

**Numerical Modelling of Complex Slope Using
FLAC/SLOPE**

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**Numerical Modelling of Complex Slope Using
FLAC/SLOPE**

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Abstract

This research presents a study on the slope stability analysis software – FLAC/Slope. The study deals with simulations work and creation of models range from mesh and boundary effect, effect of complex geometry and layer soil, effect of geo-grid, effect of water table and effect of surcharge loads. Generally, the purpose of this research is to learn and assess this FLAC/Slope software regarding to its user-friendliness and reliability. The results regarding to these issues will be obtained via analyzing 5 models by using the range of models mention above. This would in turn use to compare with on-the-shelf reference such as from literature review, and several texts. If the value for the factor of safety is close to the value for the factor of safety in these references, it can be conclude that its given result is reliable. As the interface of the software is relatively easy, it can be conclude that it is user-friendly.

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ENG4111 & ENG4112 *Research Project*

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Chapter 1 Introduction

1.1 General

In recent years, there are numbers of landslides occur everywhere. Most of the landslides happen on the cut slopes or embankment along roads, highway and sometimes within the vicinity of highly populated residential areas especially those in the highly terrain. Thus, a proper understanding, monitoring and management of slope stability are essentially important to minimize the severity or casualty in any landslide.

Generally, there are a number of on the shelf slope stability analysis software available in the market. Although, all of them are capable to analyze the stability of slope, their user friendliness and the accuracy of the result will vary from each other. In this project, FLAC/SLOPE software will be used to analyze a number of complex slopes. In addition, the accuracy of the result provided by FLAC/SLOPE will also be taken into consideration.

1.2 Project Objective

The primary objective of this project is to develop a number of numerical models to analyze the complex slope stability by using analysis software – FLAC/SLOPE. The ranges of the problem that will be covered in this project are:

- Simple Slope
 - mesh effect
 - boundary effect
- Non-homogeneous soil
- Thin and weak layer
- Geo-grid reinforcement
- Earthquake loadings

Chapter 2 Literature review

2.1 Background information on Slope problems

2.1.1 Introduction

In natural, surface topography have never exists in stable stage. By aided of wind and rain, the gravity force moves the hills into the valleys and the valleys into the oceans. Continuous tectonic and intermittent seismic action forms new hills and the cycle of change is continues. However, the construction works locally interrupt the natural cycle of change by excavating into the ground with slope in the natural soil, by filling on top of the ground with slopes outlining the embankment, by covering the ground with impervious blankets, by stepping the surfaces and holding the upper levels with retaining walls, by modifying the groundwater content or level, by storing soil-like materials with bins and so on. In some of these construction works, the strength of natural soil is degraded or the necessary strength of the soil in the relocated position is not provided. Consequently, this failure will lead to a landslide.

2.1.2 Cause of slope failures

The cause of slope failures may be divided into two categories, which are external and internal failures.

2.1.2.1 External

The external causes of failures are those which produce an increase in the shearing stresses at unaltered shearing resistance of the material. They included steepened of the slope, deposition of material along the edge of slopes, removal of lateral support through the erosive power of streams, glaciers, waves, and long-shore and tidal current, through weathering, wetting, drying and freeze-thaw cycles in surface materials, and earthquake forces.

2.1.2.2 Internal

The internal causes of failures are those which lead to a slide without any change in surface conditions which involve unaltered shearing stresses in the slope material. Such a condition is the decrease in shearing resistance brought about by excess pore water pressure, leaching of salts, softening, breakage of cementation bonds and ion exchange.

2.1.3 Short and Long term failures

The study of the stability of natural slope and cuts may be divided into two conditions namely, short and long term conditions. The short term instability is due to non-availability of sufficient time for the dissipation of pore water pressure. However, the long term condition is one in which the pore water pressure gradually adjusts itself in the long run and shows values corresponding to a certain ground water condition.

In the stability analysis of slopes, one may adopt effective or total stress analysis depending on the field situation. In effective stress analysis, according to Raj (1995), the proportion of the shear strength mobilized (actual stress) for limiting equilibrium is expressed as

$$\tau = \left(\frac{c'}{F}\right) + (\sigma_n - u_w)\left(\frac{\tan\phi'}{F}\right)$$

According to Raj (1995), a suitable normal stress distribution have to be assumed and an appropriate value of the pore water pressure, u_w has to be used, which depends on the class of stability problem as below:

- In class A problems, where the pore water pressure is an independent variable, the value of u_w will be obtained from ground water level if there is no flow or from a flow net, if a state of steady seepage exists.
- In class B problems, where the magnitude of pore water pressure depends on a change in stress.

Furthermore, he also claim that in total stress analysis, the proportion of the shear strength mobilized for the $\phi_u = 0$ condition is expressed as

$$\tau = \frac{C_u}{F}$$

2.1.4 Types of landslide and slope movements

According to Raj (1995) in Skempton and Hutchinson (1969), report that there are five types of basic landslide and six complex forms of movements.

2.1.4.1 Basic types of landslides

➤ Falls

Removal of lateral earth support causes bulging at the toe and tension crack at the top.



Figure 2.1 Falls (Raj, 1995)

➤ Rotational slides (slips, slump)

This occurred when the curved of failure being concave upwards, impacts a back-tilt to the slipping mass resulting in sinking at the rear and heaving at the toe.



Figure 2.2 Rotational slides (Slips & Slumps) (Raj, 1995)

➤ Compound slides

The surface of failure is pre-determined by the presence of heterogeneity with the slope material.

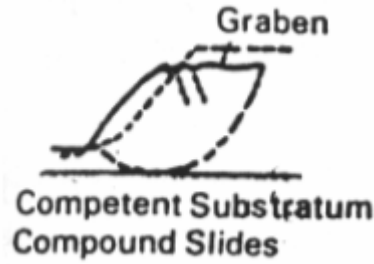


Figure 2.3 Compound slides(Raj, 1995)

➤ Translational slides

These are planar and most commonly occur in a mantle of weathered material, the heterogeneity being at a shallow depth. Normally such slides occur as block or slab slides.

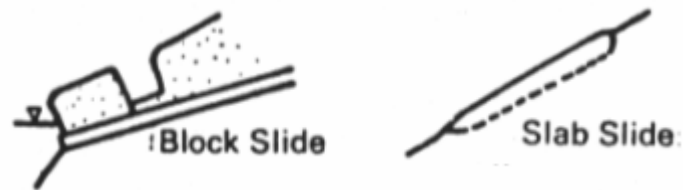


Figure 2.4 Translational slides (Raj, 1995)

➤ Flows

This occurs as a mass movement which may be of either earth flow or mud flow.

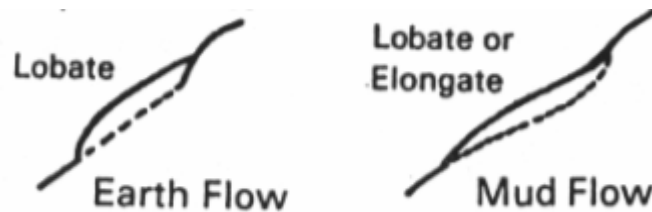


Figure 2.5 Flows (Raj, 1995)

2.1.4.2 Multiple and complex slides

➤ Successive slips

Normally occur consists of an assembly of individual shallow rotational slips.



Figure 2.6 Successive slides (Raj, 1995)

➤ Multiple retrogressive slides

These slides occur more frequently in actively eroding slopes of fairly high relief in which a thick stratum of over consolidated fissured clay or clay-shale is overlain by a rock of considerable strength.

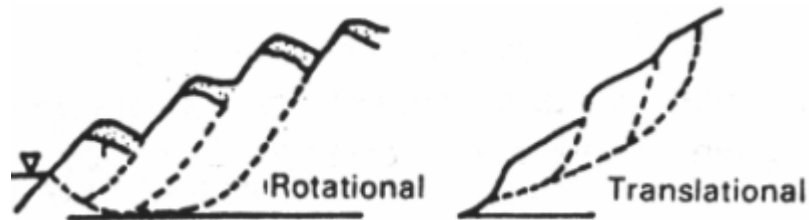


Figure 2.7 multiple retrogressive slides (Raj, 1995)

➤ Slump-earth flows

These are a fairly common type of mass movement which are intermediate between rotational slides and mud flows.



Figure 2.8 Slump earth flow (Raj, 1995)

➤ Slide colluviums

These develop typically in the accumulation zones below freely degrading cliffs.



Figure 2.9 Slides in Colluvium (Raj, 1995)

➤ Spreading failures

These are a particular type of retrogressive translational slide.

➤ Quick clay slides

Such slides generally begin with an initial rotational slip in the bank of a stream incised into quick clay deposits.

2.2 Analysis and design of slope failure

In the slope stability analysis, there are a lot of methods available can be used to present slope stability analysis. According to Huang (1983) in Hopkins, Allen and Deen (1975), it is stated that the methods can be broadly divided into three categories, which is based on the number of equilibrium equation to be satisfied.

2.2.1 Methods which satisfy Overall Moment Equilibrium

2.2.1.1 Fellenius Method

The fellenius method has been used extensively for many years because it is applicable to non-homogeneous slopes and is very amenable to hand calculation. This method is applicable only to circular failure surfaces and considers only the overall moment equilibrium and the forces on each side of the slice are ignored. When high pore water pressures are present, this method have been modified based on the concept of submerged weight and hereafter called the normal method. (Huang, 1983)

2.2.1.2 Simplified Bishop 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 2.10).

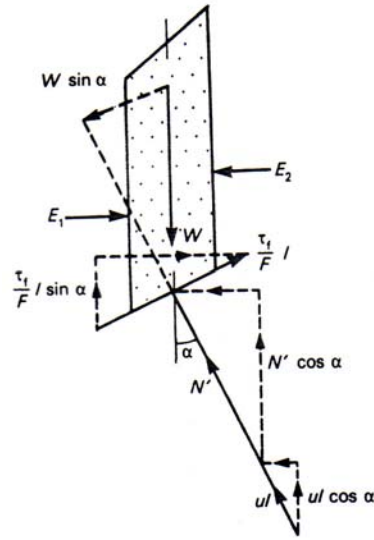


Figure 2.10 Bishop's simplified slice (R. Whitlow, 1995)

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

For the equilibrium along the base of the slice:

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

So that,

$$F = \frac{\sum (c' l + N' \tan \phi')}{\sum W \sin \alpha}$$

For equilibrium in a vertical direction

$$\begin{aligned} 0 &= W - N' \cos \alpha - ul \cos \alpha - \frac{\tau_f}{F} l \sin \alpha \\ &= W - N' \cos \alpha - ul \cos \alpha - \frac{c'}{F} l \sin \alpha - \frac{N' \tan \phi'}{F} \sin \alpha \end{aligned}$$

Then,

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

After substituting for,

$$l = b \sec \alpha$$

And N' rearranging

$$F = \frac{1}{\sum W \sin \alpha} \sum \frac{[c'b + (W - ub) \tan \phi'] \sec \alpha}{1 + \frac{\tan \alpha \tan \phi'}{F}}$$

“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)

2.2.2 Force Equilibrium Methods

In this category, the methods have been use is only satisfy the overall vertical and horizontal force equilibrium as well as the force equilibrium in individual slices or blocks. Although moment equilibrium is not explicitly considered, these methods may give accurate results if the inclination of the side forces is assumed in such a manner that the moment equilibrium is implicitly satisfied. Arbitrary assumptions on the inclination of side forces have a large influence on the factor of safety. Depending on the inclination of side forces, a range of safety factors may be obtained in many problems. (Huang, 1983)

2.2.3 Moment and Force equilibrium Methods

In this category, the methods included are Janbu's Method, Morgenstern and Price's Method, and Spencer's Method.

2.2.3.1 Janbu's Method

In Janbu's Method, the location of the interslice normal force or the line of thrust must be arbitrarily assumed. For cohesionless soils, the line of thrust should be selected at or very near the lower third point. However, in cohesive soils, the line of the thrust should be located above the lower third point in a compressive zone (passive zone) and somewhat below it in an expansive zone (active condition). This method is very easy to use and does not require a lot of individual judgment.

2.2.3.2 Morgenstern and Price's Method

This method is developed by Morgenstern and Price (1965) which consider not only the normal and tangential equilibrium but also the moment equilibrium for each slice. In this method, a simplifying assumption is made regarding the relationship between the interslice shear force and the normal force. This method needs a lot of individual judgment. For example, when the assumption has been made and the output has been obtained from the computer, all the quantities must be examined to determine whether they seem reasonable. Otherwise, a new assumption has to be made. According to Huang (1983) in Whitman and Bailey (1967), it is stated that by solving several problems using Morgenstern and Price's method and the simplified Bishop method, it will found that resulting difference will be seven percent or less. However, in practice, it is normally less than two percent.

2.3 Computer Applications in slope stability analysis

2.3.1 Introduction

As computer applications are gradually become common in many fields, engineers also keep track to take advantage of computer to solve engineering problems. There are several advantages of using computerized solution for engineering problems, there are as below:

- The amount of time to perform an analysis can be greatly reduced.
- Computer solutions can be more detailed than hand calculations. Performing a solution manually often requires many simplifying assumptions.
- The solution process may be less error-prone. For example, unit conversion and the rewriting of equations to solve for any variable, where hand calculation often tend to have mistakes, while a well-tested computer program can be avoid these error.
- The solution is easily documented and reproducible.
- Because of the speed and accuracy of a computer model, more comparisons and design trials can be performed in less time than a single computation done by hand. This results in the exploration of more options, which eventually leads to better and more efficient designs.

This part of literature review presents the review of several on the shelf software for slope stability analysis. There are Slope/w and T/slope.

2.3.2 Slope/w Software

Slope/W is the leading software product that used for computing the factor of safety of earth and rock slopes. With Slope/W, engineer can analyze both simple and complex problems for a variety of slop surface shape, pore-water pressure conditions, soil properties, analysis methods and loading conditions. Besides that, by using limit equilibrium, Slope/W can model heterogeneous soil types, complex stratigraphic and slip surface geometry, and variable pore-water pressure condition using a large selection of soil models. Analyses can be performed using deterministic or probabilistic input parameters. Stresses computed by a finite element stress analysis may be used in addition to the limit equilibrium computation for the most complete slope stability analysis available.

The features of the software are:

- Limit equilibrium methods include Morgenstern-Price, GLE, Spencer, Bishop, Ordinary, Janbu and more.
- Soil strength models include Mohr-Coulomb, Bilinear, Un-drained ($\Phi = 0$), anisotropic strength, shear/normal function and many types of strength functions.
- Specify many types of inter-slice shear-normal force functions.
- Pore-water pressure options include R_u coefficients, piezometric line, pressure contours, a kriged grid of value, or finite element computed heads or pressures
- Define potential slip surfaces by a grid of centers and radius lines, blocks of slip surface points or fully specified shapes
- Use probabilistic soil properties, line loads and piezometric lines
- Undo and redo commands

Typical application of Slope/W into any stabilities problem includes:

- Natural earth and rock slopes

- Sloping excavations
- Earth embankments
- Open-pit high walls
- Anchor retaining structures
- Berms at the toe of a slope
- Surcharges at the top of a slope
- Earth reinforcement, including soil nails and geofabrics
- Seismic and earthquake loading
- Tension cracks
- Partial and total submergence
- Line load at any point
- Unsaturated soil behavior

2.3.3 T/Slope

T/Slope is an easy-to-use program that helps civil engineers with the slope stability analysis. This software is designed for limit equilibrium slope stability analyses of noncircular slip surfaces by either the Spencer or Morgenstern and Price Method. In order to start analysis, the user only needs to specify the potential slip surface and soil properties along that slip surface, than the program will search for the critical seismic coefficient in which this seismic coefficient is reduces the factor of safety to unity.

The major components of the software include:

- Graphical interface for problem input
- Application of line loads and pressures to the slope for easy modeling of anchors and internal reinforcement that provided by geo-grids.
- Pseudo-static analyses and automatic searches for the critical seismic coefficient

- Computation of pressures on a submerged slope and pressures due to fluid in tension cracks.
- Computation of pore pressures given the phreatic surface or average pore pressure ratio.

Besides that, this software also provides the functionality as below:

- Variation of un-drained shear strengths with initial shear stress and direction.
- Two-stage rapid drawdown analyses with strengths used in second stage based on stresses calculated in first stage.
- Specification of curved Mohr-Coulomb strength envelopes and combined S-R strength envelopes.
- Generation of plots of slope geometry, specified slip surfaces, normal and shear stresses on bases of slices and inter-slice forces.
- Complete listing of inter-slice and base forces.

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:

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

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]

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.

Chapter 3 Overview of FLAC/SLOPE

3.1 Introduction

FLAC/SLOPE is a program that designed specifically to perform factor of safety calculation for slope stability analysis. This program is a mini version of FLAC and operated entirely from FLAC's graphical interface (the GIIC). It also provides rapid creation of model for soil and/or rock slope and solution of their stability condition.

FLAC/SLOPE also provides a full solution of the coupled stress/displacement, equilibrium and constitutive equation. Given slope geometry and a set of material properties, the system is determined to be stable or unstable. By automatically performing a series of calculations with different properties, the factor of safety is found corresponding to the point of instability and the critical failure surface can be located.

The model tools within FLAC/SLOPE allow for rapid model development, including:

- Creation of the slope geometry,
- Specification of material either manually or from a database,
- Definition of weak planes or interfaces though the slope,
- Addition of a water table,
- Application of surface loading at any location, and
- Installation of structural support such as soil nails of rock bolts.

3.2 Analysis Procedure

FLAC/SLOPE is specifically designed to perform multiple analyses and parametric studies for slope stability projects. The structure of the program allows different models in a project to be easily created, stored and accessed for direct comparison of model results. A FLAC/SLOPE analysis project is divided into four stages, which is models stage, Build stage, solve stage and plot stage.

3.2.1 Models stage

In this stage, each model can be created, named and listed in a tabbed bar in a project. This allows easy access to any model and results in a project. New models can be added to the tabbed bar or deleted from it at any time in the project study. Models can also be restored (loaded) from previous projects and added to the current project. It is also can define the slope boundary for each model at this stage. The figure 3.1 below shows the toolbar and icon that found inside the model stage.



Figure 3.1 toolbar and icon found in Model stage

3.2.2 Build stage

For specific model, the slope conditions are defined in the Build stage. This includes:

- Changes to the slope geometry,
- Addition of layers,

- Specification of materials and weak plane (interface),
- Application of surface loading,
- Positioning of a water table
- Installation of reinforcement

All this condition can be added, deleted and modifier at any time during this stage. The figure 3.2 below shows that the toolbar and icon inside Build stage.

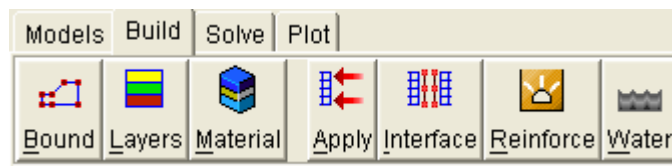


Figure 3.2 toolbar and icon found in Build stage

3.2.3 Solve stage

In the solve stage, the factor of safety is calculated. The resolution of the numerical mesh is selected first (coarse, medium, fine and user-specified) and then the factor of safety calculation is performed. Besides that, different strength parameters can be selected for inclusion in the strength reduction approach to calculate the safety factor. By default, the material cohesion and friction angle are used. The figure 3.3 show below is the toolbars and icon found inside the Solve stage.



Figure 3.3 toolbar and icon found in the Solve stage

3.2.4 Plot stage

After the solution is complete, several output selections are available in the Plot stage for displaying the failure surface and recording the results. Model results are available for subsequent access and comparison to other models in the project. The figure 3.4 below shows the toolbars and icon that found inside the Plot stage.



Figure 3.4 toolbar and icon found in Plot stage

Chapter 4 Details on Using FLAC/Slope

4.1 General

FLAC/Slope is designed to perform a series of analyses for a slope stability analyses project. A parametric study involving several model simulations can easily be set up, executed and the viewed of results. Each model simulation involves four modeling stages, which is Models, Build, Solve and Plot. Several tools are associated with each stage to assist with the model analysis. Each of the tools is described in the following sections.

4.2 Model Stage

4.2.1 Selecting model options

When first begin a FLAC/Slope analysis, the Model options dialog box as shown in Figure 4 .1 will be appear and allow different condition and optional facilities to be set for the project. Besides that, the system of units for the analysis also can be select in this dialog box. Parameters in the model will then be labeled with the corresponding units and predefined values, such as gravitational magnitude and material properties in the material database will be converted to the selected system.

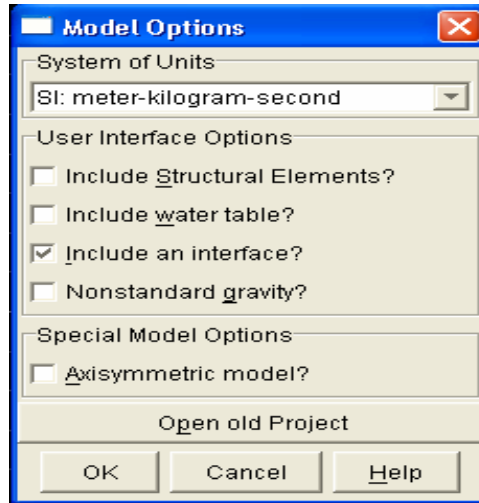


Figure 4.1 Model Options dialog

4.2.2 Creating a Slope Model

After set up the units and option facilities, we can enter the Models stage of the analysis and a New Model dialog box will be appear as shown in Figure 4.2. In this stage, we can create different type of slope boundary, such as a simple, bench slope, dam embankment or nonlinear slope shapes.

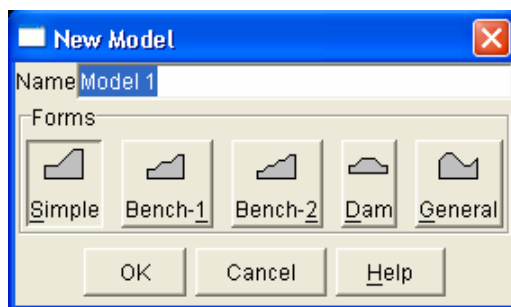


Figure 4.2 New Model dialog

If the simple boundary is being selected, an Edit slope parameters dialog box will then open for input the dimensions of the simple slope model as shown in Figure 4.3. A

diagram is included in this dialog to guide in the selection of geometry parameters. After inputting and applying the parameters, the dialog will remain open and the slope boundary will be plotted. This allows any alterations to the boundary and results can be view directly.

