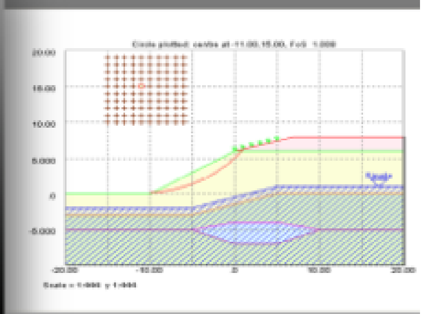
Oasys

The software house of Arup

Slope Tutorial Manual



Oasys Slope

Printed: August 2013

Contents

1. Introduction

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, as well as to rock slopes and waste heaps.

The program offers a variety of established methods for calculating interslice forces. Choose from Fellenius or Swedish slip circle analysis, the Bishop horizontal method or the constant inclined method. For non-circular slip surfaces, the software offers you the equivalent Janbu methods. Slope also includes a variably inclined interslice force method which ensures that each slice is in equilibrium, both vertically and horizontally. Slope allows the user to apply partial factors, including Eurocode 7, to run Ultimate Limit State (ULS) analysis.

The software analyses reinforcing elements such as soil nails, rock bolts, ground anchors and geotextiles to BS8007/BS8081. The user can specify water pressure, material shear strength, surface loads and horizontal ground acceleration. Slope checks a range of slip circles and gives the user the option to force slips through a point or keep them tangential to a strata.

The calculation itself is based on verified and robust numerical methods. The simplicity of calculation enables new users to set up and run a slope stability problem within hours of training.

The tutorial examples deal with a simple slope stability analyses, but this Tutorial Manual is intended to familiarise the user with Slope. The examples should therefore not be used as a basis for practical projects.

Users are expected to have an understanding of soil mechanics and geotechnical theory, and should be able to work in a Windows environment. The tutorial lessons are also available in the examples folder and can be used to check you results.

It is important to realise that Slope is an advanced program analysing a complex problem and the user must be fully aware of the various methods of analysis, requirements and limitations discussed in the User Manual before use. The Tutorial Manual will not provide theoretical background information on the analysis method, nor does it explain the details of various methods of analysis available in the program. These details can be found in the User Manual for Slope. This also contains detailed information on the available program features. Short courses are also regularly organised and should you be interested in more hands-on experience you can contact oasys@arup.com for dates and program content.

2. Slope analysis methods

Slope offers the following analysis methods:

- Swedish Circle (Fellenius)
- Bishop's methods
- Janbu's methods (for non-circular slip surfaces)

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 User Manual.

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. Slope allows the user to import dxf drawings to specify layers.

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 Ru.

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** .

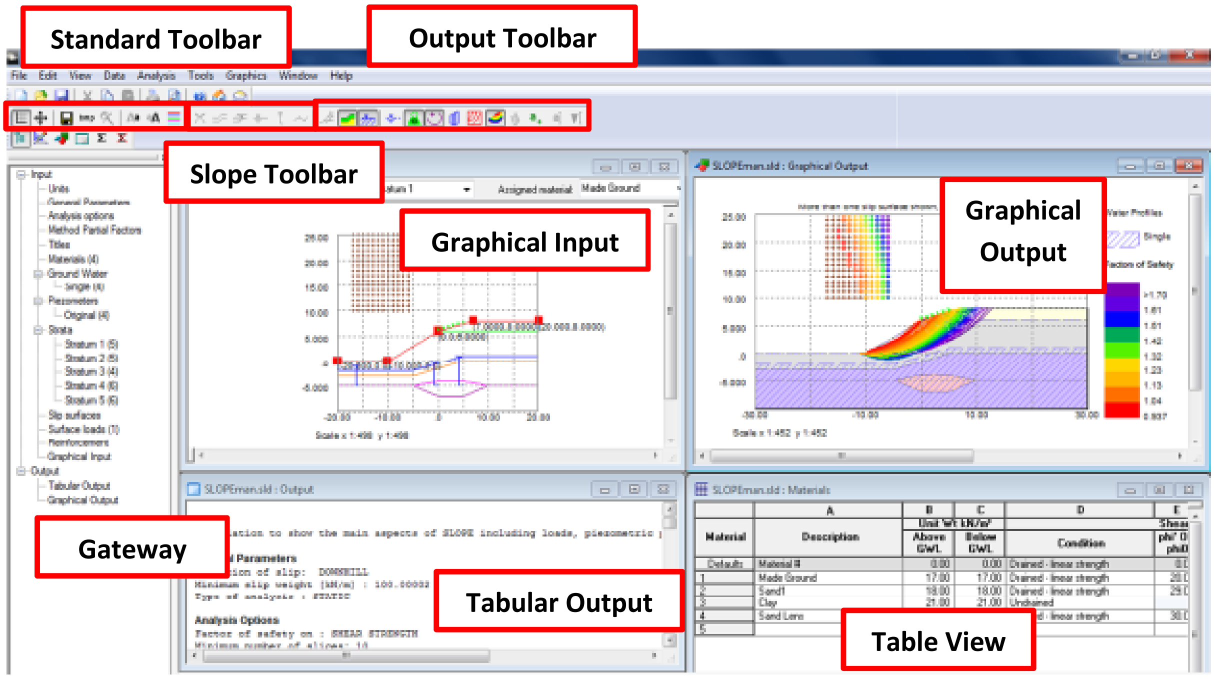
The calculated factor of safety can be applied to soil strength or the magnitude of the applied loads, by either

a) causing failure - to represent bearing capacity problems, or
b) preventing failure - for anchor forces.

Over-Design Factor can be calculated for an ultimate limit state factor set using Partial Factor Analysis.

3. Slope User Interface

The principal components of the user interface are illustrated below and these will be referred to in the tutorial manual.



4. Simple Slope Analysis

To cover the features available, the stability of a slope with varied stratigraphy and water table and will be covered in this tutorial. This serves as a quick introduction to the Slope program.

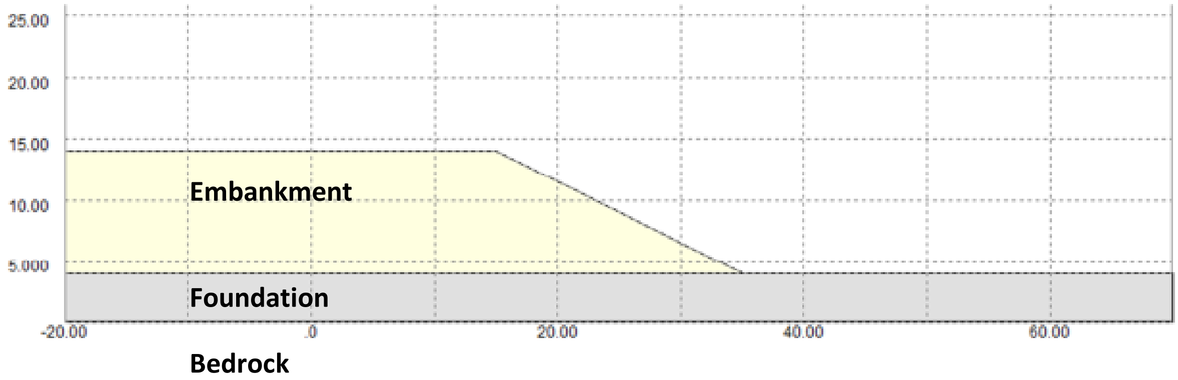
Objectives

- Start a new project
- Create soil stratigraphy and input material properties using the *Model Wizard* feature
- Use the *Graphical Input* interface
- Apply water data and surcharges
- View calculation results
- Export tabular outputs
- Print and adapt graphical outputs

4.1 Geometry and Input Values

For a design problem, the site investigation data and testing should be used to determine the stratigraphy data and the material properties.

For this slope stability analysis, the following geometry will need to be plotted.



Material Properties

Description	Unit Weight (kN/m2)		Condition	Phi (deg)	Cohesion c' (kN/m2)
	Above GWL	Below GWL			
Embankment Soil	15	19.5	Drained - linear strength	20	5
Foundation Soil	18	21.5	Drained - linear strength	25	10
Bedrock	22	24	Drained - linear strength	40	15

Strata Co-ordinates

Embankment

x	y
0	14
15	14
35	4
50	4

Foundation

x	y
0	4
35	4
50	4

Bedrock

x	y
0	0
50	0

Groundwater Profiles

Original

x	y
0	11
15	10
35	3
50	3

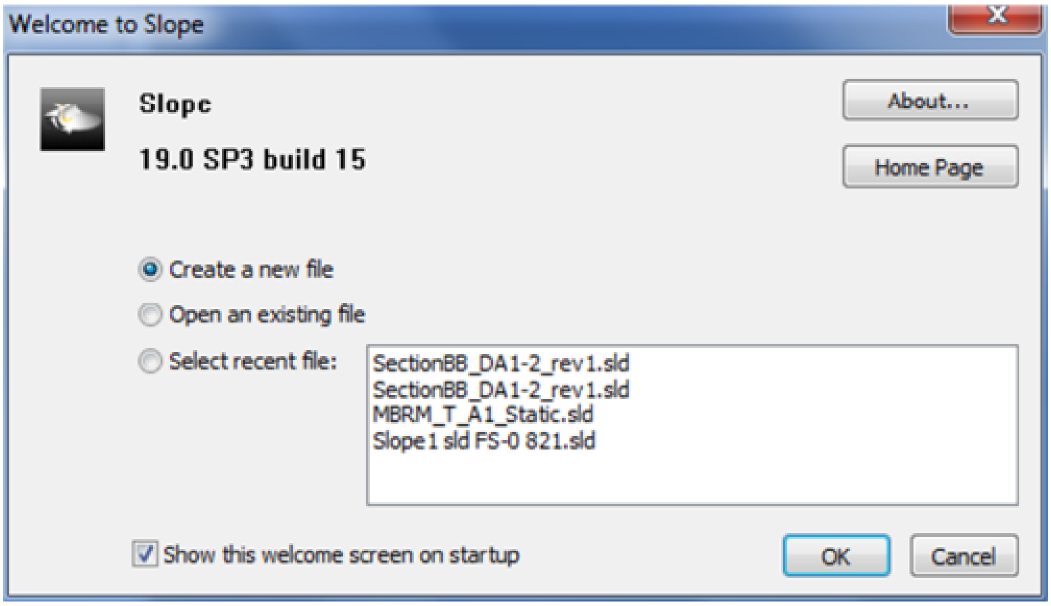
Raised

x	y
0	14
15	14
35	4
50	4

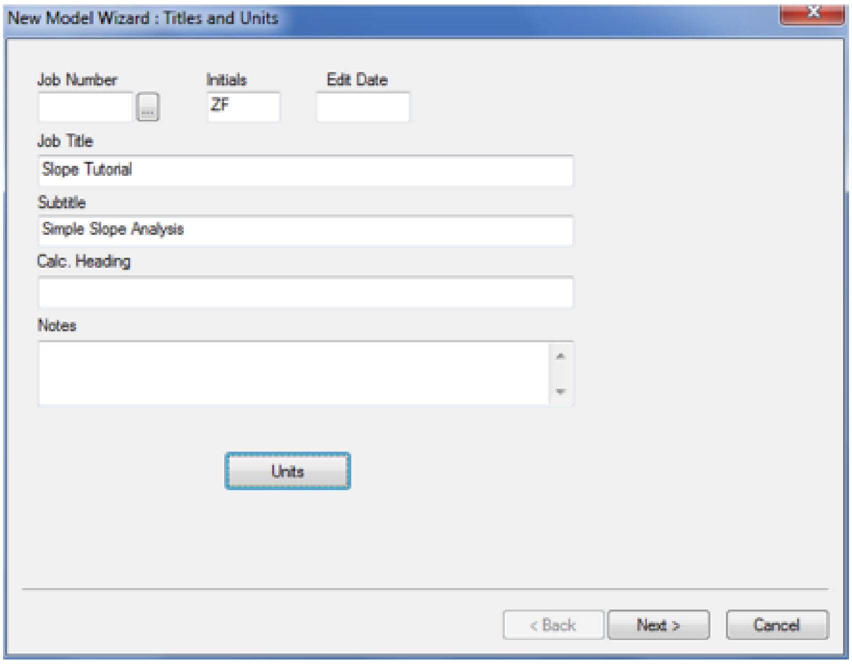
4.2 Creating the Input

1. Open the Oasys Slope Program.

2. In the Welcome Screen, select *Create a new file*



3. The Input Wizard will open. In the Titles and Units box, fill in the information about the analysis.
   Click on *Next*.

