine Theory assumes:

- There is no adhesion or friction between the wall and soil
- Lateral pressure is limited to vertical walls
- Failure (in the backfill) occurs as a sliding wedge along an assumed failure plane defined by φ

- Lateral pressure varies linearly with depth and the resultant pressure is located one-third of the height (H) above the base of the wall.
- The resultant force is parallel to the backfill surface.

The Rankine active and passive earth pressure coefficient for the condition of a horizontal backfill surface is calculated as follows:

- (Active) $Ka = (1 - \sin(\varphi)) / (1 + \sin(\varphi))$.......(2.0)
- (Passive) $Kp = (1 + \sin(\varphi)) / (1 - \sin(\varphi))$......(3.0)

Table 1: Tabulated values base on Expression (2.0) and (3.0)

φ (deg)	Rankine Ka	Rankine Kp
28	.361	2.77
30	.333	3.00
32	.307	3.26

2.1.2.3 Coulomb's Lateral Earth Pressure

The Coulomb active and passive earth pressure coefficient is a more complicated expression that depends on the angle of the back of the wall, the soil-wall friction value and the angle of backfill. Although the expression is not shown, these values are readily obtained in textbook tables or by programmed computers and calculators. The Table below shows some examples of the Coulomb active and passive earth pressure coefficient for the specific case of a vertical back of wall angle and horizontal backfill surface.

Table 2 : Coulomb Active Pressure Coefficient

δ (deg)					
φ (deg)	0	5	10	15	20
28	.3610	.3448	.3330	.3251	.3203
30	.3333	.3189	.3085	.3014	.2973
32	.3073	.2945	.2853	.2791	.2755

Table 3 : Coulomb Passive Pressure Coefficient

δ (deg)					
φ (deg)	0	5	10	15	20
30	3.000	3.506	4.143	4.977	6.105
35	3.690	4.390	5.310	6.854	8.324

Some points to consider are:

- For the Coulomb case shown above with no soil-wall friction (i.e. δ = 0) and a horizontal backfill surface, both the Coulomb and Rankine methods yield equal results.
- As the soil becomes stronger the friction value (φ) increases. The active pressure coefficient decreases, resulting in a decrease in the active force and the passive pressure coefficient increases, resulting in an increase in the passive force.
- As the soil increases in strength (i.e. friction value increases) there is less horizontal pressure on the wall in the active case

2.2 Other Forces Acting on the Wall

Aside from the earth pressure force acting on wall, other forces might also act on the wall. These forces include:

- Surcharge load
- Earthquake load
- Water Pressure

2.2.1 Surcharge Load

A surcharge load results from forces that are applied along the surface of the backfill behind the wall. These forces apply an additional lateral force on the back of the wall. Surcharge pressures result from loads such as a line load, strip load, embankment load, traffic (such as a parking lot), floor loads and temporary loads such as construction traffic. Generally, elastic theory is used to determine the lateral pressure due to the surcharge and these methods have been extensively published.

In the case of a uniform surcharge pressure (q) taken over a wide area behind the wall, the lateral pressure due to the uniform surcharge:

- K()q ....(7.0)

where K() is the applicable at rest, active or passive pressure coefficient.

The pressure diagram behind the wall for a uniform surcharge is rectangular and acts at a height of H/2 above the base of the wall. Thus, the additional lateral force (Ps) acting behind the wall resulting from a uniform surcharge is the area of the rectangle, or:

- Ps = K()qH ....(8.0)

Whether the total surcharge load is calculated from elastic theory or as shown in expression (8.0), the force (pressure) is superimposed onto the calculated lateral earth pressure.

2.2.2 Earthquake Force

Additional lateral loads resulting from an earthquake are also superimposed onto the lateral earth pressure where required.

2.2.3 Water Pressure

Walls are typically designed to prevent hydrostatic pressure from developing behind the wall. Therefore the loads applied to most walls will not include water pressure. In cases where water pressure might develop behind an undrained wall, the additional force resulting from the water pressure must be superimposed onto the lateral earth pressure. Since water pressure is equal in all directions (i.e. coefficient (K) = 1), the water pressure distribution increases linearly with depth at a rate of γwz where γw is the unit weight of water (62.4 pcf) and z is the depth below the groundwater level. If the surface of water behind a 10-foot high wall (H) were located 5-feet (d) below the backfill surface, then the superimposed total lateral force resulting from groundwater pressure would be:

- $W = \frac{1}{2} (\gamma w)(H-d)2 = 780$ pounds, which is the area of the linearly increasing pressure distribution.
- W acts at a height of (H-d)/3 (or 1.67-ft) above the base of the wall.
- Note that the earth pressure would be calculated using the submerged unit weight of soil γ' below the groundwater level.

If seepage occurs, then the water pressure must be derived from seepage analysis.

2.2.4 Compaction

If heavy rollers are used to compact soil adjacent to walls, then high residual pressures can develop against the wall. Although a reasonable amount of backfill compaction is necessary, excess compaction should be avoided.

2.3 Lateral Forces on Retaining Walls

Figure 1 shows a concrete retaining wall of height H. It is called a gravity wall because it depends only on its weight for stability. The zone behind it is backfilled with clean sand. Sand will exert some lateral force on the wall where the lateral force has to be the weight of the retained sand, or the force of gravity.

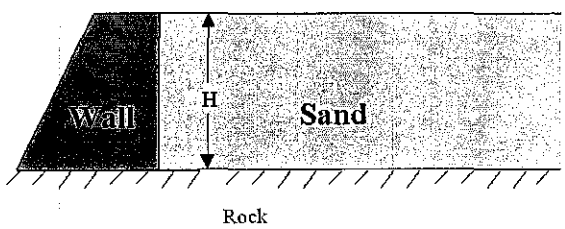


Figure 1 : Gravity wall

If the sand were a fluid, it would be a simple problem of hydrostatics. The lateral pressure would be the same as the vertical pressure. It would increase directly with depth, so that a diagram of pressure would be a triangle. As will be developed further on, the sand will also cause a triangular horizontal pressure. However, it has an internal strength which makes the lateral pressure less than the vertical pressure.

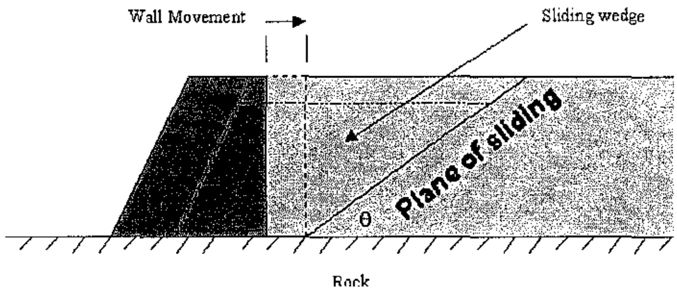


Figure 2 : Mechanism of sliding

Figure 2 illustrates the mechanism by which, for this analysis, the sand crowds against the wall. A plane of sliding forms at some angle theta with the horizontal. The sand between this plane and the wall forms a sliding wedge, and slides down and toward the wall, causing the wall to displace to the left. The amount of movement is greatly exaggerated for illustration.

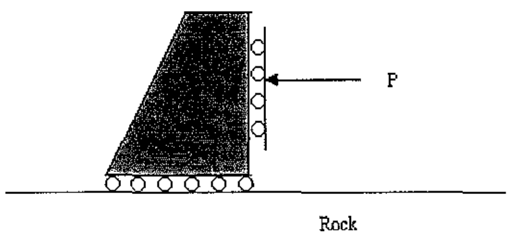


Figure 3 : Free-body diagram

Figure 3 shows the same thing as figure 2, except that it called a free-body diagram. The total, or resultant, force from the sand is represented by P. The rollers between P and the wall represent the slippery condition on the back of the wall, assuring that P can only be applied perpendicular to the wall. The rollers under the wall represent the concept that it can easily move ahead of the sand.