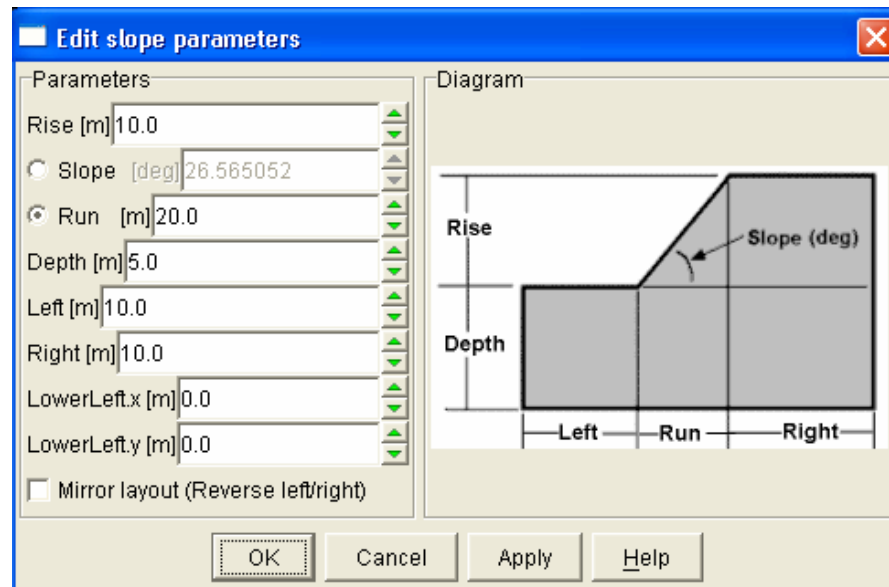


Figure 4.3 Edit Slope Parameters dialog

When selecting the dimensions for *DEPTH*, *LEFT* and *RIGHT*, it is important that these dimensions are large enough such that artificial boundaries (i.e., left, right and bottom boundaries) do not influence the development of the failure surface. If the final calculated slip surface is found to intersect any of these boundaries, then the model should be rerun with a larger dimension so that the surface does not intersect the boundary. Once all the dimensions are entered, the dialog box will close and the outline of the slope model will be drawn in a boundary view as shown in Figure 4.4. The boundary can be edited further in this view, either by dragging the mouse to move the boundaries or by pressing the *EDIT* button to open the Edit slope parameters dialog box again.

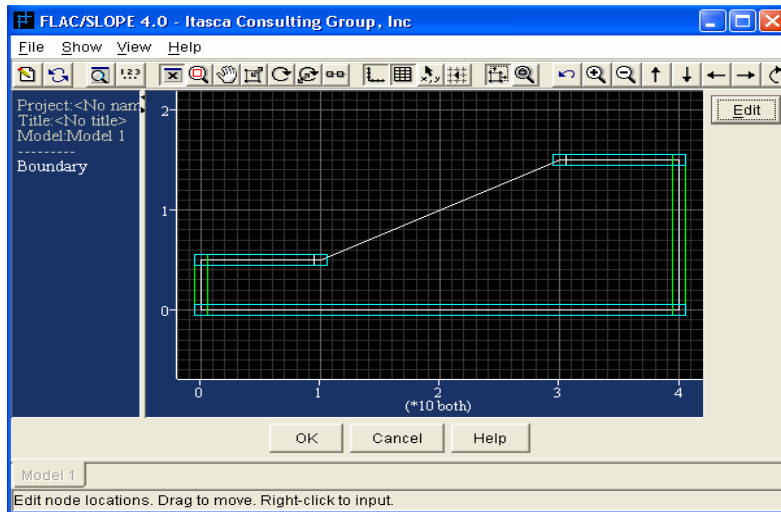


Figure 4.4 Boundary View

After all the dimensions are satisfied, the model boundary will now be drawn in the model view, as shown in Figure 4.5. Note that a tab with the model name will appear at the bottom of the model view when a model is created.

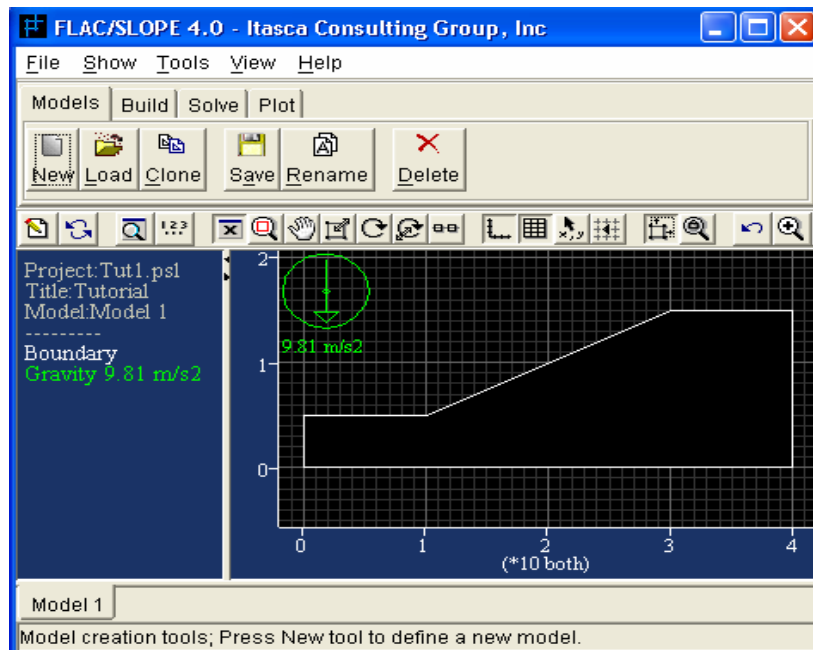


Figure 4.5 Model View

Several options are available once the model boundary is created. The model name can be changed with the *RENAME* button. The model can also be removed from the project with the *DELETE* button. Individual models can be saved at this stage with the *SAVE* button and also can be loaded with the *LOAD* button. Besides that, model can be copy by using the *CLONE* button. This will copy all the information on the model into a new model. Once the model is copy, alteration of the model boundaries can be done by using the *BOUND* button in the *BUILD* tool bar. This will open the Edit slope parameters dialog and allow changes to the boundary.

4.3 Build Stage

4.3.1 Adding Layers

If the slope-stability analysis involves layered materials, layer boundaries should be defined first in the model. This is accomplished by clicking on the *LAYER* button in the *BUILD* tool bar. The Layers tool box will then open. To add layer boundaries in a model, click the mouse on a position within the model close to the location of the boundary between two layers. A green horizontal line with square handles at each end will appear as shown in Figure 4.6 with two layer-boundary lines visible in the Layer tool box.

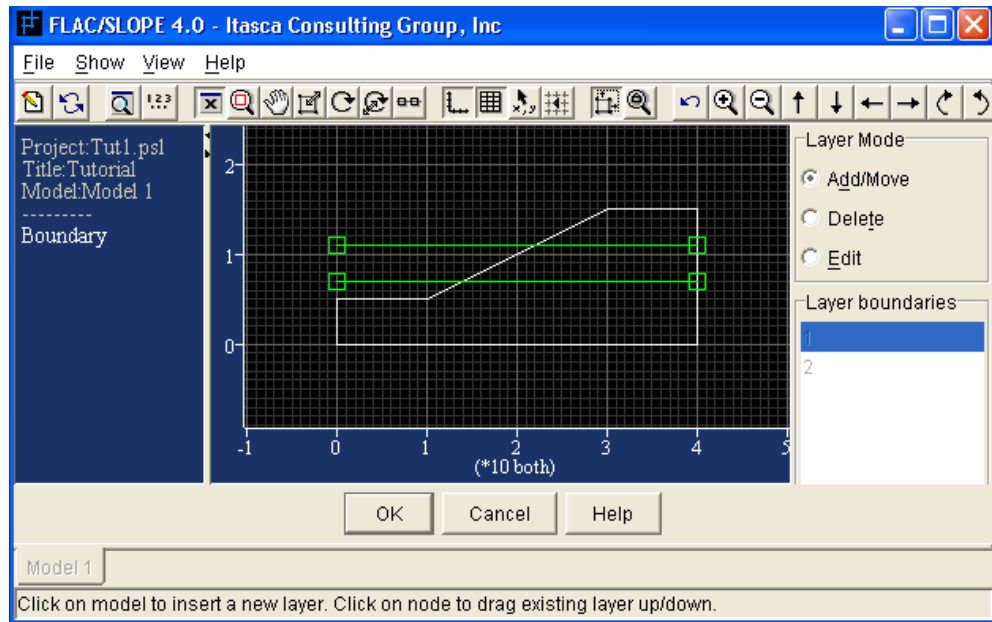


Figure 4.6 Slope model with two layer-boundary lines in the Layers tool

Each line corresponds to a table of points that defines the location of the layer boundary. When the *ADD/MOVE* radio button is pressed, lines can be added or moved within the model. In order to move a line, click and hold the left mouse button over one of the square handles and drag the mouse in the vertical direction. The line will move up or down.

Besides that, the shape of the boundary line can be modified by adding more handles points along the line and then dragging these points to different positions. To do so by clicking on the *EDIT* radio button and then add points along the line. Handle points can be located at specific *x*- and *y*- coordinate position by right-clicking the mouse over the handle. Figure 4.7 shows a model with the upper layer boundary has been edited by adding two points which are then dragged to new positions and Figure 4.8 shows the model view with layer.

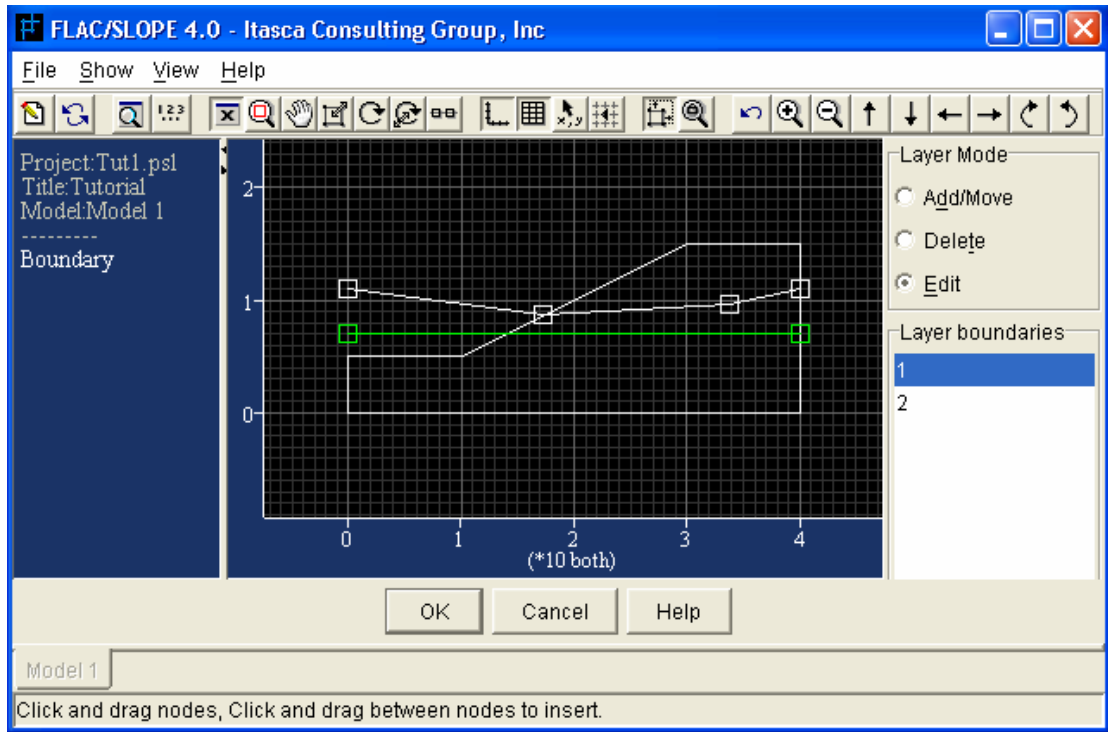


Figure 4.7 The upper layer boundary line is edited to include two points

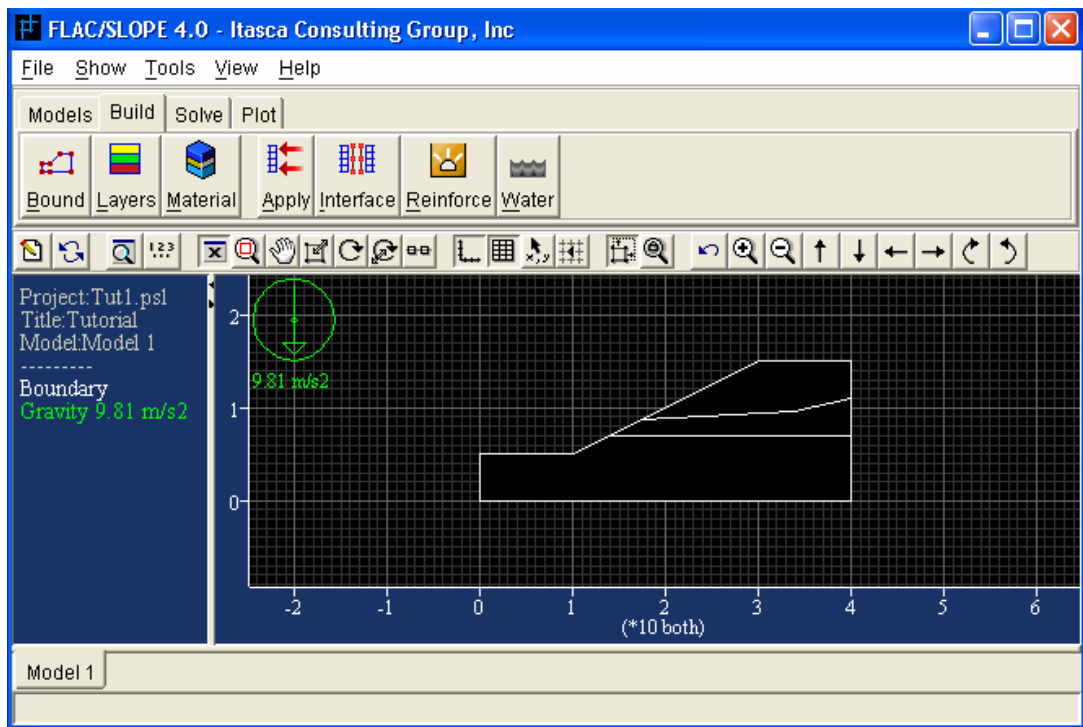


Figure 4.8 Model view with layer

4.3.2 Assigning Material and Properties

After all layer boundaries have been defined in the model, material can be assigned to each layer. This assignment is a two-step process. First, the material is created and its associated properties are prescribed. Then, the material is assigned to a specific layer. Material creation and assignment are both done within the Material tool which is open by clicking on the *MATERIAL* button. Under Material tool, material can be created under *CREATE* button. Figure 4.9 shows the Define Material dialog box. A material is defined by its classification and name (i.e., classification: embankment soil and name: silty sand). The classification is useful when a database is created to store common materials to use on different projects.

The mass density and the material strength properties are assigned for each material. Note that the corresponding units for each property are shown in the dialog, depending on the system of units selected in the Model Option dialog. Mass density is specified in (mass/volume) units. This value times the gravitational magnitude is equal to the unit weight of the material [(weight/volume) units].

If the water table tool is not active, only the dry mass density is assigned. This is the density of the material above the water table in situ. If the water table tool is active, then either porosity or a wet mass density must also be assigned. The relation between wet and dry mass densities is defined in FLAC/Slope by the formula

$$\rho^{\text{WET}} = \rho^{\text{DRY}} + n \rho_w$$

where ρ^{WET} is the wet density, ρ^{DRY} is the dry density, n is the porosity and ρ_w is the density of water. When the water table is assigned to the model, all zones with centroids located below the water table are assumed to be fully saturated and will automatically be assigned the value for wet density for the factor-of-safety calculation.

Material failure is defined by the Mohr Coulomb plasticity model in terms of the cohesion and internal angle of friction. A tensile strength and dilation angle may also be specified for the material. If associated plastic flow is specified for the analysis, the dilation angle will be automatically adjusted to match the friction angle. By default, the bulk modulus and shear modulus of all materials in the model (assuming SI units) are set to 100MPa and 30 MPa, respectively.

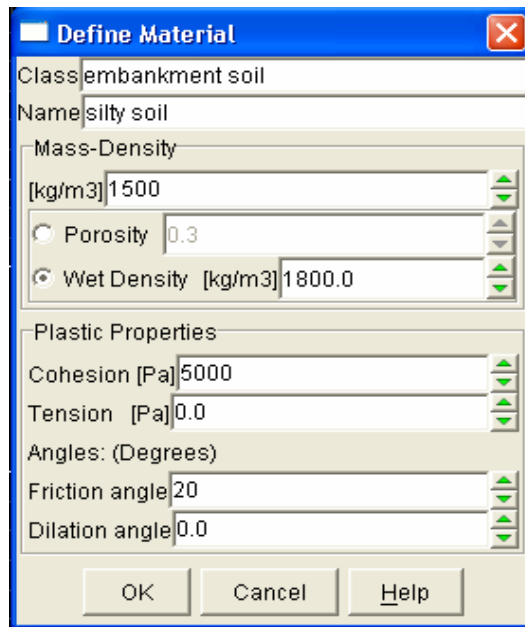


Figure 4.9 Define Material dialog box

By default, a database of soil and rock materials is provided, as shown in Figure 4.10. The database is divided into groups, designated by classification names and shown in a collapsible tree structure.

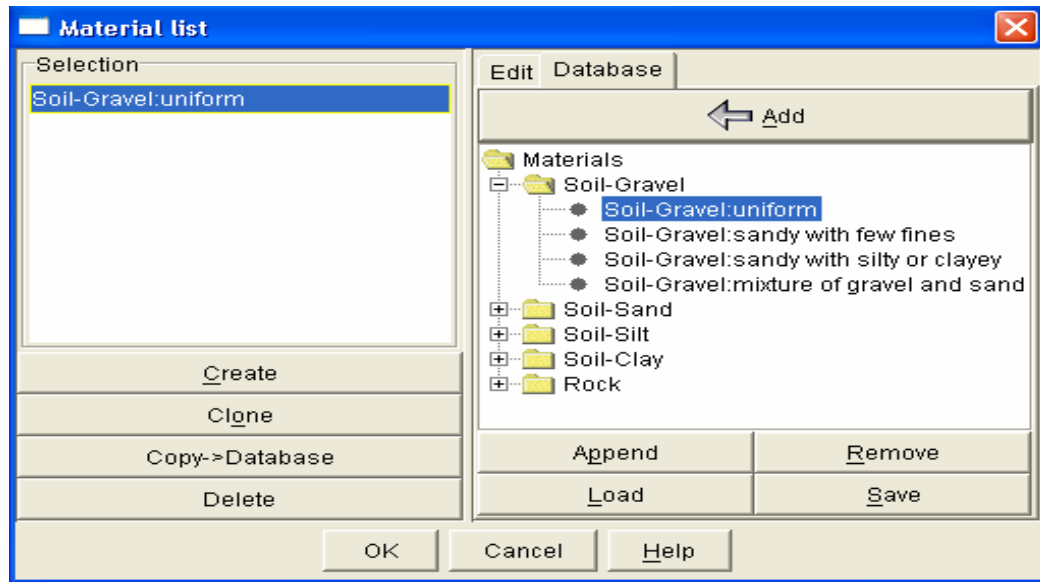


Figure 4.10 Material List dialog

4.3.3 Adding a Weak Plane (Interface)

A weak plane or interface can be added to the slope model by clicking on the *INTERFACE* button in the *BUILD* tool bar. This will open the Interface tool as shown in Figure 4.11. The tool contains a blue horizontal line with square handles at each end. The line corresponds to a table of points that define the location of the interface. The line can be positioned in the model in the following manner. By clicking on and dragging the square handles, the ends of the line can be moved up and down in the model. Besides that, new handles can be added by clicking along the line and can be moved to distort the line as needed to fit the interface location. Handle points can also be right-clicked with the mouse to open a Table dialog to input x - and y - coordinates for the points. Figure 4.12 shows the interface line repositioned with two handle points added along the line.

