Generalized Anisotropic Material

1. Introduction

This tutorial describes how to simulate an anisotropic material in Slide2. There are actually five different ways to do this, but the emphasis of this tutorial will be on using the Generalized Anisotropic option, which allows you to specify different material types in different directions. The tutorial will also explain how to perform a probabilistic analysis with this type of material.

The finished product of this tutorial can be found in the *Tutorial 20 Generalized Anisotropic.slmd* data file. All tutorial files installed with Slide2 can be accessed by selecting **File > Recent Folders > Tutorials Folder** from the Slide2 main menu.

2. Model

For this tutorial, we will read in a file.

Select **File > Recent Folders > Tutorials Folder** from the Slide2 main menu, and open the *Tutorial 20 Generalized Anisotropic start.slmd* file.

MATERIAL PROPERTIES

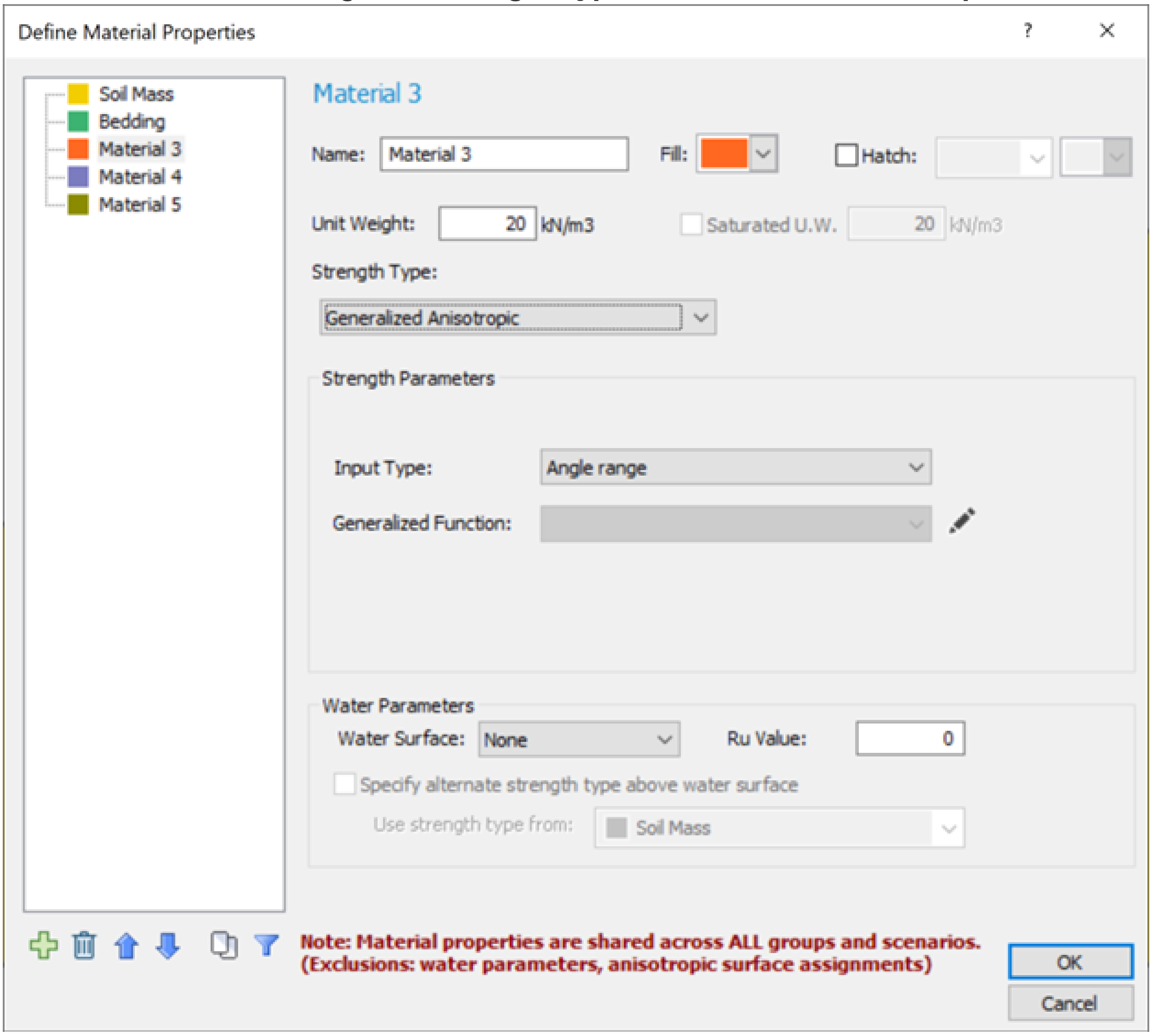
For the slope material, we will use the **Generalized Anisotropic** option. This allows you to specify different material types in different directions. (**Note:** there are other anisotropic material models available in Slide2, see the next section for information).

Before we set up the Generalized Anisotropic material, let's look at the sub-materials that make up the generalized material. For this example, we will assume the soil has weak, subhorizontal bedding. Two materials have been set up: one that represents the direction parallel to bedding and one that represents all other orientations.

1. Select **Define Materials** from the **Properties** menu.

   Look at the **Soil Mass** and **Bedding materials**. So in this case, both sub-materials use **Mohr-Coulomb** strength but have different values of cohesion and friction angle. These two materials will be assigned to a Generalized Anisotropic material as described below.