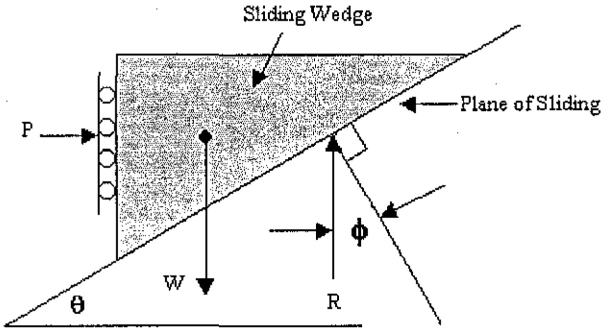


Figure 4 : Free-body diagram of the sliding wedge

Figure 4 shows a free-body diagram of the sliding wedge, not the wall, and the forces acting on it. The forces are:

1. P, which is the same as the P of Figure 3, except that it is the force the wall exerts on the sand. For equilibrium, the wall and the sand must exert the same force on each other.
2. W, which is the force due to the weight of the sand. This simply the area of the wedge times the sand density, gamma, pounds per cubic foot. W must of course act vertically.
3. R, which is the sand's internal friction resistance to sliding. R acts at an angle phi with the perpendicular, or normal, to the plane of sliding. More about R and phi in Figure 5.

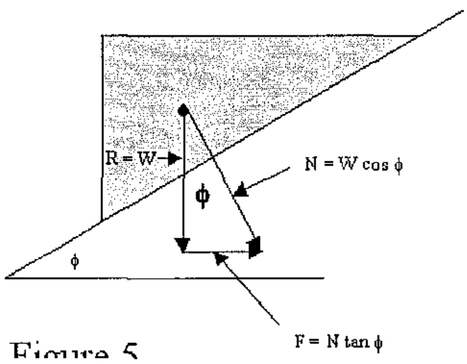


Figure 5 : Free-body diagram of the angle phi

Figure 5 is inserted to show the significance of the angle phi. It is called the angle of internal friction and is an important parameter for geotechnical engineers. It is more or less unique to each type of soil, kind of dependent on the roughness of the individual soil grains. It is determined through laboratory tests. Values for sand are in the range of 25 to 35 degrees.

Figure 5 is drawn with the slope angle theta equal to phi, and that the wedge is sitting there with no force P holding it. At this angle, R = W which means the friction just balances the sliding force. R can be broken down into two components: N perpendicular to the sliding surface and F parallel to it. The trig relations between W, N, and F are shown. If you have had the sliding block friction part of physics then you will recognize a similar situation here. Obviously, if theta is less than or equal to phi, no sliding will occur and there will be no P. As theta increases beyond phi, W will overcome R, the block will slide, and P will develop. R. can only resist so much because it is limited by phi. Plus, as theta increases, N and F decrease. However, as discussed further on, the highest theta may not give the greatest P because then the sliding wedge and W get smaller.

Lateral earth pressure is a significant design element in a number of foundation engineering problems. Retaining and sheet-pile walls, both braced and unbraced excavations and other earth structures require a quantitative estimate of the lateral pressure on a structural member for either a design or stability analysis. The magnitude and direction of the pressures as well as the pressure distribution exerted by a soil backfill upon a wall are affected by many variables. These variables include, but are not limited to, the type of backfill used, the drainage of the backfill material, the level of the water table, the slope of the backfill material, added loads applied on the backfill, the degree of the soil compaction, and movement of the wall caused by the action of the backfill.

2.4 Types of Retaining Walls

2.4.1 Mechanically Reinforced Earth Walls

At the moment, the mechanically stabilized earth and gravity walls are probably the most used – particularly for roadwork where deep cuts or hillside road locations required retaining walls to hold the earth in place. These walls eliminate the need for using natural slopes and result in savings in both right-of-way costs and fill requirements. This type of retaining walls used the principle of placing reinforcing into the backfill using devices such as metal strips and rods, geotextile strips and sheets and grids, or wire grids. There is little conceptual difference in reinforcing soil or concrete masses – reinforcement carries the tension stresses developed by the applied loads for either materials.

2.4.2 Cantilever Retaining Walls

The cantilever wall is the most common type of retaining structure and generally is used for walls in the range from 10 to 25 ft in height. It is so named because its individual parts (toe, heel, and stem) behave as, and are designed as, cantilever beams. Aside from its stability, the capacity of the wall is a function of the strength of its individual parts. A retaining wall must be stable as a whole, and it must have sufficient strength to resist the forces acting on it. Cantilever walls or stem walls of reinforced concrete are composed of a vertical or inclined slab monolithic with a slab base. Simple forms of cantilever wall utilize the weight of the earth or backfill on the heel. This weight is added to the concrete weight to provide resistance against active thrust. Such cantilever wall types are known as T shaped. *(refer Figure 6)*

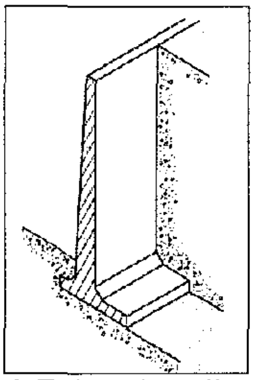


Figure 6: T shaped cantilever wall

2.4.3 Counterfort / Buttress Walls

Counterfort walls are cantilever walls strengthened with counterforts monolithic with the back of the wall slab and base slab. The counterforts act as tension stiffeners and connect the wall slab and the base to reduce the bending and shearing stresses. Counterforts are used for high walls with heights greater than 8 to 12 m. They are also used for situations where high lateral pressures occur, e.g. where the backfill is heavily surcharged. Counterforts should be designed as cantilevers of T-section and the wall stem as a continuous slab. *(refer Figure 7)*. The design should transfer the main part of the earth thrust from the slab to the counterfort. Buttress walls are similar to counterfort walls except that the vertical braces are placed on the wall instead of along the back. *(refer Figure 8)*. The vertical braces or stiffeners act as compression braces. They are used for tall walls, but are not as common as counterfort walls.

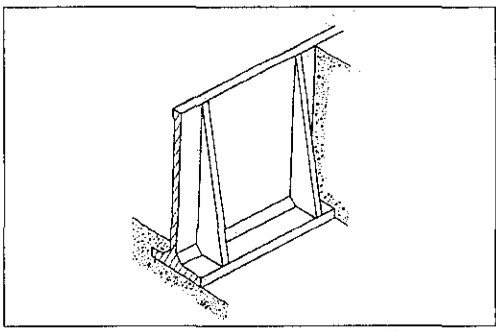


Figure 7: Counterfort Wall

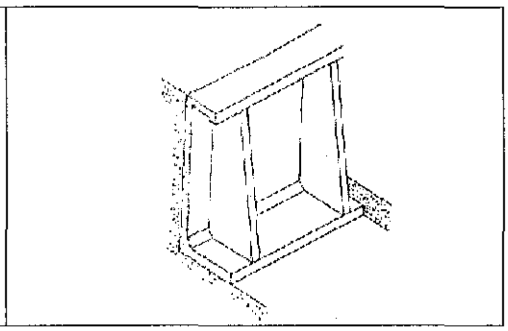


Figure 8: Buttress Wall

2.4.4 Anchored Walls

There are several forms of anchored earth wall. In essence, any wall which uses facing units (of any type) tied to rods or strips (of any material) which have their ends anchored into the ground is an anchored earth wall. To aid anchorage, the ends of the strips are formed into a shape designed to bind the strip at the point into the soil. These anchor ends of the strips can take one of many forms. It is important to realize that anchored earth walls act in a fundamentally different manner to reinforced soil walls. With anchored earth the resistance of the strips to movement is controlled by their end anchor. In contrast, the reinforcing strips used in reinforced soil, are found fully into the soil mass along their full length.

CHAPTER 3.0

METHODOLOGY/PROJECT WORK

3.1.1 Procedure Identification

This research will be based on the following project design flow chart. This methodology was design to have a basic view of the project and a preparation for this research. Figure 9 below shows the design flow chart that will be followed in carrying out this project.