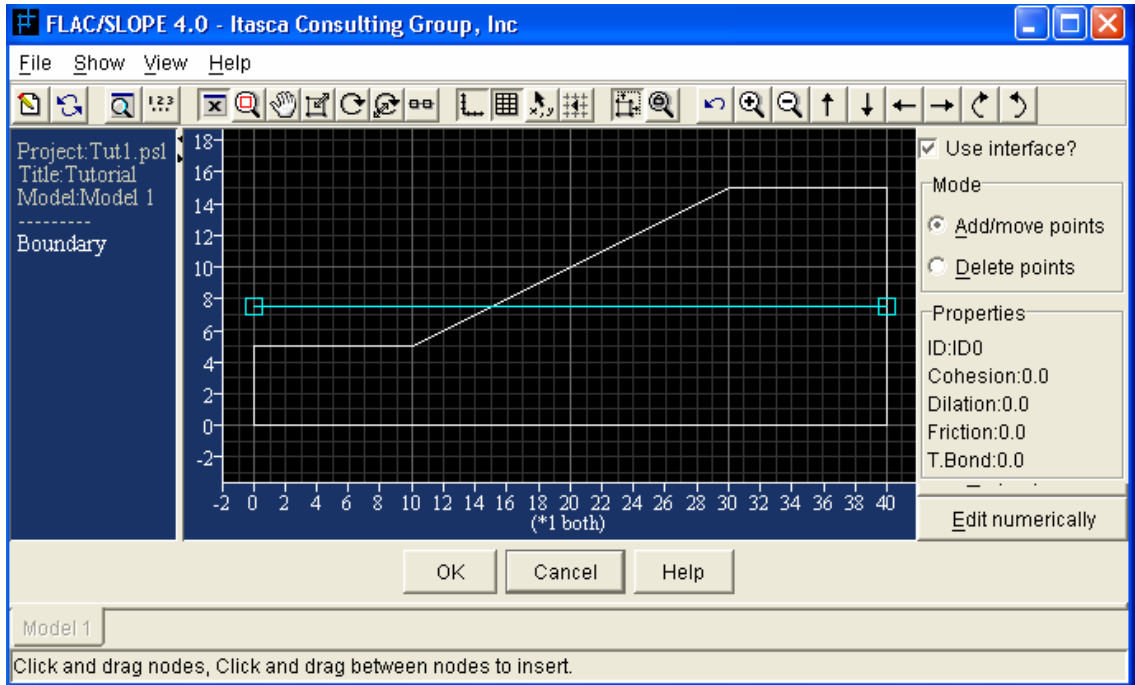


Figure 4.11 Interface tool

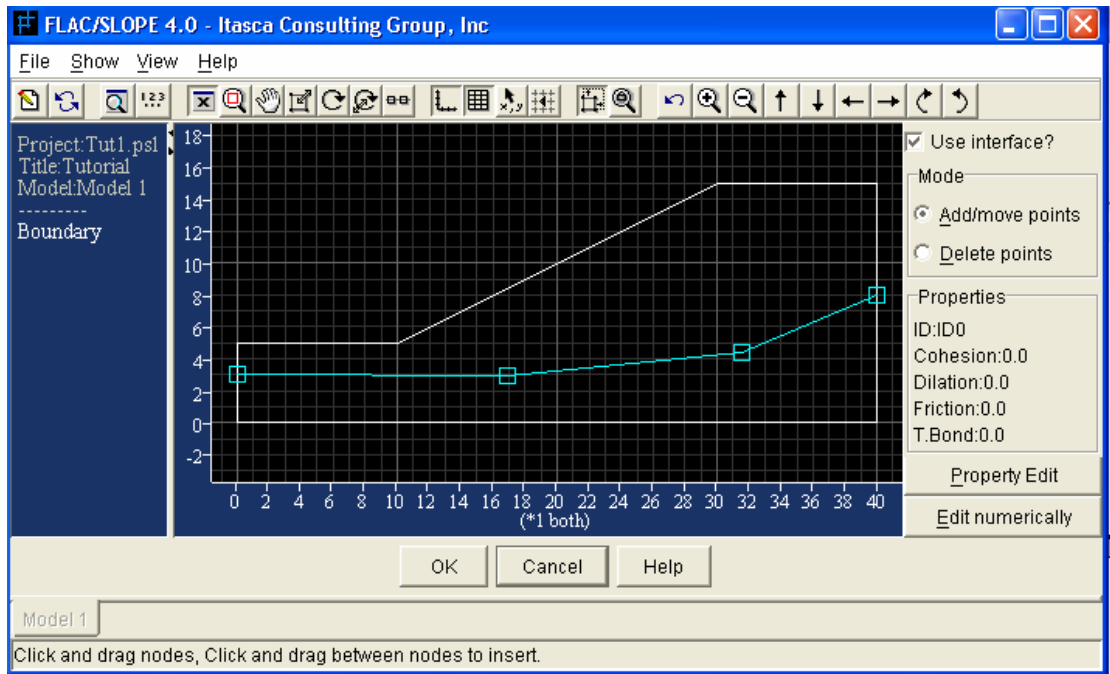


Figure 4.12 Interface line repositioned

After the interface is located in the model, interface properties should be prescribed. This is done by pressing the *PROPERTY EDIT* button to open the Interface property list dialog box as shown in Figure 4.13. The interface is defined by a classification and name (i.e., classification: bedding plane and name: smooth). The interface properties are then prescribed to this interface material and applied by clicking *APPLY* button. Several interface materials can be created at one time in this dialog. The highlighted material will be applied to the interface when the *OK* button is pressed. The interface material and properties are listed in the Properties list in the Interface tool.

The behavior of the interface is defined by the Coulomb slip criterion which limits the shear force, F_{\max} , along the interface by the relation

$$F_{\max} = cL + \tan \Phi F_n$$

Where

c = cohesion (in stress units) along the interface,

L = effective contact length,

Φ = friction angle of the interface surface and

F_n is the normal force acting on the interface.

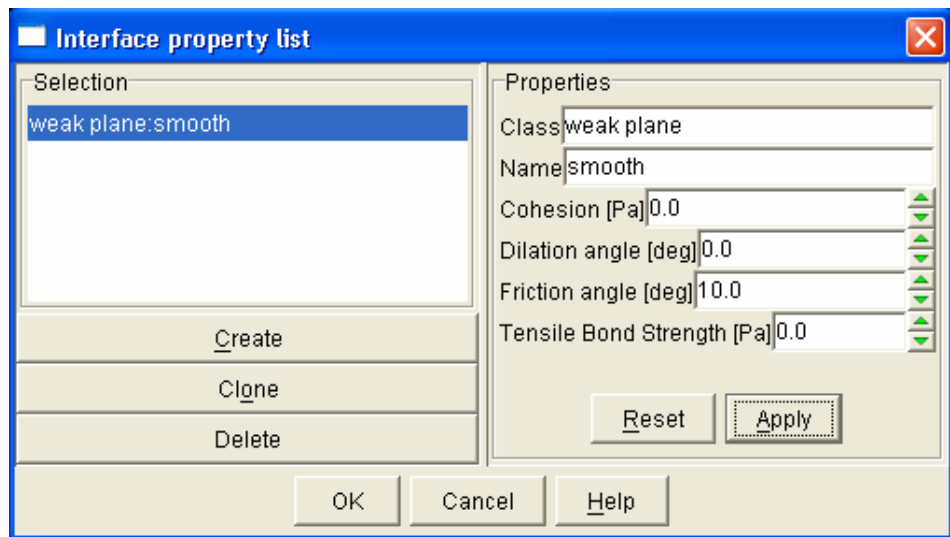


Figure 4.13 Interface Property list dialog box

4.3.4 Locating a Water Table

A water table can be added to the slope model by clicking on the *WATER* button in the *BUILD* tool bar. This will open the Water table tool as shown in Figure 4.14. The tool contains a blue horizontal line with square handles at each end. The line corresponds to a table of points that define the location of the water table (piezometric surface). The line can be positioned in the model in the following manner. By clicking on and dragging the square handles, the ends of the line can be moved up and down in the model. Besides that, new handles can be added and moved to distort the line as needed to fit the water table location. Handle points can also be right-clicked with the mouse to open a Table dialog to input x - and y - coordinates for the points. Figure 4.15 shows the water table line repositioned with two handle points added the line.

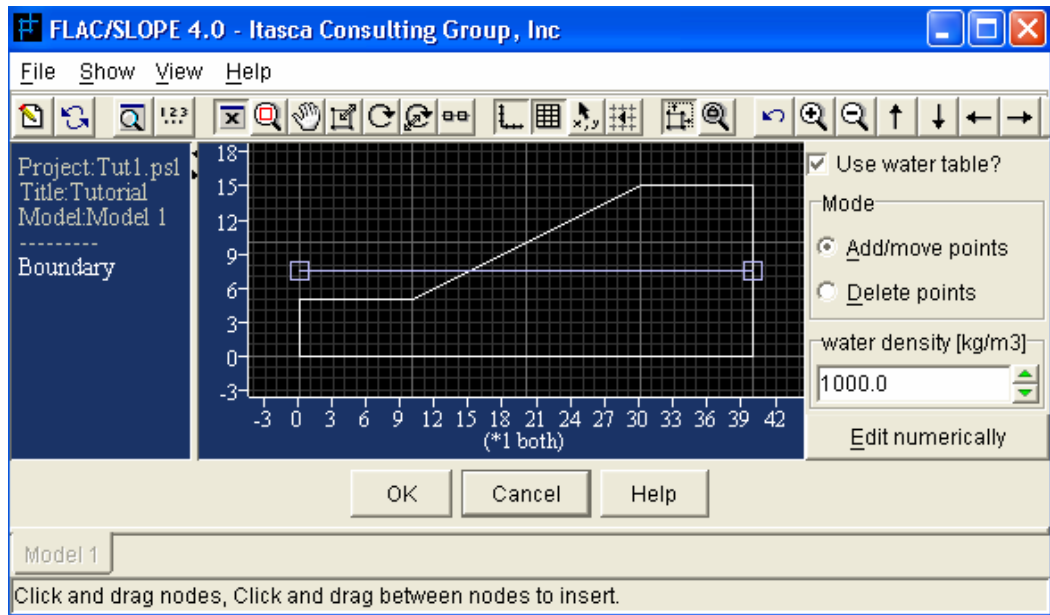


Figure 4.14 Water table tool

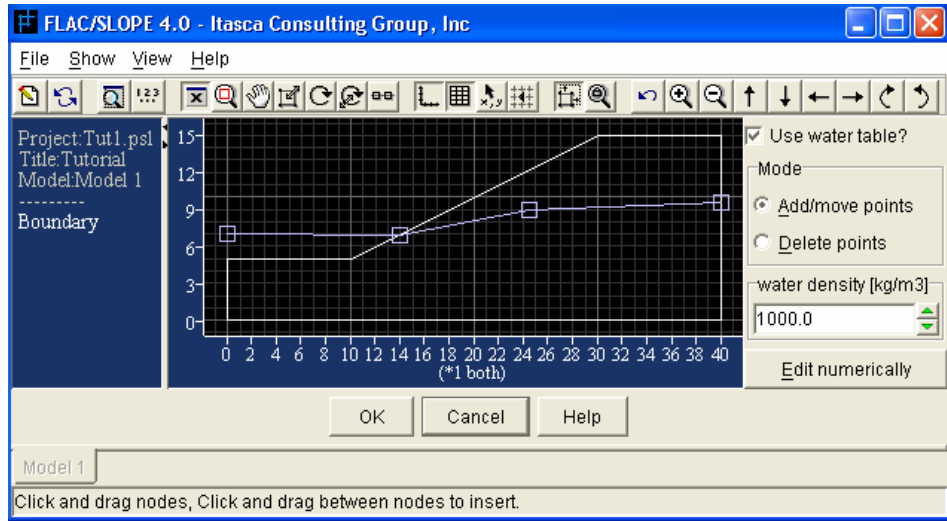


Figure 4.15 Water Table repositioned with two handle points added

The water table can be turned on and off in the model by clicking on the *USE WATER TABLE* box. The water density is assigned automatically with a value corresponding to the selected system of units. The density value can be set manually in the *WATER DENSITY* box. When the water table is active, failure in the factor-of-safety calculation is controlled by the effective stress state of the model. The value for water density is used in the calculation of the pore-pressure distribution which is then applied to determine the effective stresses in all zones below the water table.

4.3.5 Applying Surface Loads

Besides, point loads and area pressures can be applied along a slope surface by clicking on the *APPLY* button in the *BUILD* tool bar. This will open the Apply tool, as shown in Figure 4.16. Various forms of loads can then be applied to the slope surface. The types of load are listed in the form of collapsible tree structure which in the B.C. types pane in the tool. In order to apply a specific load, click on the name in the tree and then click and drag the mouse over the portion of the boundary which the load need to apply. Figure 4.17 shows a pressure is applied at the top of the slope along the region designated by the

pressure bar. When the apply load is ready, an *ASSIGN* button becomes active and the Apply value dialog box will opens by clicking on it as shown in figure 4.18.

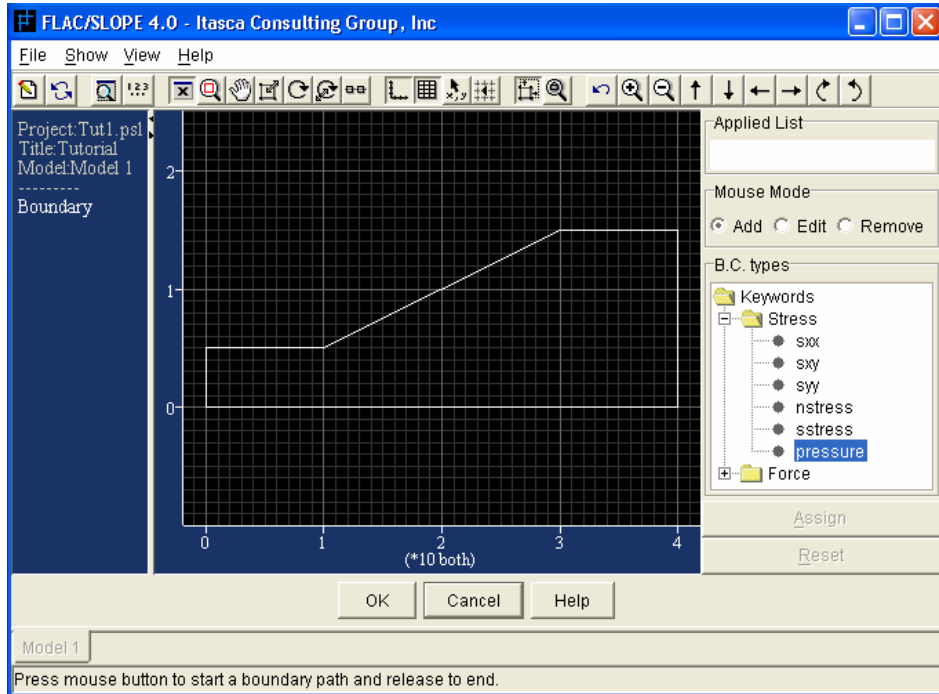


Figure 4.16 Apply tool

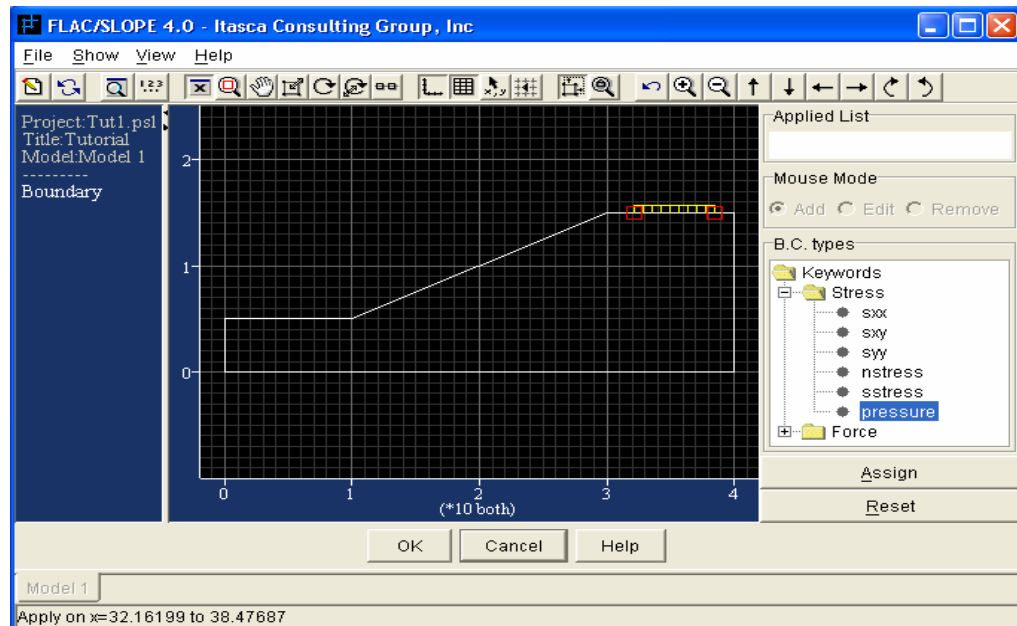


Figure 4.17 A pressure is applied at the top of the slope

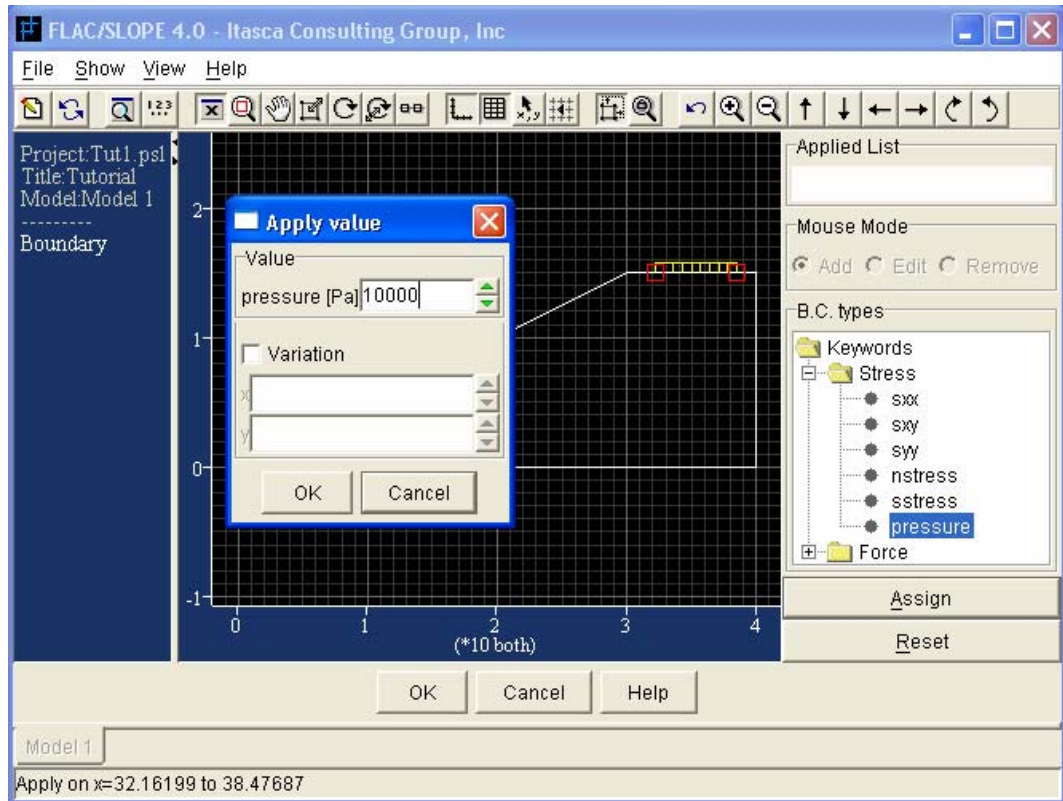


Figure 4.18 Apply value dialog in the Apply tool

4.3.6 Installing Structural Reinforcement

Reinforcement can be installed in a slope by clicking on the *REINFORCE* button in the *BUILD* tool bar. This opens the Reinforcement tool, as shown in figure 4.19. Cable elements are installed in a slope by first checking the *ADD BOLT* radio button and then pressing the mouse button at one end of the cable, dragging the mouse to the other endpoint and then releasing the button. A yellow line with square white handles will be drawn as shown in Figure 4.20. Any number of cables can be installed within the slope in this manner. The end nodes of the cable can be positioned more precisely by right-clicking on the handles. This opens a Coordinate dialog to enter x- and y- coordinates of the end node. End nodes can also be relocated by checking the *MOVE NODES* radio button. Then, press and drag the end node with the mouse. Besides that, cables can also

be deleted by checking the *DELETE* radio button and then click the mouse over the cables.

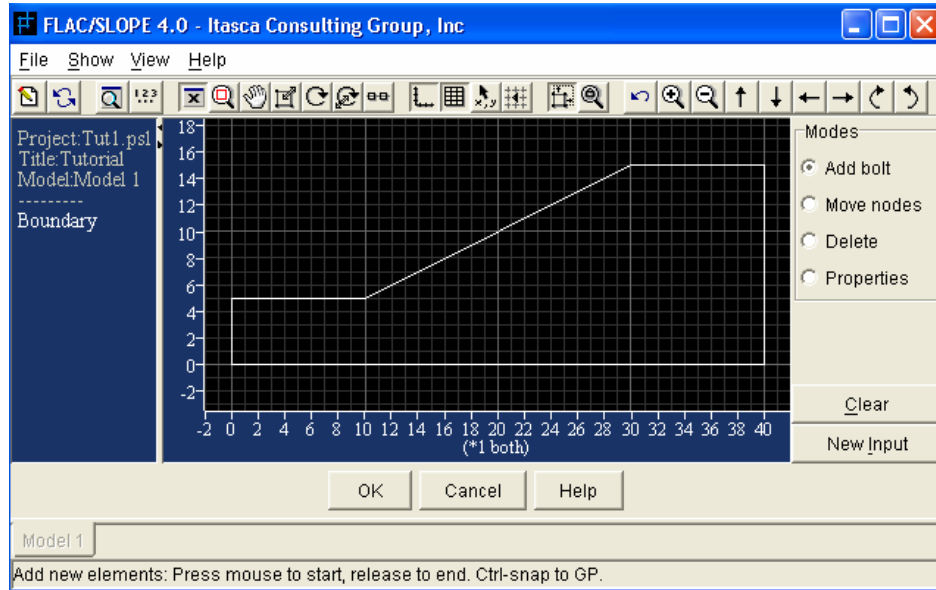


Figure 4.19 Reinforcement tool

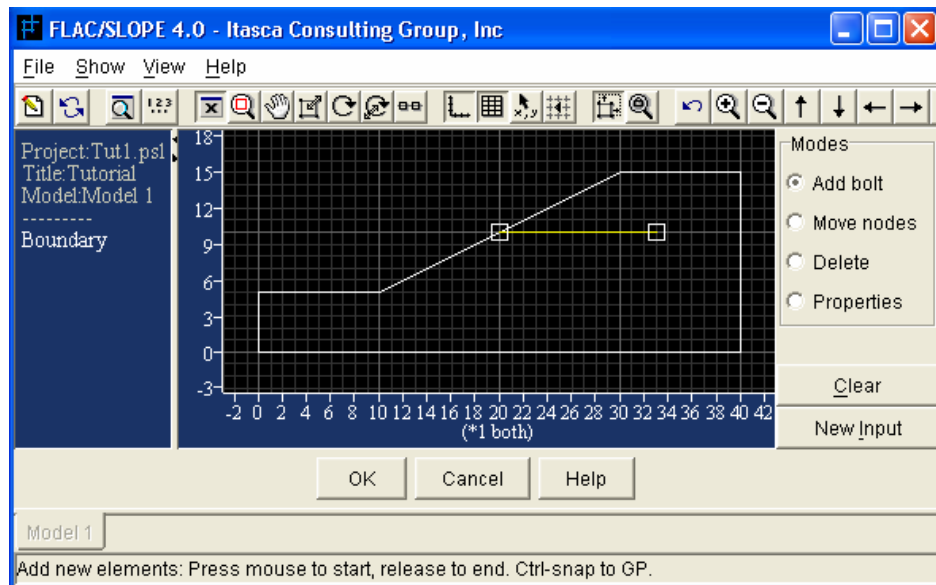


Figure 4.20 shows the reinforcement installed in a slope

After the reinforcement is installed in the slope, the next step is to assign the material properties to the reinforcement. This can be done by checking the *PROPERTIES* radio button. Properties are assigned to cable elements in FLAC/Slope via a property identification number. This number will appear over each cable when the *PROPERTIES* button is pressed. By default, all cables are given the property number C1 as shown in Figure 4.21.

