STABILITY ANALYSIS OF UNSTABLE SLOPES WITH REINFORCEMENTS AND BY THE USE OF "FLAC" SOFTWARE

A PROJECT REPORT SUBMITTED IN PARTIAL
FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

In

Civil Engineering

By

Prasanjit Prusty

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Department of Civil Engineering

National Institute of Technology, Rourkela

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Under The Guidance of

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Date: May 3, 2007 Prasanjit Prusty

National Institute of Technology
Rourkela

CERTIFICATE

This is to certify that the project report entitled, “STABILITY ANALYSIS OF UNSTABLE SLOPES WITH REINFORCEMENTS AND BY THE USE OF *FLAC* SOFTWARE” submitted by “Prasanjit prusty” in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Civil Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the project report has not been submitted to any other university / institute for the award of any Degree or Diploma.

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ABSTRACT

Failures of Unstable slopes have been a major disaster for the people of the world. It causes a lot of damage to public life as well as properties. Therefore proper analysis of the unstable slopes needs to be done with proper installation of nails to have adequate “factor of Safety” so that the slopes should not fail.

There are various methods available for the analysis of the existing slopes and to find the “Factor of safety”. Some of the common methods used in this regard are the “Friction circle method”, “Bishop’s method” etc. But all these methods are tedious and time consuming. But with the use of “FLAC” software, it has been possible to determine the “Factor of Safety” of the existing slope easily. Also the time consumed is very less.

The properties of a soil nail are studied in this project. The nail parameters, such as the bond strength, tensile strength, and diameter were studied in detail. The variation of “Factor of Safety” with the change of these parameters were observed and tabulated. Then the detailed optimal design of a given slope was carried out and proper combination of nails was determined by trial and error. The finally designed slope has a “Factor of Safety” equal to 1.61 with compared to 0.88 when it was not reinforced.

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Chapter 1

INTRODUCTION

INTRODUCTION

Slope failure is a very common case in the world today. A lot of people loose their life and a huge amount of property gets damaged due to slope failure. In the past, there are many evidences of slope failure on account of improper analysis and design. But now-a day, various methods have been developed to analyze a slope and to find the factor of safety.

The ratio of the resisting forces to the overturning forces in a slope is called its factor of safety. The various forces that resist the overturning include friction and cohesion. The forces that contribute to the overturning of the slope include rain, wind, earthquake and human activities like blasting etc. Now if the resisting forces are more than the overturning forces, i.e the factor of safety is more than one, then the slope is a stable one. If on the other hand, the overturning forces exceed the resisting forces, i.e the factor of safety is less than one, then the slope is termed as unstable. The unstable slopes are liable to failure and need to be analyzed and designed properly.

In case of unstable slopes, reinforcements in the form of steel bars are provided to increase the factor of safety to more than one. These are called “soil nails”. These nails may be driven into the slopes by driving equipments or these may be drilled into the pre drilled bore holes in the slope and then grouted with cement mortar.

The analysis of the slope necessarily means to find the factor of safety of the slope against overturning. For this, various manual methods are available like method of slices, Bishop’s method etc. But these methods are very tedious and time consuming. “FLAC” is software which is used to find the factor of safety of a given slope. It is very quick and easy to perform. The details of the software are explained below.

Chapter 2

Overview of “FLAC”

<u>OVERVIEW OF “FLAC”</u>

FLAC/*Slope* is a *mini*-version of *FLAC* that is designed specifically to perform factor-of-safety calculations for slope stability analysis. This version is operated entirely from *FLAC*’s graphical interface (the *GIIC*) which provides for rapid creation of models for soil and/or rock slopes and solution of their stability condition. *FLAC*/*Slope* provides an alternative to traditional “limit equilibrium” programs to determine factor
of safety. Limit equilibrium codes use an approximate scheme — typically based on the method of slices — in which a number of assumptions are made (e.g., the location and angle of interslice forces). Several assumed failure surfaces are tested, and the one giving the lowest factor of safety is chosen. Equilibrium is only satisfied on an idealized set of surfaces. In contrast, *FLAC*/*Slope* provides a *full* solution of the coupled stress/displacement, equilibrium and constitutive equations. Given a set of properties, the system is determined to be stable or unstable. By automatically performing a series of simulations while changing the strength properties (“shearstrength reduction technique”) the factor of safety can be found to correspond the point of stability, and the critical failure (slip) surface can be located. *FLAC*/*Slope* does take longer to determine a factor of safety than a limit equilibrium

FLAC/*Slope* can be applied to a wide variety of conditions to evaluate the stability of slopes and embankments. Each condition is defined in a separate graphical tool.

1. The creation of the slope boundary geometry allows for rapid generation of linear, nonlinear and benched slopes and embankments. The *Bound* tool provides separate generation modes for both simple slope shapes and more complicated non-linear slope surfaces. A bitmap or DXF image can also be imported as a background image to assist boundary creation.

2. Multiple layers of materials can be defined in the model at arbitrary orientations and non-uniform thicknesses. Layers are defined simply by clicking and dragging the mouse to locate layer boundaries in the *Layers* tool.

3. Materials and properties can be specified manually or from a database in the *Material* tool. At present, all materials obey the Mohr-Coulomb yield model, and heterogeneous properties can be assigned. Material properties are entered via material dialog boxes that can be edited and cloned to create multiple materials rapidly.

4. With the *Interface* tool, a planar or non-planar interface, representing a joint, fault or weak plane can be positioned at an arbitrary location and orientation in the model. The interface strength properties are entered in a properties dialog; the properties can be specified to vary during the factor-of-safety calculation, or remain constant.

5. An *Apply* tool is used to apply surface loading to the model in the form of either an area pressure (surface load) or a point load.

6. A water table can be located at an arbitrary location by using the *Water* tool; the water table defines the phreatic surface and pore pressure distribution for incorporation of effective stresses and the assignment of wet and dry densities in the factor-of-safety calculation.

7. Structural reinforcement, such as soil nails, rock bolts or geotextiles, can be installed at any location within the model using the *Reinforce* tool. Structural properties can be assigned individually for different elements, or groups of elements, through a properties dialog.

8. Selected regions of a *FLAC*/*Slope* model can be excluded from the factor-of-safety calculation. This is useful, for example, when studying complex slope geometries in which the user wishes to disregard selected regions, such as localized sloughing of the slope.

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. The modeling-stage tool bars for each stage are shown and described below.

Models Stage

Fig 2.1: Model stage of "FLAC"

Each model in a project is named and listed in a tabbed bar in the *Models* stage. This allows easy access to any model and results in a project. New models can be added 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. Note that the slope boundary is also defined for each model at this stage.

Build Stage:

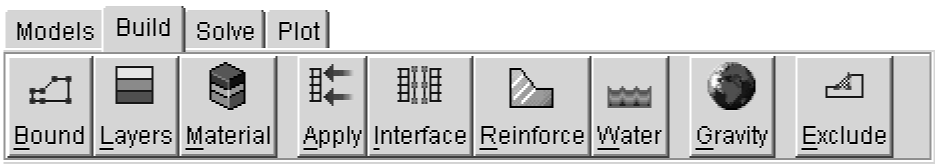

Fig 2.2: Build stage of "FLAC"

For a 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 and installation of reinforcement. Also, spatial regions of the model can be excluded from the factor-of-safety calculation. The build-stage conditions can be added, deleted and modified at any time during this stage.

Solve Stage:

Fig. 2.3: Solve stage of "FLAC"

In the *Solve* stage, the factor of safety is calculated. The resolution of the numerical meshes selected first (coarse, medium, fine or user-specified), and then the factor-of-safety calculation is performed. 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.

Plot Stage:

Fig 2.4: Plot stage of "FLAC"

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.