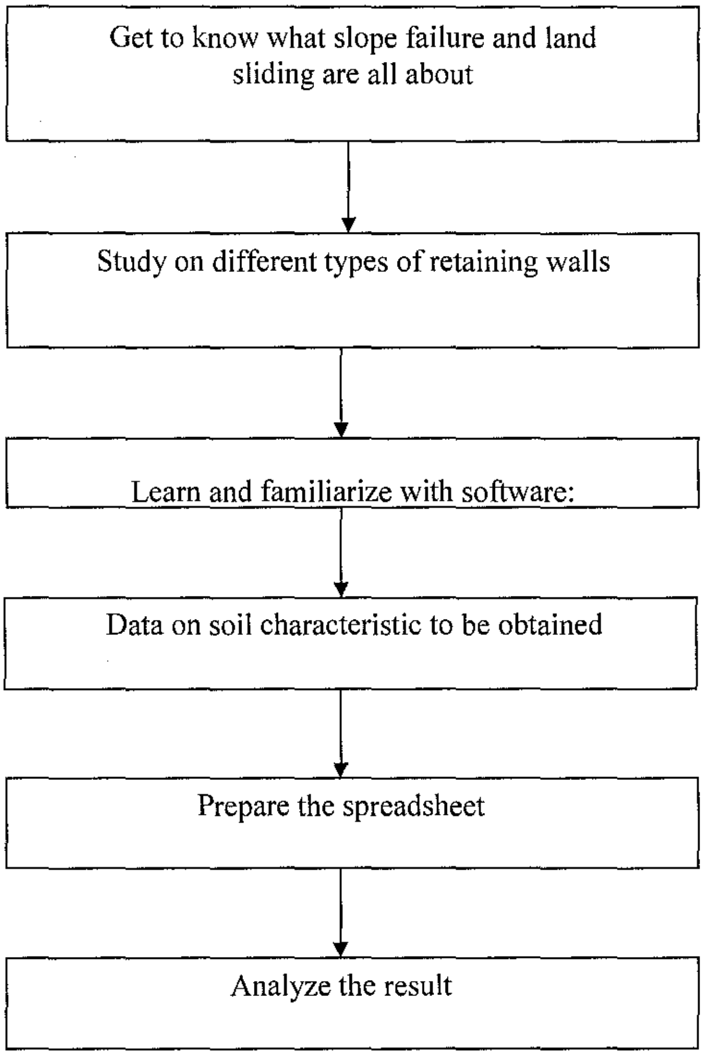


Figure 9: Flowchart of the project's methodology

This project begins with the investigation of slope failure and land sliding. Every information regarding slope failure and land sliding that are relevant to this project have been gathered. Most of the data acquired from books and a few websites.

The next step is to conduct study on different types of retaining walls. Different types of retaining wall will required different design procedure. Each type can be differentiates by how they produce stability, their limitations, construction method, time and cost as well as their appearance. The most obvious different that can be observed is that they are design at different height where at this height, the design of the structure is said to be safe and the cost is optimized.

The project proceeds with the application of the Microsoft Excel Design Spreadsheet Program. In order to get familiarize with all the function in this program, initial design spreadsheet have been develop. At the beginning of these spreadsheets development process, the design procedure example was taken from a book. From this example, all the soils data, the retaining structures properties and the pressure acting on the structures have been rearranged and transferred into the design spreadsheet. From this pioneer spreadsheet, details assessments have been made in order to determine its weaknesses. This is to ensure that the same weaknesses or mistakes will not appear again in developing other spreadsheets.

After completing the design spreadsheet program, analysis can be made by user. Just by following the instruction given in the spreadsheet, it can help user in designing a retaining wall. From this program, the optimum height of different types of retaining walls can be determined based on the initial data that have been inserted by the users.

3.2 Tools/Equipments Required

1. Personal Computer Pentium 4
2. Excel Program

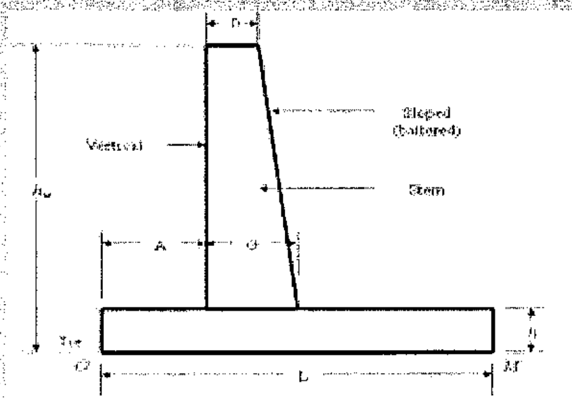
CHAPTER 4.0

RESULTS AND DISCUSSION

4.1 Result

4.1.1 Spreadsheet on Retaining Wall

Project : **Spreadsheets for Retaining Walls Design**
Title : **Design of Reinforced Concrete Cantilever Retaining Wall**
Date : **30-May-2007**



Data : *Insert data in colored box

Height of wall, H =	5	m
Allowable soil pressure, Pa =	10	kN/m²
Surcharge load, ws =	10	kN/m²
Ultimate bearing capacity, qu =	75	kN/m²
Unit weight of concrete, γc =	24	kN/m³
Unit weight of earth, we =	5	kN/m³
Equivalent fluid weight, Kawe =	1.5	kN/m³
fcu =	35	N/mm²
fy =	460	N/mm²
Coefficient of friction, f =	0.3	
FS against overturning =	1.0	
FS against sliding =	1.0	
FS against bearing capacity =	1.5	

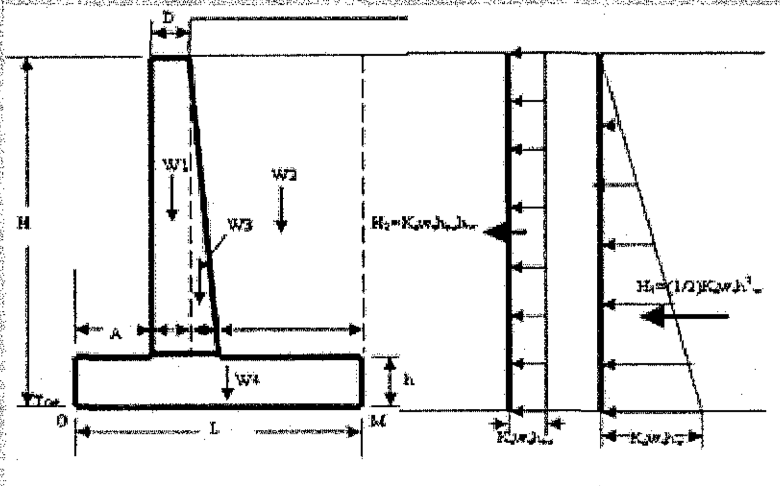
Results :

Tentative proportions for the wall

Footing width, L =	3.33	m	
Footing thickness, h =	0.50	m	
Toe width, A =	1.11	m	
Stem thickness, G =	0.42	m	> D
D =	0.20	m	minimum 0.20m

Figure 10: Reinforced Concrete Cantilever Retaining Wall Spreadsheet

Project : Spreadsheets for Retaining Walls Design
Title : Design of Reinforced Concrete Cantilever Retaining Wall
Date : 30-May-2007



Stabilizing Moments (Vertical Forces)

Force	Magnitude (kN)	Lever Arm (m)	Moment (kN.m)
W1	21.6	1.21	26.16
W2	65.72	2.32	152.62
W3	11.70	1.38	16.19
W4	40.00	1.67	66.67
	Σ = 139.02		Σ Mv = 261.63

Overturning Moments (Horizontal Forces)

Force	Magnitude (kN)	Lever Arm (m)	Moment (kN.m)
H1	18.75	1.67	31.25
H2	15.00	2.50	37.50
	Σ = 33.75		Σ Mh = 68.75