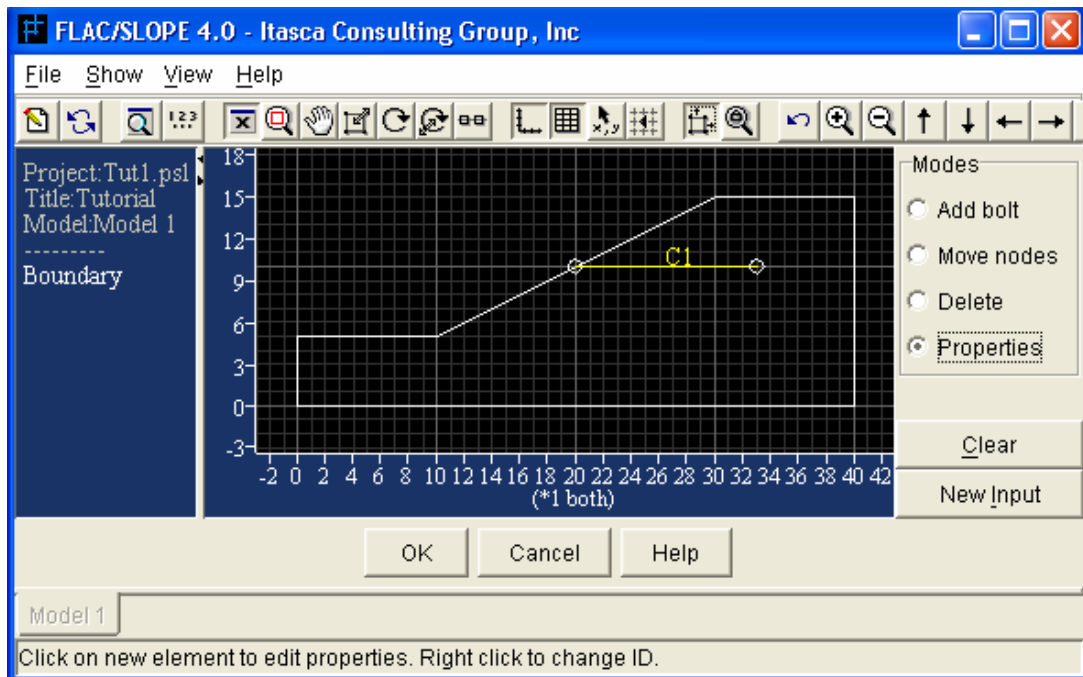


Figure 4.21 Property identification number for reinforcement

By clicking the mouse over the property number, a Cable Element Properties dialog box will open as shown in Figure 4.22. Properties are then assigned to a specific property number. There are two types of reinforcement can be simulated, which are a continuous *GEOSYNTHETIC SHEET* and a *SPACED REINFORCEMENT*. If the *SPACED REINFORCEMENT* is selected, the spacing in the out-of-plane direction is also specified. The spacing parameter is used to automatically scale properties and parameters to account for the effect of the distribution of the cables over a regularly spaced pattern.

Young's modulus for the reinforcement is also needed by either users defined or allows the modulus to be computed automatically to optimize the calculation process. It is recommended that, if the modulus of the reinforcement is two orders of magnitude or more greater than the elastic stiffness of the slope material, the computed value for modulus be selected. If the reinforcement modulus is more than two orders of magnitude greater than the slope material stiffness, the calculated factor of safety will be essentially the same for the input modulus as for the computed modulus, but the solution convergence will be slow.

In addition to the Young's modulus, the tensile yield strength and cross-sectional area of the reinforcement must be defined. For a Geosynthetic sheet, the area is equal to the thickness of the sheet times a unit depth in the out-of-plane direction.

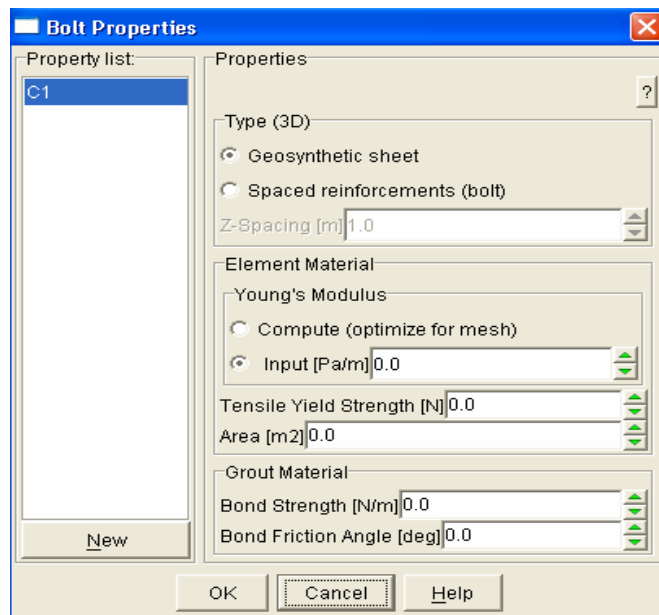


Figure 4.22 Cable Element Properties dialog

The properties describing the shear interaction at the reinforcement/slope material interface are input under the Grout Material heading in the dialog box. These properties are prescribed in terms of a cohesive or bond strength and a bond friction angle. The

following relation is used to determine the maximum bond shear force, F_s^{\max} , that can develop along the interface per length, L of the cable.

$$\frac{F_s^{\max}}{L} = S_{bond} + \sigma_c' \times \tan(S_{friction}) \times \text{perimeter}$$

where S_{bond} = bond strength or cohesion;
 σ_c' = mean effective confining stress normal to the element;
 $S_{friction}$ = bond friction angle
Perimeter = perimeter of the element (based on input area)

The elastic shear stiffness at the interface does not affect the calculation of the factor-of-safety. Therefore it is computed automatically to optimize the solution convergence.

4.4 Solve Stage

4.4.1 Solving for a Factor of Safety

The calculation of the factor of safety is done in the Solve stage which is divided into three steps: grid generation, factor of safety parameter selection and factor of safety solution.

4.4.1.1 Grid Generation

When the Solve stage is entered, a numerical mesh must first be created. There are four zoning choice available, such as coarse, medium, fine and user-selected (special). Figure 4.23 shows the Coarse mesh and Medium mesh has been selected and the generation of

the grid. Generally, the fineness of the zoning will affect the accuracy of the factor of safety calculation. Normally, the finer zoning will provide better accuracy of the solution.

The coarse grid model is recommended for preliminary analyses. The solution time for this kind of model is quite rapid. When on a 1 GHz computer, it is about a few seconds of solution time. Hence, a project with several models can easily be run to provide a quick estimate for the effect of different conditions on the factor of safety.

The medium grid model is recommended for more comprehensive studies. The results for this type of zoning are found to be in good agreement with limit analyses and limit equilibrium model results. A medium grid model takes longer to calculate the factor of safety, probably requires a few minutes to complete on 1 GHz computer.

The fine grid model is recommended as a check on analyses made with the medium grid model. The factor of safety calculation with the fine grid model should agree very closely with that from the medium grid model. However, because this type grid takes longer to calculate a safety factor, it usually is not warranted to use fine grid models for comprehensive studies.

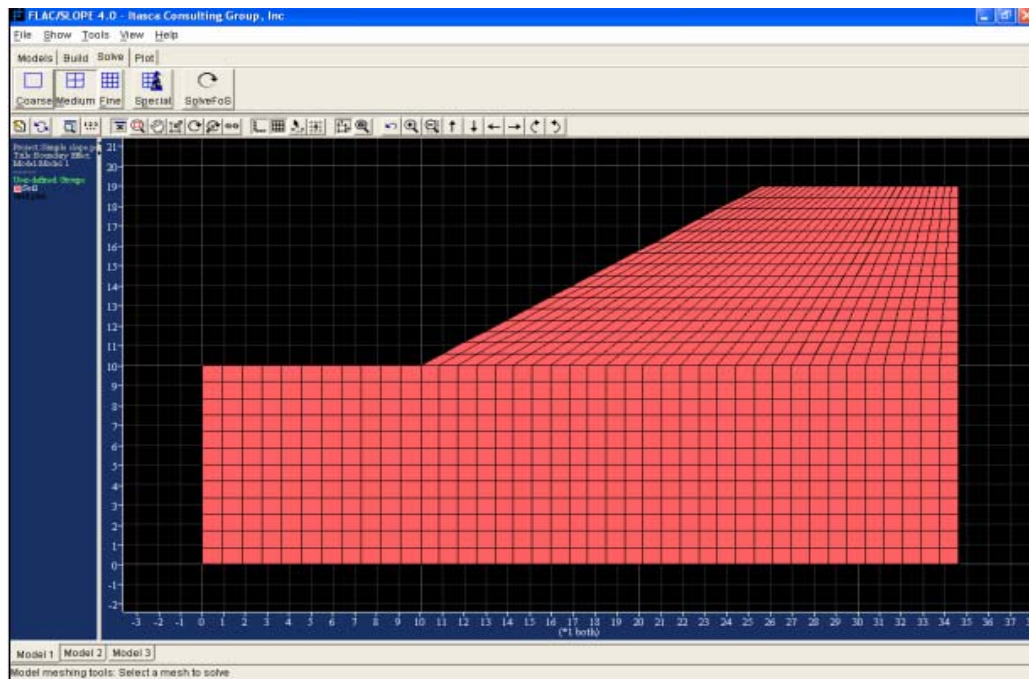
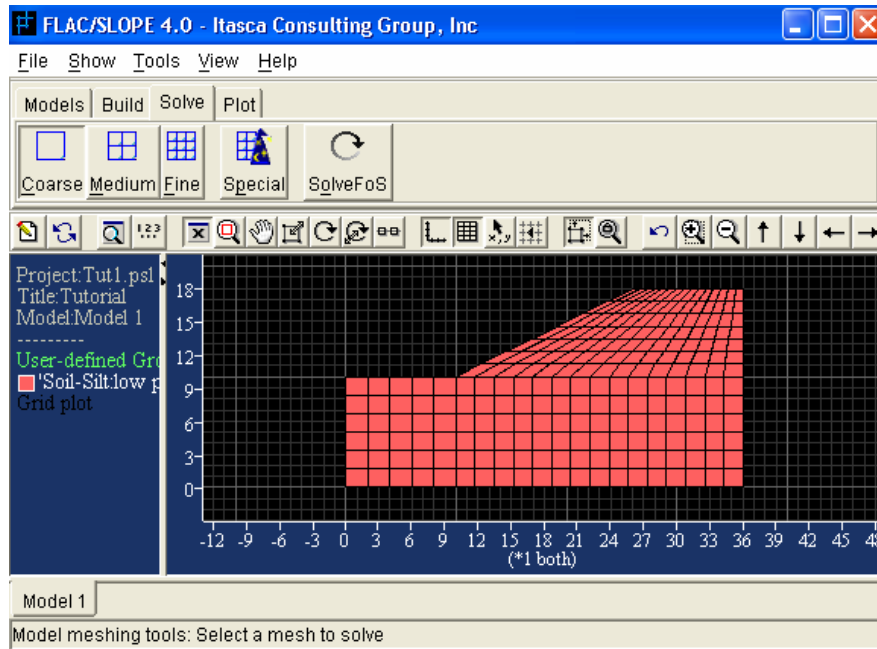


Figure 4.23 shows the generation of Coarse and Medium mesh

4.4.1.2 Factor of Safety Parameters

After complete the grid generation, the factor of safety can be calculated. This is done by clicking on the *SOLVEFOS* button. The factor of safety calculation is based on the strength reduction technique which reducing the shear strength of the material to bring the slope to a state of limiting equilibrium. When *SOLVEFOS* button is pressed, a Factor of Safety parameter dialog box opens with *FRICITION ANGLE* and *COHESION* boxes checked as shown in Figure 4.24. It is also possible to include other strength parameters in the safety factor calculation such as Tension Cutoff and Interface Friction & Cohesion.

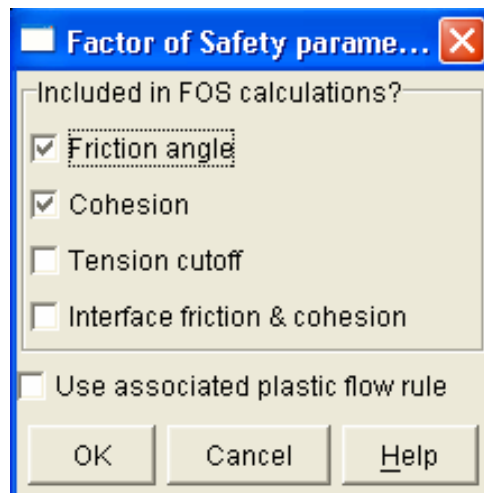


Figure 4.24 Factor of Safety parameters dialog box

4.4.1.3 Factor of Safety Solution

After the parameters have been selected, the factor of safety calculation begins by clicked on the *OK* button in the Factor of Safety parameters dialog box. The status of the calculation will be reported in a Model Cycling dialog box as shown in Figure 4.25. This dialog box displays the percentage of steps completed for an individual simulation stage, the total number of stages that have been performed thus far in the series, the operation

currently being performed and the bracketing values of the factor of safety. The bracket range will be decrease until the final value is determined.

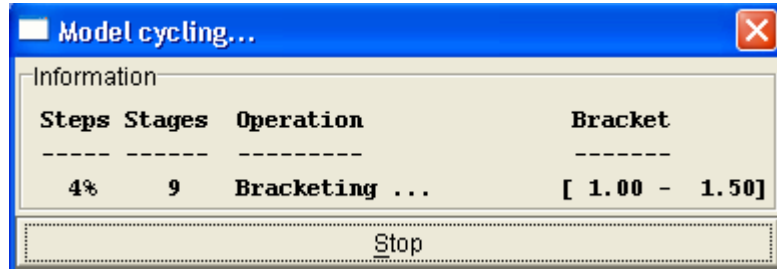


Figure 4.25 Model Cycling dialog box

4.5 Plot Stage

4.5.1 Producing Output

After the factor of safety calculation, the results can be viewed in the Plot tool by pressing the *PLOT* button. When calculation is complete, a failure plot button is added to the *PLOT* tool bar with a name corresponding to the type of zoning and factor of safety parameters selected for the calculation. For example, in Figure 4.26, the button contains a single square indicating a coarse grid model and the descriptors f_c indicating that friction angle and cohesion were included in the calculation.

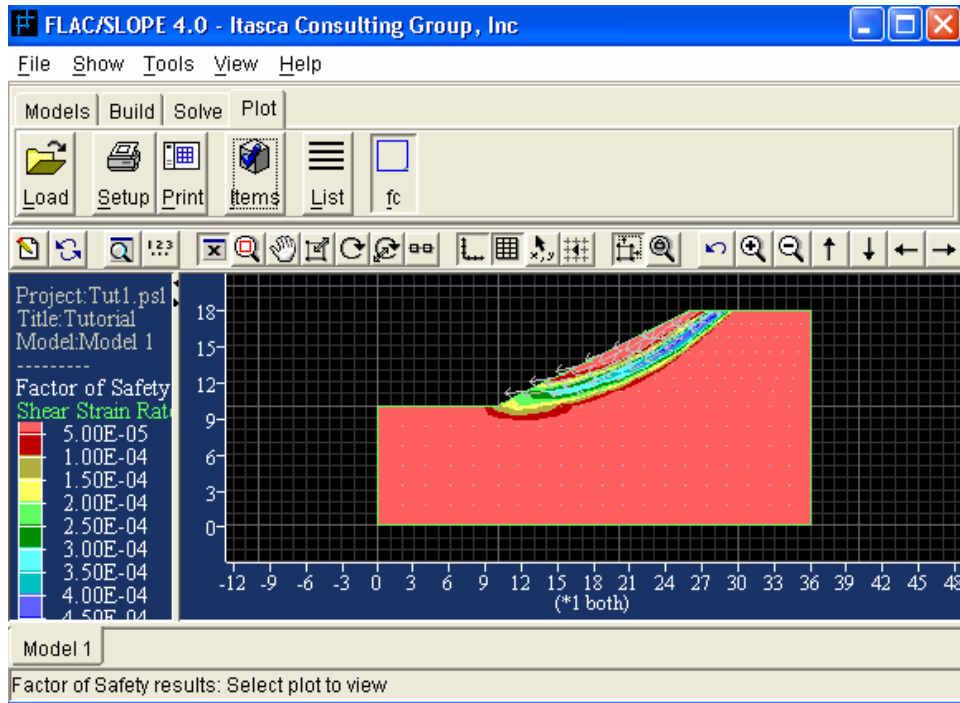


Figure 4.26 Failure plot for coarse grid model with friction angle and cohesion included in the factor of safety calculation

The failure displayed in this tool contains a filled contour plot of shear strain-rate contours and velocity vectors. These parameters indicate the extent of the failure region at the last non-equilibrium state and show a well-defined failure surface as illustrated in Figure 4.26. Besides that, different parameters can be displayed in the failure plot by pressing the *ITEMS* button and a Plot items dialog box opens as shown in Figure 4.27.

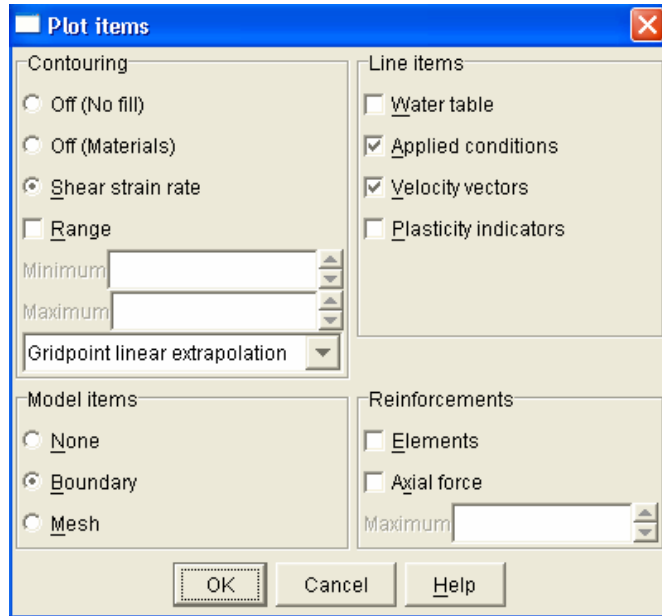


Figure 4.27 Failure plot items dialog box

In addition, a hardcopy printout of the failure plot can also be created in the Print setup dialog box, which is opened by pressing the *SETUP* button. The dialog box is shown in Figure 4.28. This dialog controls the type and format of graphics hardcopy output.

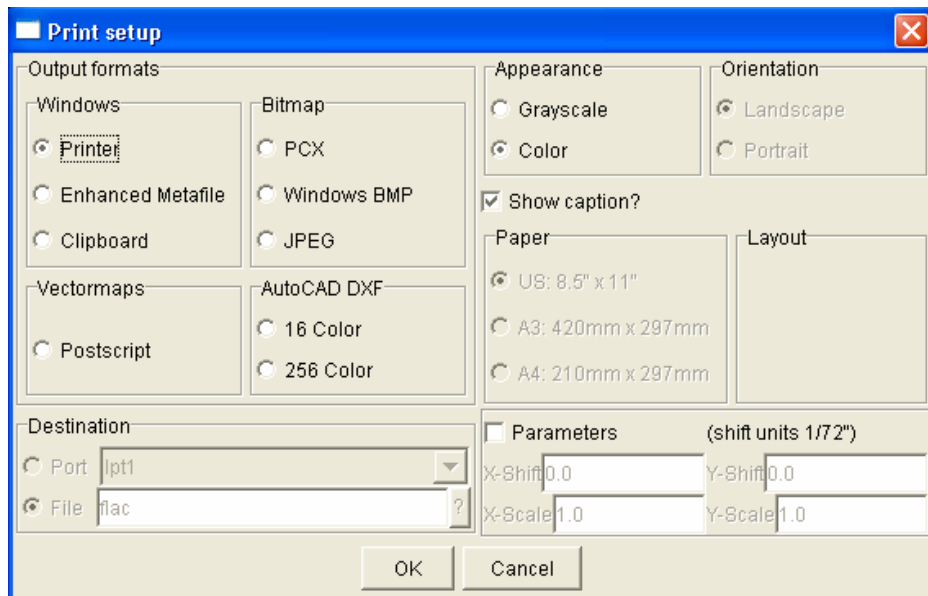


Figure 4.28 Print setup dialog box

Chapter 5 Validity of the Analysis Software – FLAC/Slope

5.1 Introduction

FLAC/Slope is an analysis program that designed specifically to perform factor of safety calculations for slope stability analysis. Thus, it is necessary to validate the analysis software before any analysis work can be carrying out. To validate the software – FLAC/Slope, an example from known sources with an answer is used to analyze with the FLAC/Slope.