FLAC SLOPE:

Start-Up—The default installation procedure creates an "Itasca" group with icons for *FLAC*/*Slope* and *FLAC*. To load *FLAC*/*Slope*, simply click on the *FLAC*/*Slope* icon. The code will start up and you will see the main window as shown in. The code name and current version number are printed in the title bar at the top of the window, and a main menu bar is positioned just below the title bar. The main menu contains File, Show, Tools, View and Help menus. Beneath the main menu bar is the *Modeling Stage* tool bar, containing modeling-stage tabs for each of the stages: Models , Build , Solve and Plot . When you click on a modeling-stage tab, a set of tools becomes available: these tools are used to create and run the

* The executable code used for *FLAC*/*Slope* is the single-precision version (“FLACV SP.EXE”). This version is better-suited to factor-of-safety calculations than the double-precision version because it

runs approximately 1.5 to 2.0 times faster, and the single-precision calculation is sufficient for this type of analysis.

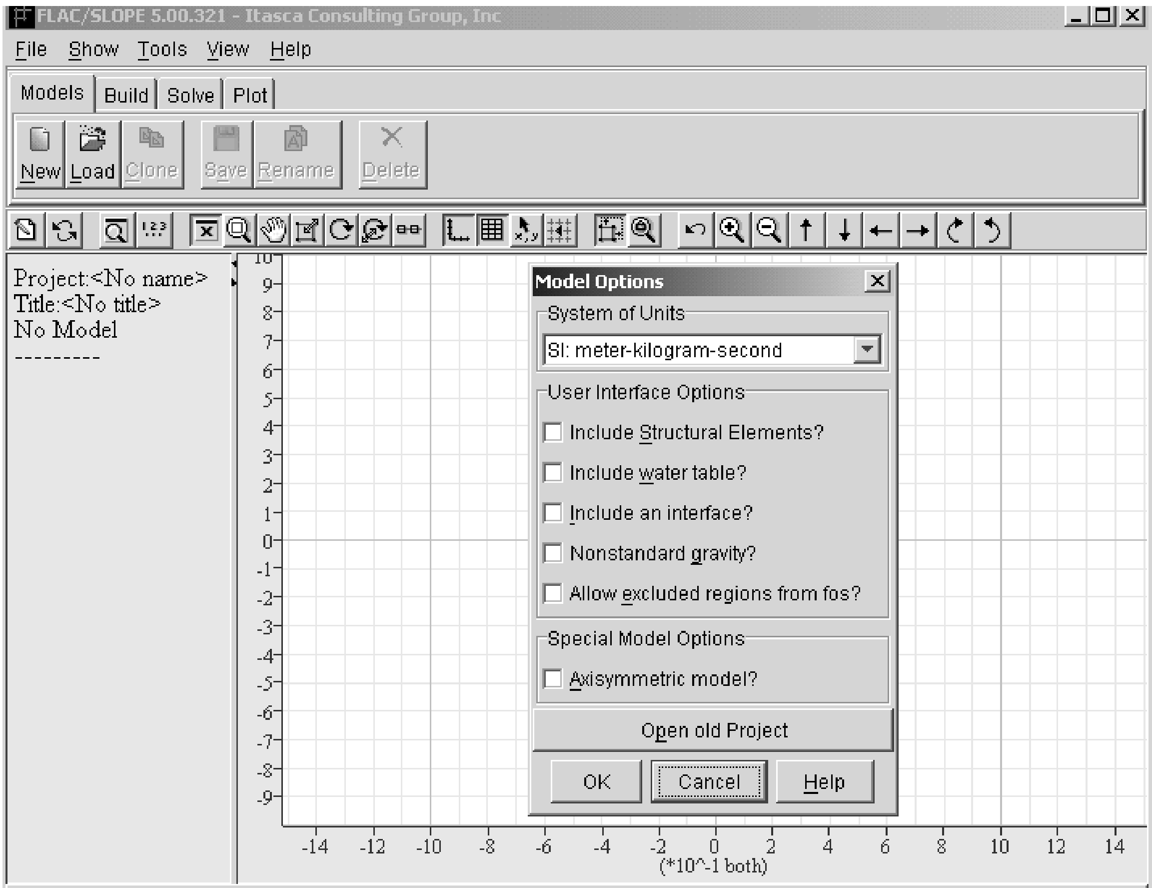

Fig.2.5: *FLAC*/SLOPE MAIN WINDOW

Beneath the *Modeling Stage* tool bar is the *model-view* pane.* The *model-view* pane shows a graphical view of the model. Directly above the *model-view* pane is a *View* tool bar. You can use the *View* tools to manipulate the
model-view pane (e.g., translate or rotate the view, increase or decrease the size of the view, turn on and off the model axes). The *View* tools are also available in the View menu. Whenever you start a new project, a *Model Options* dialog will appear, as shown in . You have the option to include different features, such as an interface (weak plane), a water table or
Reinforcement, in the model and specify the system of units for your project with this dialog. The menus and tools are described in detail in . An overview of the *FLAC*/*Slope* operation is provided in the Help menu.

Defining the Project — We begin the project by checking the Include water table? box in the *Model Options* dialog. The water table tool will be made available for our analysis. We also select the *SI: meter-kilogram-second* system of units. Press OK to include these options in the project analysis. We now click on File / Save Project As ... to specify a project title, a working directory for the project and a project save file. The *Project Save* dialog opens, as shown in and we enter the project title and project save file names. The working directory location for the project is
selected in this dialog. In order to change to a specific directory, we press ? in this dialog. An *Open* dialog appears to allow us to change to the working directory of our choice. We specify a project save file name of "SLOPE" and note that the extension ".PSL" is assigned automatically—i.e., the
file "SLOPE.PSL" is created in our working directory. We click OK to accept these selections.

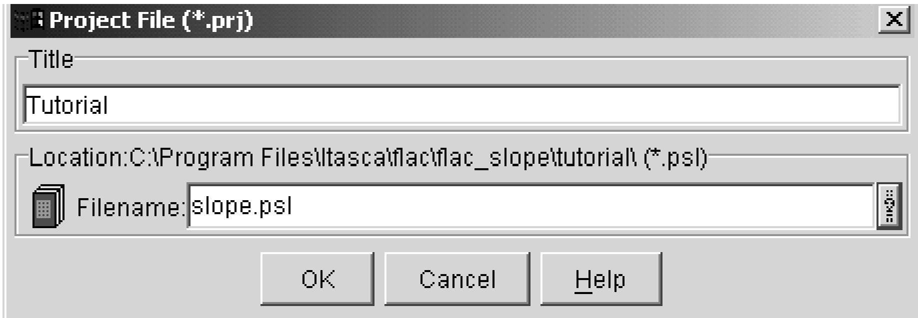

Fig 2.6: Project file

We next click on the Models tool and enter the *Models* stage to specify a name for the first model in our project. We click on New and use the default model name *Model 1* that appears in the *New Model* dialog. There will be two models in our project: *Model 1*, which does not contain a water table;

and *Model 2,* which does. We will create *Model 2* after we have completed the factor-of-safety calculation for *Model 1*. (Note that, alternatively, we can create both models first before performing the calculation.). There are several types of model boundaries available to assist us in our model generation. For this tutorial, we select the Simple boundary button.

When we press OK in the *New Model* dialog, an *Edit slope parameters* dialog opens and we enter the dimensions for our model boundary, as shown in. Note that we click on Mirror Layout to reverse the model layout to match that shown in. We click OK to view the slope boundary that we have created. We can either edit the boundary further or accept it. We press OK to accept the boundary for *Model 1*. The layout for the *Model 1* slope is shown in. A tab is also created with the model name (*Model 1*) at the bottom of the view. Also, note that an icon is shown in the upper-left corner of the model view, indicating the direction and magnitude of the gravity vector. The project save file name, title and model name are listed in the legend to the model view.