2. Click on **Material 3.** Change the **Strength Type** to **Generalized Anisotropic.**

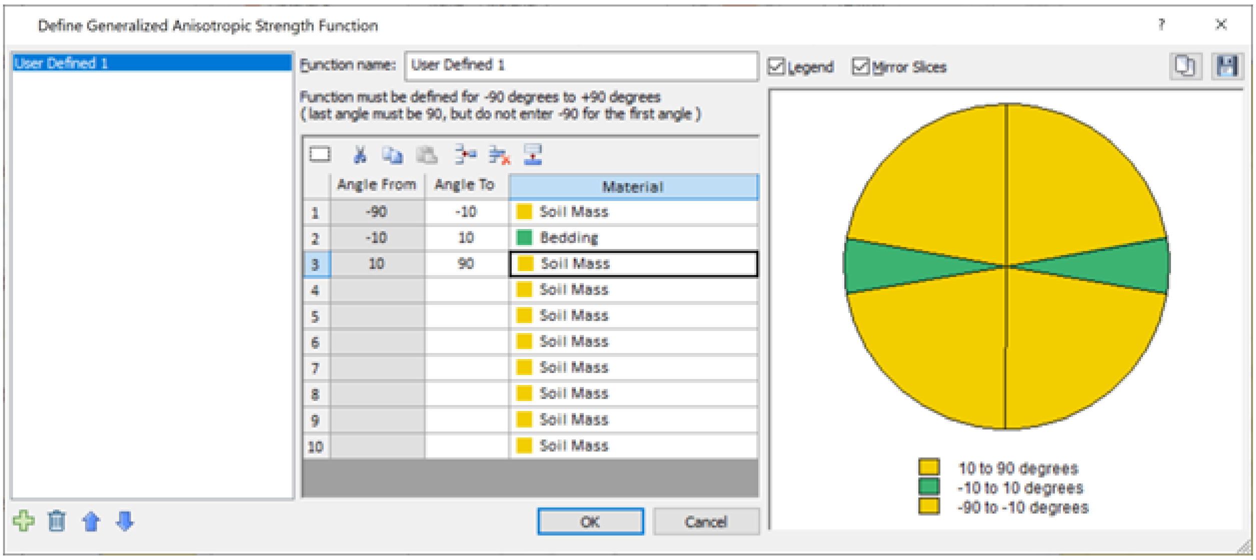


Notice the Input Type dropdown which contains the options “Angle range” and “Angle or surface, A, B”. We will look at both Input Types in this tutorial. For now, keep Input Type as Angle range.

3. Click the **pencil** icon next to the Generalized Function input.

   You will see a dialog in which you can specify different materials over different angular ranges. We want the Bedding material to be active within plus/minus 10° of horizontal and the Soil Mass to be active in all other directions. Angles in the dialog are measured from horizontal, so 90° represents vertical.

4. Enter **–10** in the **Angle To** column. Leave the **Material** as **Soil Mass**.
5. In the next row, enter **10** in the **Angle To** column and change the **Material** to **Bedding.**
6. Finally, in the next column, set the **Angle To = 90** and leave the **Material** as **Soil Mass**. Select **OK**.



Material 3 is now assigned the Generalized Function 'User Defined 1'. The material is currently named "Material 3." Rename it to "Angle Range."

7. Click **OK** to close the Define Material Properties Dialog.

ANISOTROPIC MATERIAL MODELS IN SLIDE2

There are actually five different anisotropic material strength models available in Slide2. These are:

- Anisotropic Strength
- Anisotropic Function
- Anisotropic Linear
- Generalized Anisotropic
- Modified Anisotropic Linear

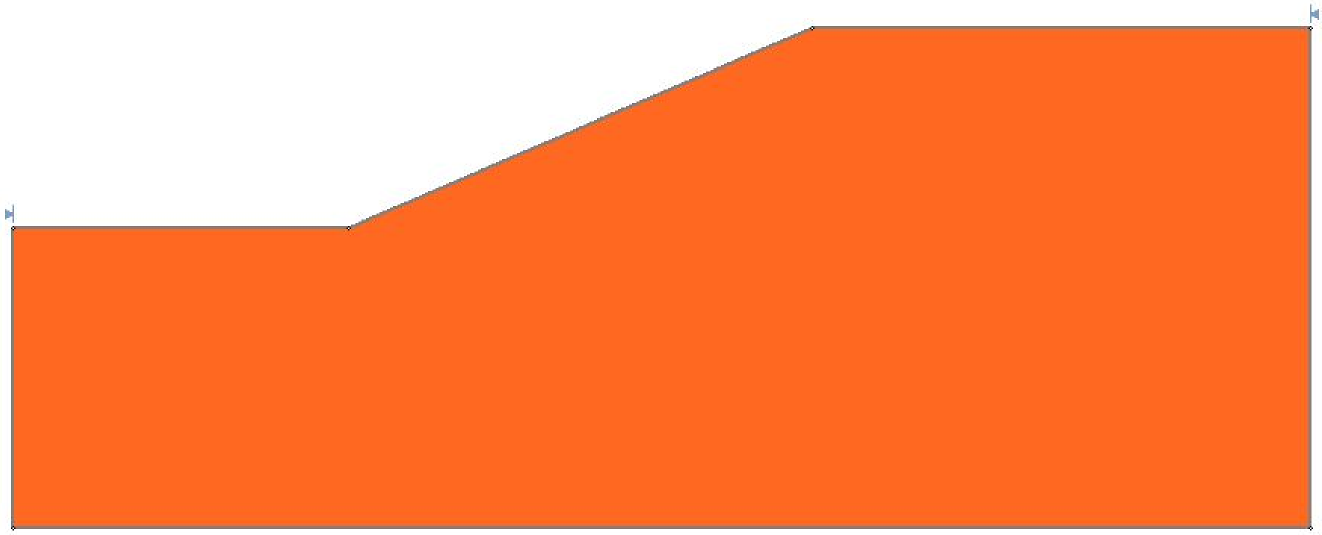
For this tutorial, you could create the same model using the **Anisotropic Function** strength type, which allows you to define discrete angular ranges with Mohr-Coulomb properties. However, the **Generalized Anisotropic** strength type offers the following advantages:

- Any material type can be assigned to each angular range. All of the materials do not have to have a Mohr-Coulomb failure criterion. You can mix and match any material types you wish (e.g. Hoek-Brown and Mohr-Coulomb).
- The Generalized Anisotropic strength type allows for probabilistic analysis whereas the Anisotropic Function strength type does not. This will be explored further later in the tutorial.
- You have the option of defining the anisotropic direction as an anisotropic surface. This too is explored further in the tutorial.

