TAGA soft

TSLOPE

Tutorial – starting with a 2D slope model and extending to 3D

1. Introduction

TSLOPE is a slope stability analysis package that has been developed around a fully 3D model of a slope. The analyses that can be carried out may be either 3D, or 2D, with the 2D sections aligned in arbitrary directions through the model.

It is expected that many TSLOPE users will have access to programs that can be used to develop a 3D geological model that will be used to constrain the 3D slope model. Importing surfaces from other programs to TSLOPE is a simple matter using common file formats.

However, some TSLOPE users may only have a 2D representation of their slope problem, and need to be able to transfer the relevant geometry into TSLOPE.

A problem that is initially defined in 2D can also be readily expanded to 3D. This tutorial is designed to help with understanding this process.

As TSLOPE works in a 3D world, all points will have x, y and z coordinates. As a consequence, when you are working in 2D, surfaces are referred to as ellipsoids or spheres (the equivalent of ellipses or circles in 2D).

TSLOPE also needs to be able to handle real world coordinate systems, with a large number of significant figures attached to each coordinate. TSLOPE may simplify the displayed values for purposes of legibility.

In a section view of a slope, TSLOPE will reset the coordinates displayed, this may be confusing at first, particularly where the section drawn is not orthogonal to one of the principal directions. In the present release of TSLOPE the displayed coordinates are reset so the origin is at the left hand end of the section. This will be changed in the subsequent release so that the user’s choice of origin is preserved.

2. 2D Slope Example

The slope problem that we are going to set up in TSLOPE is an example that has been described by Duncan et al. (2014)[1]. It is their Example 3: Excavated slope in stiff-fissured clay, as described by Skempton and LaRochelle (1965)[2], a deep excavation in the London Clay at Bradwell.

The geometry of the excavation and the layers forming the slope are shown in Figure 1.

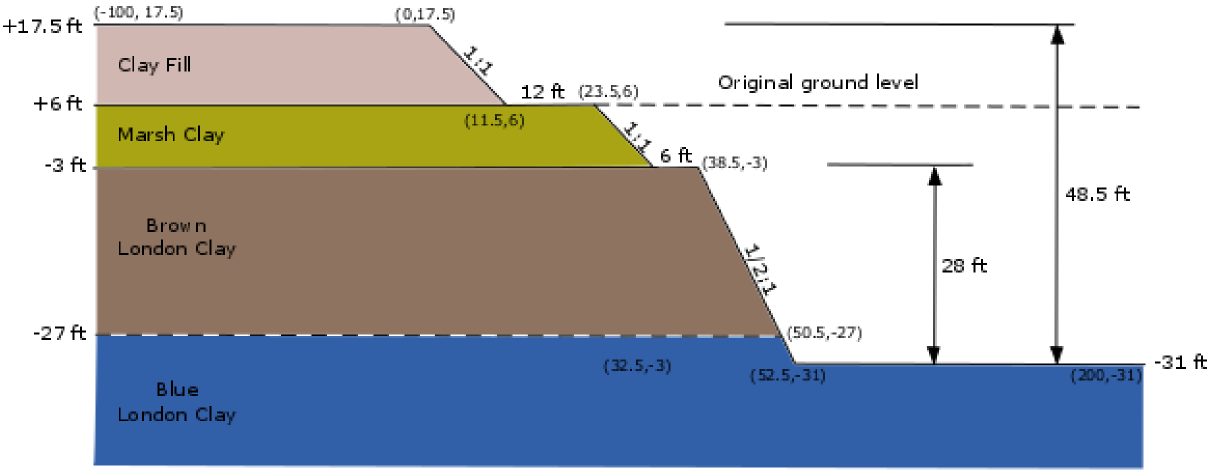


Figure 1. Cross section of excavated slope.

The materials in the slope have the following properties:

Material	*Unsaturated density*	*Saturated density*	*cohesion*	*Friction angle*
Clay Fill		110 pcf	0	0
Marsh Clay		105 pcf	300 psf	0
London Clay		120 pcf	Varies from datum 290 psf at 6 ft with gradient of 70 psf/ft to maximum of 3000 psf	0

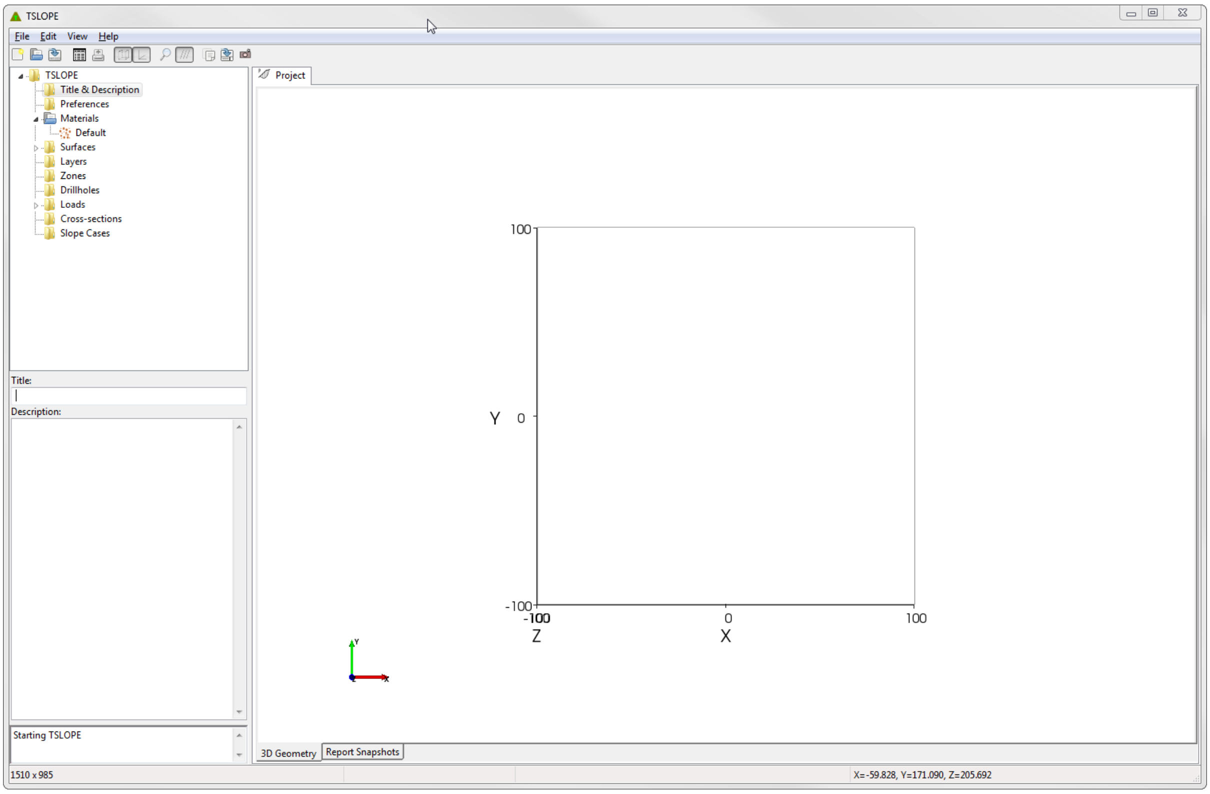
Table 1. Material properties.

[1] Duncan, J.M., S.G. Wright, T.L. Brandon 2014 Soil strength and slope stability (second edition) John Wiley & Sons, Inc. 317pp
[2] Skempton, A.W. and LaRochelle, P. 1965 The Bradwell Slip: A short-term failure in London clay. Geotechnique 15 (3); 221-242

3. Setting up TSLOPE

Open TSLOPE by clicking on the icon on your desktop

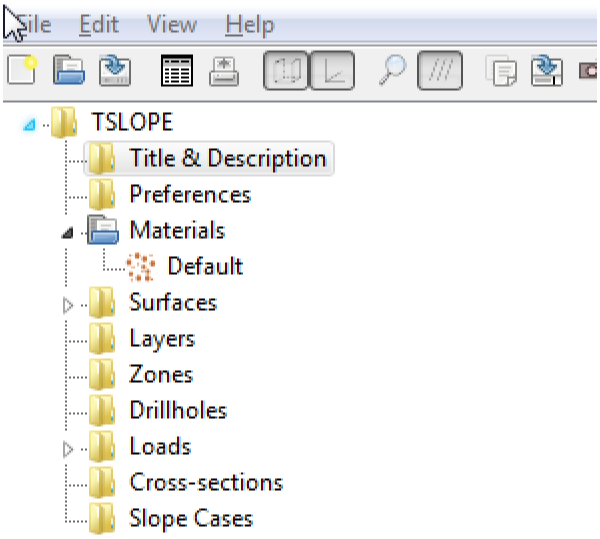
This opens a new project as shown on the next figure. There are menu items down the left hand side, and a ***Project*** pane where a graphical representation of the slope model will be shown.

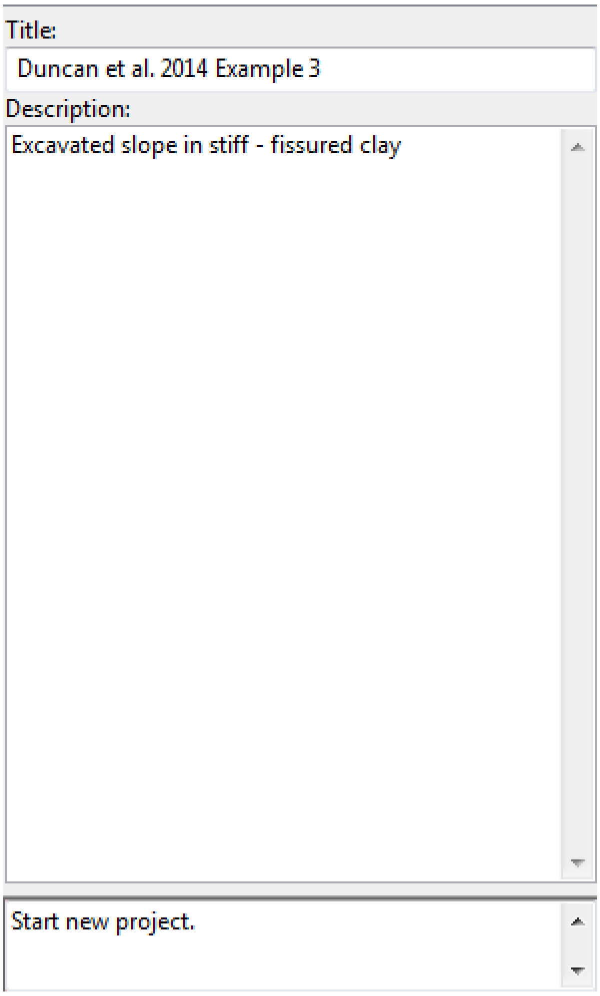


We will work down each item in the ***directory tree*** panel, starting with the first item - ***Title & Description***. The labelled panels ***Title:*** and ***Description:*** below the menu tree are shown, and are open for data entry.

In ***Title:***, we will put Duncan et al 2014 Example 3

In ***Description:***, we will put Excavated slope in stiff – fissured clay



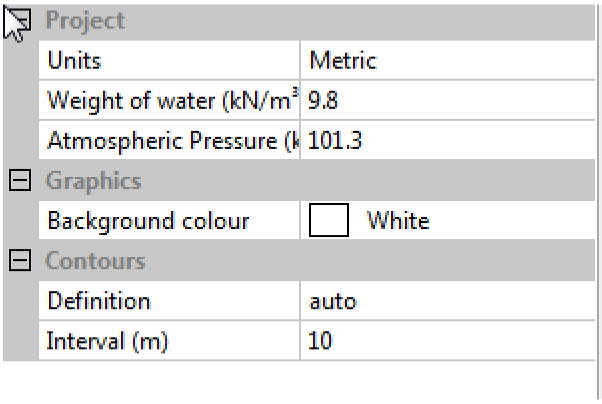


We can use the ***Description:*** box to add any other useful information related to this TSLOPE project file.

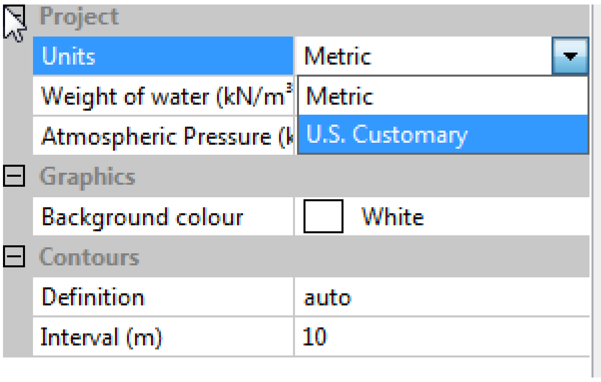
Now that we have some data entered, it is good practice to save our work. From the ***File*** tab choose ***Save As …*** and provide an appropriate file name and directory for the project file to be saved.

TSLOPE saves project files with a .tsz extension.

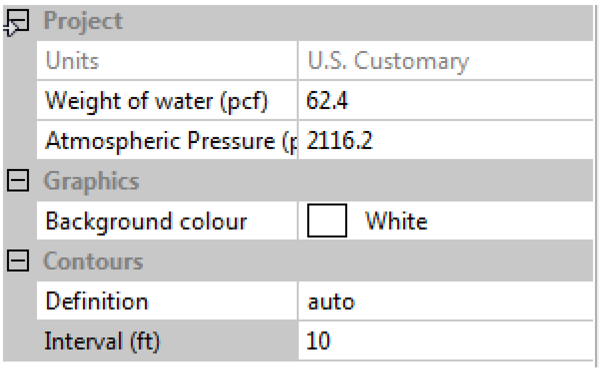
The next menu item is ***Preferences.*** This opens a panel with default values that we may need to change:



The defaults are shown, we will need to make some changes as we are working in units of feet and pounds



We will use the right tab to pull down the menu item U.S. Customary, and set this for the project units.



Appropriate values are then provided for Weight of water, and Atmospheric Pressure. If necessary, they can be changed.

The Contour Interval is also given, and can be changed.

4. Entering slope data

The ***Materials*** menu shows a ***Default*** tab already set up. Selecting ***Default*** we open a panel with the following:

Material 0	
Id	0
Label	Default
Failure criterion	Mohr-Coulomb
Unit Weights	
Unsaturated (pcf)	100
Saturated (pcf)	112
Mohr-Coulomb	
Cohesion function	Constant
Cohesion (psf)	0
Angle of friction (deg)	10

Sometimes the user will want to leave the default label intact - for instance if there is only one material in the problem – but normally the user will want to overwrite the default label and properties with his/her own choices.

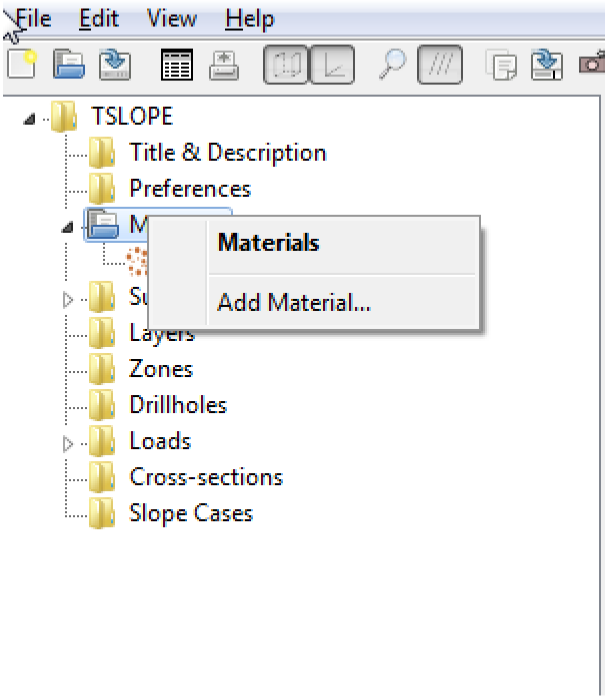
In this case we need to input the appropriate values for the three layers, as given in Table 1. Starting with the first layer in the stratigraphy:

Material 0	
Id	0
Label	Clay Fill
Failure criterion	Mohr-Coulomb
Unit Weights	
Unsaturated (pcf)	110
Saturated (pcf)	110
Mohr-Coulomb	
Cohesion function	Constant
Cohesion (psf)	0
Angle of friction (deg)	0

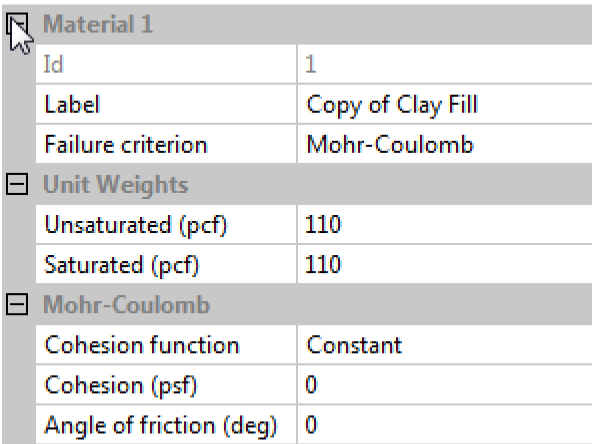
The Material Id is used internally and provides an alternative label should the user not provide input into the Label field

TSLOPE requires that a total unit weight be specified for both saturated and unsaturated conditions. In this example there is no phreatic surface and all materials are presumed to be unsaturated so we just specify the same value for the saturated unit weight.