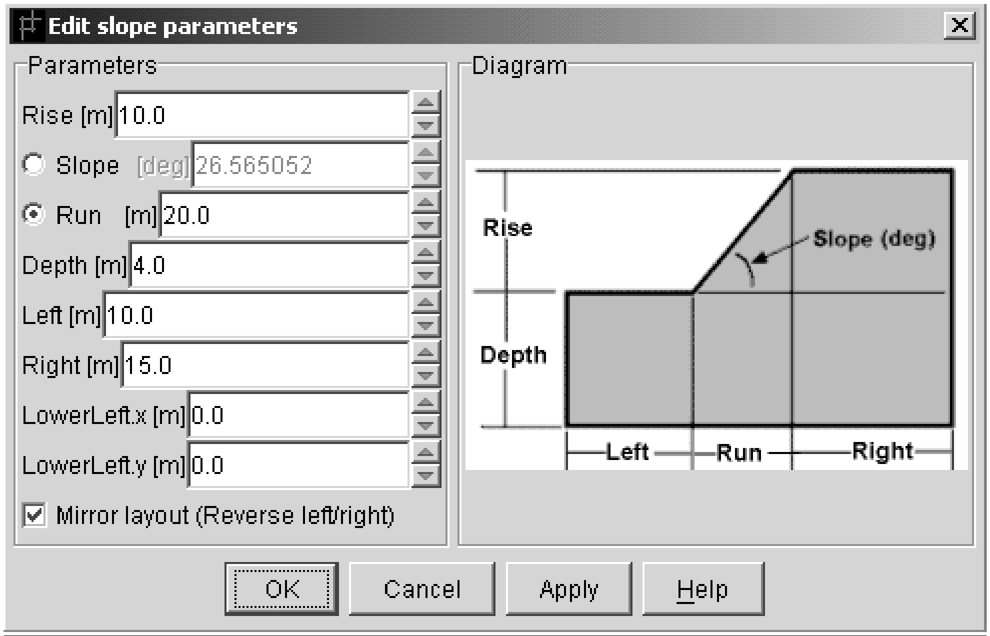

Fig 2.7: Edit slope parameter

"EDIT SLOPE PARAMETER" DIALOUGE

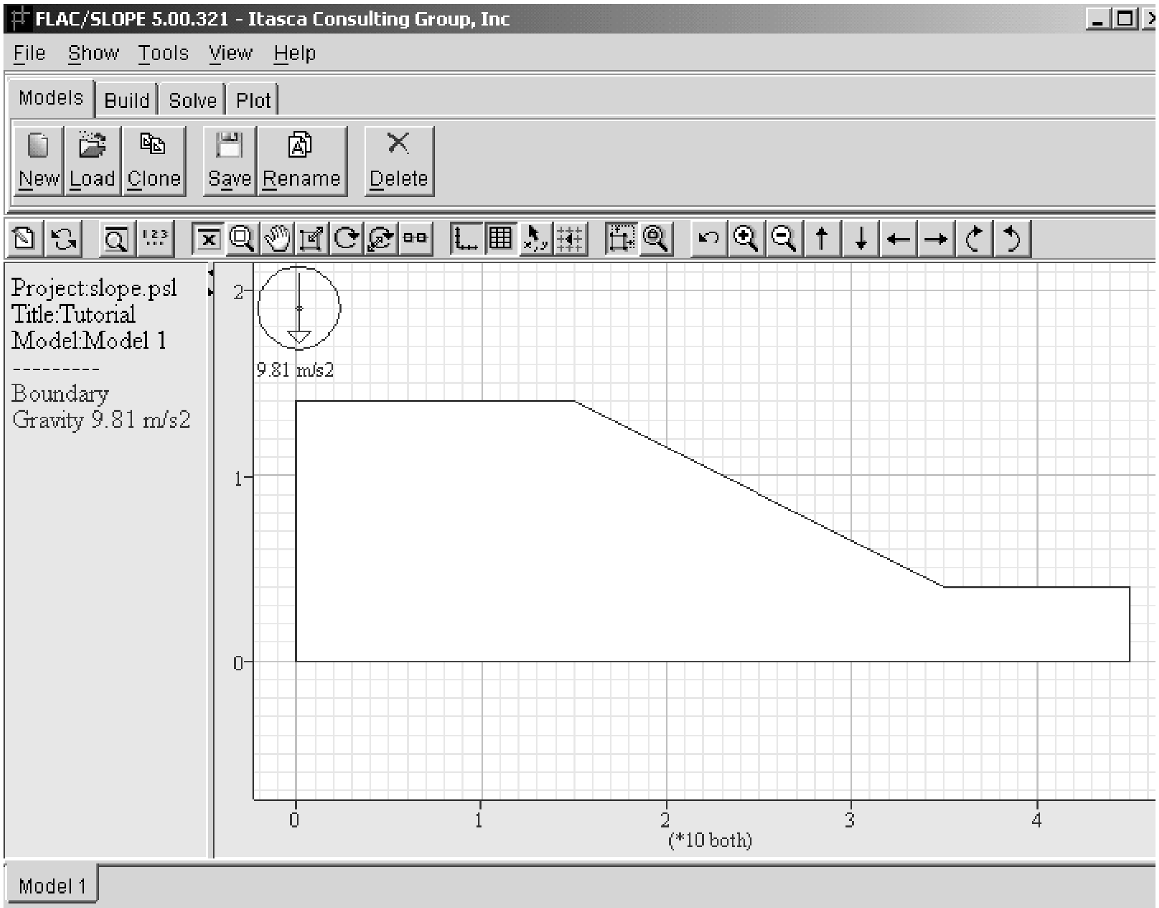

Fig.2.8: LAYOUT OF THE MODEL

Building the Model—We click on the Build tool tab to enter the *Build* stage and begin adding the slope conditions and materials to *Model 1*. We first define the two soil layers in the model. By clicking on the Layers button, we open the *Layers* tool. A green horizontal line with square handles at each end is shown when we click on the mouse inside the slope boundary;

this line defines the boundary between two layers. We locate this line at the level y = 9 m by right-clicking on one of the end handles and entering 9.0 in the *Enter vertical level* dialog. We press OK in the dialog and then OK in the *Layers* tool to create this boundary between the two layers.