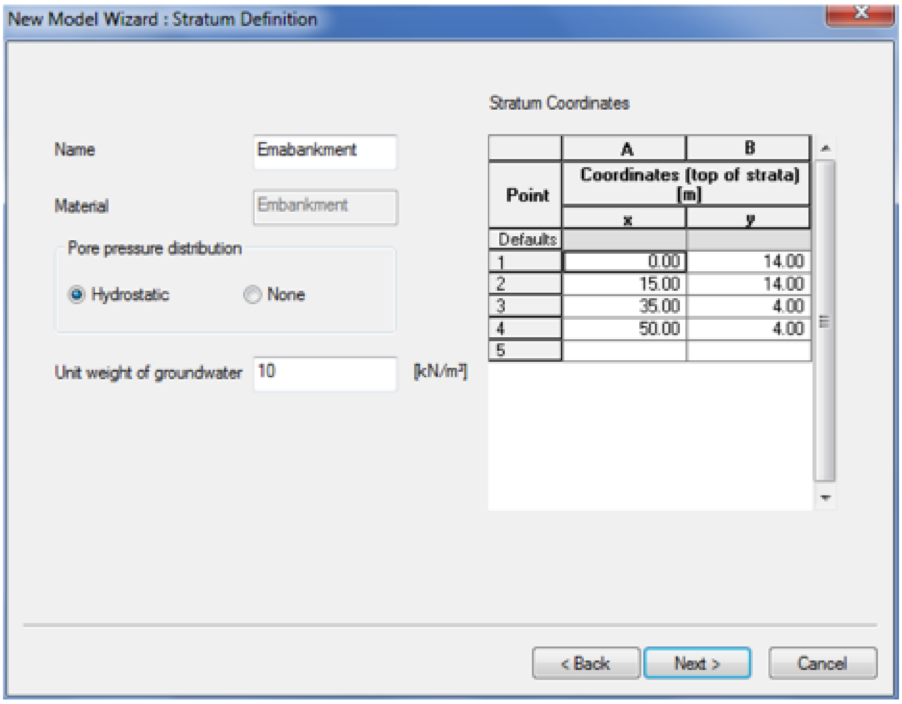


(Hint: Choosing Units allows you to change the units from the standard SI option)

4. In the **Material** section of the Wizard, enter the Embankment material values given in Section 4.1.

5. In the **Stratum Definition** section of the Wizard, enter the co-ordinates for the Embankments given in Section 4.1.

   Select a Hydrostatic pore pressure distribution with the Unit weight of groundwater equal to 10 kN/m³.



6. In the **Groundwater Co-ordinates** section of the Wizard, enter the co-ordinates of the Original groundwater profile given in Section 4.1.

   (Note: Should the user wish to compare the impact of different groundwater profiles, they can add water profiles in the Ground Water section of the Gateway, once they have exited the wizard, and apply this in the Strata section).

7. In the **Slip Surface Definition** section of the Wizard, choose a Grid with centre (25, 15) with an angle of rotation at -20 degrees. This information is entered into the *Circle Centre Specification* section.

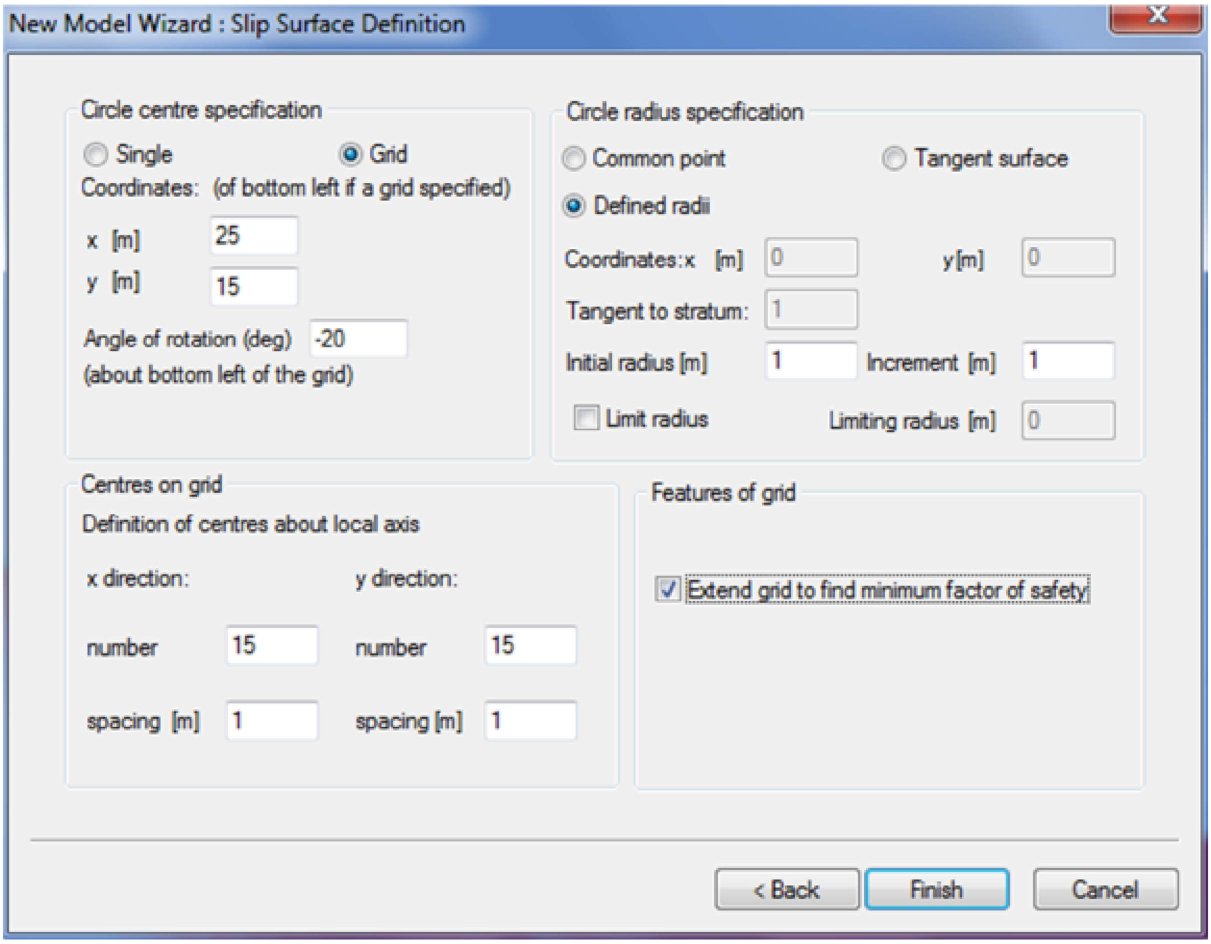
   In the *Centres on Grid* section, the Grid should have 15 points at 1m distance. These points represent centres at which slip circles would be calculated.

   (Hint: Choosing a finer grid gives more accurate Over Design Factors. However, the Slope analysis will take longer to carry out as more calculation points have been chosen.
   The user would be advised to refine the grid around the worst case slip circle centre after the initial analysis has been carried out.)

For the Circle Radius Specification, choose the Defined radii method with an initial radius of 1m and an increment of 1m.

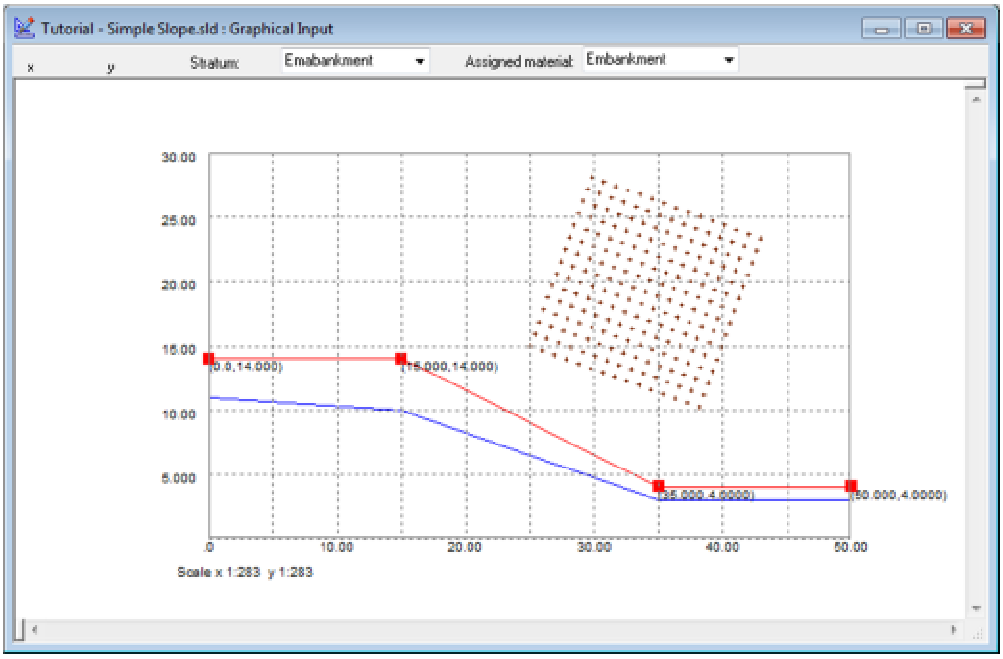
(Note: For a discussion of the different methods, please refer to the User Manual, Section 4.3.10.)

Check Extend Grid to find minimum factor of safety. This will enlarge the grid if the minimum factor of safety is outside the specified grid.



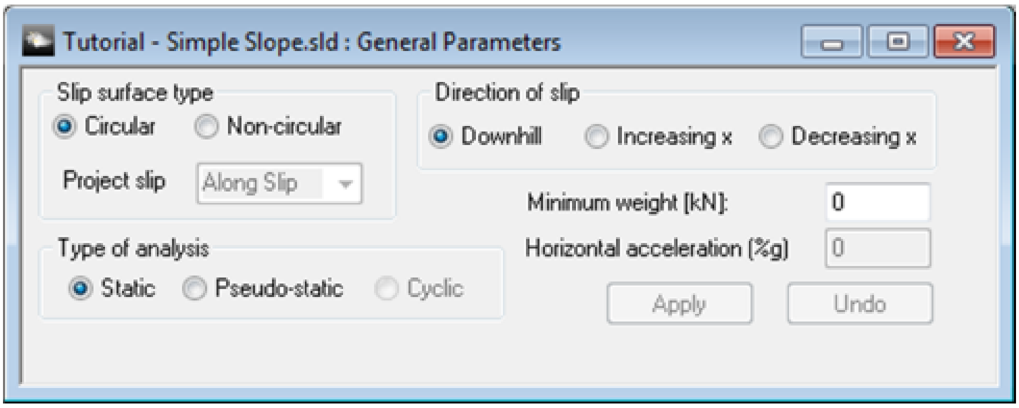
Now select **Finish**.