Stability Check

F S (overturning) = 3.8 >1.00 OK

FS (sliding) = 1.2 >1.00 OK

FS (bearing capacity) = 1.2 <1.50 FAIL

Figure 11: Reinforced Concrete Cantilever Retaining Wall Spreadsheet

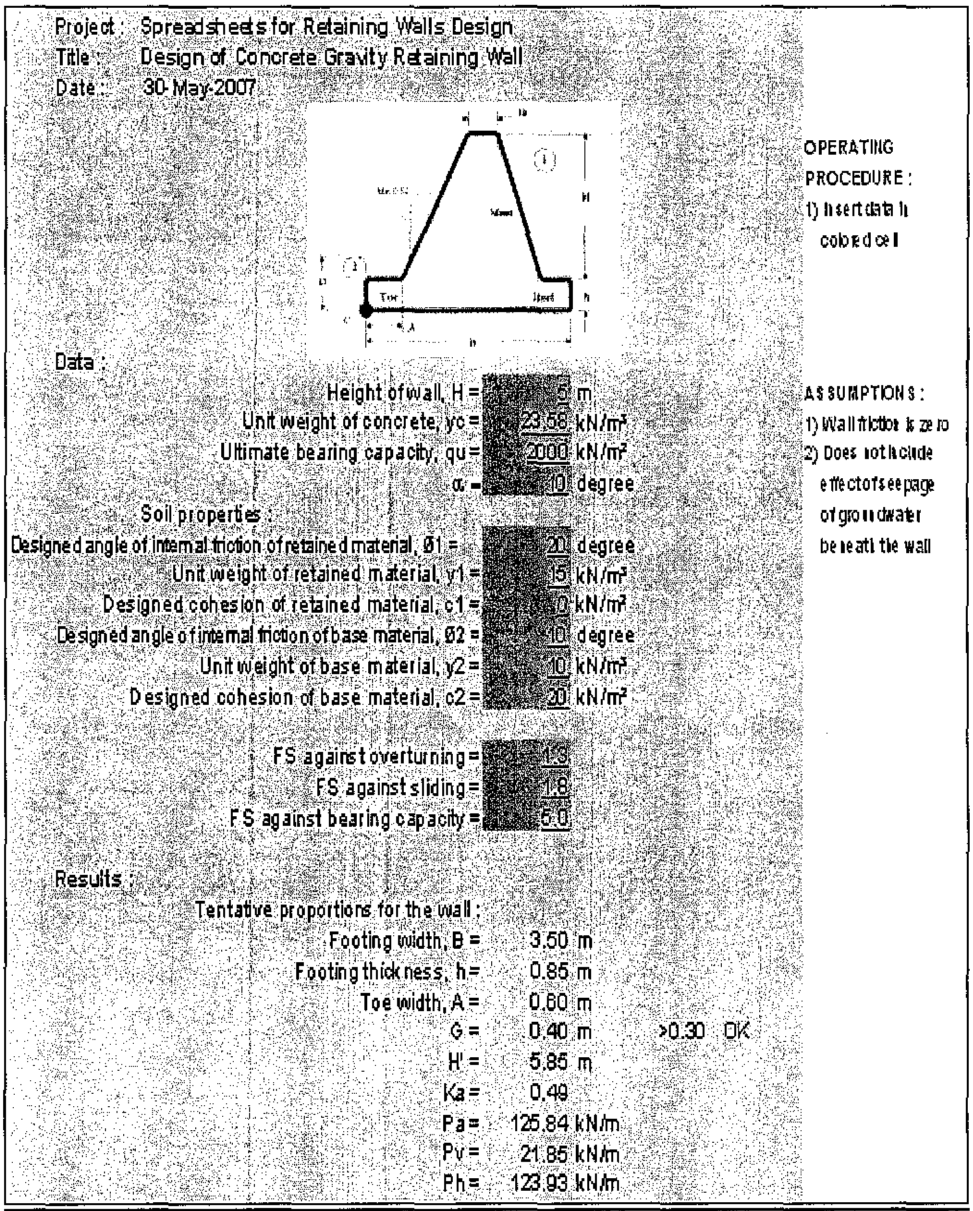
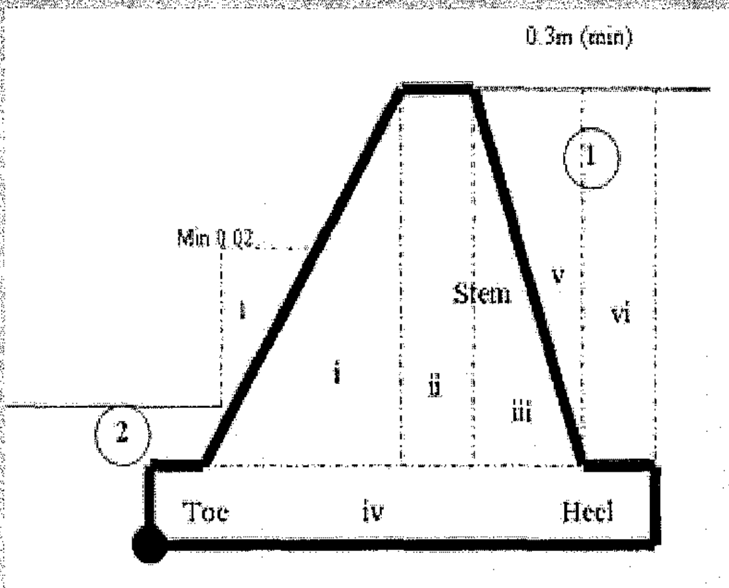


Figure 12: Concrete Gravity Retaining Wall Spreadsheet

Project : Spreadsheets for Retaining Walls Design
Title : Design of Concrete Gravity Retaining Wall
Date : 30-May-2007



Area	Magnitude (kN)	Lever Arm from Toe (m)	Moment (kN.m)
i	23.5800	0.8667	20.44
i	88.4250	1.3750	121.58
ii	147.3750	2.5833	380.72
iv	70.1505	1.7500	122.76
v	93.7500	3.4167	320.31
vi	56.2500	4.6250	260.16
	Σ = 479.53		Σ Mr = 1225.97

