

Slope

Version 18.2

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Slope Oasys GEO Suite for Windows

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This document has been created to provide a guide for the use of the software. It does not provide engineering advice, nor is it a substitute for the use of standard references. The user is deemed to be conversant with standard engineering terms and codes of practice. It is the users responsibility to validate the program for the proposed design use and to select suitable input data.

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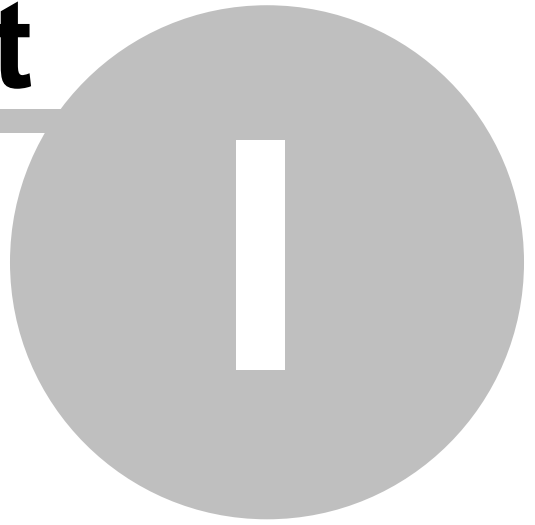
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About Slope

Part



1 About Slope

1.1 General Program Description

Slope has been designed primarily to analyse the stability of slopes, with an option to include soil reinforcement. It can also be used to analyse earth pressure and bearing capacity problems.

The program can check circular and non-circular failures, thereby allowing calculations to be carried out for both soil and rock slopes.

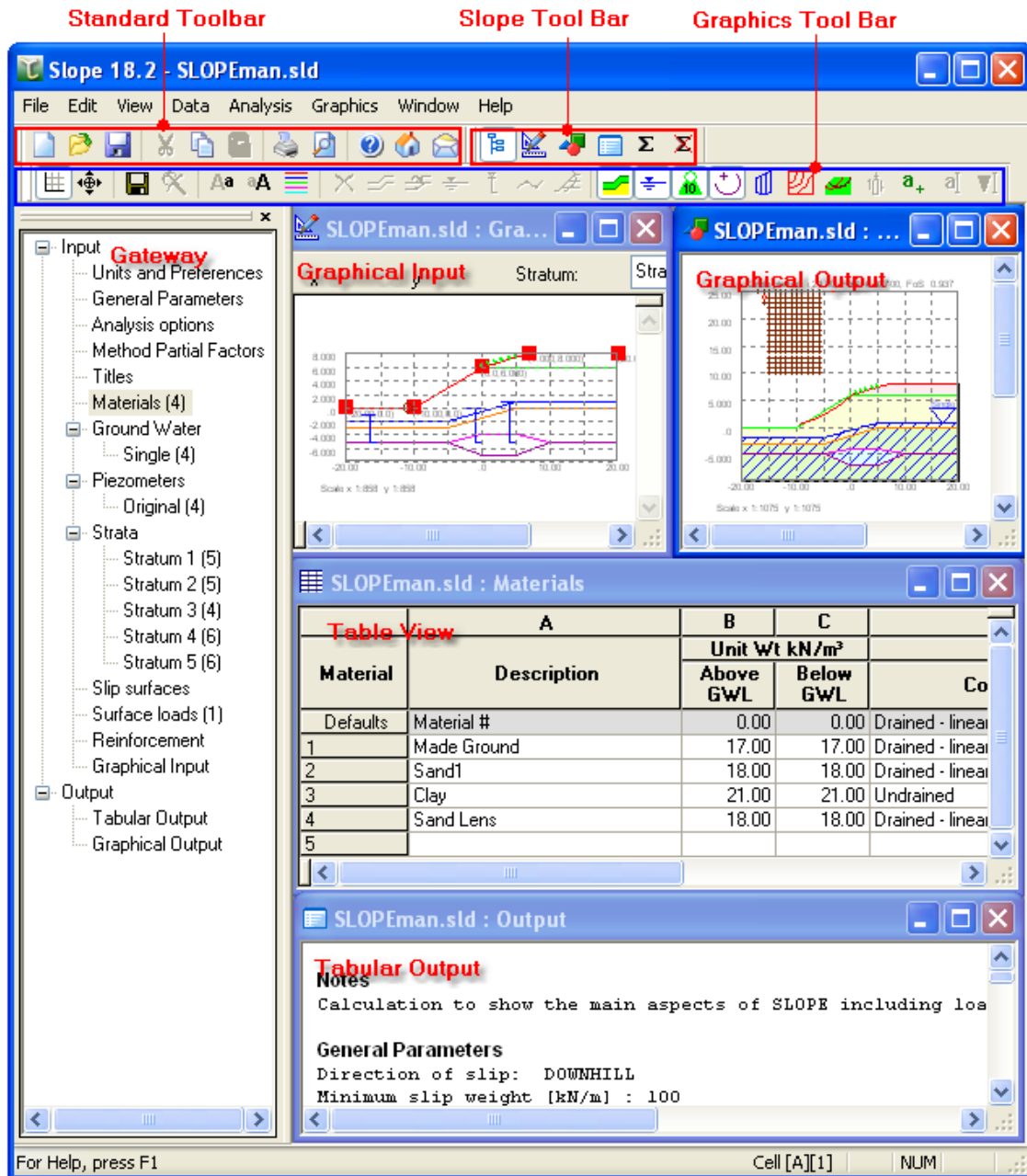
1.2 Program Features

The main features of **Slope** are summarised below:

- **Slope** provides the following methods of analysis:
 - Swedish circle (Fellenius) method
 - Bishop's methods
 - Janbu's methods
- The use of these methods allows analysis of both circular and non-circular slip surfaces to be carried out.
 - The location of **circular surfaces** is defined using a rectangular grid of centres and then: a number of different radii, a common point through which all circles must pass or a tangential surface which the circle almost touches.
 - Non-circular** slip surfaces are defined individually as a series of x and y coordinates.
- The **ground section** is built up by specifying each layer of material, from the surface downwards, as a series of x and y coordinates.
- The **strength of the materials** is represented by specifying cohesion and an angle of shearing resistance. Linear variations of cohesion with depth can also be entered.
- The **ground water** profile and pore water pressure distribution can be set individually for each soil stratum, using either:
 - A phreatic surface with hydrostatic pore pressure distribution.
 - A phreatic surface with a user-defined "piezometric" pore pressure distribution.
 - An overall value of the pore pressure coefficient R_u .
 - A maximum soil suction can also be specified for each stratum.
- Any combination of **reinforcement**, consisting of horizontal geotextiles or horizontal or inclined soil nails, rock bolts or ground anchors, can be specified. The restoring moment contributed by the reinforcement is calculated according to BS8006:1995.
- Slopes which are **submerged** or **partially submerged** can be analysed.
- External **forces** can be applied to the ground surface to represent building loads or strut forces in excavations.
- Horizontal acceleration of the slip mass can be included to represent **earthquake loading**.
- The calculated **factor of safety** can be applied to:
 - Soil strength or
 - the magnitude of the applied loads, either
 - a. causing failure - to represent bearing capacity problems, or
 - b. preventing failure - for anchor forces.

1.3 Components of the User Interface

The principal components of Slopes's user interface are the Gateway, Table Views, Graphical Output, Tabular Output, toolbars, menus and input dialogs. These are illustrated below.



1.3.1 Working with the Gateway

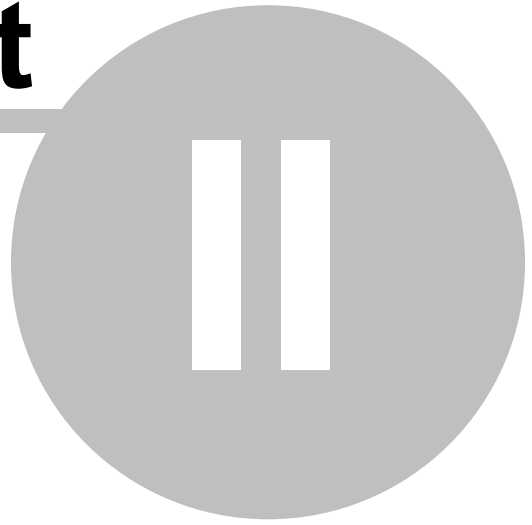
The [Gateway](#) gives access to all the data that is available for setting up a Slope model.

Top level categories can be expanded by clicking on the '+' symbol beside the name or by double clicking on the name. Clicking on the '-' symbol or double clicking on the name when expanded will close up the item. A branch in the view is fully expanded when the items have no symbol beside them.

Double clicking on an item will open the appropriate table view or dialog for data input.

Methods of Analysis

Part



2 Methods of Analysis

2.1 General

The methods of analysis available in **Slope** are as follows:

[Swedish \(Fellenius\)](#)

Bishop

[Horizontal Interslice Forces](#)

[Parallel Inclined Interslice Forces \(Spencer's Method\)](#)

[Variably Inclined Interslice Forces](#)

Janbu

[Horizontal Interslice Forces](#)

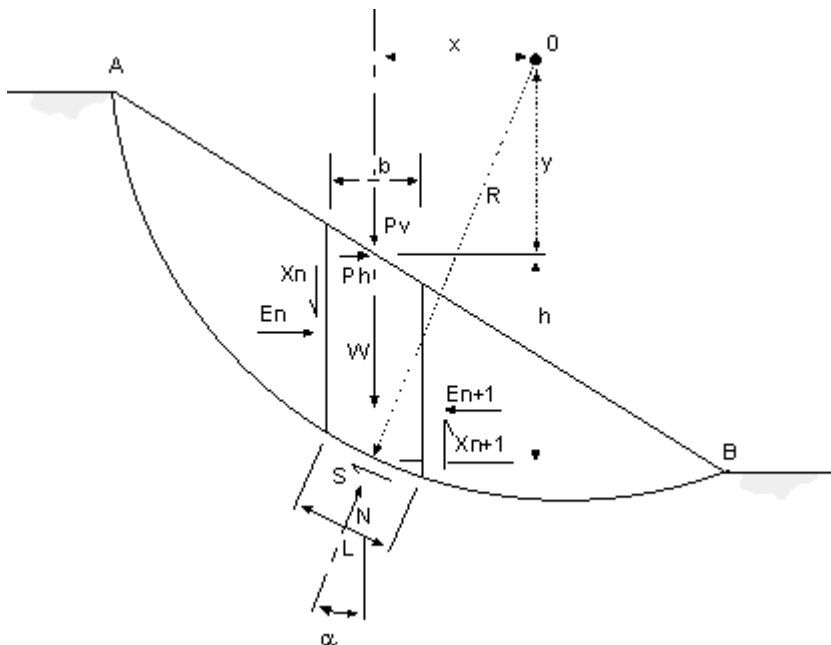
[Parallel Inclined Interslice Forces](#)

[Variably Inclined Interslice Forces](#)

All these methods of analysis use the [method of slices](#) to determine the factors of safety for slope stability. The detailed derivation for each solution is given in the individual references.

2.2 Theory of Slices

The following provides details of the basic annotation and sign convention for the method of slices:



All forces are given as total forces (i.e. including water pressure).

F - Factor of Safety

Ph - Horizontal component of external loads

Pv - Vertical component of external loads

E - Horizontal Interslice Force

X - Vertical Interslice Force

W - Total weight of soil = γbh

N - Total normal force acting along slice base

R - Distance from slice base to moment centre

S - Shear force acting along slice base

h - Mean height of slice

b - Width of slice

L - Slice base length = $b/\cos\alpha$

u - Pore pressure at slice base

α - Slice base angle to horizontal

x - Horizontal distance of slice from moment centre

y - Vertical distance of slice surface from moment centre

γ - Unit weight of soil

c - Cohesion at base

ϕ - Angle of friction at base

More:

[General Equations](#)

2.2.1 General Equations

The general expression to calculate the average overall factor of safety for a **circular slip circle** is:

$$F = \frac{\sum_A^B S.R}{\sum_A^B [(W + P_v)x + P_h y]} = \frac{\text{Restoring moment}}{\text{Disturbing moment}}$$

Where

$$S = cL + (N - uL) \tan \phi$$

and

$$N = (W + P_v + X_n - X_{n+1}) \cos \alpha - (E_n - E_{n-1} + P_h) \sin \alpha$$

Note : As the factor of safety (F) is directly related to c and $\tan \phi$, it is a factor of safety on material shear strength.

For models which include soil reinforcement, the additional restoring moment contributed by the reinforcement is added to the soil strength restoring moment. For details of the method of calculation, see [Reinforcement Calculations](#).

In addition other expressions for equilibrium are as follows:

For vertical equilibrium:

$$N \cos \alpha = W + P_v + (X_n - X_{n+1}) - (S \sin \alpha) / F$$

For horizontal equilibrium:

$$N \sin \alpha = (E_{n+1} - E_n) - P_h + (S \cos \alpha) / F$$

For **non-circular slip circles** the equations for moment equilibrium change to:

$$\sum_A^B S \{ (h + y) \cos \alpha + x \sin \alpha \} = \text{Restoring moment}$$

$$\sum_A^B \{ (W + P_v - N \cos \alpha) x + (P_h + N \sin \alpha) y \} = \text{Disturbing moment}$$

For full details of notation see [Theory of Slices](#).

More:

[Method of iteration](#)

[Interlock](#)

[Positioning of Slices](#)

2.2.1.1 Method of Iteration

Slope uses iteration to reach convergence for each of the Bishop and Janbu methods as follows:

Factors of safety

For each iteration i , **Slope** calculates a new factor of safety F_i using the ratio of restoring moment to disturbing moment (which is a function of F_{i-1}). when the difference between F_i and F_{i-1} is within the specified tolerance, the calculation is complete.

The factor of safety, F , is the ratio of restoring moment to disturbing moment. However, this ratio is itself a function of F , (except in the Swedish circle method) so an iterative solution is necessary.

Horizontal interslice forces

1. **Slope** starts at slice 1 (Note : Slices are numbered from left to right) and, by maintaining vertical equilibrium it calculates the resultant horizontal force.
2. The program then uses this as the interslice force with slice 2. The process continues until

the last slice which ends up with a resultant horizontal force.