To add the next material, go back to the ***Materials*** menu and right click on the mouse to open the tab for ***Add Material…***



The ***Material*** pane then comes up with:



Material 1	
Id	1
Label	Copy of Clay Fill
Failure criterion	Mohr-Coulomb
Unit Weights	
Unsaturated (pcf)	110
Saturated (pcf)	110
Mohr-Coulomb	
Cohesion function	Constant
Cohesion (psf)	0
Angle of friction (deg)	0

We make appropriate changes:

Material 1	
Id	1
Label	Marsh Clay
Failure criterion	Mohr-Coulomb
Unit Weights	
Unsaturated (pcf)	105
Saturated (pcf)	105
Mohr-Coulomb	
Cohesion function	Constant
Cohesion (psf)	300
Angle of friction (deg)	0

We then add a further material, for London Clay

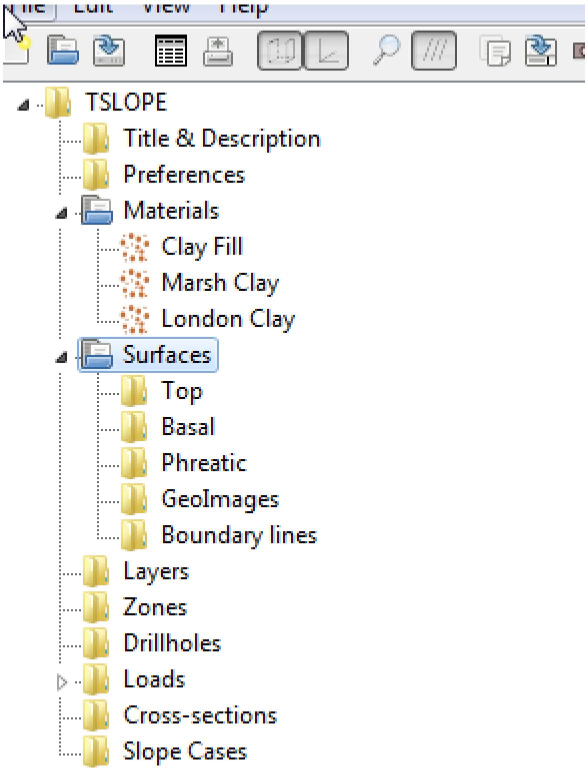
Material 2	
Id	2
Label	London CLay
Failure criterion	Mohr-Coulomb
Unit Weights	
Unsaturated (pcf)	120
Saturated (pcf)	120
Mohr-Coulomb	
Cohesion function	Constant
Cohesion (psf)	Constant
Angle of friction (deg)	Varies with depth
	Varies from datum

We set the appropriate unit weights, and use the pull down tab to choose Cohesion function - Varies from datum

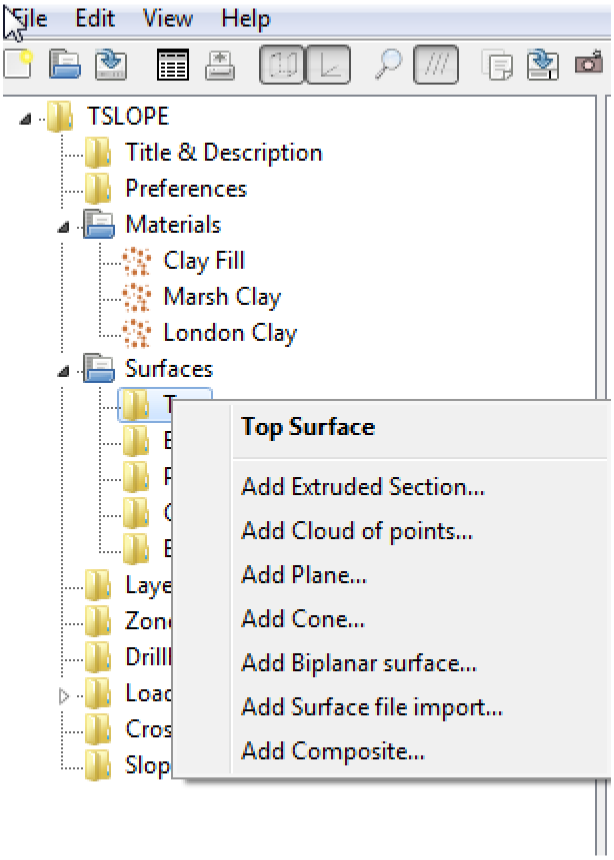
Material 2	
Id	2
Label	London Clay
Failure criterion	Mohr-Coulomb
Unit Weights	
Unsaturated (pcf)	120
Saturated (pcf)	120
Mohr-Coulomb	
Cohesion function	Varies from datum
Cohesion (psf)	290
Datum z (ft)	6
Delta cohesion (psf/ft)	70
Max. cohesion (psf)	3000
Angle of friction (deg)	0

We fill in the appropriate values from Table 1 in the ***Mohr-Coulomb*** panel

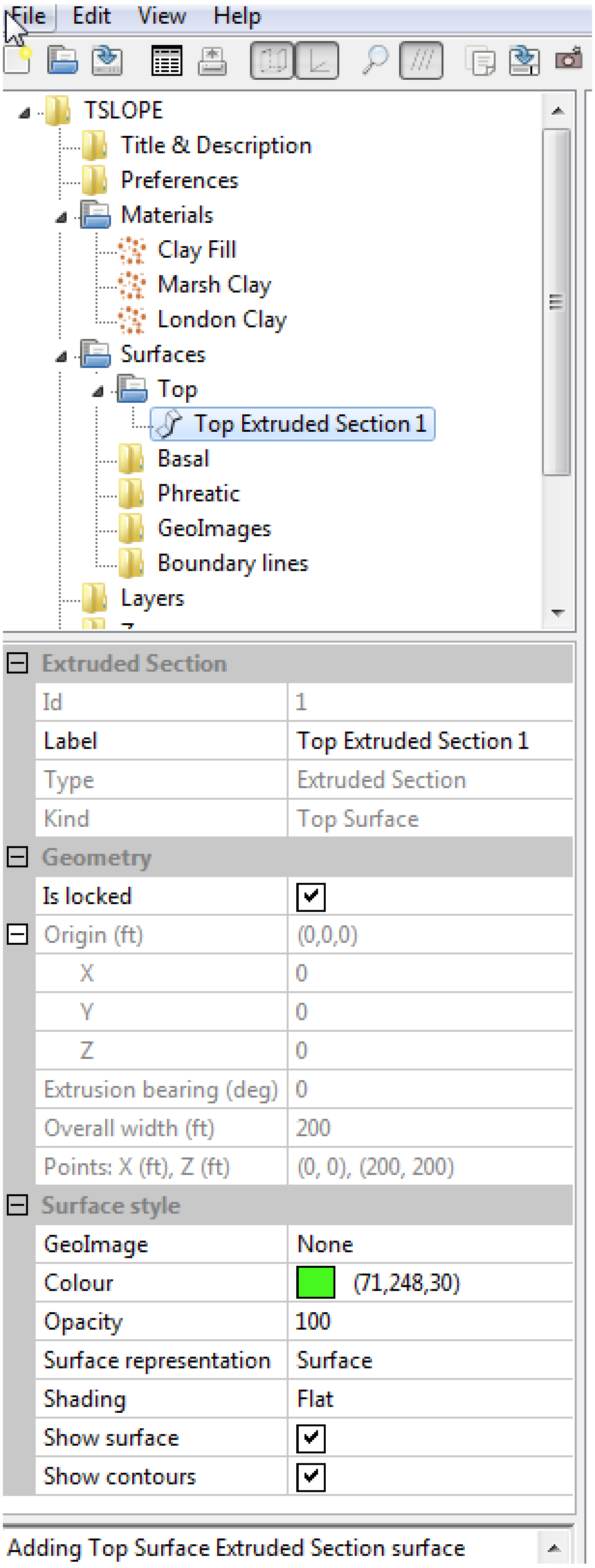
The next menu item, ***Surfaces***, allows us to begin to define the geometry of the slope problem.



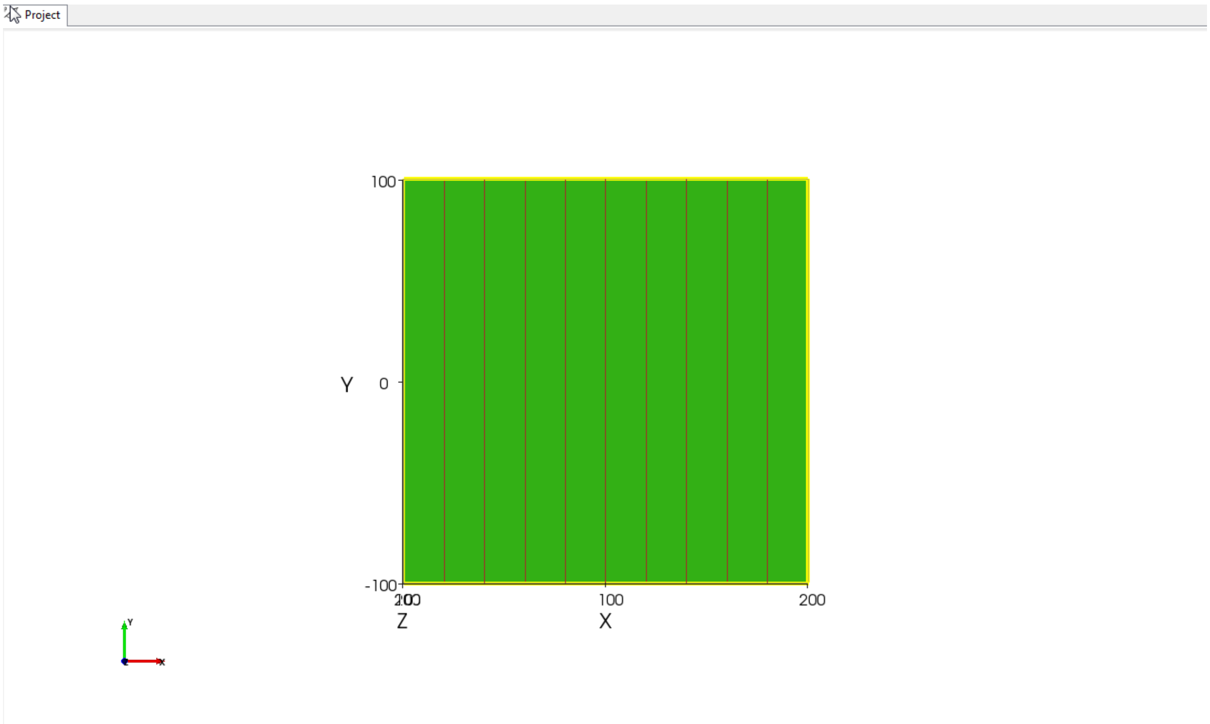
We will open the ***Top*** menu option by right mouse click, and we get the following:



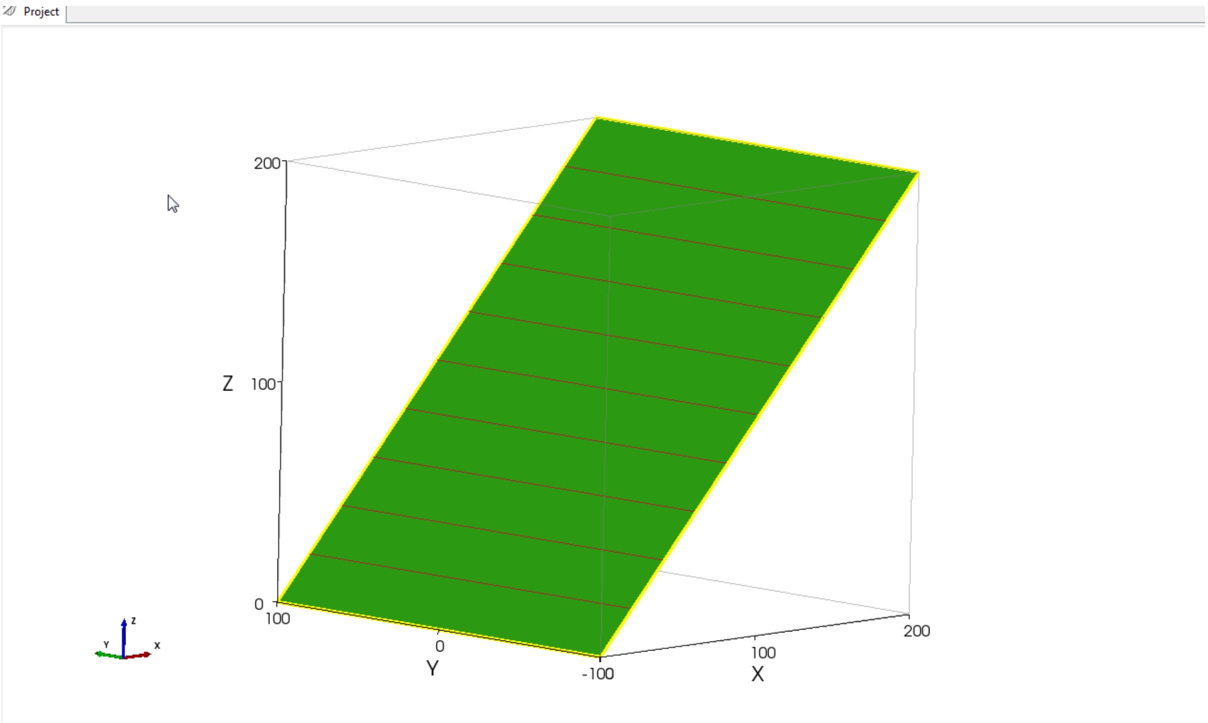
We then select ***Add Extruded Section…*** and automatically generate a simple 3Dsurface. This is initially a horizontal plane, with the parameters shown in the panel (again, we are at present only interested in the 2D cross section of this surface but the program calls it an "extruded" section because the 2D section is automatically extruded to 3D and may be used in 3D at a later point if that is desired.


File Edit View Help
TSLOPE
Title & Description
Preferences
Materials
Clay Fill
Marsh Clay
London Clay
Surfaces
Top
Top Extruded Section 1
Basal
Phreatic
GeoImages
Boundary lines
Layers
Extruded Section
Id 1
Label Top Extruded Section 1
Type Extruded Section
Kind Top Surface
Geometry
Is locked
Origin (ft) (0,0,0)
X 0
Y 0
Z 0
Extrusion bearing (deg) 0
Overall width (ft) 200
Points: X (ft), Z (ft) (0, 0), (200, 200)
Surface style
GeoImage None
Colour (71,248,30)
Opacity 100
Surface representation Surface
Shading Flat
Show surface
Show contours
Adding Top Surface Extruded Section surface

The ***Project*** panel now shows the surface with a top down view (X – Y axes).

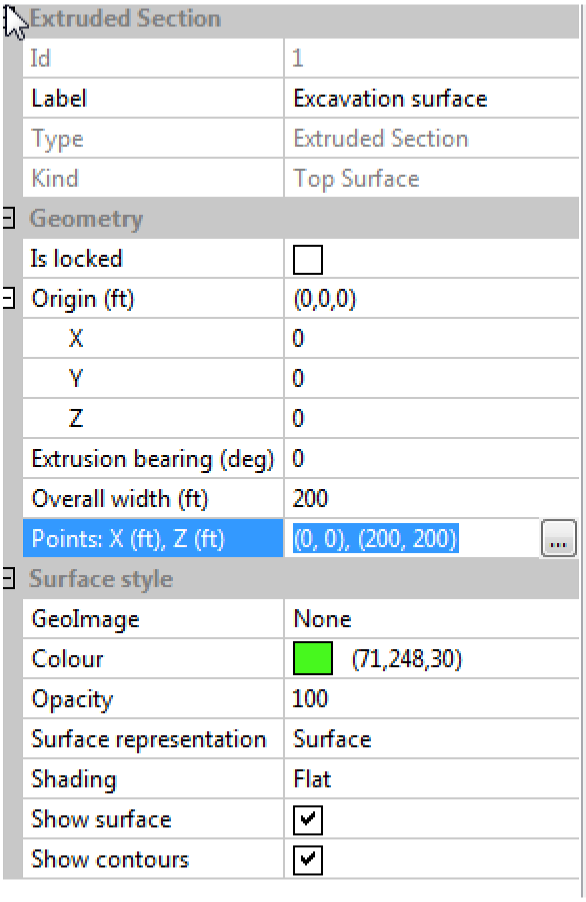


Using the mouse buttons, the plane can be rotated, panned, and zoomed as required. Left mouse is for rotation, centre mouse for dragging, right mouse for zooming.