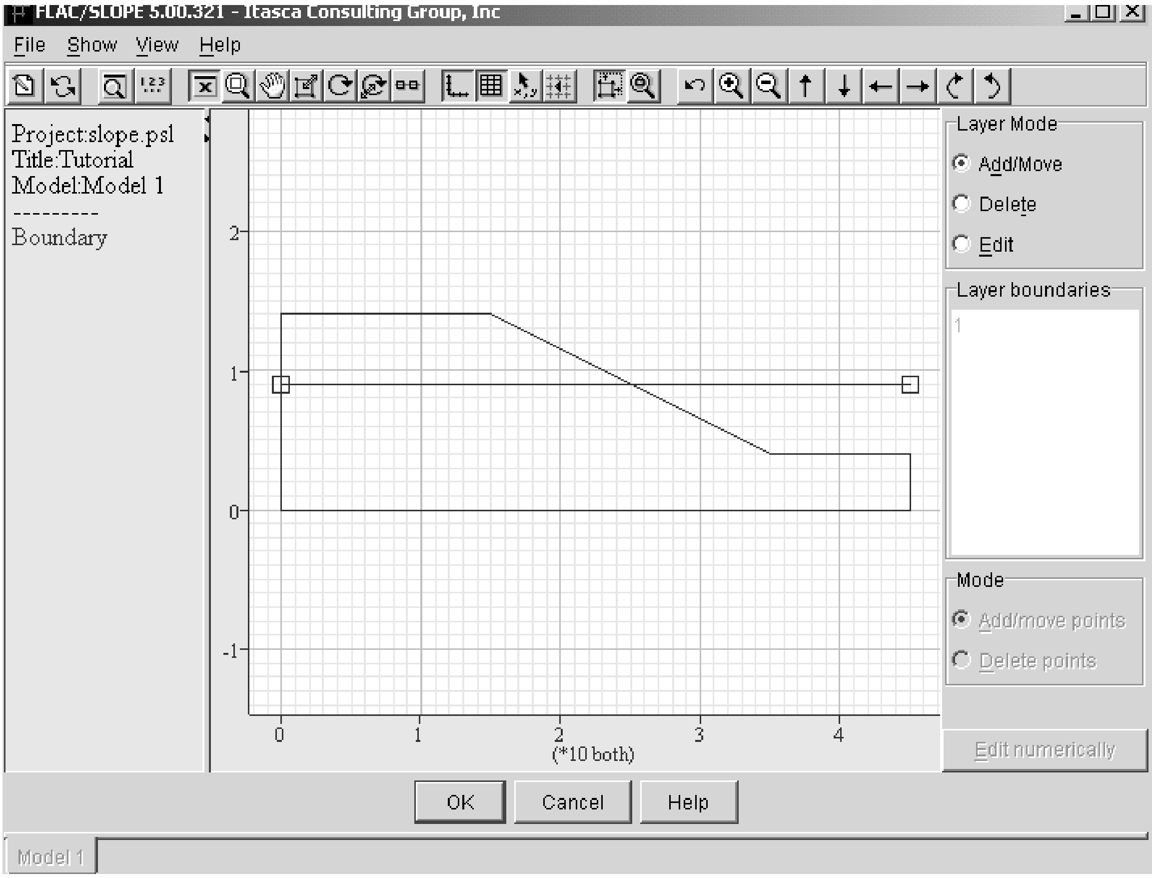

Fig. 2.8 LAYERS TOOL

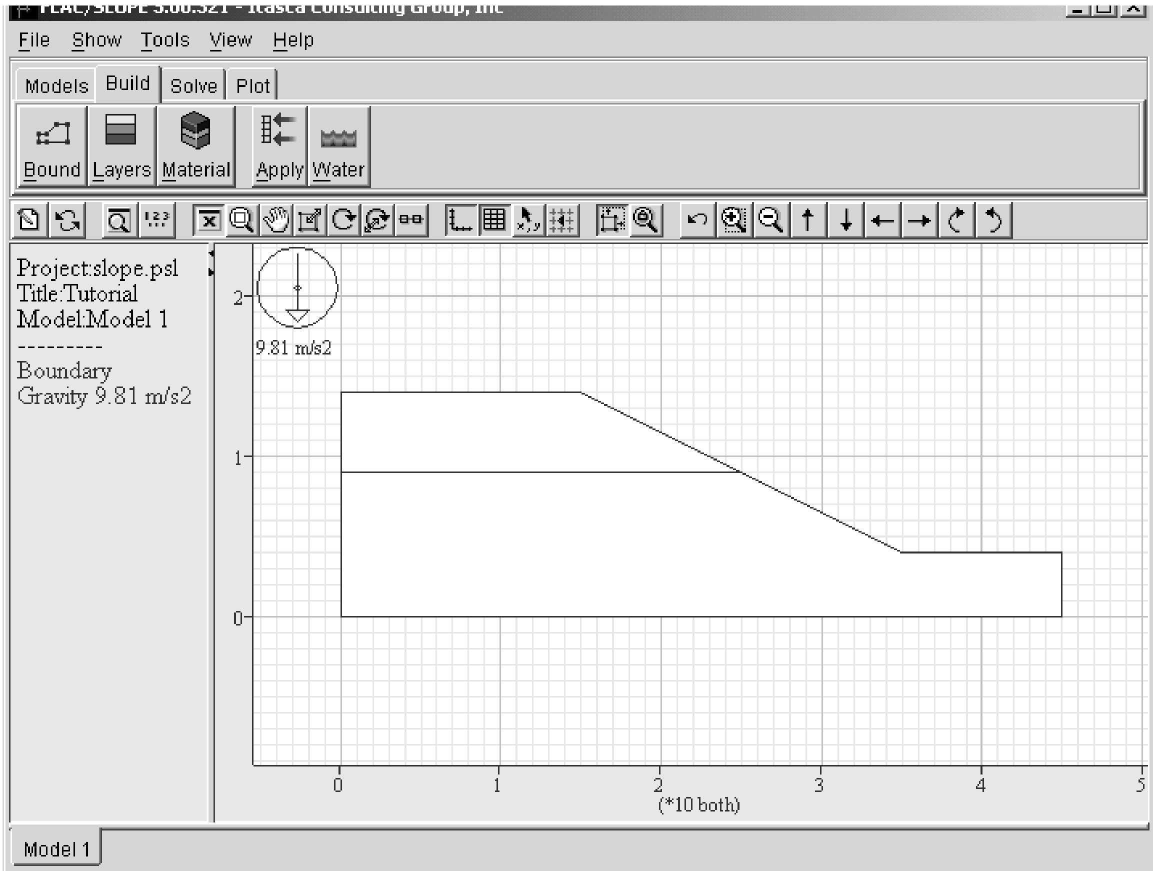

Fig. 2.9: TWO LAYERS CRAETED BY BOUDARY TOOL

There are two materials in the slope. These materials are created and assigned to the layers using the Material tool. After entering this tool, we first click on the Create button which opens the *Define Material* dialog. We create the two materials, *upper soil* and *lower soil*, and assign the densities

and strength properties using this dialog. (Note that after one material is created, it can be cloned using the Clone button, and then the properties can be modified to create the second material.) The properties assigned for the *upper soil* material are shown in. (A *Class*, or classification name, is not specified; this is useful if materials are stored in a database.

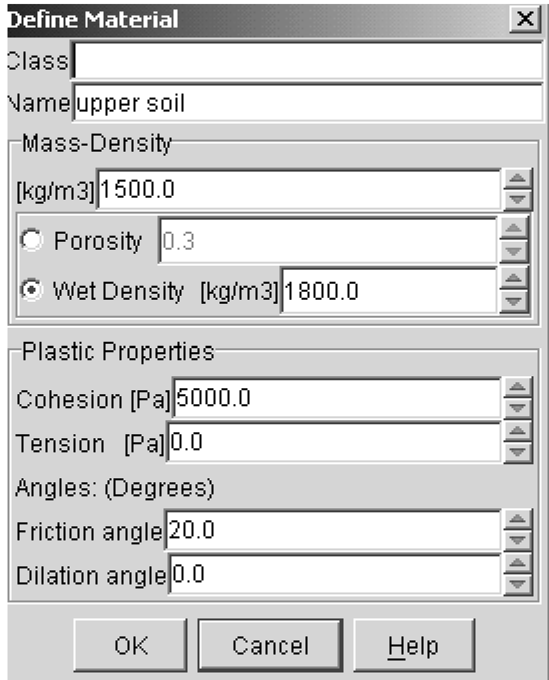

Fig. 2.10: INPUT OF PROPERTIES

After the materials are created, they are assigned to the two layers. We highlight the material in the *List* pane and then click on the model view inside the layer we wish to assign the material. The material will be assigned to this layer, and the name of the material will be shown at the position that we click on the mouse inside this layer. The result after both materials are assigned . We press OK to accept these materials in *Model 1*.

Calculating a Factor of Safety — We are now ready to calculate the factor of safety. We click on the Solve tool tab to enter the factor-of-safety calculation stage. When we enter this stage, we must first select a numerical mesh for our analysis. We choose a "medium-grid" model by pressing the Medium button, and the grid used for the *FLAC* solution appears in the model view.