8. The Graphical Input Screen should show the following:



If the Strata, Groundwater or Grid are showing incorrectly, the user can amend these through the Gateway with the correct values.

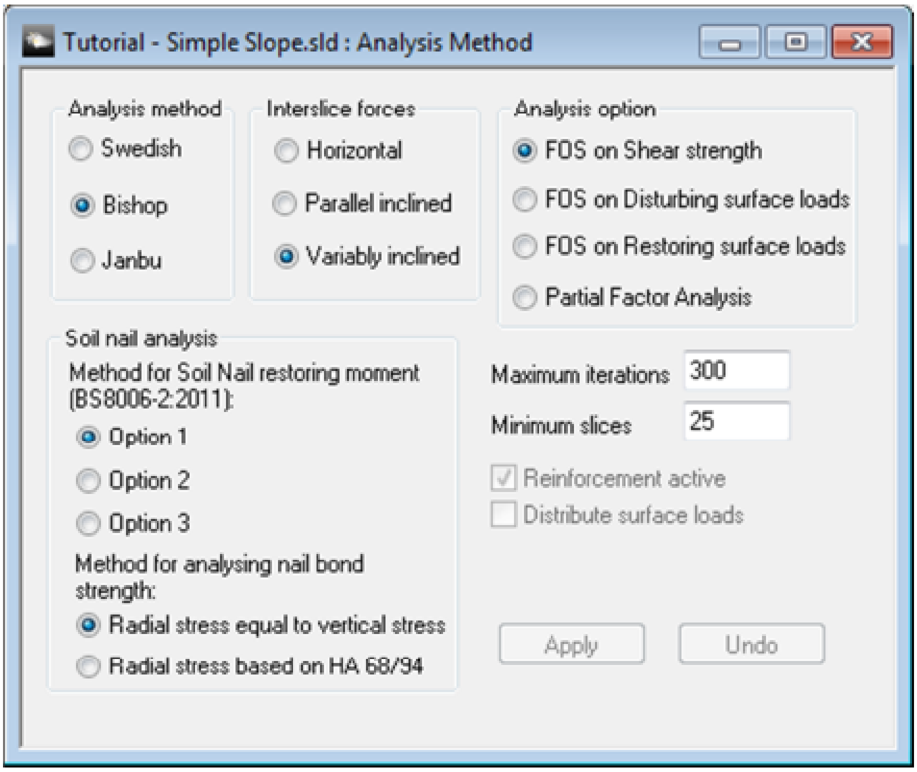
9. Double click on **General Parameters** in the Gateway.
   The default options of a static analysis of a circular slip surface should be selected.



(Note: Should the user wish to carry out Pseudo-static analysis or analyse a Non-circular slip surface, guidance is given in the Slope User Manual)

10. Double click on **Analysis options** in the Gateway.

    The default options of a Bishops analysis using variably inclined interslice forces should be selected.

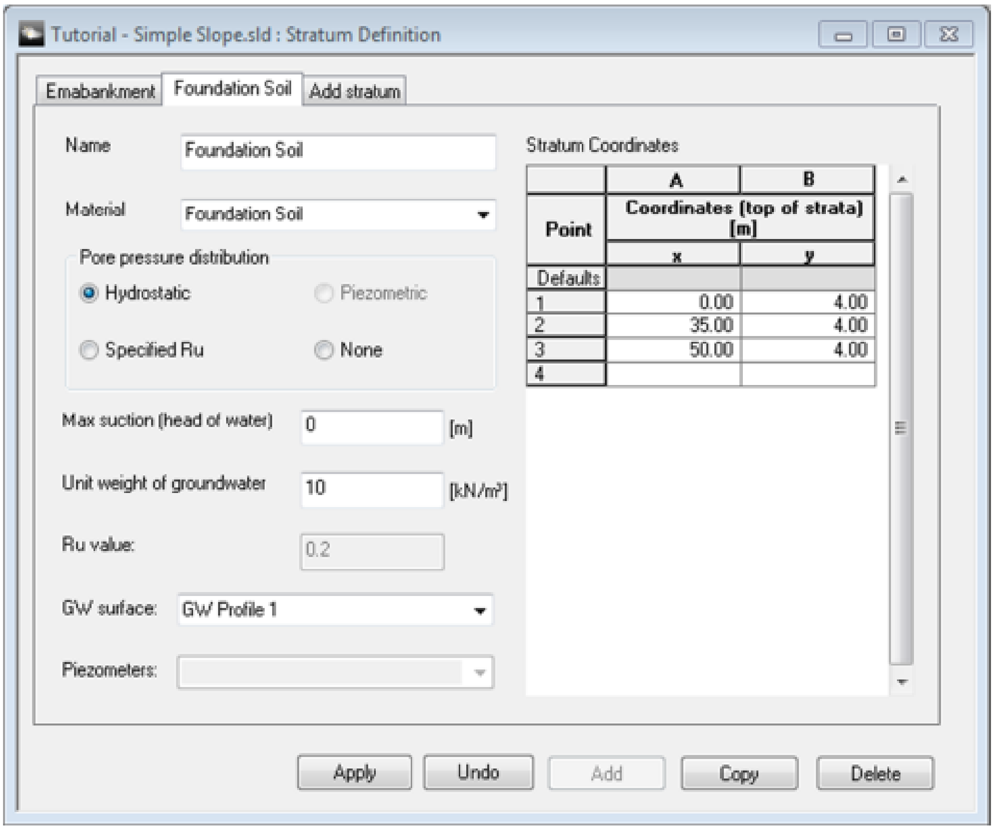


(Note: . The user can familiarise themselves with the different methods by reading Section 3 of the User Manual)

11. Double click on **Materials** in the Gateway Inputs.
    Enter the material properties for Foundation Soil and Bedrock (given in section 4.1).

12. Double click on Embankment in the **Strata** section of the Gateway Inputs.

    Click on the *Add stratum* tab at the top of the window.
    Enter the Foundation strata co-ordinates given in Section 4.1.
    Click on Apply when complete.

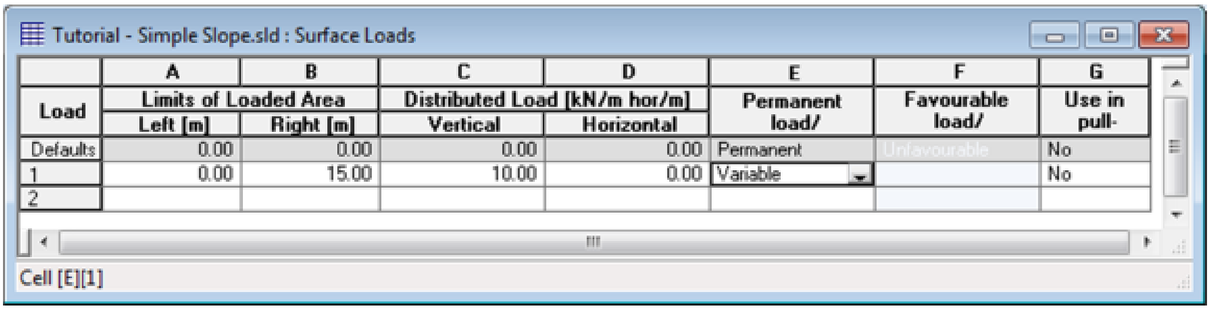


Now repeat to enter the Bedrock strata details.

13. Double click on **Surface Loads** in the Gateway.

Enter a vertical live load of 10 kN/m per horizontal m.
This load should act between (0,14) and (15,14) along the crest of the slope.

(Note: A default of No is selected for the Use in-pull column. This excludes the surcharge in the In-pull calculation for reinforcement. Section 3.6 of the User Manual gives more details about this calculation.)

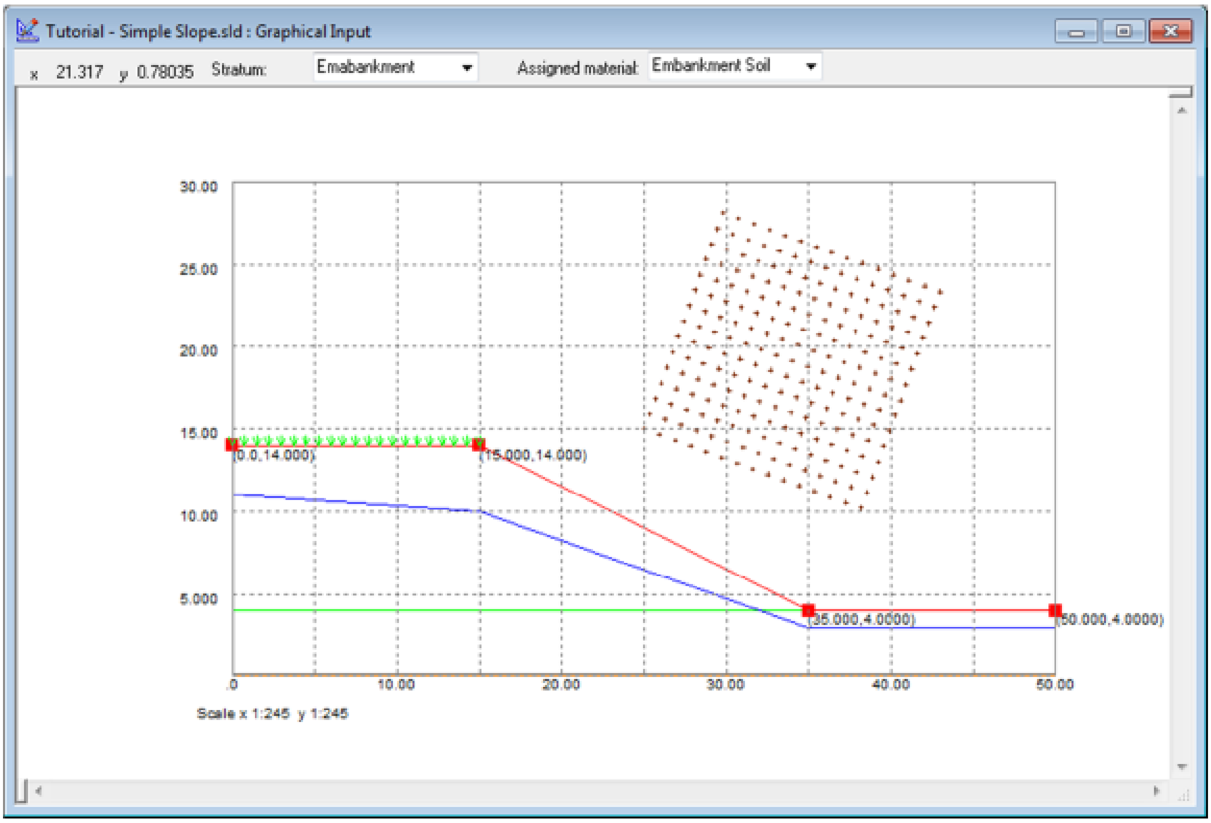


Tutorial - Simple Slope.sld : Surface Loads

	A	B	C	D	E	F	G
Load	Limits of Loaded Area		Distributed Load [kN/m hor/m]		Permanent load/	Favourable load/	Use in pull-
	Left [m]	Right [m]	Vertical	Horizontal			
Defaults	0.00	0.00	0.00	0.00	Permanent	Unfavourable	No
1	0.00	15.00	10.00	0.00	Variable		No
2							

Cell [E][1]

14. Check the **Graphical Input**. This should show the added strata and the surcharge.



15. Save the file prior to analysis by selecting **File > Save**.
    Save the file as Simple Slope.sld

Σ Click on the analyse button to carry out the Slope Stability Analysis.