Or, more usefully it can be viewed in 2D by going to the View pulldown menu and selecting another view, normally S> N.

We then need to make appropriate changes to the ***Extruded Section*** parameters:

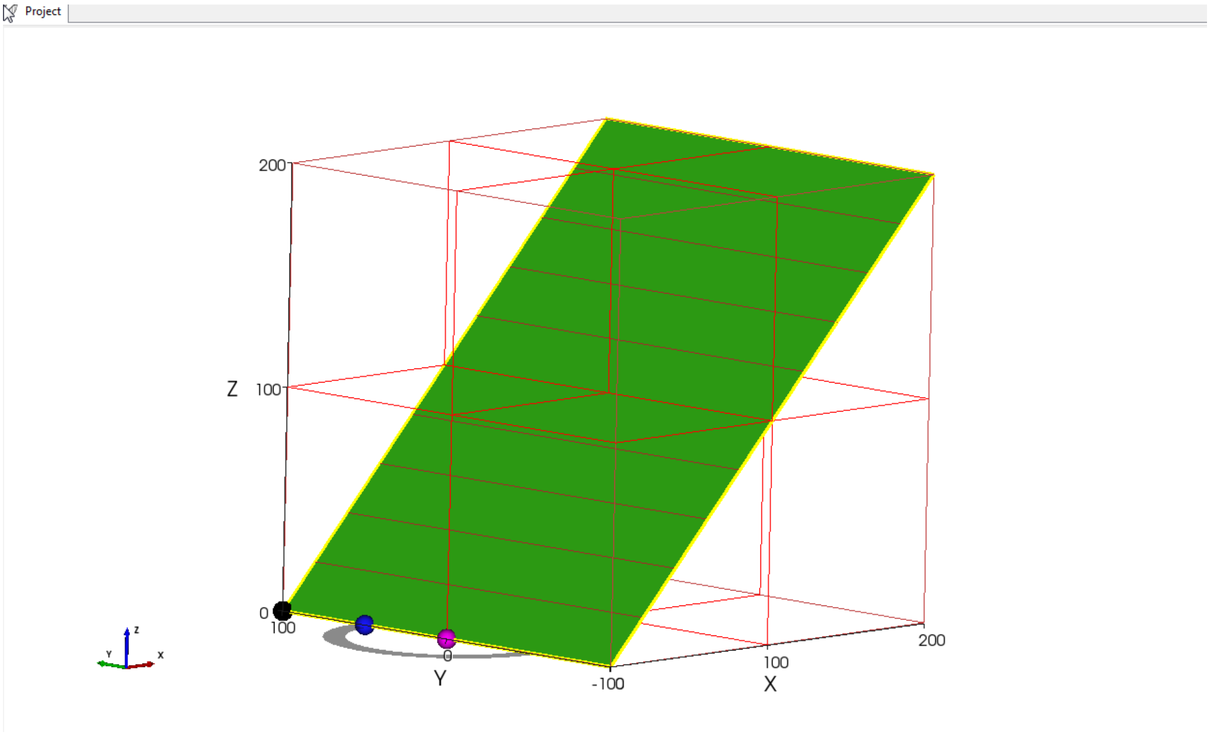


Change the ***Label*** to a suitable one for the slope

Uncheck the ***Is locked*** box

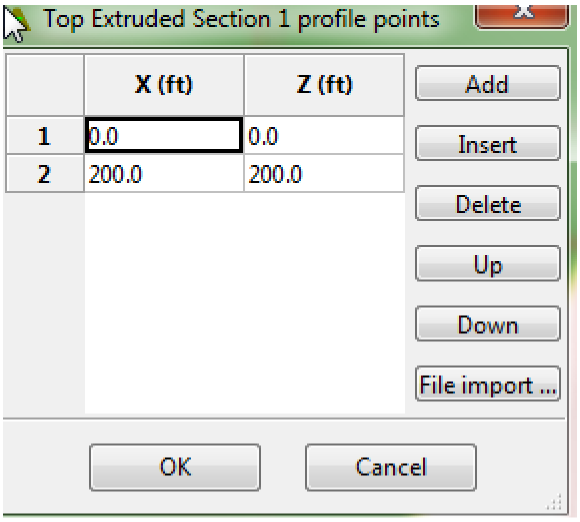
From the ***Points*** box, mouse click on the button to the right to activate the edit profile points menu

Unlocking the Extruded Section Geometry changes the display in the Project panel:



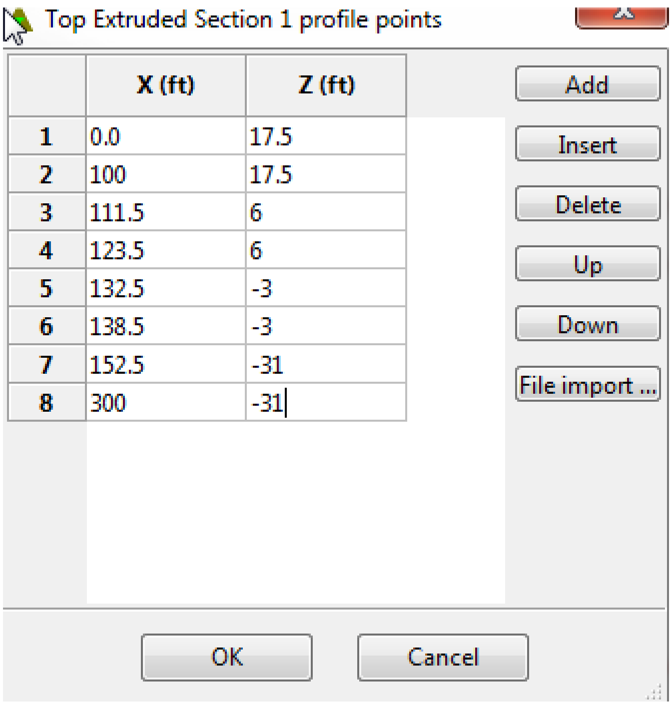
The solid balls can be moved by the mouse to alter the width and orientation of the plane. However we will use the Edit Profile Points menu so that we can add new points, and have precise control of our changes.

The Edit Profile Points menu pops up in the Project panel. It can be moved and expanded as necessary.



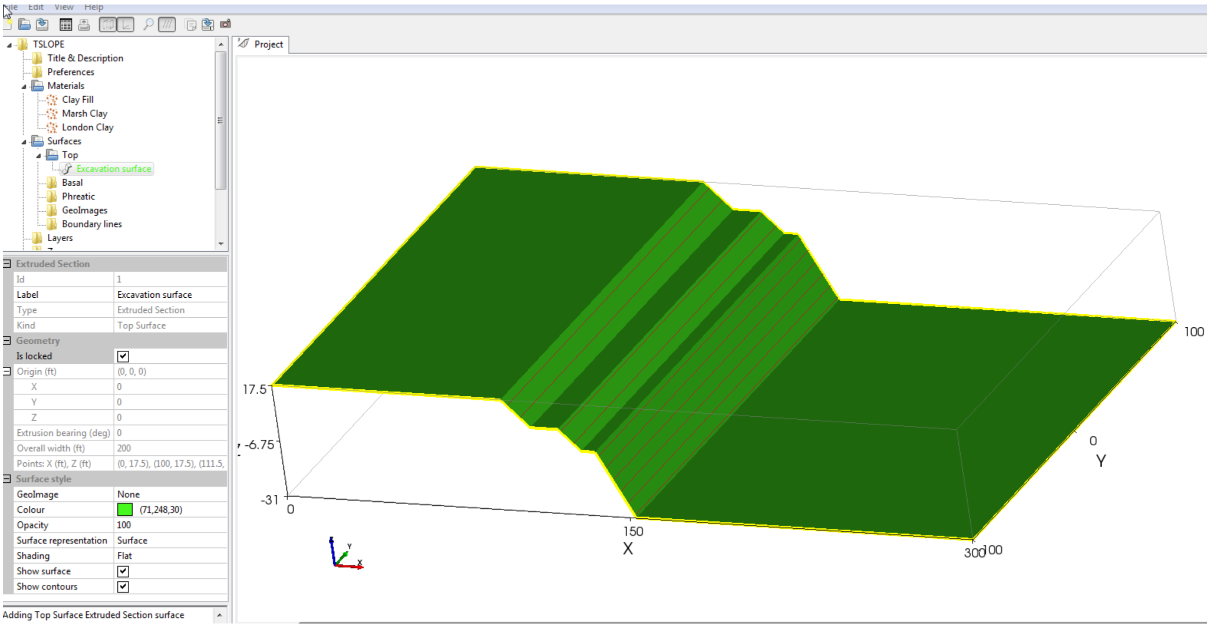
Because we are working from a 2D representation of the slope we can align the section with the X Z axes. If the section you are importing has full 3D coordinates, we could load those through the File import option shown to the right of the box. In this example we choose to put the origin at the left hand side of the X Z section to fit in with the way the program will display the coordinates in the graphics views. TSLOPE sets the positive Y axis oriented to the "north" of the model. Z is always positive in an upward direction.

Referring to the coordinates shown on Figure 1, we will add 100 to each of the X values so that we have the origin of the model at X=0 Y=0.

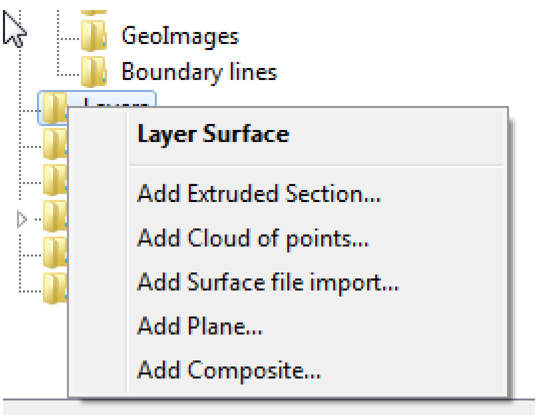


Using the ***Add*** button, we input the X Z coordinates for all the points where there is a changes in slope.

We mouse click on OK, and the Project view changes to show the 3D view of the excavated surface. We need to check the ***Is Locked*** box again to ensure that we don't inadvertently move the surface relative to its origins when viewing the 3D graphics.

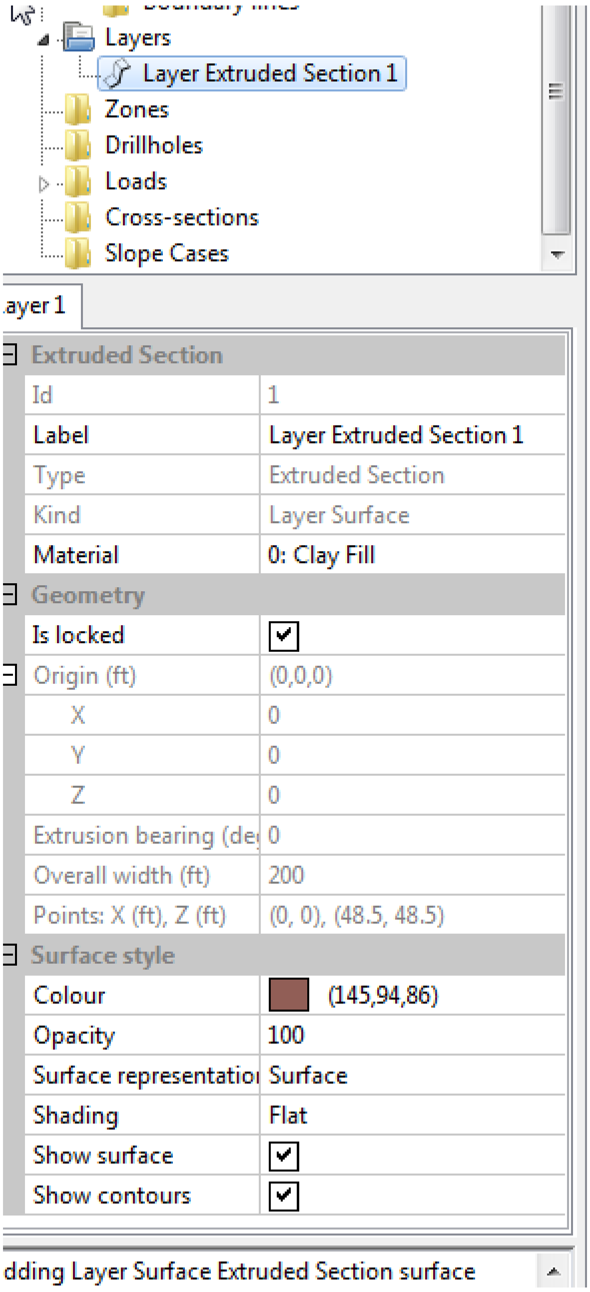


The next step is to right mouse click on ***Layers*** and follow a similar process we have been through for the Excavation surface.



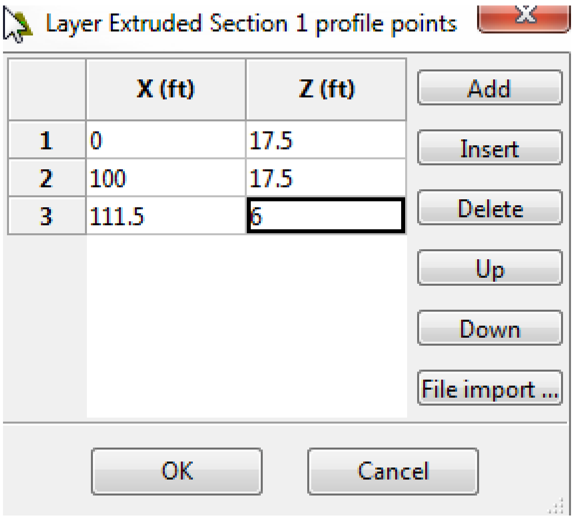
From the ***Layers*** menu item we select ***Add Extruded Section …***

We expand the ***Layers*** menu to show the new ***Layer Extruded Section 1***



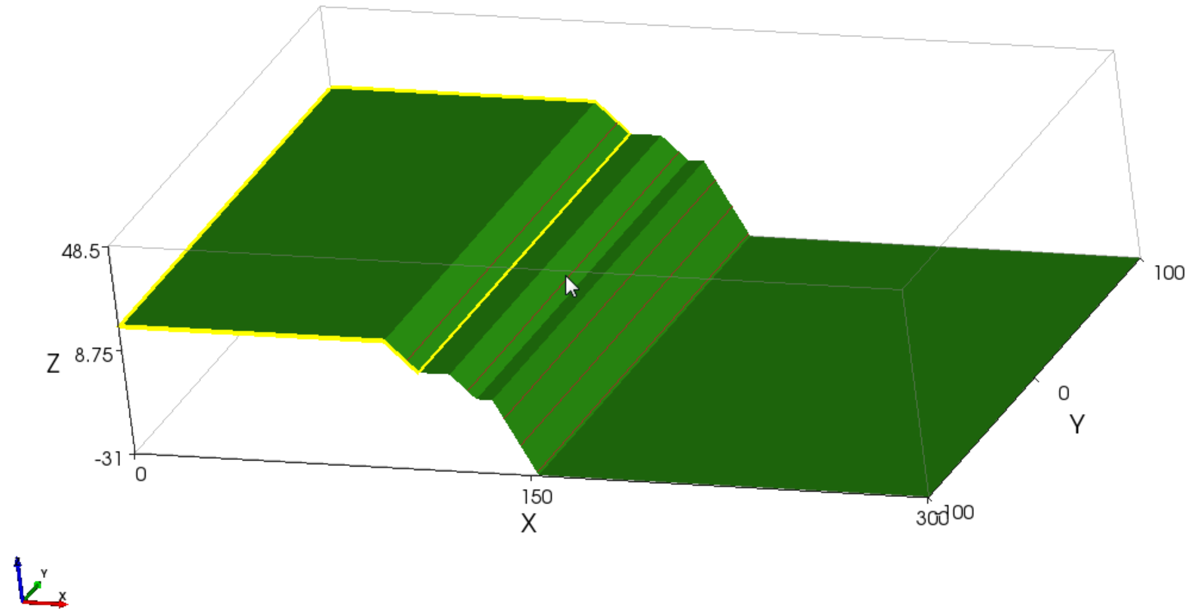
We unlock the Geometry check box, and make the appropriate changes to show the top layer. In this slope, the uppermost layer is Clay Fill (this was entered as a default value). To define its geometry, we input the coordinates for the top of the layer. The bottom of the layer is defined as the top of the next lower layer. The lowest layer does not have a bottom defined. Referring to Figure 1, there will only be 3 points defining the top of Clay Fill coincident with the excavation surface, and terminating at the contact with underlying Marsh Clay.