See the Slide2 Help system for details about the different anisotropic strength models which are available.

ASSIGN MATERIALS

By default, the slope is assigned **Material 1 (Soil Mass)**. We need to set the slope material to the **Generalized Anisotropic** material that you defined above. Right-click inside the model and select **Assign Material > Angle Range**. The model will look like this.

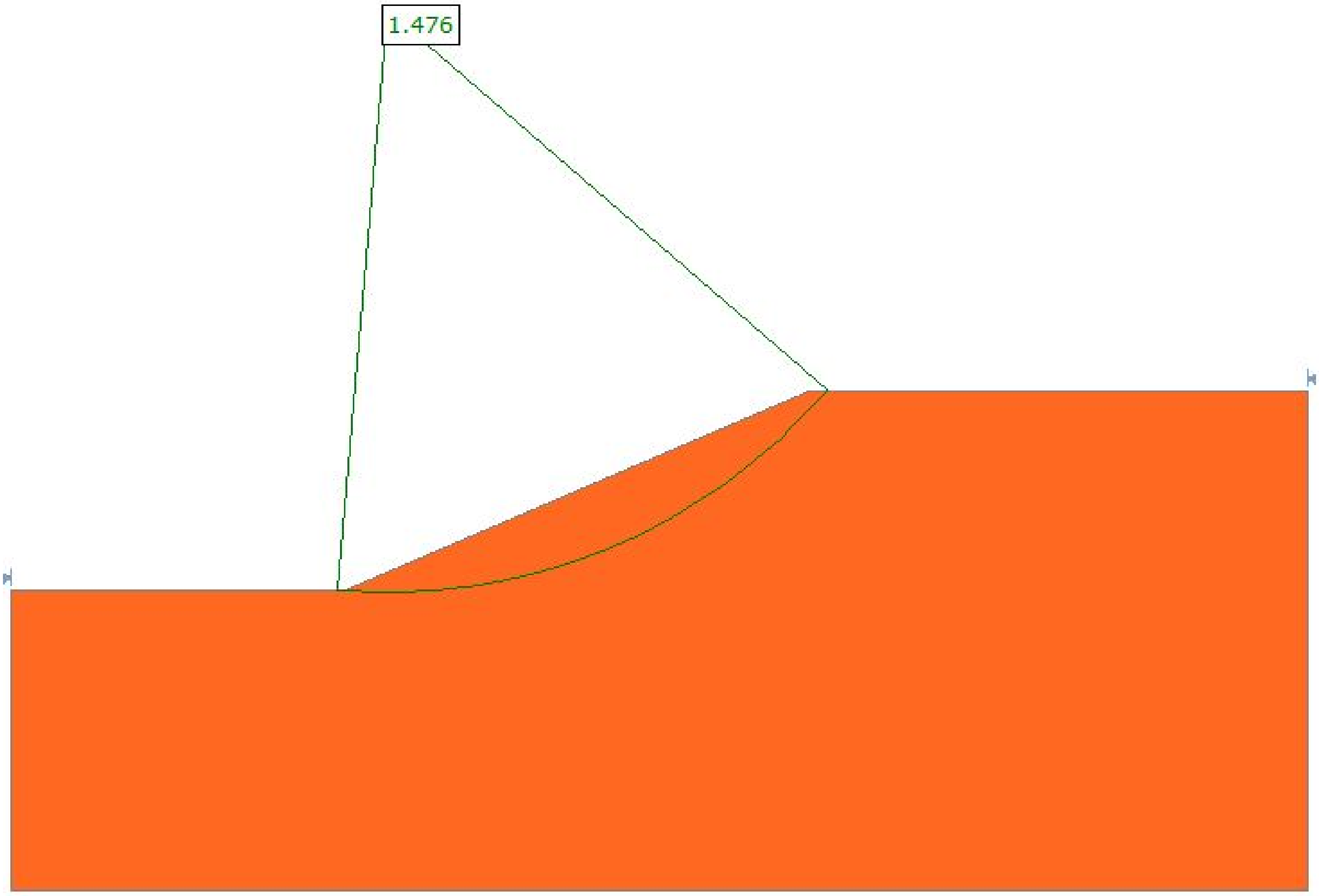


3. Compute

1. Save the model by selecting **File > Save As** in the menu.
2. Select **Analysis > Compute** in the menu to perform the analysis.
3. Then select **Analysis > Interpret** to view the results.