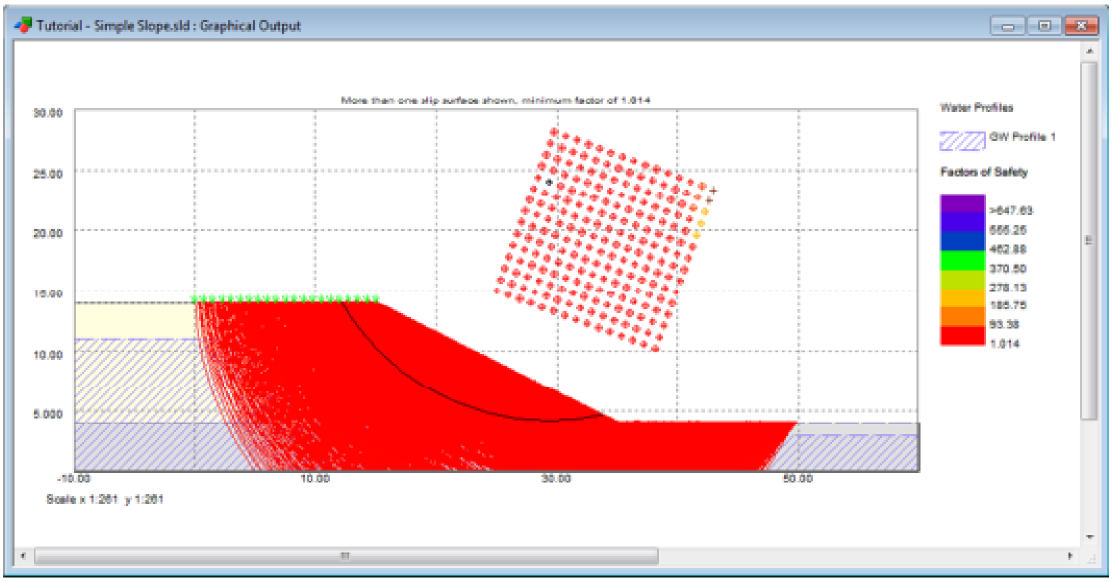
4.3 Viewing the Results

4.3.1 Graphical Output

Viewing a number of Slip Circles

1. On completion of the analysis, the Graphical Output window will show.

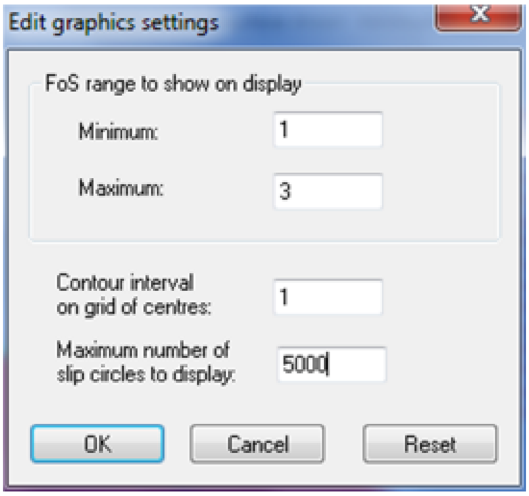
   This shows the minimum factor of safety and the worst case slip circle.



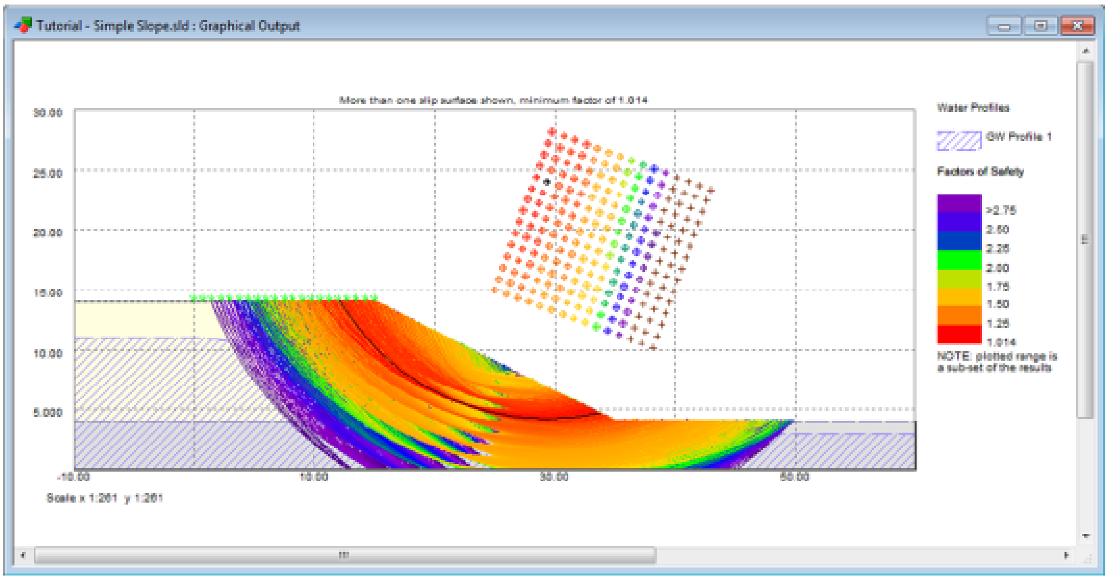
It also shows the range of slip circles around the worst case slip circle.

A large range of Factors are shown.
To view a more realistic range, select **Graphics > Graphical Output > Display Settings**

Select a Maximum FOS of 3.



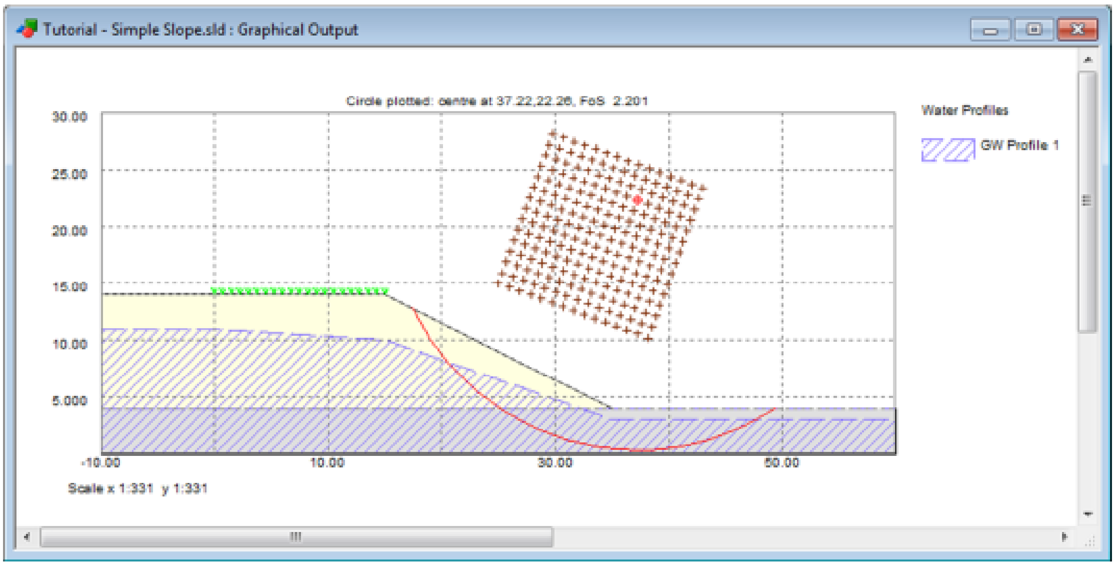
A more realistic range will now show:

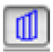


Viewing a Single Slip Circle

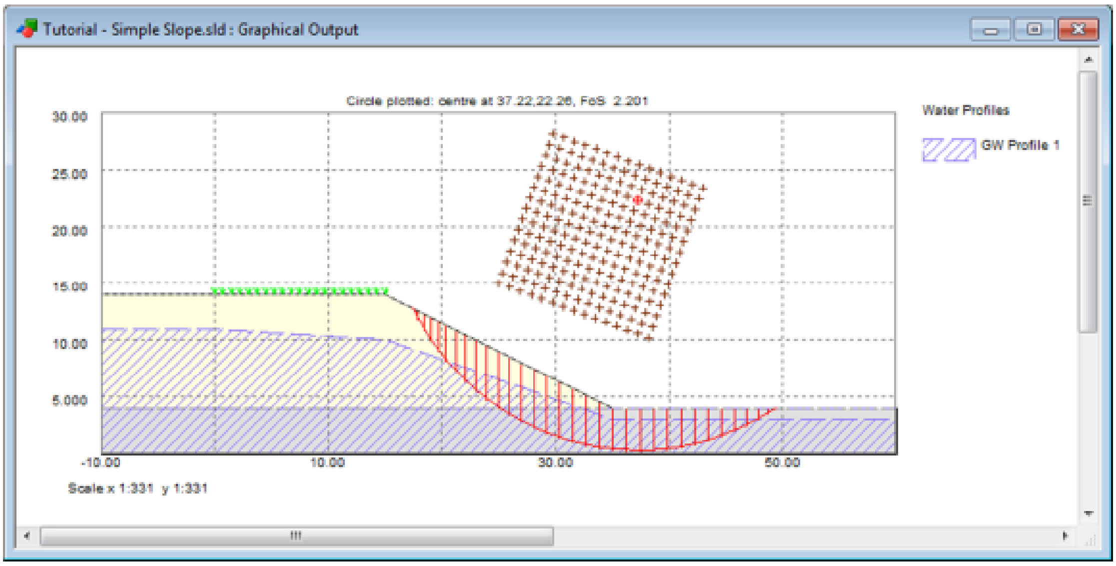
To view the worst case slip circle, switch off the *Plot all circles* icon.

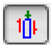
1. Right click on the circles in the grid to view Factors of Safety for different circles.