The TSLOPE convention is to enter the layer tops. The bottom of the layer is then automatically defined as the top of the next layer in the negative Z direction. The lowest layer will extend below the limit of the model.



Following addition of the X Z coordinates defining the top of Clay Fill, we mouse click OK.

Remember to check the ***Geometry Is locked*** box before manipulating the model in the Project panel.

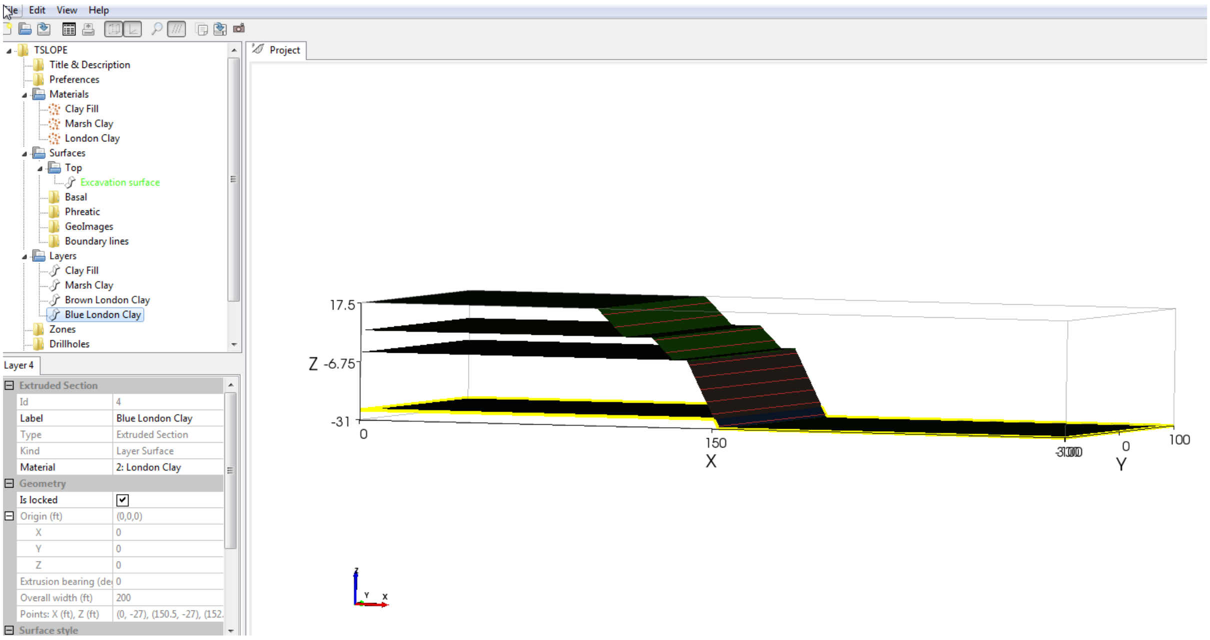


The yellow highlighted shape is the top of the Clay Fill layer that we have just entered.

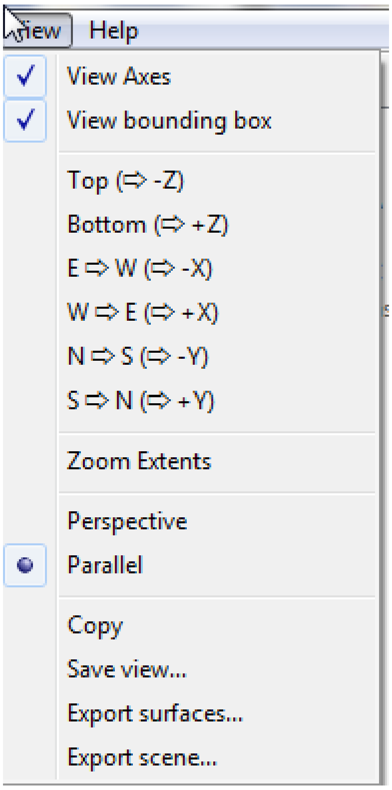
Using the same process, we enter the top of the Marsh Clay, Brown London Clay, and Blue London Clay layers.

Make sure that you set the appropriate ***Material*** for each of the layers. The London Clay material will be used for both Brown London Clay and Blue London Clay layers.

We now have the full geometry and material property information entered and we can view the 3D model in the Project panel:

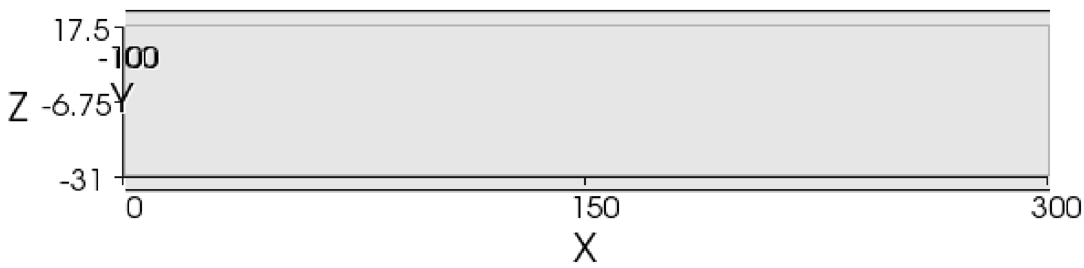


If we want to view the model in a section view, we can use the ***View*** tab to get the options as shown:

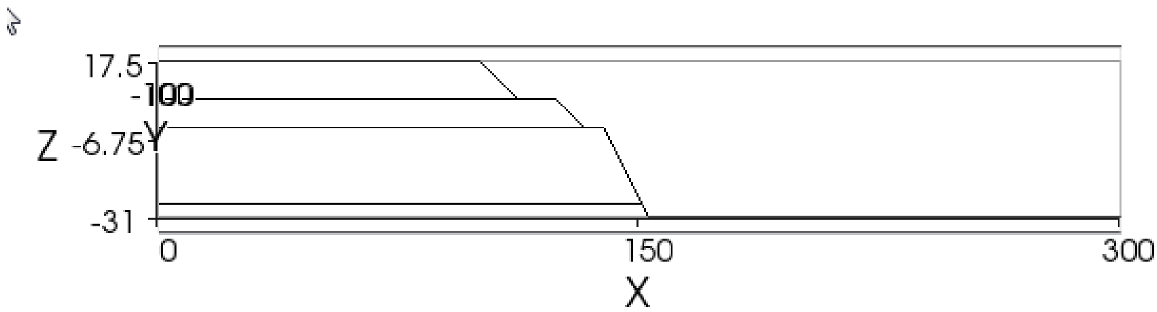


We chose the bottom option S – N to get a section view

With the section perfectly aligned with the model axes, the layer boundaries do not show; you will get what looks to be a blank model.



We need to change the graphic representation of the model to wireframe. On the keyboard, type w.   To toggle back to the solid view, type s. A wireframe view can be useful when you have complex 3D models, and want to look at detailed relationships between surfaces.

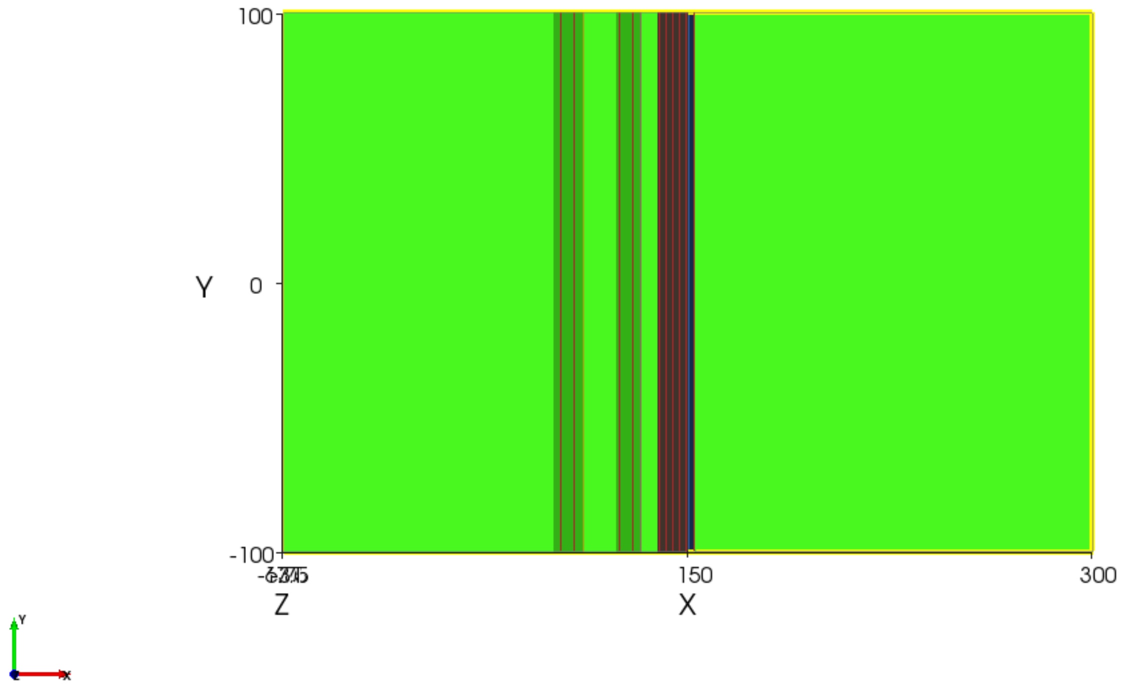


5. Building a 2D Slope Case

Slope Case is the term used to describe the combinations of surfaces, layers and other elements that make up a particular slope stability analysis. The Slope Cases can be either 3D, or 2D.

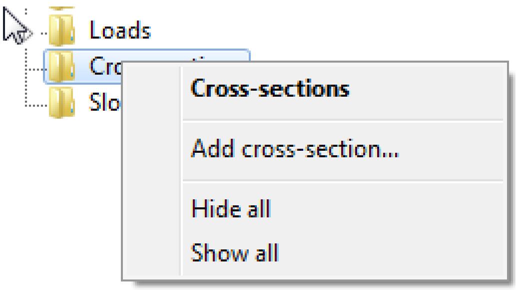
To build a 2D Slope Case, we must define a Cross-section. This is our next task.

From the ***View*** tab we then select Top and view the model in the X Y plane:

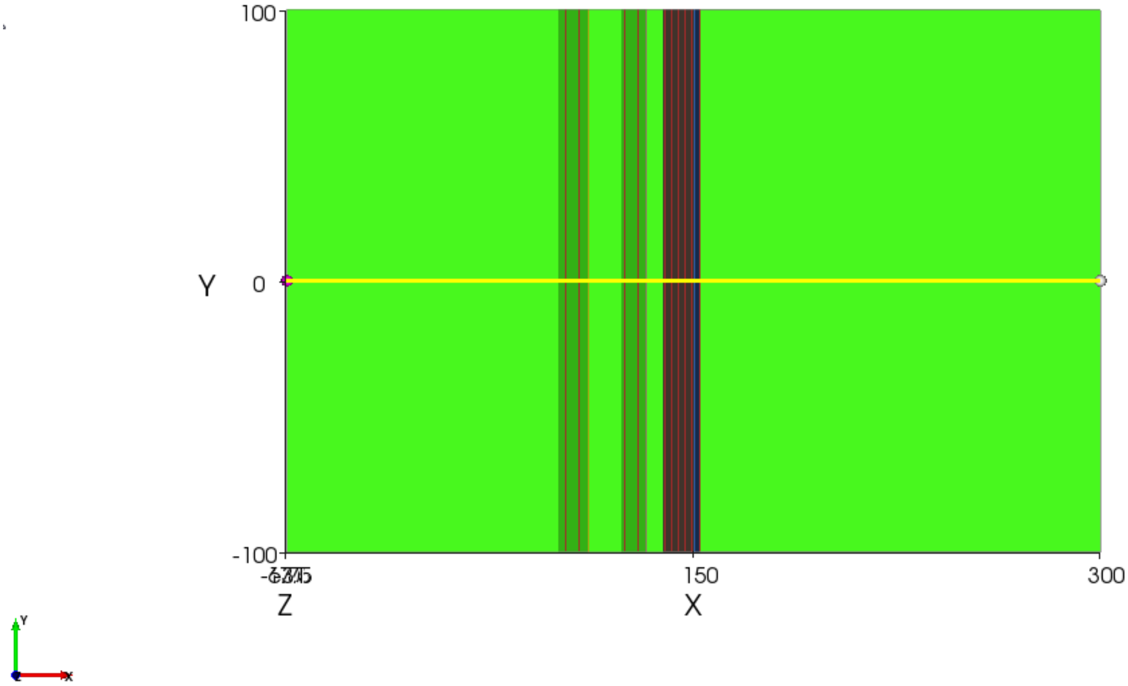


This is a good view to locate a cross section. If we want to be able to show the section used to generate the model, then we need to orient the section in the X axis direction, at Y=0.

From the ***Cross-sections*** menu, select ***Add cross-section…***



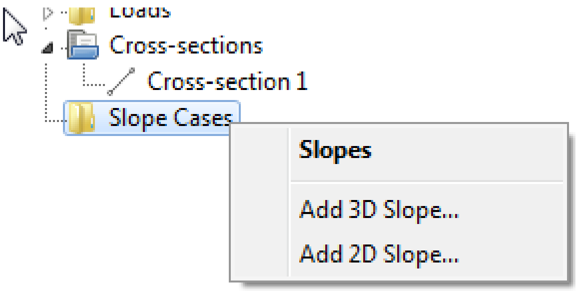
The section line will show up as a yellow line with balls at each end of the section. The end point balls can be dragged with the mouse to change the section length, and orientation. The line can also be selected and moved retaining the length and orientation.



Cross-section 1	
Label	Cross-section 1
Is locked	☑
Start point (ft)	(0,0)
X	0
Y	0
End point (ft)	(300, 0)
X	300
Y	0
Bearing (deg.)	90
Length (ft)	300
Visual Properties	
Colour	(189,191,195)
Opacity (0..100)	50
Show	☑

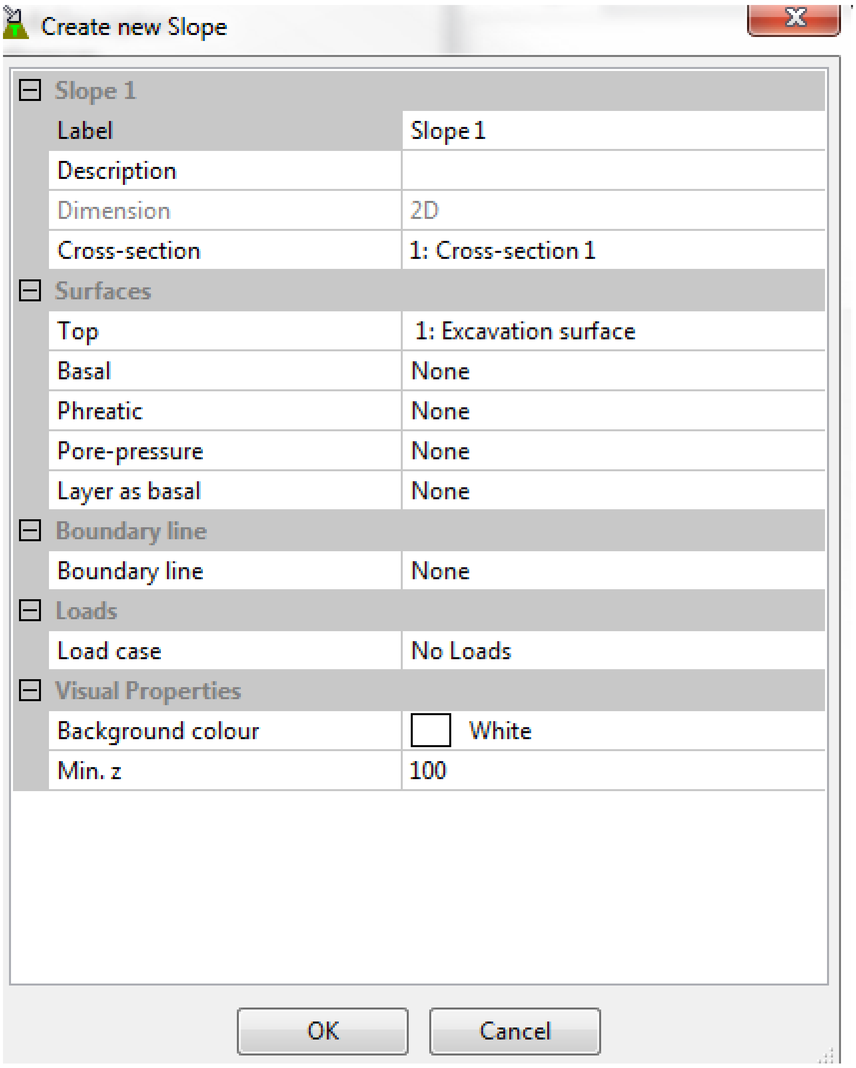
When the section is in the correct location, remember to lock it.