Stability Check

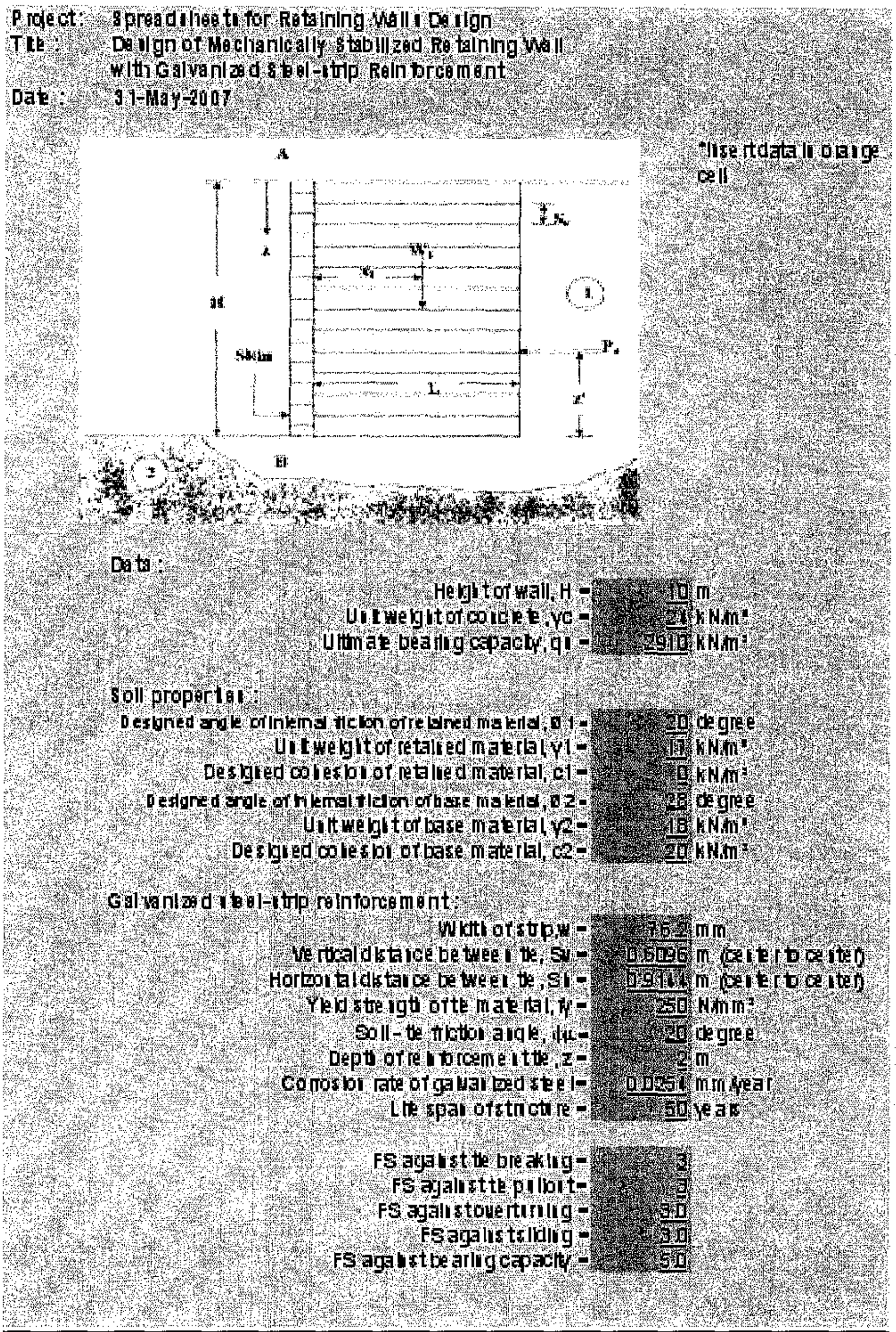
Mo = 245.4 kN.m

FS (overturning) = 5.0 >1.30 OK

FS (sliding) = 0.8 <1.80 FAIL

FS (bearing capacity) = 29.5 >5.00 OK

Figure 13: Concrete Gravity Retaining Wall Spreadsheet



Project: Spreadsheets for Retaining Walls Design
Title: Design of Mechanically Stabilized Retaining Wall
with Galvanized Steel-strip Reinforcement
Date: 31-May-2007

*Insert data in orange cell

Data:

Height of wall, H =	10	m
Unit weight of concrete, γc =	24	kN/m³
Ultimate bearing capacity, qu =	2910	kN/m²

Soil properties:

Designed angle of internal friction of retained material, ø1 =	20	degree
Unit weight of retained material, γ1 =	17	kN/m³
Designed cohesion of retained material, c1 =	0	kN/m²
Designed angle of internal friction of base material, ø2 =	28	degree
Unit weight of base material, γ2 =	18	kN/m³
Designed cohesion of base material, c2 =	20	kN/m²

Galvanized steel-strip reinforcement:

Width of strip, w =	76.2	mm
Vertical distance between tie, Sv =	0.6096	m (center to center)
Horizontal distance between tie, Sh =	0.9144	m (center to center)
Yield strength of tie material, fy =	250	N/mm²
Soil - tie friction angle, ϕμ =	20	degree
Depth of reinforcement tie, z =	2	m
Corrosion rate of galvanized steel =	0.0254	mm/year
Life span of structure =	50	years

FS against tie breaking =	3
FS against tie pullout =	2
FS against overturning =	3.0
FS against sliding =	3.0
FS against bearing capacity =	5.0

Figure 14: Mechanically Stabilized Retaining Wall Spreadsheets with Galvanized Steel-strips Reinforcements

Project: Spreadsheets for Retaining Walls Design
Title: Design of Mechanically Stabilized Retaining Wall with Galvanized Steel-strip Reinforcement
Date: 31-May-2007

Results:

Internal stability check:

Ka = 0.49
$\sigma_{v(max)}$ = 83.35 kN/m²
Tie thickness, t = 3.71 mm

σ_a = 16.67 kN/m²
σ_v = 34.00 kN/m²

z (m)	Tie Length, L (m)
2	20.38
4	18.98
6	17.58
8	16.18
10	14.78
12	13.38

Use maximum tie length, L = 20.38 m

External stability Check:

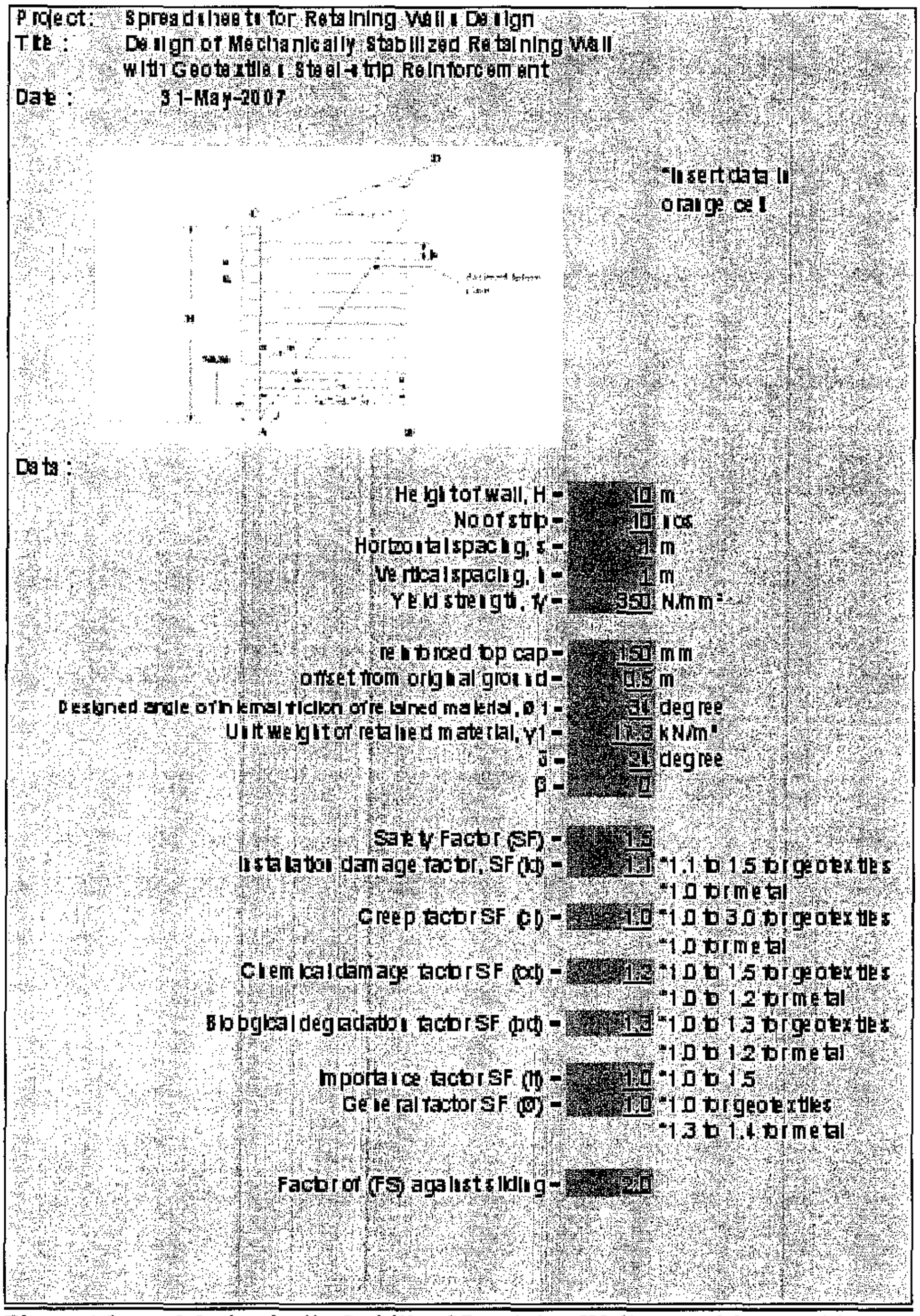
W1 = 3465.06 kN/m
Pa = 416.75 kN/m
z' = 3.33 m

FS (overturning) = 25.42 > 3.00 OK

FS (sliding) = 1.97 < 3.00 FAIL

FS (bearing capacity) = 17.12 > 5.00 OK

Figure 15: Mechanically Stabilized Retaining Wall Spreadsheets with Galvanized Steel-strips Reinforcements



Project: Spreadsheets for Retaining Walls Design
Title: Design of Mechanically Stabilized Retaining Wall with Geotextiles Steel-strip Reinforcement
Date: 31-May-2007