In this method each slice and the slope as a whole is in vertical equilibrium, with zero vertical interslice forces. Horizontal equilibrium is not achieved within each slice or the slope as a whole. Therefore the only force check within each slice is for vertical equilibrium.

Constant inclined interslice forces

In this method **Slope** varies the ratio (which is constant), between the vertical and horizontal interslice forces, until the resultant of each is reduced to zero.

For this method each slice is not in equilibrium, only the slope as a whole. In the calculation equilibrium is effectively maintained for each slice in the direction normal to the interslice forces.

Variably inclined interslice forces

The variably inclined method is superior as it keeps every slice in horizontal and vertical equilibrium at all times. However, it can exceed the soil strength along the slice interface as it does not check the vertical interslice forces against the shear strength of the material. The results should therefore be checked for this criterion.

The interslice force is adjusted separately, for both the vertical and horizontal direction, by adding the fraction of the residual values from the previous iteration. The fraction is determined by the horizontal length of the slip surface represented by that slice. The interslice force direction can vary by this method, but each slice is in equilibrium at all times as is the slope as a whole.

2.2.1.2 Interlock

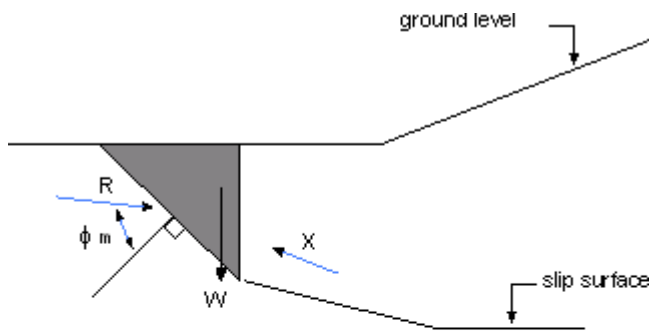
[Bishop \(1955\)](#) pointed out that there are a variety of force distributions which will satisfy the conditions of equilibrium. In many cases the assumption of horizontal or parallel inclined interslice forces is reasonable and leads to sensible results.

An important case where errors can occur for horizontal or parallel interslice forces, is that of '**interlock**'. This arises in the case of a deep slip with a low factor of safety, where the toe of the slip surface passes through a dense granular material.

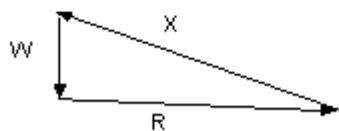
If the deep slip emerges at a steep angle and has a high mobilised angle of friction ϕ_m where:

$$\tan \phi_m = (\tan \phi) / F$$

Then the direction of the resultant force, R, on the base of the slice may be almost horizontal or even pointing downwards.



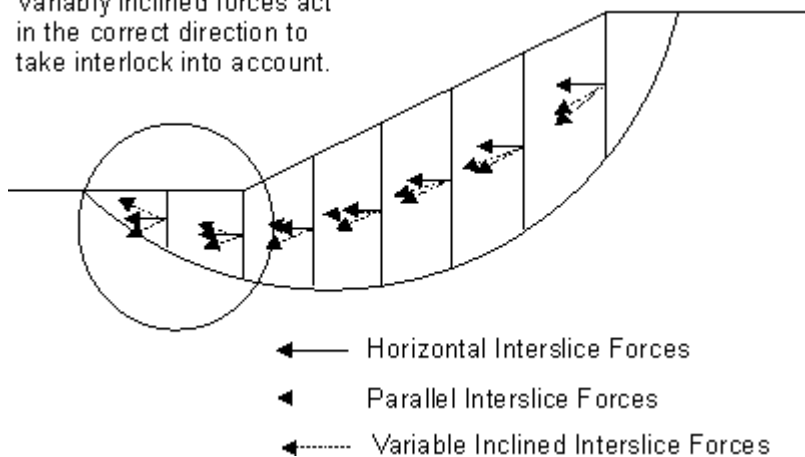
a. Section



b. Force Diagram

In order to satisfy equilibrium of this slice the interslice force, X , must point upwards. This direction is not consistent with the assumption of either horizontal or parallel inclined interslice forces.

Variably inclined forces act in the correct direction to take interlock into account.



In such cases the method of **variably inclined interslice forces** should be used.

Note : **Slope** does not provide a warning when this problem may occur.

2.2.1.3 Positioning of Slices

Slope divides each slip mass into a number of slices. The resulting slice boundaries are located at the following points:

- at the left and right hand extent of the slip surface.
- at the change in gradient of a stratum.
- at each slip surface/stratum intersection.
- at each slip surface/phreatic surface intersection.
- at the mid point of a slice whose width is greater than the average slice width given by:

$$(X_{\text{right}} - X_{\text{left}}) / \text{Minimum number of slices}$$

2.3 Swedish Circle Method (Fellenius)

This method is applicable to **circular** slips, but may not be used for submerged slopes or where there are horizontal surface loads.

Assumptions:

1. The method assumes that for each slice the resultant of the interslice forces is zero. The forces are resolved on each slice parallel to the base.

$$\text{i.e. } \{X_n - X_{n+1}\} = 0 \text{ and } \{E_n - E_{n+1}\} = 0$$

2. The method satisfies overall moment equilibrium.

$$F = \frac{\sum_A^B S.R}{\sum_A^B [(W + P_v)x + P_h y]} = \frac{\text{Restoring Moment}}{\text{Disturbing Moment}}$$

Where:

$$S = cL + (N - uL)\tan \phi$$

$$P = \{W + P_v + (X_n - X_{n+1})\}\cos \alpha - \{(E_n - E_{n-1}) + P_h\}\sin \alpha$$

For undrained materials where $\phi = 0$ this method of analysis gives identical results to [Bishop's Simplified method](#). For drained frictional (ϕ' , c') materials the assumed force distribution does not satisfy conditions of overall horizontal or vertical equilibrium. The factors of safety therefore usually fall below the lower bound values obtained from solutions which do satisfy statics.

The above assumptions do not satisfy Newton's principle of 'action equals reaction' between adjacent slices. The errors, although on the safe side, can be large (up to 60%). Other methods of analysis are therefore normally preferred.

2.4 Bishop's Methods

Bishop's methods ([Bishop AW, 1955](#)) are applicable to **circular** slip surfaces. One of the Bishop methods must be used if reinforcement is specified.

Three methods of solution are available. These are:

Horizontal Interslice Forces

Parallel Interslice Forces

Variably Inclined Interslice Forces

More:

[Bishop's Simplified Method - Horizontal Interslice Forces](#)

[Bishop's Method - Parallel Inclined Interslice Forces](#)

[Bishop's Method - Variably Inclined Interslice Forces](#)

2.4.1 Bishop's Simplified Method - Horizontal Interslice Forces

This method is applicable to all **circular** slip surfaces.

Assumptions:

1. The interslice **shear** forces are assumed to sum to zero. This satisfies vertical equilibrium, but not horizontal equilibrium, where;

$$\{X_n - X_{n+1}\} = 0$$

This leads to errors in the calculated factors of safety, but these are usually small and on the safe side ([Spencer 1967](#)).

2. The method satisfies overall moment equilibrium.

The limitations of the method have been investigated by [Whitman and Bailey \(1967\)](#). They concluded that the method can occasionally give misleading answers particularly in the case of interlock, see [Interlock](#).

If it is suspected that this may be a problem then the user should select the method of [Variably Inclined Interslice Forces](#).

2.4.2 Bishop's Method - Parallel Inclined Interslice Forces

This method (also known as **Spencer's Method**) is applicable to **circular** slip surfaces. It is a refinement of [Bishop's Simplified Method](#) and satisfies conditions of horizontal, vertical and moment equilibrium for the slip as a whole.

Assumptions:

1. The program assumes that all the interslice forces are parallel, but not necessarily horizontal, i.e. at a constant inclination throughout the slope. Where:

$$\tan \theta = X_n / E_n = X_{n+1} / E_{n+1}$$

θ = angle of resultant of the interslice forces from the horizontal.

2. This satisfies the condition of overall horizontal and vertical equilibrium.
3. The method also satisfies overall moment equilibrium.

This method has been assessed by [Spencer \(1967\)](#). He has shown that in most cases the results differ only slightly from those obtained by the simplified method, which assumes only horizontal interslice forces.

The differences between the two methods increase with slope angle. For steep slopes Spencer's method is more accurate and is therefore recommended.

This method can have problems of interlock, see [Interlock](#). If it is suspected that this may be a problem the method of [variably inclined interslice](#) forces should be used.

2.4.3 Bishop's Method -Variably Inclined Interslice Forces

This method is applicable to **circular** slip surfaces. It is a further refinement of Bishop's method designed to over-come the problems of [interlock](#).

Assumption:

- In this method the program calculates the interslice forces to maintain horizontal and vertical equilibrium of **each slice** .

The inclinations of the interslice forces are then varied in each iteration until overall horizontal, vertical and moment equilibrium is also achieved.

2.5 Janbu's Methods

Janbu's methods are applicable to **non-circular** slip surfaces. The method reduces to the Bishop solution for circular slip surfaces.

Three methods of solution are available:

Horizontal Interslice Forces

Parallel Inclined Interslice Forces

Variably Inclined Interslice Forces

More:

[Janbu's Method - Horizontal Interslice Forces](#)

[Janbu's Method - Parallel Inclined Interslice Forces](#)

[Janbu's Method -Variably Inclined Interslice Forces](#)

2.5.1 Janbu's Method - Horizontal Interslice Forces

This method is taken from [Janbu, 1957](#) and is applicable to **non-circular** slip surfaces.

Assumptions:

- The assumed force distribution satisfies overall vertical and horizontal equilibrium, but **not moment equilibrium**.

The above leads to errors in the calculated factors of safety. These are on the safe side, but can be up to 15%. The more refined Janbu methods, using [Inclined Interslice Forces](#) are therefore recommended.

2.5.2 Janbu's Method - Parallel Inclined Interslice Forces

This method is applicable to both circular and non-circular slip surfaces.

Assumptions:

- Horizontal and vertical equilibrium are satisfied for each slice, and moment equilibrium for the slipped mass as a whole. This is achieved by taking moments about a point near to an

equivalent centre of a circle.

When applied to circular slip surfaces the equations become identical to Bishop's method with parallel inclined forces and the calculated factor of safety is the same.

The benefits and limitations of the method are similar to those of [Bishop's Method](#). The method is capable of giving misleading results due to the problem of interlock, (see [Interlock](#)). The program prints a warning message if the calculated factor of safety is likely to be in error.

In such cases the method of [Variably Inclined Interslice Forces](#) should be used.

2.5.3 Janbu's Method -Variably Inclined Interslice Forces

This method is applicable to both circular and non-circular slip surfaces. It is designed to overcome the problem of interlock.

When applied to circular slip surfaces the equation becomes identical to Bishop's method with [Variably Inclined Interslice Forces](#) and the calculated factor of safety is the same.

More:

[Initial Distribution of Surface Loads](#)

2.5.3.1 Initial Distribution of Surface Loads

This method is applicable to slopes having surface loads. It is an extension of Janbu's method with variably inclined interslice forces, adding an initial calculation using elastic stress distribution to include for the spreading effects of the surface loads.

Note : This method has been used infrequently in design. Any results should therefore be treated with caution.

2.6 Reinforcement Calculations

If reinforcement is specified and active, the forces in the reinforcement are calculated and can be either specified as contributing additional restoring moment (hence increasing the factor of safety) **or** as surface loads, where the surface load applied equals the capacity of the reinforcement derived for the current slip surface.

If the reinforcement is used to contribute additional restoring moment, the soil restoring moment is calculated as usual (but with any partial factors taken into account), then divided by the moment correction factor. The reinforcement restoring moment is then added and the factor of safety calculated.

Calculation of design capacity of reinforcing elements where they cross the slip surface

For end anchored elements (rockbolts Type B):

$$T_j = T/S$$

For ground anchors without pre-stress or soil nails, capacity is the minimum of design pullout force, tensile force and stripping force, so

$$T_j = \min\{T/S, BL_o/S, (P+BL_i)/S\}$$

For ground anchors with prestress, the applicable prestress cannot exceed this value. The input prestress is reduced in proportion to the amount of fixed length outside the slip surface. In the output, the applicable prestress and any additional capacity are shown separately. The applicable prestress per m run of slope is:

$$T_{pj} = \min\{T_j, (T_p/S \times L_O/L)\}$$

and the additional capacity is $(T_j - T_{pj})$.

For geotextiles, capacity is the minimum of design tensile force and pullout force, so

$$T_j = \min\{T, 2L_O\tau\}$$

where

T is design tensile capacity per m run of slope $(T_{ult} \times f_{cr} / (f_{m11} \times f_{m12} \times f_{m21} \times f_{m22} \times f_n))$

where

f_{cr} is the partial factor for creep reduction

f_{m11} is the partial factor for manufacture

f_{m12} is the partial factor for extrapolation of test data

f_{m21} is the partial factor for damage

f_{m22} is the partial factor for environment

f_n is the partial factor for economic ramification of failure

T_p is input prestress per anchor

S is out-of-plane spacing

B is bond strength (force per unit length of anchor/nail)

P is design surface plate capacity

L_i is bonded length within the slip circle

L_O is bonded length or length outside the slip circle

L is total bonded length

The calculation of pullout and stripping forces are mentioned above. To calculate them the shear / bond strength of the appropriate soil strength model has to be applied to the material the reinforcement is in (linear, hyperbolic etc).