Right click with the mouse on the ***Slope Cases*** menu item:



Select Add 2D Slope…

A pop up box then appears that shows the Surfaces and other parameters that will be used in the analysis.

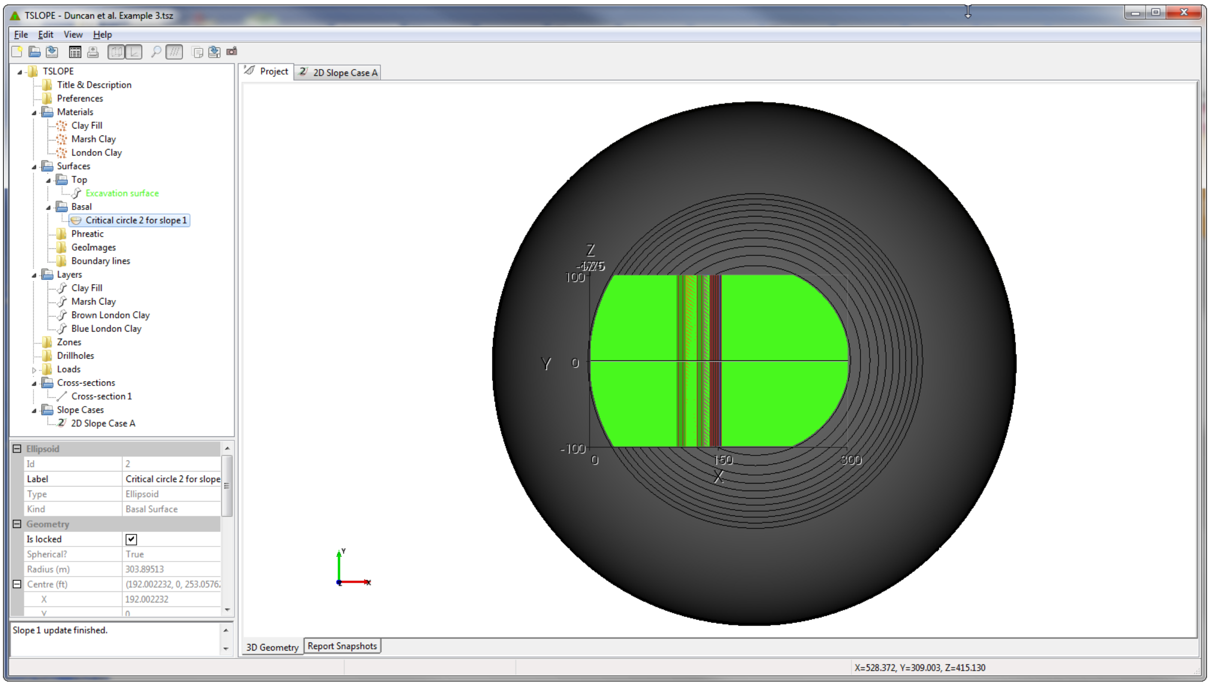


In this case, the values that have been put in automatically are correct. However we may want to change the Label, and add a Description

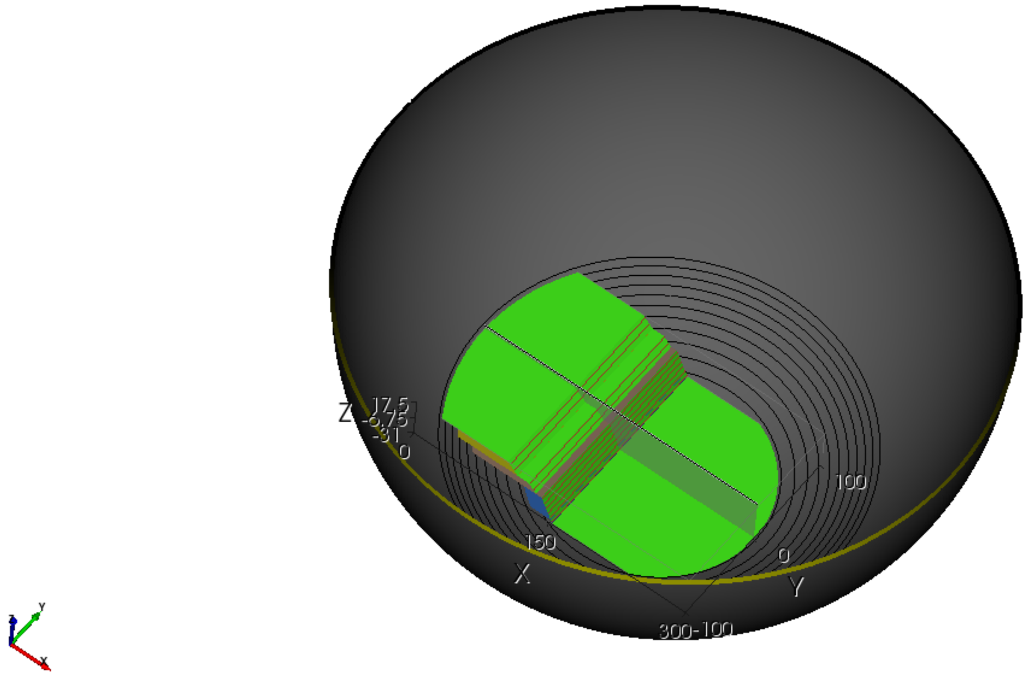
With the mouse, click on OK to accept the values.

We now have another tab alongside the Project tab labelled “2D Slope Case A”.

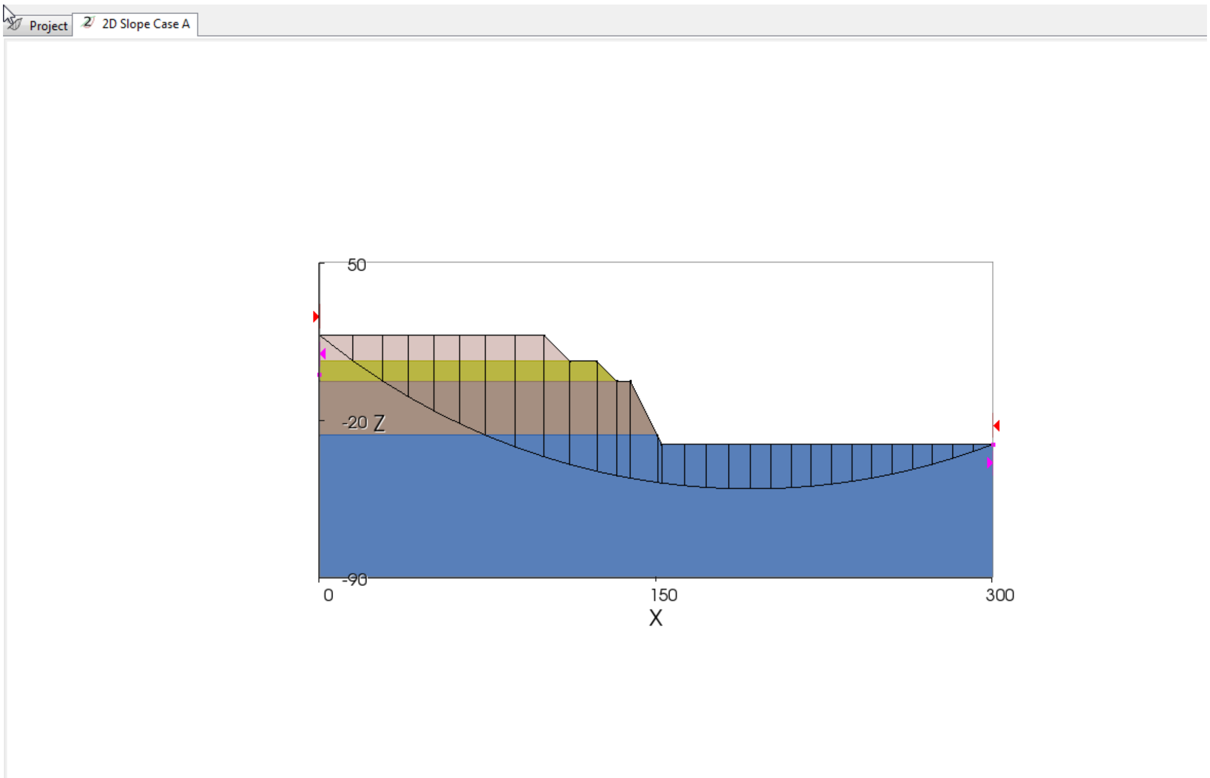
The Project view is shown in plan view with a new surface created under the ***Surfaces – Basal*** menu; It is automatically labelled as “Critical circle 2 for slope 1”. We will change the label to Critical circle for Slope Case A. The bottom panel on the left shows that the new surface is an Ellipsoid (a circle is a 2D representation of a sphere, which is a special case of an ellipsoid).



We can change the graphic view, and see how the ellipsoid intersects the 3D model:

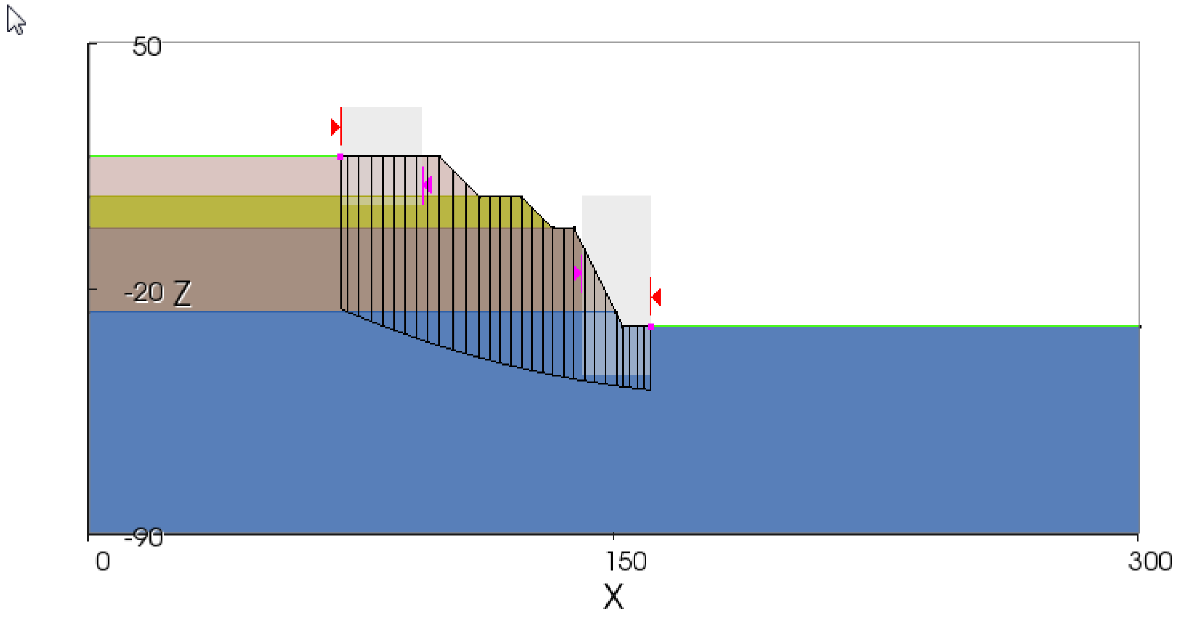


We then open the ***2D Slope Case A*** panel.



Here we have the 2D cross section that shows the layers and excavation surface. There is a large circle (from the automatically generated basal ellipsoid), and red and purple sliders at each end of the circle. When we set up the Slope Case, there was an option to specify a Basal surface. We did not have a basal surface set up in our model, and the default became a critical circle; TSLOPE then automatically generated an ellipse that would provide a starting point for a search.

We then left mouse click on the slider (solid triangle) and drag the sliders to define a grey box at either end of the slope to control the location of exit points of the critical circle:

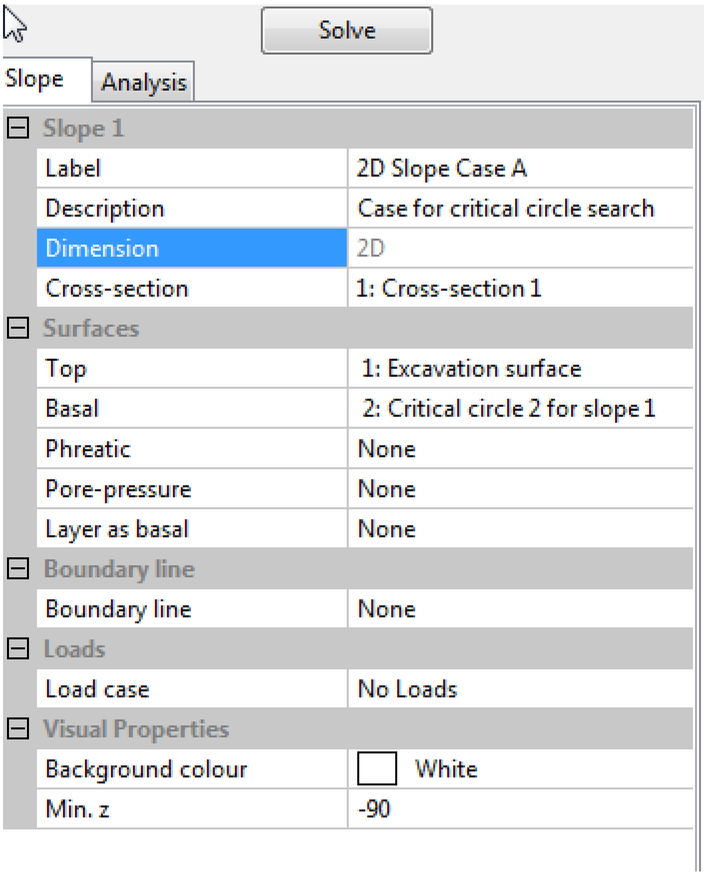


Tip: If you fumble the slider selection, you may end up with a zoom to fill the screen. To recover, go to the ***View*** tab and select Zoom Extents to get back to a useful view. There is also a short cut way to do this – use the icon, fifth from the left (looks like a magnifying glass).

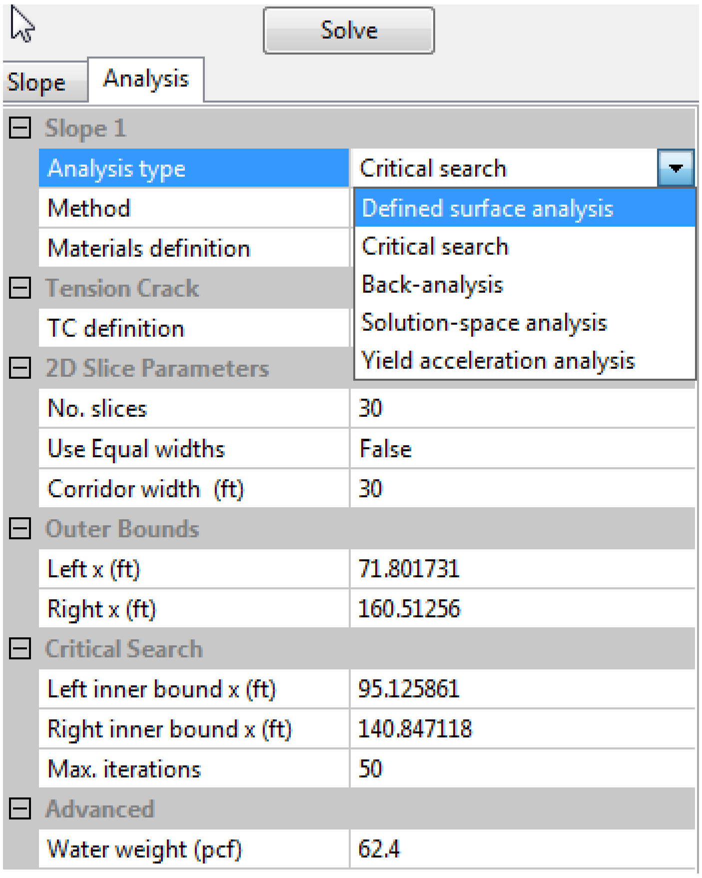
The critical circle is now truncated, and will be regenerated once we start the stabililty calculations.

While we have the 2D Slope Case A tab open, we also get access to the ***Slope*** and ***Analysis*** panels on the left.

Note that there is now a Surface selected for the Basal surface.