*Insert data in orange cell

Data:

Height of wall, H =	10	m
No of strip =	10	nos
Horizontal spacing, s =	1	m
Vertical spacing, h =	1	m
Yield strength, fy =	350	N/mm²
reinforced top cap =	150	mm
offset from original ground =	0.5	m
Designed angle of internal friction of retained material, ø1 =	34	degree
Unit weight of retained material, γ1 =	[illegible]	kN/m³
δ =	24	degree
β =	0	
Safety Factor (SF) =	1.5	
Installation damage factor, SF (id) =	1.1	*1.1 to 1.5 for geotextiles *1.0 for metal
Creep factor SF (cr) =	1.0	*1.0 to 3.0 for geotextiles *1.0 for metal
Chemical damage factor SF (cd) =	1.2	*1.0 to 1.5 for geotextiles *1.0 to 1.2 for metal
Biological degradation factor SF (bd) =	1.3	*1.0 to 1.3 for geotextiles *1.0 to 1.2 for metal
Importance factor SF (n) =	1.0	*1.0 to 1.5
General factor SF (G) =	1.0	*1.0 for geotextiles *1.3 to 1.4 for metal
Factor of (FS) against sliding =	2.0	

Figure 16: Mechanically Stabilized Retaining Wall Spreadsheets with Geotextiles Steel-strips Reinforcements

Project : **Spreadsheets for Retaining Walls Design**
Title : **Design of Mechanically Stabilized Retaining Wall with Geotextiles Steel-strip Reinforcement**
Date : **31-May-2007**

Results :

Tensile stress, fa = 204 N/mm²
Rankine active earth pressure coefficients, *Ka* = 0.283
f = 0.4452
strip width, b = 0.1 m
ρ = 62 degree

Strip no	z_i, *(m)*	strip tensile force, *Ti (kN)*	L_e, *(m)*	L_R, *(m)*	L_o, *(m)*
1	0.5	2.45	4.76	0.27	5.03
2	1.5	7.34	4.76	0.80	5.56
3	2.5	12.23	4.76	1.33	6.09
4	3.5	17.12	4.76	1.86	6.62
5	4.5	22.01	4.76	2.39	7.16
6	5.5	26.90	4.76	2.92	7.69
7	6.5	31.79	4.76	3.46	8.22
8	7.5	36.68	4.76	3.99	8.75
9	8.5	41.57	4.76	4.52	9.28
10	9.5	46.46	4.76	5.05	9.81
		Σ = 244.55			

one unit wide of weight, W = 1284 kN
F_R = 866 kN
sliding stability = 3.5 >2.00 OK

Figure 17: Mechanically Stabilized Retaining Wall Spreadsheets with Geotextiles Steel-strips Reinforcements

4.2 Discussion

4.2.1 The Spreadsheet

Designing retaining walls requires an engineer to perform very long, tedious calculations steps. As there are so many types of earth retaining walls, the function is still the same; to retain the backfill earth. However, each type of retaining walls will have different calculations procedures which basically determine by the way loads are acting toward the retaining structures. This depends on how the engineer wants the walls to act according to the site conditions. Furthermore, the design should be safe enough for a very long time and economically viable. To design retaining walls properly, an engineer must know the basic soil parameters – that is, the unit weight, angle of friction, and cohesion – for the soil retained behind the wall and the soil below the base slab.

At the beginning of these spreadsheets development process, the design procedure was taken from a book. In order to familiarize with the Microsoft Excel Design Spreadsheet Program, an easier example was selected. From this example, all the soils data, the retaining structures properties and the pressure acting on the structures have been rearranged and transferred into the design spreadsheet. Sample drawing of the retaining wall that being analyzed also included giving clearer view to the user. Few problems have been encountered which will be discuss later. From this pioneer spreadsheet, details assessments have been made in order to determine its weaknesses. This is to ensure that the same weaknesses or mistakes will not appear again in developing other spreadsheets.

After going through few rectifications and improvements, the final spreadsheets of designing retaining walls have been completed. Each spreadsheet has been designed separately to differentiate the types of retaining walls. From the spreadsheet that has been developed, analysis on the retaining wall can be conducted. Users are required to enter or to specify a few data before analysis can be carried out. The data will be such as the height of the wall, the retained soil properties, the base soil characteristics and other information. All these data are needed thus must be filled to allow the analysis take place.

The study is to observe the impact of different height to the factor of safety against overturning, sliding, and bearing capacity. At different wall height will give different value of factor of safety. At certain height, both factor of safety against overturning and sliding will be insufficient. However, at another wall height, the factor of safety can only sufficient for one criterion, either against overturning or against sliding. From this spreadsheet, the ideal height that will satisfy all the parameters can easily be determined. There is no need for recalculation at different wall height. The wall height can be changed and resulting changes in the factor of safety. So, from this spreadsheet, the most optimum height that satisfy the factor of safety for overturning, sliding, and bearing capacity can be obtained.

Based from the wall height, the spreadsheet also will analyze the dimensions of retaining wall proportions. These proportions will allow the engineer to check trial sections for stability. If the stability checks yield undesirable results, the sections can be changed and rechecked. With the application of this spreadsheet, trial and error method will become more convenient, easy and faster.

The retaining wall can be made for landscaping purposes where the additional of geotextiles material while constructing it will enhance the wall's performance. Many aspects of requirements need to be analyses for the design with economical criteria also plays a vital role.

4.2.2 The Application of the Lateral Earth Pressure Theories to Designed Spreadsheets

The fundamental theories for calculating lateral earth pressure have been discussed earlier. To use these theories in design, an engineer must make several simple assumptions. In the case of cantilever walls, use of Rankine earth pressure theory for stability check involves drawing a vertical line AB through point A, as shown in figure 18, (which is located at the edge of the heel of the base slab). The Rankine active condition is assumed to exist along the vertical plane AB. Rankine active earth pressure equations may then be used to calculate the lateral pressure on the face AB. In the analysis of stability of the wall, the force $P_{a(\text{Rankine})}$, the weight of soil above heel, Ws, and the weight of the concrete, Wc, all should be taken into consideration. The assumption for the development of Rankine active pressure along the soil face AB is theoretically correct if the shear zone bounded by the line AC is not obstructed by the stem of the wall. The angle, η, that the line AC makes with the vertical is

$$\eta = 45 + (\alpha / 2) - (ø / 2) - \sin^{-1} (\sin \alpha / \sin ø)$$

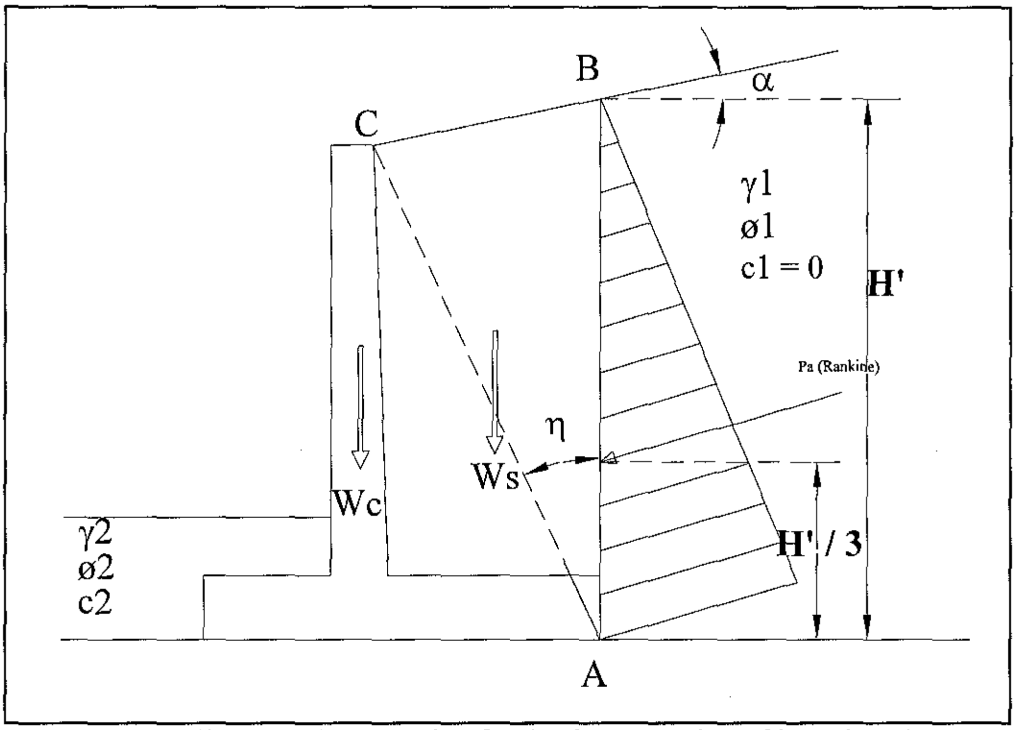


Figure 18: Cantilever wall assumption for the determination of lateral earth pressure

Similar types of analysis have been applied for gravity walls, as shown in figure 19 below.