5.2 Selected Problem

In order to validate the FLAC/Slope software an example of a slope problem from an available text book has been chosen. The selected example problem is the Example 11.3 from the book “GEOTECHNICAL ENGINEERING SOIL MECHANICS” by John N. Cernica, John Wiley & Sons, Inc. 1995.

From the example, the data is given as below:

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/m³

Cohesion, c is 28 kN/m²

Angle of internal friction, ϕ is 18°

The calculated factor of safety is 2 and the detail of the calculation of the problem can be referred to Appendix G.

5.3 Analysis Process

5.3.1 Build of Model

As for the data given from the text book, we create a model according to the data given and key in the data to the software as shown in figure 5.1.

5.3.2 Define the Material

Next is to define a material to the model by enter the data obtained from the text book to the Define Material tool box as shown in figure 5.2.

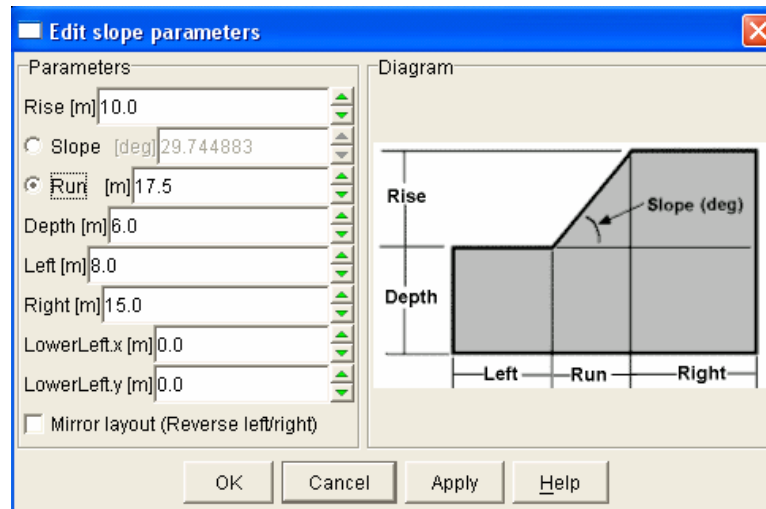


Figure 5.1 Edit slope Parameters Dialog Box

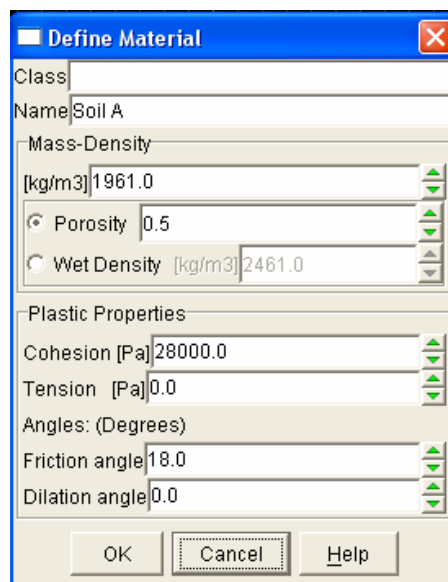


Figure 5.2 Defining Material Dialog Box

5.4 Results

By using the coarse mesh element in the FLAC/Slope software to solve for the factor of safety for the given problem and the factor of safety obtain is 1.97 and the failure mechanism is shown at figure 5.3. From here we can see that the result obtain from the

software is approximately to the results from the text book which give Factor of Safety equal to 2.00. Thus, we can conclude that the results given from the software is valid and the used of the software for this project can be proceeding.

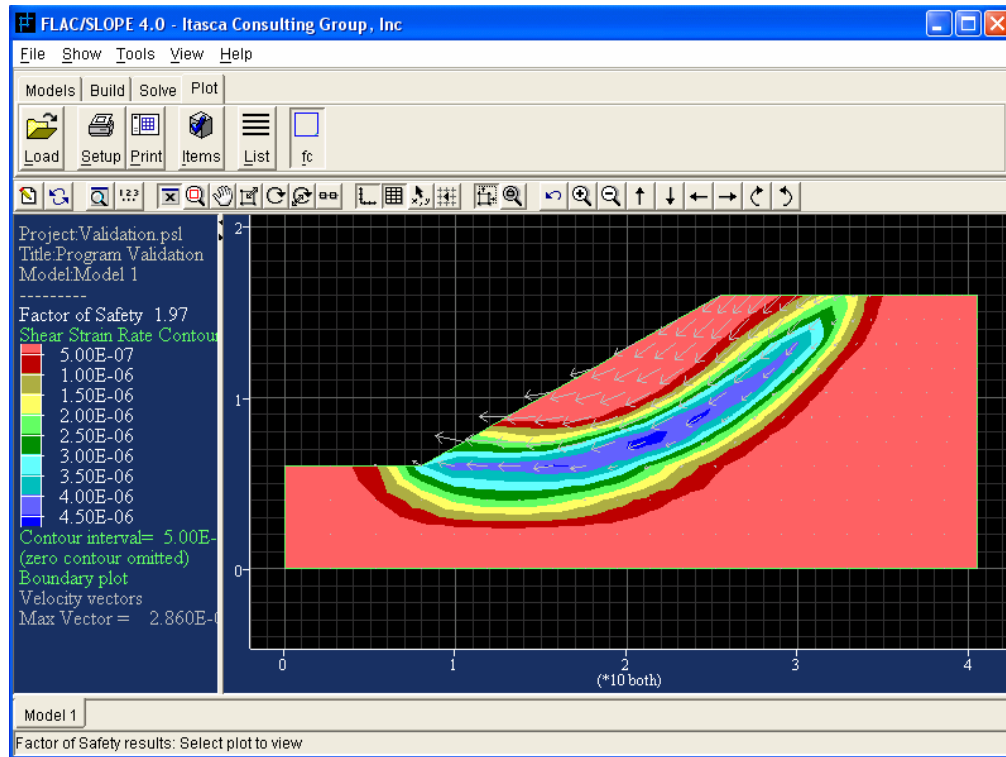


Figure 5.3 Failure Mechanism of the Validity Model

Chapter 6 Methodology

6.1 Simulation Program

In achieving the final objective of this project on the simulation of several model to study the behavior of the slope failure and the accuracy of the software, the following steps have to be done in priority are as below.

1. Learn the finite difference software – FLAC/SLOPE.

2. Develop five numerical models for analyzing complex slope stability problems
 - Simple slope
 - mesh effect
 - boundary effect
 - layered and non-homogeneous material property
 - water table
 - surcharge loads
 - geo-grid reinforcement

3. Where possible, compare the results obtained in this project with other available methods.

6.2 Case analysis

6.2.1 Model 1 : Simple slope

6.2.1.1 Mesh effect

A simple model will be created by using the FLAC/Slope program with the dimensions and properties as shown in table B-1. After the model has been created, different mesh element will be used to study the effect to the model. The procedures adhered in the creation of the model are show in Appendix B.

6.2.1.2 Boundary Effect

Three simple models with different dimensions will be created by using the FLAC/Slope program. The dimensions and properties are shown in table B-2. Coarse mesh will be used in the three models in order to calculate the factor of safety. The procedures and details adhered in the creation of the models are shows in Appendix B.

6.2.2 Model 2 : Surcharge Loads

Two models will be created by using FLAC/Slope program with the same dimension and material properties as shown in table C-1. A surcharge load of 100 kPa will be applied on top of a model. Meanwhile, the other model will not have any surcharge loads applied on it. For the two models, element used for the factor of safety calculation will be the coarse mesh. The procedures and details for the creation of the models are show in Appendix C.

6.2.3 Model 3 : Water Table

Two models will be created by using FLAC/Slope program with the same dimension and material properties as shown in table D-1. One model will include a water table. Meanwhile, the other one will not include any water table. Element used for the factor of safety calculation will be the coarse mesh. The procedures and details for the creation of the models are shown in Appendix D.

6.2.4 Model 4 : Complex Geometry and Layer Slope

Three models will be created by using FLAC/Slope program with the same dimension, but different material properties will be used as shown in table E-1. Two models will be created with same boundary and position of soil layer but different material been used. However, the other one will be created with same boundary as the two models previously but with a different position of soil layer and material. These three models will use to show the capabilities of the software to analyse the complex slope with layer soil.

For these three models, element used for the factor of safety calculation will be the coarse mesh. The procedures and details for the creation of the models are shown in Appendix E.

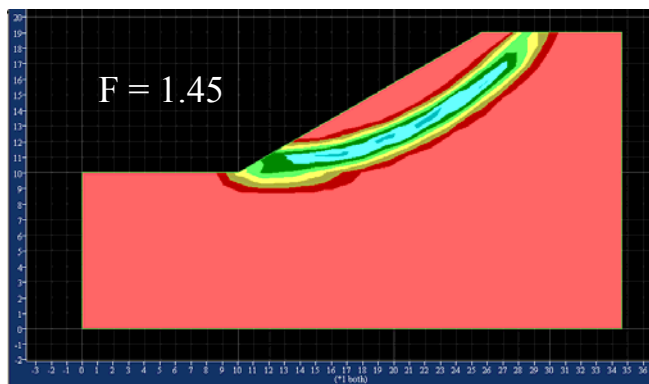
6.2.5 Model 5 : Geo-Grid Reinforcement

Four models will be created by using FLAC/Slope program with the same dimensions and material properties as shown in table F-1. For the four models, element used for the factor of safety calculation will be the coarse mesh. The procedures and details for the creation of the models are shown in Appendix F.

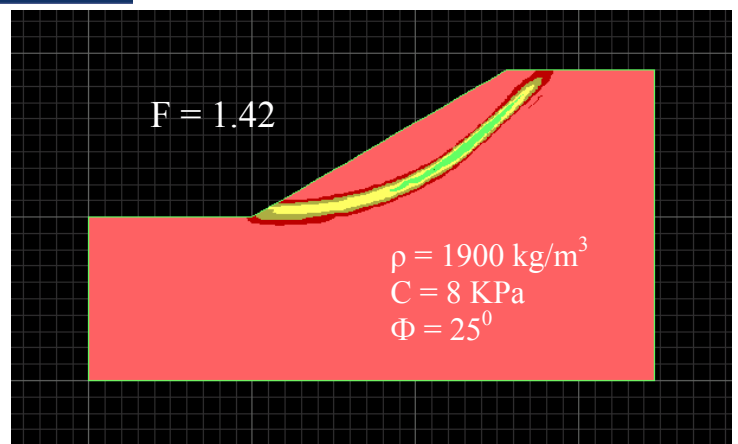
Chapter 7 Results and Discussion

7.1 Model 1 : Simple slope

7.1.1 Mesh effect



Coarse Mesh

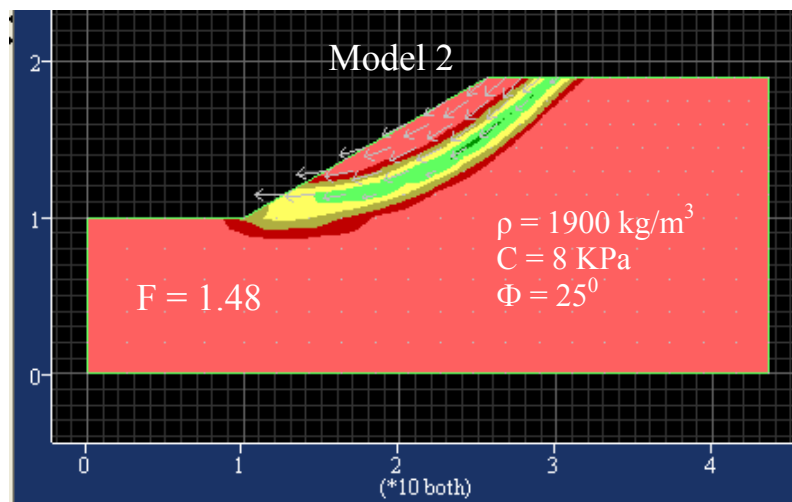
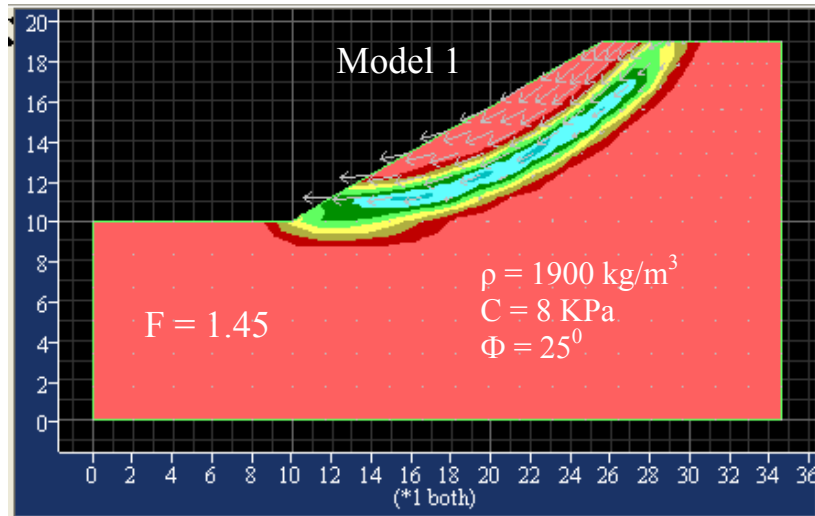


Fine Mesh

Figure 7.1 Plot of the Coarse mesh and Fine mesh

These two models will be used to show the effect of element or mesh of the software. From the results obtained, we can see that the failure mechanism and the factor of safety for the two models are different. This is because the coarse mesh is recommended for preliminary analysis of slope. Meanwhile, the fine mesh is recommended for more comprehensive studies of slope. Hence, we can conclude that the factor of safety obtain in fine mesh is more precise.

7.1.2 Boundary effect



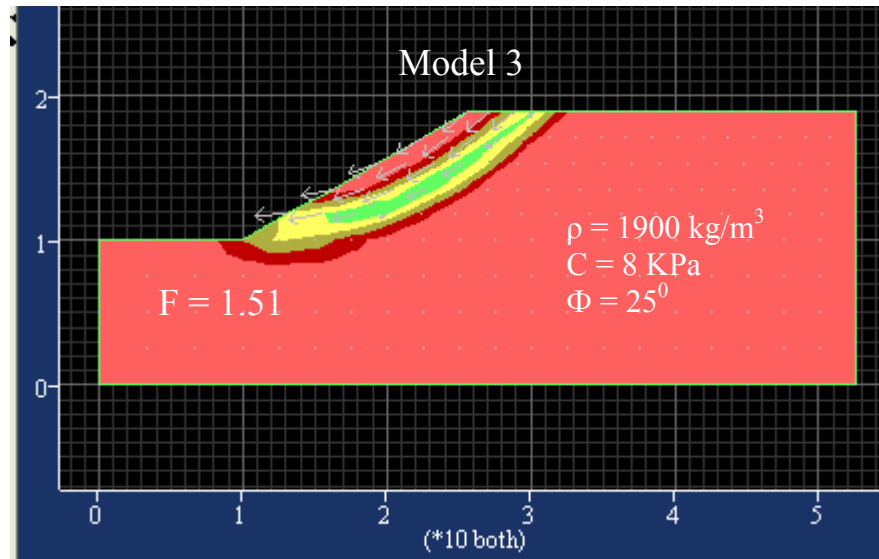


Figure 7.2 Show the effect of boundary

Generally, the factor of safety obtained varies not only from the used of different element but also different boundary. The effect can see from the results obtained in figure 7.2, where the length of right hand side's boundary increase and lead to obtained different factor of safety. Hence, judgmental results have to be taken by the engineer.

7.2 Model 2 : Surcharge Loads

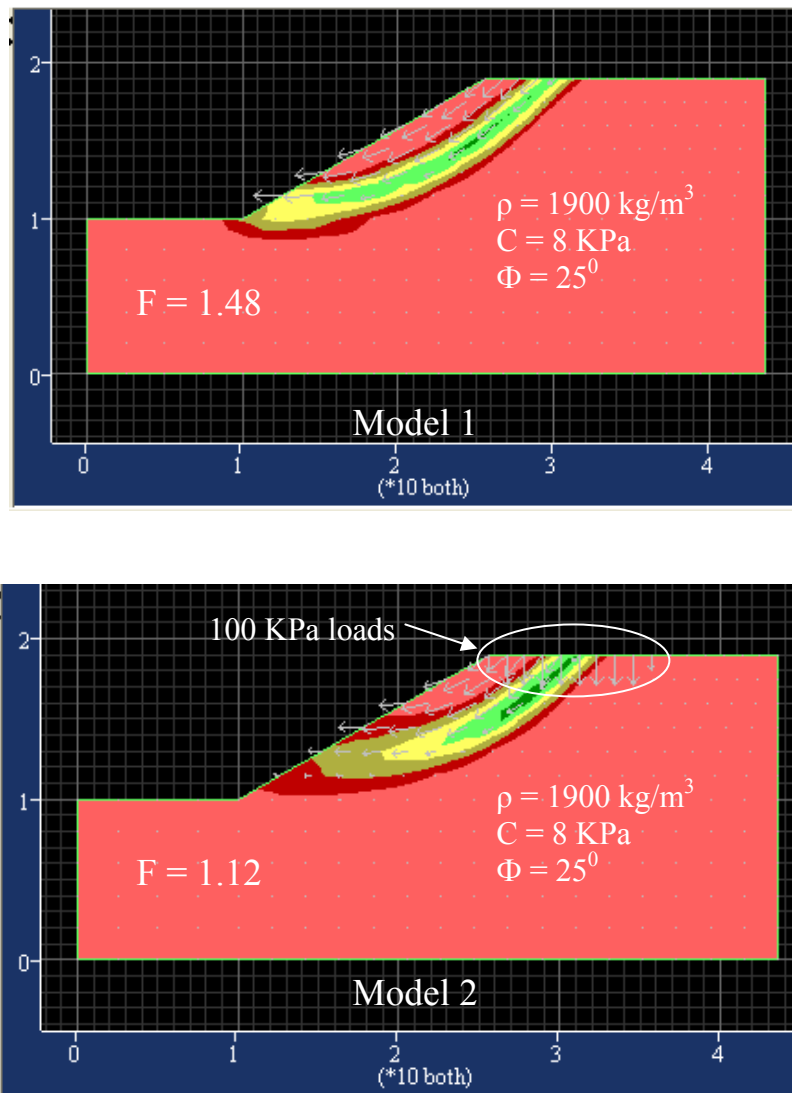


Figure 7.3 show the effect of the surcharges loads

By examining model 1 in figure 7.3, we can see that the factor of safety obtained without applying any surcharge loads is larger than the factor of safety obtained with surcharge loads in model 2. By theoretical, when a surcharge loads is applied to the slope, the slope tend to be not stable. By seeing the results obtain in figure 7.3 the factor of safety drop from 1.48 to 1.12 after applied the surcharge loads. Hence, we can conclude that FLAC/Slope is also capable to analyze model with surcharge loads and give reasonable results.

7.3 Model 3 : Water Table

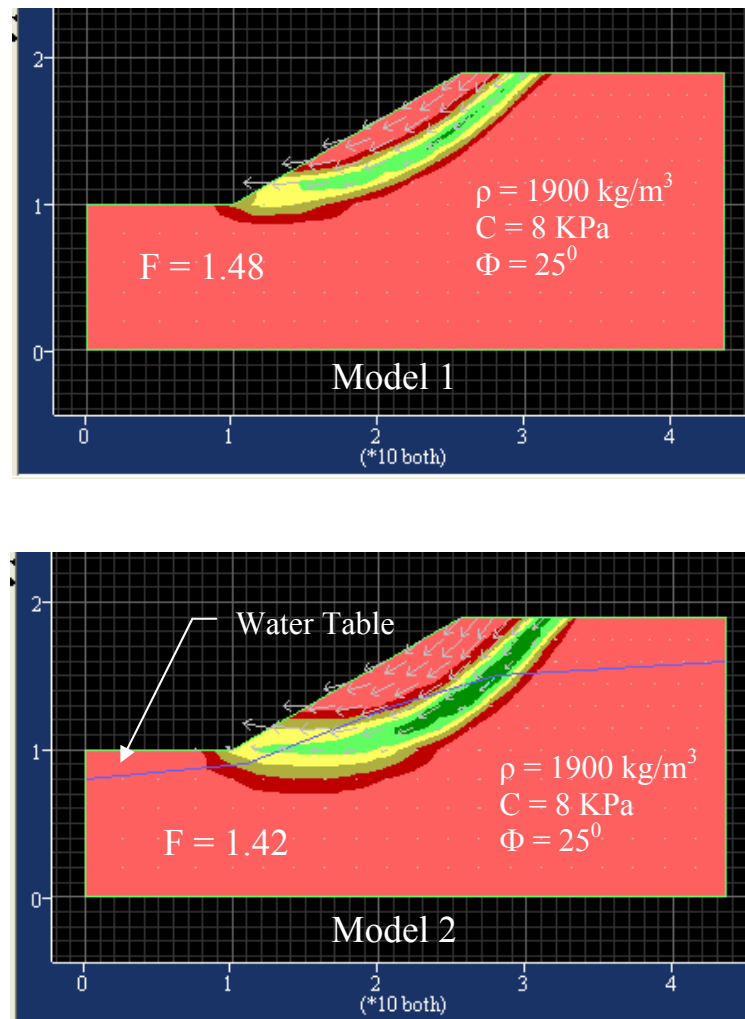


Figure 7.4 Show the effect of water table

By examining model 1 in figure 7.4, we can see that the factor of safety obtained without applying any water table is larger than the factor of safety obtained with applying water table in model 2. Hence, we can conclude that FLAC/Slope is also capable to analyze model with water table and give reasonable results.