In the ***Analysis*** panel we get the following:

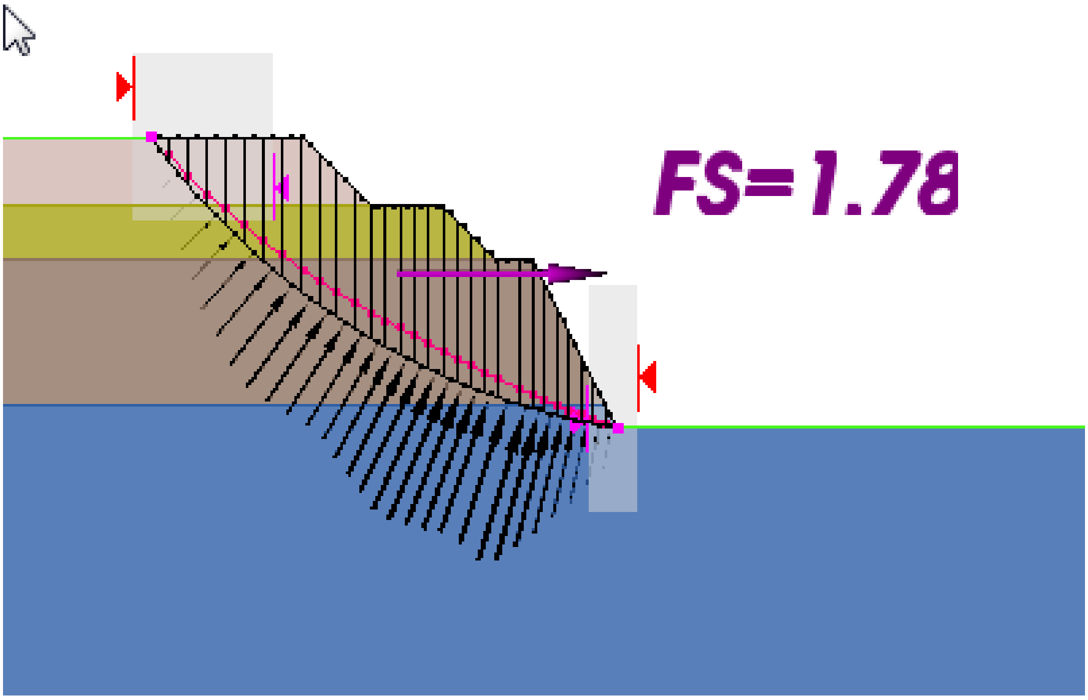


We need to select Critical search

We will accept the other default values.

Then mouse click on the ***Solve*** button.

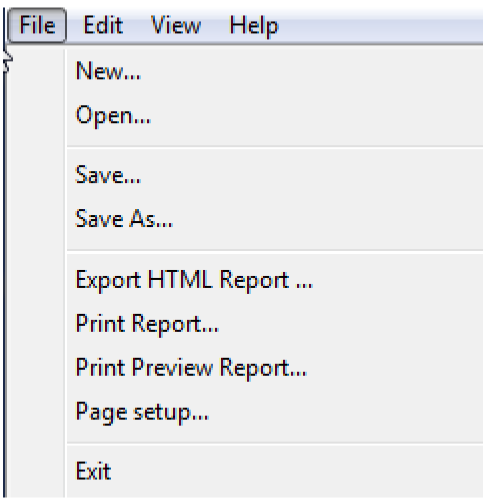
You will then enjoy a little animation as TSLOPE iterates to find the critical circle before presenting the results:



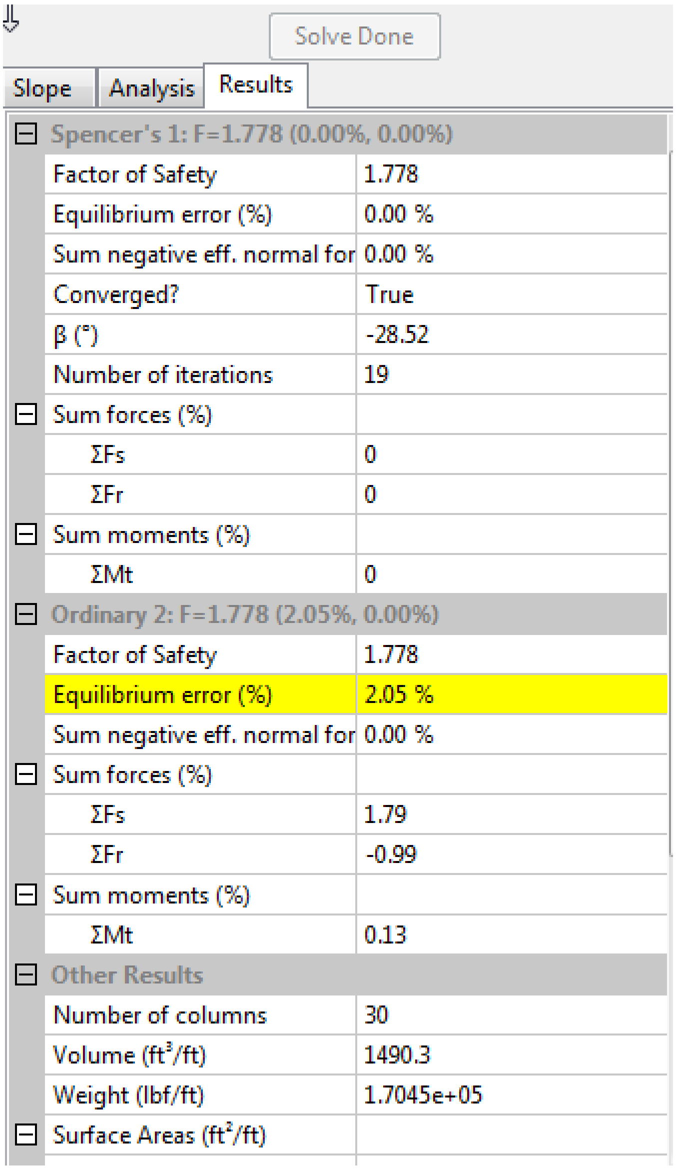
Congratulations!   You have carried out a successful slope stability calculation using TSLOPE.

The program firstly finds the critical circle for the Ordinary Method, then proceeds with the calculations for Spencer's Method.   We only present the critical circle for the minimum factor of safety calculated using Spencer's Method, and report out the corresponding results for Spencer's Method and the Ordinary Method using that circle.

TSLOPE compiles a report as you work through the various steps of the analysis. This can be viewed by selecting Print Preview Report from the ***File*** menu.

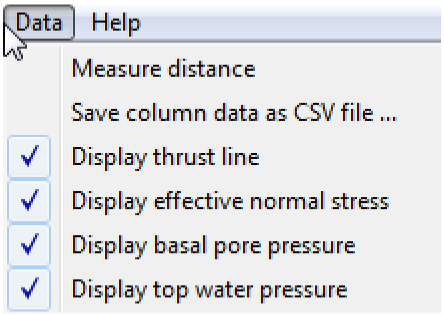


The lower left panel gives further information related to the stability calculations:



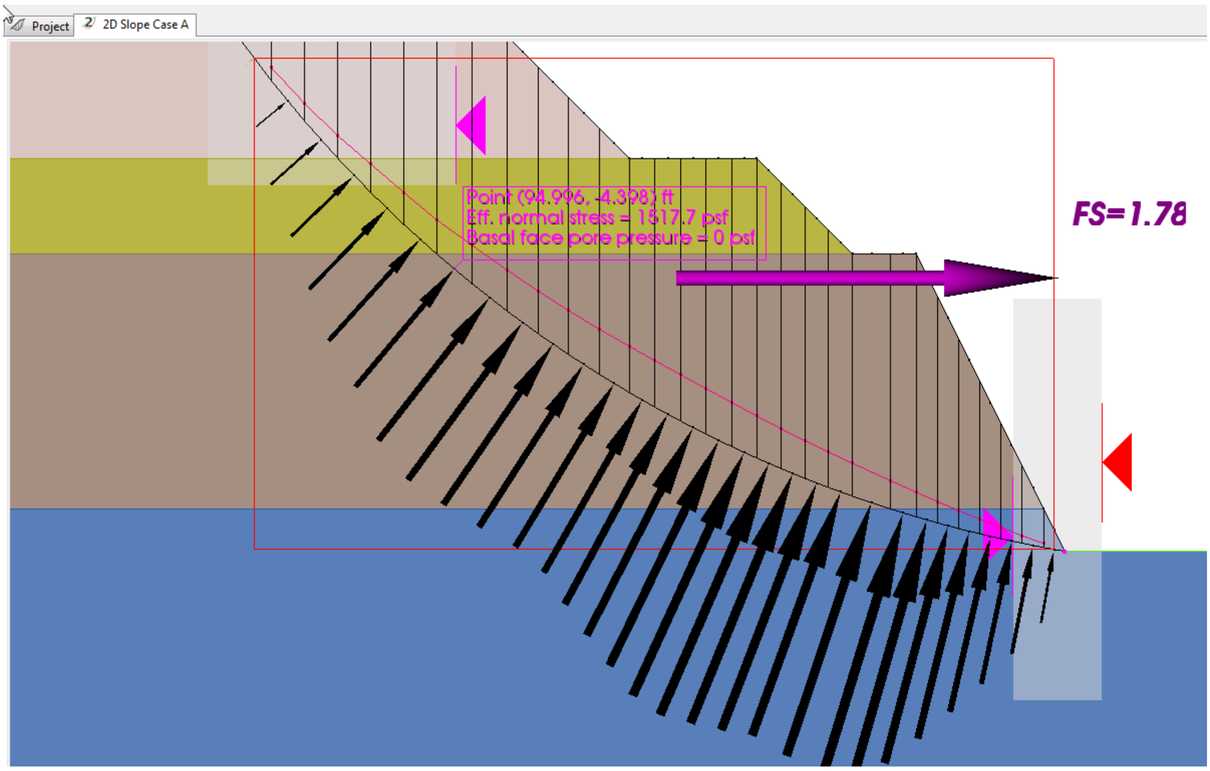
Note that the factor of safety calculated by Spencer's and Ordinary Method are the same, and close to the results tabulated from other software packages by Duncan et al. (2014).

Full data from the stability analysis can be sent to a .csv file by selecting the Save column data as CSV file… option from the ***Data*** menu.



Further information related to the calculations can be obtained by ***Ctrl left mouse click*** on a point in the graphics panel.

The black arrows show effective normal stress at the base of each slice, and the red line above the failure surface is the calculated line of thrust.



You may not have exactly the same factor of safety that is shown above. It depends on how you have set the limits for the potential slip circle, which is the area shaded in grey.

With the present implementation of TSLOPE, we have not given the user access to the parameters that control the minimisation routine. As a guide, you should make the width of the zone between each of the limits as narrow as possible, so long as the exit point of the potential slip circle that is calculated is near the middle of the zone you will have a satisfactory result. It is recommended that you try a number of settings until you are able to find a minimum factor of safety, but at all times making sure that the circle that you are investigating is credible.

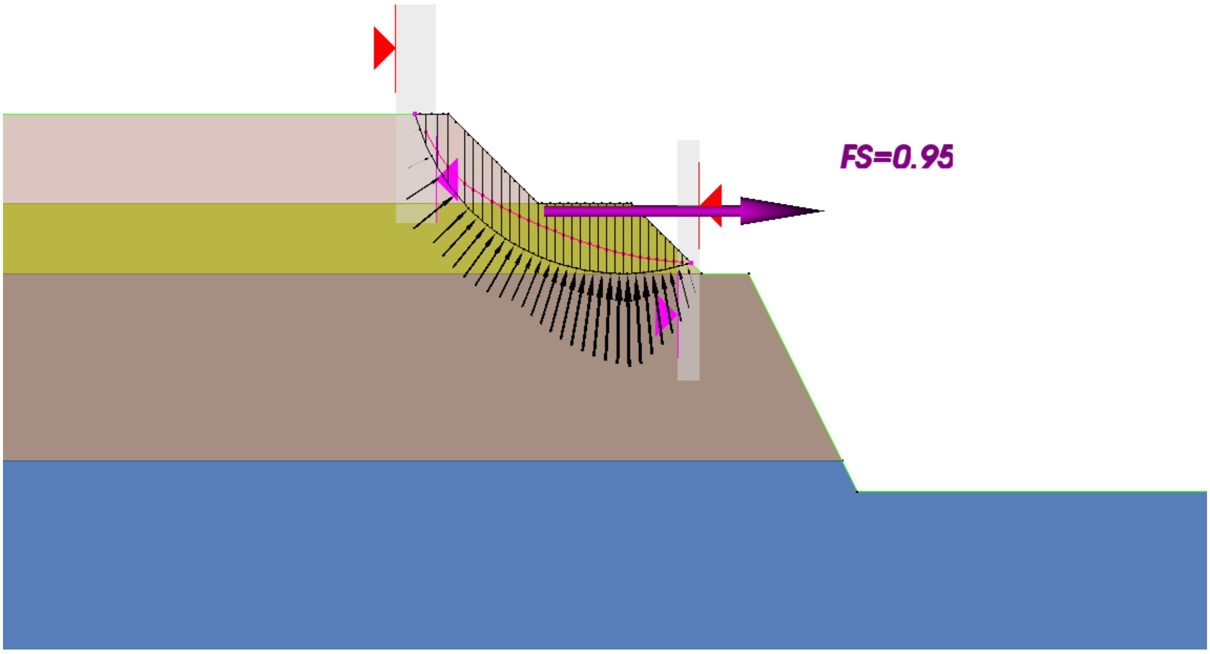
For this example, it would seem a good idea to check on other potential modes of slope failure.

Given the soil stratigraphy, it might be possible for a shallow near surface slope failure to occur in the Marsh Clay.

Therefore we will set up another 2D Slope Case to consider that possibility. We will call this 2D Slope Case B.

We recommend that you do not change the input parameters in a slope case that you have already run as this can lead to confusion. Set up a new slope case for each variation of the problem and the program will keep track of all the cases and results for you.

We will set up the new Slope Case following the steps we used for 2D Slope Case A. A new Basal surface is created, the Critical circle for slope 2, and we get the result shown in the next figure:



The above results suggests that the top of the London Clay might be a potential slide surface, therefore we should investigate a further 2D slope case where we set the Brown London Clay layer as a basal surface for the analysis.

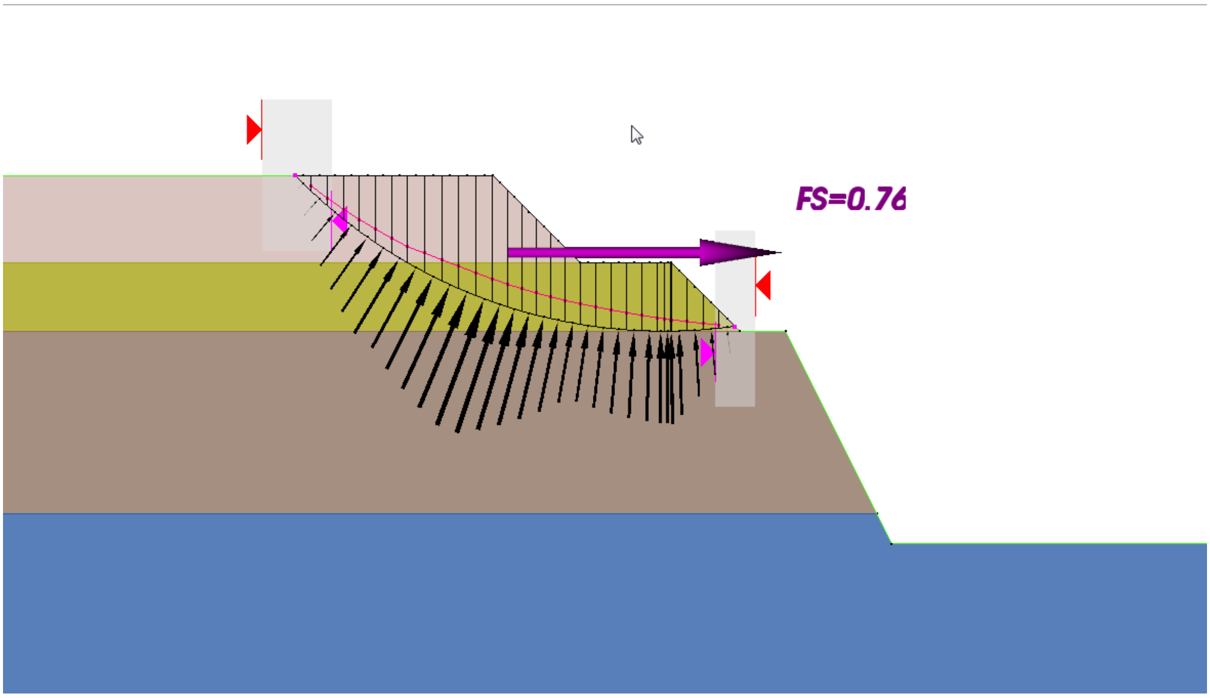
This is shown in the Slope panel for a new 2D Slope Case C:

Solve

Slope | Analysis

Slope 3	
Label	2D Slope Case C
Description	
Dimension	2D
Cross-section	1: Cross-section 1
Surfaces	
Top	1: Excavation surface
Basal	4: Critical circle 4 for slope 3
Phreatic	None
Pore-pressure	None
Layer as basal	3: Brown London Clay
Boundary line	
Boundary line	None
Loads	
Load case	No Loads
Visual Properties	
Background colour	White
Min. z	-60

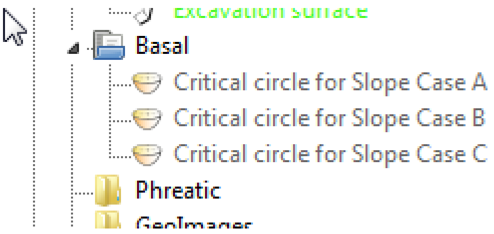
When we ***Solve*** this Slope Case, we get the following result:



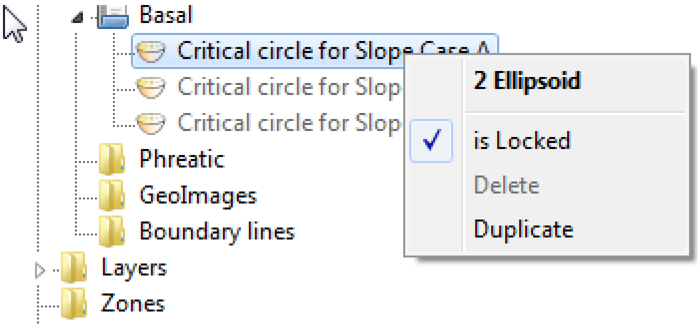
6. Building a 3D Slope Case

To build a 3D slope case, we follow the same procedure as with a 2D slope case. We need to make sure that there is a defined basal surface that we can use; TSLOPE has not yet implemented a routine for 3D search for a critical surface.