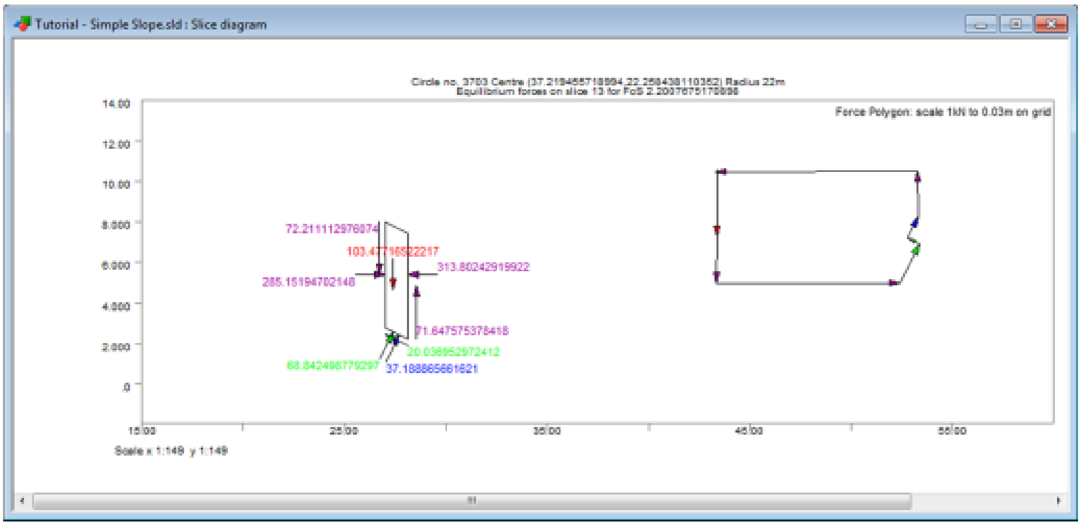


Click on the *Slices* icon to view the slices analysed for the specific Slip Circle.





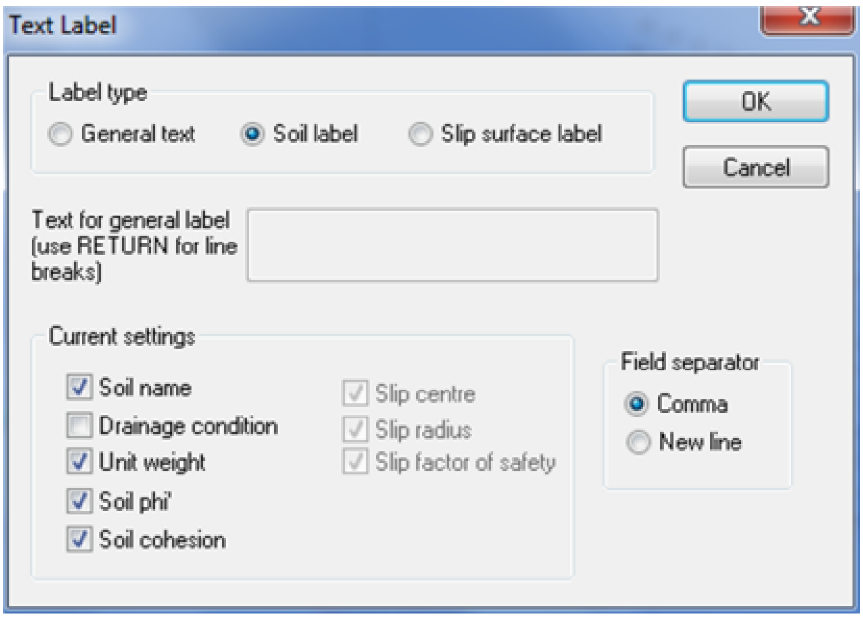
To view the slice diagram for a particular slice within the interslice analysis, click on the *Slice Diagram* icon. Then click on a slice of interest in the Graphical Output screen.



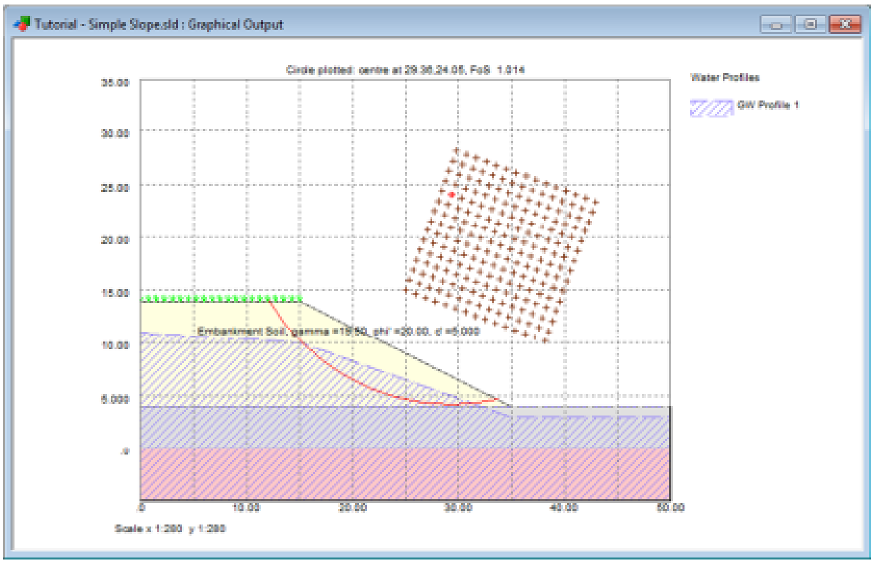
Annotating and Printing Graphical Outputs

1. Close the Graphical Output box to delete all the changes to the users selection of slip circle. Reopen to show the worst case slip circle.

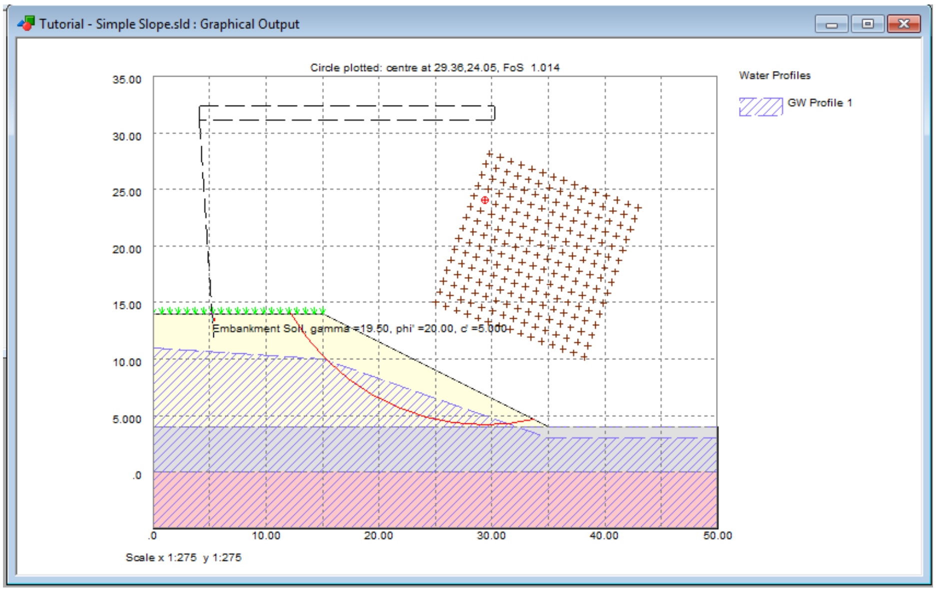
Click on the *New Label* icon.
In the Text Label Box choose to label the Soil label and check the soil name and properties boxes.
Click the OK button.



Now click on the embankment strata.



Click on the *Edit Label* icon. Position the cursor near the red spot shown on the top left of the label.
Click and drag the label to a more suitable position.



2. Select **File > Print Preview** to view the final output.

The user will note their inputs in the Titles section of the Gateway show in the printout.

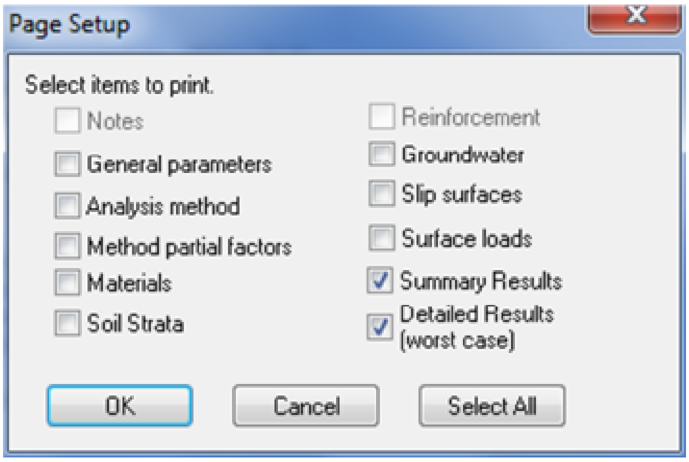
Should the user wish to change any information regarding the analysis, they can do so by changing the inputs in the **Title** section of the Gateway.

(Hint: The user can change the company information by selecting **Tools > Preferences**)

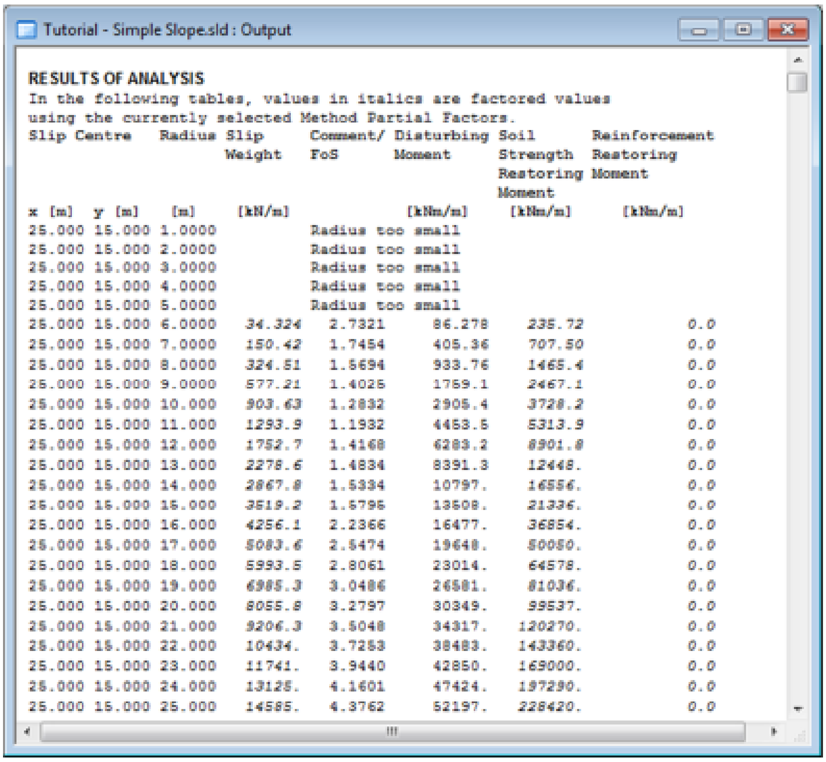
4.3.1 Tabular Output

1. Double click on **Tabular Output** in the Gateway

2. Select to view the Summary Results and Detailed Results (Worst Case)



3. View the results for each slip centre:

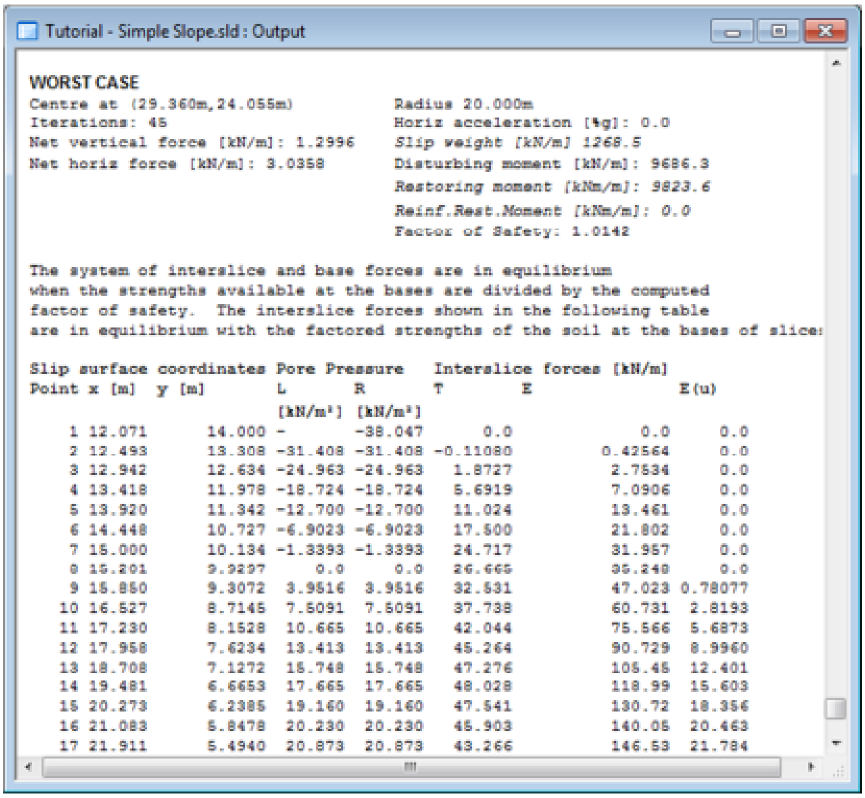

Tutorial - Simple Slope.sld : Output

RESULTS OF ANALYSIS
In the following tables, values in italics are factored values using the currently selected Method Partial Factors.