B is bond strength (force per unit length of anchor/nail), which can be calculated or specified by the user. If calculated, the value is based on equation 12 from BS8081 and is:

$$\pi D(\sigma_v' \tan \delta + c_a) / (f_p \times f_n)$$

where

$$\sigma_v' = \gamma_h + W_{\text{vertical}}$$

h is vertical distance between reinforcement and slope surface

Shear strength of soil = $\tau = (\sigma_v' \tan \delta + c_a) / (f_p \times f_n)$ (for drained linear strength model)

δ is factored soil friction angle $(\tan^{-1}(\tan \phi / f_{\text{msphi}}))$ where f_{msphi} is factor on friction angle

c_a is factored soil cohesion (c / f_{msc})

γ_h is weight of soil above the reinforcement behind the slip surface - soil unit weight is multiplied by the applicable partial factor

- w is surcharge on the surface above reinforcement behind the slip surface - with factors on dead and live load applied, so $w = (\text{dead load} \times \text{dead load factor}) + (\text{live load} \times \text{live load factor})$
 a is coefficient of interaction between reinforcement and soil relating to the ϕ' of soil
 a_c is coefficient of interaction between reinforcement and soil relating to the c' of soil
 f_p is partial factor on pull-out (BS8006 =1.3)
 f_n is partial factor for structure importance (BS8006 =1-1.1)

The only partial factor not used at the moment is f_s – sliding along reinforcement, which will be added in a later stage of development. This would apply if the slip surface is within a certain distance from the reinforcement, to reduce strength on slip surface.

Surcharges are excluded from the pullout calculation by default, but can be included by setting the field "Use in pullout calc" in the Materials table to Yes.

See [Partial Factors](#) for definition of the method and material partial factors.

Calculation of additional restoring moment due to reinforcing elements

The additional restoring moment due to the reinforcement is defined as

$$M_{RR} = M_{RT} + M_{RV}$$

where M_{RT} is the sum of moments due to tension in the nails/anchors and M_{RV} is the sum of moments due to shear in soil nails. Calculation of shear developed in soil nails is **not** included, so the equation reduces to:

$$M_{RR} = M_{RT} = \sum_{j=1}^m \{T_j R_{dj} \sin(\theta_j - \omega_j)\}$$

For anchors with prestress, BS 8081 applies and an additional restoring moment due to prestress is :

$$M_{RF} = \sum_{j=1}^m [T_{pj} R \tan \phi' \cos(\theta_j - \omega_j)]$$

where T_{pj} is the applicable prestress as defined above.

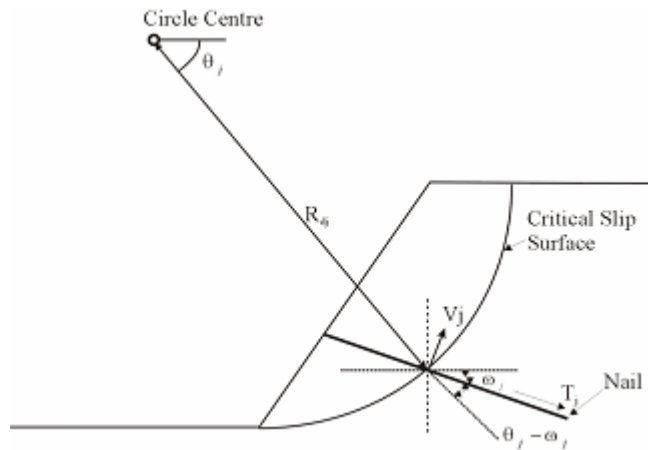


Figure 1.

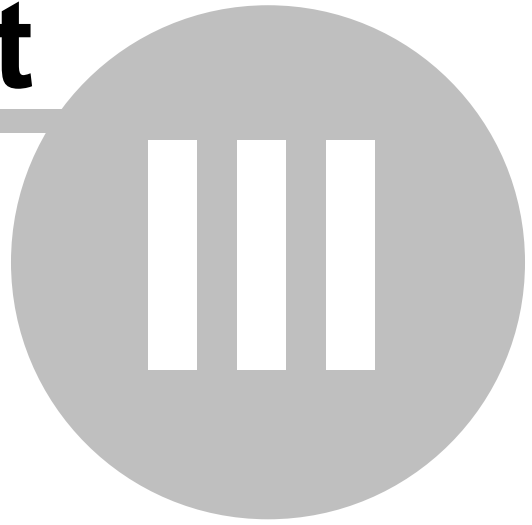
- T_j = design tensile capacity of the reinforcing element
 V_j = design available shear resistance
 R_{sj} = radius of the slip circle
 θ_j = angle of the radius from the horizontal
 ω_j = angle of the reinforcing element from the horizontal.

Application of reinforcement forces as surface loads

If the "Apply as Surface Loads" box is ticked (currently available for soil nails and ground anchors) then the design capacities T_j and T_{pj} will be resolved into horizontal and vertical load components and applied at the point where the reinforcing element intersects the ground surface. The load applied to each slice will be shown in the "Point Loads" columns of the detailed results output table.

Input Data

Part



3 Input Data

3.1 Assembling Data

It is recommended that **before the computer is approached** the following features are marked on an accurate cross-section, drawn to natural scales:

- ground surface
- location of each of the soil or rock strata
- phreatic surface
- location of any piezometers
- location and magnitude of any loads
- location of the grid of centres for circular failure or the plane of failure for a non-circular slip surface

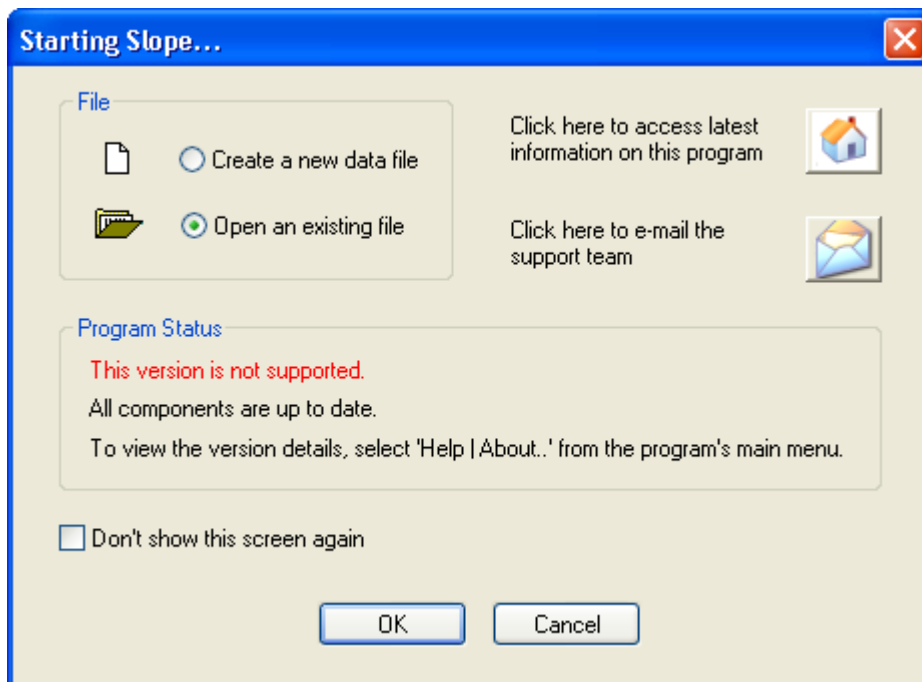
Note: The co-ordinates for all changes in slope for both the strata and phreatic surface should also be defined.


3.2 Opening the Program

The following provides details of all the information required to run the **Slope** program.

On selection of the **Slope** program the main screen will open. All data, graphics and results are entered and viewed in a series of smaller or "child" windows, which are placed inside the main screen.

- To start a new project file select : The "Create a new data file" option on the opening screen



- File | New or
- the icon .

This will open a new Titles window and allow you to proceed.

It is possible to open more than one data file at any one time. The file name is therefore displayed in the title bar at the top of each child window.



More:

[Titles](#)

3.2.1 Titles

The first window to appear, for entry of data into **Slope**, is the **Titles** window.

This window allows entry of identification data for each program file. The following fields are available:

Job Number	allows entry of an identifying job number.
Initials	for entry of the users initials.
Date	this field is set by the program at the date the file is saved.
Job Title	allows a single line for entry of the job title.
Subtitle	allows a single line of additional job or calculation information.
Calculation Heading	allows a single line for the main calculation heading.

The titles are reproduced in the title block at the head of all printed information for the calculations. The fields should therefore be used to provide as many details as possible to identify the individual calculation runs.

An additional field for **notes** has also been included to allow the entry of a detailed description of the calculation. This can be reproduced at the start of the data/results output by selection of notes using File | Print Selection.

More:

[Titles Window - Bitmaps](#)

3.2.1.1 Titles Window - Bitmaps

The box to the left of the Titles window can be used to display a picture beside the file titles. To add a picture place an image on to the clipboard. This must be in a RGB (Red / Green / Blue)

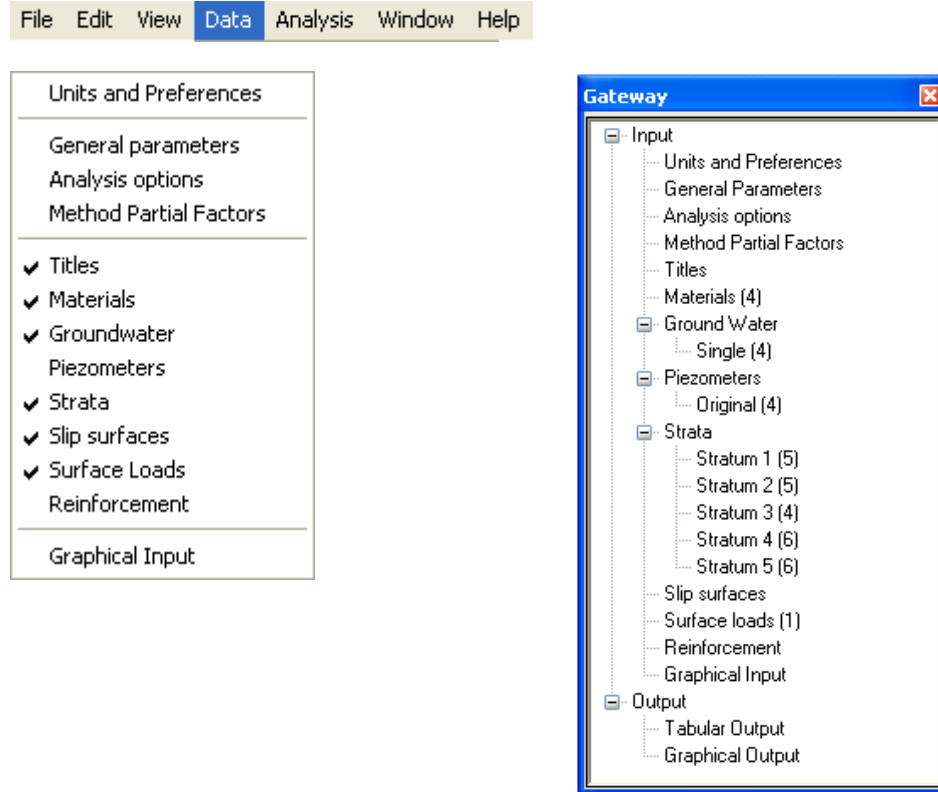
Bitmap format. Select the  button to place the image in the box.

The image is purely for use as a prompt on the screen and can not be copied into the output data. Care should be taken not to copy large bitmaps, which can dramatically increase the size of the file.

To remove a bitmap select the  button.

3.3 Data Input

All data is input via the Data menu, or the [Gateway](#).



The information can generally be entered in any order. Exceptions are that the material data must be entered before the strata. It would also be advisable to enter groundwater and piezometer data before the strata, so that the associated groundwater information is available for each stratum as it is entered.

Once data has been entered the program places a tick against that item in the menu list.

Graphical input allows the strata, water table and any non-circular slip coordinates to be drawn rather than entered as tabular input. Data entered in the graphical view is shown in the tabular input and vice versa.

The following topics describe each of the menu items in detail.

More:

[Units and Preferences](#)

[General Parameters](#)

[Analysis Method](#)

[Material Properties](#)

[Strata](#)

[Groundwater](#)

[Slip Surface Definition](#)

[Surface Loads](#)

[Graphical Input](#)

[Strata - Graphical Input](#)

[Co-ordinates of the Water Table - Graphical Input](#)

[Piezometers](#)

[Non-circular Slip Surfaces](#)

3.3.1 Units and Preferences

The Data | Units and preferences menu command opens this dialog or it can be opened by clicking on the [gateway](#). This option allows the user to specify the units for entering the data and reporting the results of the calculations.

Automatic file backup

This option allows a time interval to be set for automatically saving the data file. Automatic saving can be disabled if required by clearing the "Save file.." check box.

Note! It is good practice to save your file after every new entry of data in each dialog box or table is completed. The Save icon on the Standard Toolbar or Ctrl + S quick keys can be used to save the file.

Units

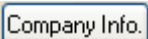
Default options are the Système Internationale (SI) units - kN and m. The drop down menus provide alternative units with their respective conversion factors to metric.

Standard sets of units may be set by selecting any of the buttons: SI, kN-m, kip-ft kip-in.

Once the correct units have been selected then click 'OK' to continue.

SI units have been used as the default standard throughout this document.

Company info.

The company information button  allows the user to change the company name and logo on the top of each page of print out. To add a bitmap enter the full path of the file. The bitmap will appear fitted into a space approximately 4cm by 1cm. The aspect ratio will be maintained. **Note!** For internal Arup versions of the program the bitmap option is not available.

3.3.2 General Parameters

The Data | General Parameters menu command opens this dialog or it can be opened by clicking on the [gateway](#). The following general information is required to describe the type of slip circle to be analysed:

Slip Surface Type, see [Slip Surface Definition](#) : [Circular](#) or [Non-circular](#)

Selection of the type of slip surface i.e Circular or Non-Circular slip surfaces. In case of Non-Circular slip surfaces the program would complete the slip to meet the ground surface by projecting the slip segments to meet the ground surface or vertically up depending upon choice by the user

Minimum Slip Weight

This is minimum weight of slipped soil and can be used to prevent the program analysing very small circles which just intersect the soil surface.

Type of analysis

Selection of static or Pseudo-static corresponds respectively to a file without or with horizontal acceleration.

Horizontal Acceleration (%g)

This allows the user to model earthquake loading. The acceleration is applied to the soil mass within each slice. A positive horizontal acceleration is assumed to be in the direction of the slip. A negative acceleration opposes the slip. The default value is zero. This application is not relevant to the Swedish circle method.

Direction of Slip Movement

Downhill	The program examines each slip surface and sets the direction of movement to be downhill. This is particularly relevant for the modelling of embankments where a full cross-section is defined.
Increasing x	This creates an anticlockwise slip.
Decreasing x	This will create a clockwise slip.

