University of Southern Queensland

Faculty of Engineering and Surveying

Seismic Stability of Slope

A dissertation submitted by

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towards the degree of

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Abstract

This project will learn and focus on the application of FLAC/Slope program to the stability of slopes under the effect of seismic forces. As to analyse slope with seismic force, there will be additional of horizontal force, hence the Pseudo-static approach will be apply to this analysis, where there is a horizontal seismic coefficient, k_h will be consider in seismic stability of slope analysis.

FLAC/Slope is a mini version the FLAC which was developed by Itasca Consulting Group, Inc. It is a general-purpose program for numerical modelling of geotechnical stability problems. FLAC/Slope is user-friendly computer software and is had been adopted in this project to investigate the stability of slopes under earthquake effects. The current used software is the student version and has the limitation to analyse as only the course mesh can be use to analyse the slope problem.

The outcome of the project will be the development of earthquake resistant design charts under constant seismic profile for a variety of slope stability problems. By using the stability number (N) and the pseudo-static approach together with the assistance of FLAC/Slope software, design chart for the seismic coefficient, k_h of 0.1, 0.2, 0.3 and 0.4 have been developed. These charts can be useful in the preliminary earthquake resistant design of slopes for determined the Factor of Safety (FOS).

To get more understanding of the FLAC/Slope, a parametric study on seismic coefficient and soil properties of slope under the effect of seismic has been done. Also a slope model problem which consist a weak layer under the seismic effect had been analyse by installing geo-reinforcements in various way in order to improve the FOS of the model under the seismic condition.

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Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course, except where specifically stated.

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Signature

Date

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For the first and foremost I would like to extend my appreciation and thanks to many individuals with their contributions towards the progressive success of this project. It was a memorable and worthwhile effort considering the knowledge acquired.

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CONTENTS

LIST OF FIGURE

LIST OF TABLE

Chapter 1:
INTRODUCTION

1.1 Background

A slope is usually is made up of soil material, where the type of soil material is greatly influence by the soil material properties. The characteristic and condition of the stability of slope is usually influence by the properties of the soil material such as the unit weight (γ), angle of internal friction (φ) and cohesion(c). It also influences by the pore water pressure inside the soil and the characteristic of the slope to the stability of slope such as the slope angle, height of the slope, and pore water pressure.

A slope may make by human excavation and construction and also it may exist as a natural slope. The slope can form from a very small angle to of slope to a very steep slope. A slope failure is a phenomenon that a slope collapses abruptly due to weakened self-ability to retain the earth under the influence of the nature or the human cause. Sudden slope failure may cause the damage to the area and near by area of the slope failure.

The cause of the slope failure can be either from human activities or natural activities to the slope. The failure of slope may be cause by removal lateral support of slope such as retaining wall or some of its soil, vibration, applying weight to the slope, pore water pressure and weathering.

Since long time ago, Engineers and geologist have done much research to determine the best slope that is safety. In order of that engineer has tried to analyse the lowest factor of safety at its line of failure. Many of the method have come out from the research with some method such as the method of slice, which is Swedish method, and Bishops method and also other method such as wedge method and block method. With this method, Graphical, Chart and Mathematical approach by using hand calculation, calculator or Computer software can do the analysis.

The earthquake trigger that causes the seismic activities to the slope may also cause the slope to fail. It may cause the slope factor of safety is lowered than it had when it's in the static condition. Hence to analyse this type of condition, there will be additional of horizontal force, hence the Pseudo-static approach will be apply to this analysis.

Due to complication and time consuming of the available method that required hand on calculation to analyse the Factor of Safety (FOS) of the slope, some design charts have been develop to simplify the procedure, example Taylor's charts. Variable computer software has been designs according to the method available to assist the analysis of slope calculation. Examples of the computer software that available at the market are FLAC/slope and Slope/W. This type of software will analyse by create a numerical modelling of slope; hence this will produce a high accuracy and faster way to obtain the result of the FOS for slope analysis.

The objective of this project will develop a pseudo-static analysis model by using FLAC/slope software, which based on the finite difference method. This project will focus on the application of modern numerical technique under constant seismic effect. The outcome of the project will be the development of earthquake resistant design charts for a variety of slope stability problems, parametric studies of soil for a slope model and to analyse a seismic slope problem.

1.2 Purpose of the Project

The objective of this project will develop a pseudo-static analysis model by using FLAC/slope software, which the software is based on the finite difference method. This project will focus on the application of modern numerical technique under constant seismic effect. By using the FLAC/Slope program to assist the project work, the outcome of the project will be:

1. The development of earthquake resistant design charts for a variety of slope stability problems. A design chart is a chart that engineer will use for convenience for the design the seismic of slope.
2. Using the program to assist parametric study of the slope
3. Develop a model case of a slope problem.

1.3 Project aim and objective

The main aim and objective of the project will show below:

1. Research the background information on slope problems including:-
   - Cause of slope failures
   - Short and long term failures
   - Types of landslides and slope movements
   - Factor of safety
2. General review on the analysis and design of slopes under earthquakes – a pseudo-static approach.
3. Learn the finite difference software – FLAC.
4. Research on the effects of slopes under constant profile
5. Development of earthquake design charts
6. Parametric studies to a slope model by using FLAC/Slope
7. Using FLAC/Slope to study a problem of a model of a slope.

1.4 Methodologies

In this project there are few methodologies will be use to assist during this project work, relevant literature was searched to identify relevant problems and to gain more fundamental knowledge relating to project objectives. The methodologies that use to assist this through the project works are:

- **Textbooks and previous USQ study book**
  By reference to the text books and previous USQ study book to gain more information and fundamental knowledge

- **Internet**
  Searching the Internet for reverent online information for more additional information and some fundamental knowledge from the other website and online journals; and also search from USQ library website.

- **USQ library service, DocEx**
  A photocopy service to obtain relevant information from the books in USQ library

- **Computer software**
  - *FLAC/Slope (Version 4.0)* – Student version software provide by Faculty of Engineering and Surveying USQ. Learning and using this software to assist the project work of the earthquake design chart, and other Seismic slope problems.
  - *Microsoft Excel® Office Excel 2003* – A commercially available computer spreadsheet software that will be use to assist the development of design chart for this project
  - *Microsoft Word® Office Word 2003*- A commercially available computer word software that will use to word typing and compile report and project dissertation
  - *Adobe® Acrobat® 6.0 Professional* – A commercially available software to convert normal word document into PDF file.

Chapter 2:
LITERATURE REVIEW

A study of the background of slope stability for literature review is done to a better understanding of the slope stability. Most of the information is obtained through Text Books and Internet and other available source. The related the reference and bibliography is listed at the Appendix G. Selection of literature review will be discussed at the rest of the section below:

2.1 Cause of slope failure

Slope failures are usually cause by variation of disturbance to the existing condition at the bodies of soil of the slope. It can be cause by either the disturbance inside the soil such as pore water pressure and seismic effect or disturbance outside the soil such as the cutting of slope and additional weight to the slope.

According to the Geoindicators website (2004), we can differentiate two types of the causes of failure of slope, the human causes and the natural causes. The failure of slope also largely depends on the type of the material of the slope and also the existing condition of the slope before it being disturbed.

2.1.1 Human causes

Human action such as cutting of slopes for roads and other structures, quarrying, removal of retaining walls, and lowering of reservoirs. All of these will cause of removal of lateral support of the slope.

The activities that lead to adding weight to the slope on top of it or on the slope surface; such as landfills, waste piles, stockpiles of ore or rock, construction of heavy structure, and water leaking from pipelines, sewers, canals, and reservoirs.

Human activities that cause vibration; examples for this is the machinery, explosion, mining, road traffic and air traffic.

2.1.2 Natural causes

Lateral support of soil is removed through the natural activities such as the erosion of streams, waves hit, glaciers, and long shore and tidal currents, through weathering, and cycles of wetting, drying and freeze-thaw in surficial materials; through land subsidence or faulting that creates new slopes.

By adding weight naturally by the rain, snow, hail, water from spring and accumulation of volcanic debris and pond of water.

Seismic activities cause liquefaction of soil that will weaken the strength of the soil that cause by vibration to the slope or near by of slope such as earthquake, thunder and volcanic activities.

Weather, continues rainfall that cause the soil weak in strength as the water seep into the soil.

Lateral pressure from water pressure in cracks and caverns, freezing of water in cracks, hydration of minerals, and change of the residual stress in soil.

Volcanic activities that disturbing the ground and rock strength, such as inflation or deflation of magma chambers, fluctuation in lava lakes level and increase in ground seismic.

2.2 Short and long term failure

To the determined the factor of safety of the stability of slope, it will depend either the short term or long term failure for a construction of slope. Both of them make up different type of condition and of analysis to be use.

For a short-term condition, the soil is being considered as undrained condition. Where the angle of the internal friction, $\varphi_u = 0$ and the shear strength will be $\tau = C_u$. For this condition total stress analysis will be consider.

For a long-term condition, the drained condition of soil may occur. For this condition effective stress analysis will be consider. Where the value c', ϕ', γ', and u. will be considered.

2.3 Type of slope failure movement

Movement of the slope failure is depending on the physical properties of the body of the slope. Types of slope failure are subdivided into three major classes, the fall, Slides and Flows.

2.3.1 Falls

A fall of material of soil and rock is normally characteristic of extremely steep slope. The material which moves can break away from the parent soil material by an initial sliding movement. In respond to gravity stresses some shear surface may develop, in the condition of the moving material, the material is projected out from the face of the slope. The failure condition of this usually assisted by the effect of the natural such as water or ice pressure.

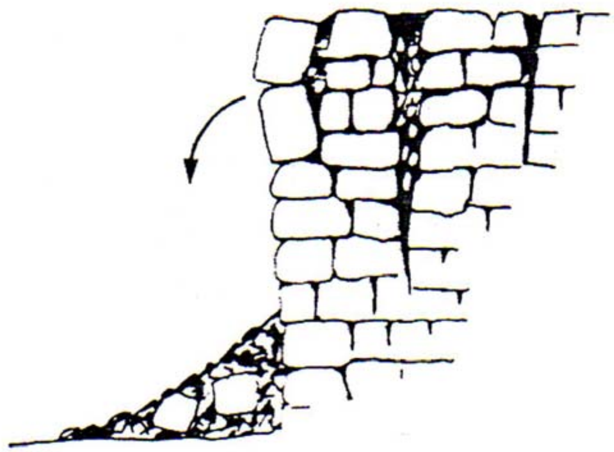


Figure 2. 1: Fall (Whitlow, 1995)

2.3.2 Slides

2.3.2.1 Transitional slide

This involve of a shallow layer of soil have failure movement on top of a hard stratum of soil. It is the slope of layered materials where the mechanism of slippage occur along a weak plane or zone that possesses a downward dip and in cohesionless soil slope where a change in condition.

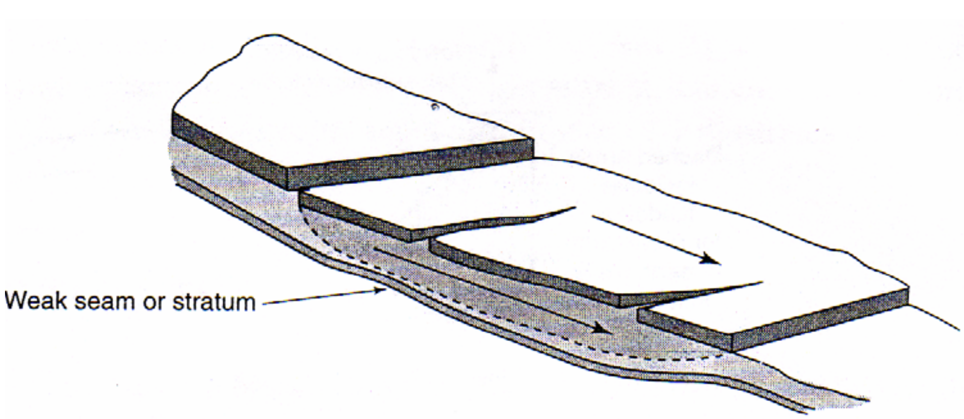


Figure 2.2: Transitional slide (McCarthy,1998**)**

2.3.2.2 Rotational slide

This occurs in a homogeneous soft rock of cohesive soils. The movement taking place along the a curved shear surface, in that the slipping mass of soil slumps down near the top of the slope and bulges up near the toe of the slope surface. The failure slip may be either in circular surface or non-circular surface.

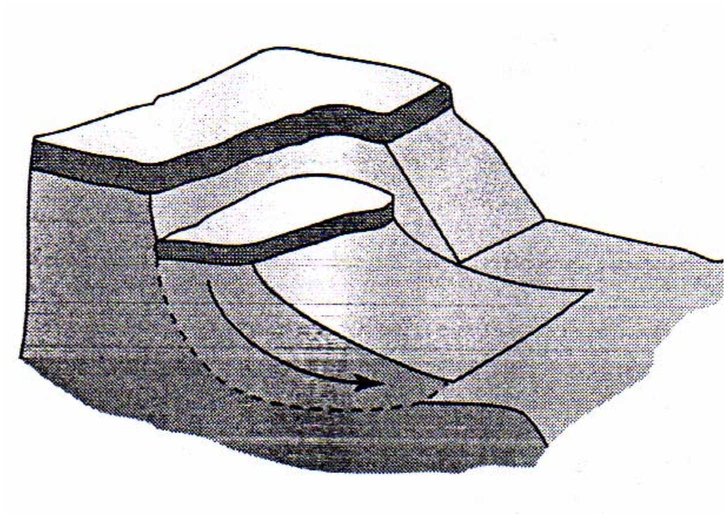


Figure 2.3: Rotational slide (McCarthy,1998)

2.3.3 Flows

The flow is a mass movement of soil material which involves much greater deformation than slide. The slipping mass is internally disrupted and moves partially or wholly as a fluid. The characteristic of the flows can term as the through movements taking place by the water content of the moving mass being so high it behaved as a fluid, usually in the case of clay soils at water content above the liquid limit of the soil. The failure of the soil may contain high saturation of water.

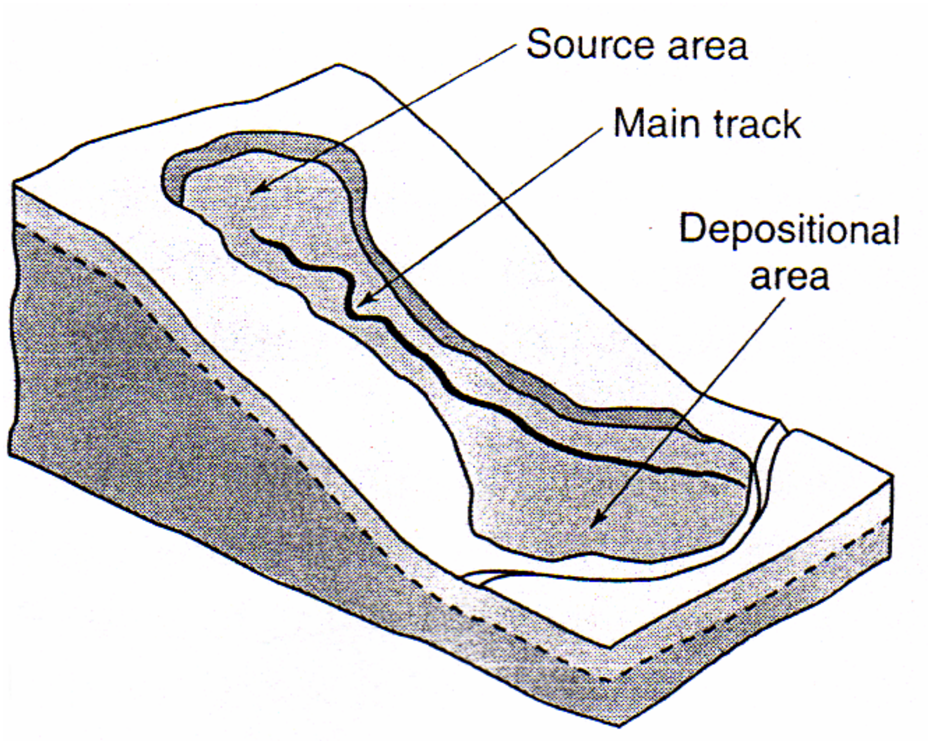


Figure 2.4: Flow (McCarthy,1998)

2.4 Factor of safety

Factor of safety can be expressed in a number of forms. Usually the determination of Factor of Safety (FOS) is determine from resisting strength of the soil over the disturbance strength act to the soil along the slip failure surface, such as it is defined the equation by M. Das (1990) as:

$$F_s = \frac{\tau_f}{\tau_d} \tag{2.1}$$

Where,

F_s is factor of safety with respect to strength

τ_f is average shear strength of the soil [kN]

τ_d is average shear strength developed along the potential failure surface [kN]

The resisting strength is the strength force act oppositely of direction of the driving force strength.

> "The resistance to down slope movement dependent on the shear strength of the slope material. And shear strength is a friction of the cohesion (ability of particles to attract and hold each other together) and internal friction (friction between grains within a material)". (S Huges 2003)

> "The shear strength of the slope materials is decreased by increasing the pore water pressure (pressure that develops in pore spaces due to the increased amount of water)" (S Huges 2003)

According to Stephen Martel (2002), the key points of the factor of safety are:

1. The factor of safety is not a measure of stability at a point; it is a number that represents averaging
2. The factor of safety cannot be measured in the field
3. The factor of safety is model-dependent
4. A factor of safety higher significantly greater than one is desirable because uncertainty regarding the geologic conditions and pore pressure variability.

Factor of safety of slope of the soil normally will be influence by the cohesion, internal angle of friction and weight density of the soil.

Generally there have been factor of safety that been determined for certain condition of the slope that are being using for. There are general guide for the value of factor of safety had been suggested by R.Whitlow (1995), he conclude the factor of safety for different type of condition as at the Table 2.1

Type of condition	F.O.S
End of construction (embankments and cuttings)	1.30
Steady seepage condition	1.25
After sudden draw down	1.20
Natural slope of long standing	1.10 - 1.20
Spoil tip	1.50
Problem involving building	2.0

Table 2.1: FOS apply for different condition

2.5 Slope Analysis

Since long time ago, Engineers and geologist have done much research to determine the best slope that is safety. In order of that engineer has tried to analyse the lowest factor of safety at its most critical line of failure.

Many of the method have come out from the research and with some of the common method such as the method of slice. The wedge method and block method also had been used to analyse the stability of the slope. In the method of slice the trial slip circle is selected and the mass of the slip is divided into slice of the equal width. Each of the slip of the slice is analyse through two common methods known as the Swedish method and Bishops method.

With these method, Graphical, Chart and Mathematical approach by using hand calculation, calculator or Computer can be apply to do the analysis. However,

> "… *pseudo-static* analysis, produces a factor of safety against seismic slope failure in much same way that static limit equilibrium analyses produce factors of safety against static slope failure". (Kramer 1996)

2.5.1 Ordinary Method of Slices

> "Stability analyses should be carried out in terms of effective stresses in problems where change in pore pressure take place, such existing embankments and spoil tips; also to estimate the long-term stability of slopes and in the case of over consolidated clays fro both immediate and long term conditions" (Whitlow 1995).

Stability analysis by using method of slices can be explained by refer to the Figure 2.5 below.

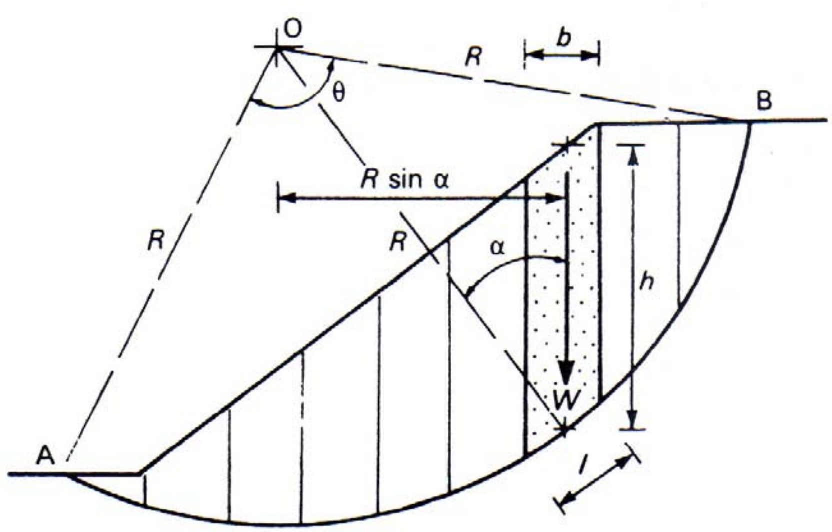


Figure 2.5(a): Method of Slice **(a)** Division of slip mass (R. Whitlow, 1995)

With this method it is assumes that a circular failure surface with the radius *r* to the point *O*. The soil mass above is the failure line is divided into several vertical series of slice of width *b*, as shown on figure. The width of each slice need not be the same; however with the standard width for the each of the slice will ease the calculation procedure. The base of the each slice is assumed to be straight line although it exists as a curve. The inclined angle α to the horizontal and height which measured on the centre-line is *h*.

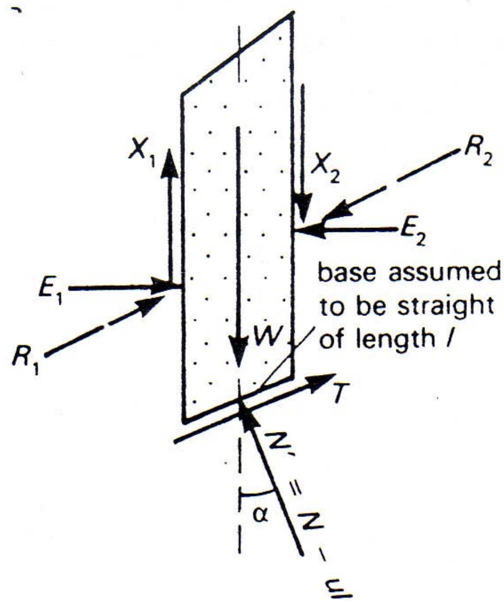


Figure 2.5(b): Method of Slice **(b)** Forces on a slice (R. Whitlow, 1995)

R. Whitlow (1995) explained the force acting on each slice length of 1 m from the terms below. Where:

W is the body weight of the slice, $\gamma h\ b$
N' is the effective normal reacting force at the base of the slide
T is the shearing force induced along the base, $W \sin\alpha$
R_1 and R_2 is the forces imposed on the sides adjacent slices, which may resolve into:
E_1 and E_2 is normal interslice forces
X_1 and X_2 tangential interslice forces

R.Whitlow (1995) cited…

> "any surcharge effect on the surface must be included in the computation of the body weight and other forces. This will give all other force will be included in the calculation."

The total disturbing moment will be exactly balanced by the moment of the moment of the total mobilised shear force along AB at the point of limit equilibrium. R.Whitlow (1995) gives the solution of the equation as follow:

$$\Sigma \tau_m lR = \Sigma \frac{\tau_f}{F} lR = \Sigma W (\sin \alpha) R$$

Giving $F = \dfrac{\Sigma \tau_f l}{\Sigma W \sin \alpha}$

Now on terms of effective stress, $\tau_f = c' + \sigma_n' \tan \varphi'$ and $\tau_f l = c' l + N' \tan \varphi'$

So that, $F = \dfrac{c' L_{ac} + \Sigma N' \tan \varphi'}{W \sin \alpha}$

Or if the soil is homogeneous

$$F = \frac{c' L_{ac} + \tan \varphi' \, \Sigma N'}{W \sin \alpha} \tag{2.2}$$

Where L_{ac} is arc length AC= θR

R. Whitlow also concludes that…

> “there are number of methods have been suggested, some relative simple and some which a quite rigorous but the most accurate estimate may be expected from rigorous methods, but may only possible if a computer routine can be employed. This may be cause by the complex of the method to be use on hand calculation. The most common method that had been applied the analysis are the Fellenius (or Swedish)’s method and Bishop’ simplified method”

2.5.2 Fellenius Method

In this method, the interslice force is assumed are equal and opposite and cancel each other out. Hence the $E_1 = E_2$ and $X_1 = X_2$. Now, it is only the force acting on the base of the slice to be resolved. R.Whitlow (1995) solved the equation for Fellenius method as follow:

$N' = W \cos \alpha - ul$

$\quad = \gamma hb \cos \alpha - ub \sec \alpha \; (l = b \sec \alpha)$

Or putting $u = r_u \gamma h$

$N' = \gamma h(\cos \alpha - r_u \gamma h)b$

Or $\Sigma N' = \gamma b \Sigma h(\cos \alpha - r_u \sec \alpha)$

Then by substituting in equation 4.2

$$F = \frac{c' L_{ac} + \gamma b \tan \varphi' \, \Sigma h(\cos \alpha - r_u \sec \alpha)}{\Sigma W \sin \alpha} \tag{2.3}$$

Larger number of slides determined for a slope problem is usually would give better estimate of F. The number of slides taken should not less than five.

2.5.3 Bishop's simplified method

In this method it is assumes that only shear forces acting on the sides of each slice are equal. Hence, $X_1 = X_2$ but the $E_1 \neq E_2$ (Figure 2.6).

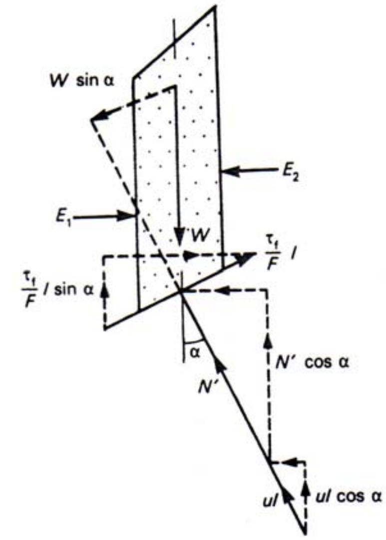


Figure 2.6: Bishop's simplified slice (R. Whitlow, 1995)

R. Whitlow (1995) formulated the equation for Fellenius method as follow:

For the equilibrium along the base of the slice:

$$0 = W\sin\alpha - \frac{\tau_f}{F} l = W\sin\alpha - \frac{c' L + N\tan\varphi'}{F}$$

So that, $F = \dfrac{\Sigma(c' l + N'\tan\varphi')}{\Sigma W\sin\alpha}$

For equilibrium in a vertical direction

$$0 = W \quad N'\cos\alpha - ul\cos\alpha - \frac{\tau_f}{F} l\sin\alpha$$

$$= W \quad N'\cos\alpha - ul\cos\alpha - \frac{c'}{F} l\sin\alpha - \frac{N\tan\varphi'}{F}\sin\alpha$$

Then, $$N' = \frac{W - \frac{c'}{F} l \sin\alpha - ul\cos\alpha}{\cos\alpha + \frac{\tan\alpha\tan\varphi'}{F}}$$

After substituting for,

$l = b\sec\alpha$

And *N*' rearranging

$$F = \frac{1}{\Sigma W \sin\alpha} \Sigma \frac{[c'b + (W - ub)\tan\varphi']\sec\alpha}{1 + \frac{\tan\alpha\tan\varphi'}{F}} \qquad (2.3)$$

> "The procedure is commenced by assuming a trial value for the F on the right-hand side and then, using an iterative process, to converge on the true value of F for a given trial circle. This is the routine procedure commonly used in programs designed for use on computers." (R. Whitlow 1995)

2.6 Design chart

> "Even early in the application of the calculation to the solution of slope stability problems it became obvious that these could involve a substantial amount of arithmetic, all of it prone to error, and most of it an unproductive use of engineer's time: a series of analyses for a modified design, for instance." (Bromhead 1986)

Now, many slope stability problems can be reduced to a much simpler design concept, particularly, at the early stage of the design for the slope problem where there is a need for repeat to analyse for the FOS of the slope problem.

> “An attempt on this problem was made by Taylor (1937)” (Broomhead 1986).

Where the stability number and Taylor’s design chart was introduced to solve the problems complex and time taking slope problem in a simple way. Soon, other approach has been done by others for the design chart such as Spencer’s stability chart, cousin stability chart.

2.6.1 Stability number

Stability number had been widely use as a guide to create a design chart for a slope.

> “In 1948, D.W. Taylor proposed a simple method of determining the minimum factor of safety for a slope in a homogeneous soil. Using a total stress analysis and ignoring the possibility of tension cracks, he produced a series of curves which relate a stability number (N) to the slope angle β.” (R Whitlow 1995)

Slope angle of “*i”* will be used for this project.

In the work of Taylor, Taylor were introduced a slope stability, N which consist the group factor which consist of soil’s cohesion (*c*), Soil unit weight (γ), slope height and factor of safety. As cited by McCarthy (1998)…

> “Taylor introduced a slope stability number N, to group factor that affect the safe inclination of a soil’s slope.”

Equation for the Stability Number introduced by Taylor is shown below.

$$N = \frac{c}{\gamma H F} \qquad (2.3)$$

Where:

N is Slope stability number (dimensionless)

c is Soil's cohesion (kN/m^2)

γ is Soil unit weight (kN/m^3)

H is Slope height (m)

F is Factor of safety (dimensionless)

2.6.2 Taylor Chart

> "When slope is at limit equilibrium (sliding is impending), a unique relationship exists between its height and inclination and soil properties (γ, c, φ)" McCarthy (1998).

With this relationship it will provide the curve as shown the Figure 2.6(a) and (b).

> "The Taylor curves are based upon the total stress analysis and the related soil strength values are obtained from undrained shear stress. (McCarthy 1998)".

The total stress is equal to the effective stress plus neutral stress due to pore water pressure.

From Figure 4.6(a), it has the stability number, N at y-axis and Depth factor, D at the x-axis. For the value of depth factor (D), Robert (2000) defined it as:

$$D = \frac{\text{Vertical distance between top of slope and lowest point on the slip surface}}{\text{Height of the slope}}$$

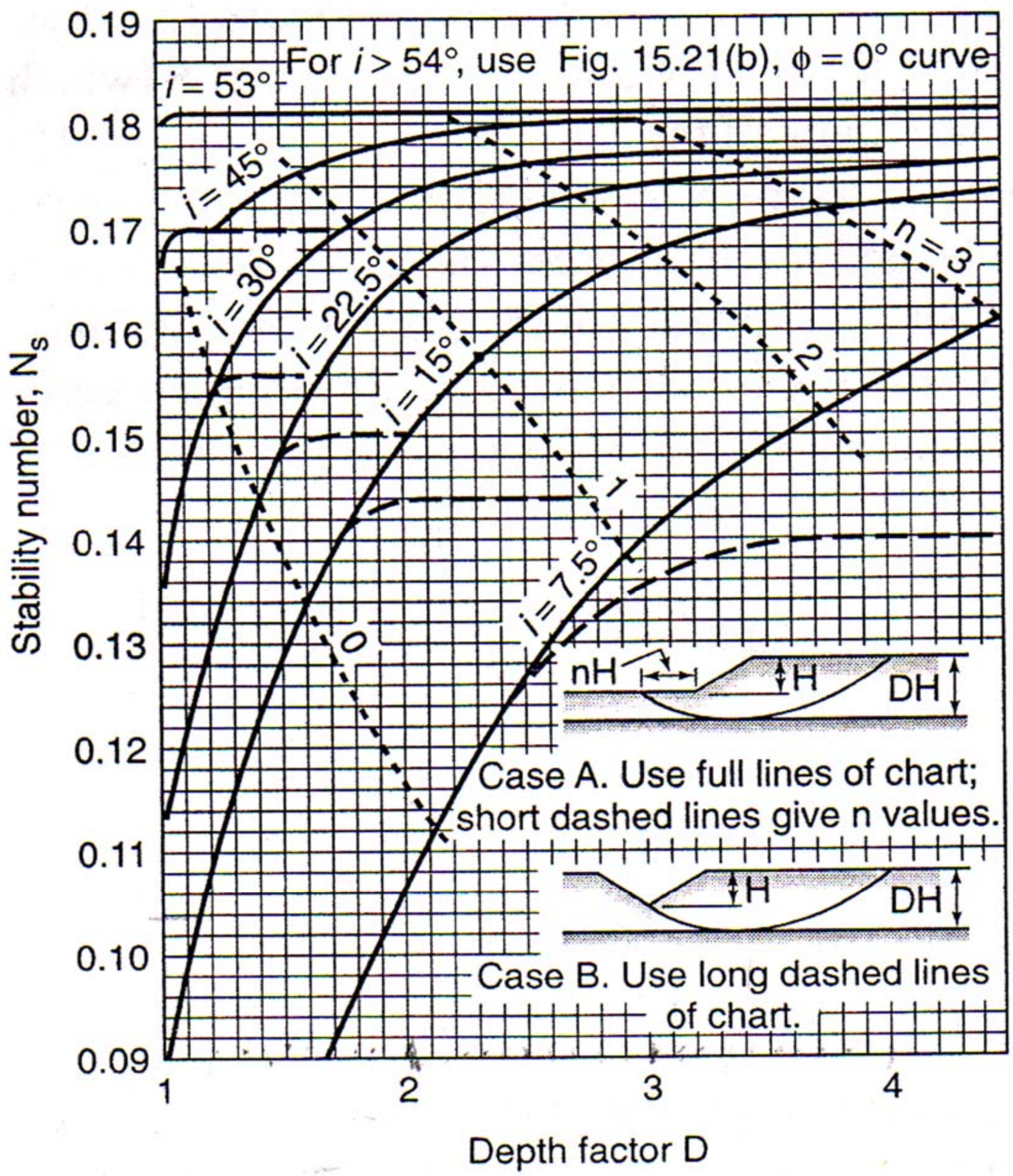


Figure 2.6(a): Taylor stability chart for φ = 0° (McCarthy 1998)

To determine the required value of Fs for the "φ = 0"soil, the following step-by-step procedure needs to be used, for using the Taylor's stability chart:

1) Determine the *c*, γ, φ, H and *i* for the given slope.
2) Determine the Depth factor, D
3) From the chart (Figure 2.6(a)), locate the D required to the line of *i*, and get the stability number, N value.
4) With the equation 2.3, substitute the N, c, γ, and H to calculate for F (factor of safety)

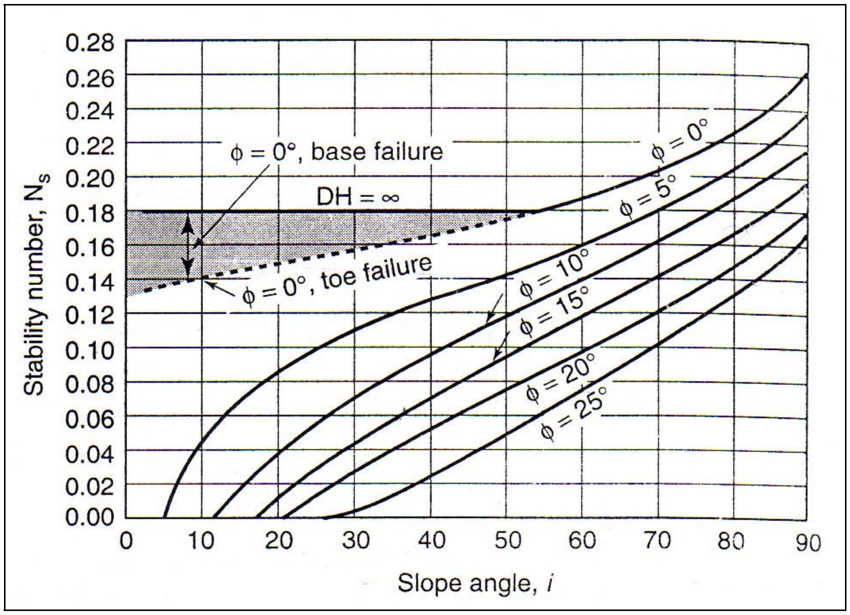


Figure 2.6(b): Taylor stability chart for c plus φ soil (McCarthy 1998)

To determine the required value of Fs for the c plus φ soil, the following step-by-step procedure needs to be used, for using the Taylor's stability chart.

1) Determine the *c*, γ, φ, H and *i* for the given slope.
2) From the chart (Figure 2.6(b)), locate the *i* required to the line of φ, and get the stability number, N value.
3) With the equation 2.3, substitute the N, c, γ, and H to calculate for F (factor of safety)

2.6.3 Spencer's stability chart

The introduction of pore water pressures will bring one extra parameter to the slope problems. Bromhead (1986) defined…

> "the pore water pressure r_u used in slope stability charts is the ratio of pore water-pressure head at a point in the slope to the vertical total stress as estimated approximately from the depth of soil above that particular point and its unit weight".

> “The first approach [to make a a design chart by consider the pore water pressure problem] is followed by Spencer(1967)”(Bromhead 1986)”

Robert (2000) defined the pore water ratio r_u, as:

$$r_u = \frac{u}{\gamma_t h}$$

Where, u is pore water pressure [kN/m^2]

γ_t is total unit weight of the soil [kN/m^3]

h is depth below the ground surface [m]

Figure 2.7 show Spencer’s stability chart. For the Spencer chart, there are three r_u had been choose for the chart, there 0, 0.25 and 0.5 for the r_u.