Slip Centre x [m]	y [m]	Radius [m]	Slip Weight [kN/m]	Comment/ FoS	Disturbing Moment [kNm/m]	Soil Strength Restoring Moment [kNm/m]	Reinforcement Restoring Moment [kNm/m]
25.000	15.000	1.0000		Radius too small			
25.000	15.000	2.0000		Radius too small			
25.000	15.000	3.0000		Radius too small			
25.000	15.000	4.0000		Radius too small			
25.000	15.000	5.0000		Radius too small			
25.000	15.000	6.0000	*34.324*	2.7321	86.278	*235.72*	*0.0*
25.000	15.000	7.0000	*150.42*	1.7454	405.36	*707.50*	*0.0*
25.000	15.000	8.0000	*324.51*	1.5694	933.76	*1465.4*	*0.0*
25.000	15.000	9.0000	*577.21*	1.4025	1759.1	*2467.1*	*0.0*
25.000	15.000	10.000	*903.63*	1.2832	2905.4	*3728.2*	*0.0*
25.000	15.000	11.000	*1293.9*	1.1932	4453.5	*5313.9*	*0.0*
25.000	15.000	12.000	*1752.7*	1.4168	6283.2	*8901.8*	*0.0*
25.000	15.000	13.000	*2278.6*	1.4834	8391.3	*12448.*	*0.0*
25.000	15.000	14.000	*2867.8*	1.5334	10797.	*16556.*	*0.0*
25.000	15.000	15.000	*3519.2*	1.5796	13508.	*21336.*	*0.0*
25.000	15.000	16.000	*4256.1*	2.2366	16477.	*36854.*	*0.0*
25.000	15.000	17.000	*5083.6*	2.5474	19648.	*50050.*	*0.0*
25.000	15.000	18.000	*5993.5*	2.8061	23014.	*64578.*	*0.0*
25.000	15.000	19.000	*6985.3*	3.0486	26581.	*81036.*	*0.0*
25.000	15.000	20.000	*8055.8*	3.2797	30349.	*99537.*	*0.0*
25.000	15.000	21.000	*9206.3*	3.5048	34317.	*120270.*	*0.0*
25.000	15.000	22.000	*10434.*	3.7253	38483.	*143360.*	*0.0*
25.000	15.000	23.000	*11741.*	3.9440	42850.	*169000.*	*0.0*
25.000	15.000	24.000	*13125.*	4.1601	47424.	*197290.*	*0.0*
25.000	15.000	25.000	*14585.*	4.3762	52197.	*228420.*	*0.0*

(Hint: Review Section 5.2.1 of the User Manual to view the definition of the Column Headings and the definition of any error messages, such as the "Radius too small" shown.)

4. Scroll down to view the detailed results for the worst case slip:



Tutorial - Simple Slope.sld : Output

WORST CASE

```
Centre at (29.360m,24.055m)            Radius 20.000m
Iterations: 45                         Horiz acceleration [%g]: 0.0
Net vertical force [kN/m]: 1.2996      Slip weight [kN/m] 1268.5
Net horiz force [kN/m]: 3.0358         Disturbing moment [kN/m]: 9686.3
                                       Restoring moment [kNm/m]: 9823.6
                                       Reinf.Rest.Moment [kNm/m]: 0.0
                                       Factor of Safety: 1.0142

The system of interslice and base forces are in equilibrium
when the strengths available at the bases are divided by the computed
factor of safety.  The interslice forces shown in the following table
are in equilibrium with the factored strengths of the soil at the bases of slice:
```

Slip surface coordinates			Pore Pressure		Interslice forces [kN/m]		
Point	x [m]	y [m]	L [kN/m²]	R [kN/m²]	T	E	E(u)
1	12.071	14.000	-	-38.047	0.0	0.0	0.0
2	12.493	13.308	-31.408	-31.408	-0.11080	0.42564	0.0
3	12.942	12.634	-24.963	-24.963	1.8727	2.7534	0.0
4	13.418	11.978	-18.724	-18.724	5.6919	7.0906	0.0
5	13.920	11.342	-12.700	-12.700	11.024	13.461	0.0
6	14.448	10.727	-6.9023	-6.9023	17.500	21.802	0.0
7	15.000	10.134	-1.3393	-1.3393	24.717	31.957	0.0
8	15.201	9.9297	0.0	0.0	26.665	35.240	0.0
9	15.850	9.3072	3.9516	3.9516	32.531	47.023	0.78077
10	16.527	8.7145	7.5091	7.5091	37.738	60.731	2.8193
11	17.230	8.1528	10.665	10.665	42.044	75.566	5.6873
12	17.958	7.6234	13.413	13.413	45.264	90.729	8.9960
13	18.708	7.1272	15.748	15.748	47.276	105.45	12.401
14	19.481	6.6653	17.665	17.665	48.028	118.99	15.603
15	20.273	6.2385	19.160	19.160	47.541	130.72	18.356
16	21.083	5.8478	20.230	20.230	45.903	140.05	20.463
17	21.911	5.4940	20.873	20.873	43.266	146.53	21.784

5. Select **File>Export**. Save the file with a .csv extension to open the results in Excel. This will allow the Engineer to further analyse the results.

4.4 Test Yourself

Using the process outlined in the previous sections, apply the Raised Groundwater Profile outlined in Section 4.1.

Compare the impact of the new groundwater profile on the factor of safety.

Print out your new results.

(Hint: Remember to change the Titles section to give appropriate headings and save this file under a different name)

5. Partial Factor Analysis and Reinforcement Design

Following setting up a Slope Stability analysis, the user may wish to carry out an Ultimate Limit State (ULS) analysis. To follow the design process, this tutorial will show the user how to apply EC7 partial factors to the analysis set up in Section 4 The user will then be guided through reinforcement design to obtain an appropriate slope design.

Objectives

- Apply partial factors
- Apply reinforcements

5.1 Partial Factor Analysis

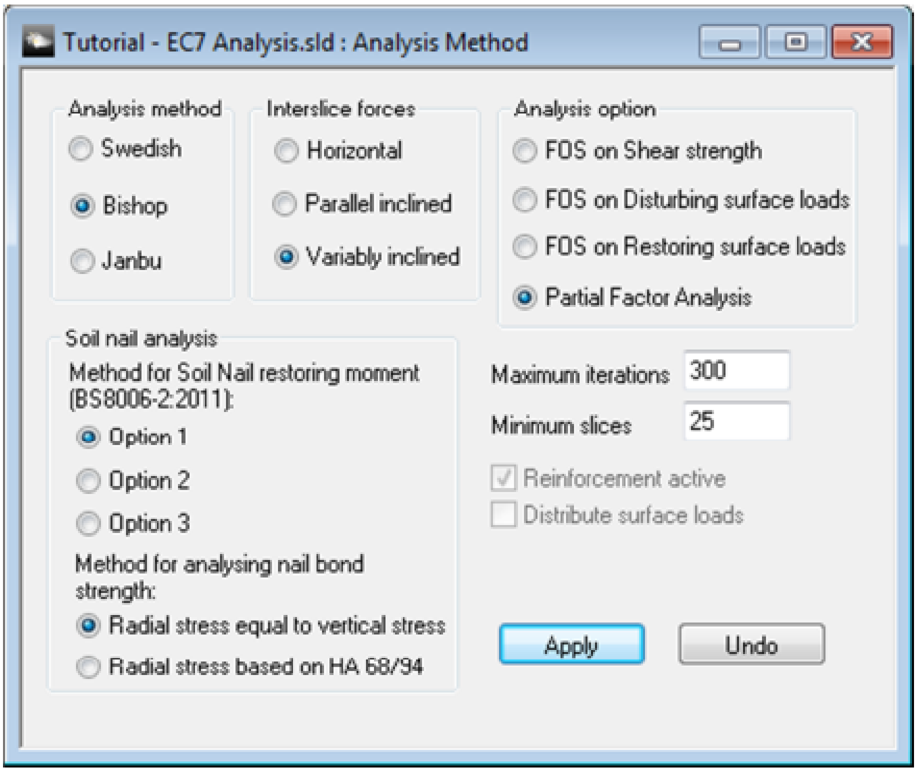
1. Open the file created in the previous section with the Original Groundwater Profile (Simple Slope.sld)

2. Save as EC7 Analysis.sld

3. Amend the **Titles** section to show that this file is carrying out a factored analysis

4. Double click on **Analysis method** in the Gateway.

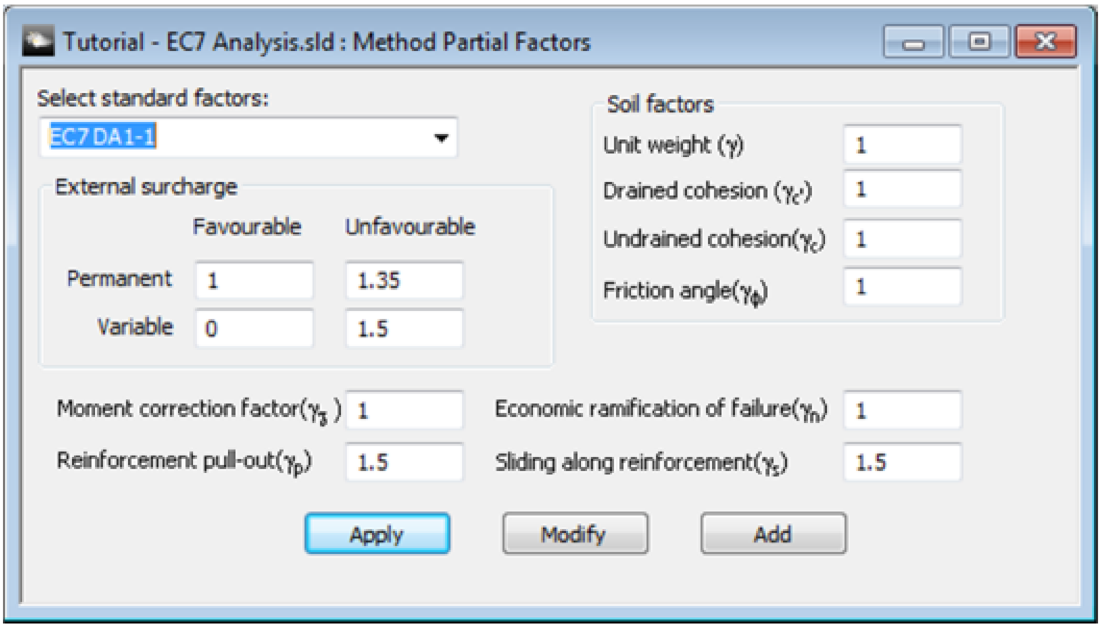
   Select Partial Factor Analysis in the Analysis option section.
   Click on Apply



5. Double click on **Method Partial Factors** in the Gateway.

   Select EC7 DA1-1 to select Eurocode 7 Partial Factors for Design Approach 1, Combination 1.