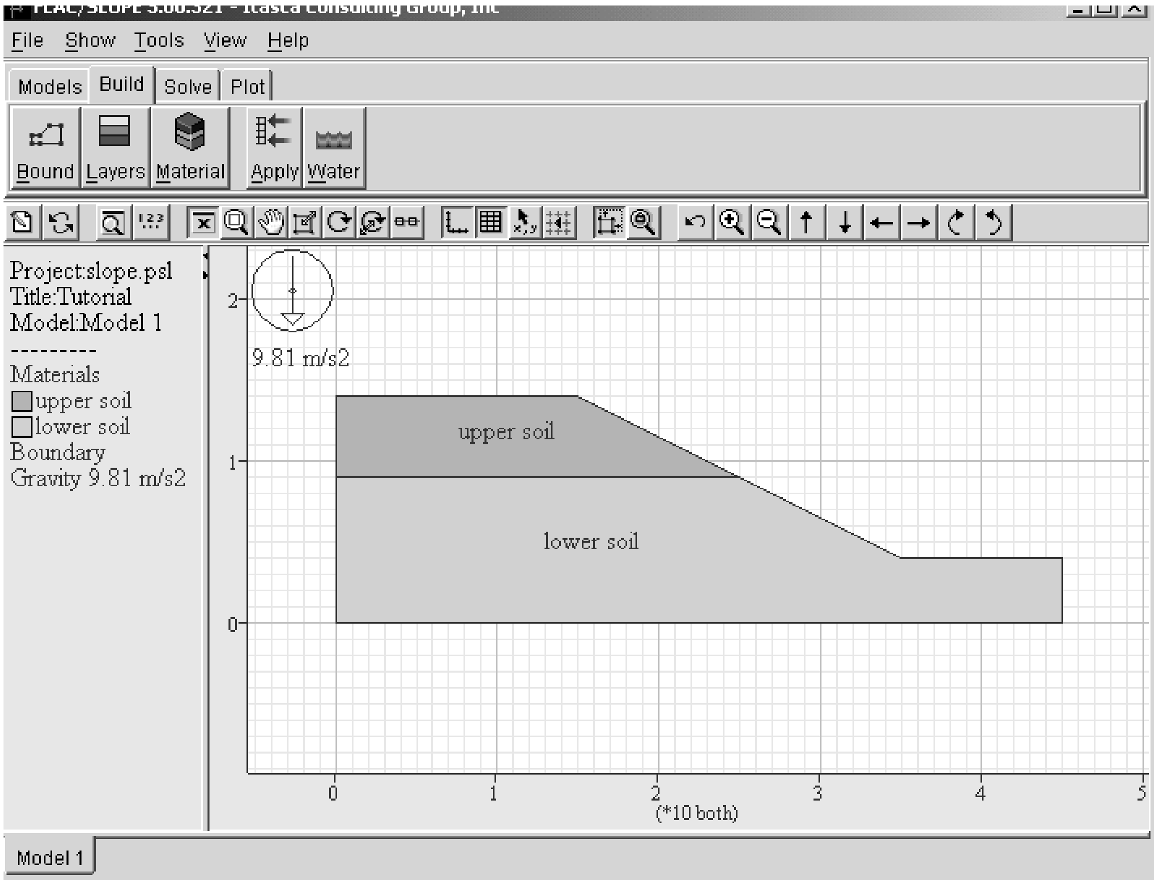

Fig. 2.11: MATERIALS ASSIGNED IN TWO LAYERS

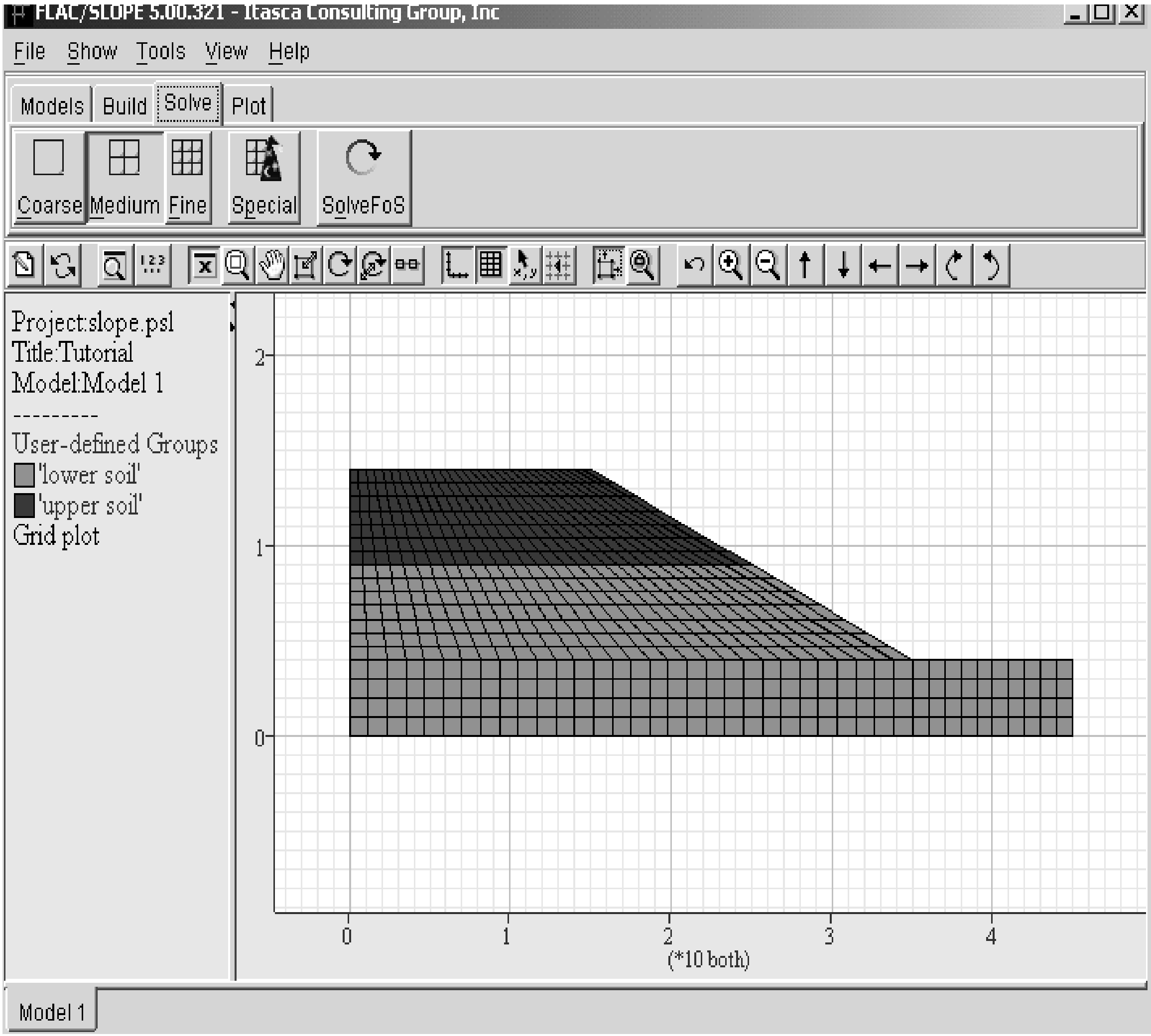

Fig.2.12: MEDIUM GRID FOR THE MODEL

We now press the Solve FoS button to begin the calculation. A *Factor-of-Safety parameters* dialog opens, we accept the default solution parameters, and press OK . *FLAC/Slope* begins the calculation mode, and a *Model cycling* dialog provides a status of the solution process. When the calculation is complete, the calculated factor of safety is printed.