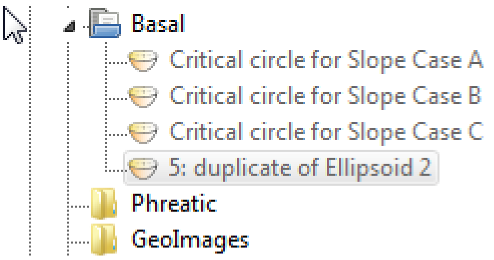
Reviewing the basal surfaces we have in the project; these are critical circles used for the 2D slope cases:



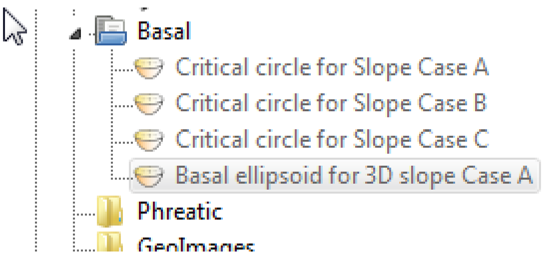
Mouse click on Critical circle for Slope Case A gives:



We will select the Duplicate option.

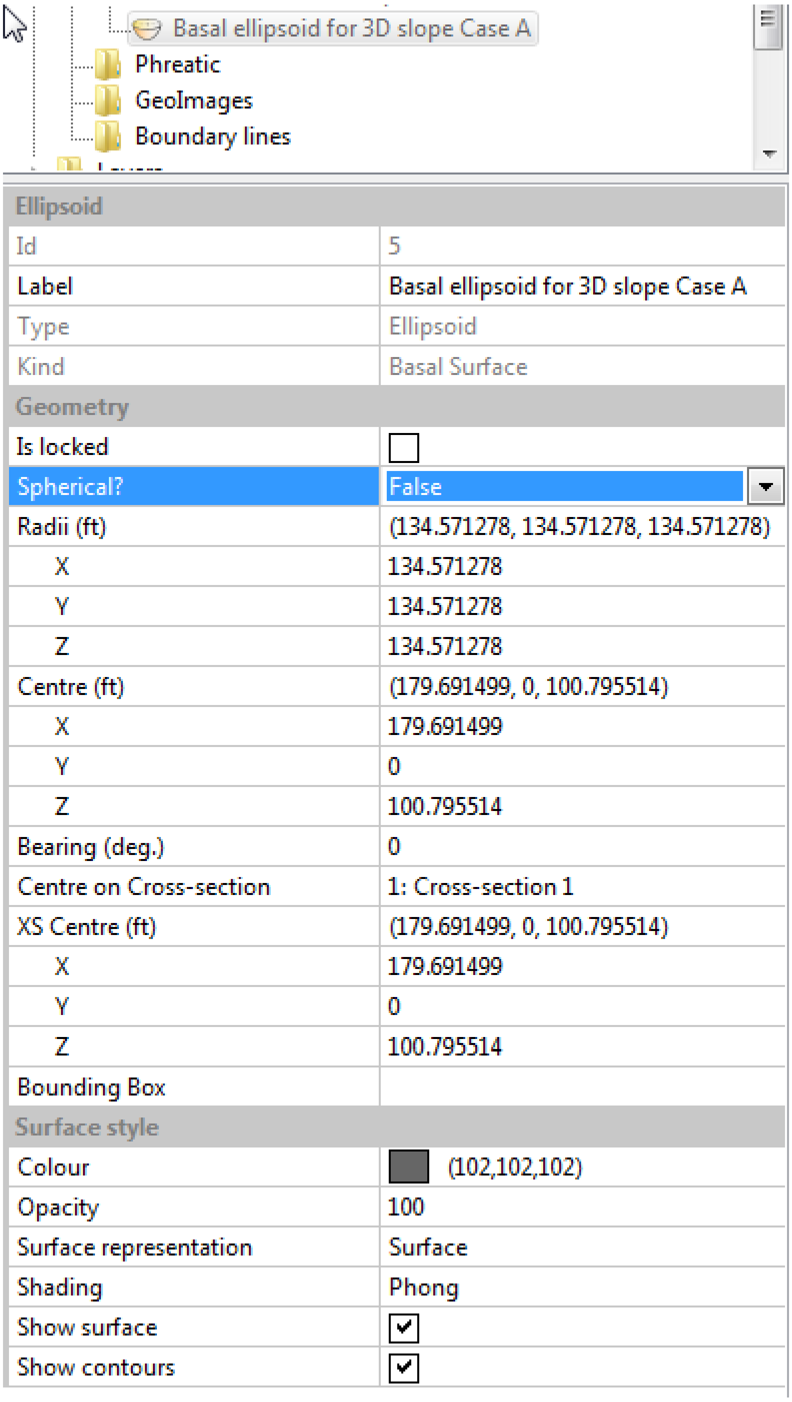


We will then rename the surface.



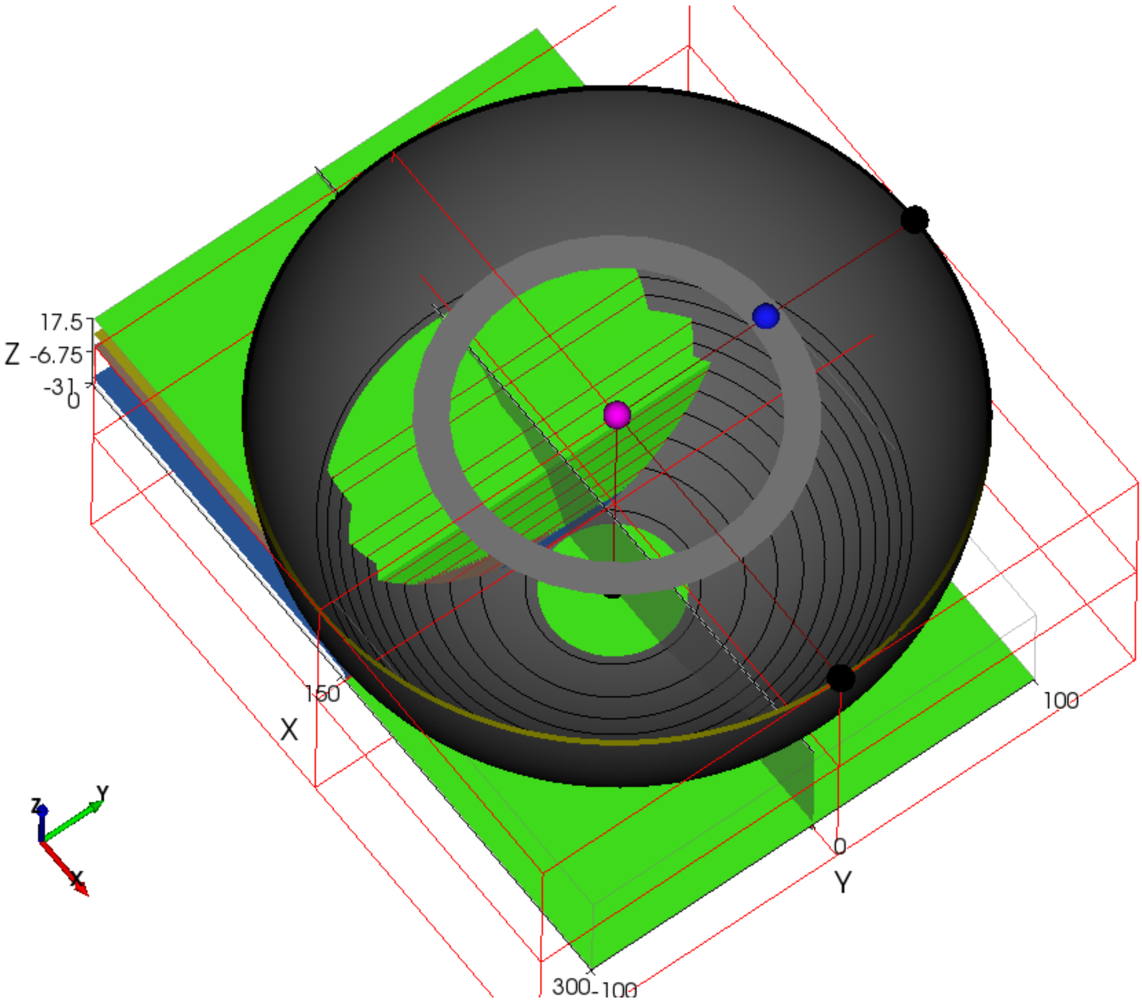
For each of the first three basal surface on the list, we will uncheck the boxes Show surface and Show contours so they are no longer visible in the Project view.

Checking the Basal ellipsoid for 3D slope Case A parameters:

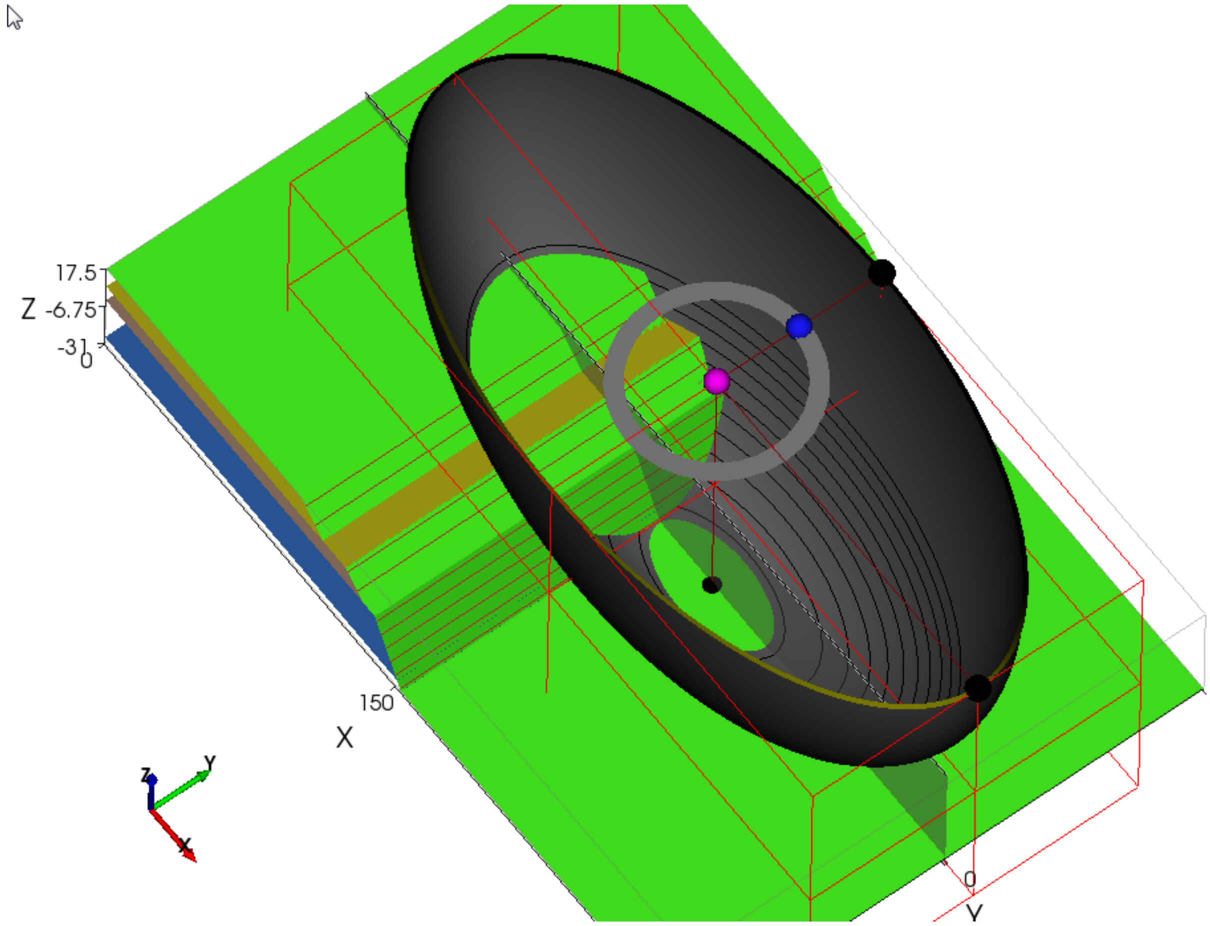


We change the Spherical? box to False

In the Project panel we see a graphical view of the ellipsoid (or sphere). The coloured balls can be selected by left mouse click and moved to change the lengths of the ellipse axes. We will move the black ball to change the Y radius of the ellipsoid.

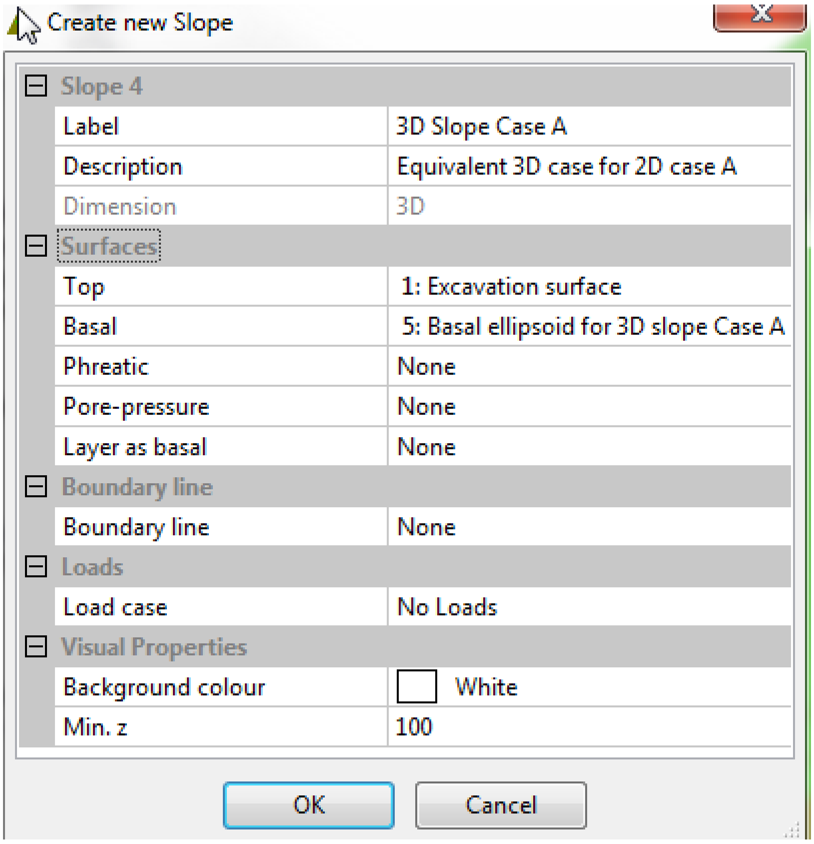


The next graphic shows the sphere modified to an ellipse elongated in the X axis direction.



When we have the ellipse with the appropriate geometry, we need to check the Is locked box in the Geometry panel.