   Click Apply.



   It can be seen that this primarily factors actions (i.e . surcharges and reinforcement).

   (Hint: To better understand the Eurocode 7 design approach, the user can download information from the Oasys Eurocode 7 seminar (https://www.oasys-software.com/index.php/webinars/webinar/ec7_and_geotechnical_analysis/) or review the Eurocode 7 design code.)

6. Prior to analysing, save the analysis file.

Σ Click on the *Analyse* icon to carry out the Slope Stability Analysis.

7. View the overdesign factor.
   Print the output showing the worst case slip circle.

 Click on the *Delete Analysis* icon.

8. Apply EC7 DA1-2 in the **Method Partial Factors** input.

9. Re-analyse and compare the overdesign factor for the worst case slip for Design Approach 1, Combinations 1 and 2.

   The results for Combination 2 demonstrate the Slope is failing in the Ultimate Limit State.

   Save this analysis.

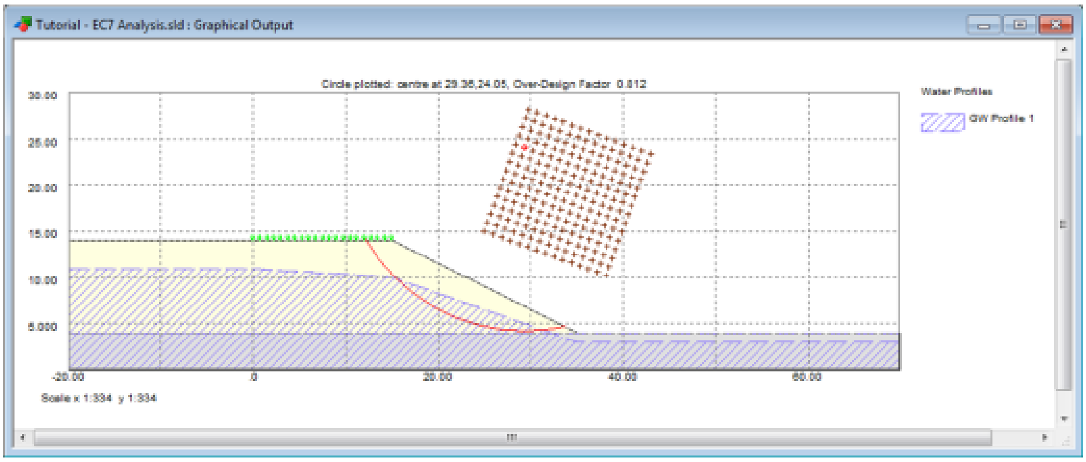
   (Note: The user should find that Combination 2 gives a lower overdesign factor. This is as expected, as Combination 2 generally factors materials. However, if reinforcement is added or extra surcharges are applied, Combination 1 may become more critical as this generally factors actions.)

5.2 Reinforcement Design

Based on the results in the Eurocode 7 analysis in Section 5.1, the user may wish to look into amending the slope or designing reinforcement. This section looks into designing reinforcement to increase the overdesign factor above 1.

1. Open the file created in the previous section (EC7 Analysis.sld)

2. Double click on the **Graphical Output** in the Gateway.
   The Ultimate Limit State analysis shows an Over design factor below 1.



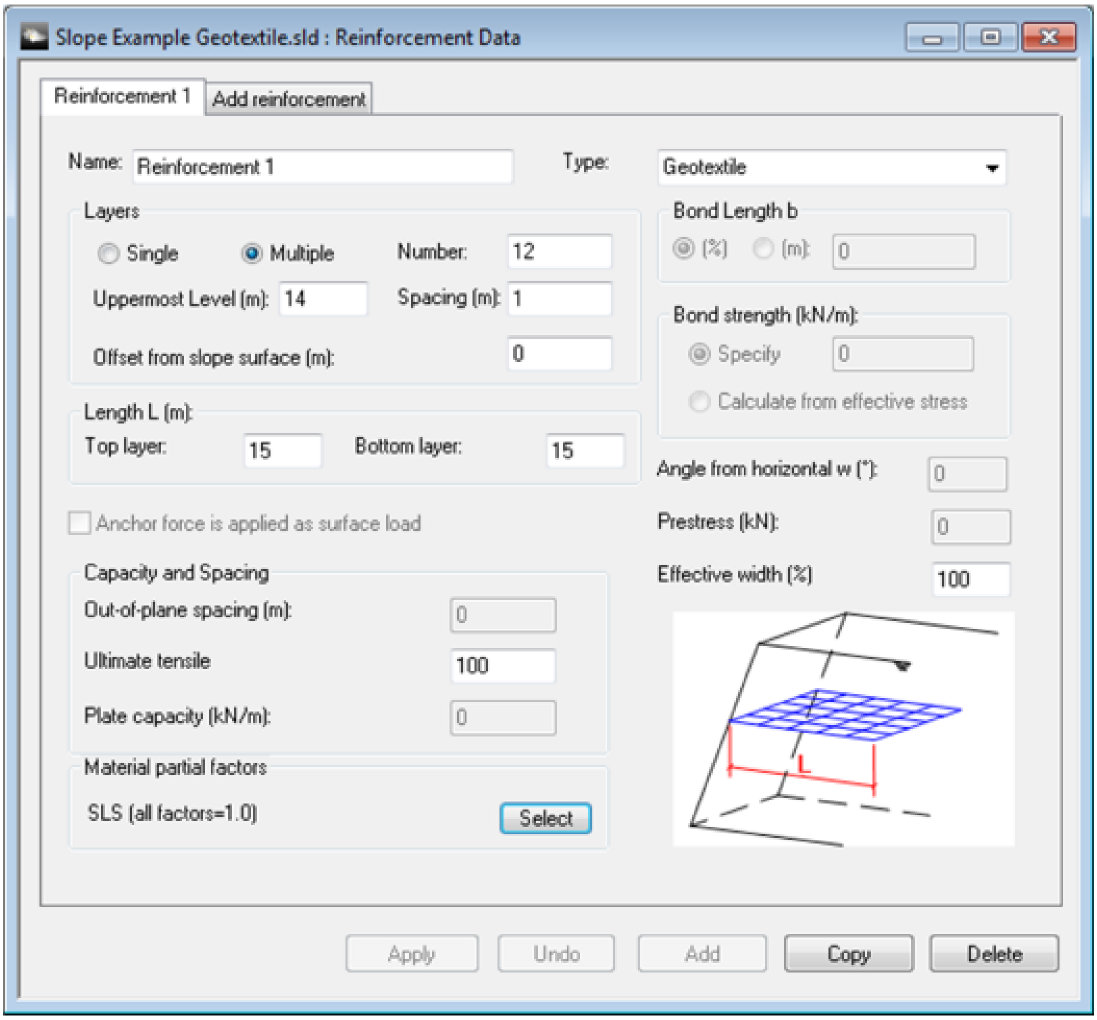
3. Double click on **Reinforcement** in the Gateway.

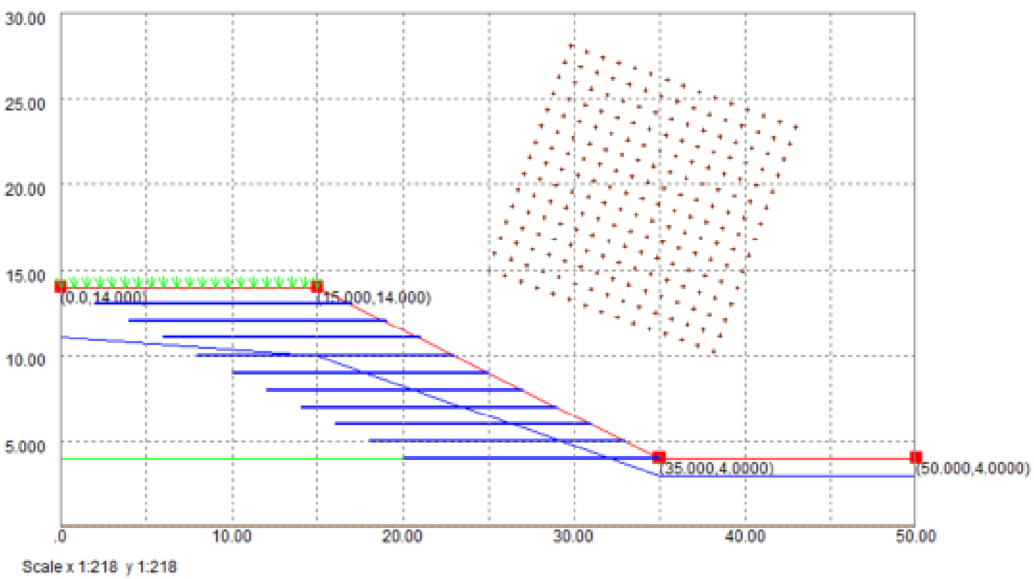
   Input data for a Geotextiles from the crest to the base of the slope with an Ultimate Capacity of 100kN.

   An example input is shown on the following page.

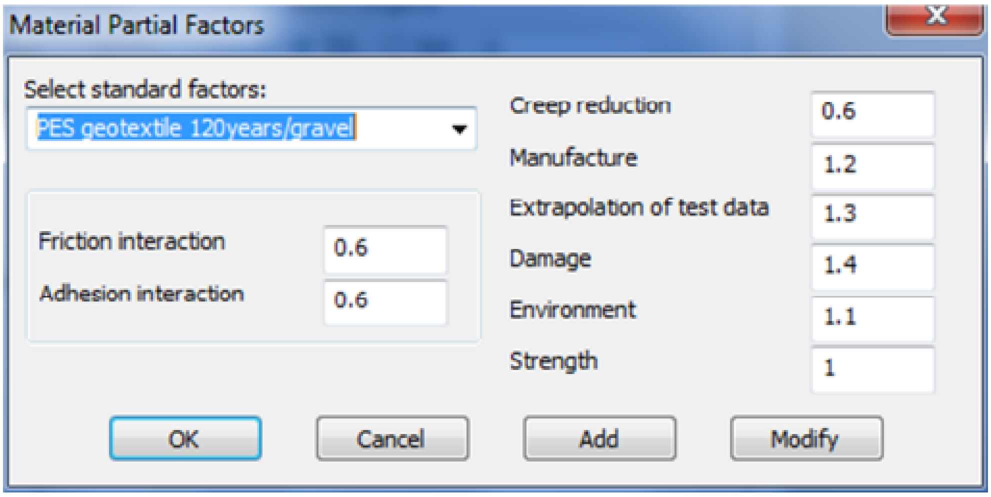
   Analyse and print the output with the new Overdesign Factor.