3.3.3 Analysis Method

The Data | Analysis Method menu command opens this dialog or it can be opened by clicking on the [gateway](#). The following types of analysis methods can be selected:

[Swedish \(Fellenius\)](#)

Bishop [Horizontal Interslice Forces](#)
[Parallel Inclined Interslice Forces \(Spencer's Method\)](#)
[Variably Inclined Interslice Forces](#)

Janbu [Horizontal Interslice Forces](#)
[Parallel Inclined Interslice Forces](#)
[Variably Inclined Interslice Forces](#)

Factor of Safety

The factor of safety can be applied to the soil shear strength or the applied loads.

Minimum Number of Slices

The program requires the minimum number of slices for each slip surface to be specified. The default value is 10.

Maximum Number of Iterations

All the methods of solution except the Swedish Circle method iterate to reach a solution. The program defaults to 100 iterations, but the user can specify any number.

Reinforcement Active

Unchecking this box allows reinforcement data to be omitted from the calculations without having to remove the data.

More:

[Factor of Safety on Shear Strength](#)

[Factor of Safety on Applied Loads](#)

[Distribute Surface Loads](#)

3.3.3.1 Factor of Safety on Shear Strength

If this option is specified the program divides the shear strength parameters (c and $\tan \phi$) of each soil stratum by a factor of safety. The program then iterates until a condition of limiting equilibrium is achieved.

The same factor of safety is applied to all strata.

3.3.3.2 Factor of Safety on Applied Loads

In this case the program calculates a load factor as the factor of safety. All the specified loads are then multiplied (or divided) by the load factor in order to bring the ground into a state of limiting equilibrium with the given shear strength parameters.

This facility only works when the loads are sufficiently large to have a significant effect on the stability of the slope.

Two types of load factor can be specified:

Disturbing In this case all loads are multiplied by the factor of safety until limiting equilibrium is achieved.

Restoring Here all loads are divided by the factor of safety until limiting equilibrium is achieved.

The first case can be used for bearing capacity or passive pressure problems and the latter for determination of required anchor forces or active pressures.

3.3.3.3 Distribute Surface Loads

This option is only available for Janbu's method with variably inclined interslice forces and surface loads. The option allows an initial calculation, using elastic stress distributions, to include for the spreading effects of surface loads.

Note : This method has been used infrequently in design. Results should therefore be treated with caution.

3.3.4 Partial Factors

Partial factors dependent on the method and on material parameters can be specified. A default set of partial factors is provided in XML files with the program. This default set includes factors recommended by:

- BS8006 Section 7 (ULS)
- BS8006 Section 8 (ULS)
- BS6031/BS8081
- SLS (all values = 1.0)
- nail mean
- nail min

Method partial factors can be applied to:

- dead or live loads
- soil unit weight
- drained or undrained cohesion
- soil friction angle
- restoring moment
- reinforcement pullout
- economic ramifications of failure
- sliding along reinforcement (not currently used)

Separately, each reinforcing element or group can be assigned a set of material partial factors by selecting the required set in each page of the Reinforcement dialog. These are:

- friction and adhesion interaction
- creep reduction
- factor on manufacture
- extrapolation of test data
- factors on damage and environment

User-specified factors can be added and will then be stored in the XML files - if a data file containing user-defined values is sent to another user, the values will be extracted from the data and saved to the second user's XML file.

For soil nailing problems, the material partial factor 'SLS' (all factors=1) should be entered if calculated bond strength is used, 'nail mean' should be used if bond strength entered is a mean value of pull-out tests and 'nail min' when the minimum value from pull-out tests is entered as the bond strength.

All available partial factors can be viewed by selecting View | Partial Factors.

3.3.5 Material Properties

The Data | Materials menu command opens this dialog or it can be opened by clicking on the [gateway](#). For each material type (soil or rock) the following data must be entered.

General

- A **description** of the stratum.
- The **bulk unit weight** (kN/m³) of the material above and below the ground water table.

Shear Strength Parameters

- The **condition** of the material i.e. undrained, drained with linear strength, or drained with strength calculated using a power or hyperbolic function. Choose the required option from the drop-down list.

For **drained, linear strength** materials enter the angle of friction ϕ' (deg) and a value for drained cohesion c' .

For **drained, power curve strength** materials, enter the angle of friction at which a linear relationship takes over, plus the two constants a and b . **Slope** calculates the material strength using a relationship of $\tau = a\sigma_n^b$.

Then $(\delta\tau / \delta\sigma) = ab\sigma_n^{b-1}$, which is equal to $\tan(\phi')$ at σ_n . The associated c' is given by $c' = ab\sigma_n^b(1-b)$.

The linear relationship $t = c' + \sigma_n \tan(\phi')$ takes over at some predetermined ϕ' , say ϕ'_0 . When σ_n exceeds the stress at which this transition takes place, the strength relationship reverts to Mohr-Coulomb.

For **drained, hyperbolic curve strength** materials, enter values for c' and ϕ_0 as follows. We assume a relationship of

$$\tau = c_{\infty} \sigma_n \tan(\phi_0) / (c_{\infty} + \sigma_n \tan(\phi_0))$$

Then

$$(\delta\tau / \delta\sigma) = \tan\phi = [(c_{\infty} \tan(\phi_0)) / (c_{\infty} + \sigma_n \tan(\phi_0))] - [(c_{\infty} \sigma_n \tan^2(\phi_0)) / (c_{\infty} + \sigma_n \tan(\phi_0))^2]$$

ϕ_0 is the angle at $\sigma_n = 0$ and $c_{\infty} =$ value of c when $\sigma_n = \infty$. Both ϕ_0 and c_{∞} are constants.

c can be calculated from $c = \tau - \sigma_n \tan \phi$.

For **undrained** materials enter:

1. A single value of undrained shear strength c .
2. Alternatively a value of undrained shear strength c_0 , which varies linearly with elevation y .

Where:

$$c = c_0 + k(y_0 - y)$$

c = undrained shear strength at any elevation y

c_0 = undrained shear strength at a specified elevation y_0

k = the rate of increase of shear strength with depth

3. A ratio of c_v/p' for normally consolidated soils, where p' is the effective vertical stress which is calculated by the program at the point on the slip surface for each slice.

4. A combination of 2. and 3. If both are selected then the higher value of strength is used.

3.3.6 Groundwater

The distribution of pore water pressures in the slope for each stratum can be defined in three ways:

1. A phreatic surface with underlying hydrostatic distribution,
2. A phreatic surface with piezometric pressures defined from individual piezometers.
3. Specified values of R_u , the ratio of pore water pressure to total overburden pressure.

The location of each required phreatic surface is defined in either the Groundwater window or the Graphical Input window. For information on data entry see [Co-ordinates of the Water Table - Graphical Input](#).

More:

[Groundwater with hydrostatic pressure distribution.](#)

[Groundwater with piezometric pore water pressure distribution.](#)

[Soil suction](#)

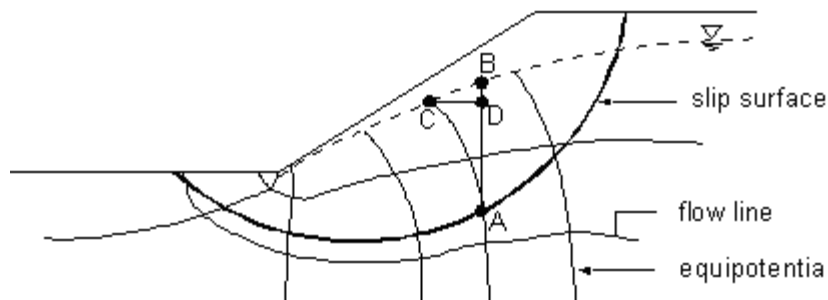
[Ru Value](#)

[Submerged Slopes](#)

3.3.6.1 Groundwater with Hydrostatic Pressure Distribution.

The pore water pressure is calculated at the slip surface using the following assumptions:

The pore water pressure at the location of the slip surface (**A**) is calculated from the level of groundwater vertically above, at **B**.



This assumes that the distribution of pore water pressure is hydrostatic and that the lines of equipotential are vertical.

As can be seen by the flow net above this is not strictly correct. The correct pore water pressure should be calculated from column **AD**, the vertical distance between **A** and **C** described by the actual line of equipotential. For most practical problems the error created is small and leads to conservative results.

The Data | Groundwater menu command opens this dialog or it can be opened by clicking on the [gateway](#). To enter the coordinates of each required phreatic surface, choose Groundwater from the Data menu. This opens the Groundwater Coordinates table.

Each groundwater table should be given a different name for easy recognition when associating the water table with the soil strata. The x and y coordinates are entered in the table on each page. For a new water table, click on the "Add water table" tab. Once finished adding or editing, click on OK. Note: when reading files created before the stratum-specific feature was added, the original water table will be named "Single". This can be renamed as required.

3.3.6.2 Groundwater with Piezometric Pore Water Pressure Distribution

The Data | Piezometer menu command opens this dialog or it can be opened by clicking on the [gateway](#). Sets of piezometers are added or edited by selecting Piezometers from the Data menu. Each piezometer set should be given a name to easy recognition when associating the piezometer set with soil strata.

A phreatic surface (with zero pressure) must also be specified in the Groundwater Coordinates table. This is required in order to provide an upper level for the interpolation of the pore water pressures.

The x and y coordinates are entered in the table on each page. For a new piezometer set, click on the "Add Piezo Set" tab. Once finished adding or editing, click on OK. Note: when reading files created before the stratum-specific feature was added, any original piezometers will be added to a set called "Original". This can be renamed as required.

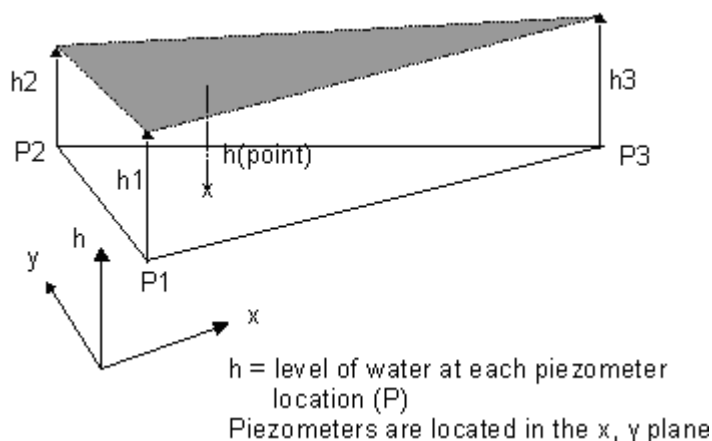
3.3.6.2.1 Interpolation of piezometer data

Interpolation is used to provide pore water pressures (u) for points at the base of each slice, and at stratum interfaces (to calculate the water force on the sides of each slice).

For points:

- **Above the phreatic surface** ; the piezometric level is taken to be the suction defined by the height of the point above the phreatic surface, limited by a maximum specified value.
- **Coincident with a piezometer** ; then the value is taken at the location of the piezometer.
- **Within or just outside the area of three piezometers** ; the values are interpolated as follows.

For this purpose, a point on the phreatic surface at the same x coordinate as the calculation point is added as a 'dummy' piezometer with zero pressure. The locations of the three nearest individual piezometers (P1 etc.) are then mapped onto a triangular grid.



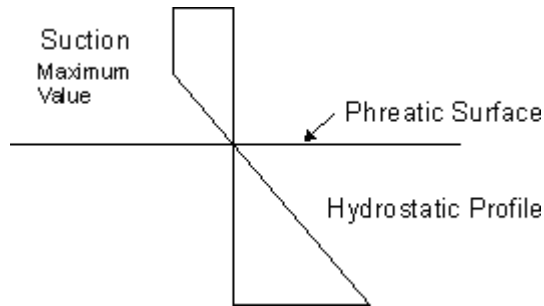
Linear interpolation is then used to create a plane of piezometric pressure from which the pressure for any individual point can be read. Note : If the program cannot interpolate due to lack of data

then an error message will be given prior to calculation.

3.3.6.3 Soil Suction

The maximum suction sustainable by the soil can be specified in terms of head of water. This is a **positive** term.

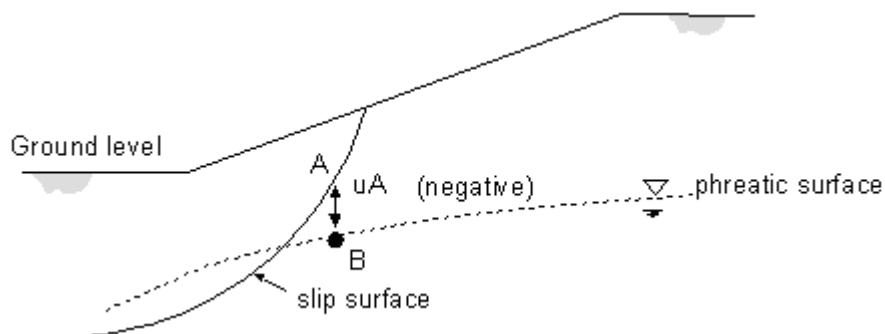
The suction at the phreatic surface is zero. The value of suction will then increase using a linear hydrostatic profile to the specified maximum height (h_s). The soil suction is then held at the constant maximum value above this level.



Note : h_s is positive and expressed in units of head of water.

The effect of soil suction on the area of the slip surface above the phreatic surface is as follows:

Slope calculates the negative pore pressure which is equal to the height of the slip surface above the phreatic surface, i.e. distance AB.



If the slip surface is above the maximum height h_s , then the suction is assumed to be constant and equal to h_s .

Note : If no suction is specified the program assumes zero pore pressures above the phreatic surface.

3.3.6.4 Ru Value

In the absence of detailed information about the position of the phreatic surface, pore pressures on the slip surface may be expressed in terms of a single Ru value.