7.4 Model 4 : Complex Geometry and Layer Slope

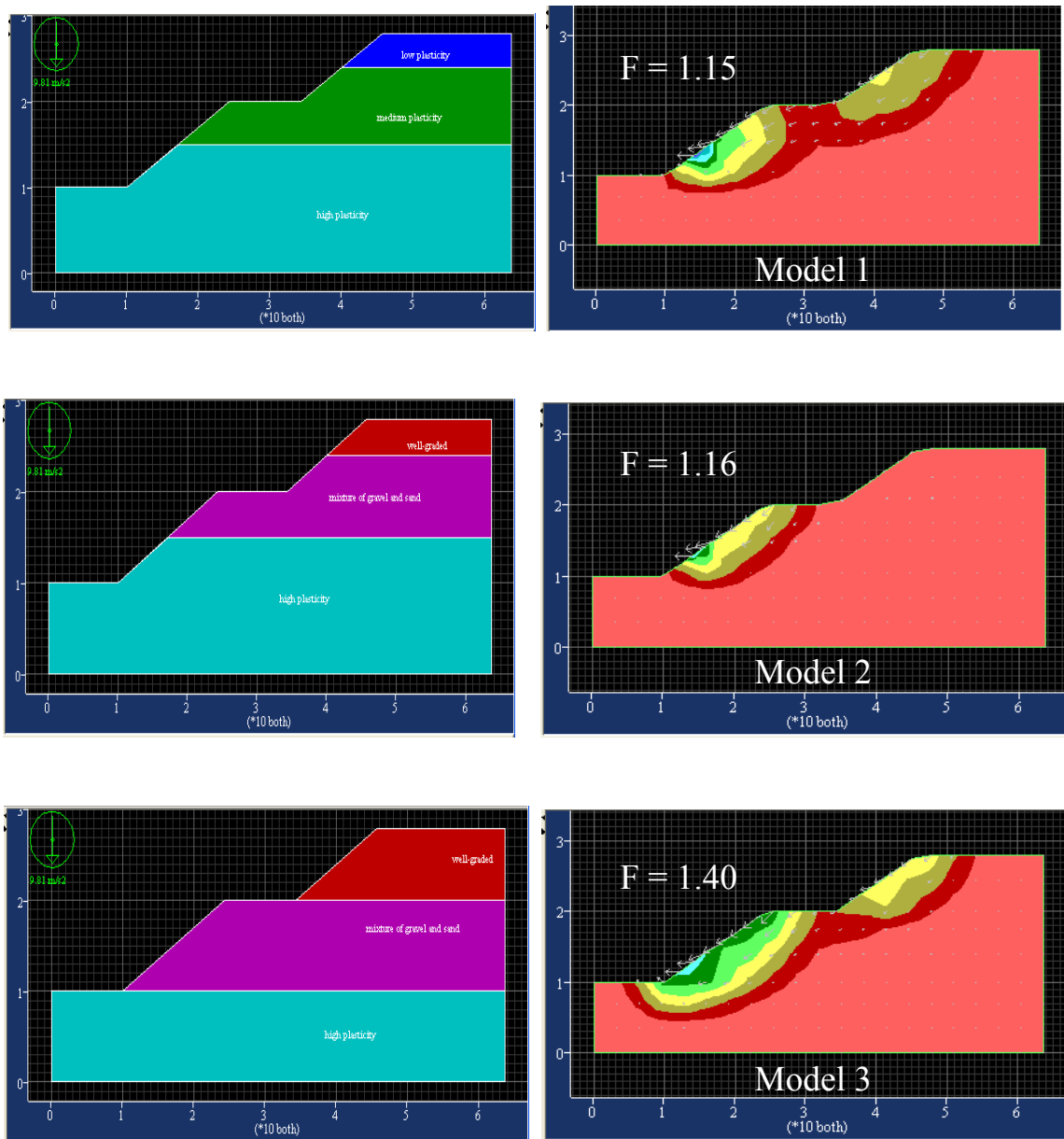


Figure 7.5 show the effect of complex geometry and layer soil

As we know, the analysis of complex geometry and layer slope is very difficult by using hand calculations. In FLAC/Slope, we can overcome this matter, this is because model can be created and solved easily. By examined the results obtain in figure 7.5 and found that the slope layering is very important which will cause the slope to reach its stable

stage. For example, when a layer slope is layered as model 3, the factor of safety obtain is larger than layer slope in model 2. Hence, we can say that the slope in model 3 is more stable than slope in model 2.

7.5 Model 5 : Geo-grid Reinforcement

7.5.1 Effect of geo-grid reinforcement

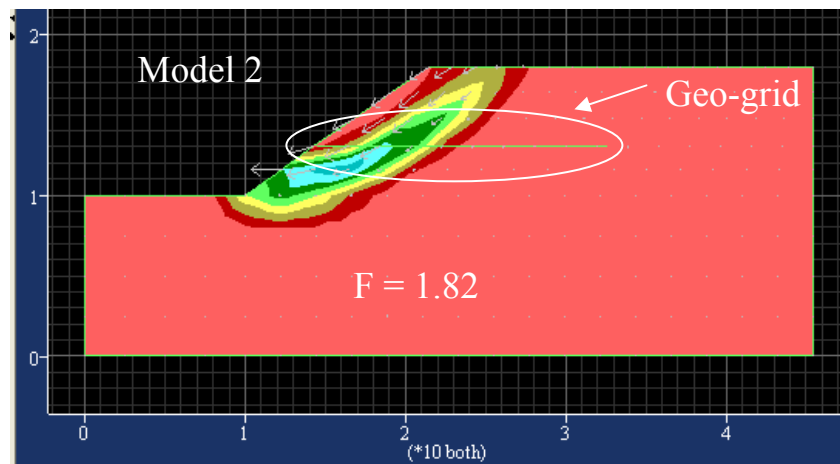
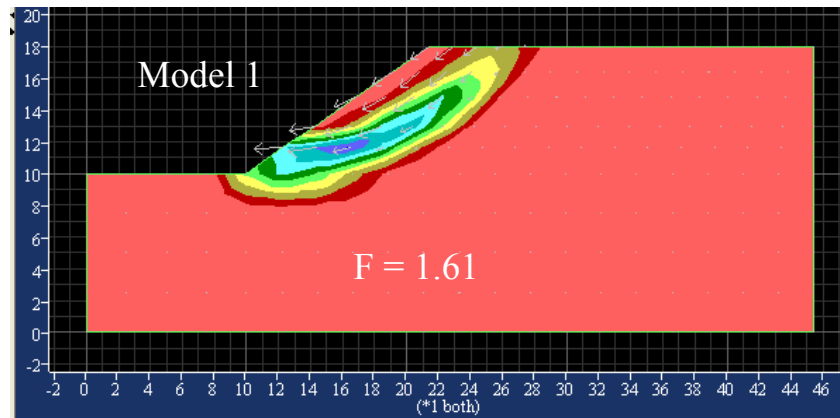
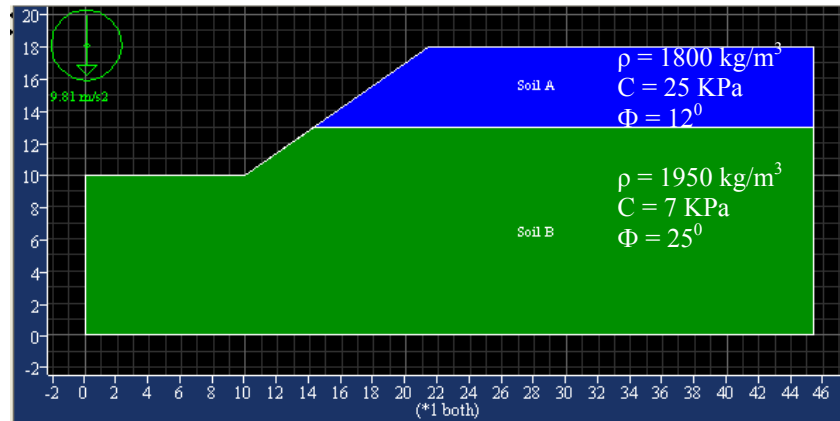


Figure 7.6 show the effect of Geo-grid Reinforcement

The model with 2 layer soil will be using to show the effect of the geo-grid reinforcement. The soil properties used was show in table F-1 and the geo-grid reinforcement will be placed at the interface between the two layers.

By examined model 1 in figure 7.6, the factor of safety obtained is equal to 1.61. However, when geo-grid reinforcement is applied to the slope as show in model 2 in figure 7.6, the factor of safety obtained increased to 1.82. This shows that the slope is more stable than the slope without geo-grid reinforcement.

7.5.2 As a tool to determine the length of geo-grid reinforcement

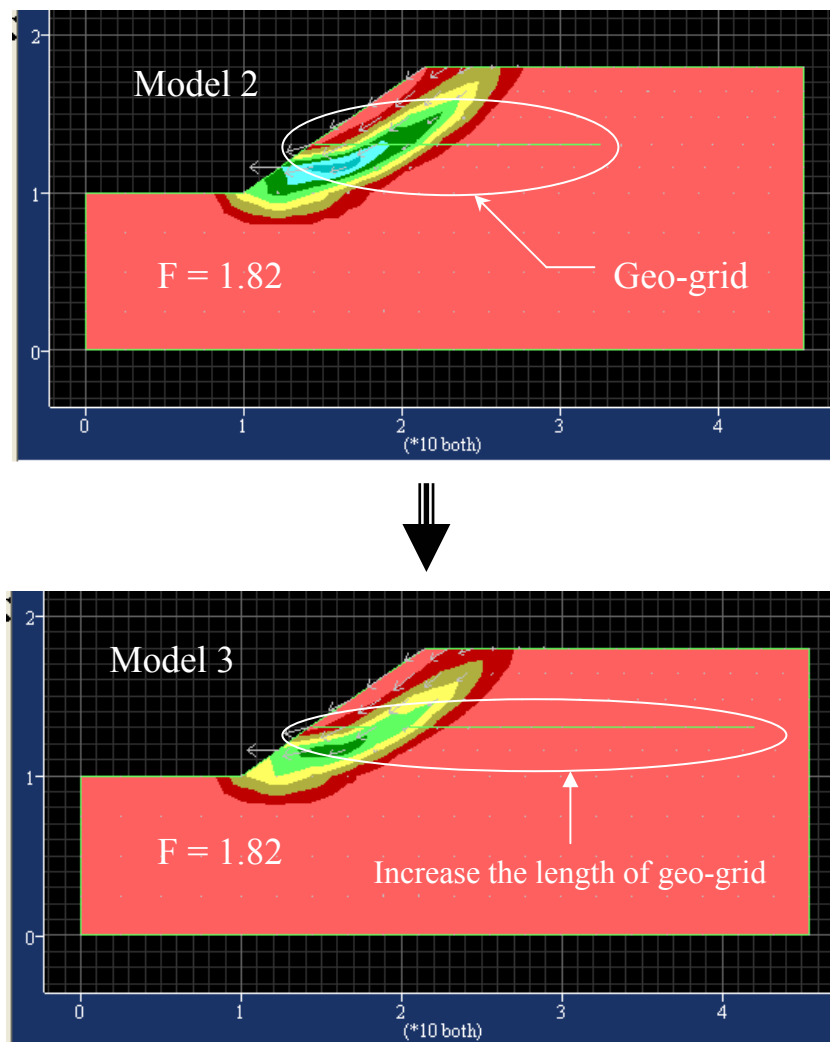


Figure 7.7 increased the length of geo-grid reinforcement

As we can see from figure 7.7, the factor of safety obtained before and after the change of length of geo-grid reinforcement is still the same, which give value of 1.82. Thus, there is not necessary to use longer geo-grid reinforcement to obtain a stable stage. This is because cost effective is an important issue in any construction project. Since this software can be use to obtain the failure surface, the necessary length of the geo-grid can be calculated. Figure 7.8 shows the length of the geo-grid reinforcement which reduced to the necessary length and obtained the same factor of safety as before.

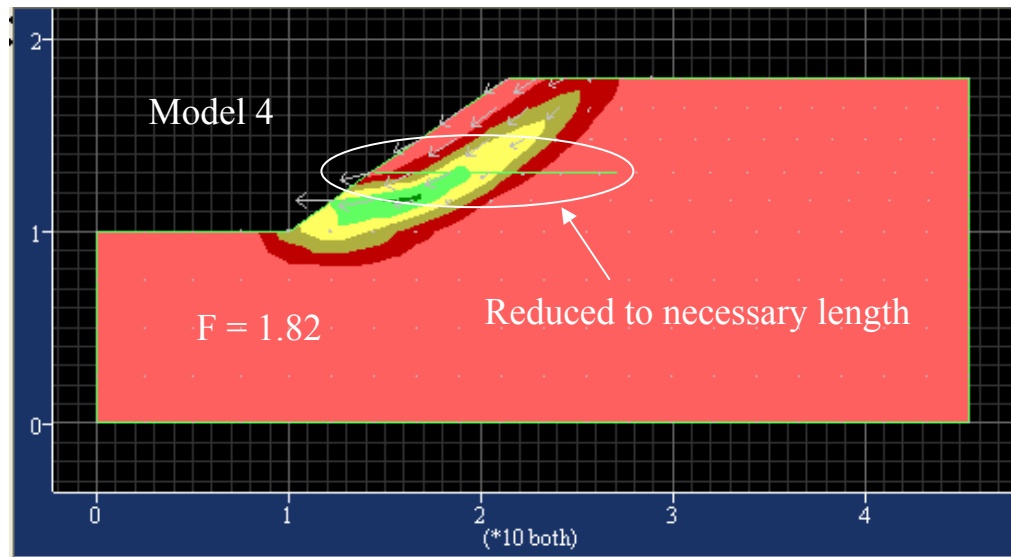


Figure 7.8 show the necessary length of geo-grid provide the same factor of safety

Chapter 8 Conclusions

Generally, a proper understanding, monitoring and management of slope stability are essentially important to minimize the severity or casualty in any landside. There is a number of slope analysis software available in the market. Although, all of them are capable to analyze the stability of slope, their user friendliness and the accuracy of the result will varies from each other. FLAC/Slope is one of the slope analysis software available in the market.

FLAC/Slope is a program that designed specifically to perform factor of safety calculation for slope stability analysis. As a learning process in this project, five models have been developed to assess its reliability and user-friendliness. The models range from mesh and boundary effect, effect of complex geometry and layer soil, effect of geo-grid, effect of water table and effect of surcharge loads. The result obtained by using these models was consistent. Theoretically, the use of fine mesh to solve the factor of safety will provide a more precise result as compare to the use of coarse mesh. For example, by using an example from an available text book, the results obtained from this FLAC/Slope program would provide a similar result. Hence, it could be concluded that FLAC/SLOPE is user-friendly and capable in providing reliable results as compare to other methods in on-the-shelf reference. However, several judgements have to be determined by the user. For example, the domain of the failure mechanism for the model Otherwise, the boundaries of the model will have to be adjusted.

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[Accessed 15 April 2004]

Appendix B

B1 Model 1 : Simple Slope

B1.1 Mesh effect

B1.1.1 Parameters:-

Dimension for the Model	
Rise (m)	9
Slope (Deg)	30
Depth (m)	10
Left (m)	10
Right (m)	9
Material Properties	
Density, ρ (kg/m ³)	1900
Cohesion, C (Pa)	8000
Friction Angle, Φ (Deg)	25

Table B-1 Dimension and Material Properties for the Model

B1.1.2 The Simulation and the procedures of the creation of the models

B1.1.2.1 Selection of the model option

The units of the system will be selected and the parameters for the model will then be labeled with the corresponding units. Meanwhile, predefined values such as gravitational

magnitude and material properties in the material database will be converted to the selected system.

B1.1.2.2 Creating a slope Model

After the units and option facilities have been set up, a model shape can be selected under the New Model dialog box. In this case, a simple boundary is selected and the dimensions used are being show in table B-1. Figure B-1 shows the boundary view of the model.

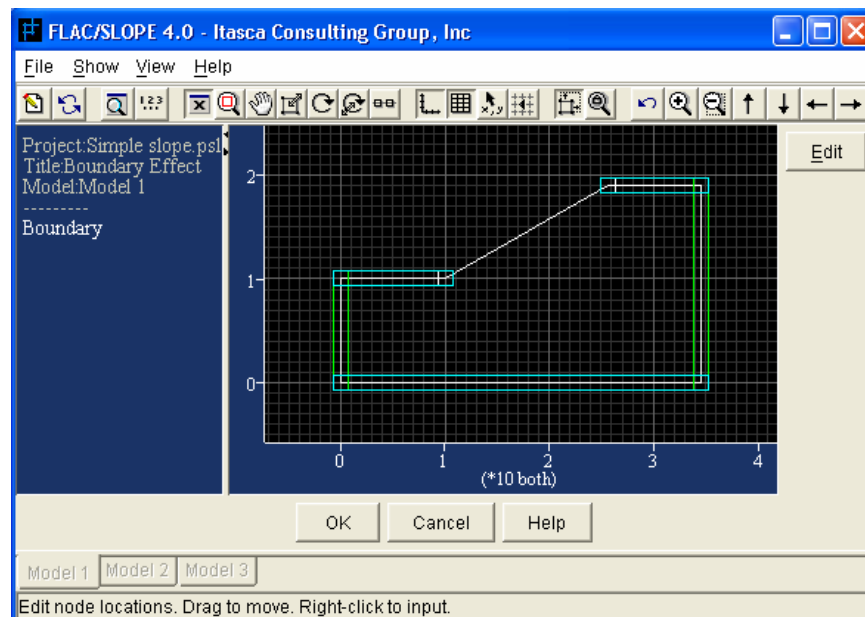


Figure B-1 Boundary view in FLAC/Slope

B1.1.2.3 Assigning Materials and Properties

In this step, material will be created and assigned to the model created previously. The material properties used in this model as shown in table B-1. Figure B-2 show the model with the material has been assigned.

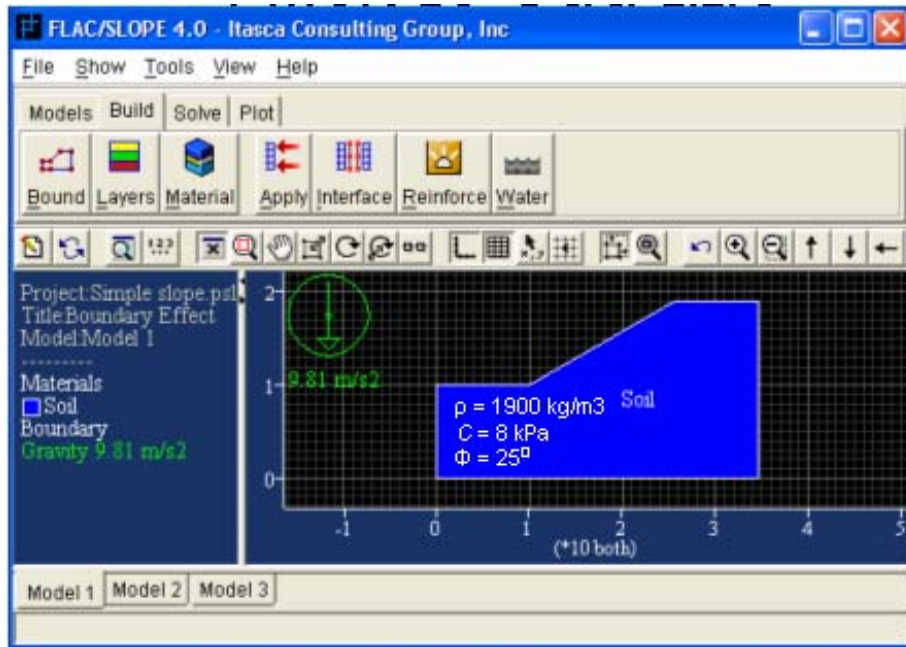
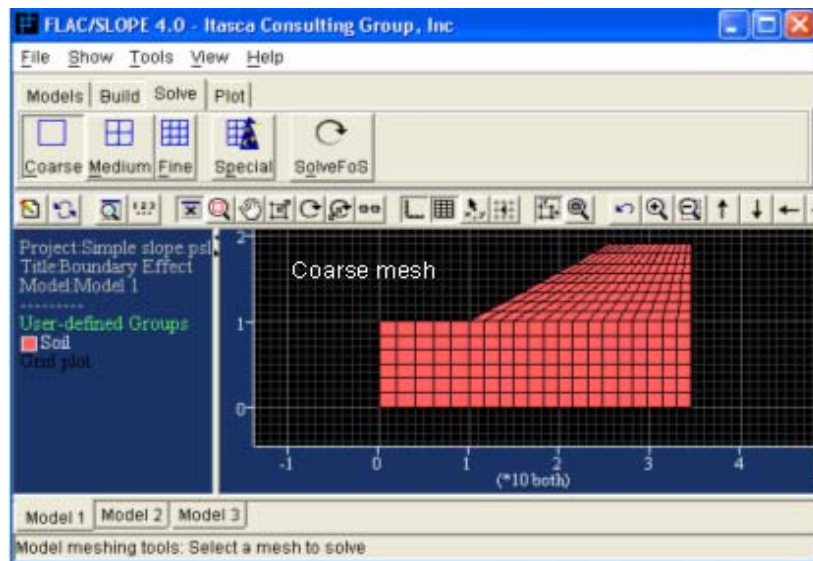


Figure B-2 Model View in FLAC/Slope

B1.1.2.4 Solve for a factor of safety

After the material properties have been assigned to the model, the next step will be the factor of safety calculation. In this model, two mesh elements will be using which is coarse and fine mesh.