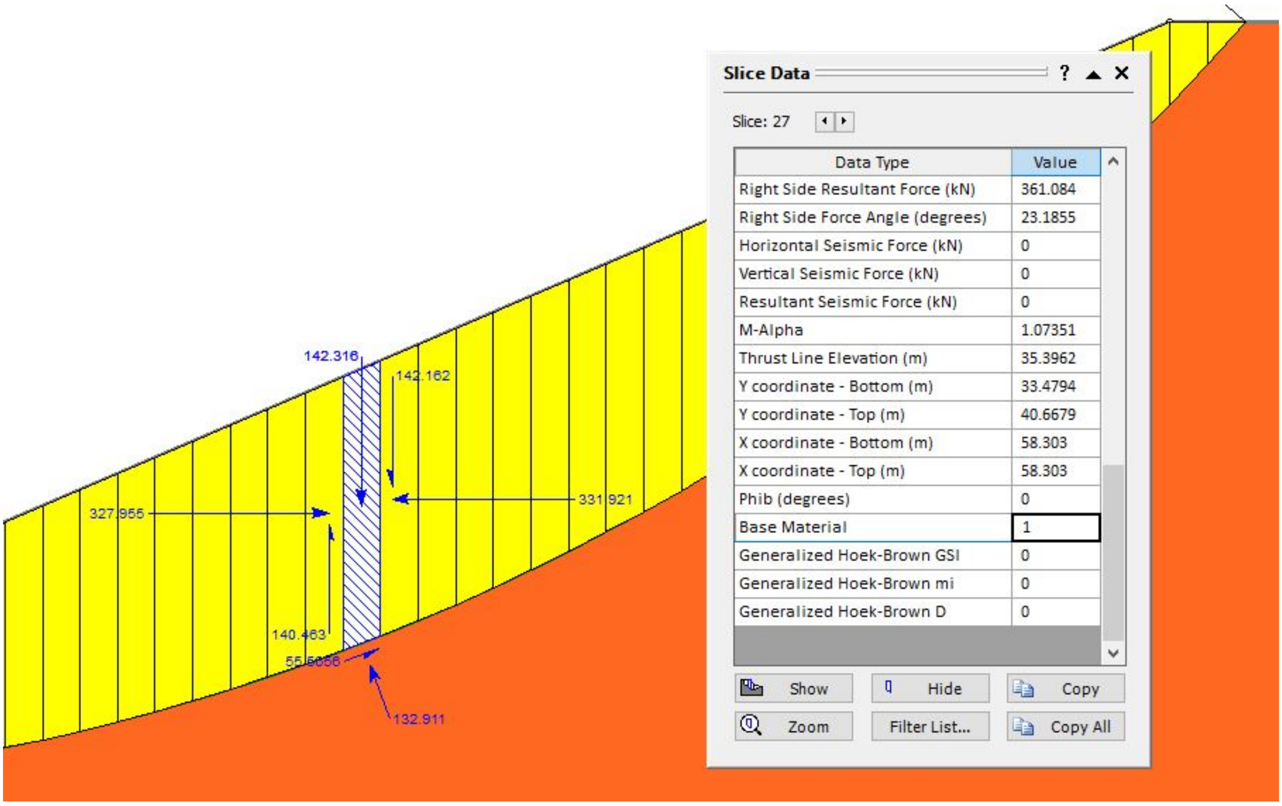
4. Interpret

The **Interpret** program shows the results of the Spencer analysis. You can see that the factor of safety is about 1.48.



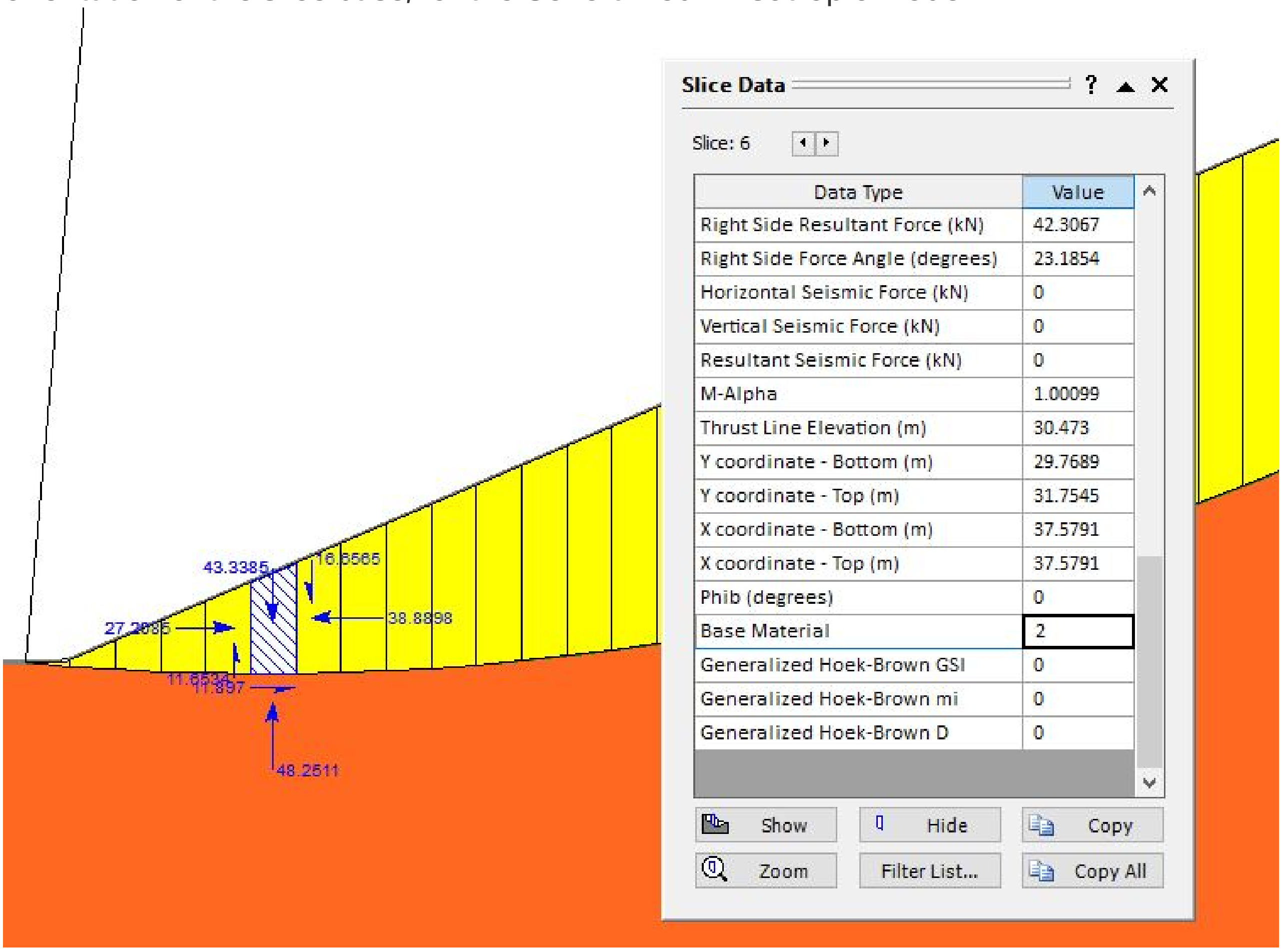
The limit equilibrium method calculates the stability of each possible failure surface by dividing up the circular area into slices and comparing the shear stress and strength on the base of each slice. With the Generalized Anisotropic material model, the angle of the base of each slice determines which material is used to calculate the strength.

1. Go to **Query > Query Slice Data**.
2. Click on a slice about halfway down the slope.
3. In the Slice Data dialog, scroll down to the bottom so that you can see the **Base Material**. For this slice, it should be 1 (Soil Mass).