Robert also theorized that…

> “if r_u = 0 is selected, then the pore water pressure are assume to be equal to zero in the slope. For r_u = 0.25 is similar to the effect of a ground water table mid height of the slope and for r_u = 0.5 would be similar to the effect of a ground water table corresponding to the ground surface”

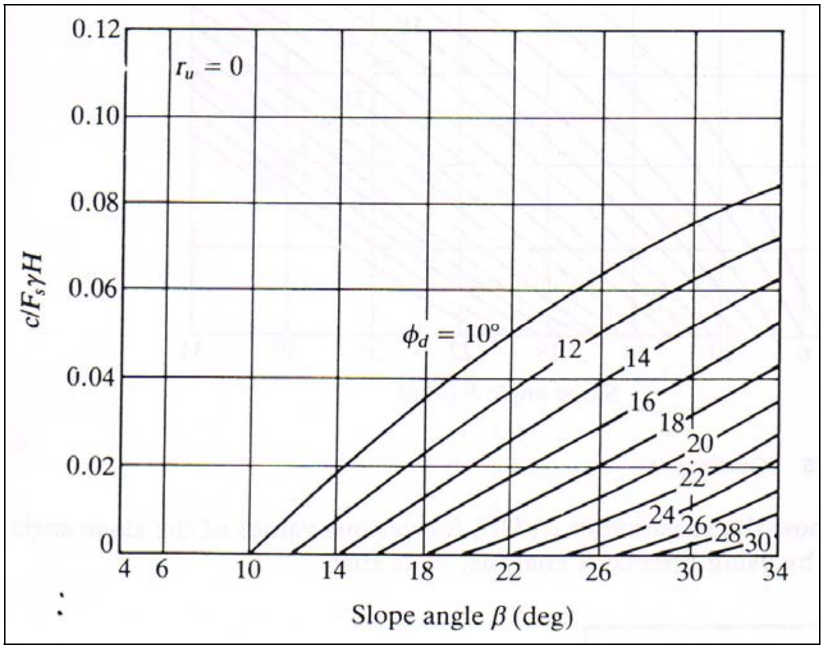


Figure 2.7: Spencer's stability chart **(a)** $r_u = 0$

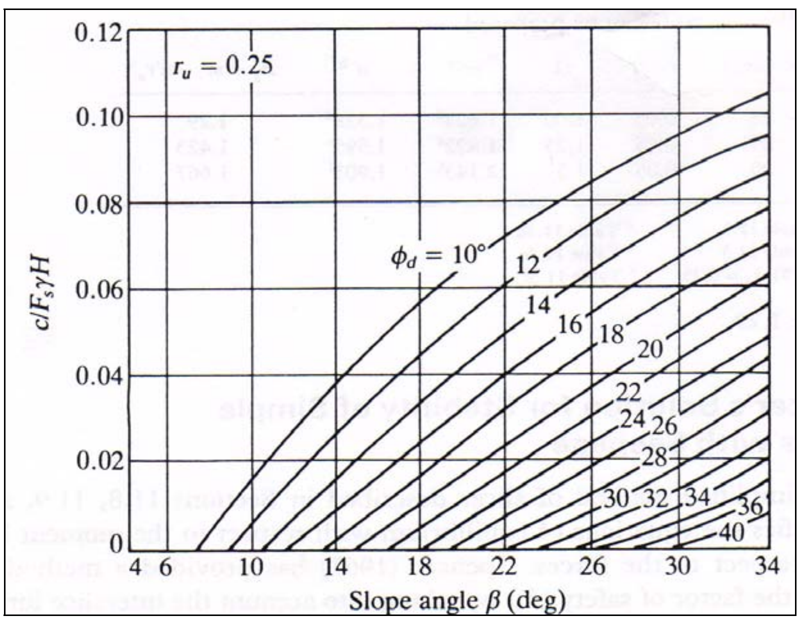


Figure 2.7: Spencer's stability chart **(b)** $r_u = 0.25$

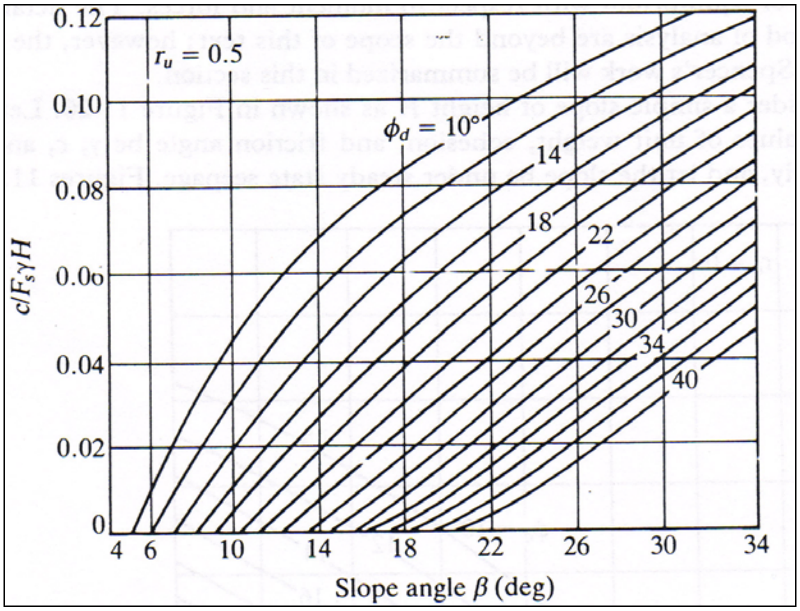


Figure 2.7: Spencer's stability chart **(c)** $r_u = 0.5$

Braja (1985) conclude that in order to use the charts given by Spencer and to determine the required value of Fs, the following step-by-step procedure needs to be used.

1) Determined the c, γ, H, β, φ and r_u for the given slope.
2) Assume a value of F_s.
3) Calculate $c/[F_{s(assumed)}\gamma H]$
4) With the value $c/[F_s\gamma H]$ calculated in Step 3 and the slope angle β, enter the proper chart in Figure 2.7 to obtain φ_d.
5) Calculate $F_s = \tan\varphi/\tan\varphi_d$
6) If the values of F_s as assumed in Step 3 are not the same as those calculated in Step 5, repeat Steps 2, 3, 4 and 5 until they are the same.

2.6.4 Cousin's stability charts

Refer to Figure 2.8, it show the stability chart by Cousins(1978).

> "These three charts were developed for a failure through the toe of the slope." (Robert 2000)

The chart had been developed for a different pore water pressure r_u such as follow:

- $r_u = 0$
- $r_u = 0.25$
- $r_u = 0.5$

"Cousin Charts can be used only if the soil has a cohesion value." (Robert 2000)

Robert (2000), conclude the steps to be use for the analysis as below:

Effective stress analysis

1) Select value the value r_u required on the basic of the existing groundwater table and use the Figure 2.8 depend on the value r_u.
2) Calculate for $\lambda_{c\varphi}$, which is defined by Robert (2000) as follows:

$$\lambda_c \varphi = \frac{\gamma_t H \tan \varphi'}{c'}$$

Where, γ_t is total unit weight of the soil [kN/m3]
H is height of the slope [m]
φ' is effective friction angle of the soil [°]
c' is effective stress cohesion of the soil [kPa]

3) Enter the chart along the horizontal axis at the value of the slope inclination α. The appropriate curve based on the value of $\lambda_c\varphi$ is select and then the stability number N_F from the vertical axis is determined.
4) The factor of safety is calculate by equation 2.3

Total stress analysis

Figure 2.8(a) will be used as the r_u will be 0. Using the same step s above to perfume the analysis but φ and c will be used instead of φ' and c'.

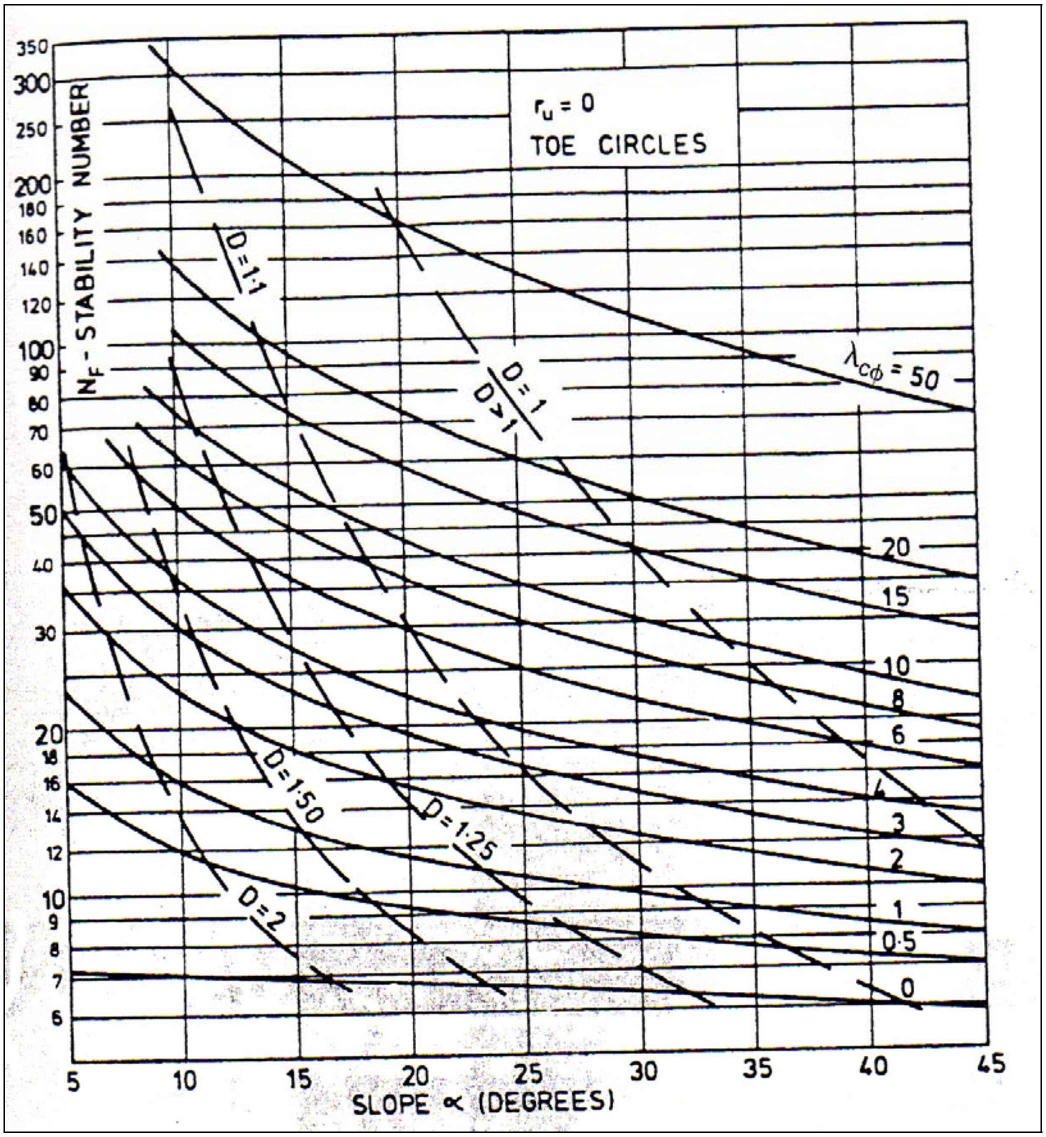


Figure 2.8(a): Cousins chart for failure analysis through the toe of the slope ($r_u = 0$)

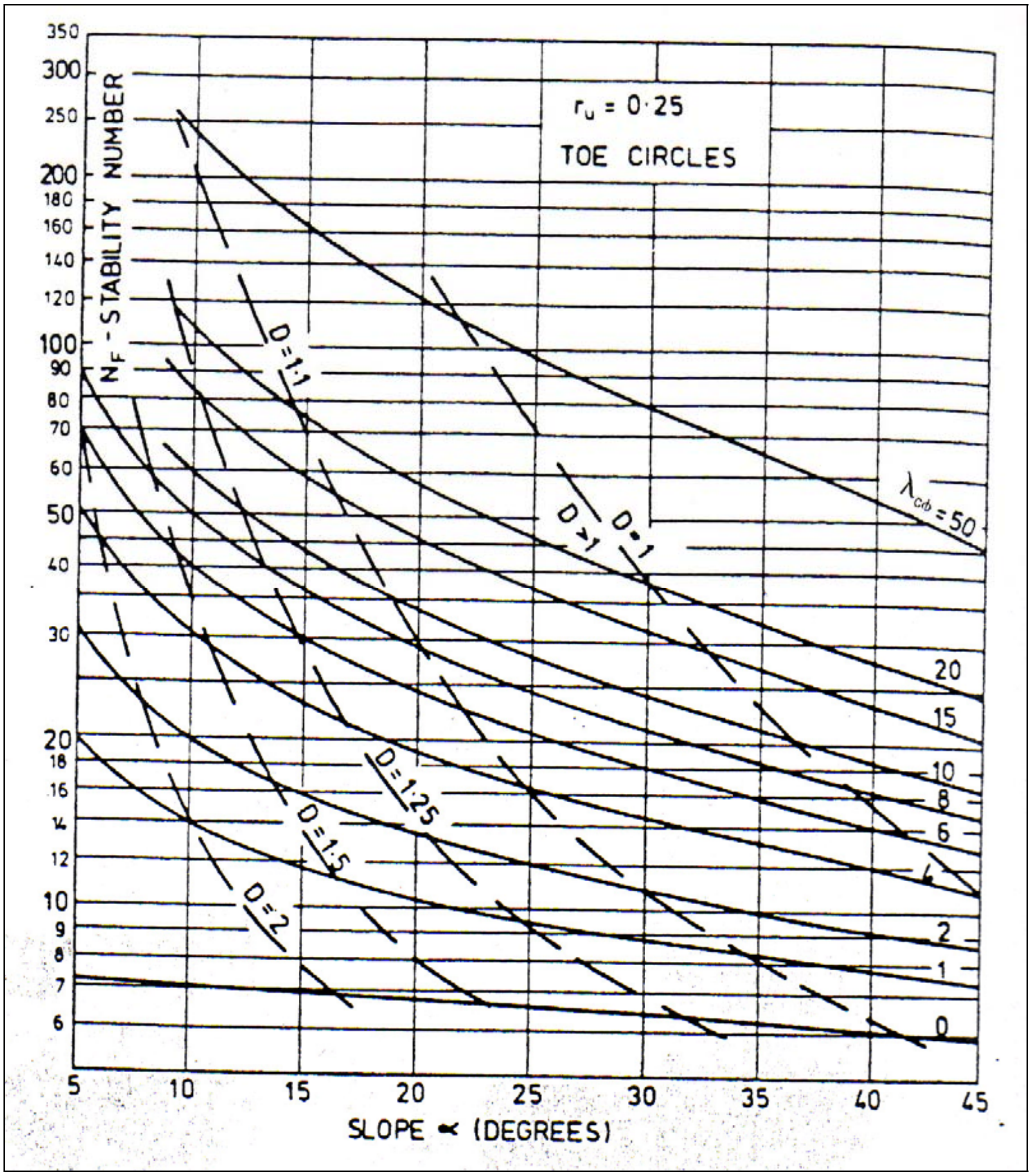


Figure 2.8(b): Cousins chart for failure analysis through the toe of the slope (r_u = 0.25)

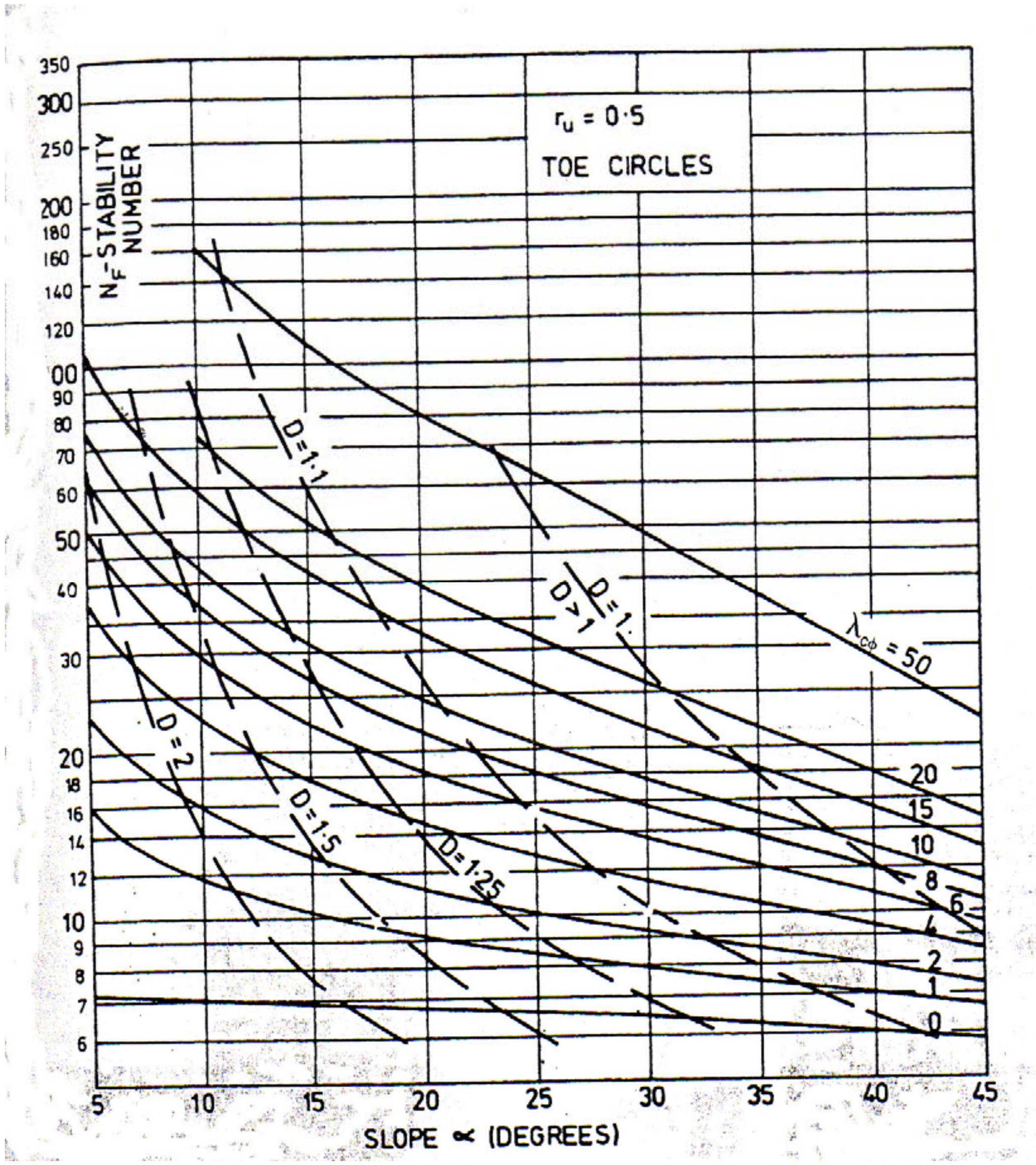


Figure 2.8(b): Cousins chart for failure analysis through the toe of the slope (r_u = 0.25)

2.7 Seismic

Seismic can be defined as…

> "'of an earthquake or earthquakes' or 'of or using vibration of the earth that are produced artificially by explosive'." (The Oxford Study Dictionary 1995).

Seismic wave generate can be cause by the earthquake event or from an explosion event of the ground, hence from this it will cause vibration to the ground. An earthquake may be form a small earth vibration to the ground or to the strong earth vibration to the ground.

> "…A strong earthquake is a rare phenomenon for a given place; its occurrence is sudden and of short duration and it is very difficult to predict its specific time, location and magnitude; but once it occur the damage is very severe. (Hu et al 1996)"

> "Cyclic loads induced by earthquakes decrease the stability of a slope by increasing shear stresses, increasing pore pressures (pore air or pore water), and decreasing soil strength. In the extreme case, increase in pore pressures can lead to liquefaction." (Hunt 1986)

Earthquakes are one of the most devastating natural disasters on earth. A strong earthquake may bring sudden fatality, great economic loss and shock to the community. An earthquake event may cause great damage to building structural and also to cause slope failure such as landslide.

> "In order to reduce the disaster caused by earthquake, it is necessary to have some means of earthquake prediction and to design structural that will withstand such shocks." (Hu et al 1996)

Generally there two approaches to evaluating the effects of earthquake loading on slopes.

These approaches are the conventional or pseudo-static approach and the dynamic-analysis approach. However, during this project pseudo-static analysis will be use.

2.7.1 Seismic Waves

Different type of seismic waves will be produce when an earthquake occurs. The waves produced are the body waves and surface waves.

The body waves are the waves which can travel through the interiors of the earth. Two types of body wave the p-waves and s-waves (Figure 2.9).

> The… "P-waves also known as primary, compressional, or longitudinal waves involve successive compression and rarefaction of the materials through which they pass. They are analogous to sound waves; the motion of an individual that p-waves can travel through solids and fluids." (Kramer 1996).

> The… "S-waves, also known as secondary, shear or traverse waves, cause shearing deformations as they travel through a material. The motion of an individual particle is perpendicular to the direction of s-wave travel."(Kramer 1996).

From these two waves, they have created their individually physical motion on earth.

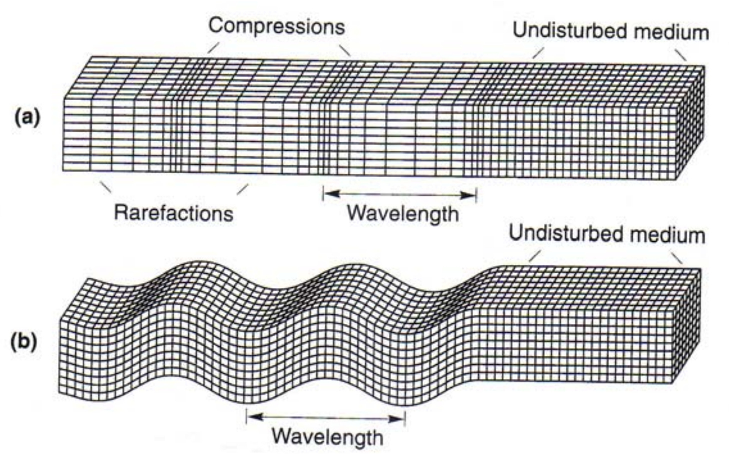


Figure 2.9: Deformation produced by body waves: **(a)** p-wave; **(b)** SV-wave (Kramer 1996)

> "The surface waves result from the interaction between body waves and the surface and surficial layers of the earth. They travel along the earth's surface with amplitudes that decrease roughly exponentially with depth [(Figure 2.10)]. Because of the nature of the interaction required to produce them, surface waves are more prominent at distances farther from the source of the earthquake. At the distance greater than about the twice the

thickness of the earth's crust, surface wave rather than body waves, will produces peak ground motion." (Kramer 1996)

Earth's crust is the outermost layer of earth of the earth where human beings live (Figure 2.11).

"The thickness of the crust ranges from about 25 to 40 km beneath the continents (although is may be as thick as 60 to 70 km under some young mountain ranges) to as thin as 5 km or so beneath the ocean – only a very small fraction of earth's diameter. With the effect of the wave is where an earthquake event will occur as the ground motion is produce by the surface waves." (Kramer 1996)

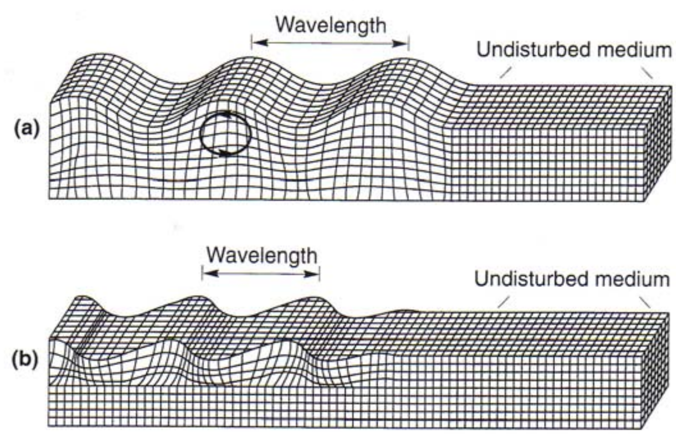


Figure 2.10: Deformation produced by surface waves: **(a)** Rayleigh wave; **(b)** Love wave (Kramer 1996)

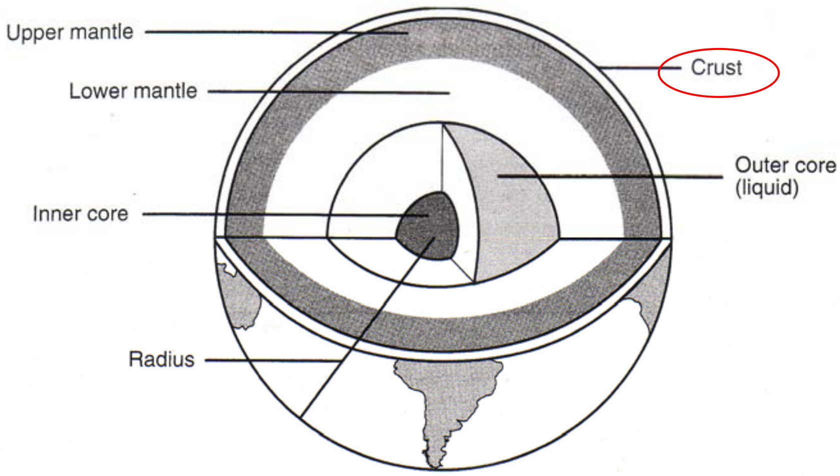


Figure 2.11: Internal structure of earth (Kramer 1996)

> "Direction of particle movement can be used to divide s-waves into two components, the SV (vertical plane movement) and SH (Horizontal plane movement)." (Kramer 1996)
>
> For the engineering purpose the most important surface wave are the p- and SV-waves with the earth's surface, involve both vertical and horizontal particle motion." (Kramer 1996)

Kramer (1996) cited that the…

"Love waves result from the interaction of SH-waves with a soft surficial layer and have no vertical component of particle motion".

2.7.2 Earthquake Intensity

Earthquake intensity is the measure of the size of an earthquake. It is obviously a very important parameter and has been describe in different ways. Kramer (1996) cited…

"the intensity is a qualitative description of the effects of the earthquake at a particular location, as evidenced by observed damage and human reactions at that location".

"There particular have few intensity scale develop during some times. "The Rossi-Rorel (RF) scale of intensity, describing intensities with values ranging from I to X, was developed in the 1880s and used for many years. It has largely been replaced in English-speaking countries by the modified Mercalli intensity (MMI) scale originally developed by the Italian seismologist Mercalli and modified in 1931 to better represent conditions in California (Richter, 1958). The qualitative nature of the MMI scale is apparent from the descriptions of each intensity level." (Kramer 1996).

Refer to the Table 2.2 its show how the MMI scale define the earthquake intensity..

Intensity	**Description**
I	Not felt except by a very few under especially favourable circumstances
II	Felt by only a few person at rest, especially on the upper floor of buildings; delicately suspended object may swing
III	Felt quite noticeable indoor, especially on the upper floor of buildings but many people do not recognise it as earthquake; standing motorcar may rock slightly; vibration like passing of truck; duration estimated
IV	During the day felt indoors by many, outdoors by few; at night some awakened; dished, door window disturbed; wall make cracking sound; sensation like heavy truck striking building; standing motorcar rock noticeably
V	Felt by nearly everyone, many awakened; dished, windows, etc. broken; few instances of cracked plaster; unstable object overturned; disturbance of tree, piles and other tall objects sometime noticed; pendulum clock may stop
VI	Felt by all, many frightened and run outdoor; some heavy furniture moved; a few instances of fallen plaster or damaged chinmneys; damage slight
VII	Everybody run outdoors; damaged negligible in building of good design and construction, slight in moderate in well-built ordinary structure, considerable poorly build or badly design structures; some chimneys broken; noticed by person driving motor cars
VIII	Damaged slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse, great in poorly built structures; panel wall thrown out of frame structure; fall of chimneys, factory stacks, columns, monuments, wall; heavy furniture overturned; sand and mud ejected in small amounts; changes in well water; person driving motor cars disturbed

Table 2.2: Modified Mercalli Intensity Scale (Kramer 1996)

IX	Damaged in considerable in specially designed structures; well defined frame structures thrown out of plumb; great in substantial building, with partial collapse; building shifted of foundations; ground cracked conspicuously; underground pipe broken
X	Some well build wooden structure destroyed; most masonry and frame structure destroyed with foundation; ground badly cracked; rails bent; landslide considerable from river banks and steep slope; shifted sand and mud; water splashed over bank
XI	Few, if ant (masonry) structure remain standing; bridges destroyed; broad fissures in ground; underground pipeline completely out of service; earth slump and lands slips in soft ground; rails bend greatly
XII	Damaged total; practically all work of construction are damaged greatly or destroyed; waves seen on ground surface; line of sight and level are distorted; object thrown into the air

Table 2.2: Modified Mercalli Intensity Scale (continue) (Kramer 1996)

2.8 Pseudo-static Analysis

2.8.1 Basic background of Pseudo-static

> "Beginning in 1920s, the seismic stability of earth structure has been analysed by a *pseudo-static* approach in which the effects of an earthquake are represent by constant horizontal or vertical accelerations" (Kramer 1996).

Hunt (1986) theorized that the…

> "horizontal force system is expressed as the product of the weight and seismic coefficient k which is related to induce accelerations."

In the pseudo-static analysis, the earthquake effect will be represent by including as an equivalent static horizontal inertia force which equal to the product of the seismic coefficient k = a/g and the weight W of the sliding mass. The magnitude of the pseudo-static force can be written as:

$$F = \frac{aW}{g} = k_h W \tag{2.3}$$

Where it's also can be written as:

$$k_h = \frac{a}{g} \tag{2.4}$$

Where, a is the earthquake acceleration [m/s²]

g is acceleration of gravity [9.81 m/s²]

Figure 2.10 show the Pseudo-static approach in slope problem. Where k_h is the seismic coefficient. W is the weight of the slope as the body force acting downward due to gravity and the $k_h W$ is the horizontal force where the seismic coefficient k_h time the weight of the slope.

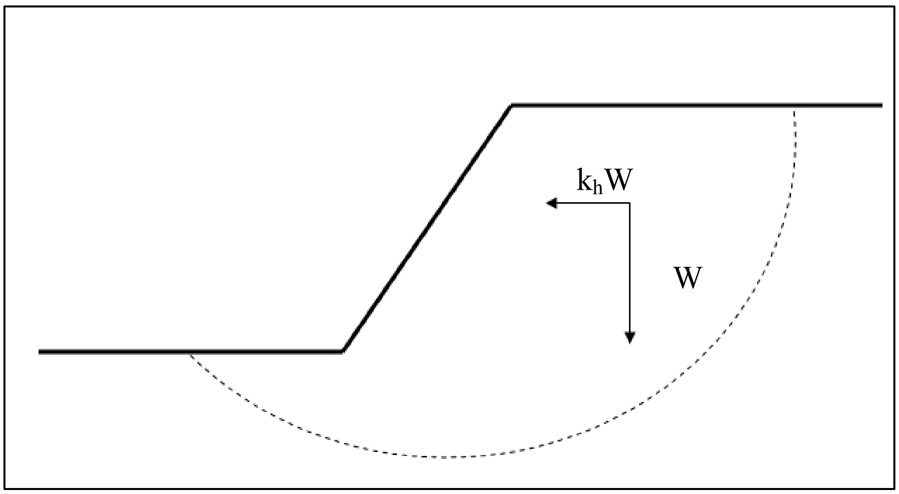


Figure 2.10: Pseudo-static analysis

Hunt (1986) cited…

> "Pseudo-static analysis now is generally recognised as being inadequate to predict behaviour during earthquakes, but may be used as a first approach. This can also can be seen that until today Pseudo-static analysis still being used in for analysis problem in the most of the publications of book.

Hunt(1986) also cited that…

> "its application, however, is restricted to compacted clayey embankments and dry or dense cohesion-less soils that experience very little reduction in strength due to cyclic loading."

2.8.2 Seismic coefficient

The seismic coefficient is variable depend on the strength of the ground motion that cause by seismic force. According Hunt (1983) he cited that…

"Terzaghi(1950) suggested using the following coefficients according to the earthquake magnitude [and had been summaries in Table 2.3]"

Earthquake magnitude, Intensity(*I*)	Seismic coefficient, k
Severe earthquake, I = IX	0.1
Violent earthquakes, I = X	0.25
Catastrophic event	0.5

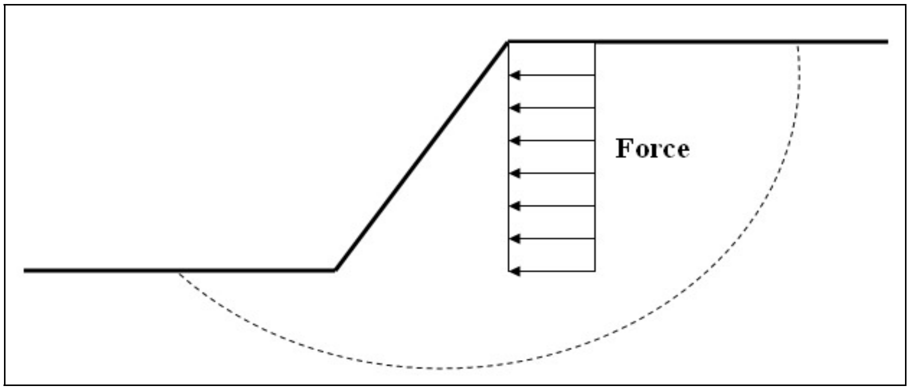
Table 2.3: Seismic coefficient for earthquake intensity

2.9 Seismic profile on slope

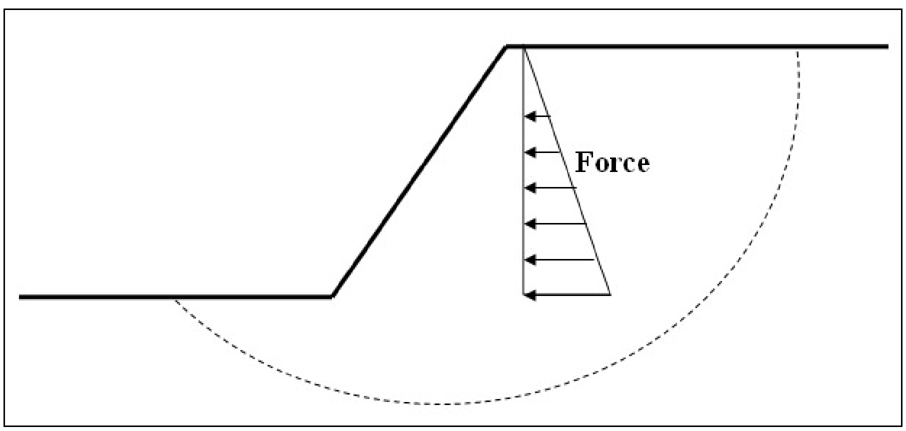
There are three different seismic profiles able to be applying on the seismic stability of slope problems. The three different seismic profile are constant, linearly and non-linear. To describe the seismic profile…

> "This force is can be assumed to act uniformly over the length of you body (constant). It can be assumed to act linearly along the length of your body, by starting from zero at the top of your head to the bottom of your feet. It can certainly be assumed as nonlinear distribution" (Shiau, Jim 2004, pers. comm., 7 May).

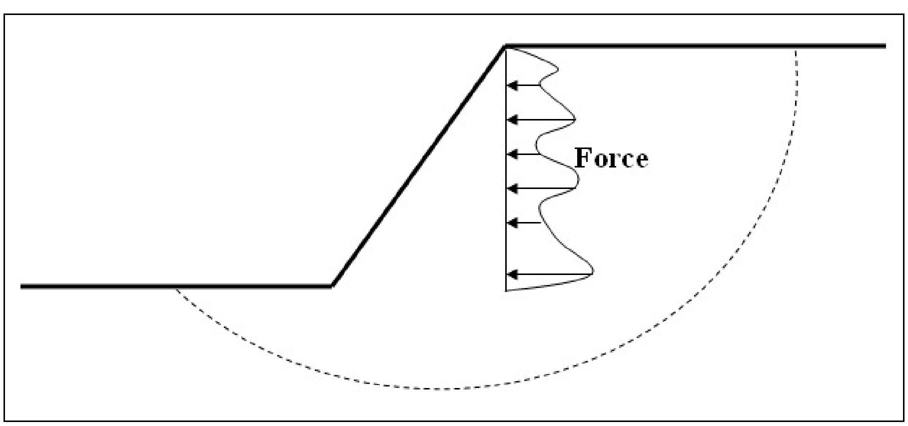
In the Figure 2.12 shows the seismic profile is explained in a form of diagrams.



(a) Constant profile



(b) Linear profile



(c) Non-linear profile

Figure 2.12: Seismic profile for slope

2.10 Geo-reinforcement

Geo-reinforcement is an application of reinforcement to the soil such as slope to stabilise the slope condition. Cernica (1995) discuss the reinforcement as Geosynthetics.