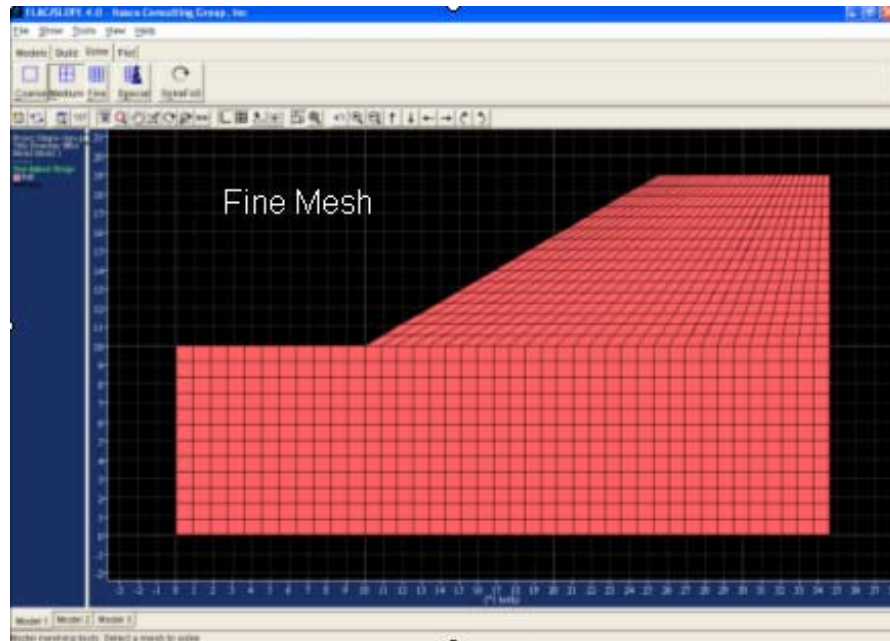


Figure B-3 Shows Coarse mesh and Fine mesh

B1.2 Boundary effect

B1.2.1 Parameters:-

	Model 1	Model 2	Model 3
Dimension for the Model			
Rise (m)	9	9	9
Slope (Deg)	30	30	30
Depth (m)	10	10	10
Left (m)	10	10	10
Right (m)	9	18	27
Material Properties			
Density, ρ (kg/m ³)	1900	1900	1900
Cohesion, C (Pa)	8000	8000	8000
Friction Angle, Φ (Deg)	25	25	25

Table B-2 Dimensions and Material Properties for the three models

B1.2.2 The Simulation and the procedures of the creation of the models

B1.2.2.1 Selection of the model option

The units of the system will be selected and the parameters for the model will then be labeled with the corresponding units. Meanwhile, predefined values such as gravitational magnitude and material properties in the material database will be converted to the selected system.

B1.2.2.2 Creating a slope Model

After the units and option facilities have been set up, a model shape can be selected under the New Model dialog box. In this case, three models will be in a simple boundary model and the dimensions used for the three models are being show in table B-2.

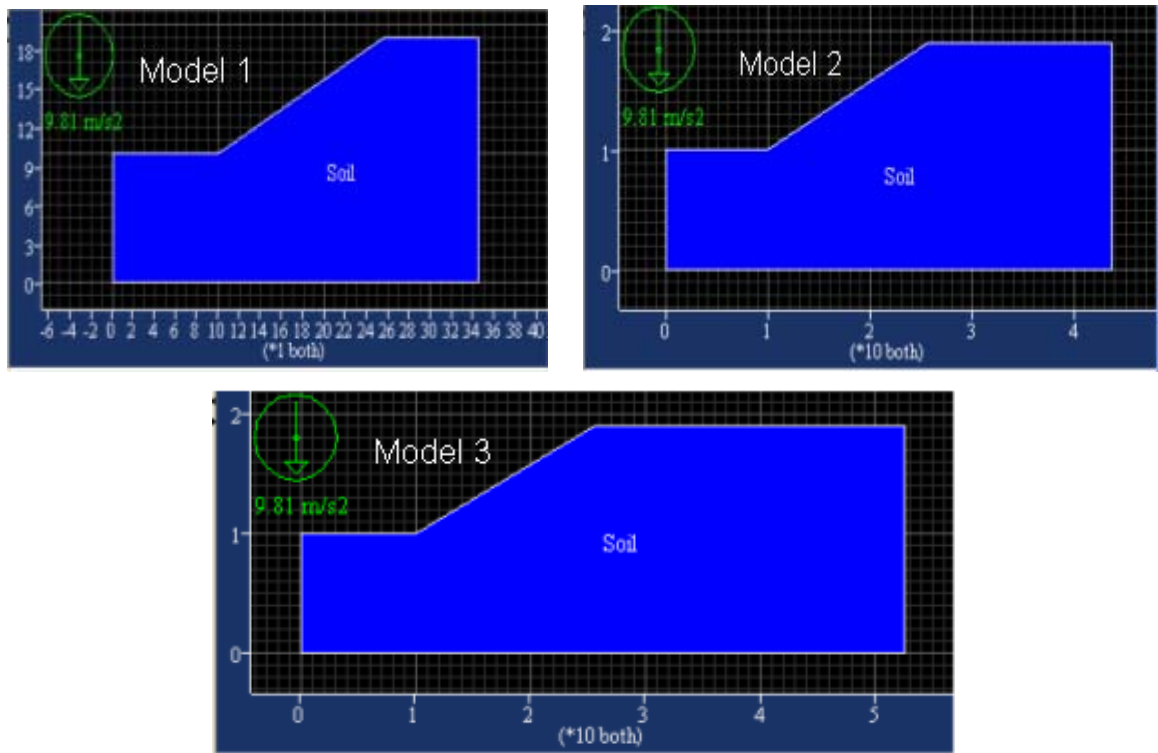


Figure B-4 Shows three model with different dimension size

B1.2.2.3 Assigning Materials and Properties

After the boundaries of the model have been created, material properties can be assigned to the model as shown in Figure B-4. For the three models, the material properties used are shown in table B-2.

B1.2.2.4 Solve for a factor of safety

After the material properties have been assigned to the model, the next step will be the factor of safety calculation. Coarse mesh elements will be used throughout the factor of safety calculation for the three models. Figure B-5 shows the coarse mesh generation for Model 3. Finally, the results obtained will be compared to each other.

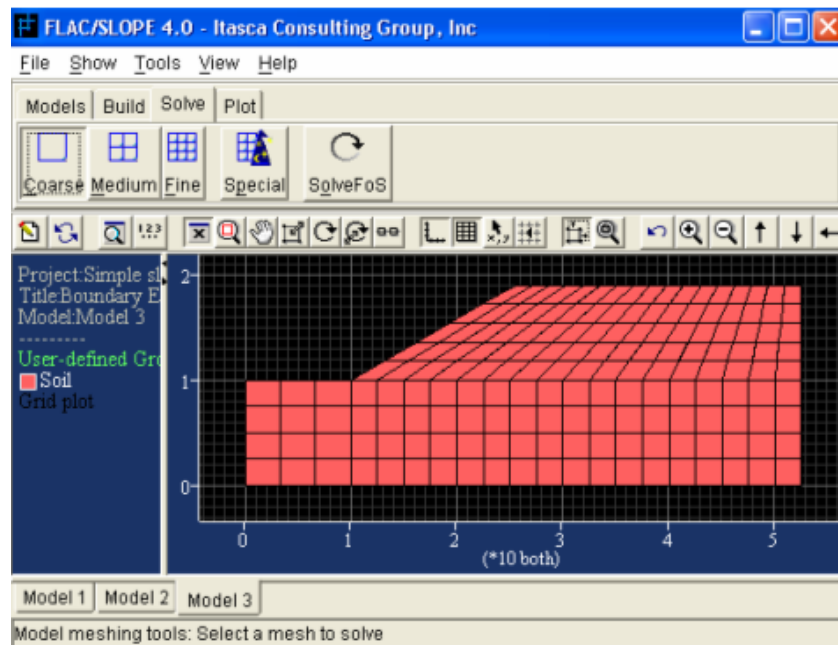


Figure B-5 Show the coarse mesh generation for Model 3

Appendix C

C1 Model 2 : Surcharge Loads

C1.1 Parameters Used:

	Model
Dimension for the Model	
Rise (m)	9
Slope (Deg)	30
Depth (m)	10
Left (m)	10
Right (m)	18
Material Properties	
Density, ρ (kg/m ³)	1900
Cohesion, C (Pa)	8000
Friction Angle, Φ (Deg)	25

Table C-1 Dimensions and material properties for the Model

C1.2 The Simulation and the procedures of the creation of the models

C1.2.1 Selection of the model option

The units of the system will be selected and the parameters for the model will then be labeled with the corresponding units. Meanwhile, predefined values such as gravitational magnitude and material properties in the material database will be converted to the selected system.

C1.2.2 Creating a slope Model

After the units and option facilities have been set up, a model shape can be selected under the New Model dialog box. In this case, two models will be in a simple boundary model and the dimensions used for the two models are being show in table C-1. Figure C-1 shows the boundary view of the model in FLAC/Slope.

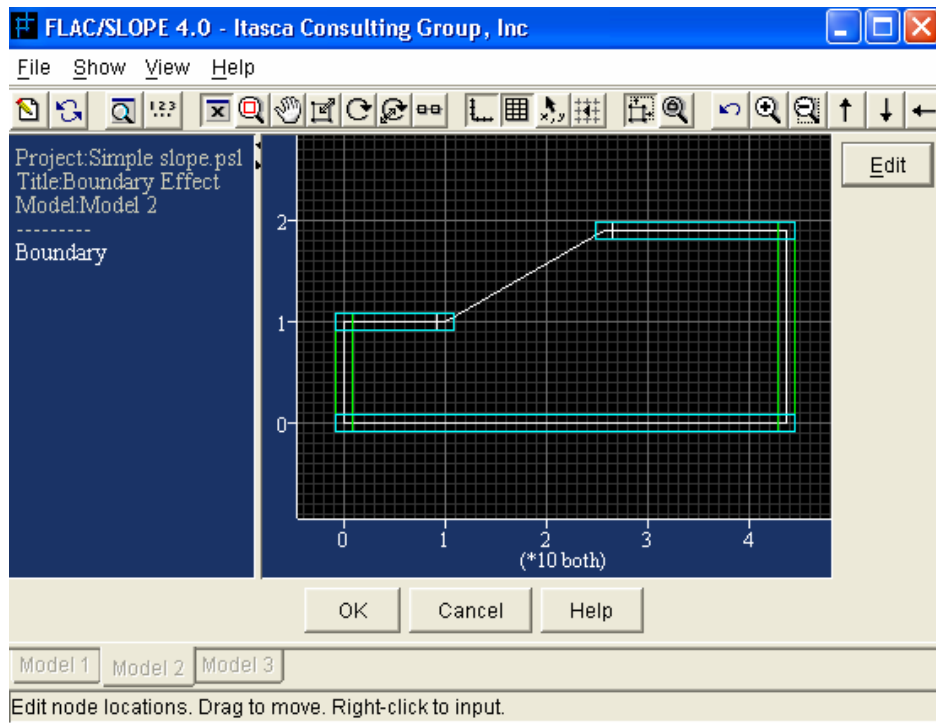


Figure C-1 Boundary view in FLAC/Slope

C1.2.3 Assigning Materials and Properties

After the boundaries of the model have been created, material properties can be assigned to the model. Figure C-2 shows the Define Material dialog box for the input of parameters in FLAC/Slope. For the two models, the material properties used are shows in table C-1.

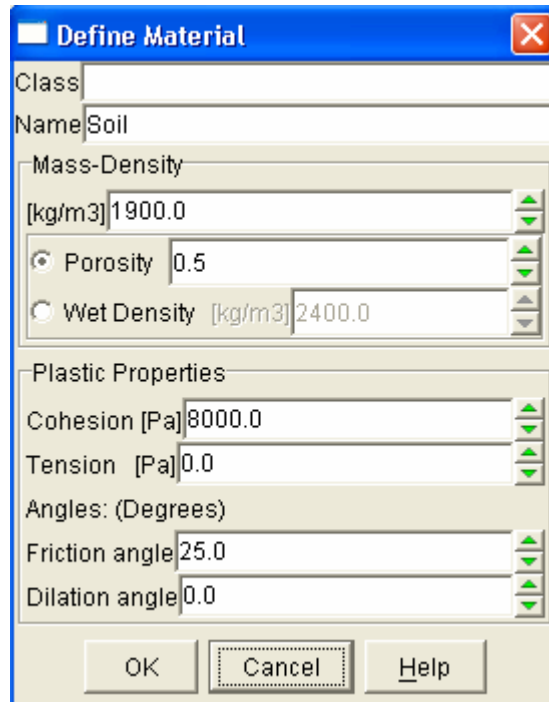


Figure C-2 Define Material dialog box

C1.2.4 Applying Surface Loads

Once the models have been created, point loads and area pressures can be applied along the slope surface. In this case, only one model will be applied an area pressure of 100 kPa at the top of the slope. The location of the pressures is show in figure C-3 and the length of the pressure is about 10 m.

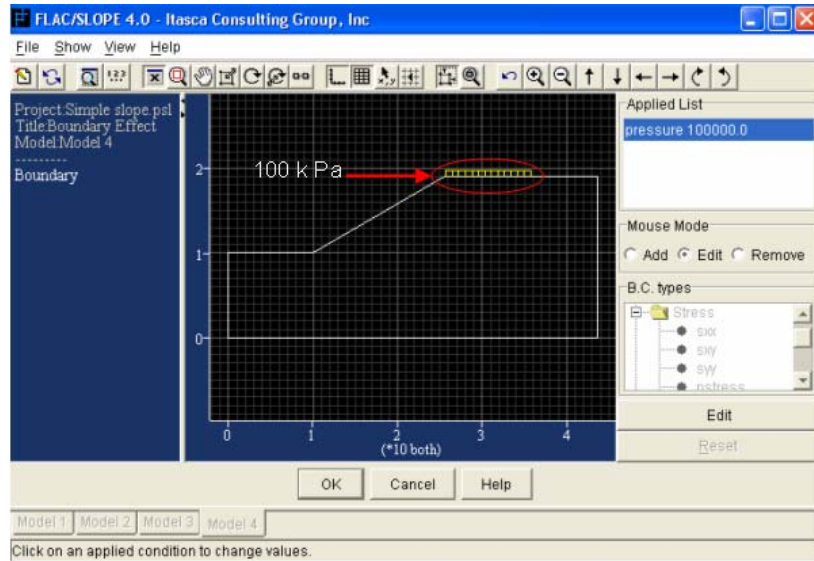


Figure C-3 show the location of the 100 kPa Pressures

C1.2.5 Solve for a factor of safety

Once the model is created, factor of safety calculation can begin. Coarse mesh elements will be used throughout the factor of safety calculation. Figure C-4 show the coarse mesh generation for Model with surcharge loads.

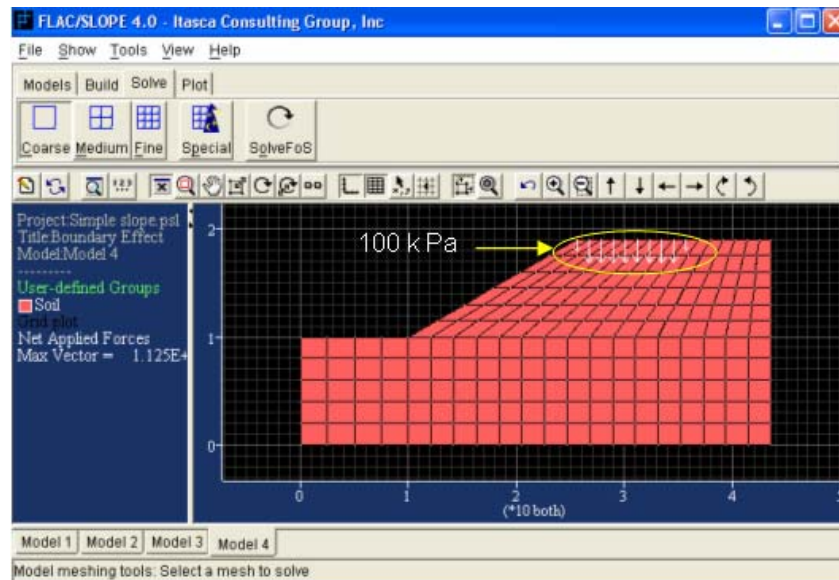


Figure C-4 Shows the generation of coarse mesh in the model with surcharge loads.

Appendix D

D1 Model 3 : Water Table

D1.1 Parameters Used:

	Model
Dimension for the Model	
Rise (m)	9
Slope (Deg)	30
Depth (m)	10
Left (m)	10
Right (m)	18
Material Properties	
Density, ρ (kg/m ³)	1900
Cohesion, C (Pa)	8000
Friction Angle, Φ (Deg)	25
Water Table Location	
(0,8), (11,9), (21,13), (28,15), (43.5,16)	

Table D-1 Dimensions and material properties for the Model

D1.2 The Simulation and the procedures of the creation of the models

D1.2.1 Selection of the model option

The units of the system will be selected and the parameters for the model will then be labeled with the corresponding units. Meanwhile, predefined values such as gravitational

magnitude and material properties in the material database will be converted to the selected system.

D1.2.2 Creating a slope Model

After the units and option facilities have been set up, a model shape can be selected under the New Model dialog box. In this case, two models will be in a simple boundary model and the dimensions used for the two models are being show in table D-1. Figure D-1 shows the boundary view of the model in FLAC/Slope.

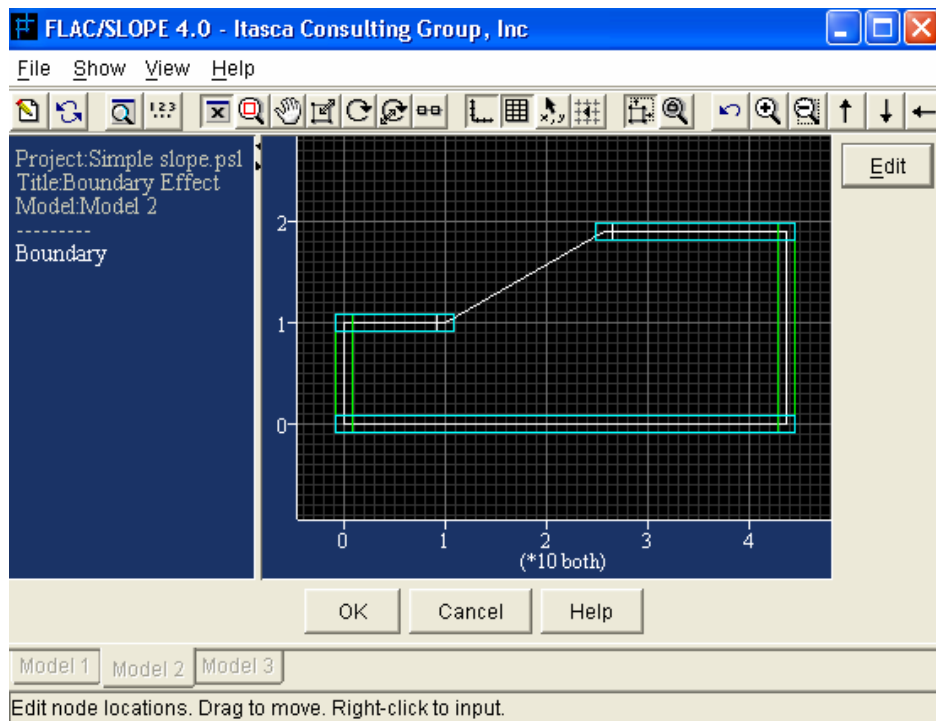


Figure D-1 Boundary view in FLAC/Slope

D1.2.3 Assigning Materials and Properties

After the boundaries of the model have been created, material properties can be assigned to the model. Figure D-2 shows the Define Material dialog box for the input of parameters in FLAC/Slope. For the two models, the material properties used are shown in table D-1.

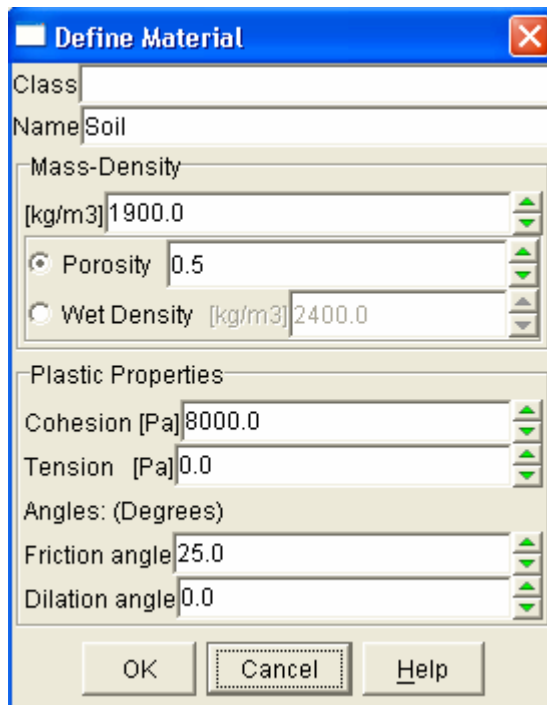


Figure D-2 Define Material dialog box

D1.2.4 Applying Water Table

Once the models have been created, water table can be added to the model. In this case, only one model will be added water table according to the coordinate in the table D-1. Figure D-3 show the location of the water table in the model.

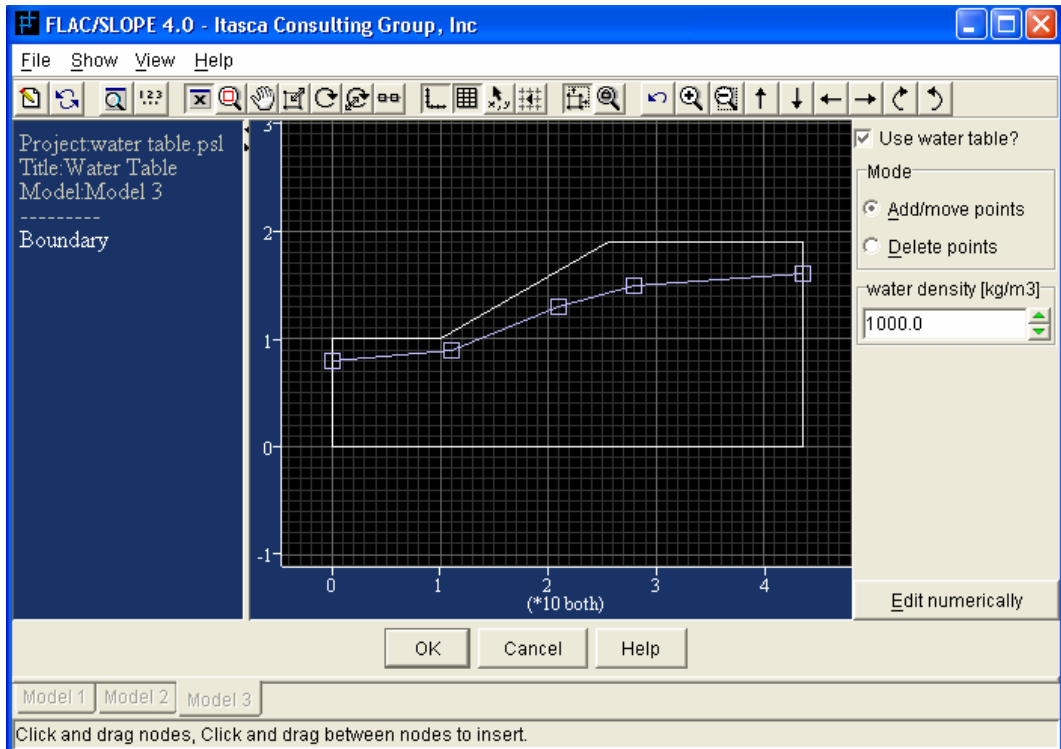


Figure D-3 Show the location of the water table in the model

D1.2.5 Solve for a factor of safety

The next step will be the factor of safety calculation. Coarse mesh elements will be used throughout the factor of safety calculation for the two models. Figure D-4 show the coarse mesh generation for Model with water table. Finally, the results obtain will be compare to each other.