4. Now click on a slice near the toe of the slope.

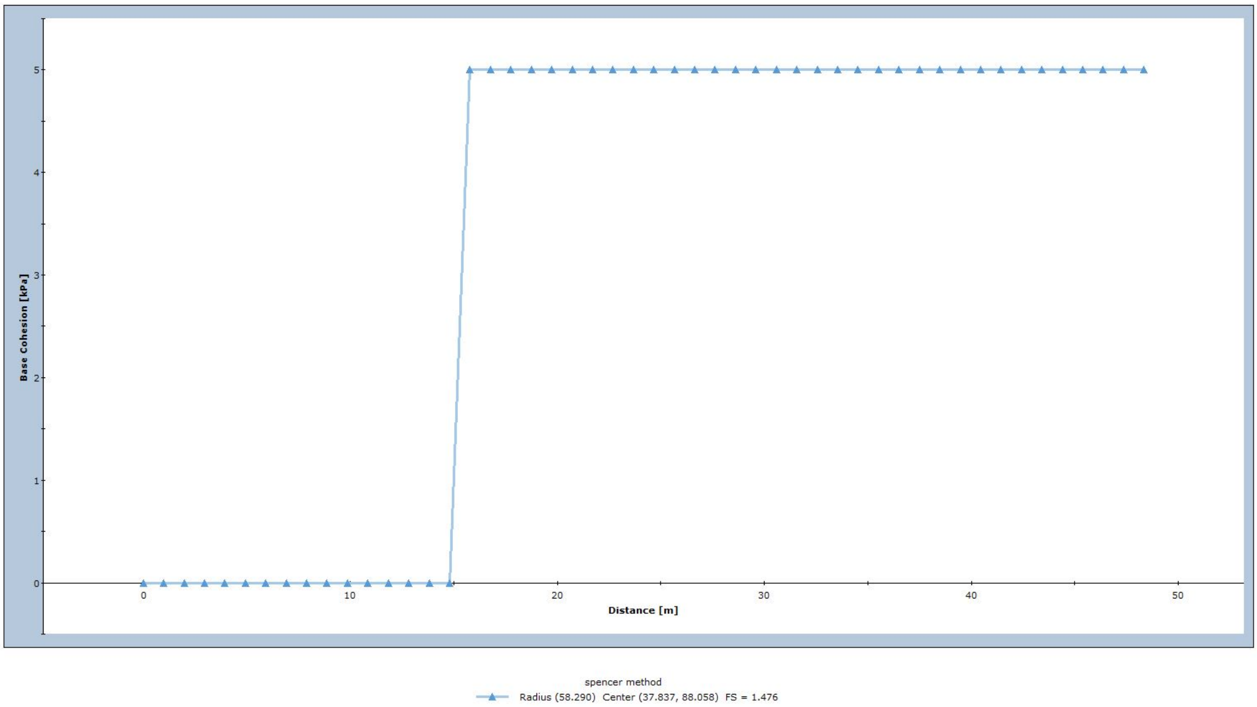
   In this region, the base of each slice is almost horizontal, so the base material is Material 2 (Bedding). This demonstrates how the applied strength model depends on the orientation of the slice base, for the Generalized Anisotropic model.



If you scroll back up in the Slice Data dialog, you will see that the base friction and cohesion reflect the values entered for Material 2 (c = 0 and φ = 20°).

5. Close the **Slice Data** dialog.
6. Now right click on the slip surface and select **Graph Query** from the popup menu.
7. In the **Graph Slice Data** dialog choose **Primary Data = Base Cohesion**.

   You should see the following plot, which shows the Bedding cohesion (=0) for the low base angle slices near the toe, and the soil mass cohesion (=5) for the higher base angle slices.