Where

$$Ru = (\text{Pore Pressure}) / (\text{Total Overburden Pressure})$$

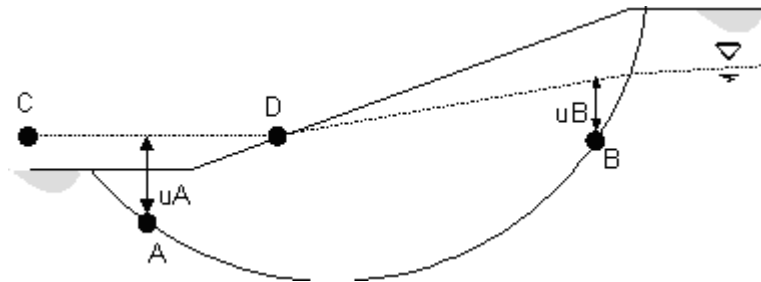
In this case the program calculates the pore pressure, u , at each point according to the equation:

$$u = pRu$$

where p is the total overburden pressure.

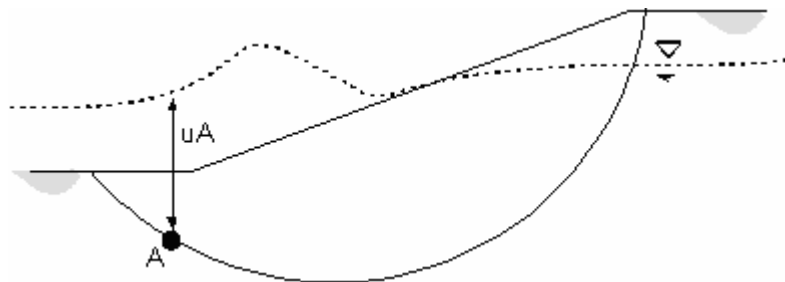
3.3.6.5 Submerged Slopes

For a submerged slope the phreatic surface is located above ground level, as in section CD below:



The pressure of water acting on the ground surface is treated as a surface load. Pore pressures on the slip surface can be specified as either hydrostatic or piezometric, see [Groundwater](#).

The portion of the water surface outside the slope is usually horizontal and corresponds to static conditions. Wave conditions could be modelled by defining a water surface as shown below.




The results, however, should be examined carefully to check that the actual pore pressure distributions on the ground and the slip surface are as required.

3.3.7 Piezometers

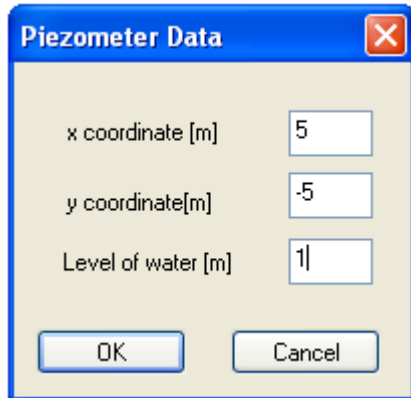
Piezometers are defined in named sets, which can then be associated with one or more strata. A piezometric distribution is specified using a series of pressure heads from individual piezometer locations within any one set. The water pressure at any point in a stratum is computed by interpolating between either the nearest three piezometers of the associated set, or the nearest two piezometers in the set and a point on the associated phreatic surface at the same x coordinate as the point at which the water pressure is required.

Note : The piezometers should be distributed throughout the area of the slope and slip surface area to provide the best interpolation.

Adding piezometers

Piezometer data is entered graphically by selecting the piezometer button  on the graphics toolbar.

A piezometric groundwater profile can be entered by placing the cursor at the appropriate level on the graphical view and clicking the right mouse button. This opens the piezometer data box.



The image shows a dialog box titled "Piezometer Data" with a blue header and a close button (X) in the top right corner. The dialog contains three input fields: "x coordinate [m]" with the value "5", "y coordinate [m]" with the value "-5", and "Level of water [m]" with the value "1". At the bottom of the dialog are two buttons: "OK" and "Cancel".

This allows the level of the piezometer to be confirmed or edited and the corresponding level of water at the piezometer h_w to be entered. The pressure (u) is given as:

$$u = (h_p - h_w)\gamma_w$$

where:

h_p = The level of the "piezometer" tip

h_w = The piezometric water level (y co-ordinate)

γ_w = Unit weight of water as entered in [Groundwater](#).

Piezometers can be deleted by placing the cursor over the location and clicking the left button whilst holding down the Shift key.

More:

[Interpolation of piezometer data](#)

3.3.8 Strata

The Data | Strata menu command opens this dialog or it can be opened by clicking on the [gateway](#) in which strata coordinates can be entered in tabular form and the water data associated with the stratum entered or selected from dropdown lists. Strata coordinates, assigned material and name can also be entered in the [graphical input](#) view.

In the tabular input separate pages are given for each stratum. To add a new stratum click on the Add Stratum tab at the top of the dialog.

For each stratum, enter a unique name and select the required soil type from the Material dropdown list. Note : By default Material 1 will be assigned to Stratum 1, Material 2 to Stratum 2, etc.

Select the required groundwater profile for this stratum, choosing between Hydrostatic, Piezometric or Ru value. If Ru value is chosen, the value (between 0 and 1) should be entered in the Ru value edit field. If Hydrostatic or Piezometric is chosen, the unit weight of groundwater and the maximum suction should be entered. The required groundwater data should be selected from the dropdown lists for "GW surface" and "Piezometers", which will show any water tables and

piezometer sets which have already been entered. For a description of how pore water pressures are calculated for each groundwater profile type, see [Groundwater](#).

When entering stratum coordinates, ground level should be defined at Stratum 1 with the soil layers below entered in order as Stratum 2, 3 etc. Note the limitations described in [Defining multiple strata](#). Strata can not cross each other and vertical surfaces should be defined as slightly off vertical (sloping upwards from left to right). For inserting wedges or lenses of material then the same rules must be applied to the tabular input as for the graphical. For further information see [Inserting a lens or wedge of material](#).

3.3.9 Slip Surface Definition

Slip surfaces can be defined in terms of:

- Circular or
- Non-circular profiles.

The type is selected in the [General Parameters](#) dialog. The remainder of the definition for circular slips is given via the following dialog box. The Data | Slip Surfaces menu command opens this dialog or it can be opened by clicking on the [gateway](#) Non-circular slips are defined using the graphical input screen or table, as shown in [Non-Circular Slip Surfaces](#).

More:

[Circular slip surfaces](#)

[Definition of Circle Centres](#)

[Definition of the Circle Radii](#)

[Non-circular slips](#)

3.3.9.1 Circular Slip Surfaces

A circular slip surface is defined by the x and y co-ordinates of the centre of the circle and the specification of the circle radius.

The centre of the circle is specified in terms of a **single point** or **grid** .

The radius of the circle is specified in terms of:

- The co-ordinates of a **common point** through which all circles must pass.
- **Defined radii** of the circles,
- A **tangent surface**, defined as a stratum boundary. In this case the circle stays just above the boundary.

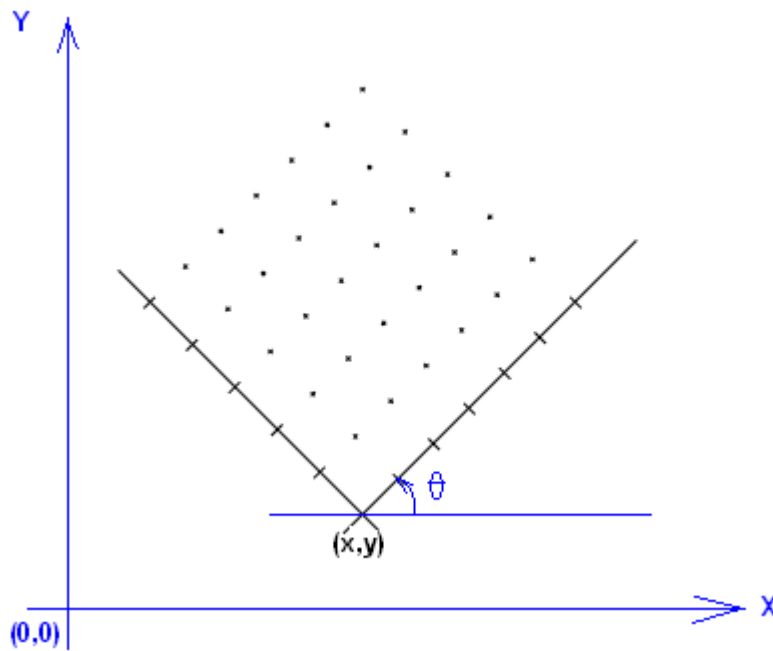
A **minimum slip weight** can also be specified to prevent the program choosing very small slip circles that just intersect the surface of the soil.

3.3.9.2 Definition of Circle Centres

Single Point

The user can specify a single centre of a circle in terms of x and y co-ordinates .

Grids



A rectangular grid of centres can be specified by giving the co-ordinates (x, y) of the bottom left hand corner of a grid and the inclination of the grid about this point in positive anticlockwise direction.

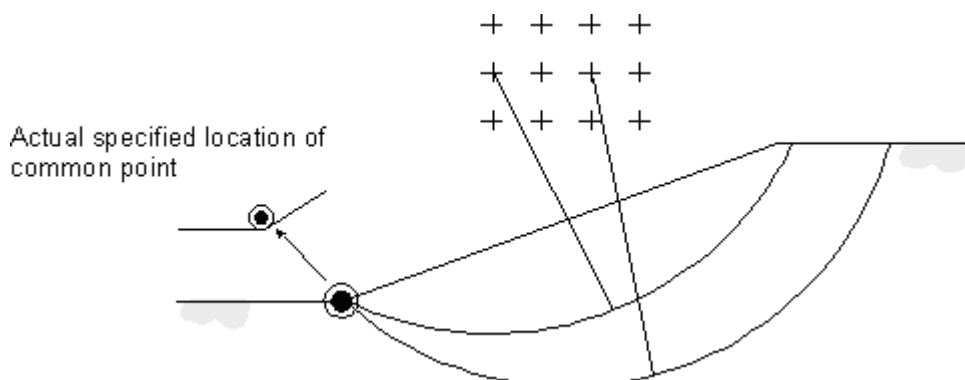
The extent of the grid is given by specifying the number of columns and the spacing of each grid line in the x and y directions.

There is an option to let the program extend the grid (at the same grid spacing and inclination) to find the minimum factor of safety. If this option is used the program will extend the grid (in any direction) if it is found that the centre of the slip surface with the minimum factor of safety is on the edge of the grid. This process is repeated until the minimum centre is no longer on the edge of the grid.

3.3.9.3 Definition of the Circle Radii

Common Point

This allows entry of co-ordinates for a common point (X_c, Y_c) through which all circles must pass.



If a common point is required at the toe of the slope then the actual point location should be set

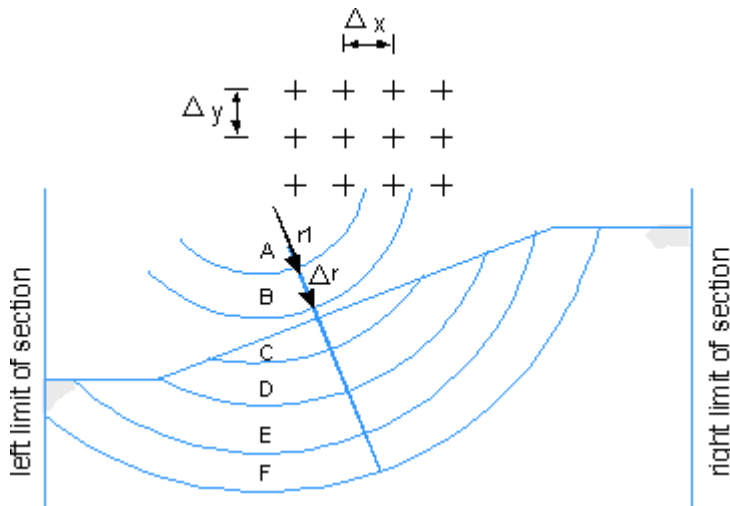
slightly above the toe. This is in order to avoid problems from rounding errors.

Defined Radii

Circles of different radii may be analysed by specifying an initial radius r_1 , and an increment of radius Δr .

For each centre the program then analyses circles of radii

r_1 , $r_1 + \Delta r$, $r_1 + 2\Delta r$ etc.



Circles of small radius are ignored by the program if they do not intersect ground level, e.g. circles A and B. The initial radius r_1 may therefore be set to a small value.

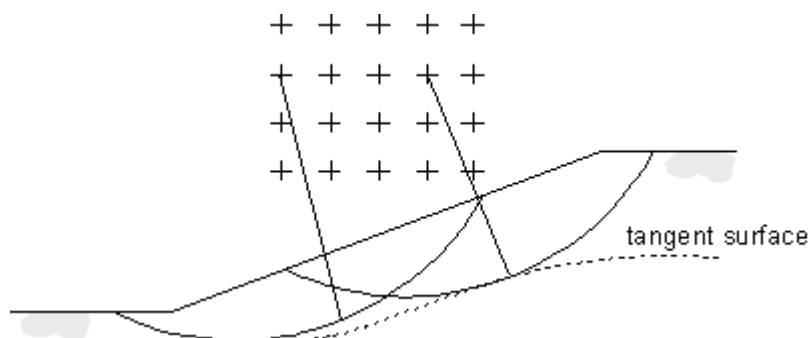
Each section of strata has defined limits in the x direction. The largest circle radius which can be analysed is determined by the limits of this section.

Circles C, D and E are therefore analysed, but not circle F.

If the value of Δr is given as zero, the program analyses a single circle of radius r_1 at each grid location.

Tangent Surface

A tangent surface is defined as a stratum boundary. The actual circle stays just above the selected boundary.



Note : An additional soil boundary may need to be added to make full use of this feature.

For sloping strata boundaries, as shown above, **Slope** will calculate the shortest radius to the boundary for each centre and take this as the location of the tangent. The calculated circle can therefore never cross the strata boundary line.

3.3.9.4 Non-circular slips

If the slip surface type entered in the General Parameters dialog box is non-circular, selection of Data | Slip Surfaces will open a table for entry of the non-circular slip surface coordinates.

The program allows a number of slip surfaces to be entered and on analysis detail results of the slip surfaces giving minimum factor of safety is provided.