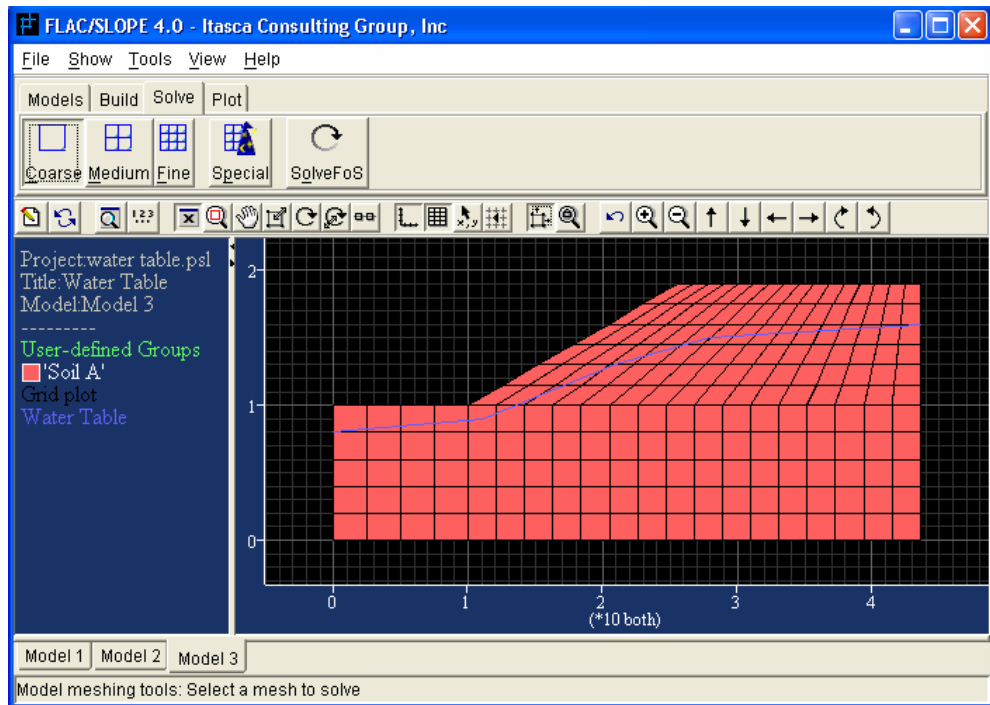


Figure D-4 Show the generation of the coarse mesh in the model with water table.

Appendix E

E1 Model 4 : Complex Geometry and Layer Slope

E1.1 Parameters:-

	Model 1	Model 2	Model 3
Dimension for the Model			
Rise 1 (m)	10	10	10
Rise 2 (m)	8	8	8
Slope 1 (Deg)	35	35	35
Slope 2 (Deg)	35	35	35
Depth (m)	10	10	10
Middle (m)	10	10	10
Left (m)	10	10	10
Right (m)	18	18	18
Layer 1 (from bottom, m)	15	15	10
Layer 2 (from bottom, m)	24	24	20
Material Properties			
First layer :			
Density, ρ (kg/m ³)	1900	1800	1800
Cohesion, C (Pa)	6000	0	0
Friction Angle, Φ (Deg)	24	33	33
Second Layer :			
Density, ρ (kg/m ³)	1800	2000	2000
Cohesion, C (Pa)	8000	3000	3000
Friction Angle, Φ (Deg)	20	38	38
Third layer :			
Density, ρ (kg/m ³)	1650	1650	1650
Cohesion, C (Pa)	10000	10000	10000
Friction Angle, Φ (Deg)	17	17	17

Table E-1 Dimensions and Material Properties for the three models

E1.2 The Simulation and the procedures of the creation of the models

E1.2.1 Selection of the model option

The units of the system will be selected and the parameters for the model will then be labeled with the corresponding units. Meanwhile, predefined values such as gravitational magnitude and material properties in the material database will be converted to the selected system.

E1.2.2 Creating a slope Model

After the units and option facilities have been set up, a model shape can be selected under the New Model dialog box. In this case, three models will be in a Bench-1 boundary model and the dimensions used for the three models are being show in table E-1.

E1.2.3 Assigning Materials Properties and Soil layer

After the boundaries of the model have been created, material properties and soil layer can be assigned to the model as shown in Figure E-1. For the three models, the material properties and the location of the layer used are shows in table E-1.

E1.2.4 Solve for a factor of safety

After the material properties have been assigned to the model, the next step will be the factor of safety calculation. Coarse mesh elements will be used throughout the factor of safety calculation for the three models. Finally, the results obtain will be compare to each other.

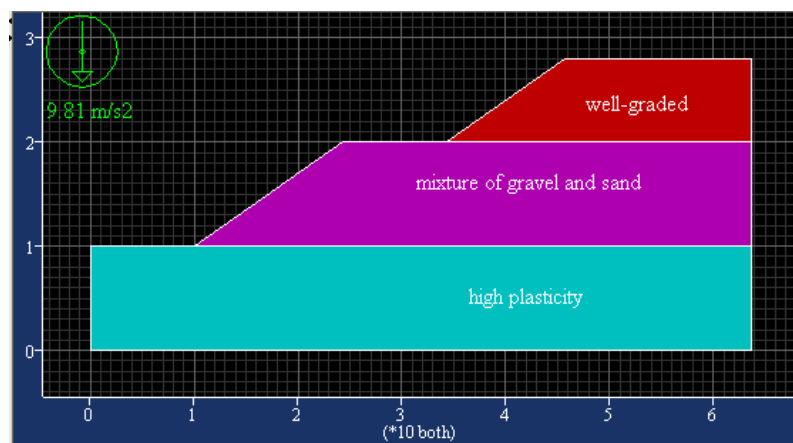
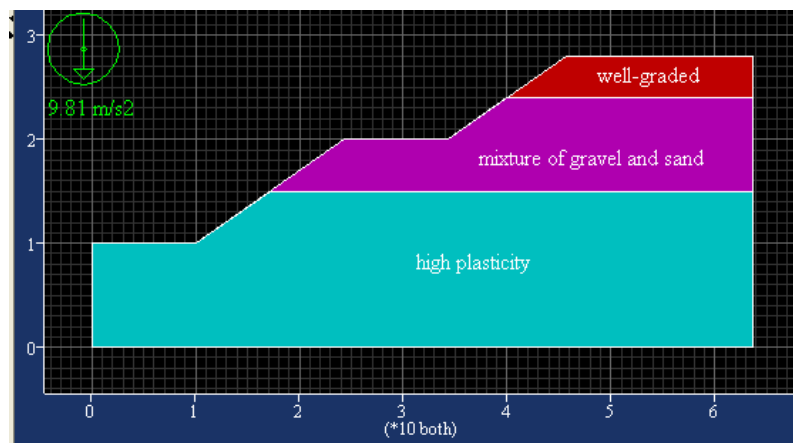
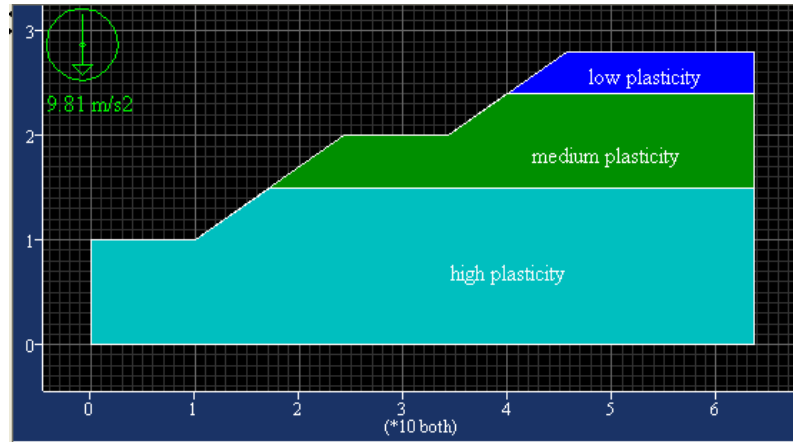


Figure E-1 Shows three models with different soil materials and layers

Appendix F

F1 Model 5 : Geo-Grid Reinforcement

F1.1 Parameters:-

	Model 1	Model 2	Model 3	Model 4
Dimension for the Model				
Rise (m)	8	8	8	8
Slope (Deg)	35	35	35	35
Depth (m)	10	10	10	10
Left (m)	10	10	10	10
Right (m)	24	24	24	24
Length of Geo-grid (m)	Nil	18	27.5	12.5
Layer position (from bottom, m)	13	13	13	13
Material Properties				
First Layer :				
Density, ρ (kg/m ³)	1800	1800	1800	1800
Cohesion, C (Pa)	25000	25000	25000	25000
Friction Angle, Φ (Deg)	12	12	12	12
Second Layer :				
Density, ρ (kg/m ³)	1950	1950	1950	1950
Cohesion, C (Pa)	7000	7000	7000	7000
Friction Angle, Φ (Deg)	25	25	25	25

Table F-1 Dimensions and Material Properties for the four models

F1.2 The Simulation and the procedures of the creation of the models

F1.2.1 Selection of the model option

The units of the system will be selected and the parameters for the model will then be labeled with the corresponding units. Meanwhile, predefined values such as gravitational magnitude and material properties in the material database will be converted to the selected system.

F1.2.2 Creating a slope Model

After the units and option facilities have been set up, a model shape can be selected under the New Model dialog box. In this case, four models will be in a simple boundary model with a layer soil. The dimensions used and the position of layer for the four models are being show in table F-1. Figure F-1 shows the boundary view of the model in FLAC/Slope.

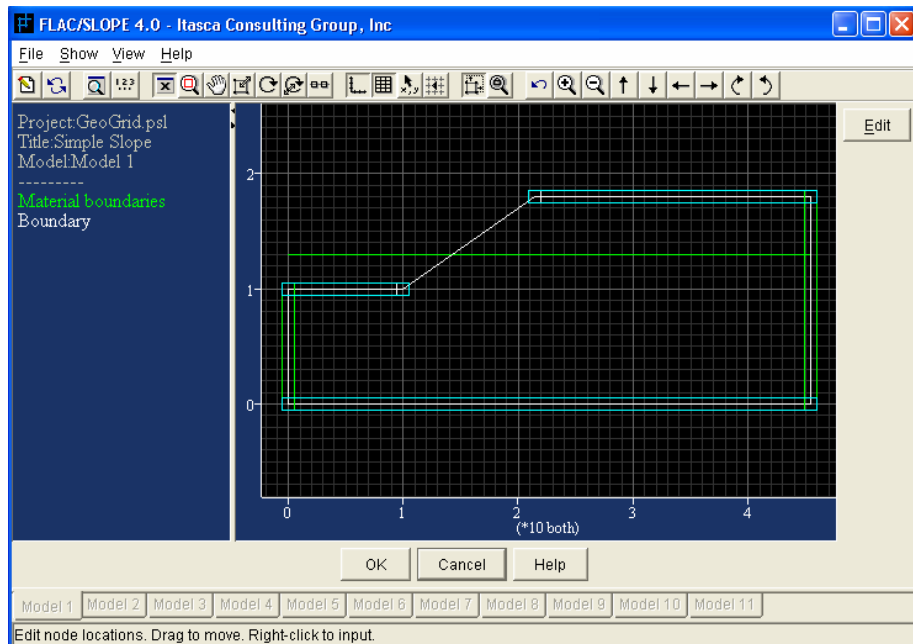


Figure F-1 show the boundary view in FLAC/Slope

F1.2.3 Assigning Materials and Properties

After the boundaries of the model have been created, material properties can be assigned to the model. Figure F-2 shows the model with the material has been assigned in FLAC/Slope. For the four models, the material properties used are shows in table F-1.

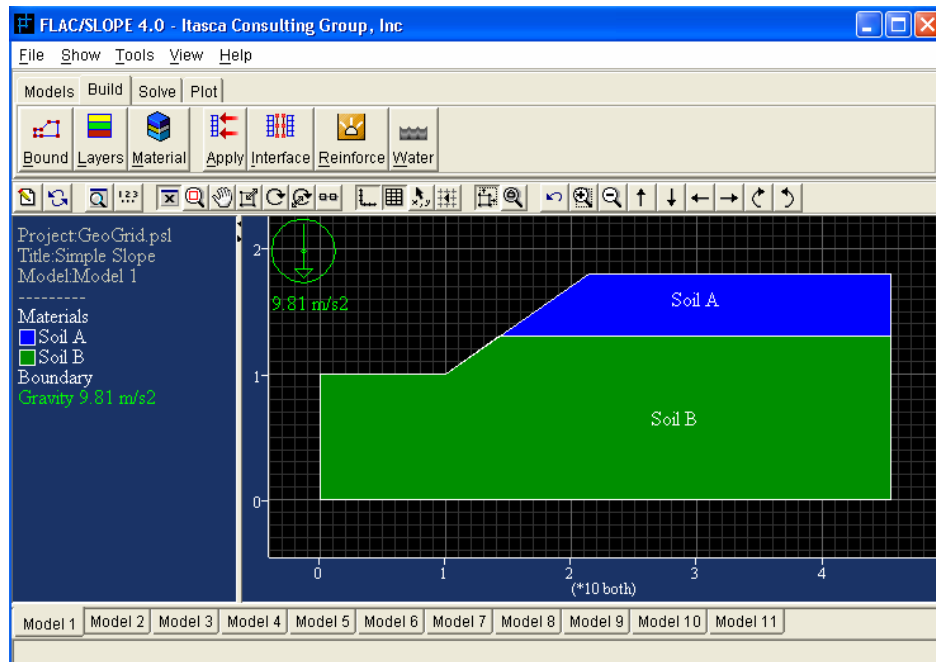


Figure F-2 Model View in FLAC/Slope with material been assigned

F1.2.4 Applying Geo-grid Reinforcement

Once the models have been created, geo-grid reinforcement can be added to the model. In this case, three models will be added geo-grid reinforcement at the interface of layer soil according to the length in the table F-1. Figure F-3 show the location of the geo-grid reinforcement in the model.

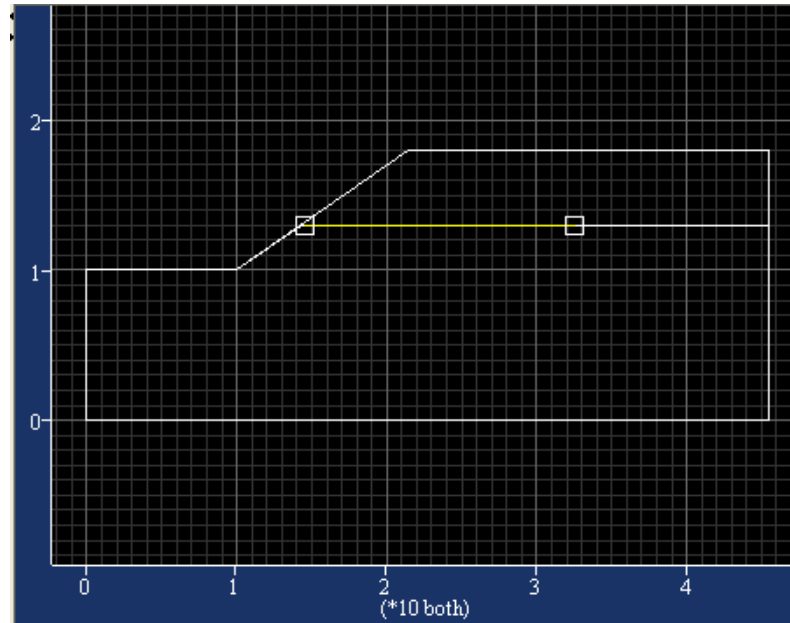


Figure F-3 Show the position of the geo-grid reinforcement in FLAC/Slope

F1.2.5 Solve for a factor of safety

Once the model is created, factor of safety calculation can begin. Coarse mesh elements will be used throughout the factor of safety calculation. Figure F-4 show the coarse mesh generation for Model with Geo-grid Reinforcement.

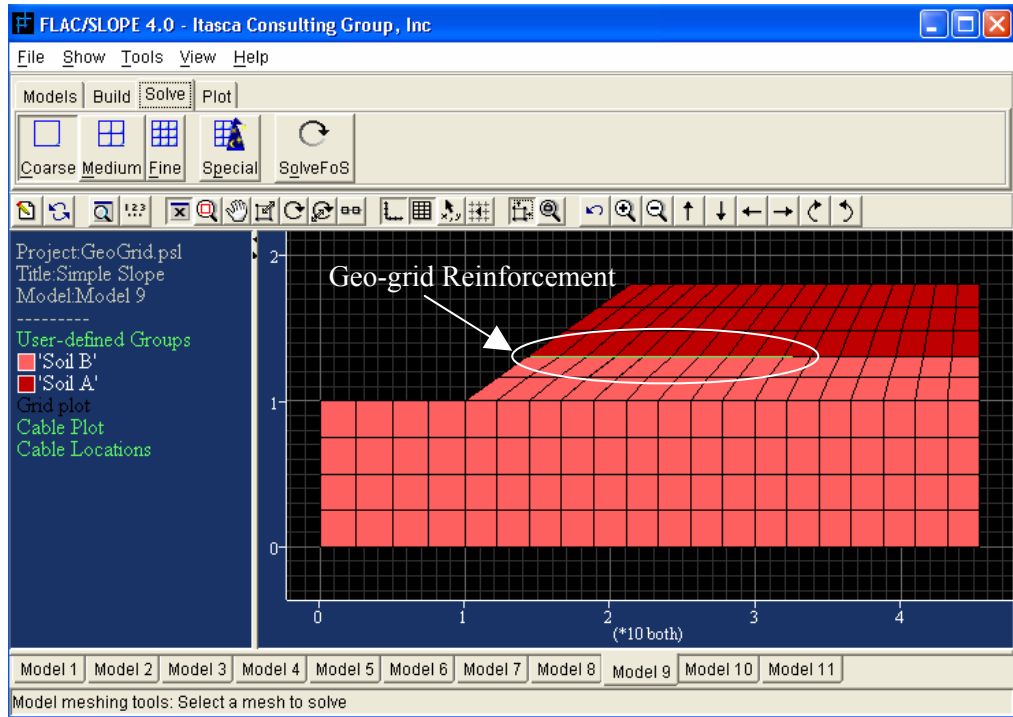


Figure F-4 Show the generation of the coarse mesh in the model with Geo-grid Reinforcement.

Appendix G

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:

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

$$\bar{N}_1 = W_1 \cos \alpha_1 = 73.6 \cos 29^\circ = 64$$

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

Figure G-1 Example from the available text book

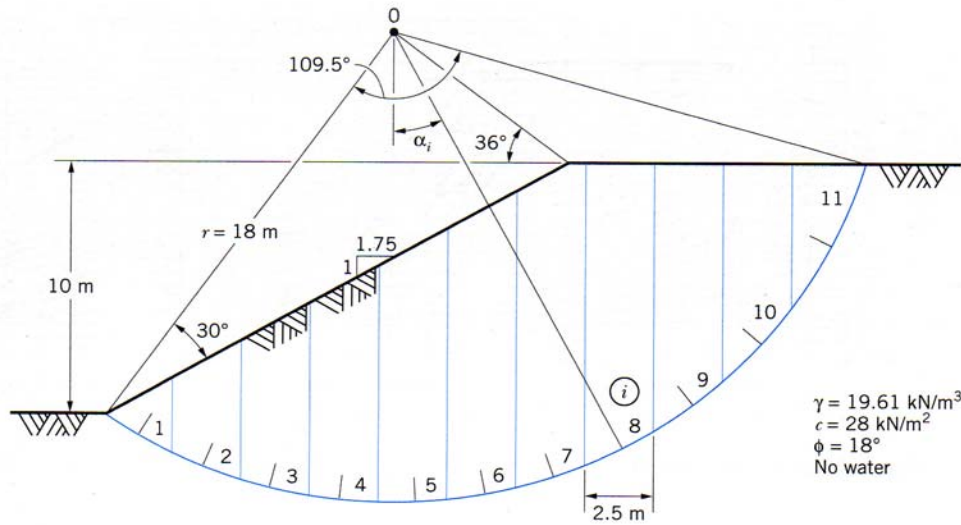


Figure 11.8 Slices encompassed by a trial failure arc.

$$T_{R_i} = 73.6 \sin 29^\circ = 37$$

$$\bar{N}_i \tan \phi = 64 \tan 18^\circ = 20.8$$

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	—
\bar{N}_i	64	183	311	405	479	528	540	480	370	236	69	—
$T_{\bar{\sigma}}$ ↺	—	—	—	—	≈0	93	186	256	284	220	130	1169
T_R ↻	37	70	42	35	—	—	—	—	—	—	—	184
$\bar{N}_i \tan \phi$	21	59.6	101	132	156	172	175	156	120	77	22.4	1190
$\Sigma \Delta L = L$						$L = 2\pi r \left(\frac{109.5}{360} \right) = 34.4$						34.4
$\Sigma c \Delta l = cL$						$cL = 28 \times 34 = 963.2$						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 G-2 Solution of the example from the text book