> "Geosynthetics is a name given to a family of man-made, sheet or net-like products derived from plastics or fibreglass compounds. Belonging to this group are Geotexiles, geogrids, geonets, and geomembranes" (Cernica 1995)

Many of this application of geosynthetic are applied to the soil to improve the strengths and the condition of the soil. Cernica (1995) give some example of the application the geo-reinforcement material, …

> "Examples of such application:
>
> - Reinforce softsoil; increase bearing capacity
> - Strata separation
> - Filtration
> - Drainage
> - Moisture barriers
> - Retention walls, embankments, and slope stability
> - Erosion control
>
> Cernica (1995)"

2.10.1 Geotexiles

Geotexiles…

> "also refered to as geofabrics because some of the geotexiles resemble a woven fabric, geotexiles constitution the largest segment of the geosynthetics group."(Cernica 1995)

It is usually shipped to the construction site in rolls and is used in various situations for various needs such as strata separation, reinforcement, filtration and drainage.

2.10.2 Geogrids

> "Geogrids resemble nets, to some extent, since they have relatively large apertures which very in size from 1in. to as much as 4 in." (Cernica 1995)

The geogrids primary purpose is used to reinforce a soil or stone formation. Their applications of their use are pavements, slope and embankments, reinforced earth walls, and increasing bearing capacity of soil.

2.10.3 Geonets

> "Somewhat similar to geogrids, geonets have a net-like appearance. They are generally extruded with intersecting ribs." (Cernica 1995)

The geonets usually used as the drainage medium under roads, solid waste sites and behind the retaining wall.

2.10.4 Geomembranes

> "These are impervious (not perforated), continuous, thin plastic sheets, typically shipped in rolls for large projects, but folded for small project". (Cernica 1995)

The used of the geomembranes are primarily for lining and cover for liquid or solid waste storage facilities. The uses of this material are in limiting moisture infiltration to potentially instable soil, in the landfill construction and also as the vapour barriers under floor slabs.

Chapter 3:
FLAC/Slope (Version 4.0) SOFTWARE

3.1 Introduction

The FLAC/Slope (Version 4.0) software is a mini version of the software of the FLAC. The Itasca Consulting Group, Inc. created FLAC, where it is a general-purpose Itasca program for numerical modelling of continues material. FLAC/Slope is designed specifically to perform the factor of safety (FOS) calculations for slope stability analysis. FLAC/Slope is operated entirely from FLAC's graphical interface (GIIC) which provide for rapid creation of models for slope (for soil or/and rock material) and solution for their stability condition. FLAC/Slope is user-friendly computer software, where it is easy to use and easy to learn.

3.2 System required for FLAC/Slope

The following are the system requirements that recommended by the Itasca to be meet for a computer in order to install FLAC/Slope:

1. Minimum of 35 MB of hard disk space must be available to install *FLAC/Slope*.
2. At least 128MBRAM required for efficient operation of *FLAC/Slope*.
3. At least a 1 GHz CPU recommended for practical applications of *FLAC/Slope*. The speed of calculation is directly related to the clock speed of your computer.

4. *FLAC/Slope* is a 32-bit software product. Any Intel-based computer capable of running. Windows 95 or later is suitable for operation of the code.

3.3 Analysis Stage

As what has founded in the FLAC/slope programme, the analysis stages of the FLAC/slope for a slope problem are divided into four stages, the model stage, build stage, solve stage and plot stage.

3.3.1 Model Stage

At this stages the model of the project is named and listed, and also saved in a file. From here, the model also have been determined the shape and boundary of the model is set. Type of boundaries model can be chosen such as simple slope, bench slope or dam. Then the dimension and the slope boundary of each models is determined here. Previous projects model can also be loaded from these stages. All the work done at this stage is done at the *Models* stage tabbed bar. Each of the tool button (Figure 3.1) have its own function, the function state here are:

- "New" - use to create a new model of a project
- "Load" - use to load an existing model that had been created
- "Clone" - use to create a new model that is same as existing model
- "Save" – use to save a particular model in a file
- "Rename" – use to rename the model that had given previously
- "Delete" – use to delete a particular model

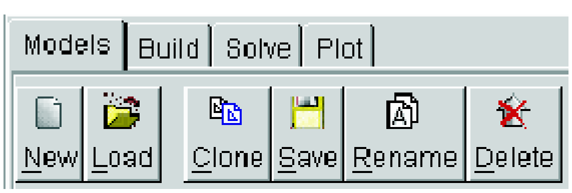


Figure 3. 1: Model Stage tool bar

3.3.2 Build Stage

The second stages, where the model of the slope is to be determined the layers, specification of material, weak plane, surface loading, installation of reinforcement of the slope and water table. Adjustment can be done the acceleration of gravity if there is seismic force to be considered. Also, from this stage the slope geometry can be change at the boundary tool bar. Each of the tool button (Figure 3.2) have its own function, the function state here is:

- "Bound" – for editing the model boundaries and parameters
- "Layer" – to create or edit layers of different soil properties
- "Material" – to create or edit the soil properties
- "Interface" – to create or edit a weak layer in the slope
- "Reinforce" – for creating or editing the reinforcement to the slope
- "Water" – to create or edit the water table
- Gravity – for edit the gravity setting

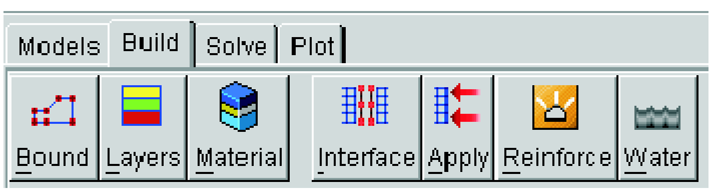


Figure 3. 2: Build Stage tool bar

3.3.3 Solve Stage

Before the model has been analysing for the factor of safety, the resolution of the numerical mesh is selected here. Three type of mesh tool button can be select the coarse, medium fine or user-specified (Figure 3.3). The "Solve FoS" tool button is used to calculate the Factor of safety. When the size of mesh is smaller the more accurate of the factor of safety.

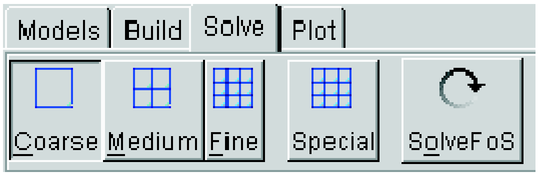


Figure 3. 3: Solve Stage tool bar

3.3.4 Plot Stage

After the solution to analyse of the factor of safety has been done, the output can be view through the plot stage (Figure 3.4), which it will display the result of the failure surface. From here a hard copy plot can be create and save at the “Setup” button, also can be printed out at the “Print” button. The “Load” tool button can be used to obtain existing model result that had been analyse. The “Items” tool is used for edit the out put of the slope result.

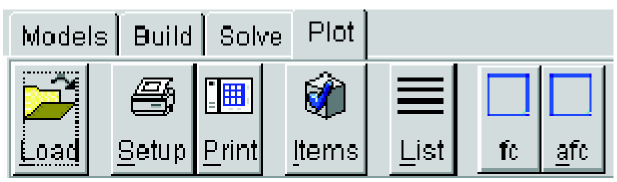


Figure 3. 4: Model Stage tool bar

3.4 Analysis Procedure

In this section, the analysis procedure will show how a typical normal procedure using the FLAC/Slope will solve a slope model.

3.4.1 Start-up

When the software of FLAC/Slope is start up, there will be a window of the “Model Option” window at the window screen as shown in the Figure 3.5.

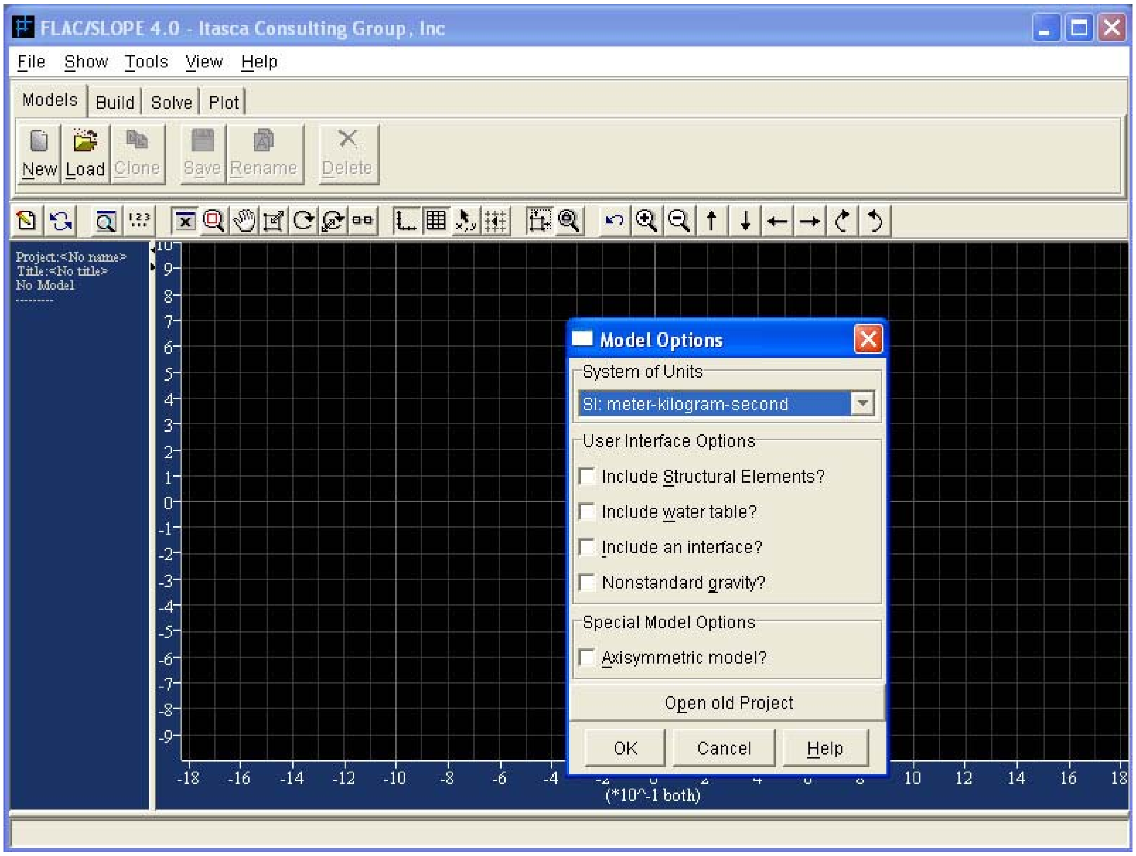


Figure 3. 5: Start up window

3.4.2 Defining the project

The project is begin by select and checking the necessary user interface option at the "Model Option" window as shown on Figure 3.5. By selecting this option, it will create the necessary table of tool will available for the later analysis procedure. The option can be select here is:

- System of Units
- User Interface options
- Special model options
- Or to "Open old Project"

Click "Ok" from "Model options" window when the selection is done. Next, from the menu bar select "File/ Save project as…", the window of project file will shown out (Figure 3.6), this is to specify a project title and to create a working directory for the project to be save as a file.

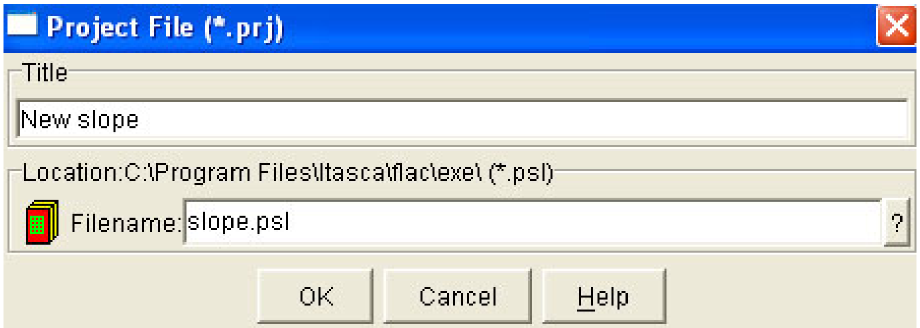


Figure 3. 6: Project file window

After the project file is created, the model is start by select the "New" button at the Model stage tool bar. A window will show the type of the shape of the model will be chosen here and also the model name (Figure 3.7)

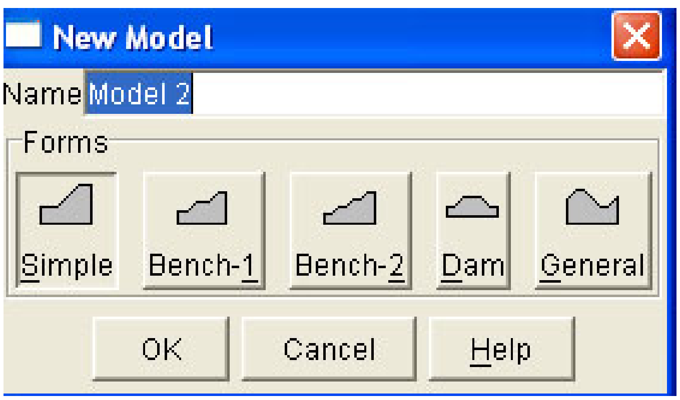


Figure 3. 7: New Model window

When click on the "OK" button at the "New Model" window, the next window "Edit Slope parameters" (Figure 3.8) will appear. From this window the boundary and parameter of the slope of the project will be decide here.

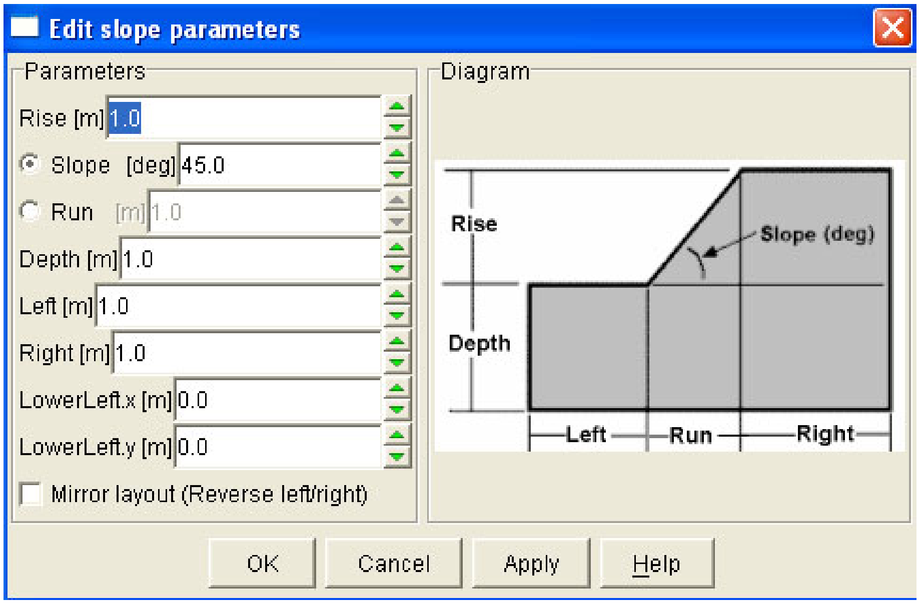


Figure 3. 8: Edit Slope parameter window

3.4.3 Building the Model

In this procedure we will use the "Builds" stages tool bar. At this "Builds" tool bar there is consist of three basic tools the "Bound"(for add/edit boundary), "Layers" (for add/edit soil layer) and "Material"(for add/edit material). Additional tool can be added such as the "Interface" (for add/edit interface layer),"Apply" (for add/edit the applying load), "Reinforce" (for adding reinforcement", "Water" (for adding water table) and "Gravity" (for edit gravity setting).

The most important part of tool is the "Material", as this is an important tool for all the slope problem, where the soil properties is add/edit here. By select the "Material" icon at the Build stage tool bar, there are numbers of material can be add or edit here and the list of material will be shown column at the right hand side of the window (Figure 3.9) of the FLAC. In this column the assigned material can be added, save and edit here. By click at the "Create" button the "Define Material" window (Figure 3.10) will be appear where the name and properties of material is decide here.

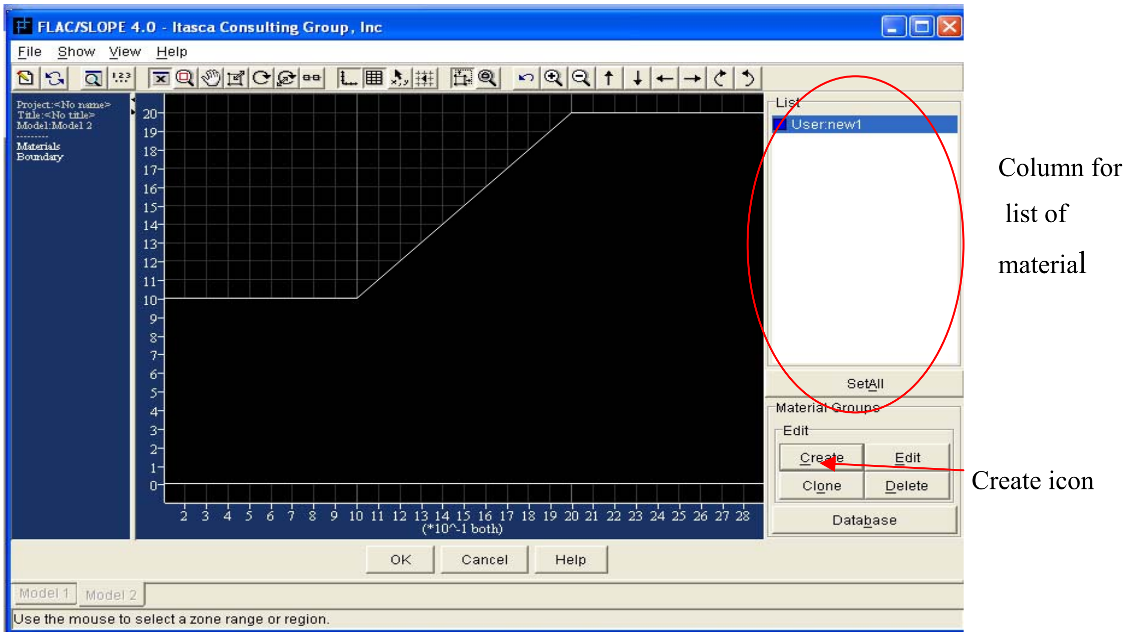


Figure 3.9: Assigned material column

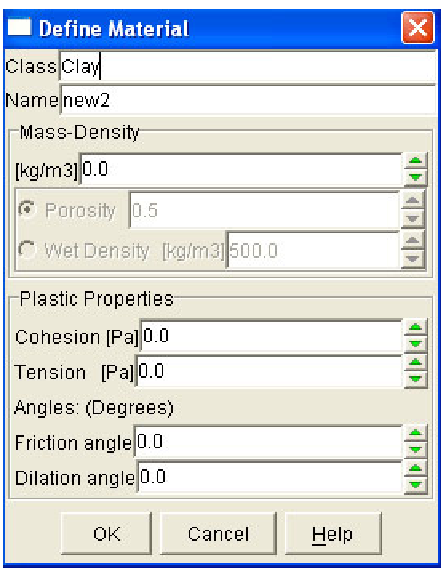


Figure 3.10: Define material window

In this Build Stages toolbar, other than define material properties, soil layer, water table and other type of condition of slope to be define can done by selecting the correct tool at the "Build" toolbar. Adding and removing of tool from the toolbar can be done clicking the "File/Model Option" at the menu.

3.4.4 Calculating factor of safety

After have complete the building stage, the factor of safety are ready to calculate. The Solve Stage toolbar is select. In this student version of FLAC/slope, only coarse mesh can be chosen. When the coarse mesh button is click it will show the grid used for the FLAC calculation will be appear in the model view (Figure 3.11).

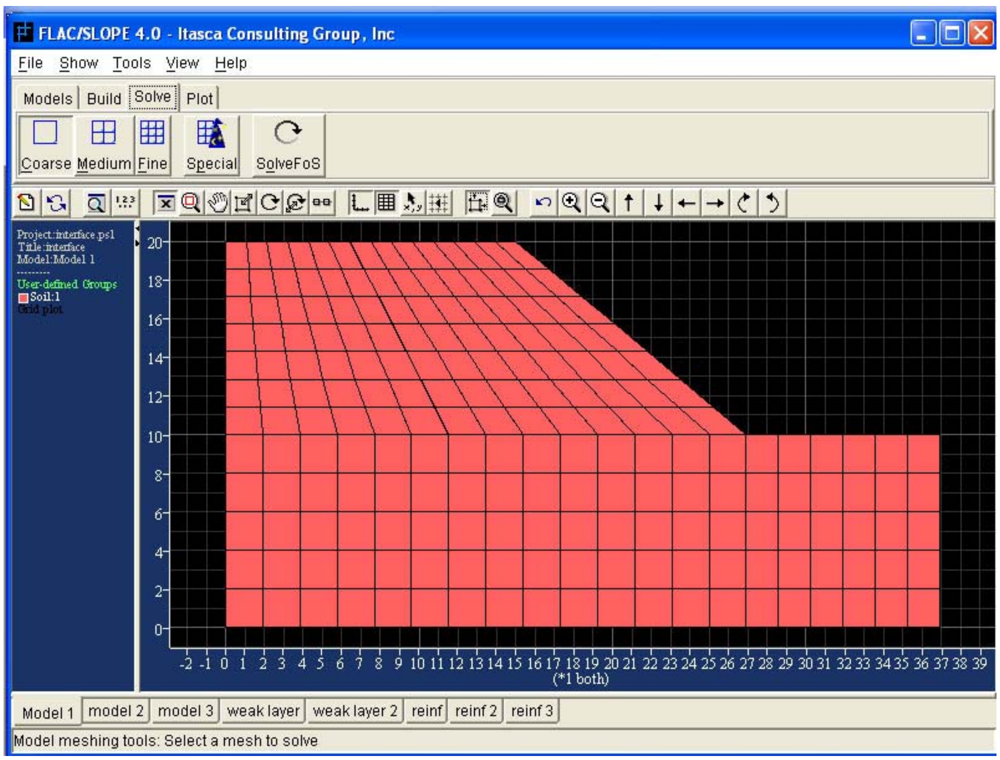


Figure 3.11: Coarse mesh

After deciding the mesh, the next procedure is start calculating Factor of Safety by clicking the “Solve button”. Before the calculating process start “Factor of Safety parameters” window (Figure 3.12) will appear and parameter need to be include in calculation of FOS is decide here, shown at Figure 3.12 the parameter can be select are “Friction angle”, “cohesion”, “Tension cutoff”, “Interface friction & cohesion” and “Use associated plastic flow rule”. The selection of these parameters will affect the result of the value of FOS.

Figure 3.13 show the window of FLAC while its analysing the calculation, note that there will be a ”Model Cycling…” window show the calculation in process. After the calculation is done there will be a window message (Figure 3.14) show the analysed Factor of safety result.

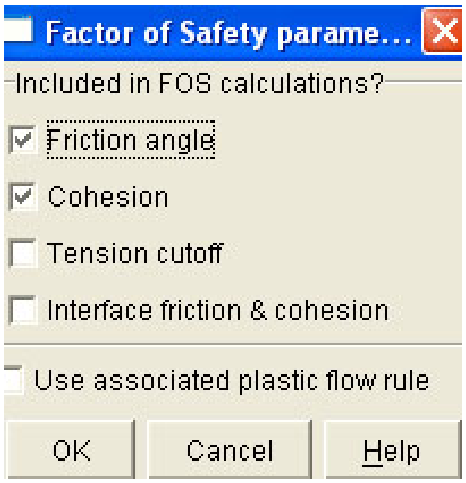


Figure 3.12: “Factor of Safety Parameter” window

Figure 3.13: “Model cycling…” window

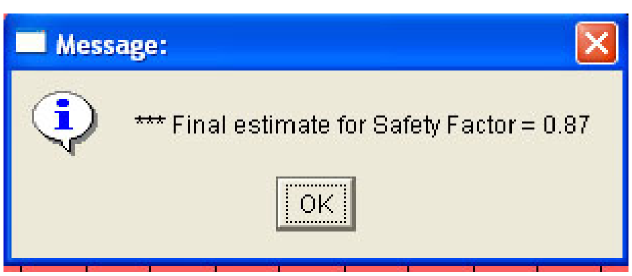


Figure 3.14: “Message” window

3.4.5 Viewing the result

By click on the Plot stages tool bar, we will able to view the result. The result of the model that had been analysed will show the line of failure in shear strain rate contour in a variety of colours; and also the vector direction of failure in the computer screen (Figure 3.15). Each colours of the contour have the different value of the shear strain, where it is shown at the left side of the screen at the plot legend. The value of the factor of safety is also printed on the plot legend at the left side.

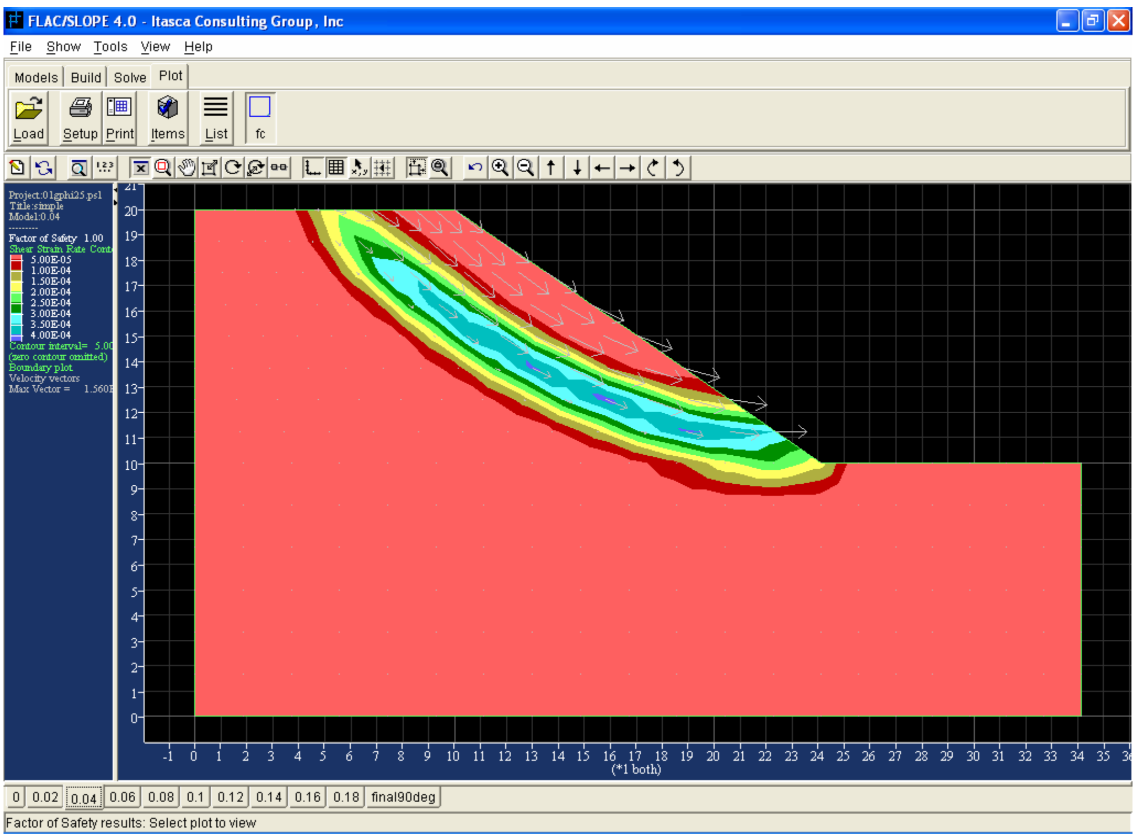


Figure 3.15: Output of the model shown in computer screen

By selecting the “Items” tool at the Plot tool bar, a “Plot items” window will show (Figure 3.16). This tool can be using to determine the type result we want to view; this will depend on the type of result need to present. Example by selecting the “Mesh” at the “model items” column (Figure 3.17) this will give a result the will show the mesh as well.

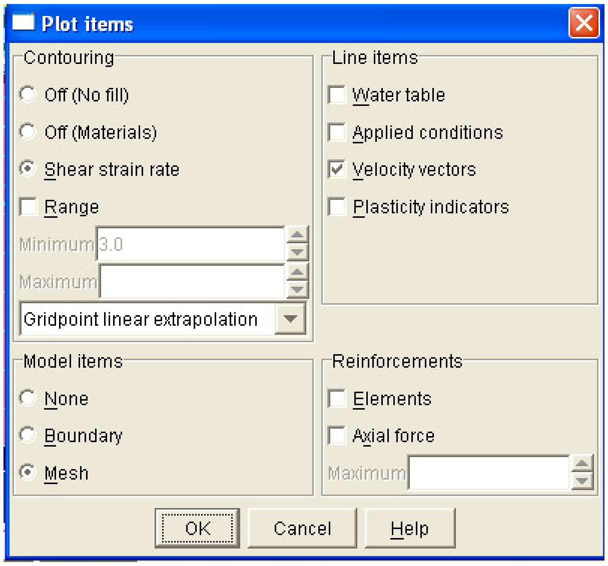


Figure 3.16: Plot items

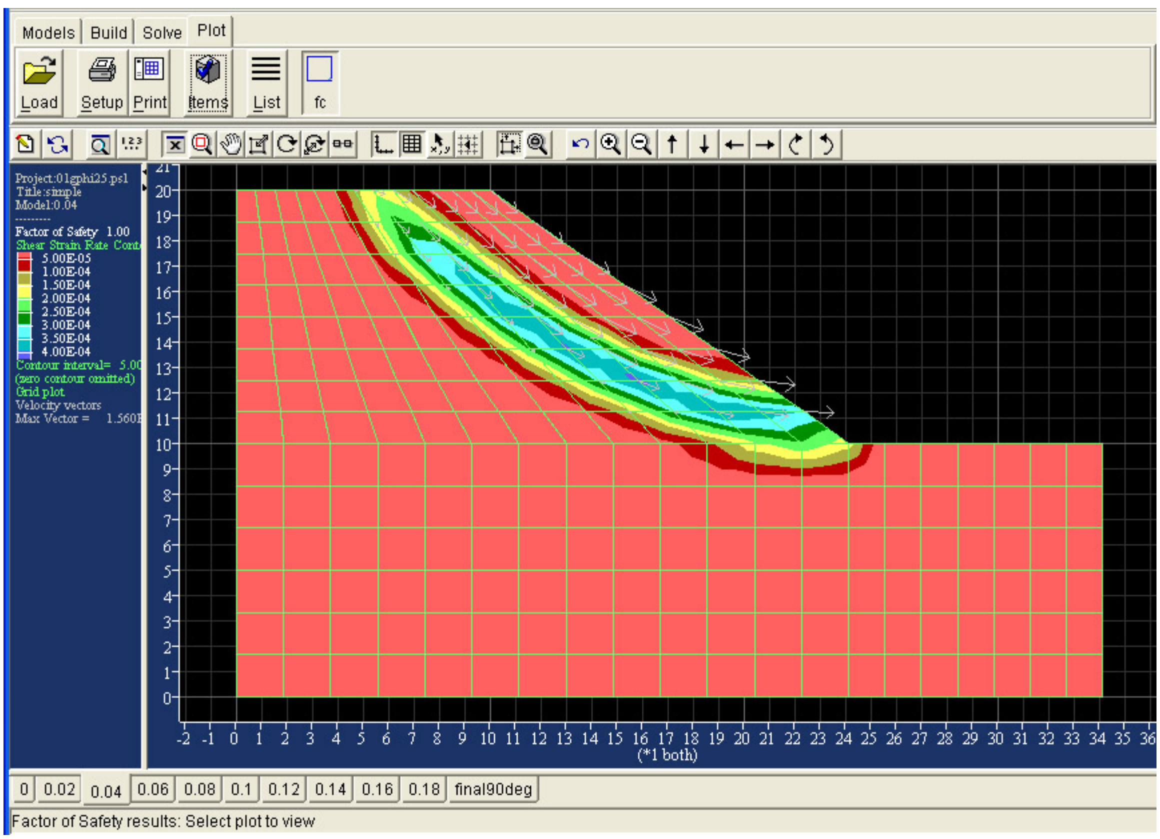


Figure 3.17: Result with mesh line

3.4.6 Hardcopy Plots

Hardcopy printout of the failure plot also can be created. The hardcopy output have several types included: Windows printer, Windows clipboard, Windows enhanced metafile, window bitmap, PCX, JPEG, Postscript and AutoCAD data exchange format (DXF).

To create a hardcopy plot, click the “Setup” button in the “Plot” stages toolbar. A “Print setup” window (Figure 3.18) will appear and from here type of hardcopy plot is decide and file name is created. Then, click the “Print” button in the Plot toolbar to create a hardcopy format file to be paste on Word document of printed out.

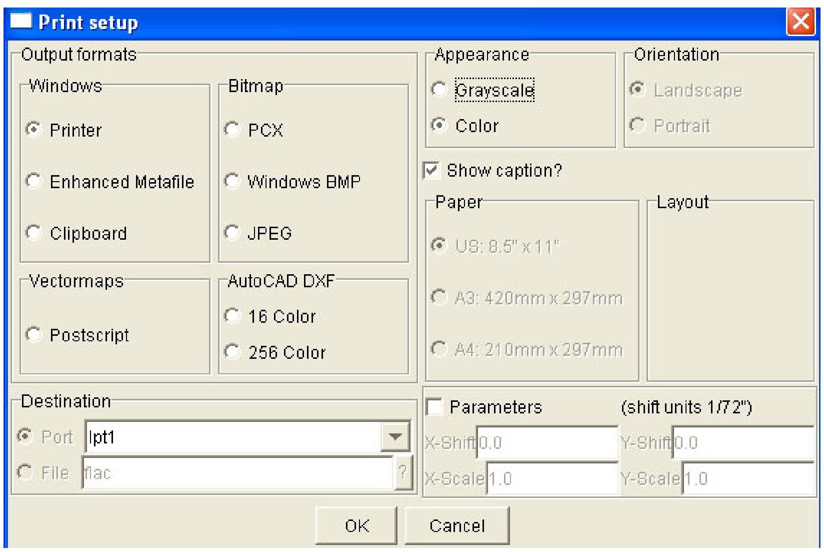


Figure 3.18: Print setup window

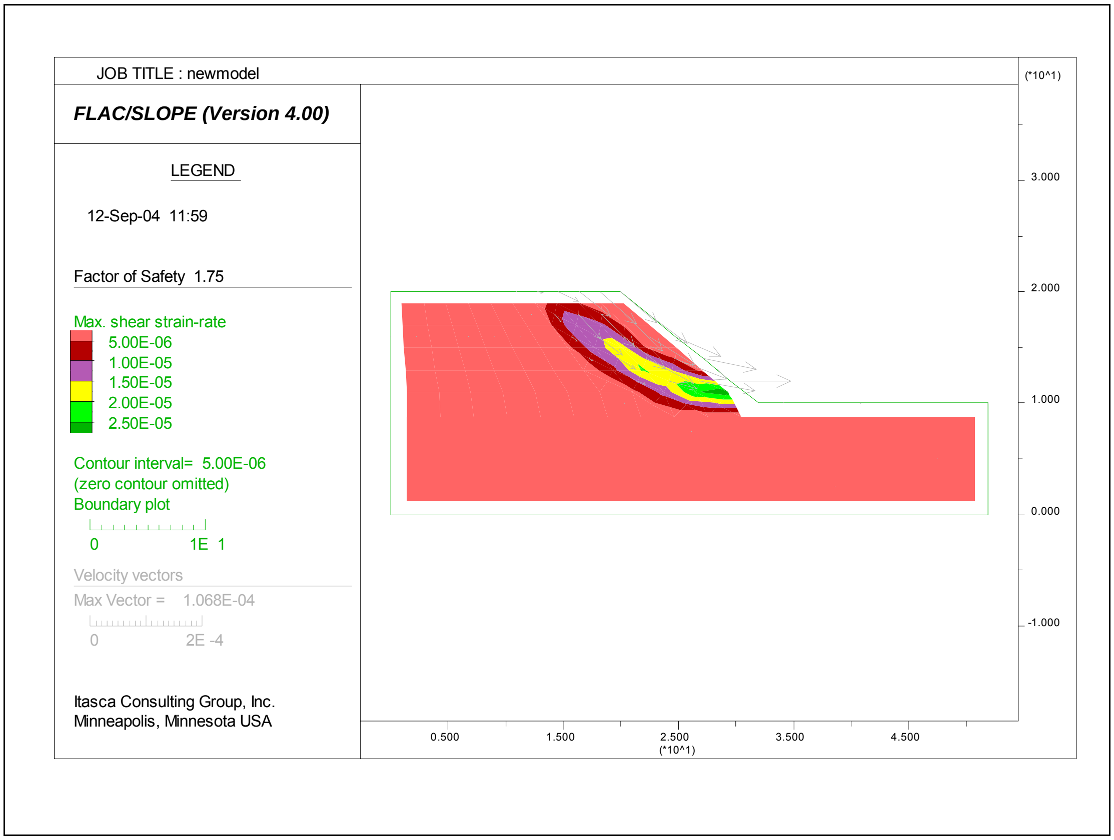


Figure 3.19: Hard copy plot

Note that the hardcopy plots are formatted slightly differently from the screen plot

3.5 Validity of the FLAC/Slope software

3.5.1 Introduction

It is necessary to validate the computer software by checking the output result of the computer software. Hence, it is important to validate the FLAC/Slope software before we can really apply to solving problem. To validate the FASC/Slope, an example from known sources with an answer is used to analyse with the FLAC/Slope. The importance of the process to validate the FLAC/slope software is:

- To confirm and to know that the process of inputting data is correct

- To ensure and be able to correctly interpret the computer data and understand enough the procedure of using the software
- To satisfy that the FLAC/Slope will give the correct answer.