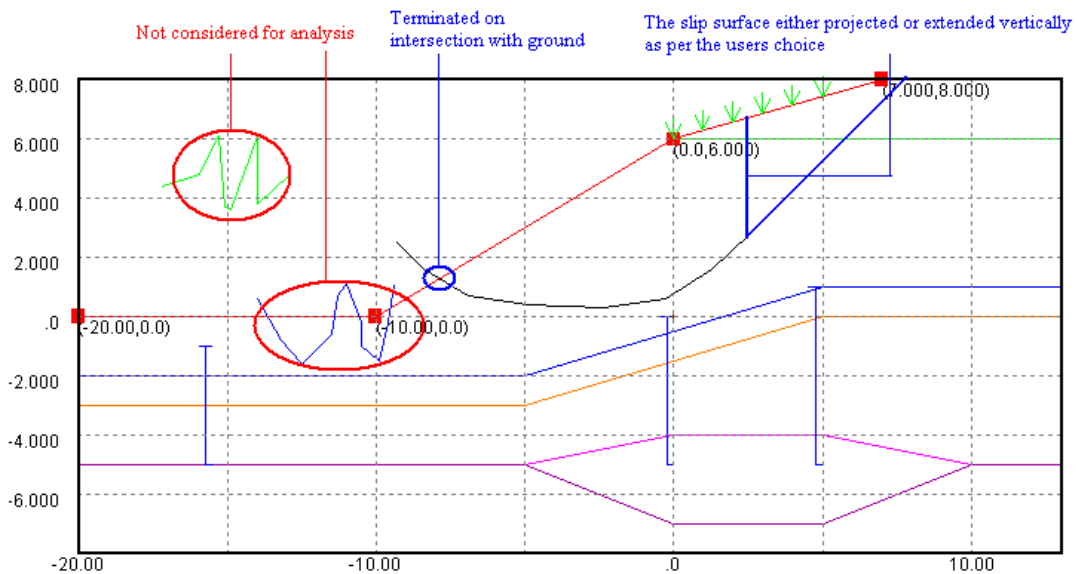
In the tabular input separate pages are given for each slip surface. To add a new slip surface click on the Add Slip tab at bottom

For each slip surface, enter a unique name

Note:

1. By default each slip surface will be named as Slip 1, Slip 2, etc: the order of the default names will be maintained even if some slip surface is deleted or renamed
2. The slip would be extended either along the slope of the last segments or vertically depending upon the choice by the user made in the [General parameters](#)

The slip surfaces can be entered in any order, however before sending for analysis the pre-processor will do the necessary editing depicted by the following image:

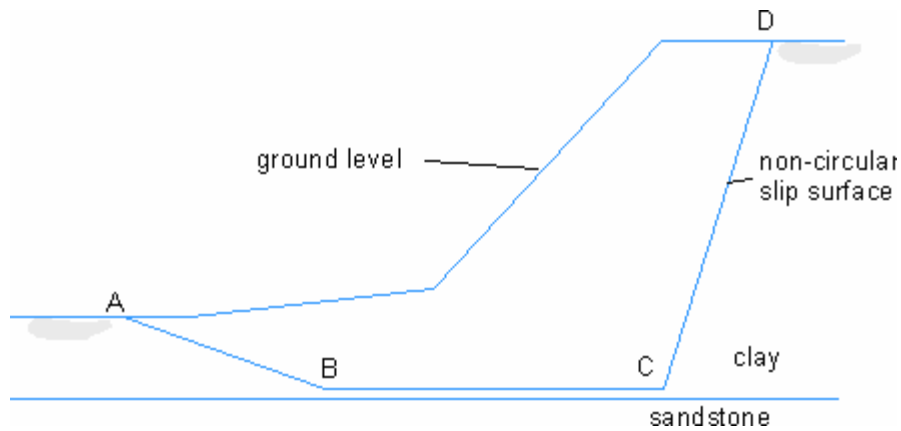


Following are the cases where the auto adjustment of slip would fail

1. Only 1 point exist for the curve
2. Curve completely outside
3. Inappropriate intersection with ground
4. On extension or vertical projection as per the choice by the user the slip does not intersect the ground surface

In all the above cases the user will be prompted to manually correct the slip surface.

Non-circular slip surfaces can also be entered using the graphical data view, see [Non-circular Slip Surfaces](#).

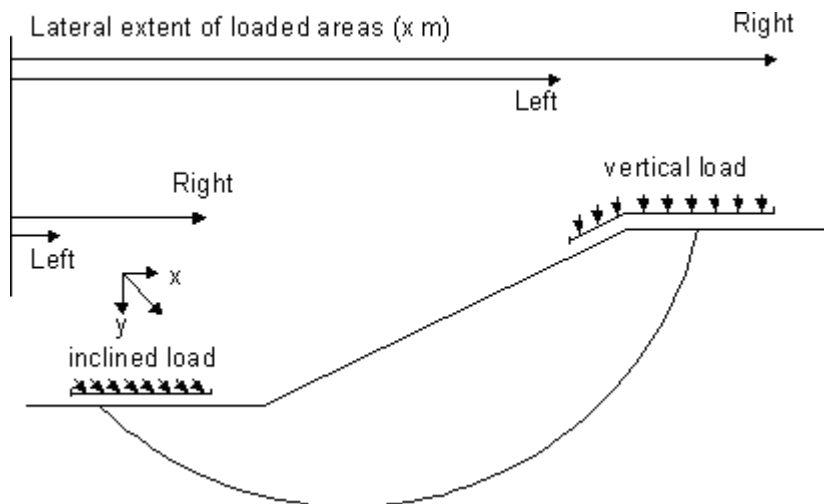


In the example shown, the coordinates entered would be A-B-C-D. There is no need to extend the coordinates of a non-circular slip to the ends of the problem.

3.3.10 Surface Loads

The Data | Surface Loads menu command opens this dialog or it can be opened by clicking on the [gateway](#) Surface loads can be added by defining the lateral extent of the loaded area in terms of the **left** and **right** limits.

Loads can be placed horizontally or vertically.



Vertical loads are expressed as the vertical force per unit horizontal width of the loaded area. For level ground this is equal to the normal stress on the ground surface. Vertical loads are positive when they act downwards.

Horizontal loads are expressed as the horizontal force also per unit **horizontal** width of the

loaded area. For level ground this is equal to the shear stress on the ground surface, but for steeply inclined surfaces the 'pressure' specified is much greater than the actual pressure acting on the ground.

Horizontal loads are positive when they act in the direction of increasing x .

Inclined loads can also be defined by using a combination of the horizontal and vertical components.

Concentrated loads, in the form of anchors or struts, can be modelled by specifying surface loads of high intensity over short lengths of the ground surface.

3.3.11 Reinforcement

The Data | Reinforcement menu command opens this dialog or it can be opened by clicking on the [gateway](#) Reinforcing elements are specified on the Reinforcement dialog. Four types of reinforcement are available:

- Ground anchors
- Rock bolts
- Soil nails
- Geotextile

The data items which are not applicable to each particular type of reinforcement are greyed out when that type is selected from the drop-down list.

Each set of reinforcing elements is given a name which is used to distinguish forces in the reinforcement in the tabular output table. Each set is drawn in a different colour on graphical input and output. NB If the reinforcement is marked inactive in the [Analysis Method](#) dialog, it is drawn in grey on the graphical input, and omitted from the output, because it has no effect on the results.

Geometry

The uppermost level, number of layers and horizontal spacing are entered. The length of the top and bottom layers of reinforcement are entered. The lengths of intermediate layers are interpolated between these two values. The angle from horizontal is entered, except for geotextiles which are always assumed to be horizontal.

Capacity

Out-of-plane spacing, tensile capacity and plate capacity (if applicable) are entered. Plate capacity must be at least 50% of tensile capacity. The tensile capacity should represent the allowable capacity if BS8081 is used or ultimate capacity if EC3 is used.

Bond details and prestress

Bond length can be entered for ground anchors and rock bolts Type B. Soil nails are assumed to be 100% bonded along their length.

Bond strength can be specified or calculated from effective stress.

Prestress can be entered for ground anchors and can not exceed the tensile capacity.

Material partial factors

Click the Select button to set material partial factors for each set of reinforcing elements. This is optional - all partial factors will be set to 1.0 if no selection is made. User-defined sets of partial factors can be added or edited by selecting "Partial Factors" from the View menu.

See [Reinforcement Calculations](#) for details of the calculations used, and the application of method and material partial factors.

3.3.12 Graphical Input

the View | Graphical Input opens the graphical input view or it can be opened by clicking on the [gateway](#). The following data can be entered in graphical form. Soil strata and groundwater level can be entered in both tabular and graphical form. The methods are fully interchangeable and will update automatically.



[Strata](#)



Inserting a [wedge of material](#)



[Phreatic surface](#)



[Piezometer levels and pressures](#)



[Non-circular slip surface](#)

Use the mouse to move the cursor around the graphical display. The left and right mouse buttons allow data to be entered and edited. Information on entering each type of data is given separately.

More:

[Entering new graphical data](#)

3.3.12.1 Entering new graphical data

Before entering data the program defaults to show a blank grid extending from -100m to +100m in the x direction, and from 0m to +100m in the y direction. This range can be edited by selecting View | Set problem limits and then entering the maximum and minimum required for the x and y axes.

The snap interval can also be edited if required. This defines the smallest interval onto which the cursor will lock to mark a point.

Use the mouse to move the cursor around the graphical display. The left and right mouse buttons allow data to be entered and edited.

To set an exact scale select View | Set Exact Scale and enter the required scale.

The following buttons are available on the graphical input toolbar:



Axis : Provides a reference grid behind the drawing.



Set Scale : This allows the user to toggle between the default 'best fit' scale and the closest available engineering scale. e.g. 1:200, 1:250, 1:500, 1:1000, 1:1250, 1:2500.

Clicking on this button if an exact scale has been set will switch off the exact scale option.

User specified : allows setting of a user defined scale which will be retained until switched off.




Save Metafile : this save icon allows the file to be saved in the format of a Windows Metafile. This retains the viewed scale. The metafile can be imported into other programs such as a word processor, spreadsheets and drawing packages.



Zoom Facility : The user can select an area to 'zoom in' to by using the mouse to click on a point on the drawing and then dragging the box outwards to select the area to be viewed. The program will automatically scale the new view. The original area can be restored by clicking on the 'restore zoom' icon as shown here.

3.3.12.2 Strata - Graphical input

When entering stratum coordinates, ground level should be defined at Stratum 1 with the soil layers below entered in order as Stratum 2, 3 etc.

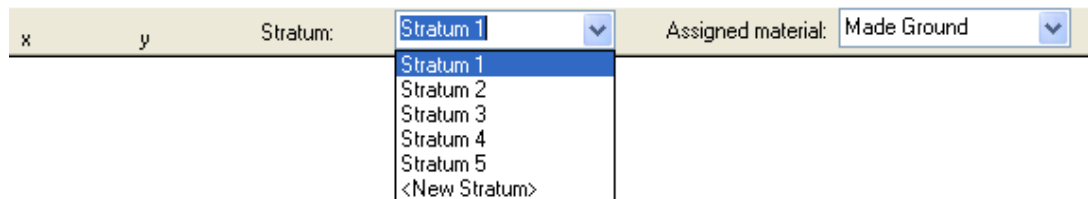
Select Data | Strata or the strata button  from the graphical input toolbar, if the graphical input view is already open.

Strata window

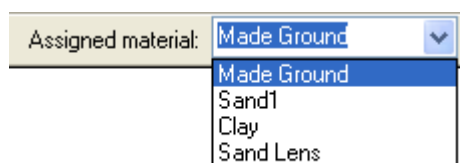
Adding strata

The procedure for entry of a new stratum is as follows:

2. Select <New Stratum> from the "Stratum" dropdown box at the top of the window.



2. Select the correct Soil name from the "Assigned material" dropdown box at the top of the window.



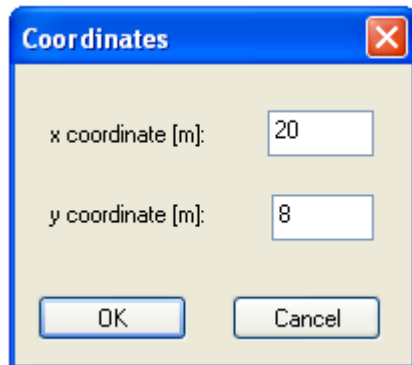
3. Place the cursor at the location of a point which you wish to define as part of the soil layer and left click with mouse button. The point will then **Snap** to the closest location defined by the given snap interval.

Note: You can follow the exact co-ordinates of the cursor by looking at the given x and y co-ordinates at the top left of the screen.

x -20.00 y -8.000

Editing strata

1. To edit the location of a point; place the cursor over the point and click the right button. This brings up an editing box as shown:



2. Amend the co-ordinates as required and then click OK.

Note: Points can be deleted by placing the cursor over the required point and clicking the left mouse button at the same time as holding down the Shift key on the keyboard.

More:

[Adding multiple strata](#)

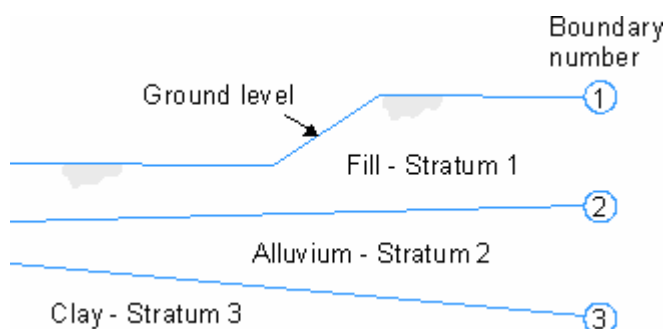
[Inserting a lens or wedge of material](#)

3.3.12.2.1 Defining multiple strata

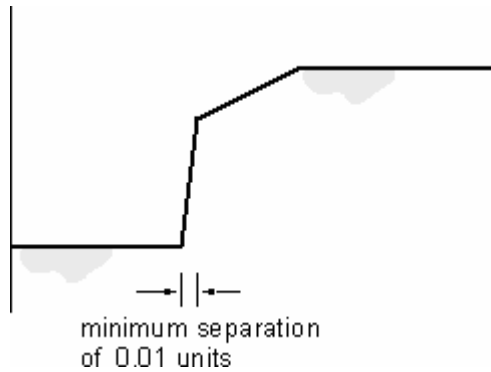
Material layers must be entered in descending order from the highest ground level.