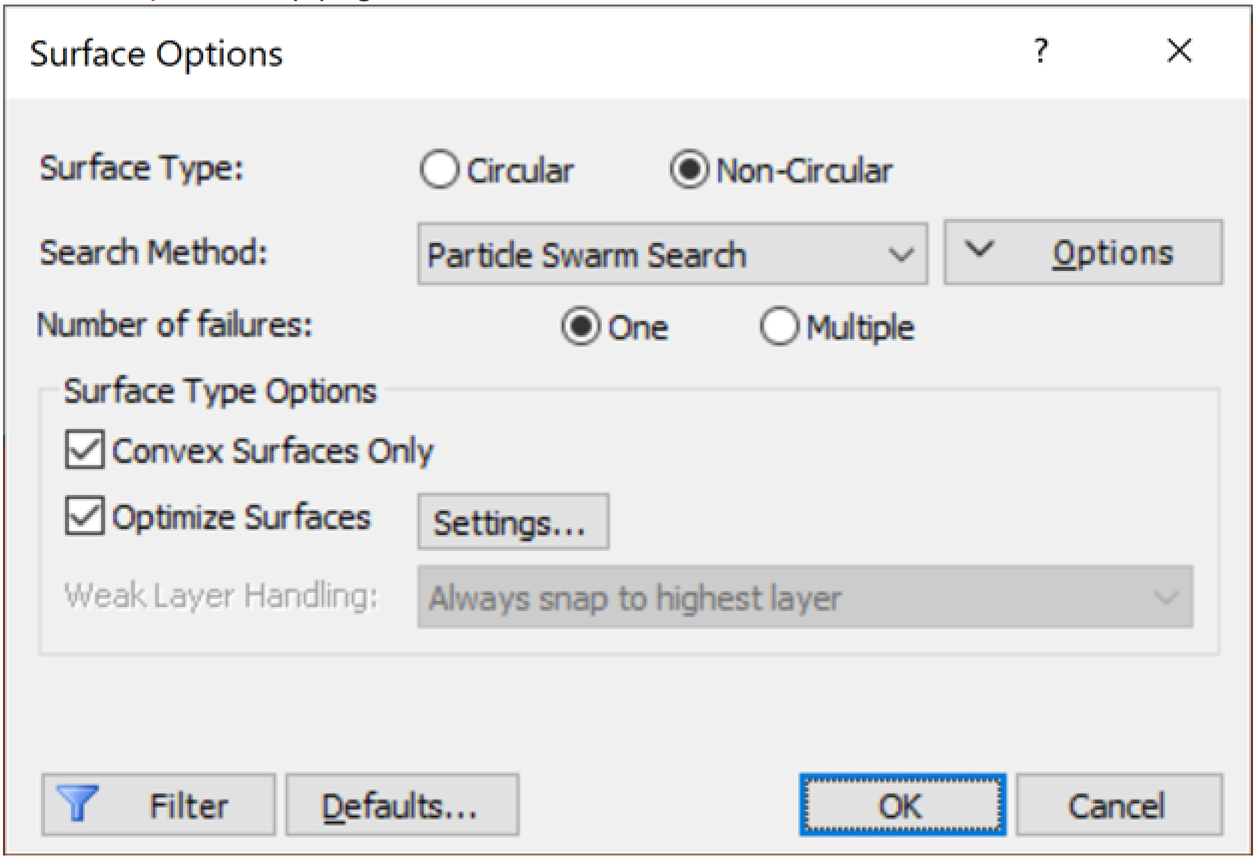
5. Non-Circular Failure Surface

Because of the weak bedding plane, it is likely that portions of the failure surface would tend to follow the bedding in a sub-horizontal direction. By forcing a circular failure surface, we are probably over-estimating the factor of safety. We can easily test this by specifying a non-circular failure surface and observing the results.

1. Go back to the Slide2 Model program.
2. Select **Surfaces > Surface Options**.
3. Under **Surface Type**, choose **Non-Circular**.
4. Under **Search Method**, choose **Particle Swarm Search**.

   This method will automatically search for the critical non-circular surface. See the

Surface Options help page for more information.



5. Click **OK** to close the dialog.

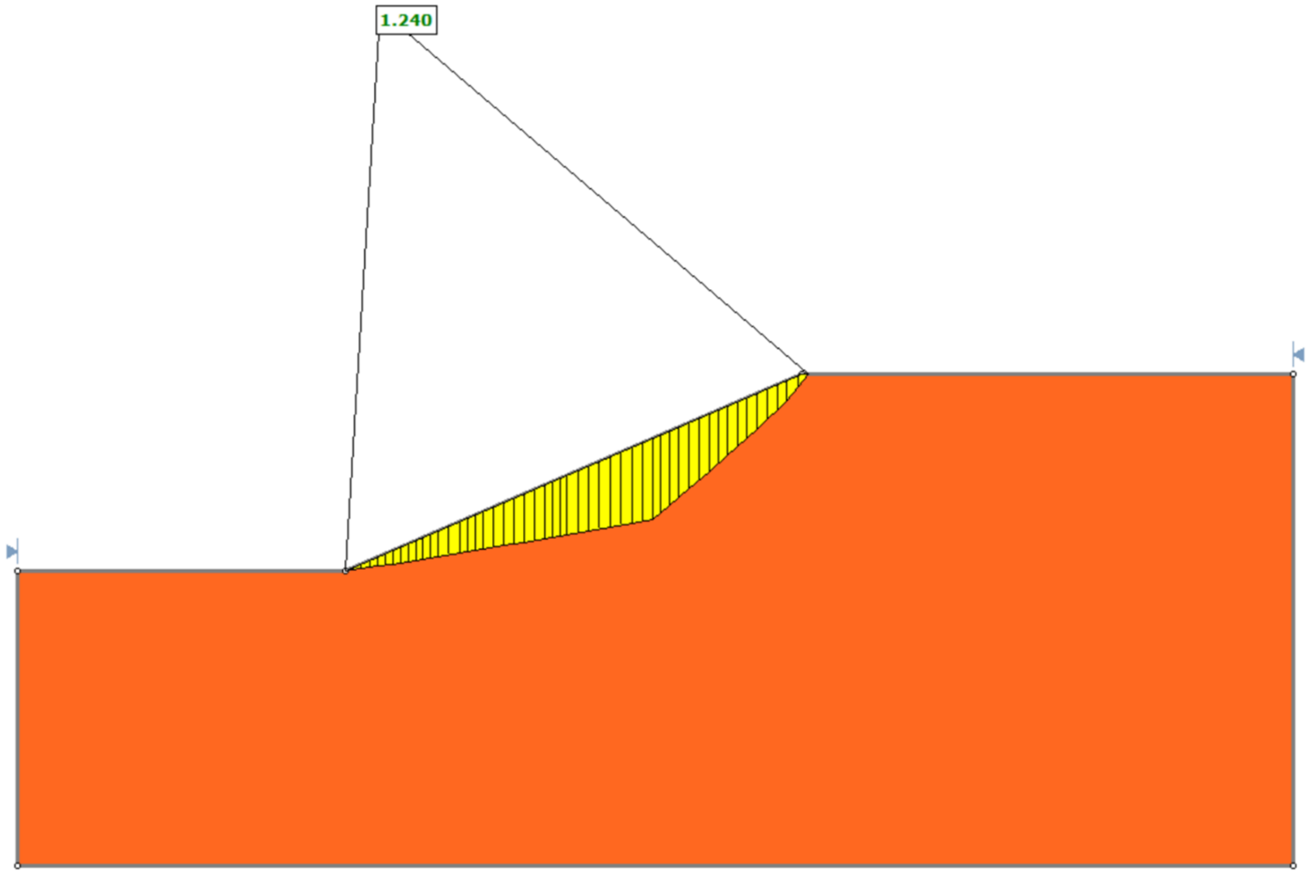
6. Compute

1. Save the model and then select **Analysis > Compute**.
2. Select **Analysis > Interpret** to view the results.

7. Interpret

You can see that the factor of safety is about 1.24. Notably less than the value of 1.48 calculated assuming a circular surface. It is also interesting to observe the shape of the critical surface – a section of sub-horizontal slip connected to the ground surface by a steep incline. If you query the slices that make up the sub-horizontal section, you will see that the base material for each slice is Material 2 (Bedding).