3.5.2 Selected problem

To validate the FLAC/Slope software an example solved of a slope problem that had is chosen. The example problem selected is the Example 11.3 from the book "GEOTECHNICAL ENGINEERING SOIL MECHANICS" by John N. Cernica, John Wiley & Sons, Inc. 1995.

Refer to Appendix B for the example of problem from the book.

3.5.3 Given data

Below are the lists of the given data from the example:

Slope geometry:
Height of the slope is 10 m
The grade of the slope is the proportion of 1 vertically: 1.75 horizontally

Soil properties:
Unit weight, γ is 19.61 kN/m^3
Cohesion, c is 28 kN/m^2
Angle of internal friction, φ is 18°

Calculated Factor of safety is 2.

3.5.4 Analysis procedure

3.5.4.1 Defining project

Before starting to build a model the project name is define and working directory is create as shown on Section 3.4.1 and 3.4.2 and for this the title for this project had named as “Validity” and the file name as “validity.psl” for this model.

3.5.4.2 Slope parameter

Then the model of slope is created by entering the slope geometry data and the boundary of the slope. Figure 3.20 show the data input had been done in the “Edit slope parameter” window. The entering data for Rise is 10 m, Run is 17.5 m, Depth is 6 m, Left is 8 m and Right is 15 m.

3.5.4.3 Build for slope material

Next is the Build stage, the soil properties data is input to “Define material” window as shown in Figure 3.21. Where the entering data for Mass-density is 1998.98 kg/m^3, Cohesion is 28000 Pa and Friction angle is 18°. After the material properties is defined. The soil is assigned into the model correctly, by click once to the defined material from the list and click once in any area of the slope.

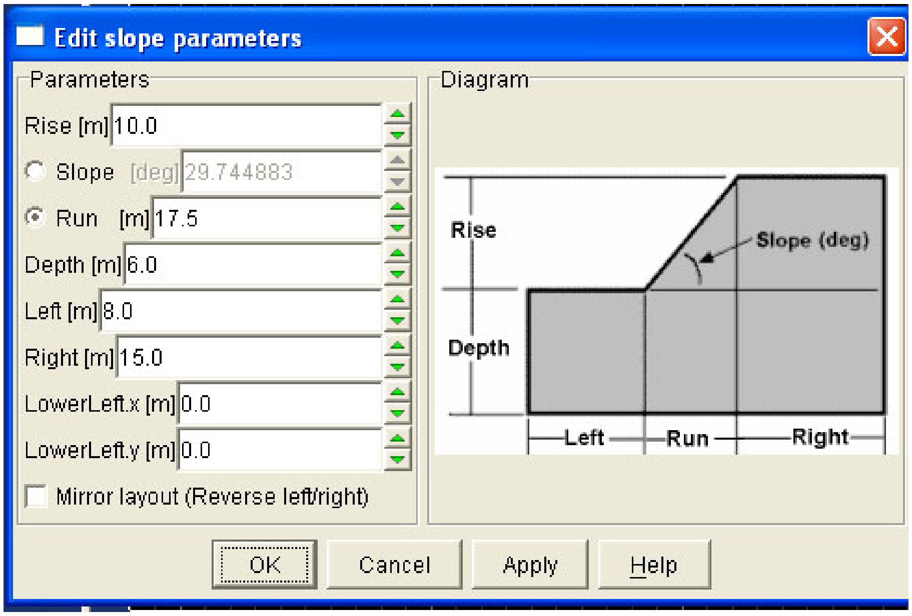


Figure 3.20: Slope parameter for validity model

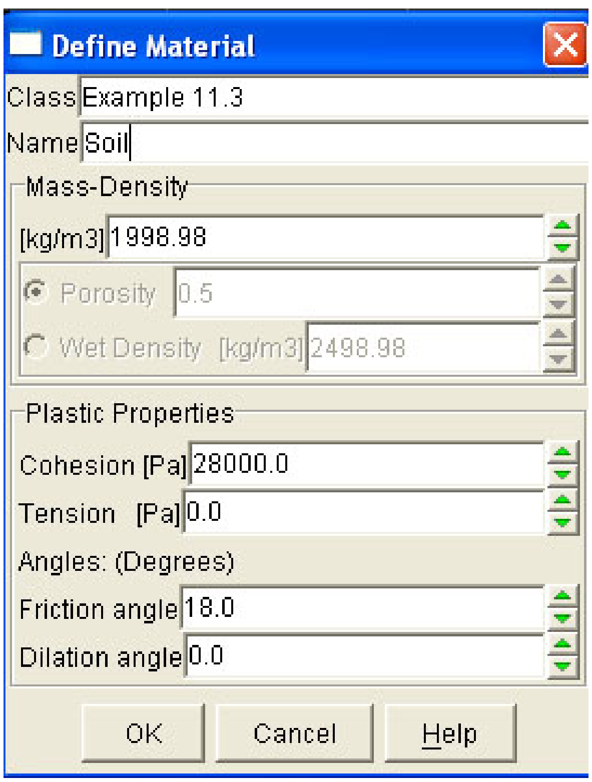


Figure 3.21: Material Definition for validity model

3.5.5 Result

3.5.5.1 Boundary condition

The boundary condition of the slope model is important, as this will give an inaccurate result if the setting for the boundary is not assign correctly. Example, for this slope example, the boundary conditions of the slope is change and set as follow:

- Rise is 10m
- Slope is 30°
- Depth is 4m
- Left is 5m
- Right is 5m

When the model is analysed it show unsatisfactory result as shown at Figure 3.22. From the failure mechanism of the result we can see that the line of the contour is extended to the boundary of the slope and this is not so prefer in analysis. This show that the boundaries geometry needs to be extends from the failure mechanism. The FOS shown here is 1.89.

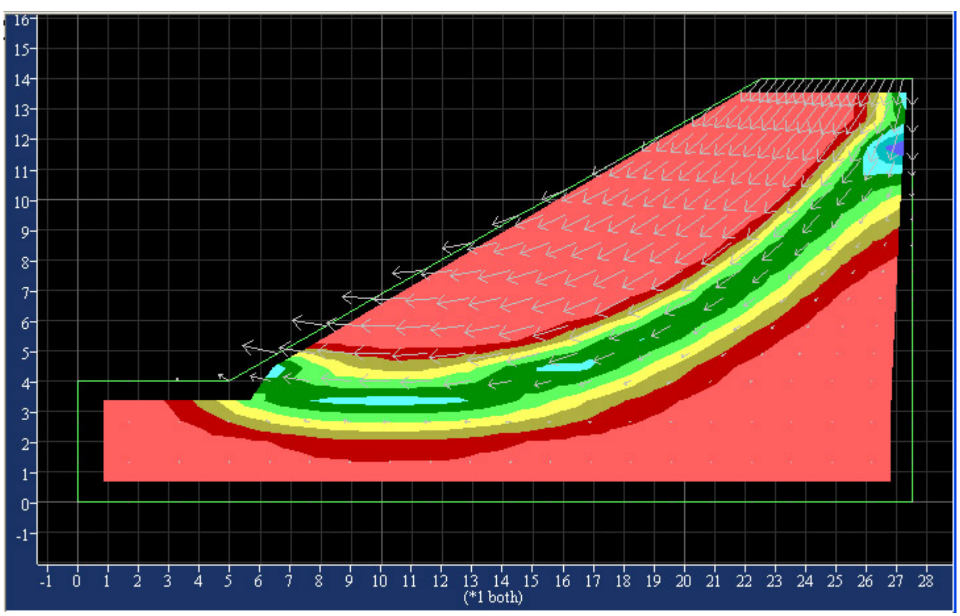


Figure 3.22: Bad boundary Geometry

3.5.5.2 Final result

By using the coarse mesh and solved the slope problem the FOS obtain from the FLAC/Slope is 1.95 and the mechanism of failure is shown at Figure 3.23. Where the FOS obtains from the chosen example with the result is 2. Again by referring with result at Section 3.5.5.1 the FOS is 1.89, this prove that a bad design boundary geometry condition will not give an accurate result. From these result the FLAC/Slope software will give a valid result if the boundary geometry condition is set correctly. Hence, it needs a good judgement and experience to determine good boundaries geometry for a slope model.

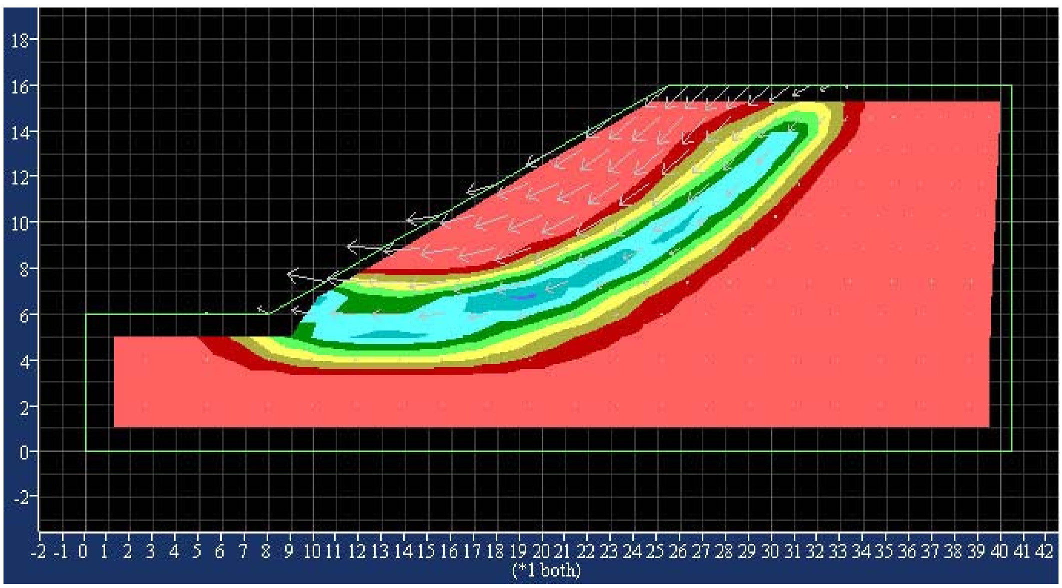


Figure 3.23: Failure mechanism of a validity model

Chapter 4:
DEVELOPMENT OF SIESMIC DESIGN CHART

4.1 Data Input Determination of the Design Chart for Slope Stability

4.1.1 Introduction

The main objective of this project is to develop the earthquake design chart for a variety of slope stability problems. FLAC/Slope software had been used to assist to obtain the data for design chart. In order to using FLAC/slope software, the input database of the slope to produce an appropriate output.

> "It becomes useless when coefficient for g exceeds approximate 0.5" (Shiau, Jim 2004, pers. comm., 15 Jun).

Hence, coefficient consider will be 0.1, 0.2, 0.3 and 0.4 for the design chart.

4.1.2 Type of input data

The input data to be considered before analysis of the FLAC/Slope software include:

- Model of slope to be use for analyse of each data, such as the boundary, height and angle of the slope

- Properties of the soil include the cohesion, unit weight, and angle of the internal friction that will be equal to the stability number
- Determined the input of the seismic acceleration of 0.1g, 0.2g, 0.3g, and 0.4g

In order to get data suitable input data, few step have been consider including
- Defining the properties of the soil
- Determined the right model for the analyse
- Determine Seismic force to be input to FLAC/Slope

4.1.3 Defining the properties of soil

Stability Number is used to decide the properties of soil material to be used as the input data for the FLAC/Slope software for the analysis. Which the stability number equation is already defined as:

$$N_s = \frac{c}{\gamma H \mathrm{F_s}} \tag{4.1}$$

Where, N_s = Slope stability number
c = Soil cohesion (kN/m²)
γ = Soil unit weight (kN/m³)
H = Slope Height (m)
Fs = Factor of Safety

The appropriate material parameters for the c and γ to be find. For the ease of the analysis the height of slope, H is decided as 10 m and the Factor of safety is decided as 1.
By trial and error of the c and γ parameters to get the Stability number that required.

Example:
The stability of number required is 0.02, from the equation 4.1, by trial and error of the parameter of soil c, γ and H:

$$N_s = \frac{10kN/m^2}{50kN/m^3 \times 10m \times 1} = 0.002$$

Hence, parameter decided for c and γ respectively is 10 kN/m² and 50 kN/m³ and the H is 10m.

The result of the rest material parameter that been decide shown at the Appendix C.

4.1.4 Seismic force

From the Pseudo-static analysis as discuss earlier the seismic force is consider as the horizontal force and it is determine by seismic coefficient. In able to input the seismic coefficient data to the FLAC/Slope program the input is determined by calculate the relative vector force between the gravity acceleration, g (9.81 m/s^2) and horizontal acceleration either as 0.1g, 0.2 g, 0.3g or 0.4g. The input data to FLAC/Slope is calculated for the relative vector also the angle of the relative vector from the normal gravity force.

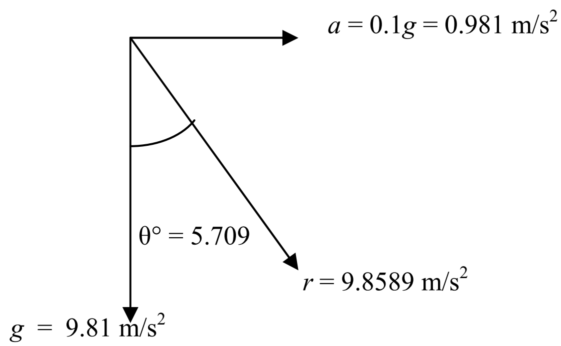


Figure 4.1: Relative vector direction

Example, when the seismic acceleration of a equal to 0.1g required, refer to Figure 4.1, where:

g is the vector of gravity acceleration [9.81 m/s^2]
a is the vector of horizontal acceleration [m/s^2]
r is the resultant of the vector g and a [m/s^2]
θ° is the angle measure from the vector g to a

The calculation can be done as below:

We have the coefficient, k_h of 0.1

For a is 0.1g,

$$a = 0.1 \times 9.81 \mathrm{m/s^2} = 0.981 \mathrm{m/s^2}$$

For *r*,

$$r = \sqrt[2]{a^2 + g^2}$$

$$r = \sqrt[2]{0.981^2 + 9.81^2}$$

$$r = 9.8589 \mathrm{m/s^2}$$

To find θ,

$$\cos\theta = \frac{9.81}{9.8589}$$

$$\theta = 5.709°$$

The relative vector, *r* of the acceleration is 19.8589 $\mathrm{m/s^2}$ and the angle from the direction of *r* from the *g* is 5.7090°.

Further data for seismic coefficients 0.1, 0.2, 0.3 and 0.4 of the input to FLAC/Slope is shown at the Appendix C.

4.2 Determine the model

4.2.1 Introduction

Determination of the valid model is an important task to analyse the require result. It is a required to determined consistent model to be used to determined each different seismic coefficient, *k*. To determine the model the Taylor's stability chart for the *c* plus φ soil is used as reference to check the validity of the models for the slope by comparing the result obtain from FLAC/Slope. By using the require data such from a particular stability number as has been determine previously

4.2.2 Validity of the model

It is important to validate the require models from the FLAC/Slope software by checking the from the Taylor's stability chart for *c* plus φ soil.

The important and objective to validate the require model is:

- To ensure that the model used is correctly
- To ensure that the process analyse data for the design chart is understand enough and able to correctly interpret the computer data.
- To justify the model used is correct and may able to use to analyse for the other chart as well

4.2.3 Slope modelling

4.2.3.1 Defining the project

We begin the project by checking the "Non-standard gravity?" boxes, then click "Ok" to include this option in the project analysis. Then the next step is to create the directory, as has been mention at the Section 3.4.2. The title of this project was given as Validity Model and the file name is name as "validity.psl" for this model problem. The file also for this project has been saved into a desirable folder in the computer.

4.2.3.2 *Slope parameter*

For the model stages, a simple model is selected, the decide slope parameter to be input to the “Edit slope parameter” windows.

The initially parameter decided, for the rise is decide as 10 m, a trial of parameter input have been decide depth is 10 m, left is 10 m and right is 10 m and the mirror layout is choose for this slope. As this analysis will analyse for the correct slope angle, hence an initial try value is enter. The slope angle of the slope will be different from each analysis of the slope according to the stability number parameter.

By right-clicking on the tab bar of the model name and click “clone” to get a same model to analyse for other result (Figure 4.2). This will be useful for the analysis as it will consist of numbers of slope properties that related to the stability number value to be analysis.

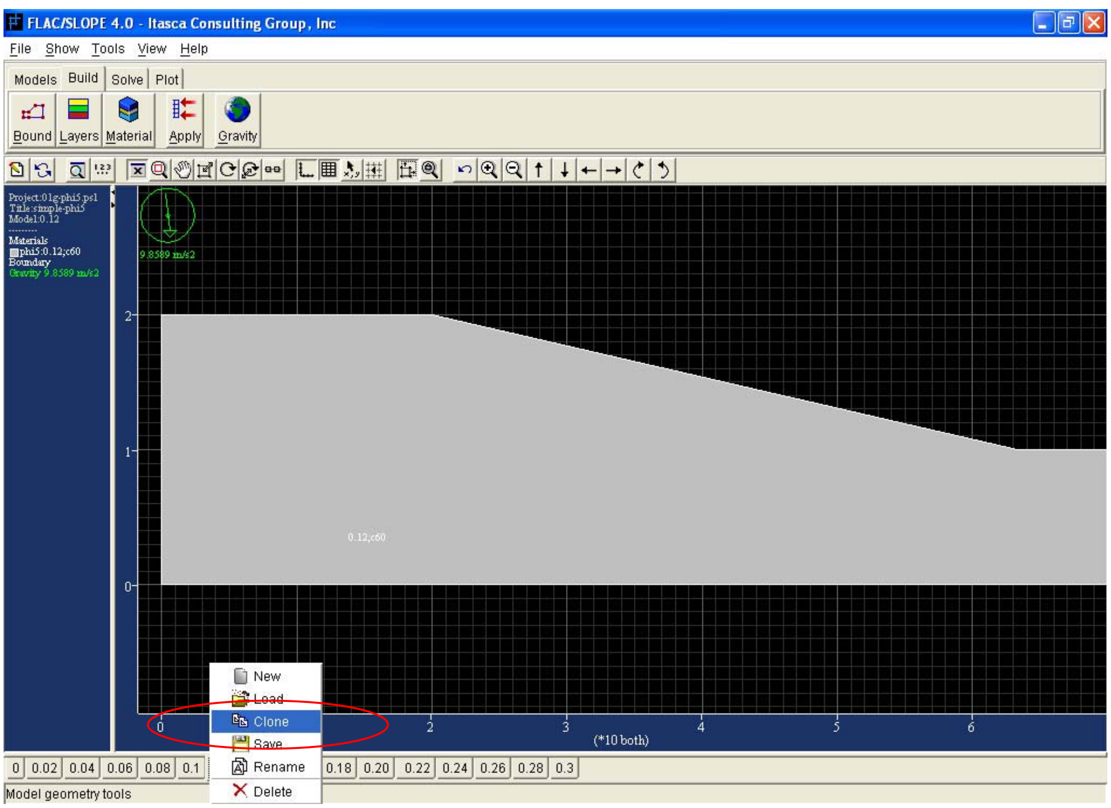


Figure 4.2: “Clone” button

4.2.4 Slope building

This is the Build stages where the material properties and seismic force will be done here.

4.2.4.1 Material properties

The soil properties had been decided previously at the Section 4.1.3. As there is number of soil properties has been found according to the stability number decide, numbers of soil properties decide is enter into the "Material" tool at the Build stage tab and list of different soil properties is create.

Five different lists of soil properties is create, as there is five different angle of internal friction angle of the soil is decided for the design chart. The internal friction angle, φ is 5°, 10° , 15°, 20° and 25°.

Typical soil properties to be enter according it's stability number of 0.02 which has the mass density, ρ is 5096.8 kg/m^3 (unit weight, γ is 50 kN/m^3); cohesion, c is 10 kN/m^2 and internal friction angle, φ is 5°. This is shown at Figure 4.3 of the "Define Material". More of the material properties need to be use shown at Appendix C.

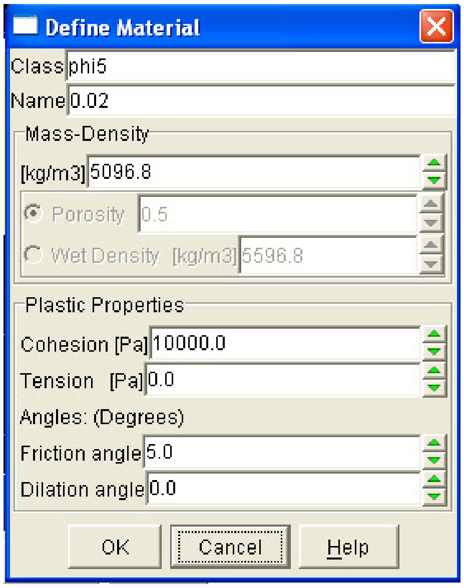


Figure 4.3: Define material

A list of soil properties according is stability number is created and it is list out according to the φ value. The list will be shown at the right hand side of the "Material" tool. Figure 4.4 show a list has been created.

This list of material is saved for later use. The list of material is saved by these steps:

1) Click on the "Database" button (Figure 4.4)
2) At the selection press "Ctrl + A" to select all of the material list (Figure 4.5)
3) Click on the "Copy->Database" button then click "Save" button
4) A file save as "phi5.gmt" for this example (Figure 4.6)

After the list of material is created, the correct material is assign to the slope model.

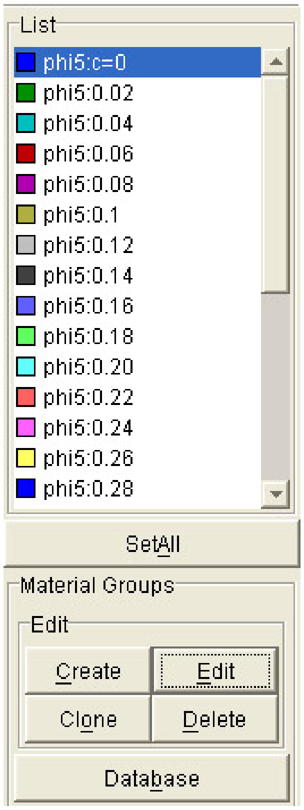


Figure 4.4: List of material

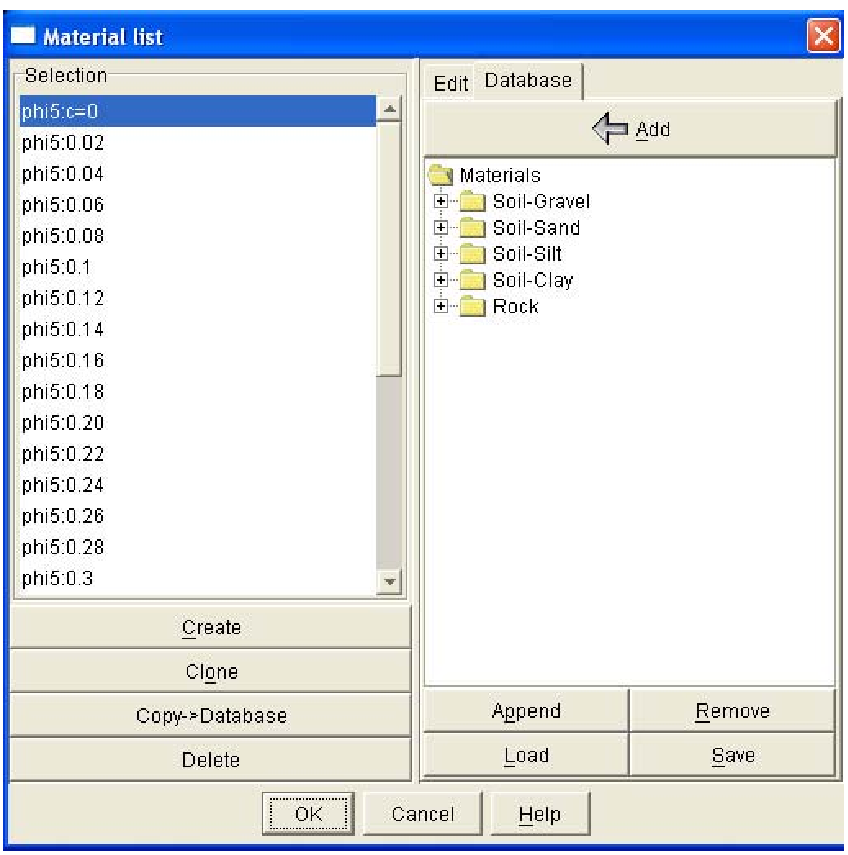


Figure 4.5: “Material list” window

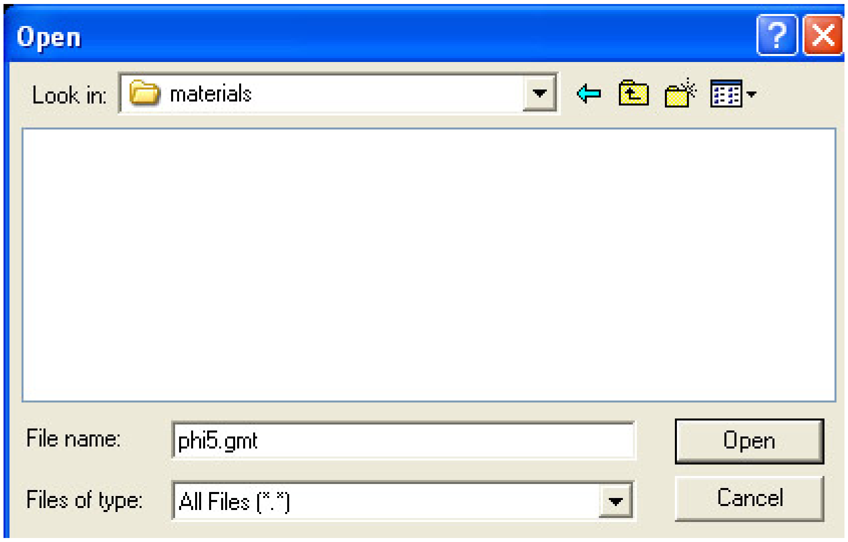


Figure 4.6: Save file window

4.2.5 Solving for the model problems

All the problems for the model, the Solve Stage toolbar is select. As this is the student version of FLAC/Slope hence only the course mesh can be selected. When the mesh is select the software will generate the mesh for the model. After the mesh is generate the FOS is solve by click on the "Solve FoS" button.

4.2.5.1 Analyse for the slope angle

For these problems required slope angle that will give the value of FOS of 1 will be find. This is because from the previously Section 4.1.3, we are using the Stability number equation to find the soil properties and with FOS is 1 for the equation.

This can be trial and error for several times as the needed to change the slope angle value and analyse again to the FOS of 1. Also, slope angle value obtain had been compare with the slope angle obtain from the Taylor's chart according to the Stability number and internal friction angle of the soil. This is to get a valid model to analyse with the slope which will apply for seismic force.

If the required slope angle for the model does match the slope angle from Taylor's chart, then the boundary condition will be change from the "Bound" tool at the Build tab bar and click "Edit button to edit the slope parameter. The change boundaries at left and right until the require model that will give require slope angle as the Taylor's chart and also the FOS is 1. (Figure 4.7)

The sequence of the analysis for the slope angle is started from the stability number of 0, 0.1, 0.2, and 0.4 and so on. With also according to the internal friction angle of arrangement 5°, 10°, 15°, 20° and 25°.

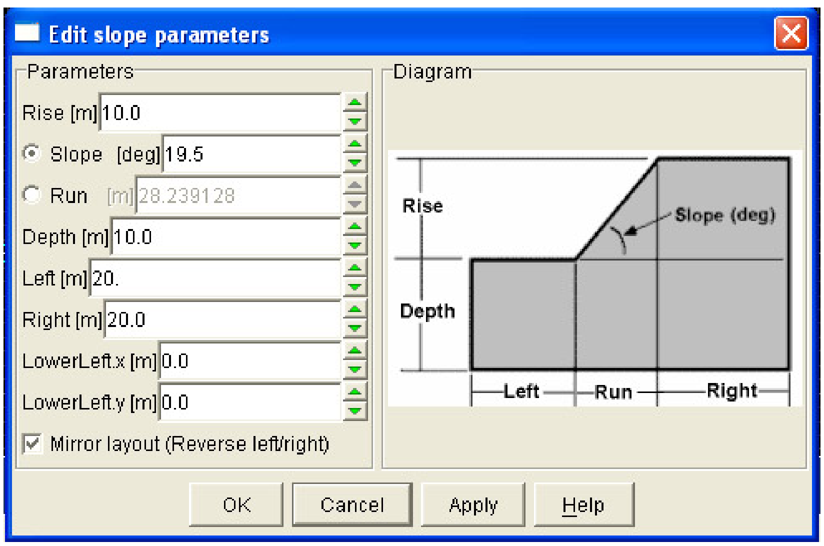


Figure 4.7: Edit slope parameter

At the Appendix C will show the comparison of the FLAC/Slope analyse result for the slope angle compare to the slope angle of Taylor's chart.

4.2.5.2 Result

After the analysis to all the decide soil material for the each value of internal friction angle arrangement to the soil properties according to the stability number and been compare with the value of the Taylor's chart. A table of the decided boundary for the model for the later analysis has been shown at Appendix D and also Figure D.1 show the chart produce by the FLAC/Slope analysis is almost similarly to the Taylor's Chart.

The result obtain for the angle, $i°$ up to approximate of 80º only as the FLAC/Slope unable to performed well to get $i°$ as same as obtain from the Taylor's chart. Although, there are numbers of boundary condition had been try for it.

4.3 Analysis Data for Design Chart

4.3.1 Introduction

By using the slope stability number (N) and the pseudo-static approach with the assistance of FLAC/Slope software, the design chart for the seismic coefficient, k_h is 0.1, 0.2, 0.3 and 0.4 have been developed. A design chart may able to help to reduce the work load in the preliminary to design a suitable slope that is safe. Different seismic coefficient for k_h is 0.1, 0.2, 0.3 and 0.4 charts can be choose to design of slope by the consideration of the slope angle (i°), angle of internal friction ($\varphi°$) and stability number (N).

4.3.2 Slope modelling

The slope modelling is perform as same as the step to find a valid model for the slope as Section 4.2.3. The project is begin by checking the "Non-standard gravity?" boxes, then click "Ok" to include this option in the project analysis. Next is the step for create the directory has been mention at the Section 3.4.2.

4.3.3 Slope Building

As same as previously at section 4.2.4, this is the Build stages where the material properties data will be done here. Also in additional the input the gravity data for the seismic force for the slope model will be build here.

4.3.3.1 Material properties

The list material data that have been done at previously at the sub section 4.2.4.1 can be obtained for the slope model for this seismic model analysis.

The list of materials can be obtained through this step at the “Material” tool at the “Build” stage tab bar (Figure 4.8):

1) Click on the “Database” button
2) From the “Database” tab at “Material list” window click at on the “Load” button.
3) Find the folder that previously saved file. The Material list file name has the ending of “.gmt”. Then click “Open” and at the “Database” tab will show the folder of the list that been select.
4) Click on the folder that obtained, and then click on the “Add” button we will have all the list of material at the “Selection” column. (Figure 4.9)

With this list of material, the required materials data can be assigned to the models that we need to analyse.

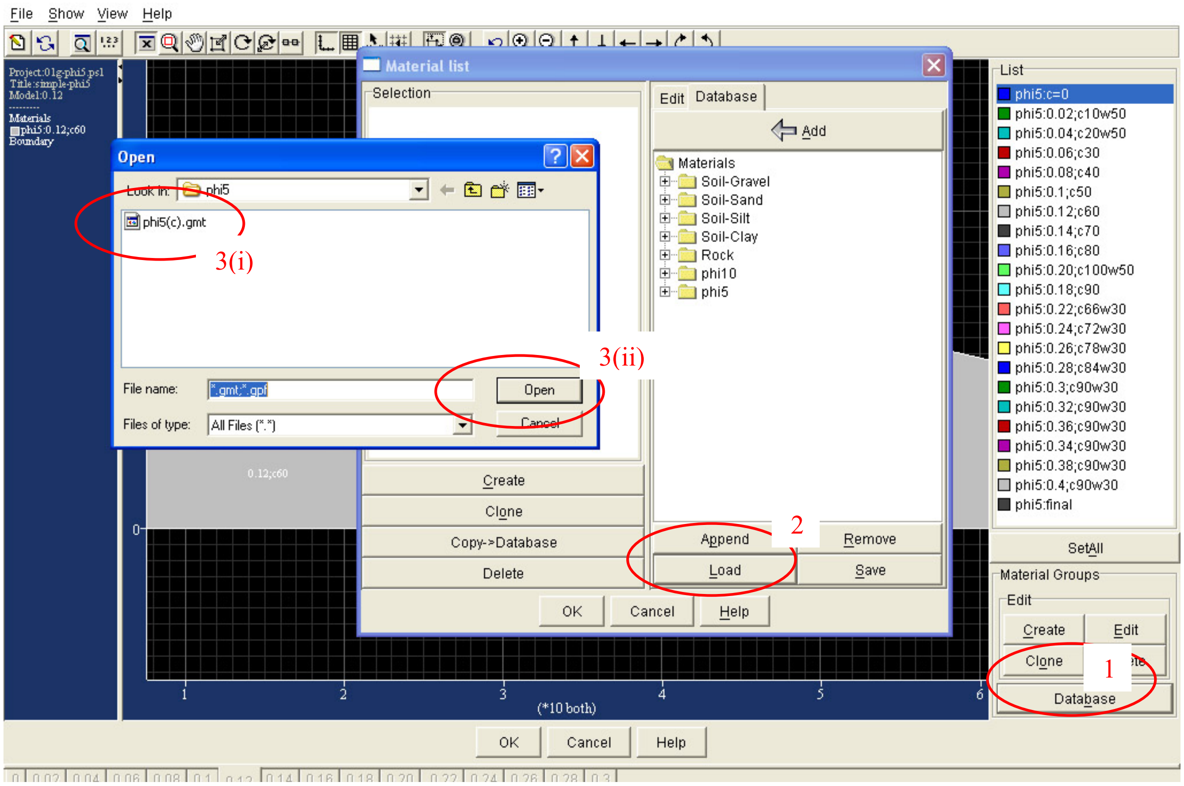


Figure 4.8: Load material list

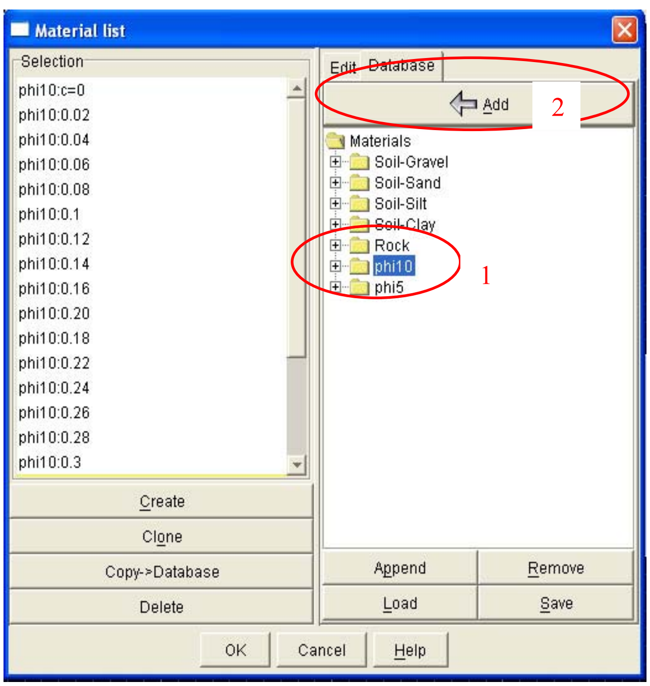


Figure 4.9: Add list

4.3.3.2 Seismic force

The gravity setting is done by select the "Gravity" tool at the "Build" tab. From the section 4.9 we have found the gravity setting input for the seismic force, the list input for gravity setting is found at Appendix C.

Example, for the seismic force to be applied to the model by pseudo-static approach is 0.1g. Hence we, the input at the "Gravity Settings" window, for magnitude are 9.8589 m/s^2 and angle is 5.709°. Figure 4.10 show the gravity setting.

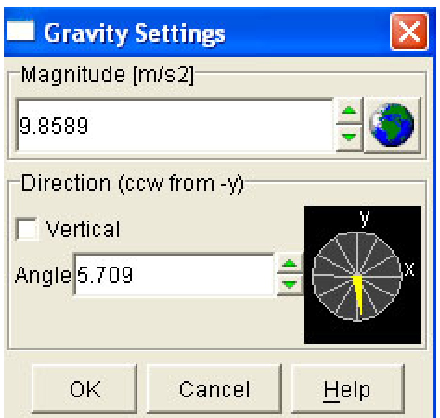


Figure 4.10: Gravity setting for weak layer model

4.3.4 Result

From the data that had been determined by using FLAC/Slope software, Microsoft Excel spread sheet is used to assist to tabulate a table of result and to form a graph for the design chart. Appendix F shows the data of the results obtain to be use for plotting graph for design charts. The proceeding section, Section 4.4 will shows and discuss for the Seismic Design Chart.