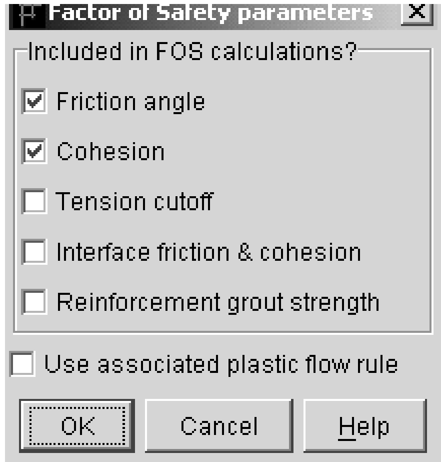

Fig.2.13: FACTOR OF SAFETY PARAMETER DIALOG

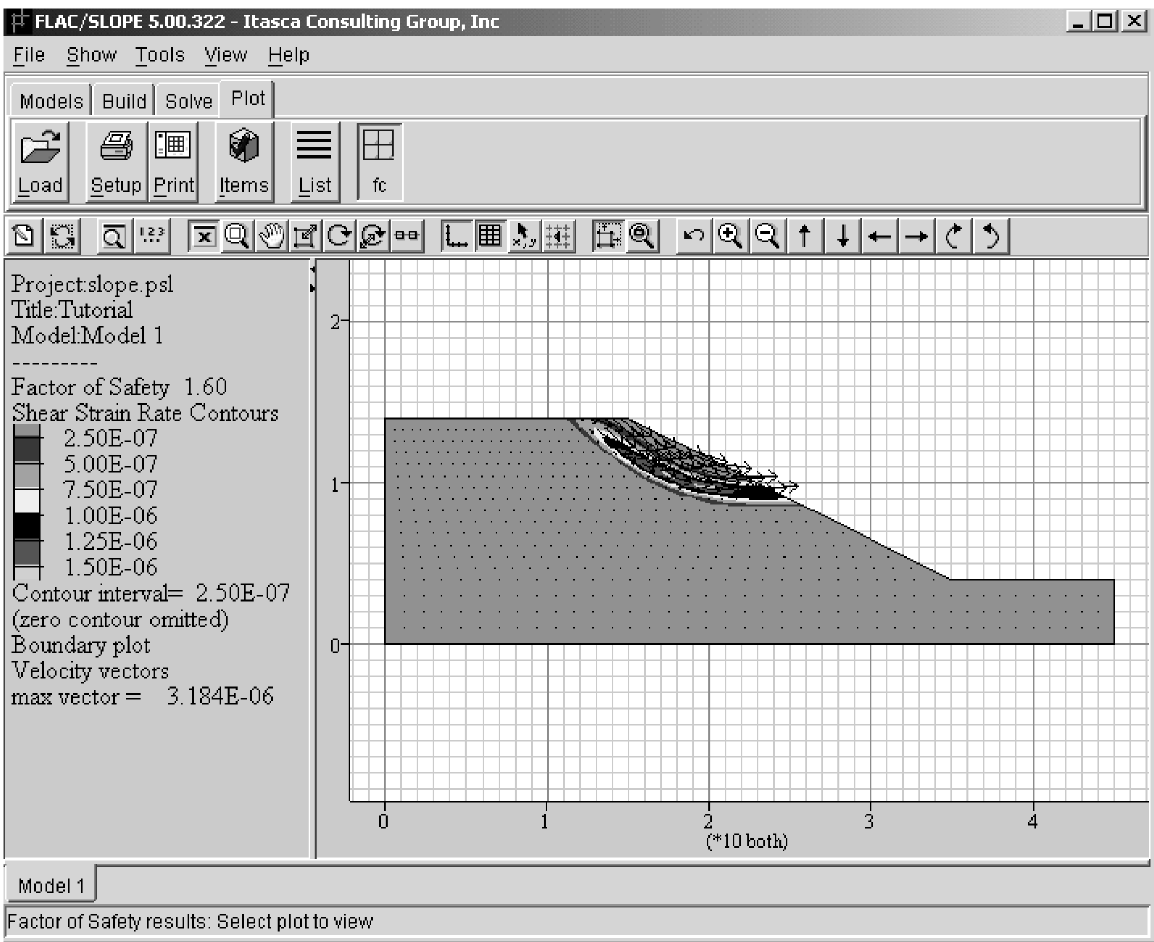

Fig.2.15: PLOT OF THE SLOPE AFTER CALCULATION OF FACTOR OF SAFETY

Chapter 3

Soil nailing

<u>SOIL NAILING:</u>

The fundamental concept of soil nailing consists of reinforcing the ground by passive inclusions, closely spaced, to create in-situ a coherent gravity structure and thereby to increase the overall shear strength of the in-situ soil and restrain its displacements. The basic design consists of transferring the resisting tensile forces generated in the inclusions into the ground through the friction mobilized at the interfaces.

Fig.3.1: A NAILED WALL

Applications:

- Stabilization of railroad and highway cut slopes
- Excavation retaining structures in urban areas for high-rise building and underground facilities
- Tunnel portals in steep and unstable stratified slopes
- construction and retrofitting of bridge abutments with complex boundaries involving wall support under piled foundations

Soil nail components:

1. The in-situ ground
2. Tension-resisting nails
3. Facing or the structural retaining element.

The nails used in soil-nailing retaining structures, are generally steel bars or other metallic elements that can resist tensile stresses, shear stresses, and bending moments. They are generally either placed in drilled boreholes and grouted along their total length or driven into the ground. The nails are not prestressed but are closely spaced (e.g., one driven nail per 2.5 ft^2, one grouted nail per 10-50 ft^2) to provide an anisotropic apparent cohesion to the native ground. A variety of proprietary nails, corrosion-protection systems, and installation techniques such as coupling nail driving with jet grouting, driving encapsulated nails, or driving prefabricated nails that consist of prestressed bars in compression tubes have been developed by specialty French contractors (Intrafor-Cofor; Solrenfor) to be used in permanent structures.

The facing of the soil-nailed structure is not a major structural load-carrying element but rather ensures local stability of the soil between reinforcement layers and protects the ground from surface erosions and weathering effects. It generally consists of a thin layer of reinforced shotcrete (4- to 6-in thick), constructed incrementally from the top down. Prefabricated or cast-in-place concrete panels have increasingly been used in the construction of permanent structures to satisfy specific aesthetic and durability design criteria and to accommodate adequate facing drainage.

Construction:

Typical construction process of soil nailed included at each excavation depth a sequence of

1. Bench cut to the specified depth of each nailing layer
2. Shot-crete or panels on the exposed facing;
3. Nail installation.

Fig 3.2: A WALL REINFORCED WITH NAILS

Nail Installation:

Conventionally, the steel reinforcing elements used for soil nailing can be classified as (a) driven nails and (b) grouted nails. However, specially designed corrosion-protected nails have also been used in permanent structures, specifically in aggressive environments. During the past decade the most significant technological innovations have been the development and use of the jet-grouted nails (Louis, 1986) and the launched soil nails (Ingold and Miles, 1996). A brief description of the available nailing systems is outline below:

Driven nails, commonly used in France and Germany, are small-diameter (15 to 46mm) rods or bars, or metallic sections, made of mild steel with a yield strength of 350MPa (50ksi). They are closely spaced (2 to 4 bars per square meter) and create a rather homogeneous composite reinforced soil mass. The nails are driven into the ground at the designed inclination using a vibropercussion pneumatic or hydraulic hammer with no preliminary drilling. Special nails with an axial channel can be used to allow for grout sealing of the nail to the surrounding soil after its complete penetration. This installation technique is rapid and economical (4 to 6 per hour). However, it is limited by the length of the bars (maximum length about 20m) and by the heterogeneity of the ground (e.g., presence of boulders).

Grouted nails are generally steel bars (15 to 46mm in diameter) with a yield strength of 60 ksi. They are placed in boreholes (10 to 15cm in diameter) with a vertical and horizontal spacing varying typically from 1 to 3m depending on the type of the in-situ soil. The nails are usually cement-grouted by gravity or under low pressure. Ribbed bars can be used to improve the nail-grout adherence, and special perforated tubes have been developed to allow injection of the grout through the inclusion.

Corrosion-protected nails generally use double protection schemes similar to those commonly use in ground anchor practice. Proprietary nails have recently been developed by specialty French contractors (Intrafor-Cofor; Solrenfor) to be used in permanent structures. For permanent applications of soil nailing, based on current experience, it is recommended (Elias and Juran, 1991) that a minimum grout cover of 1.5 inches be achieved along the total length of the nail. Secondary protection should be provided by electro statically applied resin-bonded epoxy on the bars with a minimum thickness of about 14 mils. In aggressive environments, full encapsulation is recommended. It may be achieved, as for anchors, by encapsulating the nail in corrugated plastic or steel tube grouted into the ground. For driven nails, a preassembled encapsulated nail, shown in Figure 3, has been developed by the French contractor Solrenfor (Louis, 1986).

Jet-grouted nails are composite inclusions made of a grouted soil with a central steel rod, which can be as thick as 30 to 40 cm. A technique that combines the vibropercussion driving and high-pressure (greater than 20MPa) jet grouting has been developed recently by Louis (1986). The nails are installed (Fig. 4) using a high frequency (up to 70Hz) vibropercussion hammer, and cement grouting is performed during installation. The grout is injected through a small-diameter (few millimeters) longitudinal channel in the reinforcing rod under a pressure that is sufficiently high to cause hydraulic fracturing of the surrounding ground. However, nailing with a significant lower grouting pressure (about 4MPa) has been used successfully, particularly in granular soils. The inner nail is protected against corrosion using a steel tube. The jet-grouting installation technique provides recompaction and improvement of the surrounding ground and increases significantly the pull-out resistance of the composite inclusion. Table I presents typical grouted nail diameter and ultimate pull out capacity values for different types of soils.