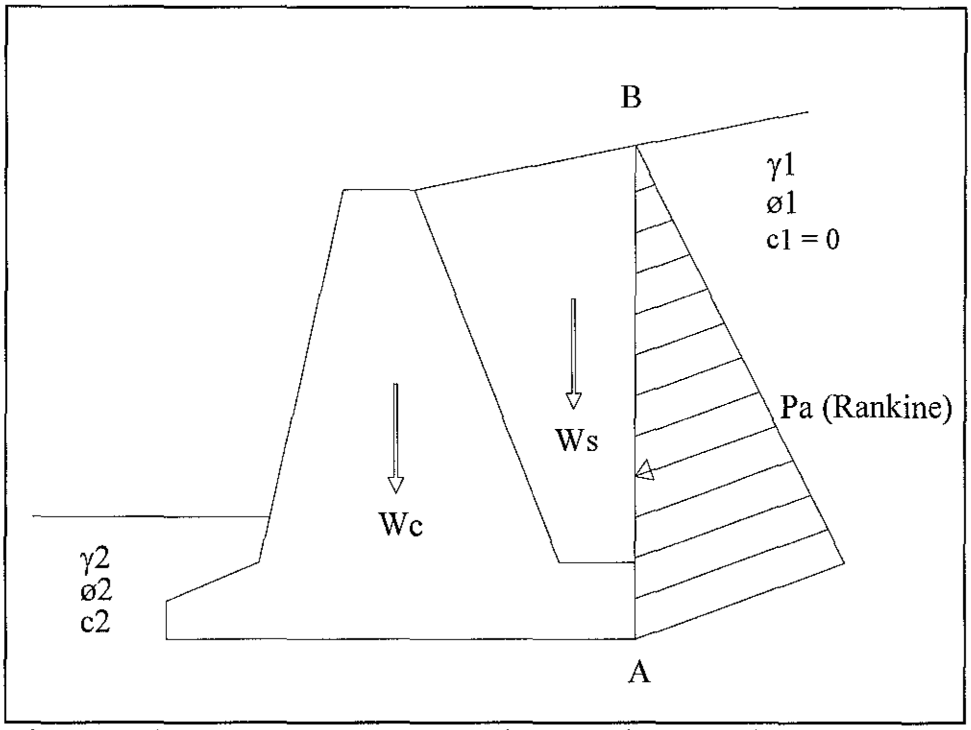


Figure 19: Gravity wall assumption for the determination of lateral earth pressure

The stability check that involve in this design spreadsheets are checking for bearing capacity failure of the base, checking for sliding failure along its base and checking for overturning about its toe. Stability of the base against a bearing capacity failure is achieved by using a suitable safety factor with the computed ultimate bearing capacity, where the safety factor is usually taken as 2.0 for granular soil and 3.0 for cohesive soil. When the soil is of low bearing capacity and/or it is not practical to use a larger base slab, it will be necessary to use a pile foundation to support the base slab, which in turn supports the wall. A retaining wall must be so proportioned that it has and adequate safety factor against sliding and overturning. Usually, the safety factor used for the sliding is 1.5 for granular backfill and 2.0 for cohesive backfill. Meanwhile, safety factor used for overturning is 1.5 for granular backfill and 2.0 for cohesive backfill.

4.2.3 The Accuracy

By the application of these design spreadsheets, the accuracy in calculations is rather high compared to the manual calculation. The design steps used in the spreadsheets is similar to the steps used in the manual calculation. The main difference is only that the program itself will perform the calculation based on the input data given by the user. While in manual calculation, user will have to do all the calculation by him/herself.

Human tend to do mistakes without realizing it. Because of designing a retaining wall requires so much effort, patients and a very long process, errors can occurs continuously. As human is emotional where environment can influence them, some simple miscalculations can happen. Things might get even worse if human being put under pressure and plus with some personal problems.

These design spreadsheets can overcome such mistakes. In addition to that, the result obtained will be much accurate and the time spends for the design process can be shortened. Users can run few simulations easily just by changing their data. This can help them to determine the best options that they can have in order to come out with a design that is safe to the publics and economically viable to the clients. Comparison has been made between the manual calculation and the spreadsheet calculation. *(refer appendix 1)*

Table 4: Accuracy checking for manual and spreadsheet calculation

CRITERIA	MANUAL CALCULATION	SPREADSHEET CALCULATION	PERCENTAGE DIFFERENCE
Total vertical force, $\sum W$	139.09 kN	139.02 kN	5 %
Total horizontal force, $\sum H$	33.75 kN	33.75 kN	0 %
Total stabilizing moment, $\sum M$	261.41 kN.m	261.63 kN.m	8 %
Total overturning moment, $\sum Mo$	68.75 kN.m	68.75 kN.m	0%

4.2.4 Problems Encountered

There are few problems encountered by author in completing this design spreadsheet. At the earliest stage, the very first problem is to find the source to be the based for the design spreadsheet. Author have tried to search for journal regarding this retaining wall design spreadsheet but managed to collect very little information on the calculations steps in designing a retaining wall.

By referring to some books, author managed to gather the vital information on the calculation steps in designing a retaining wall. The spreadsheets have been designed based on few examples in these books.

Applying formulae into the Microsoft Excel Design Spreadsheet Program require a very details check up. First of all, author will have to draft all the calculation steps and also the formulae. The formulae must be perfectly arranged complete with all the brackets, commas and any other necessary notation marks to ensure that the calculations being carried out based on the formulae are correct. Author somehow managed to learn few functions that can be fine and use in the spreadsheets. One of the most part that author can remember clearly is that in Microsoft Excel Design Spreadsheet Program, the angle is in radian. At the beginning, author finds that the results from the design spreadsheets are different compared to the manual calculation. Author was somehow confused because the procedures or steps are the same. After consulting the supervisor, then only author was told about the fact that in Microsoft Excel Design Spreadsheet Program, angle calculated are in radian instead of degree. So, the angle needs to be changed to degree before calculation can proceed.

CHAPTER 5.0
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Recently, there are several cases reported on slope failure and land sliding which is now a common problem in the Peninsular Malaysia. Some of the cases are minor and some are major cases such one that happen at Putrajaya. One way to counter this problem is to ensure the stability of every sloppy area. Area that has potential to fail need to be adjusted and here is where the need of retaining wall can be applied. Designing a retaining wall is a tiring and time consuming process, if it were to be done manually. However, by the application of Microsoft Excel Design Spreadsheet Program, design can be completed by the program, time can be reduced with more trials can be carried out. As the conclusion, the objective of this project has been achieved. The design spreadsheet has been successfully completed. As this project was never attempted before in UTP, author hopes that this can be the foundation and reference for further development in the future.

5.2 Recommendations

For the student that are about to expand this project, few recommendations can be take into considerations.

1. One of the aims of this project is to make life easier for the engineer using the spreadsheets. Further studies can be performed on how to minimize the data input by the user, but still the design can be completed without any problems. The less the data that need to be insert means the less time needed for the data acquisitions.

2. Every single spreadsheet represents one type of retaining wall. Research can be conducted on how to link all these different types of retaining wall into a single spreadsheet. This can allow user to have more options on choosing the most suitable, safe and economic types of retaining wall to be constructed.