Although the design chart can be created with FLAC/Slope software assist, there still some limitation for the usage of the chart. It can be seen that there are limitation of the chart as the FLAC/Slope (Student version) had the limitation to analyse further for certain model or soil properties. All the model has been analyse by using the course mesh.

4.4 Seismic Design Chart

4.4.3 Design Chart for k = 0.1

Figure 4.11 show the final developed Design Chart for the k_h value of 0.1

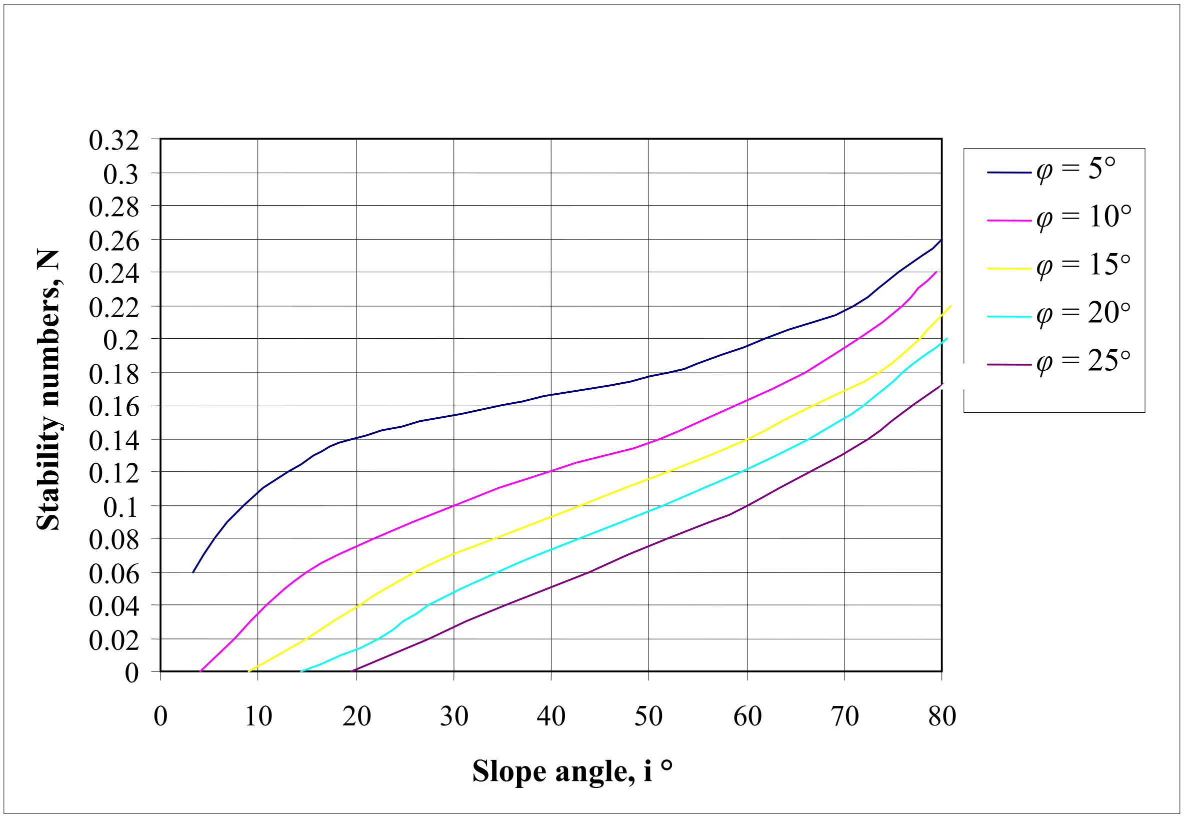


Figure 4.11: Design Chart for k = 0.1

After some analysis and consideration from the result obtain the design range of design chart slope angle, i where is considered from the graph line for the angle of internal friction, φ.

4.4.3.1 Limitation of the k=0.1 chart

The range for the angle of internal friction, i for a material is decided from 5° to 25°. Maximum slope angle, *i* up to 80° decide for all material. For the line of the *i* equal to 5° only has the minimum stability number of 0.06 where for *i* equal to 10°,15°, 20° and 25° has the minimum stability number of 0.

4.4.4 Design Chart for k = 0.2

Figure 4.12 show the final developed Design Chart for the k_h value of 0.2

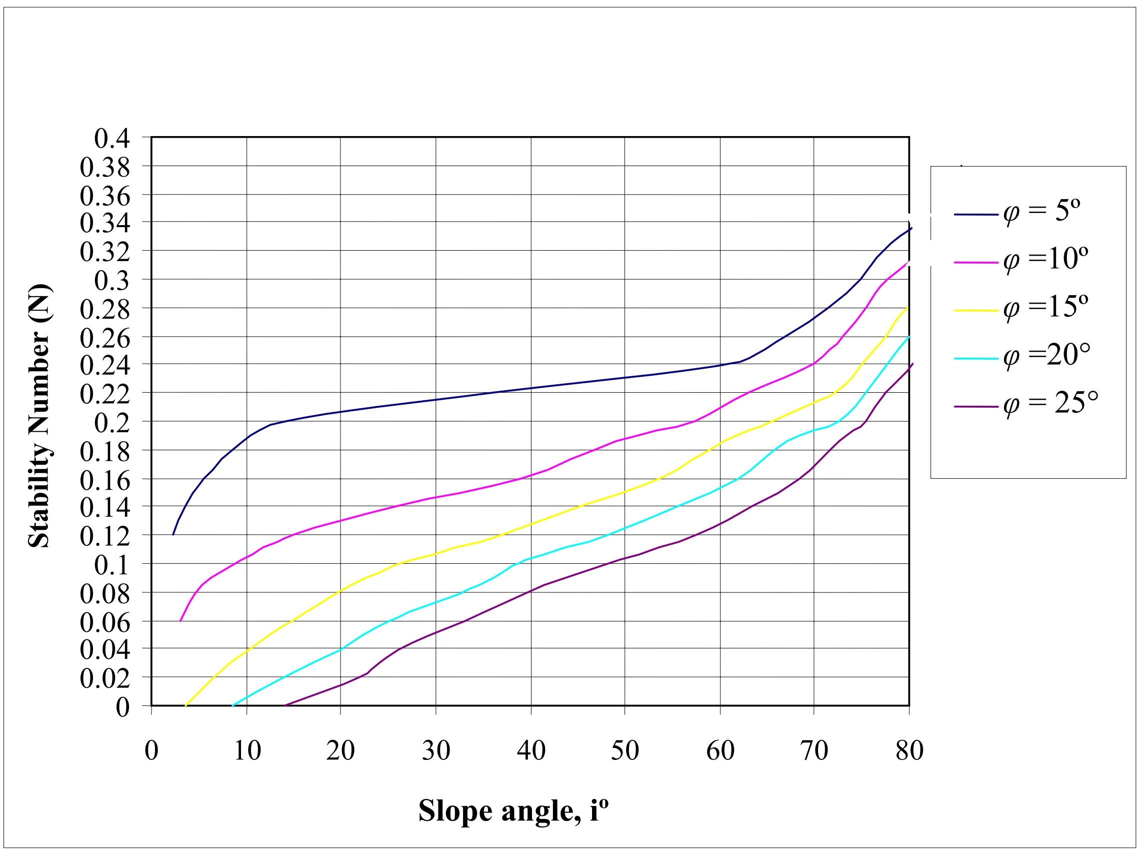


Figure 4.12: Design Chart for k = 0.2

4.4.4.1 Limitation of the k=0.2 chart

The range for the angle of internal friction, i for a material is decided from 5° to 25°. Maximum slope angle, *i* up to 80° decide for all material. For the line of the φ equal to 5° has the minimum stability number of 0.12, φ equal to 10° has the minimum stability number of 0.06 where for i equal to15°, 20° and 25° has the minimum stability number of 0.

4.4.5 Design chart for k = 0.3

Figure 4.13 show the final developed Design Chart for the k_h value of 0.3

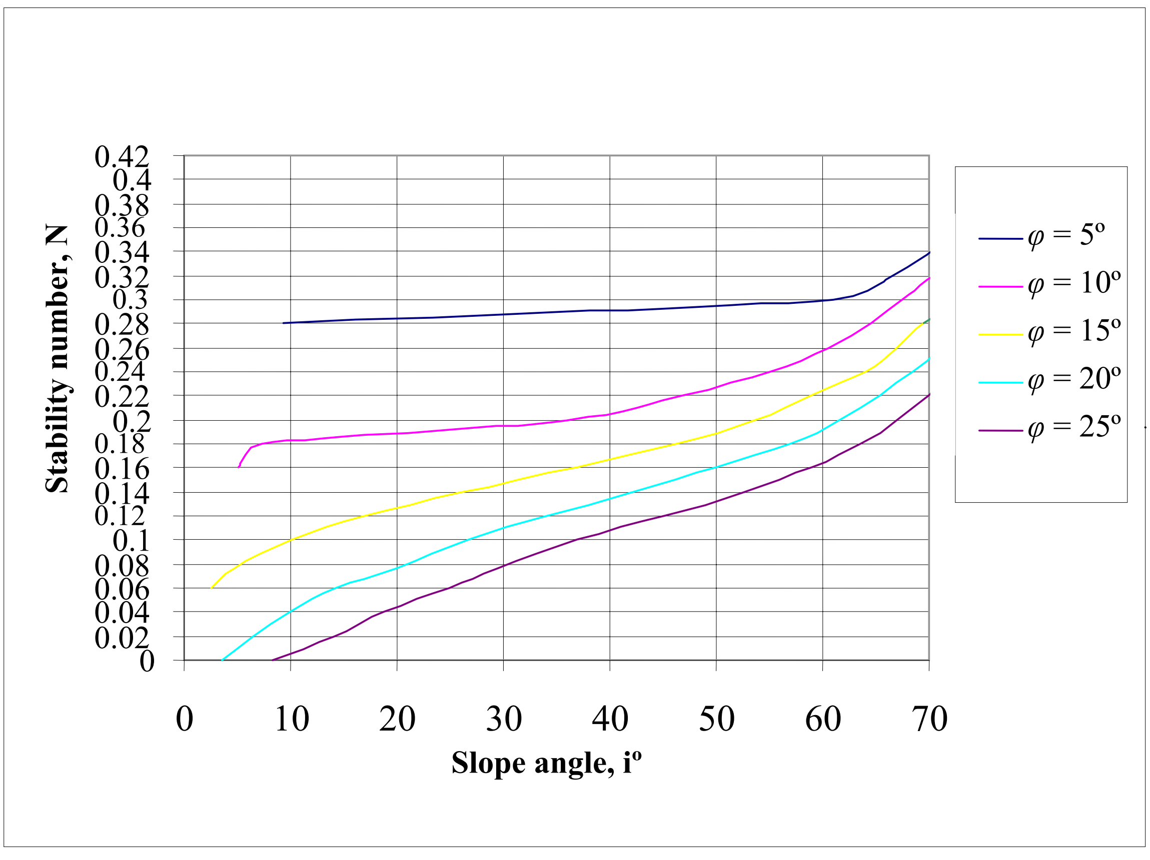


Figure 4.13: Design Chart for k = 0.3

4.4.5.1 Limitation of the k=0.3 chart

The range for the angle of internal friction, i for a material is decided from 5° to 25°. Maximum slope angle, *i* up to 70° decide for all material. For the line of the φ equal to 5° has the minimum stability number of 0.28, φ equal to 10° has the minimum stability number of 0.16, φ equal to 15° has the minimum stability number of 0.06 where for i equal to 20° and 25° has the minimum stability number of 0.

4.4.6 Design Chart for k = 0.4

Figure 4.14 show the final developed Design Chart for the k_h value of 0.4

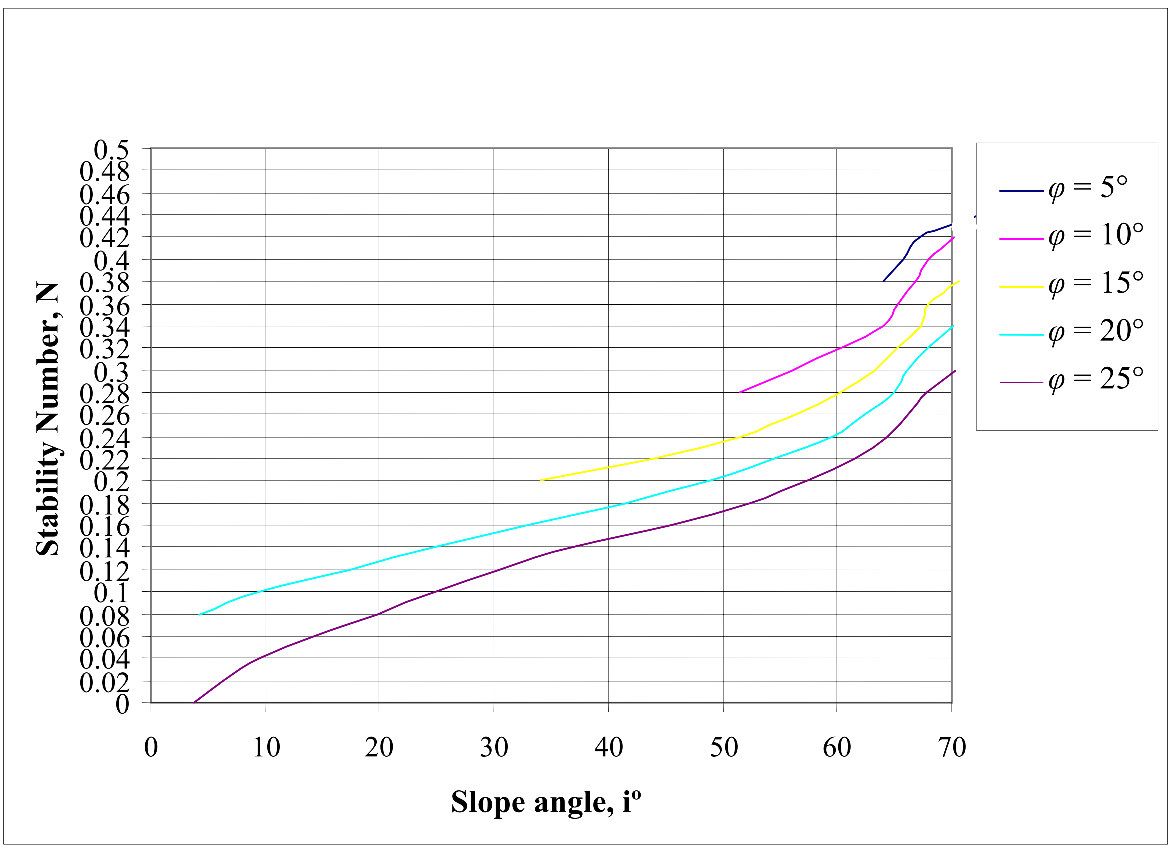


Figure 4.14: Design Chart for k = 0.4

4.4.6.1 Limitation of the k=0.4 chart

The range for the angle of internal friction, i for a material is decided from 5° to 25°. Maximum slope angle, *i* up to 70° decide for all material. For the line of the φ equal to 5° has the minimum stability number of 0.38, φ equal to 10° has the minimum stability number of 0.28, φ equal to 15° has the minimum stability number of 0.2, φ equal to 20° has the minimum stability number of 0.08 and 25° has the minimum stability number of 0.

4.5 Summary of the step taken to develop seismic design chart using FLAC/Slope

Below, are the summary of the steps had been used to develop the seismic design chart:

1) From the stability number equation, (equation 6.1) the required properties of the soil that is determined here according the stability number required.
2) The Pseudo-static analysis will be use for applying seismic force. Hence, the relative vector of *g*(gravity) and *a*(horizontal earthquake acceleration force) is to be determined and also angle of the vector *a* from *g*. The k_h coefficient will be used is 0.1, 0.2, 0.3 and 0.4. This data will be use to input to the FLAC/Slope.
3) Determined the validity of the model to be used for analyse the slope under seismic condition. The properties of soil found previously will be entering to the FLAC/Slope to find the slope angle for particular stability number. Taylor's chart is used to guide and obtain a model required.
4) From the model obtain previously, is used to analyse data for the required stability number that related to the slope angle under the certain seismic condition which the k_h applied is 0.1, 0.2, 0.3 and 0.4.
5) From the data found, the data is used to plot a graph by using Microsoft Excel spreadsheet software. This where the seismic design chart for k_h is 0.1, 0.2, 0.3 and 0.4. already developed.

4.6 Discussion of the Stability Number

Stability number which has the group factor which consist of soil's cohesion (c), Soil unit weight (γ), slope height and factor of safety that will influence the stability of the soil. Where it is show a relationship of the stability number and the factor of safety. By consider stability number shown below:

By using the soil properties of:

Cohesion, c is 10kN/m^2
Soil unit weight, γ is 50kN/m^3
Height of slope, H is 10 meter
two different factor of safety of 1 and 1.5

Apply to the stability number equation:

For Factor safety equal to 1.5,

$$N = \frac{10kN/m^2}{50kN \times 10m \times 1.5} = 0.0133$$

For factor of safety equal to 1,

$$N = \frac{10kN/m^2}{50kN \times 10m \times 1} = 0.02$$

From the consideration of the above, a smaller stability number is to be safer as it has more Factor of Safety.

By comparison and consideration of the chart, a slope that induced by an earthquake force tend to reduce the value of factor of safety than its normal state. By consider any of the line of angle of internal friction, generally, when the slope getting steeper (slope with higher angle) the stability number for the respective angle for the angle of internal friction will increase. Hence, it can be said that when the slope getting steeper, stability number is increase and the factor of safety reduce. From the Design charts, it can be see that when the value of seismic coefficient (k_h) is increase, the chart tend to has higher range stability number.

4.7 How to use the chart?

In this section will discuss about the step for using the chart. Generally the steps to use this chart it is as same as using the Taylor's chart that had been shown at section 2.6.2 and also from example from most of the available books.

By taking an example, we are going to check the FOS for design a slope that having the seismic coefficient, k_h is 0.2, the slope angle, *i* is 60°, and the slope height is 10m. Also, we have the soil properties which the angle of internal friction, φ is 20°, cohesion, *c* is 50kN/m2 and unit weight, γ is 20 kN/m3.

Since, we are to be design the slope for the k_h is 0.2, hence the chart of k_h is 0.2 will be used for checking the factor of safety of the slope.

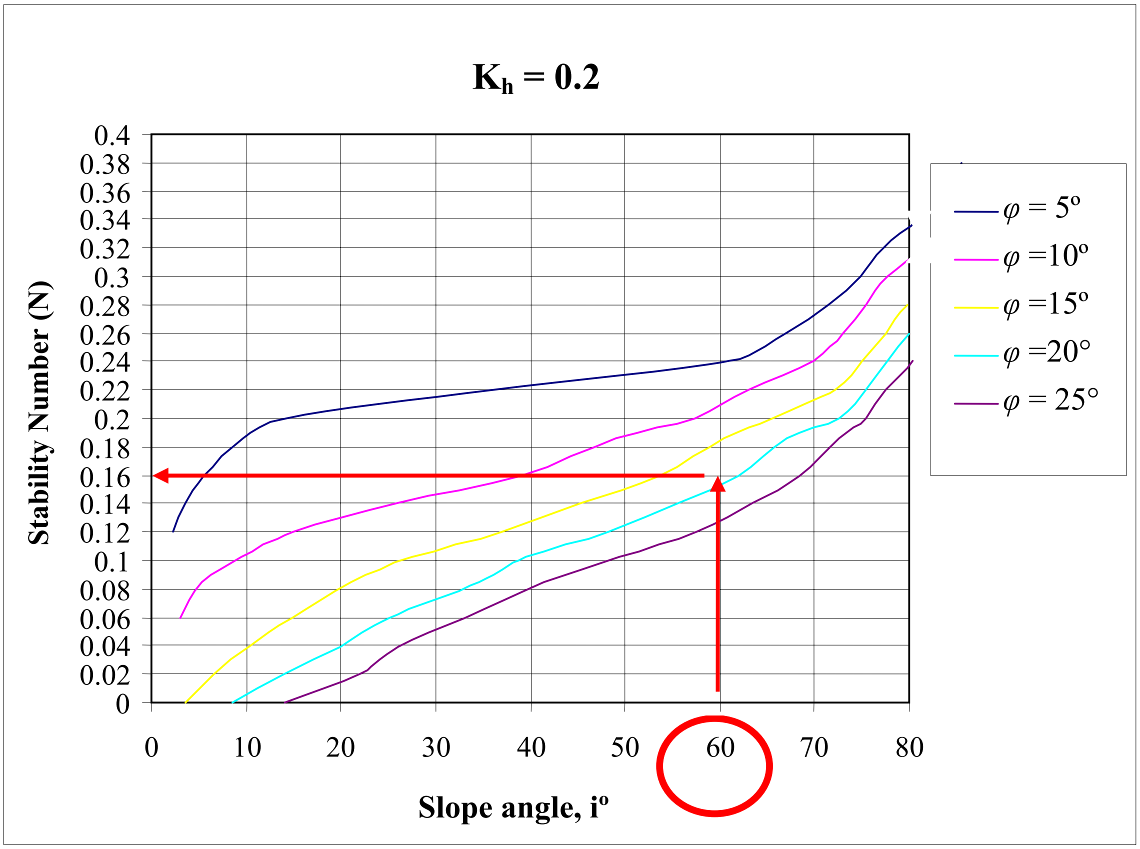


Figure 4.15: Using the design chart

The steps obtain the value of stability number as follow:

1) We have φ is 20° which will be the line represent the green colour line and we have the slope angle, *i* of 60° , From the point of at *i* is 60° we move vertically to the line of φ is 20°.
2) Then to the horizontally to the vertical axis we get the stability number is at approximately 0.16.

Next, from the soil properties we have *c* is 50kN/m^2 and γ is 20kN/m^3. Also the considered of slope height is 10m. By substitute these value together with the stability number we found previously to the stability number equation (equation 2.3). We get the FOS is 1.56 and this indicate that the slope is stable.

Chapter 5:
PARAMETRIC STUDIES

5.1 Introduction

To understand further about parameters of the materials properties of the slope for the seismic stability, a model of slope with seismic force is set out to analyse further about the material properties and seismic force toward the slope. The analysis include analysis parameters of the different horizontal seismic horizontal coefficient (k_h) and soil material properties which include the angle of internal friction (φ), cohesion (c) and unit weight (γ).

5.2 Slope model

5.2.1 Defining the project

As same as the section 3.4.1 and 3.4.1, with the parametric study project is begin by checking the "Non-standard gravity?" boxes, then click "Ok" to include this option in the project analysis. The title of this project is name as parametric studies and the file name is name as "parametric.psl" for this model problem.

5.2.2 Slope parameters

The "Simple" model is selected from the "New" tool at the "Models" stage tab bar. A simple model is selected, the decide slope parameter to be input to the "Edit slope parameter" windows.

A constant geometry model of slope was select for all the parameters studies. At the "Edit slope parameter" window (Figure 5.1), the decided slope parameter to be input is:

- Rise is 10m
- Slope is 40°
- Depth is 10m
- Left is 20m
- Right is 20m
- Mirror layout is select for this slope

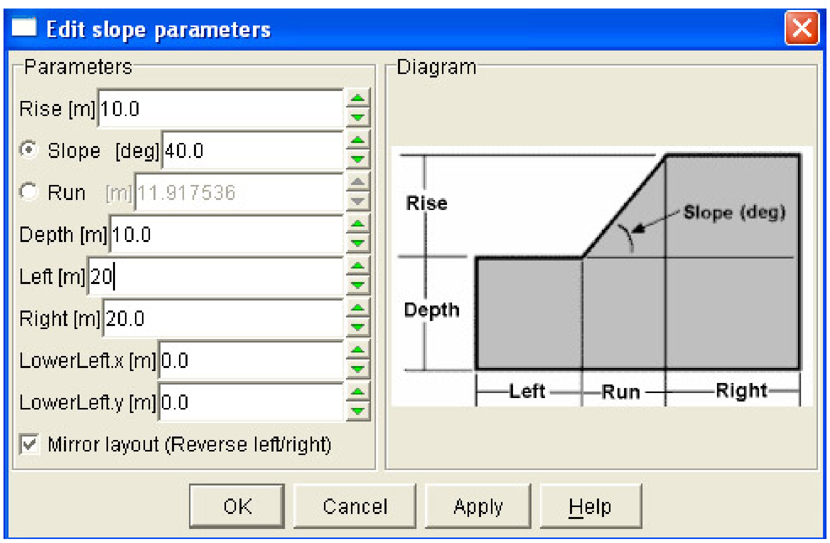


Figure 5. 9: "Edit slope parameter" window

5.3 Slope Building

At the Build stages of the FLAC/Slope where the material properties and seismic force, will be determined here.

5.3.1 Material properties

A fixed material property is determined and the parameter of the properties will be change later and it's depending on which parameter to be study.

Initial parameter of the properties of the soil had been set. This was done at the "Materials" tool at the Builds" tab bar. Where the properties of the soil have been set for:

- Unit weight of the soil, γ is 50 kN/m^3 (ρ is 5096.8 kg/m^3)
- Cohesion of the soil, c is 70kN
- Angle of internal friction, φ is 20°

The step to input the material properties had been discussed in section 3.4.3. At the Figure 5.2 show the "Define material" window where soil properties that already key in the value.

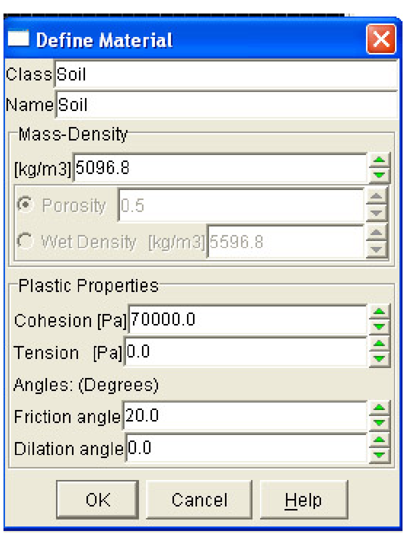


Figure 5.2: "Define material" window

5.3.2 Seismic force

All the parameter of the soil property will be analyse under the seismic condition, hence the standard horizontal force coefficient, k_h is 0.1 was used. The parametric studies for the different seismic coefficient slope also to be study, where the decide k_h for study where the k_h will be 0 (at static condition), 0.1, 0.2, 0.3 and 0.4 of the coefficients.

The seismic force to be applied to the model by pseudo-static approach is 0.1g. Hence, seismic force setting for pseudo-static approach can be done at the "Gravity" tool at the "Build" tool tab. Example for the setting of seismic coefficient for k_h is 0 .1, the input value for the "Gravity Settings" window can be found at Appendix C. The input for k_h is 0.1 to be key in the value as the magnitude is 9.8589 m/s^2 and angle is 5.709°. At the Figure 5.3 show the gravity setting for seismic coefficient setting.

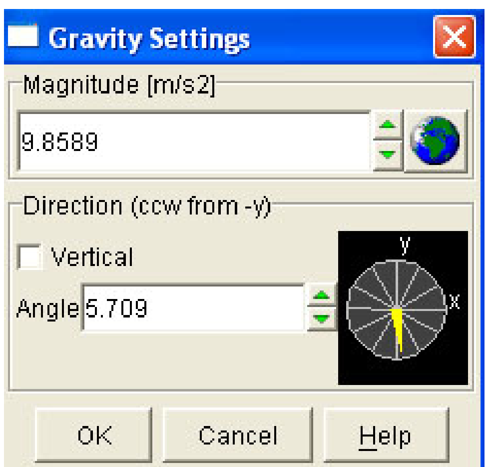


Figure 5.3: Gravity setting for weak layer model

5.4 Solving for slope model

The model for the parametric studies is solved at the "Solve" tab bar. Only course mesh can be selected for the student version of FLAC/Slope. At the Figure 5.4 show a typical screen view of the model course mesh for this model. After the mesh is generate the FOS is solve by click on the “Solve FoS” button. The failure mechanism for the each parametric studies of the slope can be view at the “Plot” tab bar.

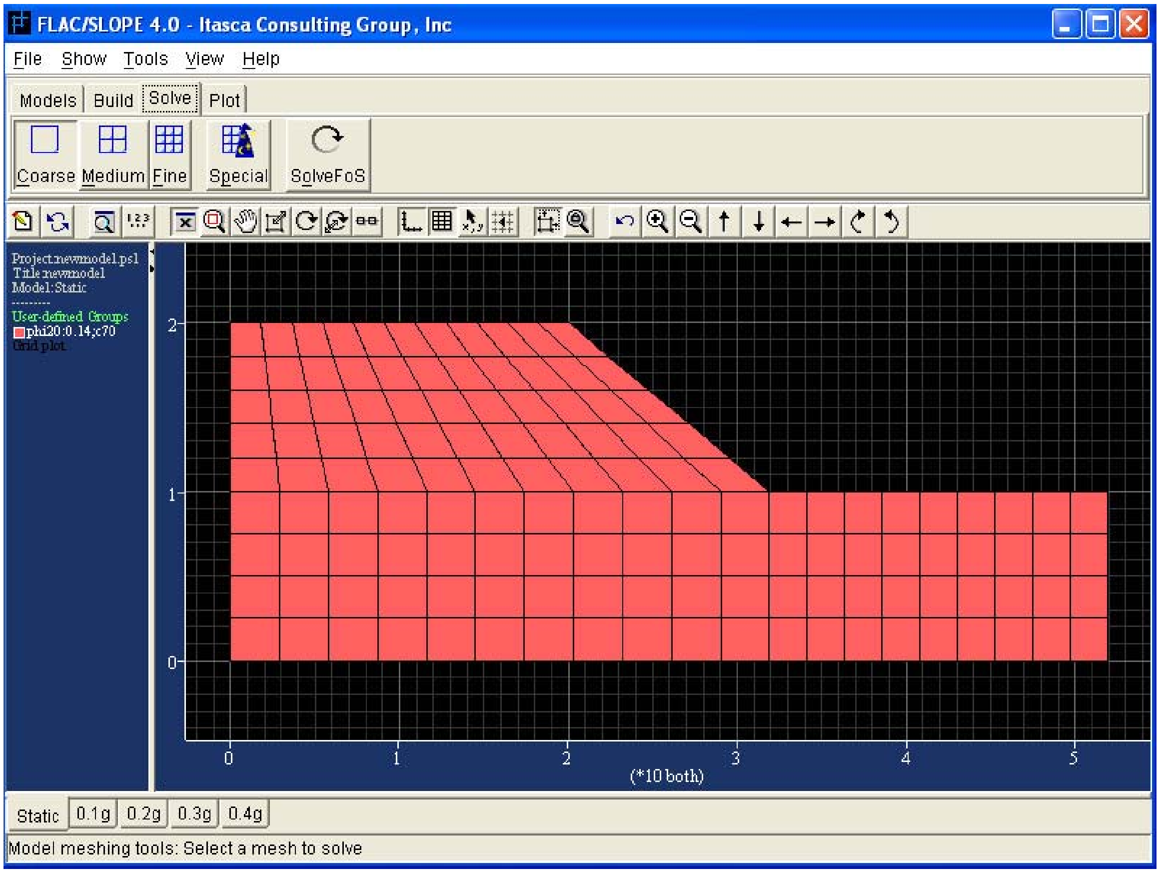


Figure 5.4: Course mesh

5.5 Result of the parametric studies

After solving all the parametric that had been consider the result for all the parametric studies is obtained as well as the failure mechanism in will show here. The analysis include the analysis parameters of the different horizontal seismic horizontal coefficient (k_h) and soil material properties which include the angle of internal friction (φ), cohesion (c), unit weight density (γ).

5.5.1 Horizontal seismic force

Different type of seismic coefficient is analysed for the factor of safety. The parameters of the seismic coefficient consider are 0, 0.1, 0.2 0.3 and 0.4 for the studies.

5.5.1.1 Summaries of results

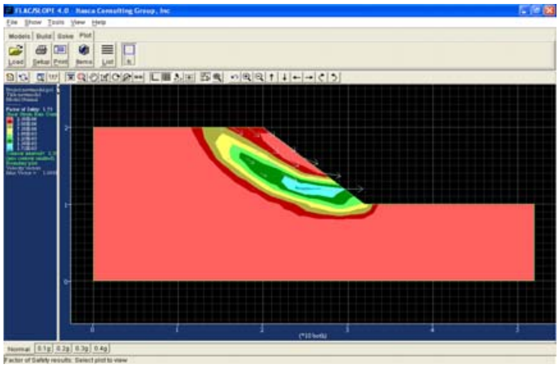
Table 5.1 show the summaries of the result of FOS for the horizontal seismic coefficient parameter study.

Horizontal seismic coefficient	F.O.S
0	1.75
0.1	1.46
0.2	1.24
0.3	1.06
0.4	0.9

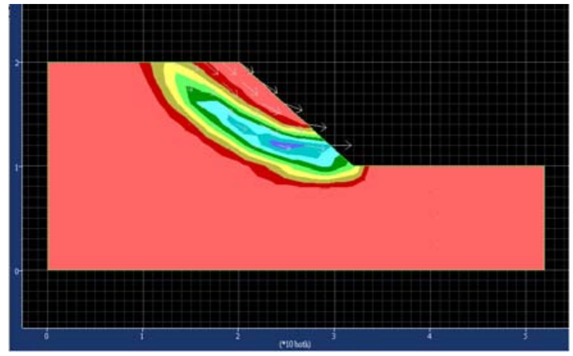
Table 5.1: FOS for horizontal seismic coefficient

5.5.1.2 Failure mechanism

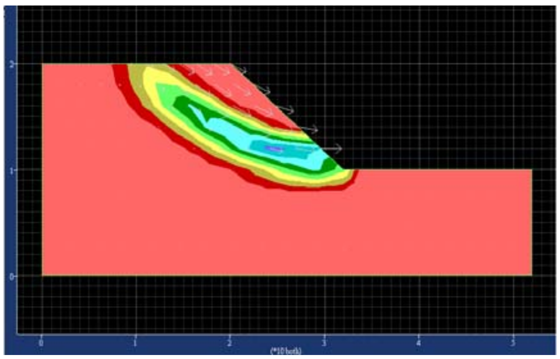
The failure mechanism is obtained at the "Plot" tab bar. Figure 5.5(a), (b), (c), (d) and (e) show the failure mechanism for the parametric studies of the horizontal seismic coefficient.



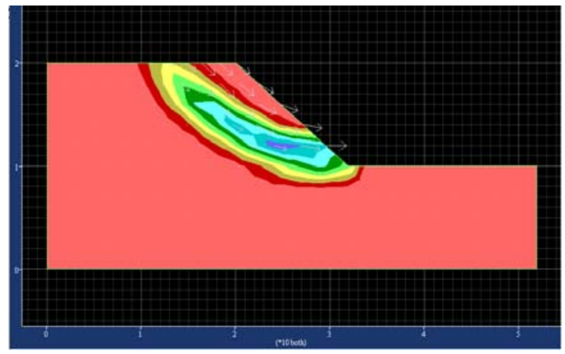
(a) Static



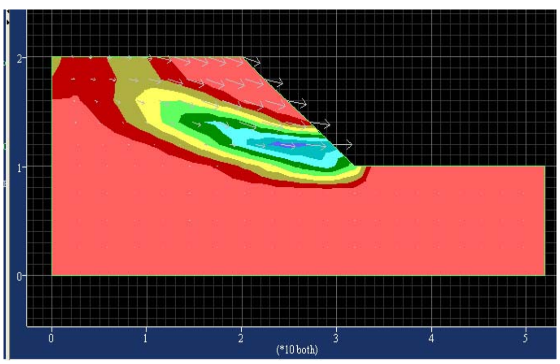
(b) k_h = 0.1



(c) k_h = 0.2



(d) k_h = 0.3



(e) k_h = 0.4

Figure 5.5: Failure mechanism for horizontal seismic coefficient.

5.5.1.3 Discussion

For the failure mechanism, for k_h value of 0.4 we have FOS lower than 1 and this indicate that the slope for this model is not stable when the k_h value 0.4 is reach.

Note that the failure mechanism is for k_h=0.4(Figure 5.5(e)) is quite different from k_h = 0.3 (Figure 5.5(d)). As we can see here the contour line of failure for k_h = 0.4 was extended further to the boundary compare to that k_h = 0.3.

As for the FOS result from the Table 5.1, it shown the value factor of safety generally will reduce when the horizontal force is increase. Hence, the larger the seismic force the slope is not stable.

5.5.2 Angle of the internal friction

Different type of Internal Friction Angle, φ is apply to analysing for the factor of safety. The parameters of the Internal friction angle consider are 10°, 15° and 20° for the studies.

5.5.2.1 Summaries of result

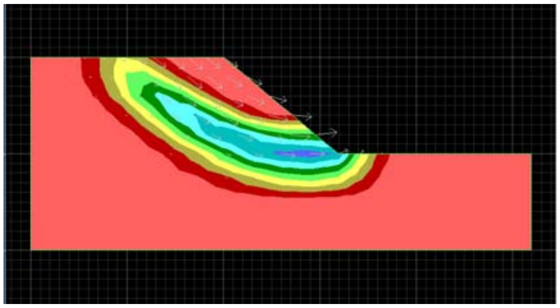
Table 5.2 show the summaries of the result of FOS for the internal friction angle studies.