The strata are numbered downwards from the ground surface which is represented by the upper boundary of Stratum 1. There is no lower boundary to the section and it is assumed that the lowermost stratum extends downwards indefinitely.

Note: Each boundary should form a continuous line across the full width of the section. If partial lines are defined, the program will assume they extend horizontally to either side of the defined area. This may cause overlapping of strata and such ambiguities should be avoided. A warning will be given if partial strata are found before analysis.



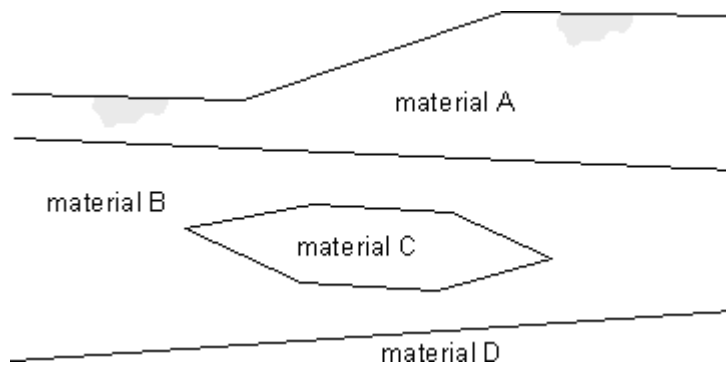
A soil boundary may not cross a vertical grid line twice, thereby creating an overhang. **Vertical lines are also not permitted**, but must instead be modelled as near vertical.



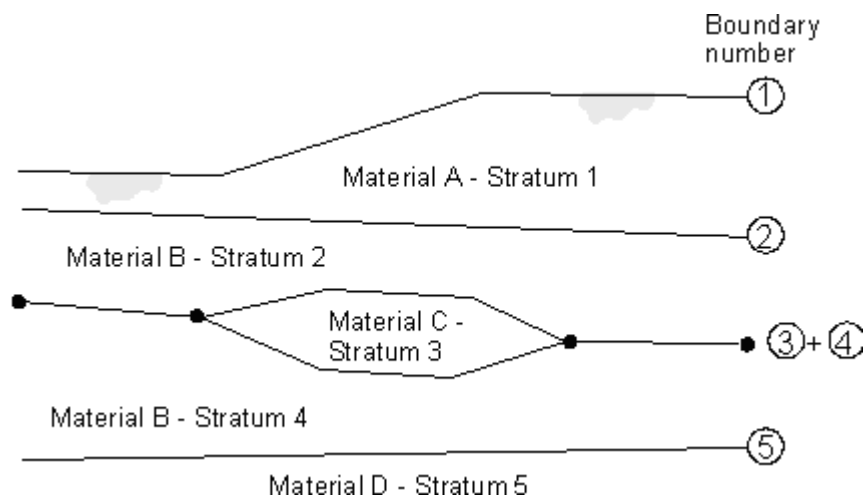
A vertical wall or cut is therefore represented by a boundary of very steep gradient using a horizontal separation of at least 0.01 units. This is so that the co-ordinates can be read correctly from printed output which is given to 2 decimal places.

3.3.12.2.2 Inserting a lens or wedge of material

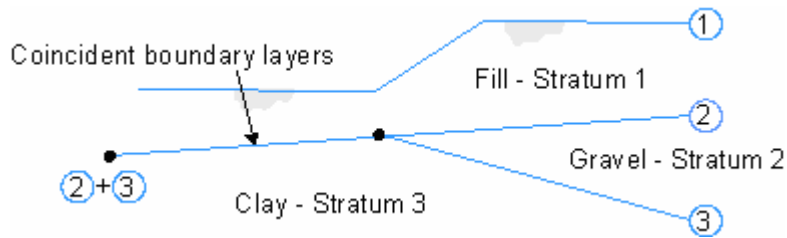
Where a lens of material (C) is embedded in another material (B), as shown below, it is drawn with upper and lower boundaries that extend to the edge of the section.



Thus material (B) is actually divided into two strata having the same properties and separated by the boundary of material (C).

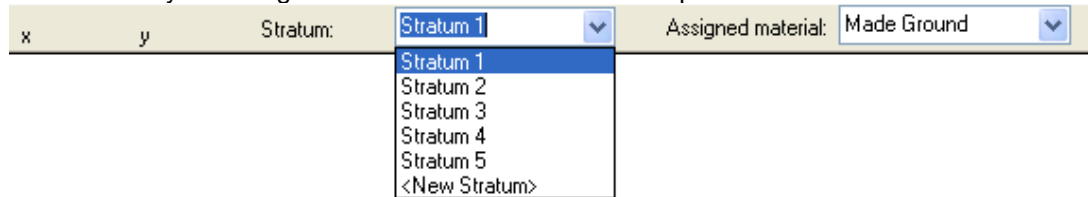



The same applies for a wedge of soil that does not extend across the full width of the section.



To enter a lens, wedge or coincident layer of material:

- highlight the strata which is required to form the partial upper boundary of the new layer. this is done by selecting the stratum number from the drop down box.



- select the wedge button  from the graphical toolbar.

This will place a new layer of material immediately on top of the highlighted layer.

- Delete the points on the line which are to be removed (Shift+Left mouse button).
- Place new points at the correct locations.
- Select the correct material type for the new layer or wedge of material.




For inserted layers the stratum numbers will automatically re-order to incorporate the new layer.

3.3.12.3 Co-ordinates of the water table - Graphical input

The co-ordinates of any number of phreatic surfaces are entered in a similar manner as for strata.

To enter a new surface

- Select the icon for addition of a phreatic surface 
- Select "<Add new ..>" from the "Stratum" dropdown box.
- Place the cursor at the correct location of a point which you wish to define as part of the surface and left click with mouse button. The point will then **Snap** to the closest location defined by the given snap interval.

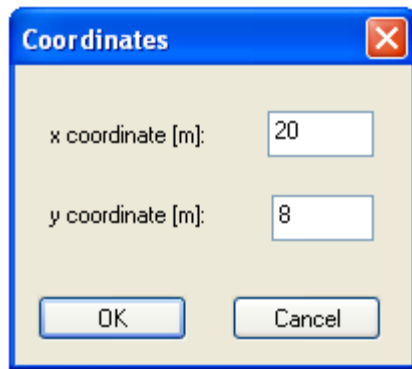
Note: You can follow the exact co-ordinates of the cursor by looking at the given x and y co-ordinates at the top left of the screen.

x -1.418 y 0.5000

Editing surfaces

To edit the location of a point;

1. Select the required phreatic surface on which to edit points from the "Stratum" dropdown box.
2. Place the cursor over the point and click the right button. This brings up an editing box as shown:



2. Amend the co-ordinates as required and then click OK.

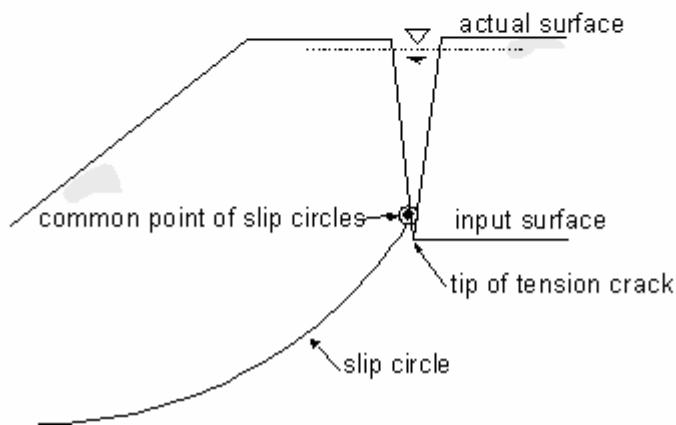
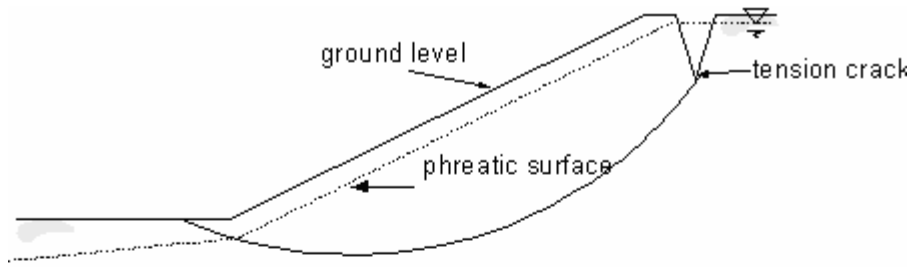
Note: Points can be deleted by placing the cursor over the required point and clicking the left mouse button at the same time as holding down the Shift key on the keyboard.

More:

[Water filled tension cracks](#)

3.3.12.3.1 Water filled tension cracks

A water filled tension crack can be modelled by defining the position of the crack as part of the surface geometry of the section (Stratum 1). The water level must then be set above the tip of the crack as shown.



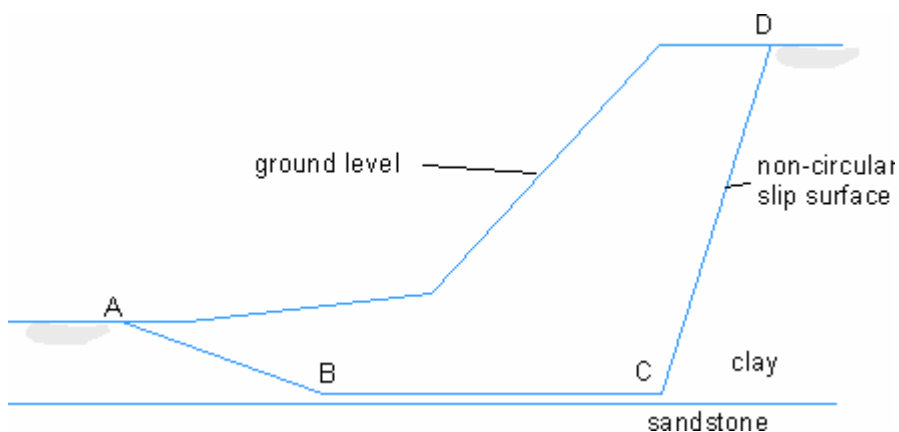
The slip surface to be analysed in such a case typically passes through the tip of the crack.

Bearing in mind the possibility of rounding errors, it is best to set the common point of the circle slightly above the tip of the crack, as shown.

To avoid analysing circles which happen to pass through the material on the other side of the crack it is advisable to lower the ground surface on the outside of the crack, as shown.


3.3.12.4 Non-circular Slip Surfaces

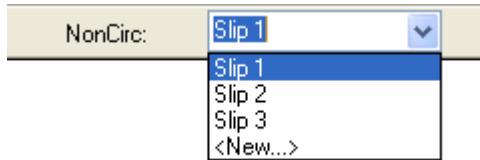
Non-circular slip surfaces are defined graphically in the same way as the Strata layers.




Adding a non-circular slip surface

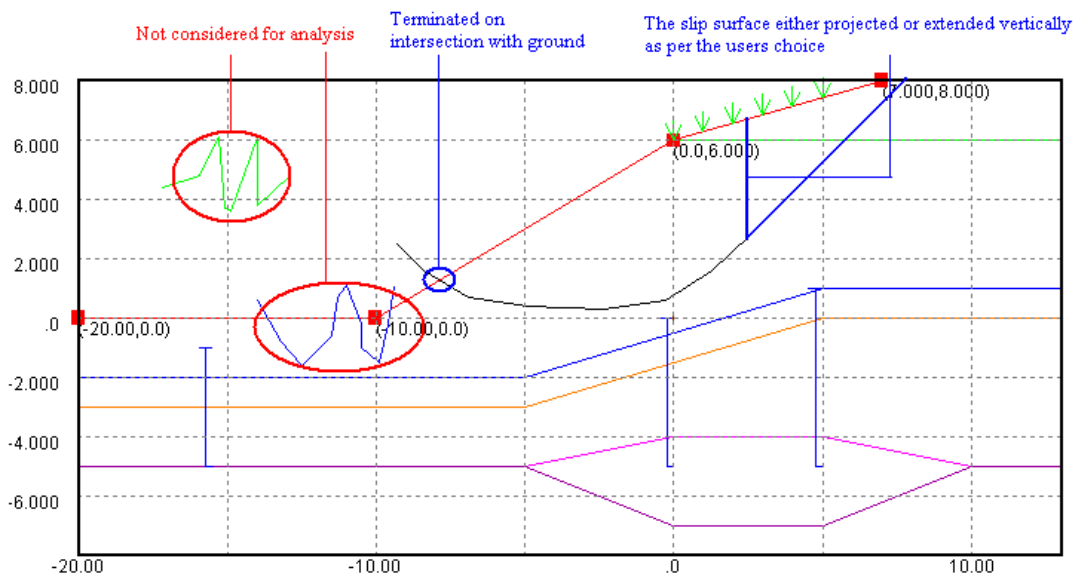
The procedure for entry of a surface is as follows:

1. Select the icon for addition of a non-circular slip surface .
2. Place the cursor at the location of a point which you wish to define as part of the soil layer and left click with mouse button. The point will then **Snap** to the closest location defined by the given snap interval.
3. To add new slip surface Select <New ...> from the "Slip" drop down box at the top of the window and repeat steps 1 and 2



The program provides an auto correct button  which is applied to each slip separately. The auto correct corrects the slip and gives the final slip that will be analysed. The slip would be extended either along the slope of the last segments or vertically depending upon the choice by the user made in the [General parameters](#)

The following figure depicts the checks and amendments done by the auto-correct function.