3. The characteristics of the load acting towards the structures can be varying. Analysis on the most critical load combinations can be included. Further investigation can be done using some other earth pressure theories rather than focusing on the Rankine and Coulomb only.

4. More complicated diagram that can change according to the data inserted by the user can be developed. This is to give clearer view to the user on the appearance of the retaining wall as well as the wall proportions.

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5. Das, M.B, Principles of Geotechnical Engineering, Fifth Edition, Brooks/Cole Thomson Learning

6. Riordan, D.G and Pauley, S.E, Technical Report Writing Today, Seventh Edition, Boston: Internal Thomson Publishing Asia

7. http://www.wikipedia.com/retaining walls

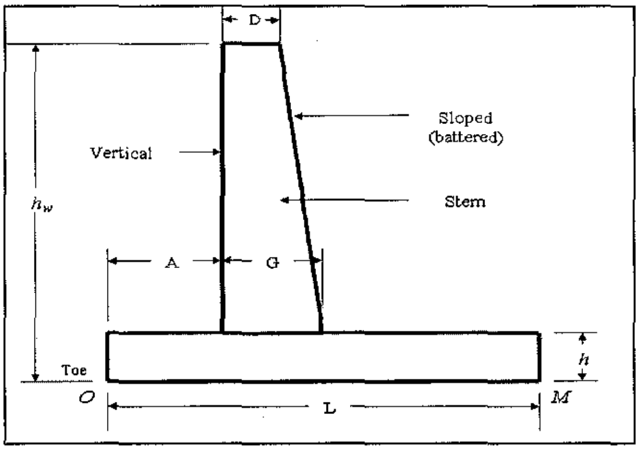
8. http://www.wikipedia.com/lateral earth pressure

APPENDIX

1) Manual Calculation : Design of Reinforced Concrete Cantilever Retaining Wall

Data :

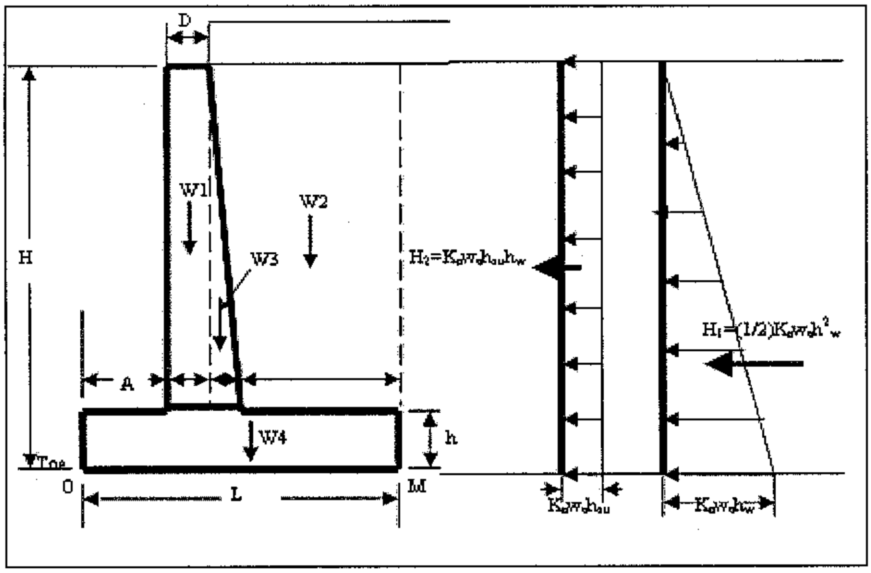
Dimensions :



Height of the wall, H	=	5	m
Allowable soil pressure, P_a	=	10	kN/m²
Surcharge load, ws	=	10	kN/m²
Ultimate bearing capacity, q_u	=	75	kN/m²
Unit weight of concrete, y_c	=	24	kN/m³
Unit weight of earth, we	=	5	kN/m3
f_{cu}	=	35	N/mm²
f_y	=	460	N/mm²
Top of stem thickness, D	=	0.2	m
Coefficient of friction, f	=	0.3	
FS against overturning	=	1.0	
FS against sliding	=	1.0	
FS against bearing capacity	=	1.5	

Tentative proportions of the wall :

i) Footing width, L	=	2/3 x Height of the wall, H
	=	2/3 x 5 m
	=	3.33 m
ii) Footing thickness, h	=	1/10 x Height of the wall, H
	=	1/10 x 5 m
	=	0.5 m
iii) Stem thickness, G	=	1/12 x Height of the wall, H
	=	1/12 x 5 m
	=	0.42 m
iv) Toe width, A	=	1/3 x Footing width, L
	=	1/3 x 3.33 m
	=	1.11 m
Equivalent height of earth, h_{su}	=	Surcharge load, ws / Unit weight of earth, we
	=	10 kN/m² / 5 kN/m²
	=	2
Equivalent fluid weight, $K_a$we	=	0.3 x Unit weight of earth, we
	=	0.3 x 5
	=	1.5 kN/m²



<u>Stabilizing Moments (Vertical Forces)</u>

i) <u>Magnitude, kN</u>

W1	=	D x (H-h) x y_c
	=	0.2 x (5-0.5) x 24
	=	21.6 kN
W2	=	(L-A-D) x (H-h+ h_{su}) x we
	=	(3.33-1.11-0.2) x (5-0.5+2) x 5
	=	65.65 kN
W3	=	0.5 x (G-D) x (H-h) x y_c
	=	0.5 x (0.42-0.2) x (5-0.5) x 24
	=	11.88 kN
W4	=	h x L x y_c
	=	0.5 x 3.33 x 24
	=	39.96 kN
Total, ∑W	=	W1 + W2 + W3 + W4
	=	(21.6 + 65.65 + 11.88 + 39.96) kN
	=	139.09 kN

ii) Moment, kN.m

W1	=	21.6 kN x (A + 0.5 x D) m
	=	21.6 x (1.11 + 0.5 x 0.2)
	=	26.14 kN.m
W2	=	65.65 kN x (A + D + 0.5 x (L-A-D)) m
	=	65.65 x (1.11 + 0.2 + 0.5 x (3.33-1.11-0.2))
	=	152.31 kN.m
W3	=	11.88 kN x (A + D + (1/3 x (G-D))) m
	=	11.88 x (1.11 + 0.2 + (1/3 x (0.42-0.2)))
	=	16.43 kN.m
W4	=	39.96 kN x (0.5 x L) m
	=	39.96 x 0.5 x 3.33
	=	66.53 kN.m
Total, ∑M	=	Moment (W1 + W2 + W3 + W4)
	=	(26.14 + 152.31 + 16.43 + 66.53) kN.m
	=	261.41 kN.m

Overturning Moments (Horizontal Forces)

i) Magnitude, kN

H1	=	0.5 x $K_a$we x H^2
	=	0.5 x 1.5 x 5^2
	=	18.75 kN
H2	=	$K_a$we x h_{su} x H
	=	1.5 x 2 x 5
	=	15 kN
Total, ∑H	=	H1 + H2
	=	(18.75 + 15) kN
	=	33.75 kN

ii) Moment, kN.m

H1	=	18.75 kN x (1/3 x H) m
	=	18.75 x (1/3 x 5)
	=	31.25 kN.m
H2	=	5 kN x (0.5 x H) m
	=	15 x (0.5 x 5)
	=	37.50 kN.m
Total, $\sum M_o$	=	Moment (H1 + H2)
	=	(31.25 + 37.50) kN.m
	=	68.75 kN.m

Stability Check

i) Factor of safety against overturning,

FS	=	stabilizing moment/overturning moment
	=	261.41 kN.m / 68.75 kN.m
	=	3.80

* if FS is greater than the specified FS given by the user, then the design is safe in term of overturning factor

ii) Factor of safety against sliding,

FS	=	resisting force, F / actual horizontal force, $\sum H$
	=	(Coefficient of friction, f x $\sum W$) / $\sum H$
	=	0.3 x 139.09 kN / 33.75 kN
	=	1.24

* if FS is greater than the specified FS given by the user, then the design is safe in term of sliding factor