Internal Friction Angle, φ°	F.O.S
10	1.08
15	1.29
20	1.46

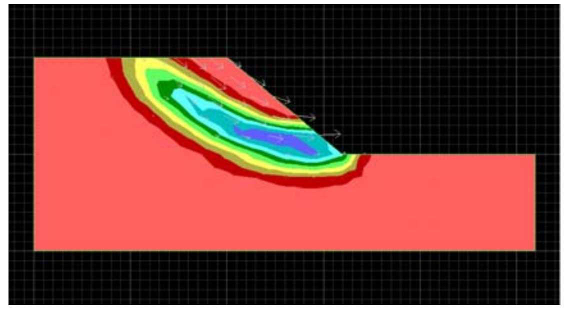
Table 5.2: FOS for internal friction angle

5.5.2.2 Failure mechanism

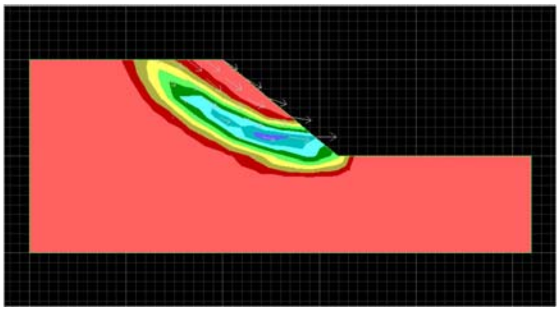
Figure 5.6(a), (b) and (c) show the different failure mechanism for the parametric studies of the internal friction angle.



(a) φ = 10°



(b) φ = 15°



(c) φ = 15°

Figure 5.6: Failure mechanism for internal friction angle

5.5.2.3 Discussion

For the failure mechanism, for φ of 10° we have the failure surface much larger then the others. Note that when the as φ value increases the line of failure will get reduce.

As from the Table 5.2, it's shown that the factor of safety for a slope will increase with the increase of angle of internal friction of soil properties. This also can be said that a soil property that has higher angle internal friction the slope is safer.

5.5.3 Cohesion

Different type of Cohesion, *c* of the soil is analysed for the factor of safety. The parameters of the cohesion, *c* were considered are 60, 70 and 80 kN/m^2 considered for the studies.

5.5.3.1 Summaries of result

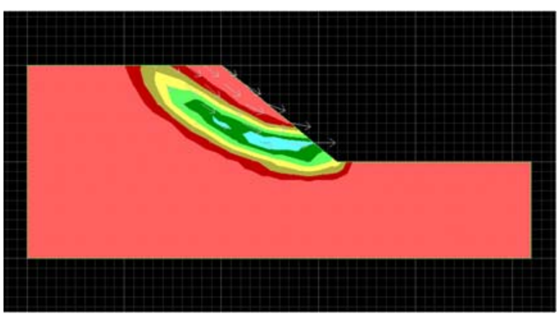
Table 5.3 show the summaries of the result of FOS for the cohesion parameter study.

Cohesion, c (kN/m^2)	F.O.S
60	1.34
70	1.46
80	1.58

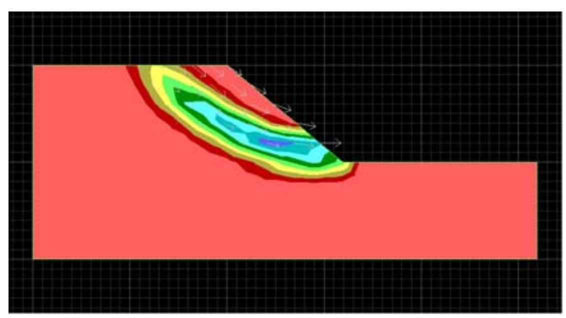
Table 5.3: FOS for cohesion

5.5.3.2 Failure mechanism

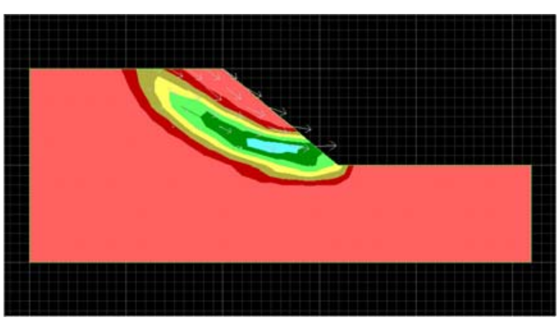
Figure 5.7(a), (b) and (c) shows the failure mechanism for the parametric studies of the cohesion.



(a) c = 60 kN/m^2



(b) c = 70 kN/m^2



(c) c = 80 kN/m^2

Figure 5.7: Failure mechanism for cohesion

5.5.3.3 Discussion

From the failure mechanism of the parametric study for the cohesion, the failure mechanism is seemed almost the same for all of the result. For this result does not show much different of the failure mechanism for the different cohesion value.

From the Table 5.3 had show that, with the increase of the cohesion of the soil properties for a slope the factor of safety for a slope will increase. When the cohesion of the soil is increase the slope is more stable.

5.5.4 Weight Density

Different parameter of unit weight, γ of the soil is analysed for the factor of safety. The unit weight, γ were considered are 30, 40 and 50 kN/m^3 considered for the studies. Note that the unit weight used is likely larger than the unit weight of any real soil had, this large unit weight is used as for the purpose to easier to analyse the range of the FOS.

5.5.4.1 Summaries of result

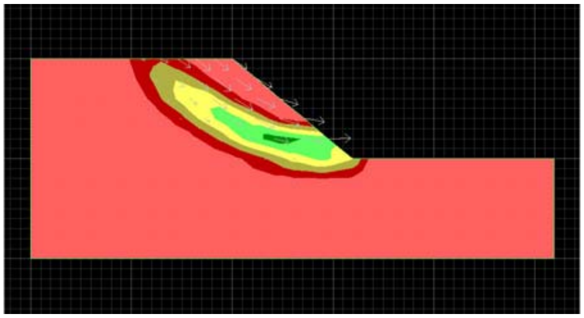
Table 5.4 show the summaries of the result of FOS for the weight density study of the soil.

Unit weight, γ (kN/m^3)	**F.O.S**
30	1.62
40	1.37
50	1.21

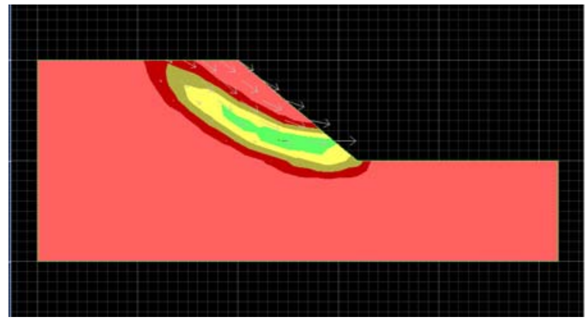
Table 5.4: FOS for unit weight

5.5.4.2 Failure mechanism

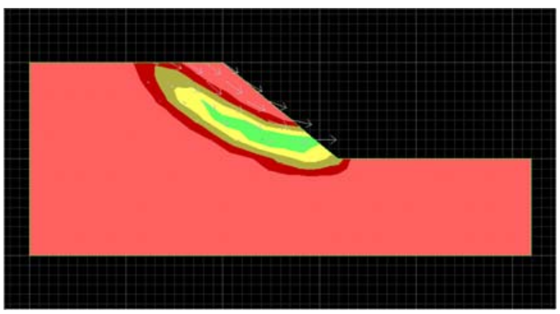
Figure 5.8(a), (b) and (c) shows the failure mechanism for the parametric studies of the cohesion.



(a) γ = 30 kN/m^3



(b) γ = 40 kN/m^3



(c) γ = 50 kN/m^3

Figure 5.8: Failure mechanism for unit weight

5.5.4.3 Discussion

From the failure mechanism of the parametric study for the unit weight, the failure mechanism from the result also had shown all of them had almost the same failure condition. For this result does not show much different of the failure mechanism for the different cohesion value.

From the Table 5.4 had show that, with the increase of the unit weight density, γ the FOS is decrease. It is likely that the lower the value of the unit weight, γ of the soil the slope is more stable

5.5.5 Weight Density

Different parameter of unit weight, γ of the soil is analysed for the factor of safety. The unit weight, γ were considered are 30, 40 and 50 kN/m^3 considered for the studies. Note that the unit weight used is likely larger than the unit weight of any real soil had, this large unit weight is used as for the purpose to easier to analyse the range of the FOS.

5.5.5.1 Summaries of result

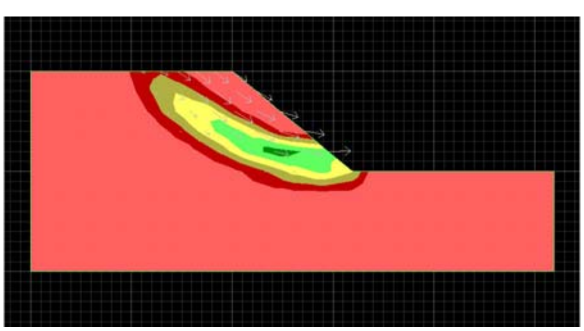
Table 5.4 show the summaries of the result of FOS for the weight density study of the soil.

Unit weight, γ (kN/m^3)	**F.O.S**
30	1.62
40	1.37
50	1.21

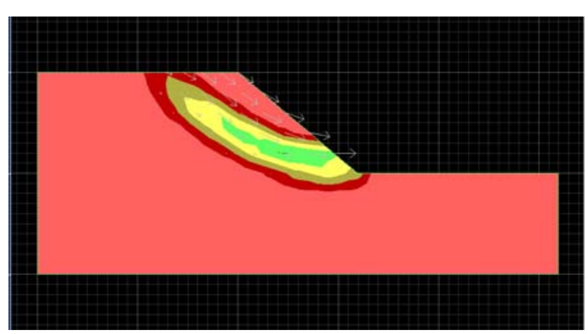
Table 5.4: FOS for unit weight

5.5.5.2 Failure mechanism

Figure 5.8(a), (b) and (c) shows the failure mechanism for the parametric studies of the cohesion.

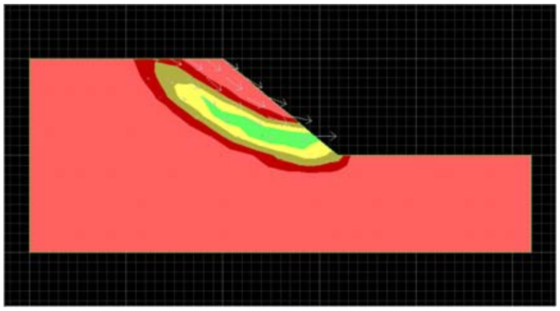


(a) γ = 30 kN/m^3



(b) γ = 40 kN/m^3

Figure 5.8: Failure mechanism for unit weight



(c) γ = 50 kN/m^3

Figure 5.8: Failure mechanism for unit weight

5.5.5.3 Discussion

From the failure mechanism of the parametric study for the unit weight, the failure mechanism from the result also had shown all of them had almost the same failure condition. For this result does not show much different of the failure mechanism for the different cohesion value.

From the Table 5.4 had show that, with the increase of the unit weight density, γ the FOS is decrease. It is likely that the lower the value of the unit weight, γ of the soil the slope is more stable

5.6 Summaries

From the analysis of a model of a slope with a constant slope geometry is used, it has been found that the soil properties such as the cohesion, angle of internal friction and unit weight density of soil that which has the interrelated to affect the value of the factor of safety of slope stability problem.

The factor of safety of a slope stability problem will also affect from the value of the horizontal acceleration applied to the slope. With the increase of the seismic coefficient, k it will also increase the horizontal acceleration. The larger the seismic coefficient, the safety factor of the slope will also reduce.

Chapter 6:
SLOPE MODEL ANALYSIS BY FLAC/Slope

6.1 Introduction

A slope model will be created to analyse various problem by using the FLAC/Slope program. This is to give more understanding and experience using the FLAC/Slope software. The problem of the slope which will cover is the seismic force applied to a slope which consist a weak layer of soil. Also Geo-Reinforcement will be applied to the slope model as well to stimulate the effect of reinforcement in the slope under seismic condition that will increase it FOS.

6.2 Slope Model

6.2.1 Defining the project

We begin the project by checking the “Include Structural Elements?” and “Non-standard gravity?” boxes, then click “Ok” to include this option in the project analysis. Next is the step for create the directory has been mention at the Section 3.4.2. The title of this project is name as Weak Layer Model and the file name is “weaklayer.psl” for this model problem.

6.2.2 Slope parameter

For the model stages, the "Simple" model is selected, the decide slope parameter to be input to the "Edit slope parameter" windows.

For parameter decided, where rise is 10m, run is 20m, depth is 15m, left is 15m and right is 30 m and the mirror layout is choose for this slope. Figure 6.1 show the "Edit slope parameter" windows.

In this model analysis various arrangement of geo reinforcement will be installed. Hence, various models are needed in other to compare the result. This can be done by right-clicking on the tab bar of the model name and click "clone" to get a same model to analyse for other result. This step had been done before at Section 4.2.3.2 (See Figure 4.2 also)

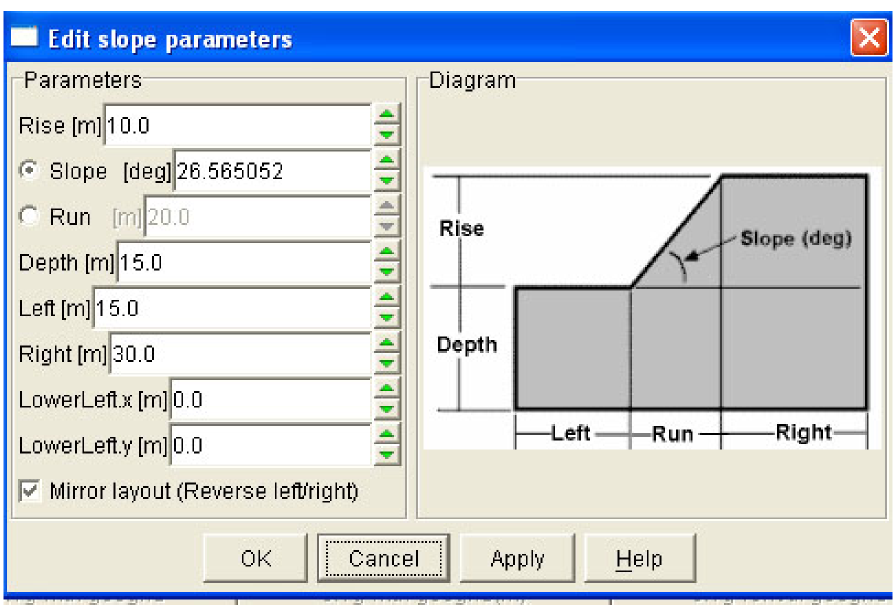


Figure 6. 10: Model "Edit slope parameter" window

6.3 Slope Building

This will be the Build stages of the FLAC/Slope where the material properties, seismic force, construct the weak layer and installing structural reinforcement for this model will be determine here.

6.3.1 Weak layer

6.3.1.1 Introduction

A weak layer of in the slope, where is it known as the layer of the soil properties which will have less cohesion, *c* and/or less angle of internal friction, φ than it surrounding of the normal the soil properties.

6.3.1.2 Adding a weak layer

To add a weak layer, this can be done by step below:

1) By click on the "Layers" button at the Build stage tab bar. The "Layers" tool window will then appear.

2) The Add/Move button was click, and two layer boundaries are added. A green horizontal line with square handles at each end will appear. (See Figure 6.2)

3) Click to the "Edit" button. Now, the points to build the shape of are done by right click of the mouse to any point along line and also the square handles at each end to get the table for entering the coordinate of the points (See Figure 6.2). By drag from

any point along the line to a desire point, it can also use to shape the layer boundaries.

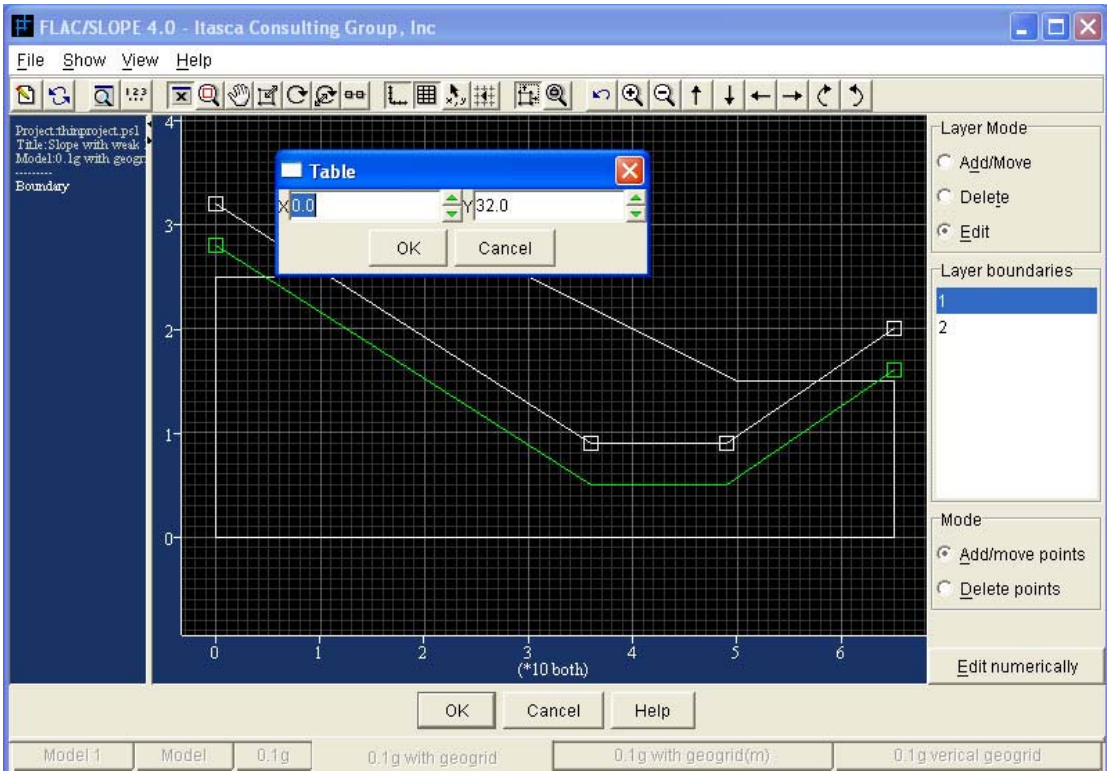


Figure 6.2: “Layers” tool window

4) To get precise line, the point from the left to right of each of each of the layer boundaries line are entered according to the coordinate shown Table 6.1 and 6.2. This is also to create a weak layer for about 4m thick. If the layer is too thin, bad mesh may result when the model mesh is performed during the Solve stage.

Points / Coordinate	**X**	**Y**
1st point (left square handle)	0	32
2nd point	36	9
3rd point	49	9
4th point (right square handle)	65	32

Table 6.1(a): Coordinate for the 1st layer boundary

Points / Coordinate	X	Y
1st point (left square handle)	0	28
2nd point	36	5
3rd point	49	5
4th point (right square handle)	65	16

Table 6.2(b): Coordinate for the 2nd layer boundary

5) When finishes build boundaries for the weak layer, "Ok" button is click to get back to the Build stage window.

6.3.2 Material properties

Two type of material will be defined here the normal soil and the weak layer soil. The decided material properties show below will be the input to the "define material" window.

Normal soil

For the normal soil, the material properties will be:

- Mass density, ρ is 2000kg/m^3
- Cohesion is, *c* 50 kN/m^2
- Friction angle, φ is 8°

See Figure 8.2.4 for the input to the "Define material" window

This will be the first soil in the list as blue colour. See figure 6.3

Weak layer soil

For the weak layer soil, the material properties will be:

- Mass density, ρ is 2000kg/m^3
- Cohesion is 10 kN/m^2
- Friction angle, is φ 8°

See Figure 8.2.5 for the input to the “Define material” window

This will be the second soil in the list show as green colour. See figure 6.4

Figure 6.3: Soil list

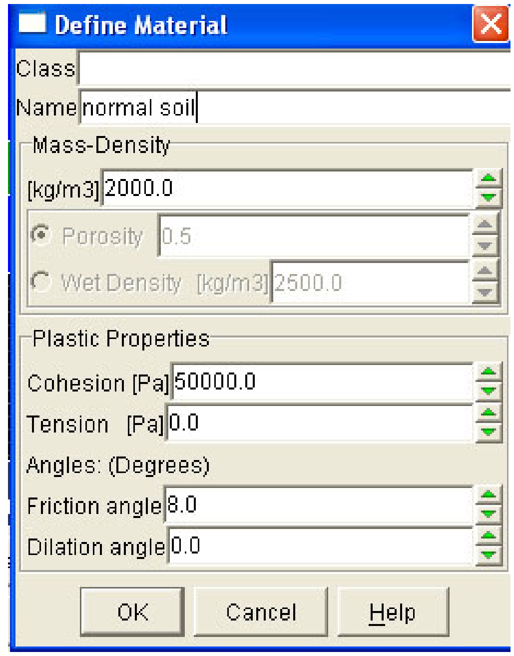


Figure 6.4: Define material for Normal soil

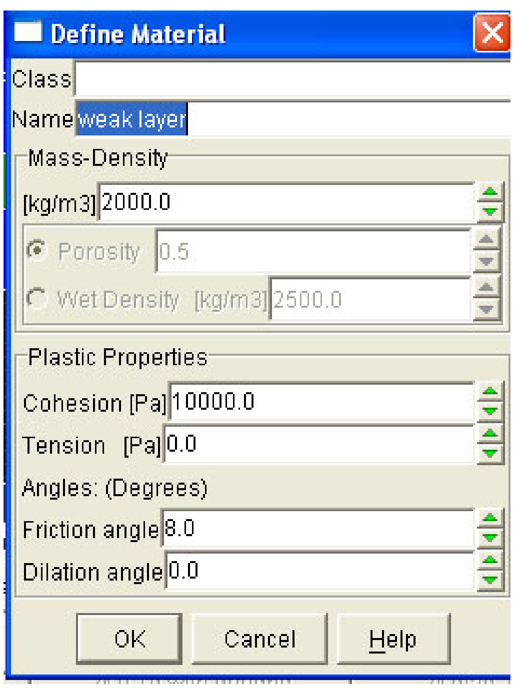


Figure 6.5: Define material for Weak layer soil

After the material properties are defined, the soil is assigned into the model according to area required correctly. The blue will be the normal soil and the green will be the weak layer as shown in Figure 6.6

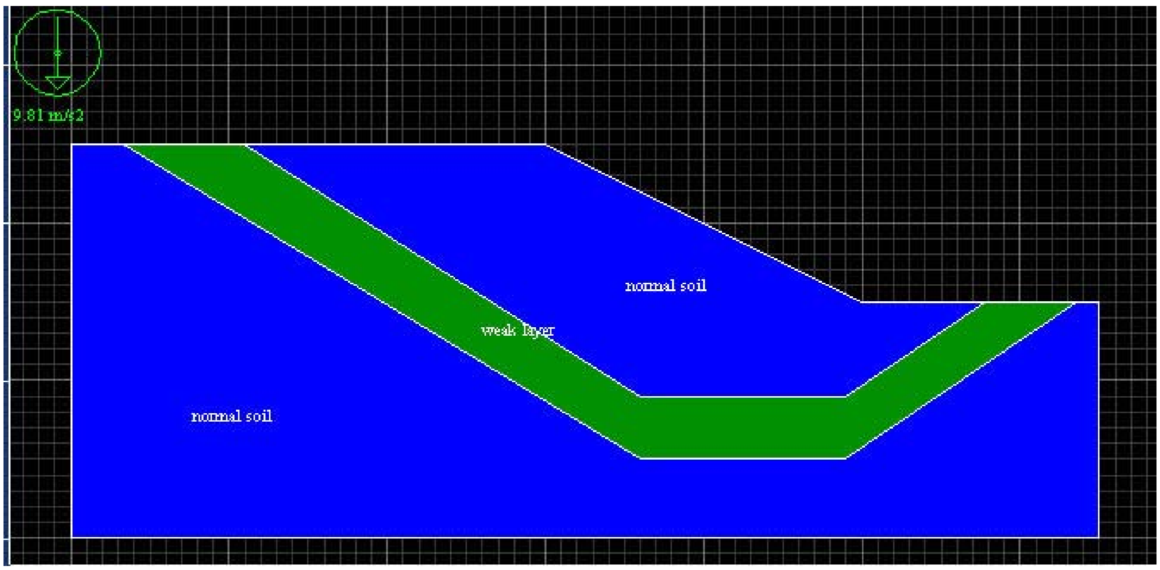


Figure 6.6: Assigned soil in model

6.3.3 Seismic force

The seismic force to be applied to the model by pseudo-static approach is 0.1g. Hence we, the input at the “Gravity Settings” window, for magnitude are 9.8589 m/s^2 and angle is 5.709° (Obtained from Appendix C). Figure 6.7 show the gravity setting.

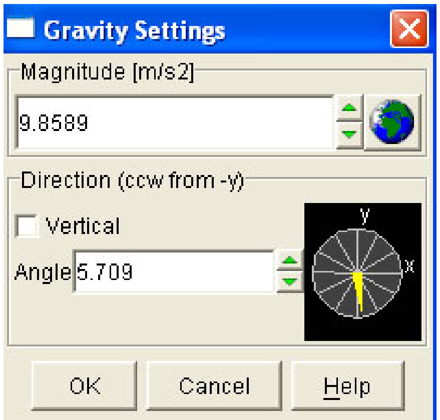


Figure 6.7: Gravity setting for weak layer model

6.3.4 Installing structural reinforcement

6.3.4.1 Introduction

Structural reinforcement has installed to the model as well. The installation of the structural reinforcement to a slope will expect increase the FOS and also give the slope more stable.

6.3.4.2 Cable element properties

The cable element properties that have been decide as:

- Tensile yield is 1 x 10^7 N
- Bond cohesion is 15000 N/m
- Bond friction angle is 35°
- Thickness is 30mm

6.3.4.3 Adding structural element

To add the structural element, this can be done as steps below:

1) By click on the "Reinforce" button at the Build stage tab bar. The "Reinforce" tool window will then appear. (Figure 6.8)

2) The “Add Bolt” button was click on, then pressing the mouse button at one end point of the cable, dragging the mouse to the other point that desire to be. A yellow line with a white square handle will be drawn on the slope model. By click on to the “move node” button the end nodes of the cable can be relocating. The end nodes cable can be positioned more precisely by right-clicking on the handle to position by input the coordinate.

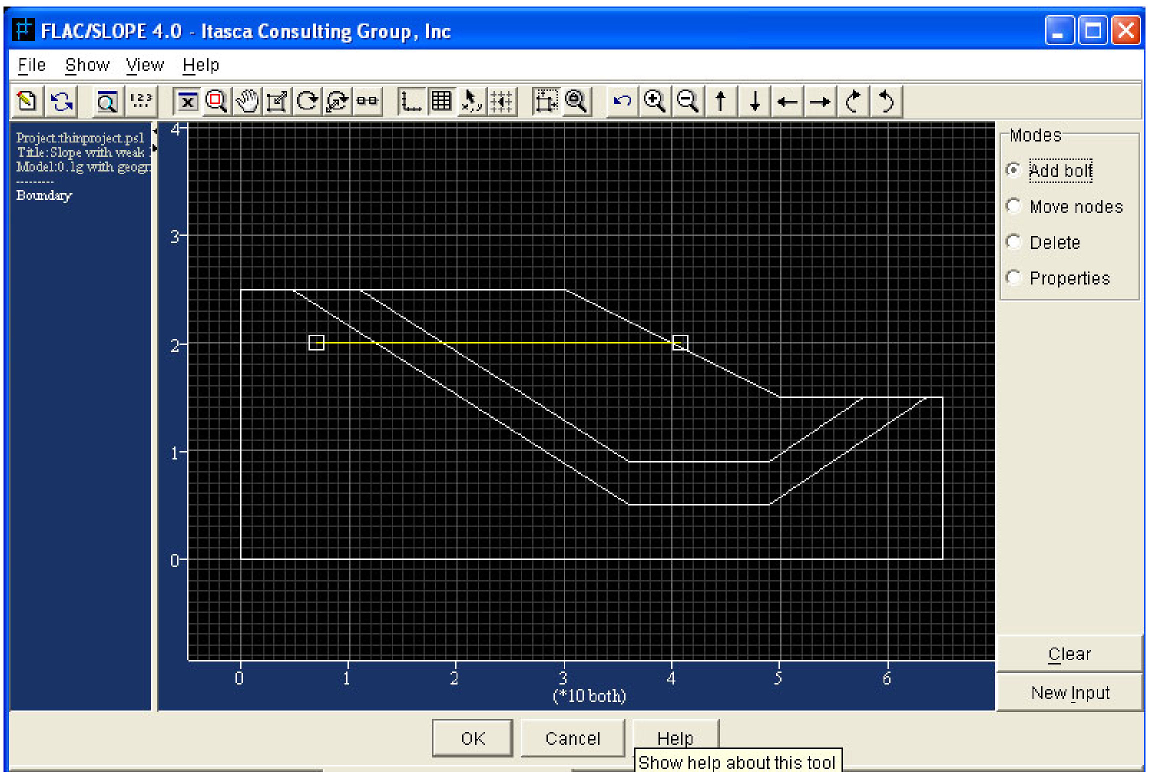


Figure 6.8: “Reinforce” tool window

3) Click on the “Properties button”. A default properties number C1 will be given to the cable. Then by click on to the cable line a window of “Cable Element Properties” will show. From here, the properties of the cable are set. Spaced reinforcement is choose with the Z-spacing is 1 m. For Element Material the young modulus “Compute” is click on, tensile yield strength is 1E7 (1×10^7) N and the area is 0.0007 m^2 (for the 30mm thickness). For the Grout Strength the bond

strength is entered 15000 N/m and Bond friction angle is 35°. Figure 6.9 show the input to the "Bolt Properties" window.

When click on the new button, at the "Property list" column at the left side of the window, this will give an extra property of reinforcement to be edit and set here. This function is not used for this model project.

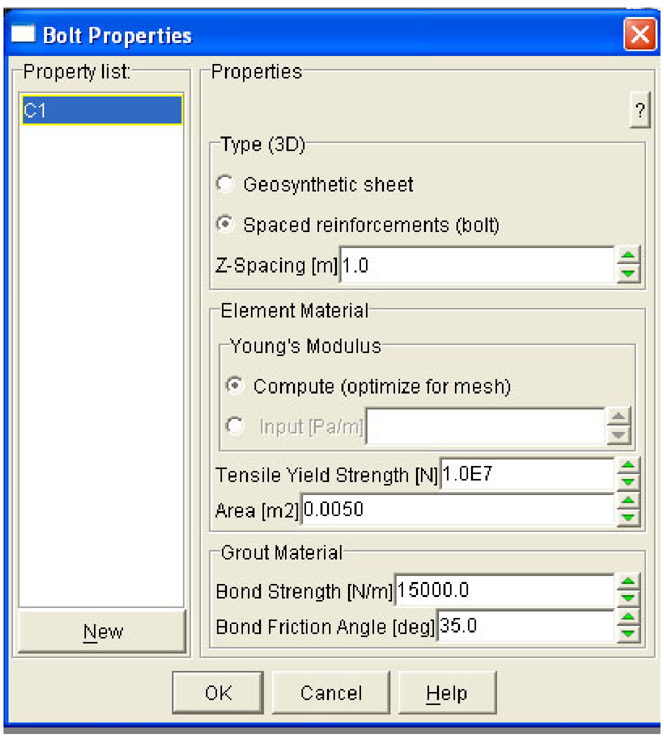


Figure 6.9: "Bolt properties" window

6.3.4.4 Structural reinforcement arrangements

A total of six different arrangements of structural reinforcements have been considered. The FOS for the each arrangement of the structural reinforcement for the slope model at horizontal seismic of 0.1g condition was calculated.