From the Slope Cases menu item, we Add 3D Slope… and get the Create new Slope menu:

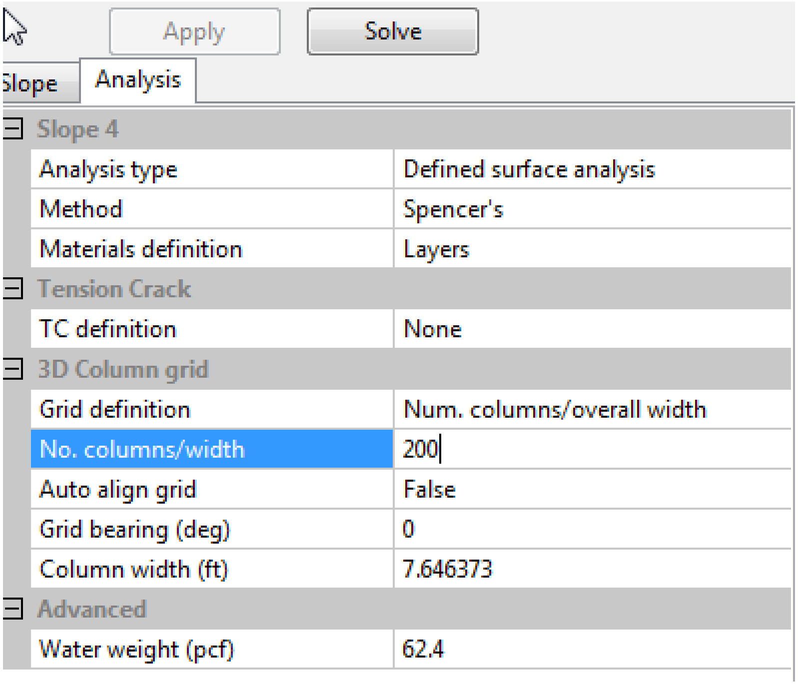


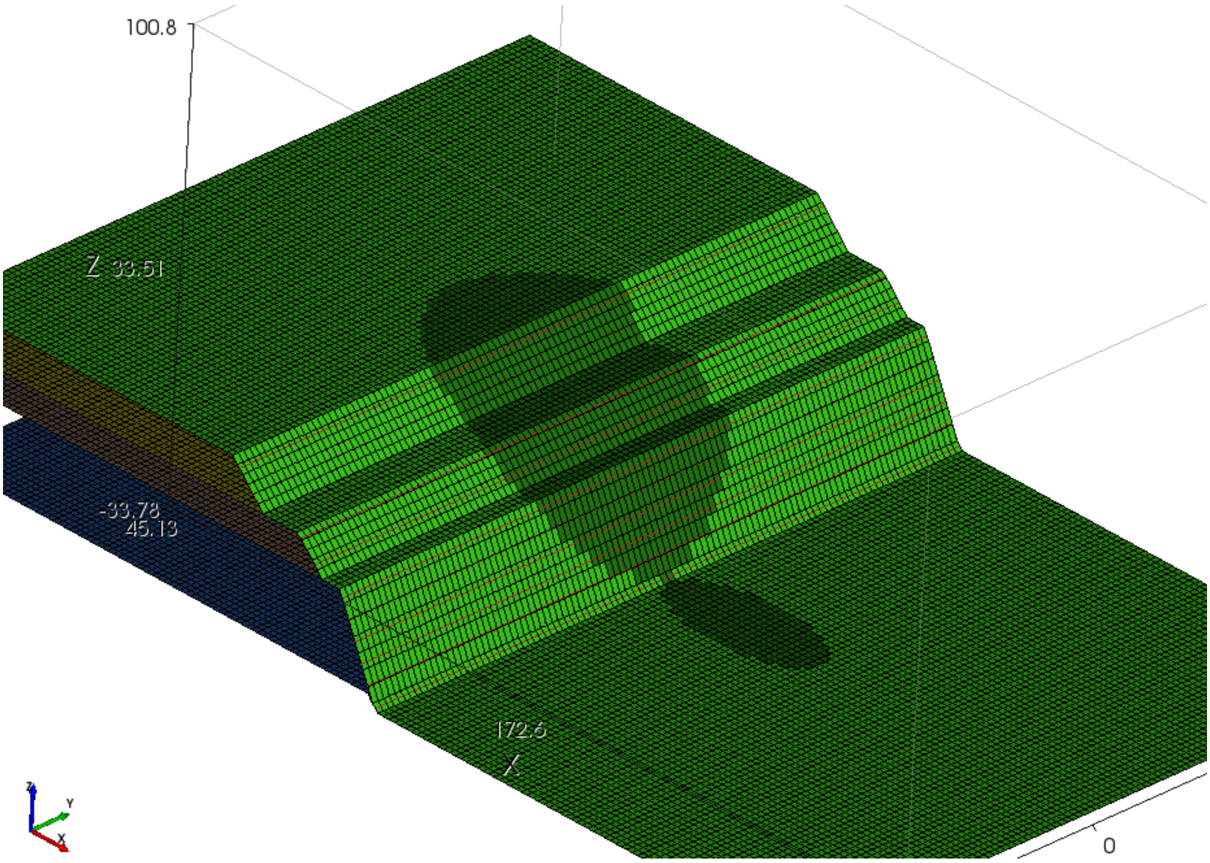
The default values for Surfaces are correct, and we can change the Label and add a Description.

When we select OK, we get a 3D view of the slope showing the discretisation with uniform vertical columns. The columns that overly the basal (failure) surface are shown in the darker shade.

There are relatively few columns that will be involved in the stability analysis, so we can increase the number of columns to provide a better model without potential edge effects.

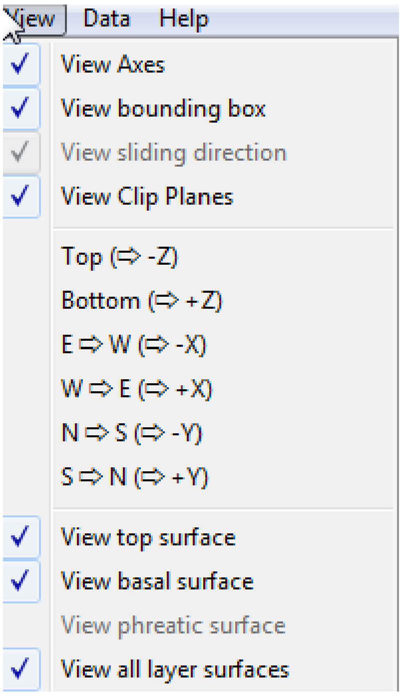
In the Analysis panel, we increase the No. columns/width to the maximum allowed, 200.


Apply
Solve
Slope
Analysis
Slope 4
Analysis type
Defined surface analysis
Method
Spencer's
Materials definition
Layers
Tension Crack
TC definition
None
3D Column grid
Grid definition
Num. columns/overall width
No. columns/width
200
Auto align grid
False
Grid bearing (deg)
0
Column width (ft)
7.646373
Advanced
Water weight (pcf)
62.4

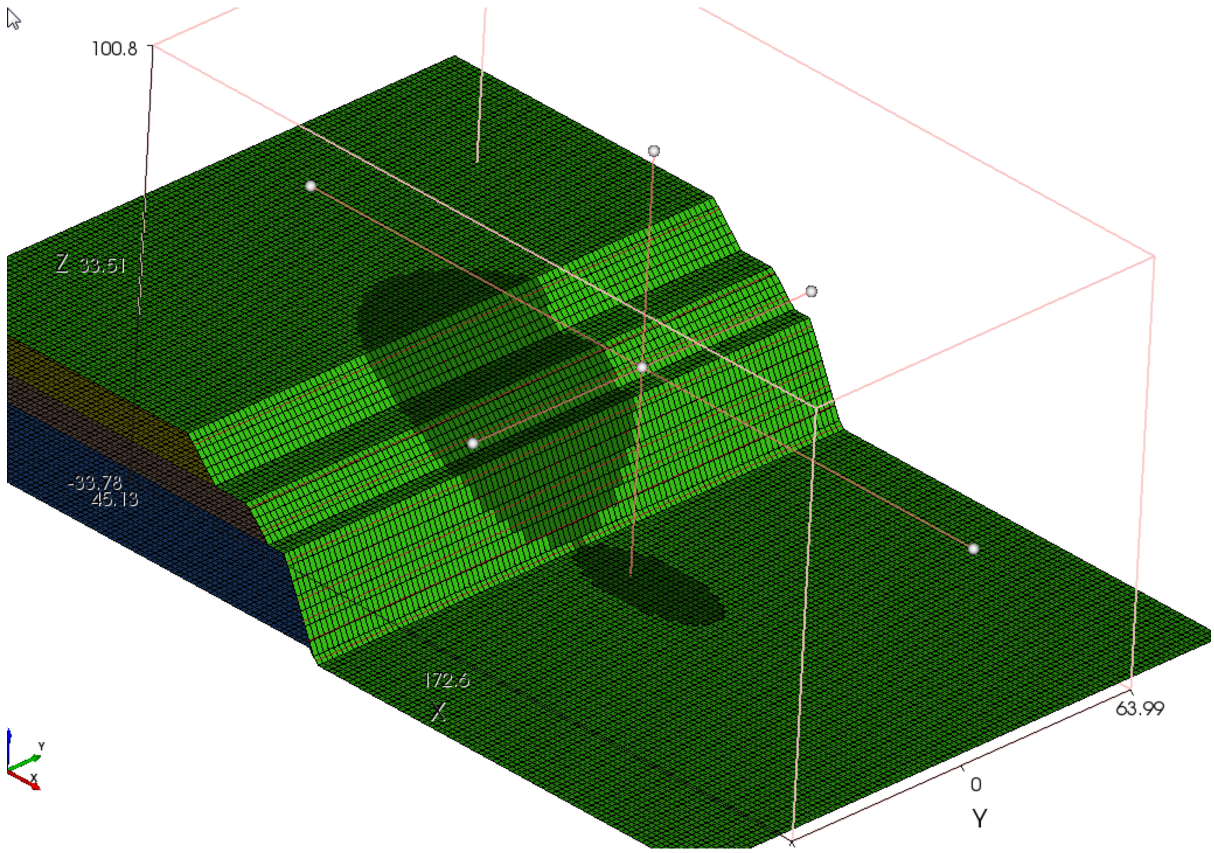

100.8
Z 33.51
-33.78
45.13
172.6
X
0

The ellipsoid that we have used to locate the active columns in the stability analysis extends beyond the slope, and includes the base of the excavation. To be consistent with the 2D analysis, we need to limit the model to the base of slope.

To do this, we go to the ***View*** tab and check the View Clip Planes box.



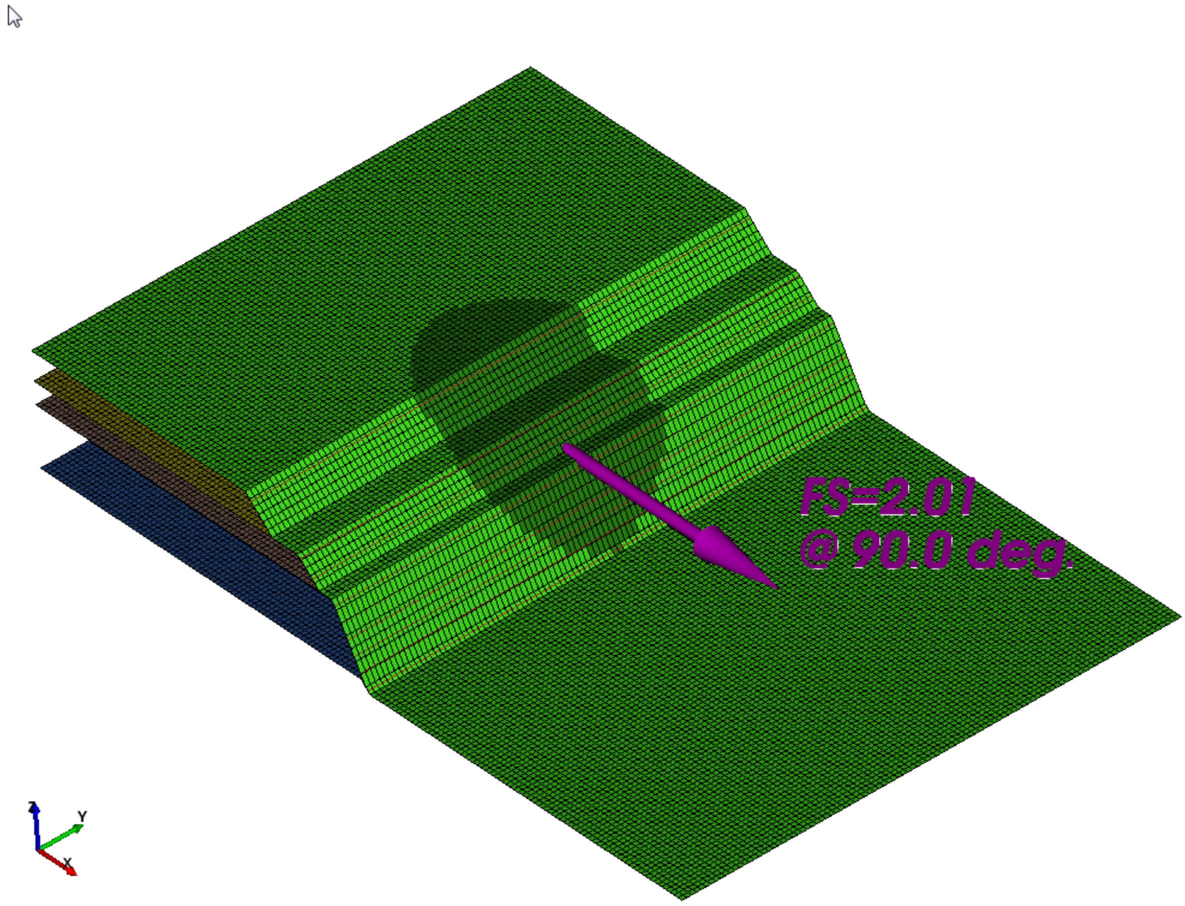
The graphic view of 3D Slope Case A then changes:



Left mouse click on one of the balls at the ends of the axes, and move as necessary to clip the model. As you move the ball, you will see the associated clipping plane move with it. In this example, we need to move the ball located at X=300 Y=0 towards the slope, until the plane coincides with the foot of the slope. The columns at the base of the excavation will not be part of the stability analysis.

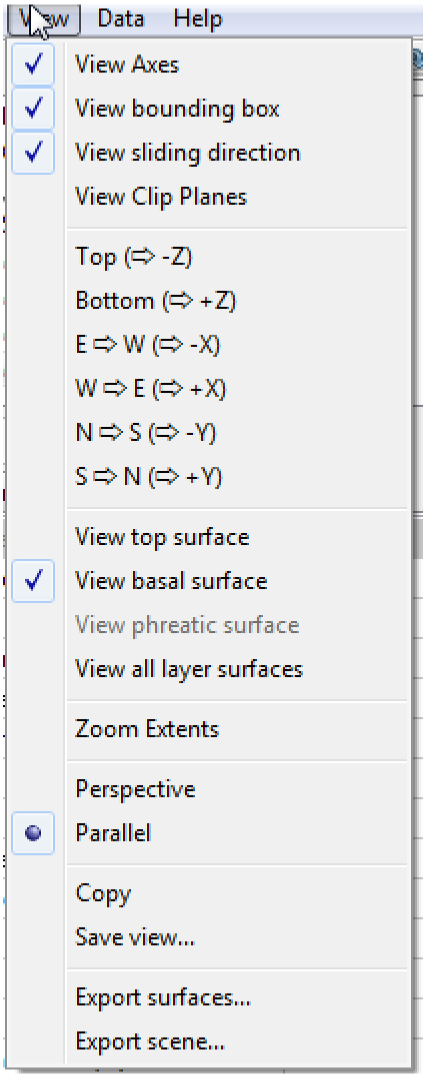
When we have the clipping planes in their correct place, we hit the ***Apply*** button. We can then turn the clipping planes off from the ***View*** menu.

Selecting the Solve button, the 3D slope stability calculations are carried out:

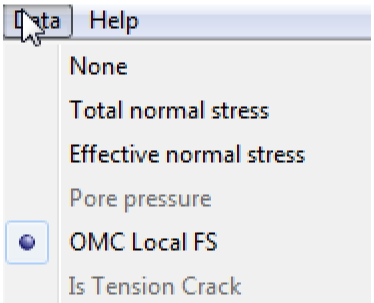


The graphic output shows the factor of safety (Spencer’s Method), and the direction of sliding.

Selecting the ***View*** tab and selecting only the View basal surface option, we can then show other parameters at the base of each column.



From the ***Data*** tab:



The graphic view of the 3D Slope Case A will now show the local factors of safety,that is the ratio of resisting to driving forces at the base of each column as calculated using the Ordinary Method of Columns.