Following are the cases where the auto adjustment of slip would fail

1. Only 1 point exist for the curve
2. Curve completely outside
3. Inappropriate intersection with ground
4. On extension or vertical projection as per the choice by the user the slip does not intersect the ground surface

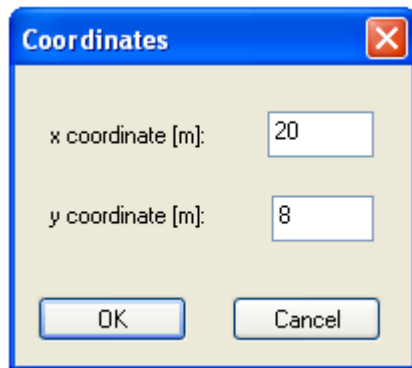
Note: You can follow the exact co-ordinates of the cursor by looking at the given x and y co-ordinates at the top left of the screen.

x -1.418 y 0.5000

Editing the surface

To edit the location of a point;

1. Place the cursor over the point and click the right button. This brings up an editing box as shown;



2. Amend the co-ordinates as required and then click OK.

Note : Points can be deleted by placing the cursor over the required point and clicking the left mouse button at the same time as holding down the Shift key on the keyboard.

Analysis and Results

Part

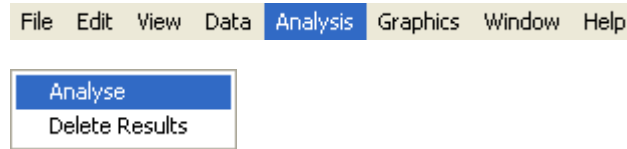


IV

4 Analysis and Results

4.1 Analysis and Data Checking

Results can be obtained by clicking the Analyse button on the [Slope Tool bar](#) or via the Analysis menu,



Prior to analysis the program carries out a data check.

The data checks carried out are as follows:

1. The presence of a non-circular slip surface if defined in the [General Parameters](#).
2. Checks the authenticity of non circular slip surfaces
2. Check if the Janbu method is defined in [Analysis Methods](#) for a non-circular slip surface
3. The presence of piezometers for a defined piezometric groundwater case.
4. The presence of upper and lower phreatic surfaces if a number of phreatic surfaces are defined in the [Groundwater](#) table.
5. For problems with horizontal loads or a submerged slope, the analysis method is Bishop or Janbu.
6. Soil bulk unit weights are not less than the unit weight of water

If no errors are found then the calculation can proceed. Select OK.

Note : The option to Examine results becomes available once the calculations have been completed. Selecting "Tabular Output" from the Gateway has the same effect. Before displaying the tabular output, the program requests confirmation of which data/results to show.

4.2 Results Output

The results are provided in tabular form. The lists of tabulated output can be highlighted and then copied to the clipboard and pasted into most Windows type applications e.g. Word or Excel. The output can also be directly exported to various text or HTML formats by selecting Export from the File menu.

Slice No.	Strength Parameters		Average	Slice	Forces on base [kN/m]		
	c'	Tan phi	Pore Pressure	Weight	Normal	Shear	Shear
	[kN/m ²]		[kN/m ²]	[kN/m]		(capacity)	(mobilised)
1	0.0	0.5543	0.0	2.275	2.451	1.359	1.450
2	0.0	0.5543	0.0	6.380	6.307	3.496	3.730
3	0.0	0.5543	0.0	9.652	9.277	5.142	5.487
4	0.0	0.5543	0.0	12.10	11.39	6.314	6.737
5	0.0	0.5543	0.0	13.75	12.69	7.035	7.506
6	0.0	0.5543	0.0	14.63	13.24	7.337	7.829
7	0.0	0.5543	0.0	14.76	13.10	7.259	7.745
8	0.0	0.5543	0.0	14.19	12.35	6.844	7.303
9	0.0	0.5543	0.0	12.98	11.08	6.140	6.552
10	0.0	0.5543	0.0	11.18	9.380	5.200	5.548
11	0.0	0.5543	0.0	8.850	7.352	4.075	4.348
12	0.0	0.5543	0.0	4.329	9.340	5.177	5.524
13	2.000	0.3640	0.0	0.4393	2.950	1.846	1.969

The results for **Slope** are reported in two formats:

A summary of the results for all the slip circles analysed and a full report of the results for the worst case slip circle with the lowest factor of safety.

More:

[Summary of Results](#)

[Full Results](#)

4.2.1 Slip Surfaces

This output summarises the results for all the slip circles analysed. The following items are tabulated for each slip circle.

- The x and y co-ordinates of the **Centre of Rotation**
- The **Radius** of the circle.
- The **Slip Weight** of the circle.
- The **Factor of Safety** .
- The **Disturbing Moment** and **Restoring Moment** of the circle.

Detailed results are provided for the slip circle with the lowest factor of safety.

The output provides details of the interslice and base forces in addition to the overall reporting of force and moment equilibrium.

4.2.1.1 Summary of Results

This output summarises the results for all the slips analysed. The following items are tabulated for each slip circle.

- The x and y co-ordinates of the **Centre of Rotation** about which Moment is taken.
- The **Radius** of the circle for circular slips.
- The **Slip Weight**.
- The **Factor of Safety** .
- The **Disturbing Moment** and **Restoring Moment** of the slip.

A column for comments provides the following information.

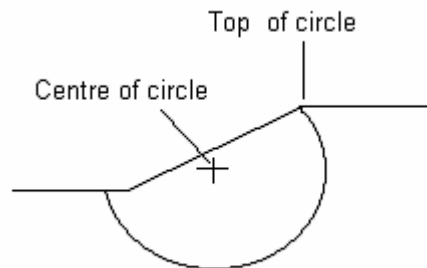
Comment	Slip Type	Definition/Response
Radius too large	Circular	Increase lateral extent of ground profile in $\pm X$ direction (if required); this message will inevitably be shown where the initial radius and increment method is used to define the circles to be analysed.

Horizontal ground	Circular/ Non- Circular	Where the location of the slip surface is entirely within an area of horizontal ground.
-------------------	----------------------------	---



Radius too small.	Circular	Occurs if the circle radius is too small to reach the specified ground surface.
-------------------	----------	---

Center embedded	Circular	Where the center of the circle is below the level of the top of the slip.
-----------------	----------	---



No loads.	Circular/ Non- Circular	Specify loads for factor of safety on loading .
Loads too small	Circular/ Non- Circular	Increase load size until they become a significant factor in the stability of the slope or change the factor of safety to shear strength .
Weight too small.	Circular/ Non- Circular	Decrease the minimum slip weight .
Failed to converge.	Circular/ Non- Circular	Increase the maximum number of iterations .
Analysis Error.	Circular/ Non- Circular	Occurs for general calculation errors. Check input data.

4.2.1.2 Full Results

Detailed results are provided for the slip circle/ slip surface with the lowest factor of safety. The output provides details of the interslice and base forces in addition to the overall reporting of force and moment equilibrium.

Full output comprises the following:

Method of Analysis : See [General](#)

Number of iterations.

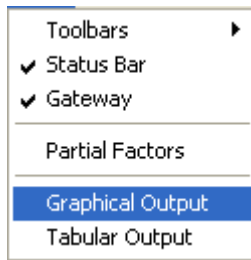
Horizontal Acceleration (%g).

Location of slip surface :	x and y co-ordinates of the center of rotation about which moment is taken.
	Radius(for circular slips).
Overall Results :	Net vertical force
Includes net vertical and horizontal forces to help provide some idea of the possible error in the calculated factor of safety.	Net horizontal force
	Slip weight
	Disturbing moment
	Restoring moment
	Factor of Safety
Slip Surface Location :	Pore water pressure u
x and y co-ordinates (m, m OD) of the base of the LEFT side of each slice are used to define the location of the slip surface.	Interslice Forces
	Vertical Shear T
	Horizontal Normal E
	Horizontal Water Pressure E(u)
Slices :	Strength Parameters
Slices are numbered from left to right.	Cohesion c' $\tan \phi'$ (degrees)
	Pore Pressure
	Slice weight
	Forces on the base
	Normal N
	Shear S
General Slice Information :	Surface Loads - Vertical and Horizontal
	Water pressure on ground surface - Vertical Horizontal

4.3 Graphical Output

Graphical output of the data and results is accessed via the View menu or the Gateway. The following provides details of the available graphics options.

File Edit **View** Data Analysis Graphics Window Help



For information on the use of the Toolbar and Status bar functions please see the Index list.

More:

[View - Data and Results](#)

4.3.1 View - Data and Results

Select View | Graphical Output to obtain a plot of the input data and results or it can be opened by clicking on the [gateway](#). If more than one slip surface has been analysed, the program defaults to show the slip circle with the lowest factor of safety.

The following graphical displays are available and can be displayed or hidden by toggling the individual icons on the graphical menu bar:



Axis : Provides a reference grid behind the drawing.



Set Scale : This allows the user to toggle between the default 'best fit' scale and the closest available engineering scale. e.g. 1:200, 1:250, 1:500, 1:1000, 1:1250, 1:2500.



Save Metafile : this save icon allows the file to be saved in the format of a Windows Metafile. This retains the viewed scale. The metafile can be imported into other programs such as word processors, spreadsheets and drawing packages.



Zoom Facility : Select an area to 'zoom in' to by using the mouse to click on a point on the drawing and then dragging the box outwards to select the area to be viewed. The program will automatically scale the new view. The original area can be restored by clicking on the 'restore zoom' icon as shown here.



Strata : Switches between showing the material layers as solid fill or as lines



Phreatic Surface : Shows the location of the phreatic surface.



View Surface loads



Surface : Shows the location of the slip surface. For circular surfaces the centre of the currently plotted circle is also highlighted.



Slices : Shows the location of the slices analysed.



Contours : Provides a contour plot of the factor of safety for the grid of slip circle centres.



Select circles for plotting

This opens a tabular view in which all analysed circles are listed in order of increasing factor of safety. Any number of circles can be selected for plotting. The circle with lowest FoS is always shown in a different colour.



Slice diagram

This button is enabled when the slices are drawn on the circle. Click this button then on the required slice. A separate view showing the forces on the slice and a force polygon will be opened, or updated if a different slice was previously shown.

Right-clicking on any force vector in the force polygon will open a dialog box showing the component of force and it's magnitude.



Add/ Edit Label

This allows entering of text labels on the view. To add a label, click the Add Label button, enter the details, then click at the required label position.

To edit or delete an existing label, click the Edit Label button, right-click near the required label, and edit the details as required.

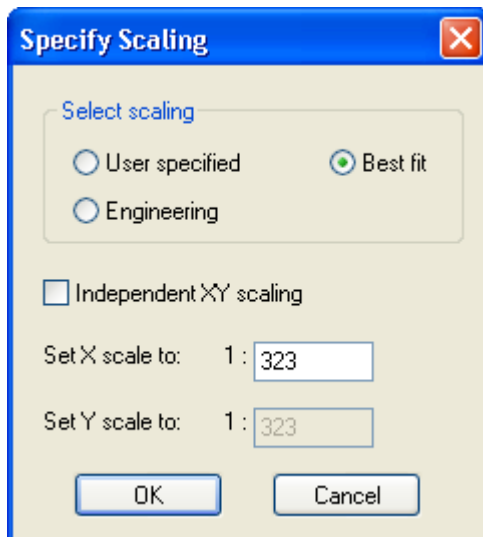
Note : To change the currently plotted circle when a grid of centres has been analysed, move the cursor into the grid (it will change to a cross-hair) and right-click on the required centre. The circle with the lowest factor of safety for that centre will be plotted.

More:

[Set Exact Scale](#)

4.3.1.1 Set Scale

Selection of Set Scale allows you to set any required scale for the graphics. This is done using the following data entry screen.



**List of
References**

Part



5 List of References

5.1 References

Bishop A W (1955). The use of the Slip Circle in the Stability Analysis of Earth Slopes. Géotechnique Vol.5 No.1 pp 7-17.

Janbu N (1957). Earth Pressures and Bearing Capacity Calculations by Generalized Procedure of Slices. Proc. 4th International Conference Soil Mech. Fdn. Engng. Vol.2 pp 207-212

Nash D (1987). A comparative review of limit equilibrium methods of stability analysis in slope stability. Anderson and Richards (eds), John Wiley & Sons.

Spencer E (1967). A Method of Analysis of Embankments ensuring Parallel Interslice Forces. Géotechnique Vol.77 pp 11.26.

Whitman R V, and Bailey W A (1967). Use of Computers for Slope Stability Analysis. International Soil Mech. Fdns. Div. Am. Soc, Civ. Engrs Vol.93 SM4 pp 475 - 498.

Manual Example

Part



6 Manual Example

6.1 General

The data input and results for the **Slope** manual example are available in the 'Samples' sub-folder of the program installation folder. The example has been created to show the data input for all aspects of the program and does not seek to provide any indication of engineering advice.

Screen captures from this example have also been used throughout this document.

This example can be used by new users to practice data entry and get used to the details of the program.

Brief Technical Description

Part

VII

7 Brief Technical Description

7.1 Slope

Slope is a program which is used for analysing the stability of slopes. The program is also applicable to earth pressure and bearing capacity problems. The methods are applicable also to rock slopes and waste heaps.

Summarised below are the main features of the program:

Analysis Methods

Swedish Circle (Fellenius)

Bishop's methods

Janbu's methods

Both **circular** and **non-circular** slip surfaces can be analysed. Circular surfaces are defined by a rectangular grid of centres and either a number of different radii, a common point through which all circles pass or a tangent surface which the circle almost touches. Non-circular slip surfaces are defined individually.

The section to be analysed is represented by a series of **soil or rock strata** with boundaries defined by cartesian co-ordinates.

The **pore water pressure distribution** can be varied in each stratum, and can be specified in any of the 3 following ways:

- Simple **hydrostatic pore pressure** distribution below a phreatic surface.
- A user-defined "**piezometric**" pore pressure distribution below a phreatic surface.
- An overall **Ru value**.

In addition a maximum pore pressure suction in a soil can be specified.

Submerged or partially submerged slopes can be analysed.

Soil strengths may be represented by specifying:

- Cohesion (c) and/or angle of shearing resistance (ϕ).
- Linear variations of cohesion with depth and/or overburden pressure.

Horizontal acceleration of the slip mass (to model earthquake loading) can be included.

External loads (e.g. due to buildings or strut forces in excavations) can be applied to the surface.

The computed **factor of safety** can refer either to the soil strength ($c + \sigma_n' \tan \phi$, where σ_n' is the effective normal stress) along the slip surface or to the magnitude of the applied loads. The loads can be specified to be causing the failure in the case of bearing capacity problems or to be preventing the failure as in the case of anchor forces.

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