1) The geo-reinforcement is installed by horizontally at the half height, where it is at 5m from the ground level of slope. The geo-reinforcement is installed from the surface of the slope and extends to about 35m which is passing thru the weak layer. The end nodes cable is adjust to be positioned more precisely by right-clicking on the handle to position by input the Y-coordinate for the two end nodes as 20m to get a straight horizontal line for the reinforcement. (Figure 6.10)

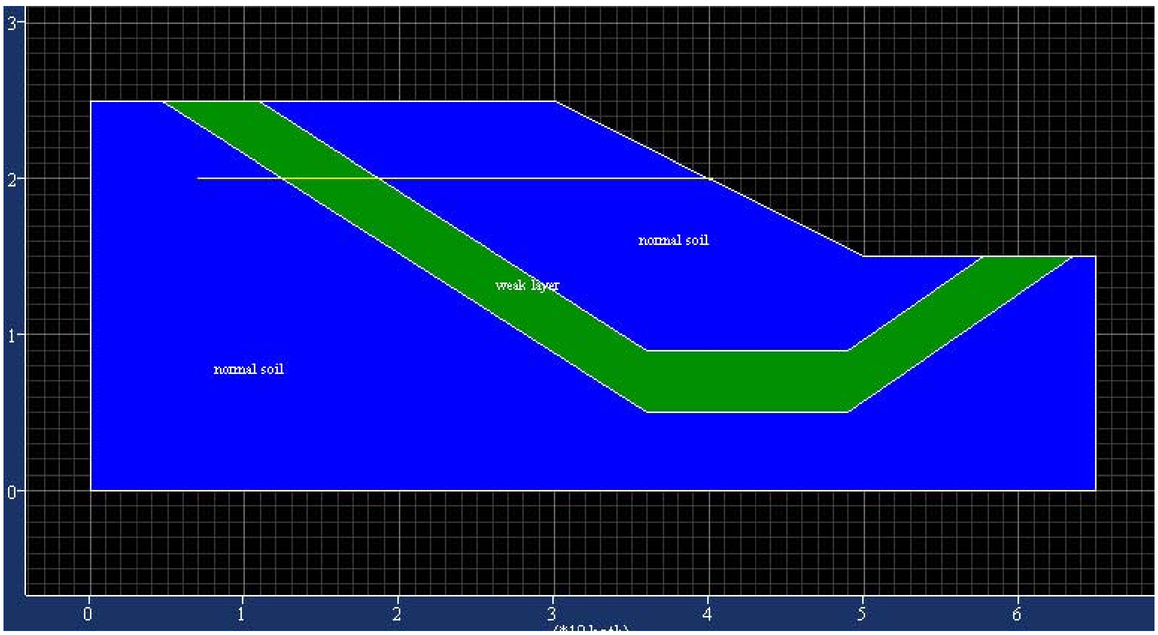


Figure 6.10: Geo-reinforcement at half height of the slope

2) The geo-reinforcement is installed by horizontally at 2.5m from the ground level of the slope. The geo-reinforcement is installed from the surface of the slope and extends to about 35m which will pass thru the weak layer. The end nodes cable is adjust to be positioned more precisely by right-clicking on the handle to position by input the Y-coordinate for the two end nodes as 17.5m to get a straight horizontal line for the reinforcement. (Figure 6.11)

3) The geo-reinforcement is installed at 2.5m from the ground level of the slope surface by diagonally downward. The end nodes cable also positioned more precisely by right-clicking on the handle to position by input the coordinate for the

two end nodes as coordinate (X, Y) as (18,9) and (40,20) so that the geo-reinforcement will position by diagonally downward and passing thru the weak layer. (Figure 6.12)

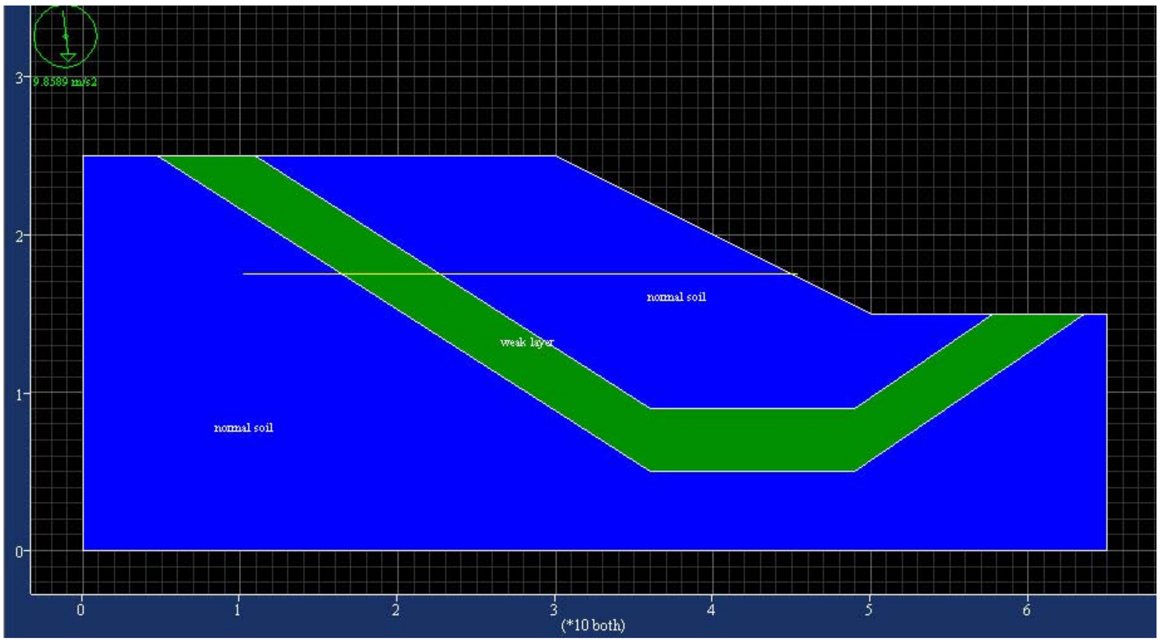


Figure 6.11: Geo-reinforcement at 2.5m from ground level of slope

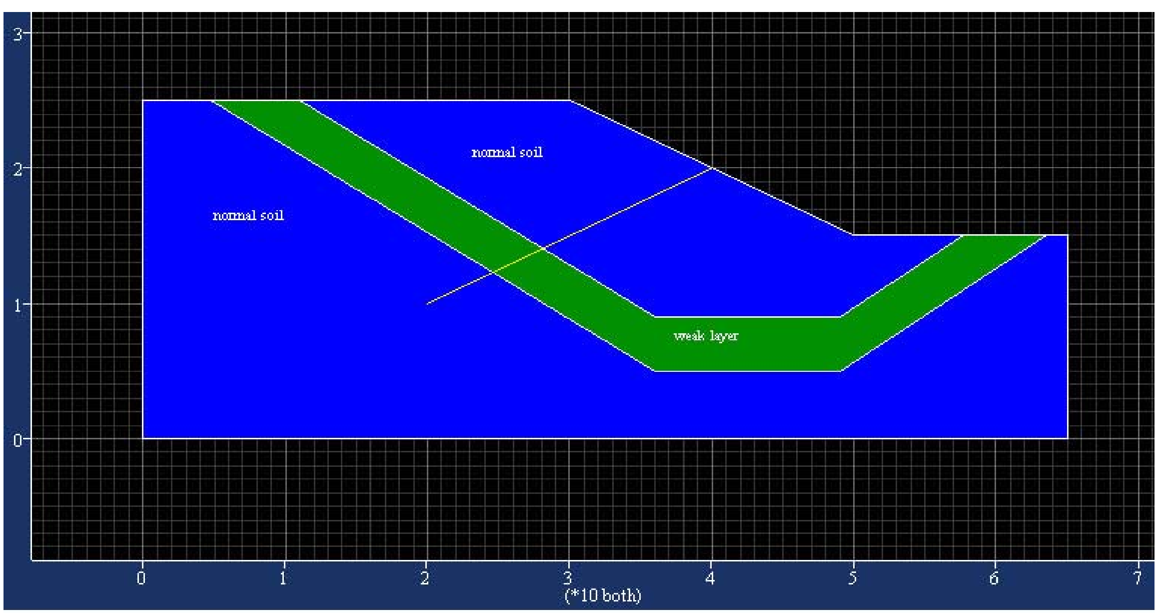


Figure 6.12: Geo-reinforcement is installed from the slope surface by diagonally downward

4) The geo-reinforcement is installed at 2.5m from the ground level of the slope surface by diagonally upward. The end nodes cable also positioned more precisely by right-clicking on the handle to position by input the coordinate for the two end nodes as coordinate (X, Y) as (6, 20) and (45, 17.5) so that the geo-reinforcement will position by diagonally upward and also passing thru the weak layer. (Figure 6.13)

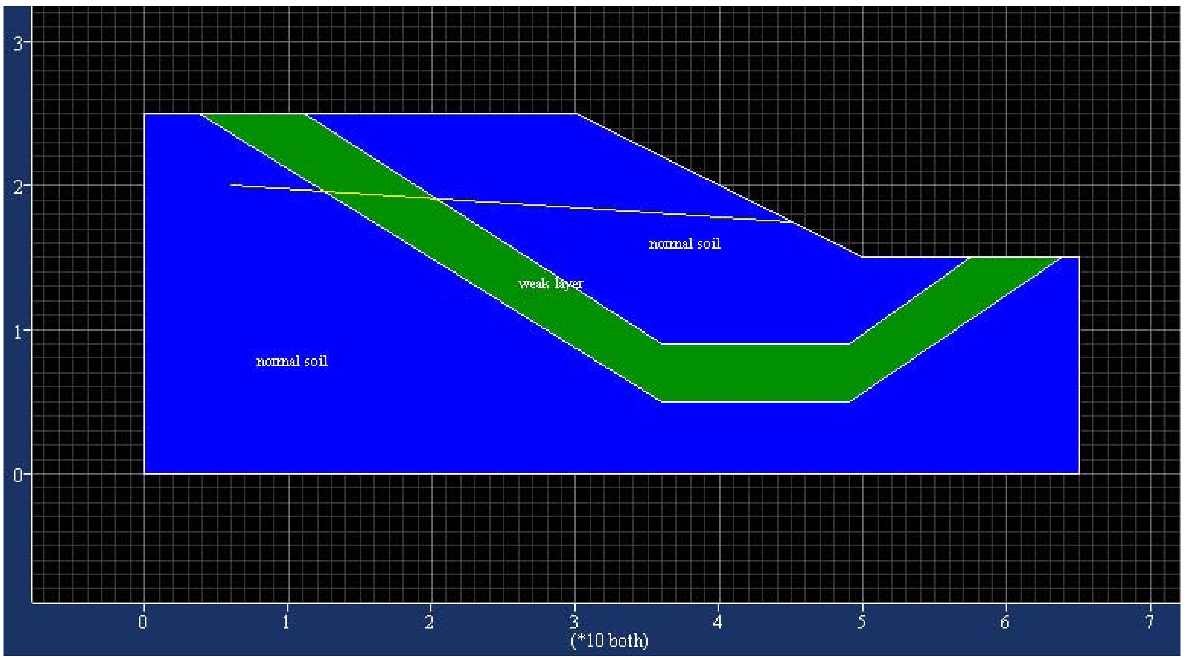


Figure 6.13: Geo-reinforcement is installed from the slope surface by diagonally upward

5) Two geo-reinforcements are installed horizontally at 2.5m and 7.5m respectively above the ground level. The geo-reinforcement is installed from the surface of the slope and extends to about 35m which is passing thru the weak layer. The end nodes cables can be adjust to be positioned more precisely by right-clicking on the handle to position by nodes as coordinate (X, Y) as (4, 22.5) and (35, 22.5) for the upper cable and the coordinate (9,17.5) and (45.5, 17.5) for the lower cable. This will make both reinforcement is located 17.5m for the lower cable and 22.5m for the upper cable to get a straight horizontal line for the reinforcements. (Figure 6.14)

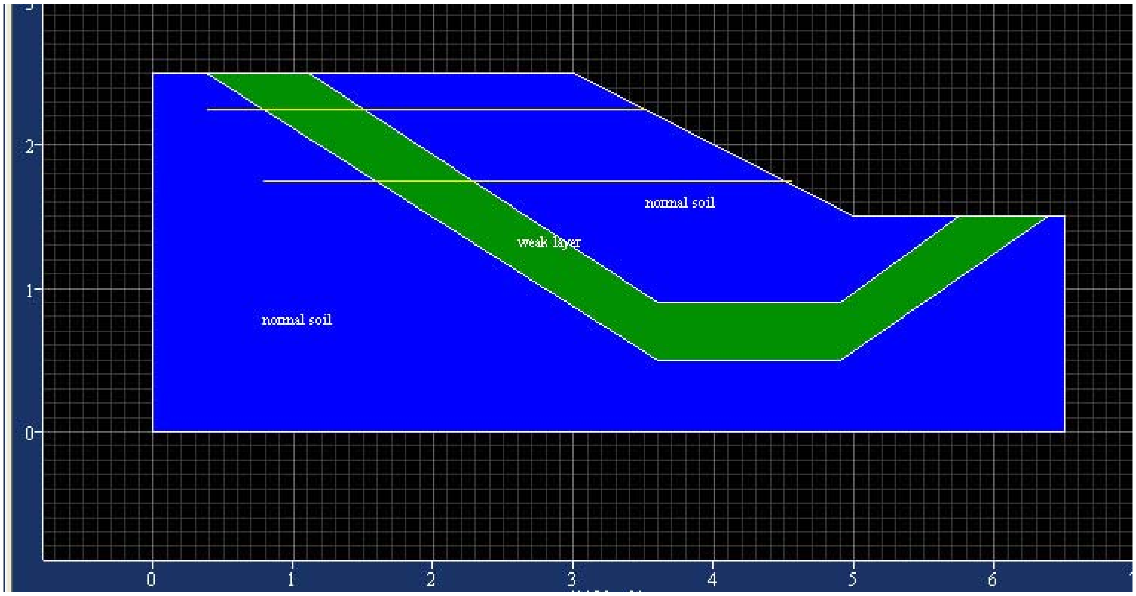


Figure 6.14: Two Geo-reinforcements is installed from the slope surface by horizontally

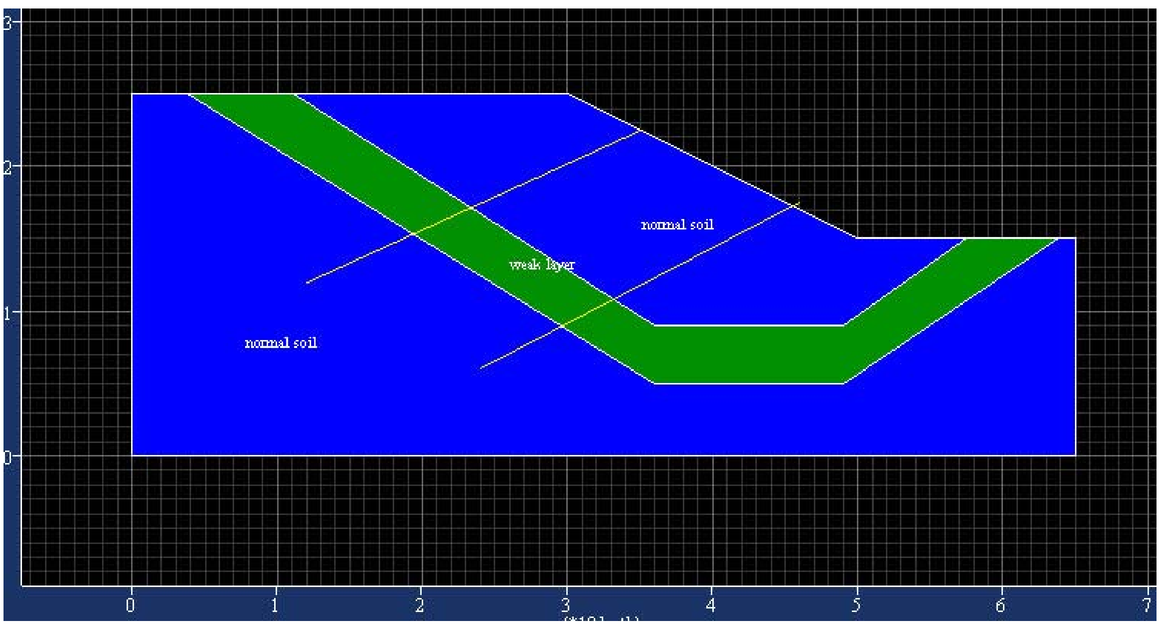


Figure 6.15: Two Geo-reinforcements is installed from the slope surface by diagonally downward

6) Two geo-reinforcements is installed at 2.5m and 7.5m respectively from the ground level of the slope surface by diagonally downward. The end nodes of both cable also positioned more precisely by right-clicking on the handle to position by input the coordinate for the two end nodes as coordinate (X, Y) as (35, 22.5) and (12, 12) for the first cable and coordinate (46, 17.5) and (24, 6) for the second cable. The

coordinate is arranged so that the geo-reinforcements will position by diagonally downward and passing thru the weak layer. (Figure 6.15)

6.4 Solving for the model problems

All the problems for the model, the Solve Stage toolbar is select. Again, this is the student version of FLAC/Slope hence only the course mesh can be selected. When the mesh is select the software will generate the mesh for the model, Figure 6.16 show a typical screen view of the model mesh. After the mesh is generate the FOS is solve by click on the "Solve FoS" button.

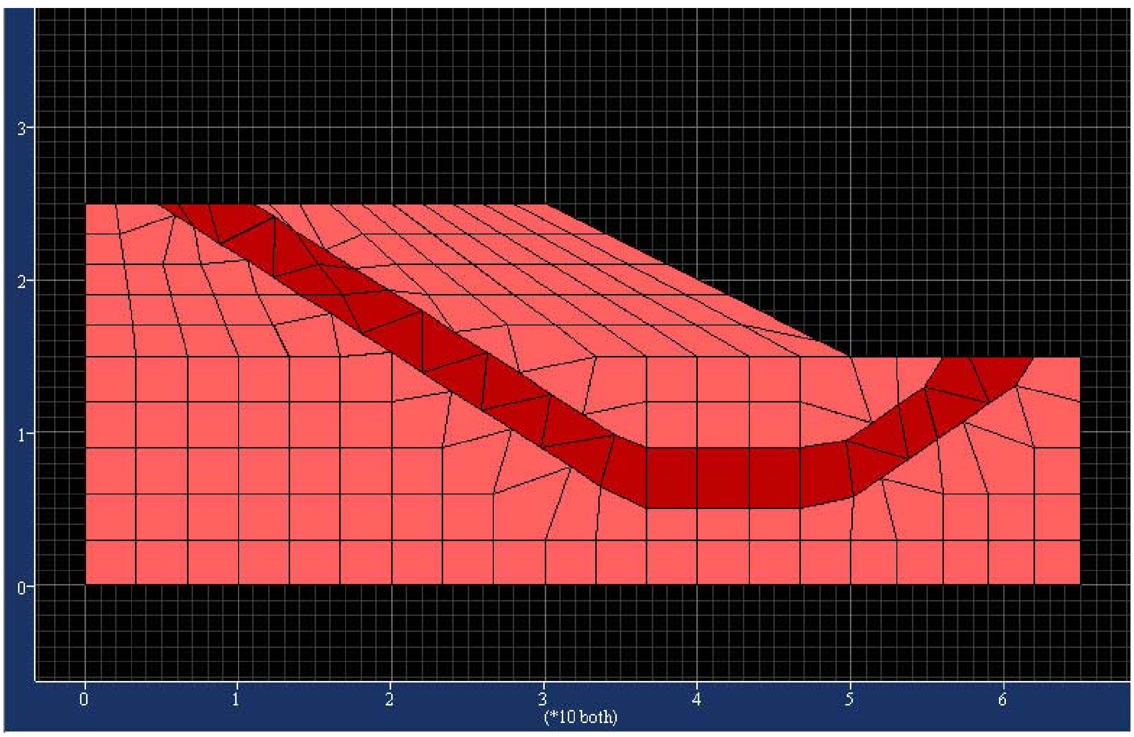


Figure 6.16: Show a typical screen view of the model mesh

6.5 Result

6.5.1 Result Obtain

After the FOS is solve, the result and the failure mechanism will be show at the at the Plot stage toolbar. As there is six different arrangement of the structural element for analysis, hence there are six results obtain for the six different structural elements. Other than that two other result also has been obtain the slope without the geo-reinforcement when in static condition and when the slope in the seismic condition with seismic horizontal force of 0.1g.

At the "Items" tool from the plot tool bar, "Applied conditions" is select at the "Line items" column in the "plot items" window (Figure 6.17). This will enable the axial force on the reinforcement can be seen on the plot result.

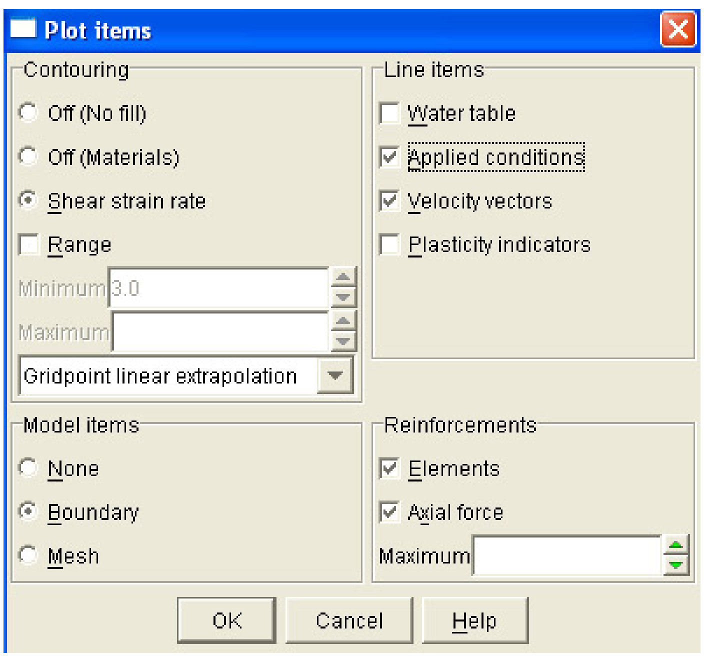


Figure 6.17: Plot items

Hence, there will be total eight result obtain for the analysis, there are:

1) The FOS for the slope at static condition is 1.24. The result and failure mechanism of the slope in static condition is shown at Figure 6.18

2) The FOS for the slope at horizontal seismic of 0.1g condition is 0.92. The result and failure mechanism of the slope at horizontal seismic of 0.1g condition is shown at Figure 6.19.

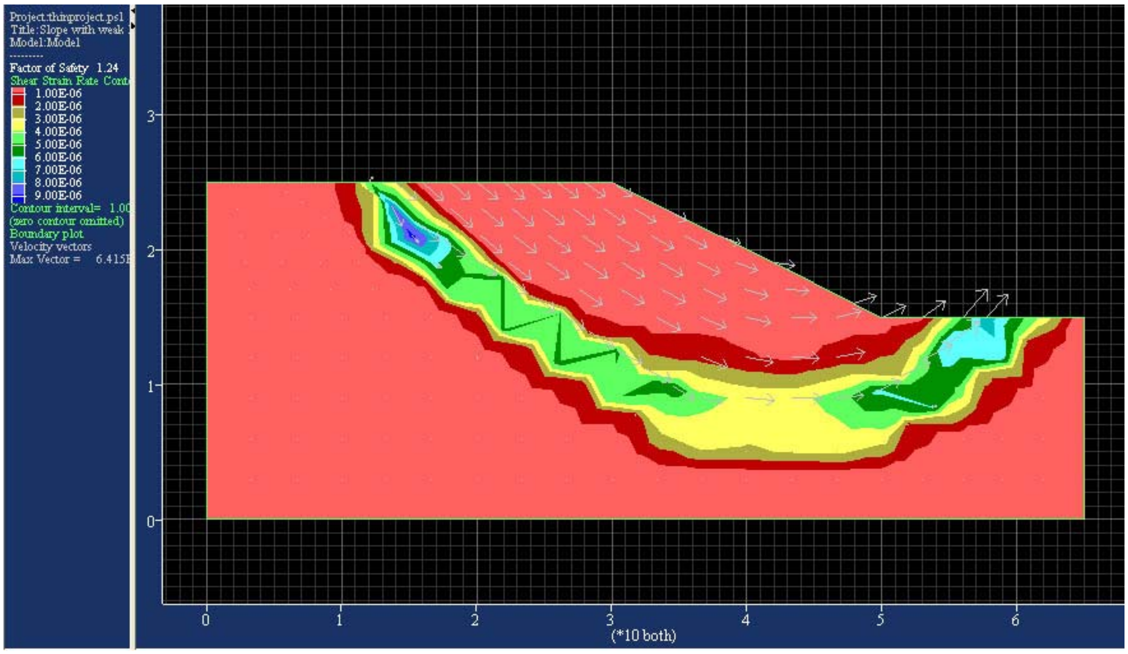


Figure 6.18: Failure mechanism for model in static condition

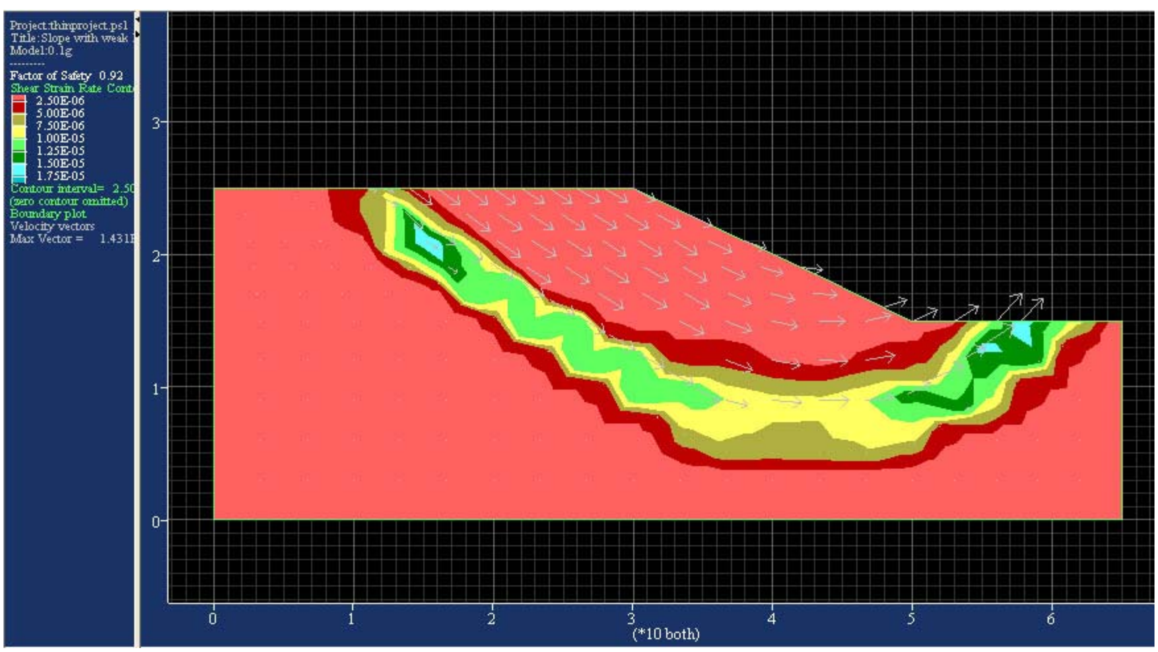


Figure 6.19: Failure mechanism for model at horizontal seismic of 0.1g condition

3) The slope which has geo-reinforcement is installed by horizontally at the half height has the FOS of 1.01. The result and failure mechanism and the axial force on the reinforcement is shown at Figure 6.20.

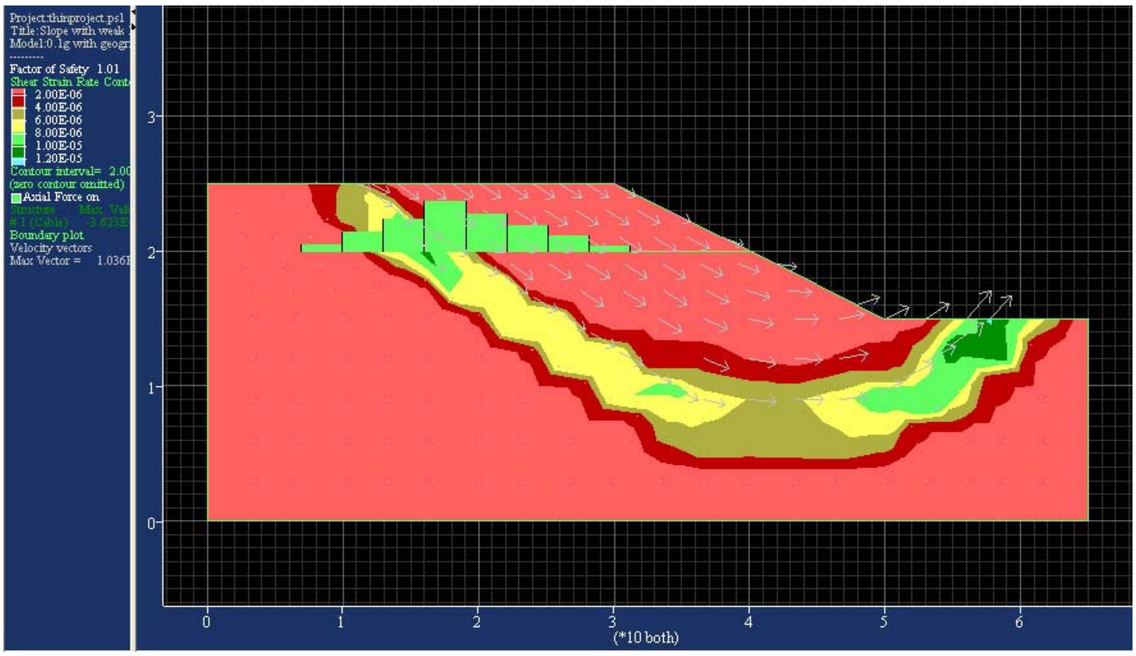


Figure 6.20: Failure mechanism for slope has geo-reinforcement is installed by horizontally of the half height.

4) The FOS for the slope which has geo-reinforcement is installed by horizontally at 2.5m from the ground level is 1.01. The result and failure mechanism and the axial force on the reinforcement is shown at Figure 6.21.

5) The FOS for the slope which has geo-reinforcement is installed at 2.5 meter from the ground level of the slope surface by diagonally downward is 1.00. Figure 6.22 show the result and failure mechanism and the axial force on the reinforcement.

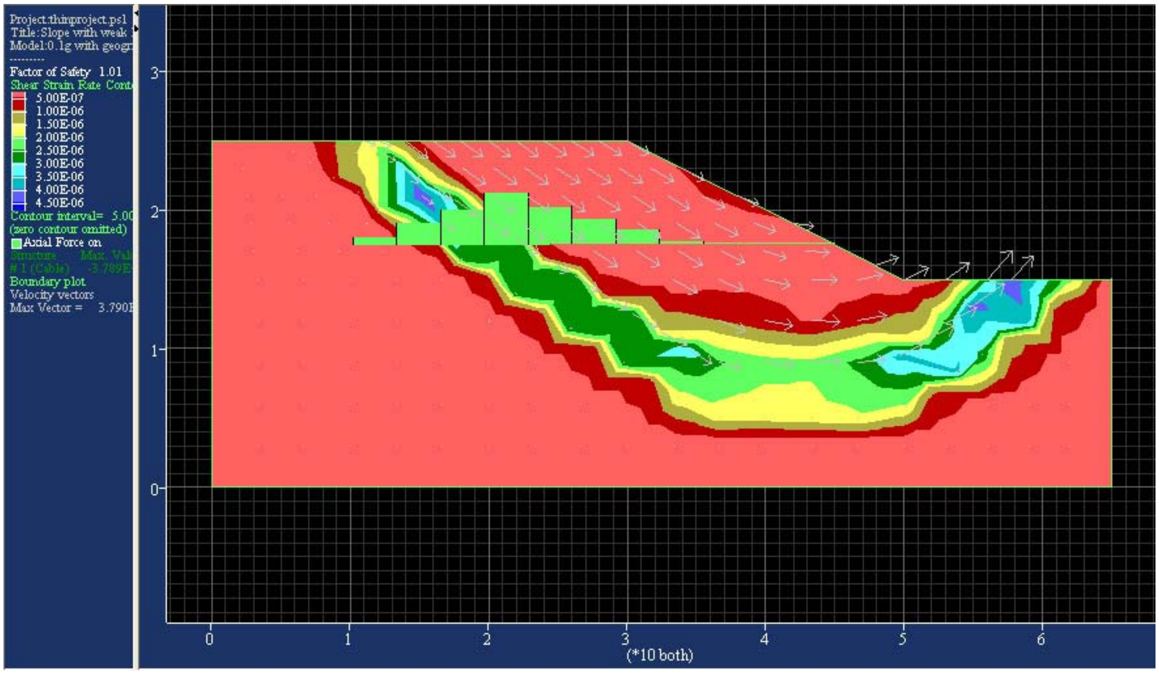


Figure 6.21: Failure mechanism for slope has geo-reinforcement is installed by horizontally at 2.5m from the ground level.

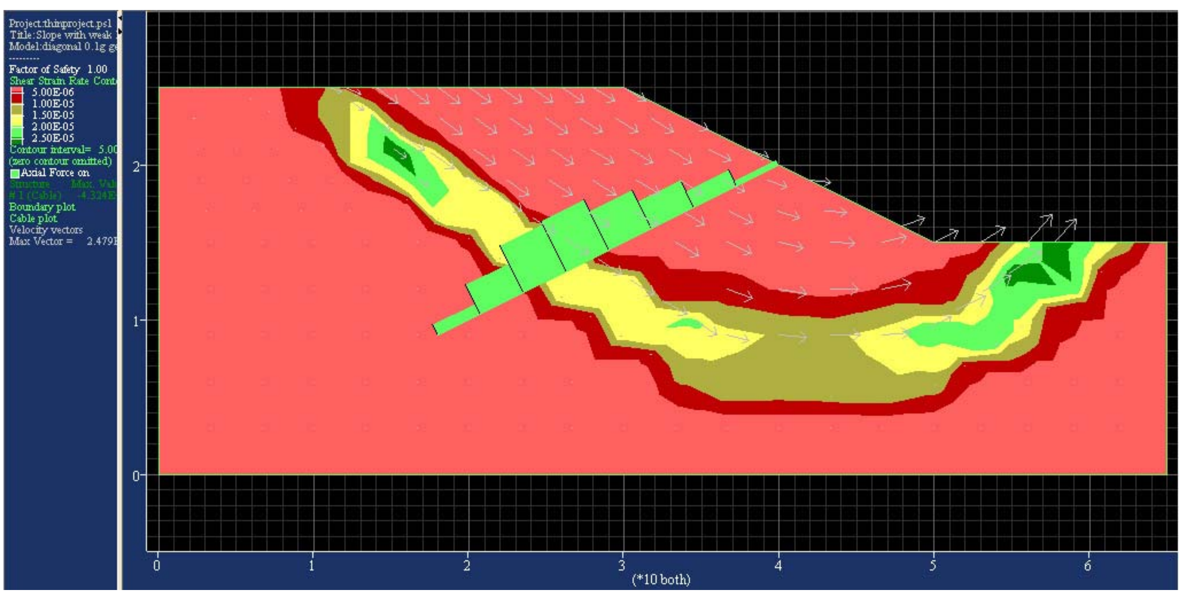


Figure 6.22: Failure mechanism for slope has geo-reinforcement is installed at the slope surface by diagonally downward.

6) The slope which has the geo-reinforcement is installed at 2.5 meter from the ground level of the slope surface by diagonally upward has the FOS is 1.01. Figure 6.23 show the result and failure mechanism and the axial force on the reinforcement.

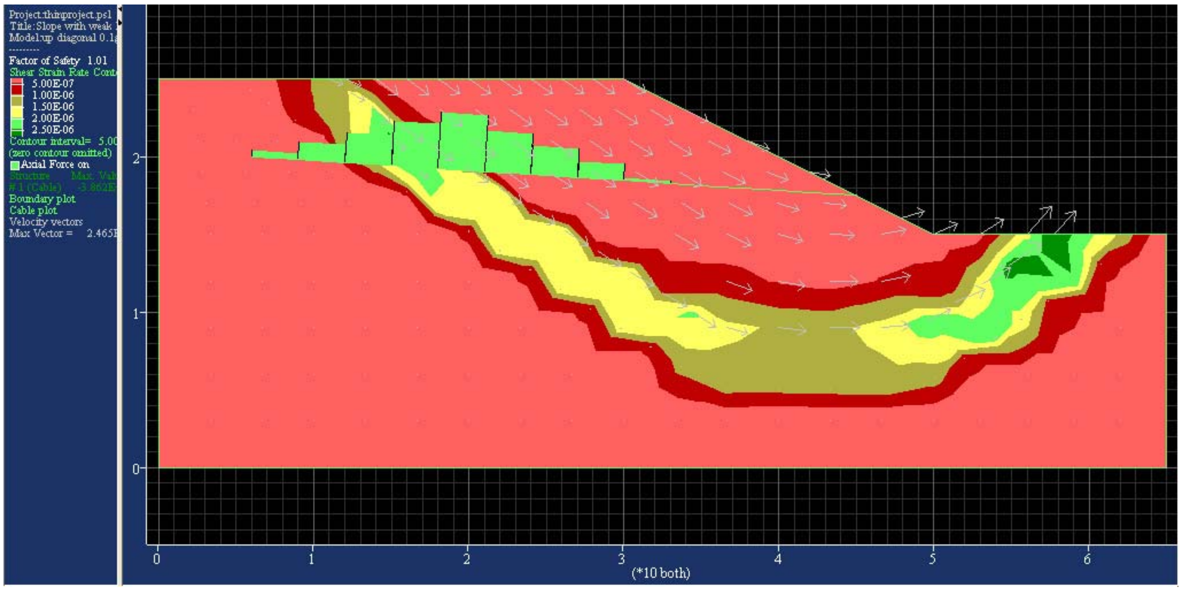


Figure 6.23: Failure mechanism for slope has geo-reinforcement is installed at the slope surface by diagonally upward.

7) The slope for the two geo-reinforcements is installed horizontally at 2.5m and 7.5m respectively above the ground level has the FOS of 1.10. Figure 6.24 show the result and failure mechanism and the axial force on the reinforcement.

8) The slope for the two geo-reinforcements is installed diagonally at 2.5m and 7.5m respectively above the ground level has the FOS of 1.15. The result and failure mechanism and the axial force on the reinforcement is shown at Figure 6.25

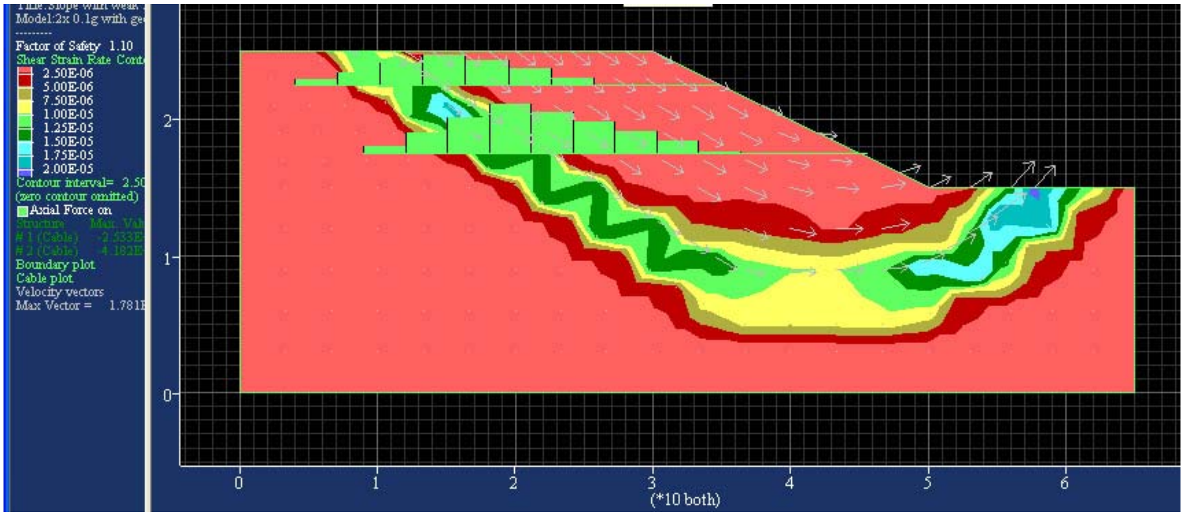


Figure 6.24: Failure mechanism for slope has two geo-reinforcements at horizontally

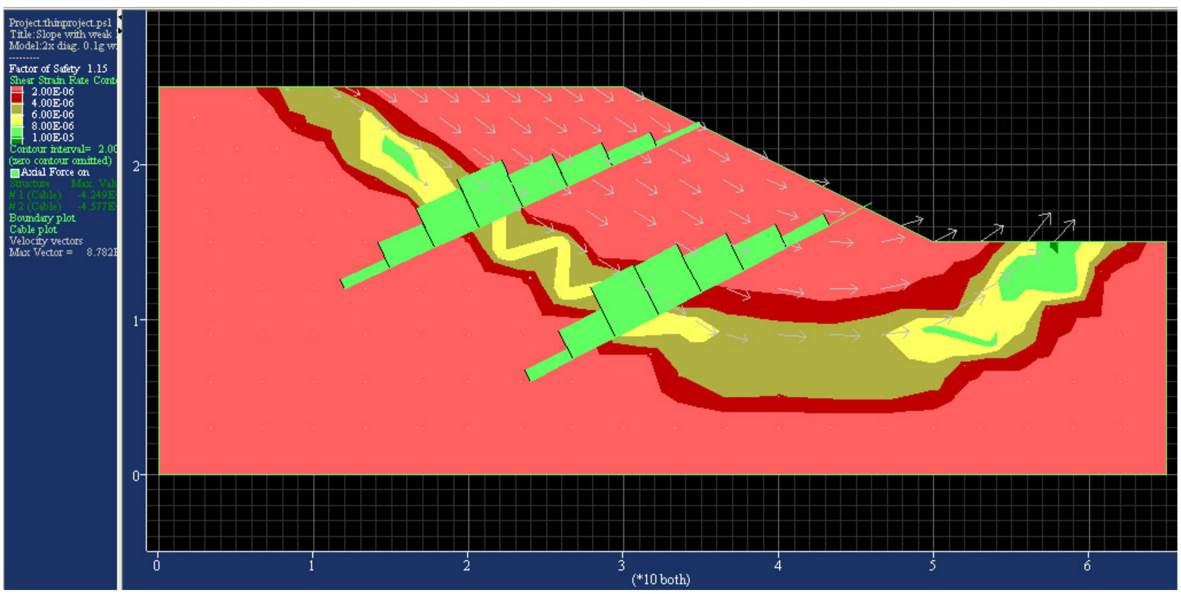


Figure 6.25: Failure mechanism for slope has two geo-reinforcements at diagonally

6.6 Summary of result and discussion

After the analysis the result of eight different condition of the slope result of the slope model had been obtain. All the result of the analysis is shown at Table 6.1.