   Is the slope with new reinforcement design acceptable?


Slope Example Geotextile.sld : Reinforcement Data
Reinforcement 1
Add reinforcement
Name: Reinforcement 1
Type: Geotextile
Layers
Single
Multiple
Number: 12
Uppermost Level (m): 14
Spacing (m): 1
Offset from slope surface (m): 0
Length L (m):
Top layer: 15
Bottom layer: 15
Anchor force is applied as surface load
Capacity and Spacing
Out-of-plane spacing (m): 0
Ultimate tensile 100
Plate capacity (kN/m): 0
Material partial factors
SLS (all factors=1.0)
Select
Bond Length b
(%)
(m): 0
Bond strength (kN/m):
Specify 0
Calculate from effective stress
Angle from horizontal w (°): 0
Prestress (kN): 0
Effective width (%) 100
L
Apply
Undo
Add
Copy
Delete


30.00
25.00
20.00
15.00
10.00
5.000
0
10.00
20.00
30.00
40.00
50.00
(0.0,14.000)
(15.000,14.000)
(35.000,4.0000)
(50.000,4.0000)
Scale x 1:218 y 1:218

4. In the Reinforcement Section of the Gateway, click on the Select button in the Materials Partial Factors section.



This section has a number of predefined partial factors for reinforcement.

Select *PES geotextile 120year/gravel* and click OK.

(Note: The user can click on **View>Partial Factors** to view the Partial Factor and Material Partial Factors available. These can be amended by the user and will be saved for future analyses.)

5. Reanalyse and view the impact on the final Overdesign Factor.

6. Importing DXF Drawings

For more complex slope profiles and stratigraphies, inputting the co-ordinates through the table interface can be time consuming. Oasys Slope allows the user to import dxf drawings and apply a strata and material or groundwater table to the different surfaces.

Objectives

- Import dxf drawings
- Limiting minimum slip circle size

6.1 Importing DXF Drawing

1. Open a new Slope analysis file.

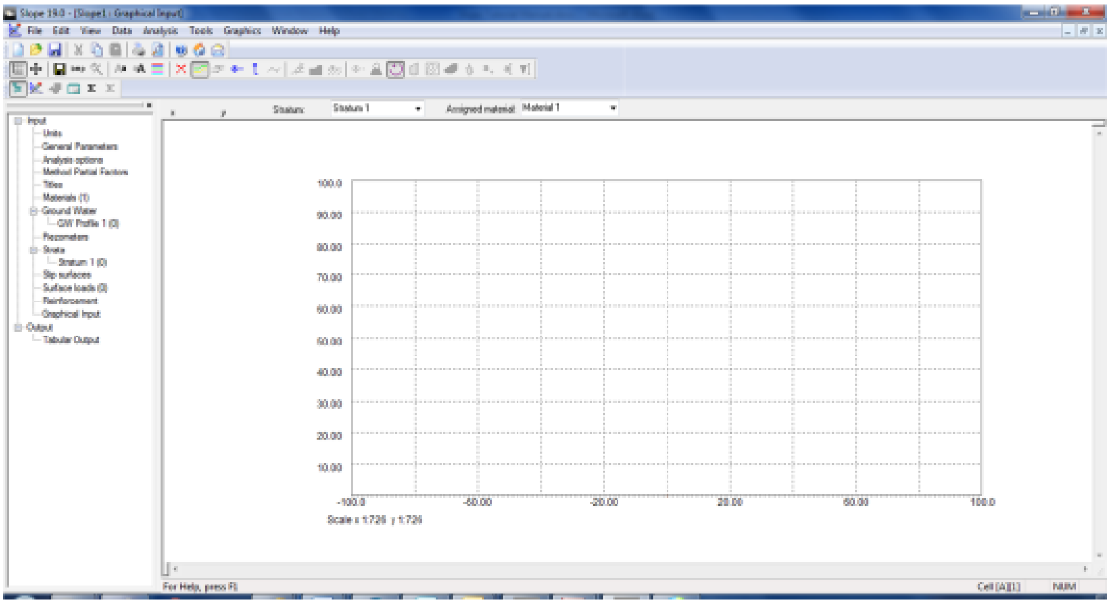
2. In the wizard, input information into the Titles and Materials section.

3. In the Materials section, input the properties of the Embankment Soil (properties in Section 4.1).

4. In the Stratum Definition, Ground Water Co-ordinates and Slip Circle definition sections of the Wizard, leave all inputs blank.

   Click Finish.

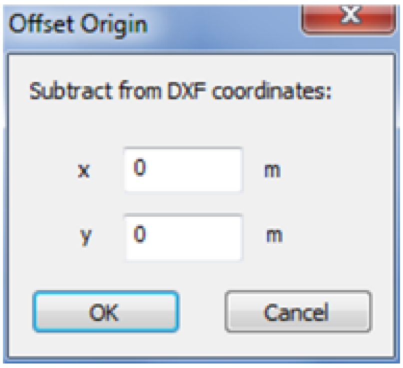
5. The following screen will show on completing the wizard:



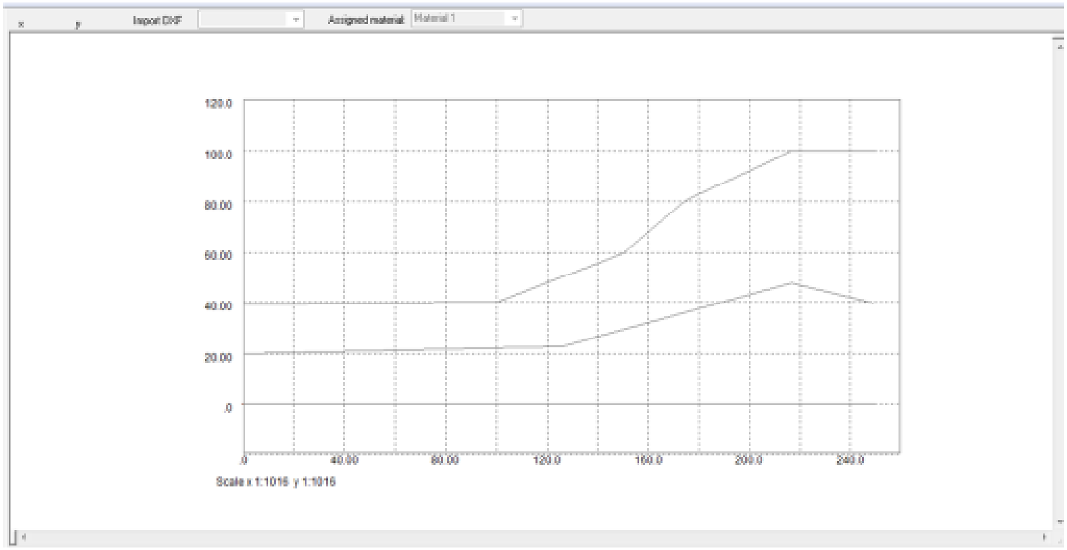
6. Click **File > Import > DXF File**

7. Import the file supplied with this tutorial (Slope Tutorial.dxf)

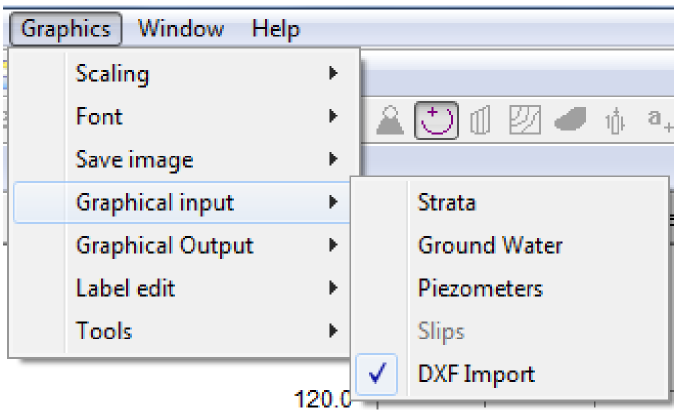
8. Place the origin co-ordinates at (0,0)



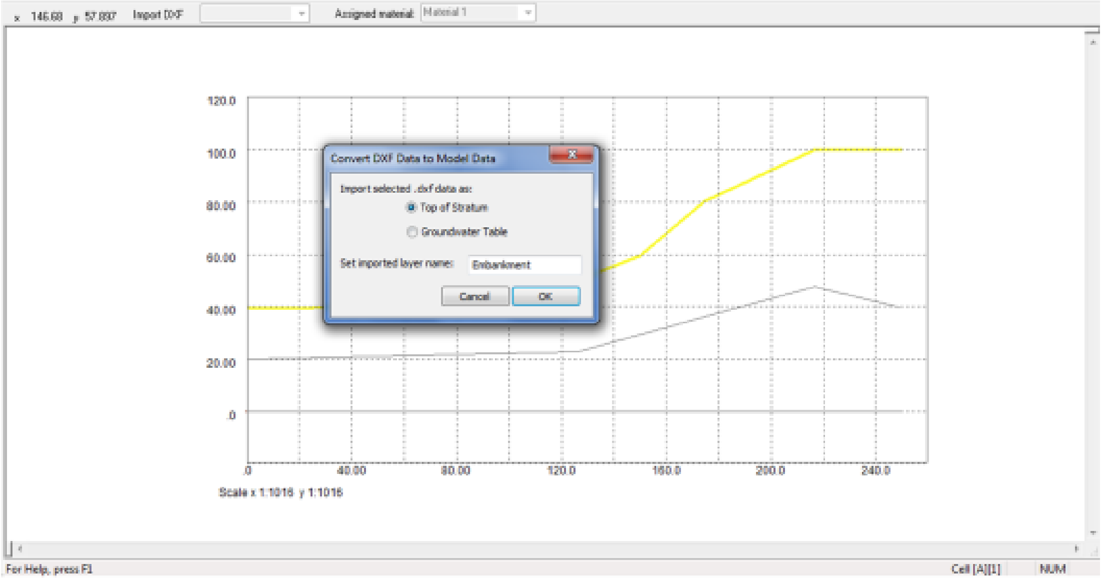
9. The dxf will show in the Graphical Input screen:



10. Click on **Graphics > Graphical input** and check *DXF Import* to allow the user to assign properties to different lines.



11. Click on the top line and assign this line the Foundation Strata.



12. Assign the next line down as a Groundwater Table titled Original WT

13. Assign the bottom line to the Bedrock Strata.

14. Double click on **Materials** in the Gateway and add the Bedrock Strata from Section 4.1.

15. Double click on **Strata** in the Gateway and assign each strata the appropriate material properties, and Hydrostatic pore pressure distribution with appropriate groundwater table (Original WT).

16. Double click on **Slip Surfaces** in the Gateway. Choose appropriate an appropriate grid location and spacing.

    (Hint: The analyses may run slowly with too many grid points. Start with a coarse grid and refine around the worst case slip circle)

    The user is required to find a slip circle that passes through the base of the slope (100,40). Choose the Common Point method of circle specification.

17. Run the analysis.

6.2 Limiting the Minimum Slip Circle Size

1. Double click on **General Parameters** to apply a Minimum slip circle weight. If a large enough weight is applied, the user can avoid picking smaller slip circles as their worst case slip surface. Choose 1000kN and compare the slip surface to the previous analysis.