Launched Nails - The nail launching technology (Bridle and Myles, 1991; Ingold and Myles, 1996) consists of firing directly into the ground, using a compressed air launcher, nails of 25mm and 38mm in diameter, made from bright bar (EN3B to BS982) with nail lengths of 6 meters or more. The nails are installed at speeds of 200 mph with an energy transfer of up to 100kJ. This installation technique enables an optimization of nail installation with a minimum of site disruption. During penetration the ground around the nail is displaced and compressed. The annulus of compression developed reduces the surface friction and minimizes damage to protective coatings such as galvanized and epoxy. The technology is presently used primarily for slope stabilization although successful applications have also been recorded for retrofitting of retaining systems.

However, a rigorous evaluation of the pull-out resistance of launched nails is required prior to their use in retaining structures..

Soil nailed slope with mesh and gunite face.

Fig.3.3: Soiled Nailed Slope

NAIL PARAMETERS:

TENSILE STRENGTH:

The tensile strength of nails varies according to the diameter of the nails. It also depends up on the grade of the steel which is used as nails. For Fe 250 grade of steel the yield stress is 250 N/mm2 and for Fe 415 grade of steel (HYSD bars) it is about 415 N/mm2. The tensile strength also depends up on the length of the nail used.

BOND STRENGTH:

The bond strength of the nail depends up on its adhesion to the soil surface. It also depends up on the tensile strength of the nail and also up on the diameter of the nail. The relation between the bond strength and the tensile strength of a nail can be expressed as follows:

$T = \pi * L * D * \sigma$, where

T = Tensile strength of the nail

L = Length of the nail

D = diameter of the nail

σ = bond strength of the nail

Chapter 4

Works carried out

WORKS CARRIED OUT:

A. Study The Behavior Of A Slope With The Variation Of It's Nail Parameters

Given Slope:

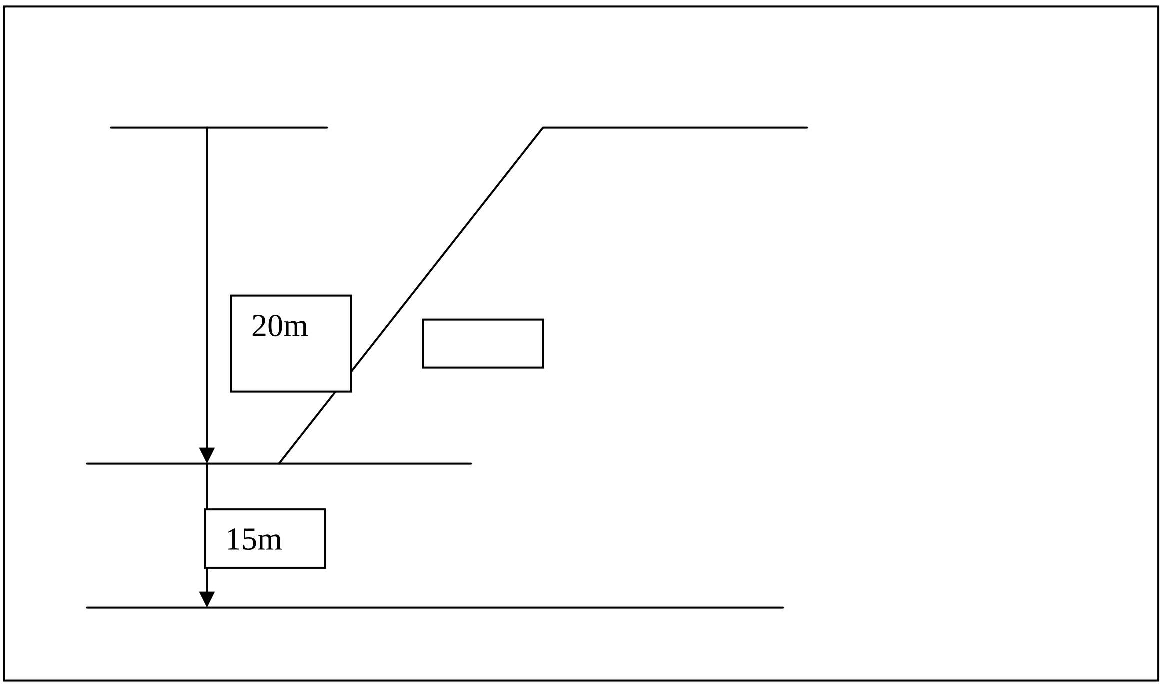

Fig 4.1: Given Slope

Data Provided:

Height of the slope = 20m

Side Slope = 2H: 1V

Unit Weight of Soil = 16 KN/M3

Cohesion = 20 mpa.

Without reinforcement, F.O.S = 1.58

Analysis with Reinforcements:

Inclination of nails with the sloping face = 90 degree

Tensile strength of nails = 330 KN

Diameter of nails = 0.11m

Horizontal spacing of nails = 3.0m

Vertical spacing of nails = 2.235m

a) **Variation of Factor Of Safety With Nail Lengths:**

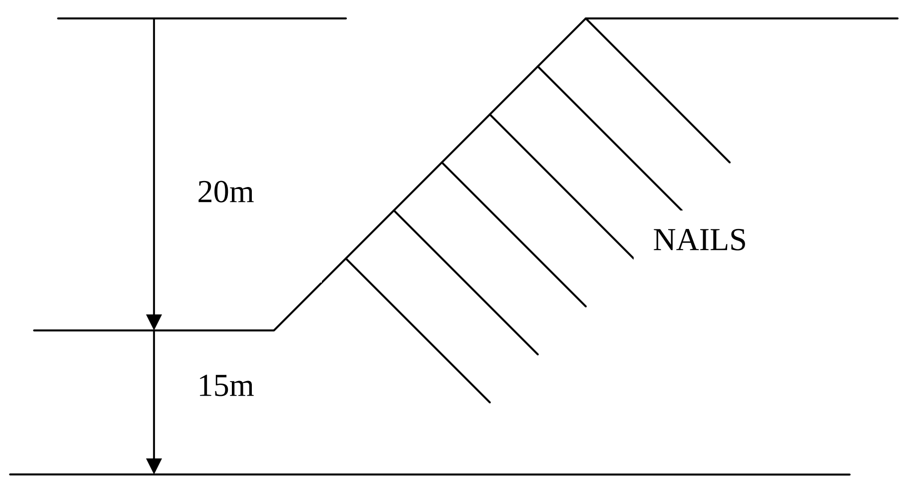

Fig 4.2: Installation of Nails ON The Slope

The nails are installed as shown in the above diagram. The lengths of nails and its other parameters such as diameter and spacing are varied to study the effect it produces on the factor of safety of the given slope. The effects of factor of safety with these parameters were obtained by using the "FLAC" software and the results obtained are tabulated.

Table 4.1: Nail length vs F.o.S

Length of Nails (m)	**Bond Strength (N/m)**	**F.O.S**
6.0	159154.94	1.67
8.0	119366.2	1.71
10.0	95492.96	1.75

From the above table it is clear that as the length of the nail increases the Factor of Safety of the given slope also increases. The parameters which remained constant during the above observations are as follows:

Tensile strength of nail = 330 kN

Diameter of nail = 110 mm

Horizontal spacing = 3.0m

Vertical Spacing = 2.235m

C/S area = 0.0095 m2

b) **Variation of Factor of Safety with Diameter**

Length of the Nail = 8.0 m

Tensile Strength = 330 kN

Vertical Spacing = 2.235 m

Horizontal Spacing = 3.0 m

Table 4.2: Nail diameter vs F.O.S

Dia of Nail (m)	**C/S area (m2)**	**Bond Strength (N/m)**	**F.O.S**
0.11	0.0095	119366.2	1.71
0.15	0.01767	87535.21	1.68
0.20	0.0314	65651.14	1.61

As shown in the above table, the factor of safety of the given slope decreases as the diameter of the nail increases keeping the bond strength and tensile strength constant.

c) **Variation Of factor of safety with vertical spacing**

Length of the nail = 8.0 m

Tensile Strength of Nail = 330 kN

Diameter of the nail = 110 mm

C/S area = 0.0095 m2

Bond Strength of Nail = 119366.2 N/m

Table 4.3: Nail Spacing vs F.O.S

Vertical Spacing (m)	**F.O.S**
2.235	1.71
4.0	1.63
5.0	1.61

As the vertical spacing increases, the "Factor of Safety" of the given slope goes on reducing, which is evident from the above table.