Slope condition	**FOS**
At static condition	1.24
At seismic horizontal force of 0.1g	0.92
Geo-reinforcement is installed by horizontally at the half height of slope (with seismic force of 0.1g)	1.01
Geo-reinforcement is installed by horizontally at 2.5 meter from the ground level (with seismic force of 0.1g)	1.00
Geo-reinforcement is installed at 2.5 meter from the ground level of the slope surface by diagonally downward	1.01
Geo-reinforcement is installed at 2.5 meter from the ground level of the slope surface by diagonally upward (with seismic force of 0.1g)	1.01
Two geo-reinforcements is installed horizontally at 2.5m and 7.5m respectively above the ground level (with seismic force of 0.1g)	1.10
Two geo-reinforcements is installed diagonally at 2.5m and 7.5m respectively above the ground level (with seismic force of 0.1g)	1.15

Table 6. 2: Summary for FOS of the model

From the table, we can see that when the slope is at static condition has the FOS of 1.24 which higher than 1, hence it is a stable slope. However when the slope model is apply with the horizontal seismic coefficient the FOS reduce to 0.92, and this show that the slope is not stable during this condition.

The geo-reinforcement(s) is added as to increase the FOS when the slope at the condition with a seismic force. With a standard properties of reinforcement is used, various arrangement of reinforcement for single reinforcement is try to the slope, however from the summary show that all the FOS for the single reinforcement is 1.01 for most of the arrangement, but only the reinforcement above 2.5, had the FOS of 1.00.

By using two reinforcements, we can say that it will increase the FOS more than when the slope model only has one reinforce, for the two horizontal reinforcements and diagonally reinforcements we have the FOS of 1.10 and 1.15 respectively. Hence, with the additional of reinforcement, this will increase the FOS and stable the slope when the slope is at the seismic activity, although we can see here the diagonal reinforcement will give a better FOS, but the arrangement of the reinforcement is still depend on the construction method that can installed at the site.

Chapter 7:
CONCLUSION AND FUTURE WORKS

7.1 FLAC/Slope software

The FLAC/Slope software had been learned through the process of this project. Although FLAC/slope is user-friendly, the current student version is limited to use for certain type of slope models. It has been found that, with this current version of FLAC/slope most of the slope only can analyse by course mesh are able to analyse the problem. The medium mesh and fine mesh has the limited usage to analyse, it only can be use to analyse slope that small angle of slope. To using the FLAC/Slope it is easy to learn but experience and engineering judgment for the slope model is essential required for more effective and accurate to obtain the FOS of the slope problem.

7.2 Slope Stability and Seismic Design Chart

By using the slope Stability number (N) and the pseudo-static approach with the assistance of FLAC/Slope software, the design chart for the seismic coefficient, k_h of 0.1, 0.2, 0.3 and 0.4g have been developed. It has been found that lower stability number is more prefer for a stability of slope analysis. As the low stability number will give a better result of factor of safety. Soil properties of c and γ together with the height of the slope is group factor of stability number will influence that choice of the stability number. The Design Chart will ease the preliminary design of a slope and also for quick checking.

With a FLAC/Slope models of slope that had been create to analyse further and to understand more about the stability of slope. A series of parametric studies have been performed using this model. The parameters of soil include the c, φ, γ and seismic coefficient k_h, is choose to determine the factor of safety. Different material properties will influence the factor of safety. It has been found that with the increase of the horizontal acceleration the slope stability will reduce it value of the factor of safety. It can be conclude that the seismic force will lower the factor of safety of a slope that will cause the slope failure.

To understand the more about the usage of the FALC/slope, a model of slope with seismic force applies to the slope has been develop using the FLAC/Slope. From this model Geo-reinforcement is add to the slopes, and it's had been found that with the Geo-reinforcement it will increase the Factor of safety of the slope and this will make the slope more stable.

7.3 Future works

The objectives of the project have been achieved. For the future works of this project to be considered are:

1) Design charts for the linear and non-linear seismic profile
2) Compare the result obtain from FLAC/Slope analysis with other software using limit equilibrium method such as Slope/W.
3) Using FLAC/Slope to analyse complex slope under seismic loading

List of References

1) Bromhead , E. N. 1986, *The Stability of Slopes*, Chapman and Hall, New York.
2) D F McCARHY 1998, Essential of Soil Mechanics and Foundations, Basic Geotechnics, Prentice Hall, New Jersey.
3) Hu, Yu-Xian et al 1996, *Earthquake Engineering*, Chapman & Hall, London
4) Hunt, Roy E. 1986, *Geotechnical Engineering Analysis and Evaluation,* McGraw-Hill, New York.
5) Itasca 2002, *FLAC/Slope User's Guide*, Itasca Consulting Group Inc.
6) John N., Cernica 1995, Geotechnical Engineering SOIL Mechanics, John Wiley & Sons Inc, New York.
7) L. Kramer, Steven 1996, *Geotechnical Earthquake Engineering*, Prentice-Hall Inc., USA.
8) M. Das, Braja 1990, *Principles of Geotechnical Engineering*, PWS-KENT, Boston.
9) R. Whitlow 1995, *Basic Soil Mechanics*, Longman, Malaysia.
10) 1995, *The Oxford Study Dictionary,* Pernerbit Fajar Bakti Sdn. Bhd., Shah Alam
11) W. Day, Robert 2000, *Geotechnical Engineer's Portable Handbook,* McGraw-Hill, New York.
12) S. Huges 2003, *Slope failure*, GEOL g406 Environmental Geology, Idaho State University, Available from: <http://wapi.isu.edu/EnvGeo/EnvGeo_Home/module_summary/EG4-MassWasting_files/frame.htm> [Accessed 5 Jun 2004]

Bibliography

1) Aysen, A 2002, *CIV3403 Geotechnical Engineering (Study Book)*, DEC University of Southern Queensland, Australia.
2) Helen Connolly 1997, *Slope Design*, University of Durham, Available from: <http://www.dur.ac.uk/~des0www4/cal/slopes/> [Accessed 3 April 2004]
3) Martel S. 2002, University of Hawaii, Available from: <http://www.soest.hawaii.edu/martel/Courses/GG454/GG454_Lec_27.pdf> [Accessed 10 April 2004]
4) North Anna n.d., *Early Site Permit Application Part 2 - Site Safety Analysis Report*, Available from: <http://www.nrc.gov/reactors/new-licensing/new-licensing-files/naesp-36.pdf> [Accessed 1 April 2004]
5) *Slope failure* (n.d.) [online], The U.S. Global research change research information office. Available from: <http://www.gcrio.org/geo/slope.html> [Accessed 30 March 2004]
6) *STABILITY OF SLOPES* n.d., Available from: <http://www.up.ac.za/academic/civil/divisions/geotechnical/pgcourses/sgm781/themes/theme5/objectives5.html> [Accessed 1 April 2004]
7) *Slope failure* n.d., Available from: <http://users.aber.ac.uk/otd2/Slope%20failure> [Accessed 1 April 2004]
8) Tony Price n.d., *Slope stability*, Warwick University, Available from: <http://fbe.uwe.ac.uk/public/geocal/SLOPES/SLOPES.HTM#SLOPES> [Accessed 30 March 2004]

Appendix A:

Project Specification

University of Southern Queensland
Faculty of Engineering and Surveying

ENG 4111/2 Research Project
PROJECT SPECIFICATION

FOR:	CHOO Yeun Feong
TOPIC:	Seismic stability of slopes
SUPERVISOR:	Dr. Jim Shiau
SPONSORSHIP:	Faculty of Engineering and surveying
PROJECT AIM:	The main objective of this project is to develop a pseudo-static analysis model based on the finite difference method of FLAC program. Our attention will focus on the application of modern numerical technique under constant seismic effects. An expected outcome of the project will be the development of earthquake resistant design charts for a variety of slope stability problems.
PROGRAMME:	**Issue B, 10 September 2004**

8. Research the background information on slope problems including:-
    - Cause of slope failures
    - Short and long term failures
    - Types of landslides and slope movements
    - Factor of safety

9. General review on the analysis and design of slopes under earthquakes – a pseudo-static approach.

10. Learn the finite difference software – FLAC.

11. Research on the effects of slopes under constant profiles.

12. Development of earthquake design charts

AGREED: …………………………… (student) ………………………. (Supervisor)
……………… (dated) ……………… (dated)

Appendix B:

Example Problem for FLAC/Slope software validation

B.1 Example

Example 11.3

Given The slope and soil properties, as shown in Fig. 11.8.

Find F via the approximate method of slices for the trial circle shown.

Procedure The slope was plotted to a convenient scale. For the assumed failure circle and the slices selected, the width of each slice is measured as 2.5 m. For each slice the angle α_i is measured, and so is the height of each slice. Unit thickness (1 m) is assumed normal to the page.

The calculations for slice 1 are as follows:

$$W_1 = (\text{area})\gamma = bh\gamma = \left(\frac{2.5 \times 3}{2}\right) 19.61 = 73.6 \text{ kN}$$

$$\overline{N}_1 = W_1 \cos \alpha_1 = 73.6 \cos 29° = 64$$

$$\alpha_1 = 29° \text{ (measured value)}$$

Figure B.1: Question

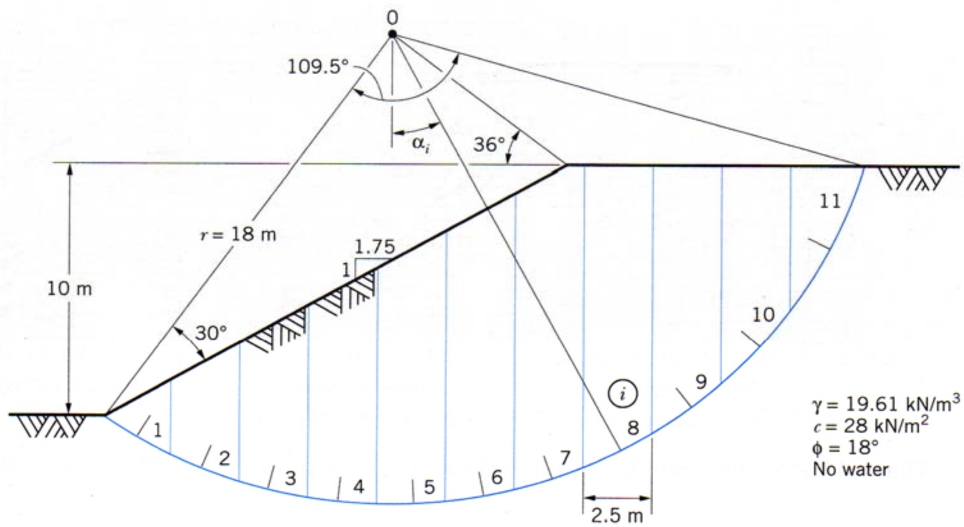


Figure 11.8 Slices encompassed by a trial failure arc.

$$T_{R_1} = 73.6 \sin 29° = 37$$

$$\overline{N}_1 \tan \phi = 64 \tan 18° = 20.8$$

The results for the entire slope are given in the following table:

Slice	1	2	3	4	5	6	7	8	9	10	11	Σ
W_i	73.6	196	319	406	479	536	571	544	467	353	142	—
$\overline{N}_i$	64	183	311	405	479	528	540	480	370	236	69	—
T_δ ↷	—	—	—	—	≈0	93	186	256	284	220	130	1169
T_R ↶	37	70	42	35	—	—	—	—	—	—	—	184
$\overline{N}_i \tan \phi$	21	59.6	101	132	156	172	175	156	120	77	22.4	1190
$\sum \Delta L = L$	$L = 2\pi r\left(\frac{109.5}{360}\right) = 34.4$											34.4
$\sum c\,\Delta l = cL$	$cL = 28 \times 34 = 963.2$											963.2
F	$F = \frac{1190 + 963.2 + 184}{1169} = 2.0$											

Note that slices 1–4 effect a counterclockwise rotation; hence they resist sliding. Slice 5 has a negligible tangential component (say 0).

Figure B.2: Solved Solution

Appendix C:

Input data for Material properties according to the Stability Number and Seismic coefficients

C.1 FLAC/Slope Soil properties input data

Initial Decide input data

Below table shown are the input data equal to the Stability Number for the angle of internal friction (φ) 5°, 10°, 15°, 20° and 25°.

Where the decided input data for height (*H*) is equal to 10 meter and the Factor of Safety is equal to1. Together with the respectively data of cohesion and unit weight to get the require stability number by using the formula of stability number.

Stability Number (N)	Cohesion (kN/m2)	Unit weight, γ (kN/m3)
0	0	50
0.02	10	50
0.04	20	50
0.06	30	50
0.8	40	50
0.1	50	50
0.12	60	50
0.14	70	50
0.16	80	50
0.18	90	50
0.2	100	50
0.22	66	30
0.24	72	30
0.26	78	30
0.28	84	30
0.3	90	30

Table C.1: Material properties according to the stability number

Stability Number (N)	Cohesion,c (kN/m2)	Unit weight, γ (kN/m3)
0.32	96	30
0.34	104	30
0.36	108	30
0.38	114	30
0.4	120	30
0.42	84	20
0.44	88	20
0.46	92	20
0.48	96	20
0.5	100	20
0.52	104	20
0.54	108	20

Table C.1: Material properties according to the stability number (continue)

C.2 Seismic coefficient input data

Seismic coefficient k	Horizontal acceleration a = kg (m/s^2)	Relative acceleration, r (m/s^2)	θ°
0.1	0.981	9.8589	5.7090°
0.2	1.962	10.0043	11.3116°
0.3	2.943	10.2419	16.6985°
0.4	3.924	10.5657	21.8015°
0.5	4.905	10.9679	26.5649°
0.6	5.886	11.4403	27.9979°

g is gravity acceleration [9.81 m/s^2]

Table C.2: Seismic coefficient input data

Appendix D:

FLAC/Slope result comparison with Taylor' Chart

D.1 Result comparison for material group of φ = 5°

N	Taylor's Chart (*i*°)	FLAC/Slope result (*i*°)
0	5	4.8
0.02	7	7.7
0.04	9	10.4
0.06	13	14.2
0.08	19	19.5
0.10	26.5	27
0.12	36	37
0.14	48	49.5
0.16	59.5	59.8
0.18	69.5	71
0.20	78	77
0.22	85	83

Table D.1: Comparison for material group of φ = 5°

D.2 Result comparison for material group of φ = 10°

N	Taylor's Chart (*i*°)	FLAC/Slope result (*i*°)
0	9	9.5
0.02	13	15.1
0.04	19	20.1
0.06	25.5	26
0.08	32.5	33.3
0.10	40	42
0.12	51	51
0.14	61	60
0.16	70	70.5
0.18	78	76
0.20	85	84.5

Table D.2: Comparison for material group of φ = 10°

D.3 Result comparison for material group of φ = 15°

N	Taylor's Chart (*i*°)	FLAC/Slope result (*i*°)
0	13	14.8
0.02	22	22.6
0.04	27	28.5
0.06	35.7	35.6
0.08	43	44.1
0.10	53	52.7
0.12	62	60.9
0.14	72	71.5
0.16	78	77.7
0.18	85	85.5

Table D.3: Comparison for material group of φ = 15°

D.4 Result comparison for material group of φ = 20°

N	Taylor's Chart (*i*°)	FLAC/Slope result (*i*°)
0	19	20.2
0.02	26	28.3
0.04	35	35.5
0.06	44	44
0.08	53	53
0.10	61	61.8
0.12	68.5	69
0.14	75.5	77.5
0.16	82	82.5

Table D.4: Comparison for material group of φ = 20°

D.5 Result comparison for material group of φ = 25°

N	Taylor's Chart (*i*°)	FLAC/Slope result (*i*°)
0	26.7	25.2
0.02	37.3	35.3
0.04	46.7	43.8
0.06	54	53
0.08	61.3	62
0.10	69.3	67.4
0.12	76	76
0.14	82.7	83.3
0.16	88	86.6

Table D.5: Comparison for material group of φ = 25°

D.6 Tabulated graph of the FLAC/slope result which k_h is 0

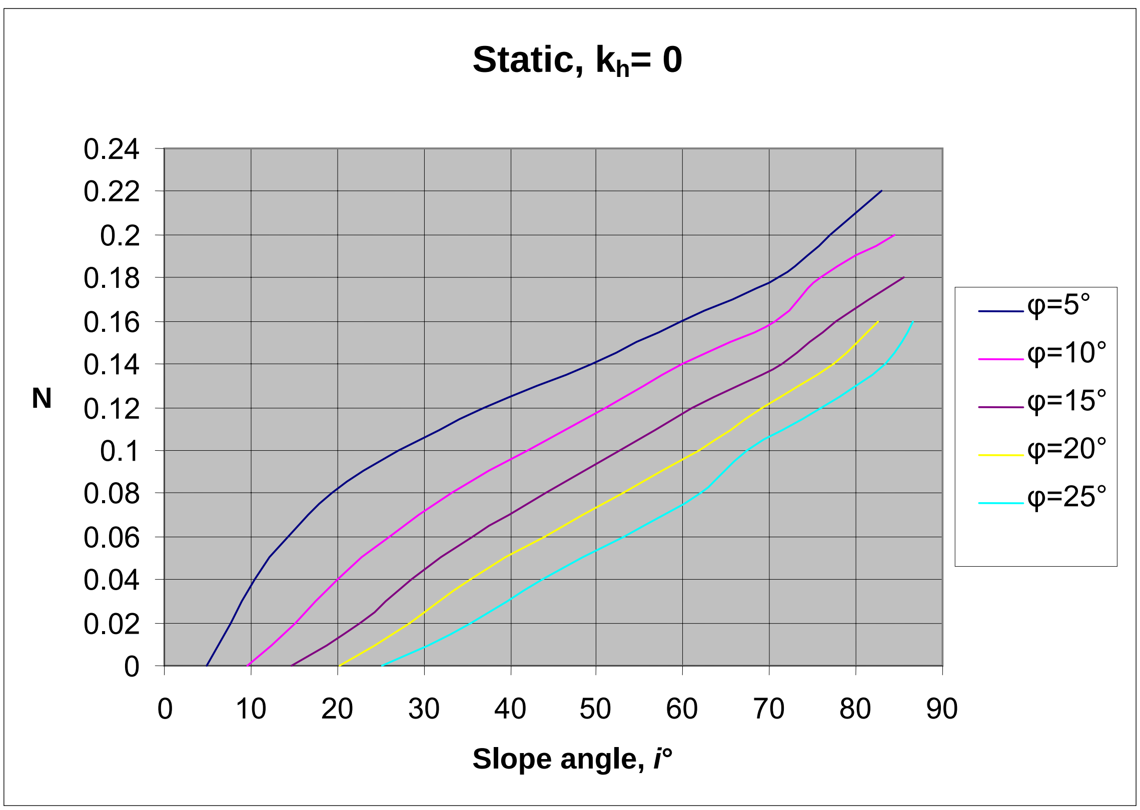


Figure D.1: Tabulated graph of the FLAC/slope result

Appendix E:

Boundary of slope analysis for Design Chart

E.1 Boundary of the model

The entire parameter rise, depth, left and right is the input data for the slope geometry at the "Edit slope parameters" window of the FLAC/Slope.

The parameter for rise, for the every slope model is decided as 10 meter.

The parameter for depth, for the every slope model is decided as 10 meter.

Boundary for the parameter of the length of the left and right of the slope is determined by the condition specify below according to its angle of internal friction, φ.

E.1.1 Boundary for the model at static (k_h = 0), [used to validity of model]

The boundary of the parameter of the slope has been produce the validity of the model by compare with the Taylor Chart

Stability number (N)	**Slope angle, *i*°**	**Left**	**Right**
0	4.8	20	20
0.02	7.7	20	20
0.04	10.4	20	20
0.06	14.2	20	20
0.08	19.5	20	20
0.10	27	20	20
0.12	37	20	20
0.14	49.5	20	20
0.16	59.8	20	20
0.18	71	30	30
0.20	77	30	30
0.22	83	39	39

Table E.1: Boundary parameter for φ = 5° (k_h = 0)

Stability number (N)	Slope angle, *i*°	Left	Right
0	9.5	10	10
0.02	15.1	10	10
0.04	20.1	10	10
0.06	26	10	10
0.08	33.3	10	10
0.10	42	10	10
0.12	51	10	10
0.14	60	10	10
0.16	70.5	20	20
0.18	76	20	20
0.20	84.5	35	35

Table E.2: Boundary parameter for $\varphi = 10°$ ($k_h = 0$)

Stability number (N)	Slope angle, *i*°	Left	Right
0	14.8	10	10
0.02	22.6	10	10
0.04	28.5	10	10
0.06	35.6	10	10
0.08	44.1	10	10
0.10	52.7	10	10
0.12	60.9	10	10
0.14	71.5	20	20
0.16	77.7	20	20
0.18	85.5	30	30

Table E.3: Boundary parameter for $\varphi = 15°$ ($k_h = 0$)

Stability number (N)	Slope angle, *i*°	Left	Right
0	20.2	10	10
0.02	28.3	10	10
0.04	35.5	10	10
0.06	44	10	10
0.08	53	10	10
0.10	61.8	10	10
0.12	69	10	10
0.14	77.5	15	15
0.16	82.5	15	15

Table E.4: Boundary parameter for $\varphi = 20°$ ($k_h = 0$)

Stability number (N)	Slope angle, *i*°	Left	Right
0	25.2	10	10
0.02	35.3	10	10
0.04	43.8	10	10
0.06	53	10	10
0.08	62	10	10
0.10	69.4	10	10
0.12	76	10	10
0.14	83.3	15	15
0.16	86.6	15	15

Table E.5: Boundary parameter for φ = 20° (k_h = 0)

E.1.2 Boundary for the model at k_h = 0.1

Stability number (N)	Slope angle, *i*°	Left	Right
0		20	20
0.02		20	20
0.04		20	20
0.06	3.4	20	20
0.08	5.5	20	20
0.10	8.5	20	20
0.12	13	20	20
0.14	19.5	20	20
0.16	35	20	20
0.18	52	20	20
0.20	62	20	20
0.22	71	30	30
0.24	75.5	30	30
0.26	80	39	39
0.28	83	39	39
0.30	85.5	39	39

Table E.6: Boundary parameter for φ = 5° (k_h = 0.1)

Stability number (N)	Slope angle, *i*°	Left	Right
0	4.1	20	20
0.02	7.5	20	20
0.04	10.8	20	20
0.06	15	20	20
0.08	22	20	20
0.10	30	20	20
0.12	39.9	20	20
0.14	51	20	20
0.16	59	20	20
0.18	66	20	20
0.20	71.5	20	20
0.22	76	20	20
0.24	79.5	20	20
0.26	84.5	35	35
0.28	87	35	35

Table E.7: Boundary parameter for φ = 10° (k_h = 0.1)

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0	9	15	15
0.02	15	15	15
0.04	20.5	15	15
0.06	26	15	15
0.08	34.3	15	15
0.10	43	15	15
0.12	52	15	15
0.14	60	15	15
0.16	67	15	15
0.18	73.5	20	20
0.20	77.8	20	20
0.22	81	20	20
0.24	85.5	30	30

Table E.8: Boundary parameter for φ = 15° (k_h = 0.1)

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0	14.3	10	10
0.02	22.3	10	10
0.04	27.5	10	10
0.06	34.5	10	10
0.08	43	10	10
0.10	51.5	10	10
0.12	59.5	10	10
0.14	66.3	10	10
0.16	72	10	10
0.18	76	10	10
0.20	80.5	15	15
0.22	83.5	15	15

Table E.9: Boundary parameter for $\varphi = 20°$ ($k_h = 0.1$)

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0	19.5	10	10
0.02	27.5	10	10
0.04	35.3	10	10
0.06	43.8	10	10
0.08	52	10	10
0.10	60	10	10
0.12	66.5	10	10
0.14	72.5	10	10
0.16	77	10	10
0.18	82	15	15

Table E.10: Boundary parameter for $\varphi = 25°$ ($k_h = 0.1$)

E.1.3 Boundary for the model at $k_h = 0.2$

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0.06	-	-	-
0.08	-	-	-
0.10	-	-	-
0.12	2.3	20	20
0.14	3.6	20	20
0.16	5.5	20	20
0.18	9.7	20	20
0.20	14.3	20	20
0.22	36.3	20	20
0.24	61	20	20
0.26	66.8	20	20
0.28	71.5	30	30
0.30	74.8	30	30
0.32	77.3	30	30
0.34	81	39	39
0.36	83.5	39	39
0.38	85.5	39	39

Table E.11: Boundary parameter for $\varphi = 5°$ ($k_h = 0.2$)

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0	-	-	-
0.02	-	-	-
0.04	-	-	-
0.06	3	10	10
0.08	5.3	10	10
0.10	9.5	10	10
0.12	15	10	10
0.14	26	10	10
0.16	39	10	10
0.18	49	10	10
0.20	57.3	10	10
0.22	63	10	10
0.24	70	20	20
0.26	73	20	20
0.28	75.5	20	20
0.30	77.8	20	20
0.32	81.8	30	30
0.34	84.3	30	30

Table E.12: Boundary parameter for $\varphi = 10°$ ($k_h = 0.2$)

Stability number (N)	**Slope angle, *i*°**	**Left(m)**	**Right(m)**
0	3.7	10	10
0.02	6.7	10	10
0.04	10.3	10	10
0.06	14.8	10	10
0.08	21	10	10
0.10	27.5	10	10
0.12	37	10	10
0.14	45.5	10	10
0.16	53.5	10	10
0.18	60.5	10	10
0.20	65.5	20	20
0.22	72.3	20	20
0.24	75	20	20
0.26	77.5	20	20
0.28	79.8	20	20
0.30	83.8	30	30

Table E.13: Boundary parameter for $\varphi = 15°$ ($k_h = 0.2$)

Stability number (N)	**Slope angle, *i*°**	**Left(m)**	**Right(m)**
0	8.6	10	10
0.02	14.1	10	10
0.04	20	10	10
0.06	25	10	10
0.08	34.5	10	10
0.10	39.5	10	10
0.12	48.3	10	10
0.14	55.7	10	10
0.16	62	10	10
0.18	67	10	10
0.20	72.5	15	15
0.22	75.5	15	15
0.24	77.8	15	15
0.26	80	15	15
0.28	82.8	20	20

Table E.14: Boundary parameter for $\varphi = 20°$ ($k_h = 0.2$)

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0	14	10	10
0.02	22	10	10
0.04	26	10	10
0.06	33	10	10
0.08	41.5	10	10
0.10	49.5	10	10
0.12	57.5	10	10
0.14	63.5	10	10
0.16	68.5	10	10
0.18	72.5	10	10
0.20	75.5	10	10
0.22	77.5	10	10
0.24	80.3	20	20
0.26	82.2	20	20

Table E.15: Boundary parameter for $\varphi = 25°$ ($k_h = 0.2$)

E.1.4 Boundary for the model at $k_h = 0.3$

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0.18	-	-	-
0.20	-	-	-
0.22	-	-	-
0.24	-	-	-
0.26	-	-	-
0.28	9.4	20	20
0.30	61	20	20
0.32	66	20	20
0.34	69.8	20	20
0.36	72.5	30	30
0.38	75	30	30
0.4	76.8	30	30

Table E.16: Boundary parameter for $\varphi = 5°$ ($k_h = 0.3$)

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0.10	-	-	-
0.12	-	-	-
0.14	-	-	-
0.16	5	10	10
0.18	7.3	10	10
0.20	36	10	10
0.22	47	10	10
0.24	55	10	10
0.26	60.5	10	10
0.28	64.5	10	10
0.30	67.5	10	10
0.32	69.8	10	10
0.34	73.5	20	20
0.36	74.5	20	20
0.38	75.6	20	20

Table E.17: Boundary parameter for $\varphi = 10°$ ($k_h = 0.3$)

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0	-	-	-
0.02	-	-	-
0.04	-	-	-
0.06	2.5	10	10
0.08	4.8	10	10
0.10	10.2	10	10
0.12	17	10	10
0.14	26	10	10
0.16	37	10	10
0.18	46.3	10	10
0.20	53.5	10	10
0.22	59	10	10
0.24	64	10	10
0.26	67	10	10
0.28	69.5	10	10
0.30	73.2	20	20
0.32	74.7	20	20
0.34	76.3	20	20

Table E.18: Boundary parameter for $\varphi = 15°$ ($k_h = 0.3$)

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0	3.5	10	10
0.02	6.5	10	10
0.04	10	10	10
0.06	14.3	10	10
0.08	20	10	10
0.10	26.7	10	10
0.12	34	10	10
0.14	42	10	10
0.16	50	10	10
0.18	57	10	10
0.20	61.5	10	10
0.22	65.5	10	10
0.24	68.5	10	10
0.26	71	10	10
0.28	72.7	10	10
0.30	73.8	10	10
0.32	74.4	10	10

Table E.19: Boundary parameter for $\varphi = 20°$ ($k_h = 0.3$)

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0	8.3	10	10
0.02	14	10	10
0.04	18.8	10	10
0.06	24.9	10	10
0.08	29.5	10	10
0.10	37	10	10
0.12	45	10	10
0.14	52.5	10	10
0.16	59	10	10
0.18	63.5	10	10
0.20	67	10	10
0.22	70	10	10
0.24	72	10	10
0.26	73.5	10	10

Table E.20: Boundary parameter for $\varphi = 25°$ ($k_h = 0.3$)

E.1.5 Boundary for the model at $k_h = 0.4$

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0.34	-	-	-
0.36	-	-	-
0.38	64	20	20
0.40	65.8	20	20
0.42	67.3	20	20
0.44	72.5	35	35
0.46	74.5	35	35
0.48	76	35	35
0.5	78	35	35
0.52	80.5	39	39

Table E.21: Boundary parameter for $\varphi = 5°$ ($k_h = 0.4$)

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0.20	-	-	-
0.22	-	-	-
0.24	-	-	-
0.26	-	-	-
0.28	51.5	10	10
0.30	56	10	10
0.32	60.5	10	10
0.34	64	10	10
0.36	65.3	10	10
0.38	66.8	10	10
0.40	68	10	10
0.42	70.3	20	20

Table E.22: Boundary parameter for $\varphi = 10°$ ($k_h = 0.4$)

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0.18	-	-	-
0.20	34	10	10
0.22	44	10	10
0.24	51.5	10	10
0.26	56.5	10	10
0.28	60.3	10	10
0.30	63.3	10	10
0.32	65.3	10	10
0.34	67.3	10	10
0.36	68	10	10
0.38	70.7	20	20
0.4	71.7	20	20

Table E.23: Boundary parameter for $\varphi = 15°$ ($k_h = 0.4$)

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0.08	4.3	10	10
0.10	9.5	10	10
0.12	17.5	10	10
0.14	25	10	10
0.16	33	10	10
0.18	41.5	10	10
0.20	49	10	10
0.22	54.5	10	10
0.24	59.5	10	10
0.26	62.5	10	10
0.28	65	10	10
0.30	66.8	10	10
0.32	68	10	10
0.34	70.2	15	15
0.36	74.5	15	15
0.38	75.6	15	15

Table E.24: Boundary parameter for $\varphi = 20°$ ($k_h = 0.4$)

Stability number (N)	Slope angle, *i*°	Left(m)	Right(m)
0	3.8	10	10
0.02	6.3	10	10
0.04	9.5	10	10
0.06	14.3	10	10
0.08	19.8	10	10
0.10	25	10	10
0.12	30.5	10	10
0.14	37	10	10
0.16	45.5	10	10
0.18	52.3	10	10
0.20	57.5	10	10
0.22	61.5	10	10
0.24	64.3	10	10
0.26	66.3	10	10
0.28	67.8	10	10
0.30	70.3	15	15

Table E.25: Boundary parameter for φ = 25° (k_h = 0.4)

E.2 Summary of the Boundary of the model decided for FLAC/slope

This is the summary of the boundary of the slope geometry that had been considered into from the analysis of the slope under static condition to be entering into "Edit slope parameters" window of the FLAC/Slope. This will be use as a guide for analysis the seismic slope to obtain data for the design chart

Slope angle, i°	Left (m)	Right (m)
0 - 80	10	10
80 and above	15	15

Table E.26: Boundary parameter for φ = 25°

Slope angle, i°	Left (m)	Right (m)
0 - 70	10	10
70 - 80	20	20
80 and above	30	30

Table E.27: Boundary parameter for φ = 20°

Slope angle, i°	**Left (m)**	**Right (m)**
0 - 70	10	10
70 - 80	20	20
80 and above	35	35

Table E.28: Boundary parameter for $\varphi = 15°$

Slope angle, i°	**Left (m)**	**Right (m)**
0 - 70	10	10
70 - 80	20	20
80 and above	35	35

Table E.29: Boundary parameter for $\varphi = 10°$

Slope angle, i°	Left (m)	Right (m)
0 - 70	20	20
70 - 80	30	30
80 and above	39	39

Table E.30: Boundary parameter for $\varphi = 5°$

Appendix F:

Table of result for Seismic Design Chart

F.1 For k = 0.1 chart

	Slope angle i				
N	**phi25**	**phi20**	**phi15**	**phi10**	**phi5**
0	19.5	14.3	9	4.1	
0.02	27.5	22.3	15	7.5	
0.04	35.3	27.5	20.5	10.8	
0.06	43.8	34.5	26	15	3.4
0.08	52	43	34.3	22	5.5
0.1	60	51.5	43	30	8.5
0.12	66.5	59.5	52	39.9	13
0.14	72.5	66.3	60	51	19.5
0.16	77	72	67	59	35
0.18	82	76	73.5	66	52
0.2		80.5	77.8	71.5	62
0.22		83.5	81	76	71
0.24			85.5	79.5	75.5
0.26				84.5	80
0.28					83
0.3					85.5

Table F.1: Data for k = 0.1 chart

F.2 For k = 0.2 chart

	Slope angle, i				
N	**phi25**	**phi20**	**phi15**	**phi10**	**phi5**
0	14	8.6	3.7		
0.02	22	14.1	6.7		
0.039	26	20	10.3		
0.06	33	25	14.8	3	
0.085	41.5	34.5	21	5.3	
0.103	49.5	39.5	27.5	9.5	
0.12	57.5	48.3	37	15	2.3
0.14	63.5	55.7	45.5	26	3.6
0.16	68.5	62	53.5	39	5.5
0.186	72.5	67	60.5	49	9.7
0.2	75.5	72.5	65.5	57.3	14.3
0.22	77.5	75.5	72.3	63	36.3
0.24	80.3	77.8	75	70	61
0.26	82.2	80	77.5	73	66.8
0.28		82.8	79.8	75.5	71.5
0.3			83.8	77.8	74.8
0.32				81.8	77.3
0.34				84.3	81
0.36					83.5
0.38					85.5

Table F.2: Data for k = 0.2 chart

F.3 For k = 0.3 chart

	Slope angle, i				
N	**phi25**	**phi20**	**phi15**	**phi10**	**phi5**
0	8.3	3.5			
0.02	14	6.5			
0.04	18.8	10			
0.06	24.9	14.3	2.5		
0.076	29.5	20	4.8		
0.1	37	26.7	10.2		
0.12	45	34	17		
0.14	52.5	42	26		
0.16	59	50	37	5	
0.18	63.5	57	46.3	7.3	
0.2	67	61.5	53.5	36	
0.22	70	65.5	59	47	
0.24	72	68.5	64	55	
0.26	73.5	71	67	60.5	
0.28		72.7	69.5	64.5	9.4
0.3		73.8	73.2	67.5	61
0.32		74.4	74.7	69.8	66
0.34			76.3	73.5	69.8
0.36				74.5	72.5
0.38				75.6	75
0.4					76.8

Table F.3: Data for k = 0.3 chart

F.4 For k = 0.4

	Slope angle, i				
N	**phi 25**	**phi 20**	**phi 15**	**phi 10**	**phi 5**
0	3.8				
0.02	6.3				
0.04	9.5				
0.06	14.3				
0.08	19.8	4.3			
0.1	25	9.5			
0.12	30.5	17.5			
0.14	37	25			
0.16	45.5	33			
0.18	52.3	41.5			
0.2	57.5	49	34		
0.22	61.5	54.5	44		
0.24	64.3	59.5	51.5		
0.26	66.3	62.5	56.5		
0.28	67.8	65	60.3	51.5	
0.3	70.3	66	63.3	56	
0.32		68	65.3	60.5	
0.34		70.2	67.3	64	
0.36			68	65.3	
0.38			70.7	66.8	64
0.4				68	65.8
0.42				70.3	67.3
0.44					72.5

Table F.4: Data for k = 0.4 chart

	Slope angle, i				
N	**phi 25**	**phi 20**	**phi 15**	**phi 10**	**phi 5**
0.46					74.5
0.48					76
0.5					78
0.52					80.5

Table F.4: Data for k = 0.4 chart (continue)