B) Optimal Design of a Given Slope by "Trial and Error" Method:

OBJECT:

"To analyze a given unstable slope by inserting nails and to get an optimal design of nails to have adequate "Factor of Safety".

Given Slope:

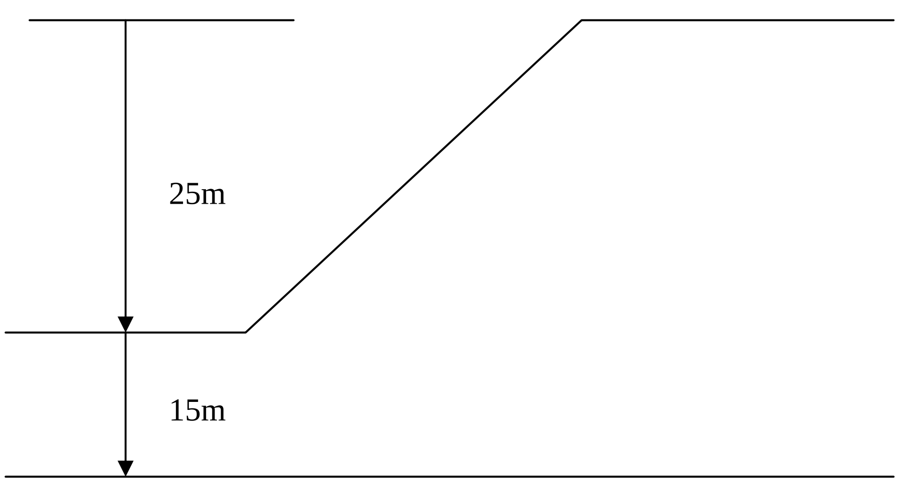

Fig 4.3: given slope

Given Data

Height of Slope = 25m.

Cohesion = 40000 Pa

Unit weight of soil = 18 kN/m3

Angle of shearing resistance = 10 degree

Factor of Safety without Reinforcement = 0.88

a)Variation of "Factor of Safety" with diameter of nail:

Length of nail = 8 m

Bond Strength = 119366.2 N/m

Horizontal spacing = 3.0

Vertical spacing = 3.0 m

Table 4.4: Nail diameter vs F.O.S

Dia of Nail (m)	Tensile Strength (N)	F.O.S
0.09	269999.98	0.92
0.11	330000.00	0.92
0.15	449999.97	0.92
0.2	599999.96	0.94

b) **Variation of "Factor of Safety" with vertical spacing:**

Length of the nail = 8.0 m

Diameter of the nail = 0.11 m

Table 4.5: nail spacing vs F.o.S

Vertical Spacing	**F.O.S**
3.0	0.92
4.0	0.91
5.0	0.91
6.0	0.91

Trial 1:

Length of the nails = 20m

Vertical Spacing = 3.0 m

Table 4.6: Nail tensile strength vs F.O.S

Tensile Strength (kN)	Bond Strength (N/m)	F.O.S
400	57874.52	1.02
450	65108.84	1.03
500	72343.15	1.04
550	72343.15	1.06
600	86811.78	1.08
650	94046.10	1.09
700	101280.41	1.10
750	108514.73	1.12
800	115749.05	1.13

Trial 2:

Length of nail = 30 m
Vertical Spacing = 3.0 m

Tensile Strength (kN)	**Bond Strength (N/m)**	**F.O.S**
300	28937.26	0.97
400	38583.02	0.99
500	48228.77	1.01
600	57874.77	1.03
700	67520.28	1.05
800	77166.03	1.11
900	86811.78	1.14
1000	96457.78	1.16
1100	106103.29	1.19
1200	115749.05	1.21
1300	125394.80	1.23
1400	135040.80	1.24
1500	1446860.31	1.26
1600	154332.067	1.27
1700	163977.82	1.28
1800	173623.57	1.30
1900	183269.32	1.32

The maximum tensile strength of the HYSD bar used can be calculated as follows:

$T = \pi/4*0.11*0.11*1000000*230$

$=> T = 2375.83$ kN

Using the above value of tensile strength, the value of the “Factor of Safety” of the given slope was found out to be 1.47.

Parametric Studies:

The diameters of the nails were varied and its effect on the “Factor of Safety” was studied at different vertical spacing. The results obtained are tabulated as follows. The lengths of the nails were kept as 30 m.

a) **Vertical Spacing = 4 m:**

Table 4.7: nail diameter vs F.O.S

Diameter of nail (m)	F.O.S
0.05	1.01
0.11	1.50
0.15	1.61
0.2	1.66

b) **<u>Vertical Spacing = 5 m:</u>**

<u>Table 4.8: Nail diameter vs F.O.S</u>

Diameter of nail (m)	**F.O.S**
0.05	0.99
0.11	1.19
0.15	1.48
0.2	1.52

C) **<u>Vertical Spacing = 6m:</u>**

<u>Table 4.9: Nail diameter vs F.O.S</u>

Diameter of Nail (m)	**F.O.S**
0.05	0.97
0.11	1.22
0.15	1.28
0.2	1.38

In all of the above cases, the tensile strength and the bond strength of nails were found out and are tabulated as follows:

From the above table, a nail diameter of 150 mm, with vertical spacing equal to 4 m is chosen for optimal design as this combination was giving high “Factor of safety” of 1.61. So, the final arrangement of nail systems is like the figure given below:

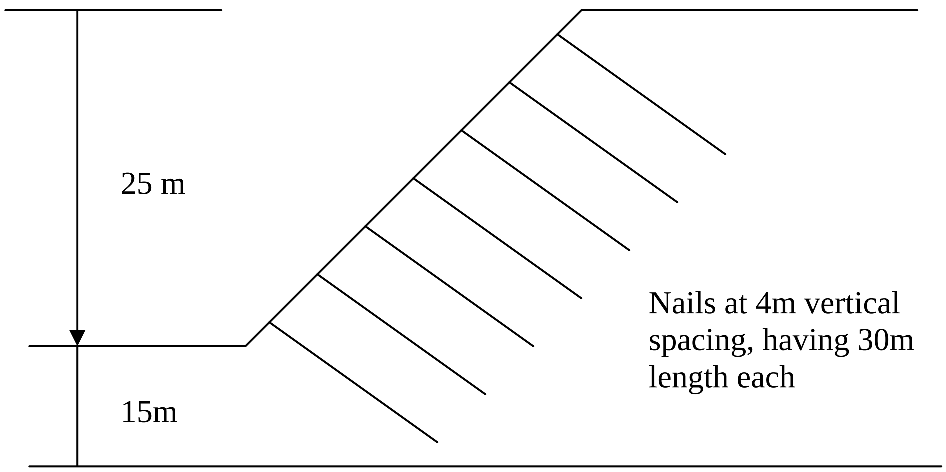

Fig 4.4: Installation of nails on the slope

Now, the lengths of the nails were varied from bottom to top and the effect it produces on the “Factor of Safety” was noted down. It is tabulated as follows. The bottom nail is termed as the “nail 1” and the top as “nail 7” the middle ones are named according

So, **the optimal lengths of all the nails are as follows**:

Table 4.10: Optimal lengths of nails

Nail no.	**Lengths(m)**
1	18
2	16
3	16
4	20
5	20
6	12
7	10

Conclusion:

By the help of the “FLAC” software, the given slope was analyzed and its optimal design was carried out. Any existing slope with any boundary condition can be analyzed by using this software. One of the chief advantages of “FLAC” is that it takes very little time to calculate the “Factor of Safety” of the slopes as compared to the other methods. A slope with varying depth of water table can also be analyzed by the use of “FLAC”. In future, the success of the “FLAC” software in analyzing the existing as well as the newly laid slopes depends up on the knowledge and experience gained by the user regarding the software. So, the modern designers need to have clear understanding of the different aspects of “FLAC” before implementing them up on the practical field problems. Once it is clearly understood, it can be a powerful tool to analyze any given slope in lesser time.

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