This shows the importance of using a non-circular failure surface in anisotropic models since the failure surface 'seeks out' the weak bedding orientation to yield a lower factor of safety.



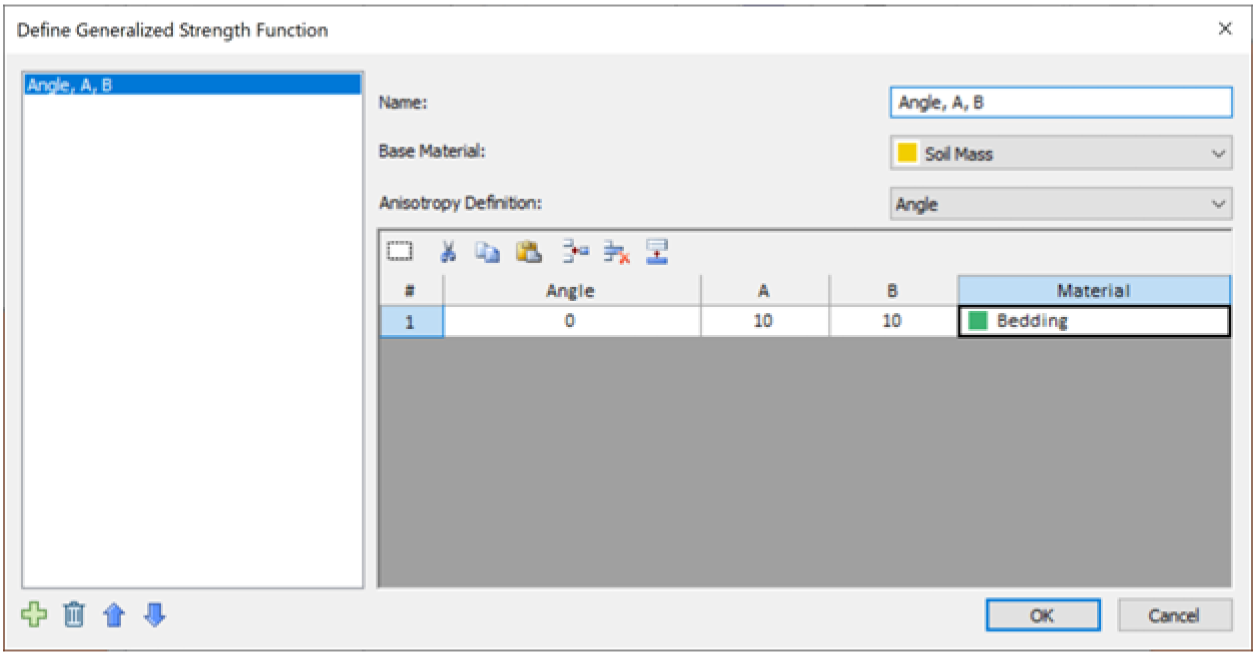
8. Input Type = Angle or Surface, A, B

One assumption of the **Input Type = Angle** range option, is that the strength of applied to the base of the slice is discrete, meaning that if the angle is in one range it takes the strength of one material, and in the other it takes the strength of the other material. However, there may be cases where you would want to consider an interpolation of the strengths of the Soil Mass and Bedding materials.

1. Return to the Slide2 modeler.
2. Right-click on **Group 1 – Master Scenario** in the Document Viewer and select **Add Scenario**.
3. Rename this child scenario **"Input = Angle, A, B**" using the right-click option.
4. Ensure you are in the child scenario. Select **Material 4** and name it "**Angle, A, B**". Now select the following:
   - Strength Type = Generalized Anisotropic
   - Input Type = Angle or surface, A, B
5. Click on the pencil to define the function. Users of Slide3 will recognize this dialog as the same on used in Slide3's Generalized Anisotropic function.
6. Define the following:
   - Name = Angle, A, B
   - Base Material = Soil Mass
   - Anisotropy Definition = Angle

7. And input the following row in the grid:
    - Angle = 0
    - A = 10
    - B = 10
    - Material = Bedding

The dialog should look as follows:



The way this is interpreted is as follows. At an angle of "Angle +/- A" (i.e. 0 +/- 10), the strength of Bedding will be applied. Otherwise, Base Material (i.e. Soil Mass) will be applied. This is identical to the function we defined previously using the Input Type = Angle Range option. (Note that due to the algorithmic difference, the results between this definition of anisotropy and the previous may exhibit a negligible numerical difference).

8. Now set B to 40.

    This means that in the ranges listed below, the strengths of Soil Mass and Bedding will be interpolated:

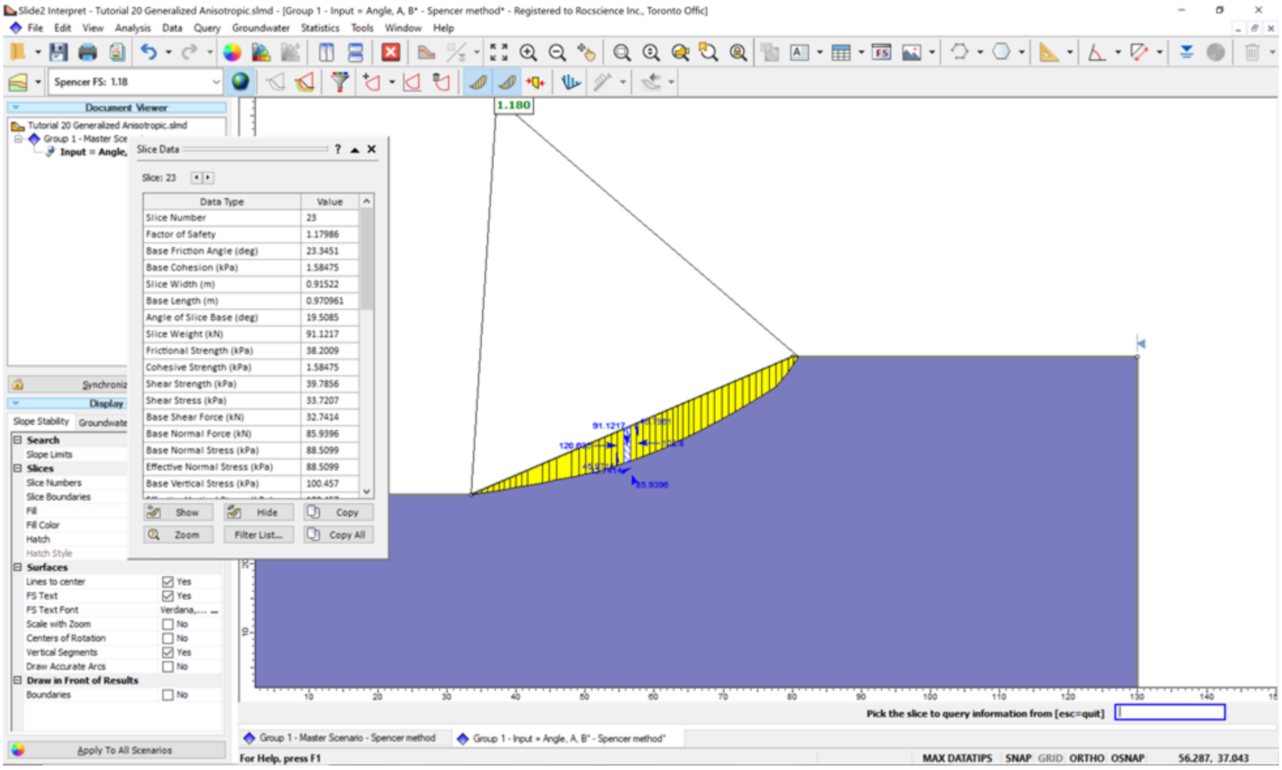
    - [Angle + A, Angle + B] = [0 + 10, 0 + 40] = [10, 40]
    - [Angle – A, Angle – B] = [0 – 10, 0 – 40] = [-10, -40]

9. Click **OK**, and click **OK** again in the Define Material Properties dialog.
10. Right-click on the slope and select **Assign Material > Angle, A, B**. **Compute** the model and select **Analysis > Interpret** to view the results.

    Notice that the FS has gone down considerably, since we have gradually expanded the anisotropic range.

11. Select **Query > Query Slice Data** and click on a slice towards the middle.

    Notice that the base cohesion is a value between the 0 and 5 kPa of the Bedding and Soil Mass materials respectively; it has been interpolated.



    In the Slice Data dialog, you can also see that the "Angle of Slice Base" falls in the [10, 40] range as expected.

12. Return to the modeler and define another child scenario named "**Input = Surface, A, B.**" Ensure you have the scenario selected.

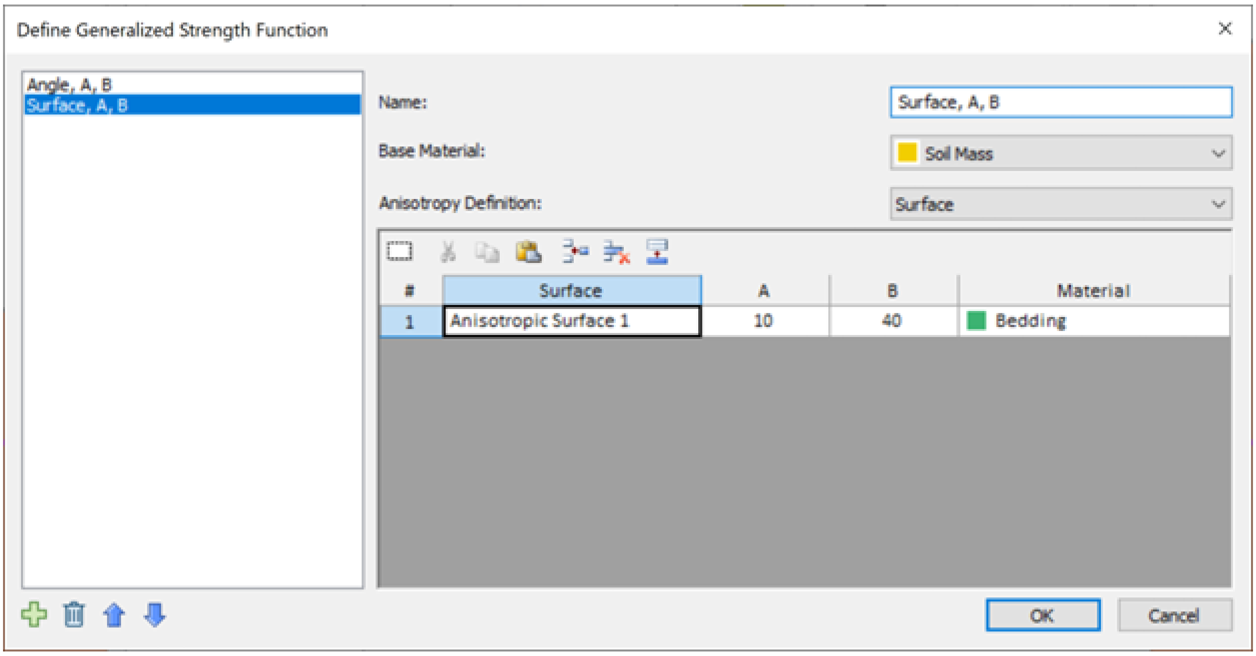
    We will define the same case with an anisotropic surface.

13. Select **Boundaries > Add Anisotropic Surface**.
14. Input the points: **(-2, 20)** and **(132, 20)**, pressing **Enter** after each one. Press **Enter** again to finish.
15. Double-click on the slope to open the Define Material Properties dialog and now select **Material 5**. Name it "**Surface, A, B**".
16. Now select the following:
    - Strength Type = Generalized Anisotropic
    - Input Type = Angle or surface, A, B
17. Click on the pencil to define a new function. In the Define Generalized Strength Function dialog, select the green plus button in the bottom left to add a new function.
18. Define the following:
    - Name = Surface, A, B

- Base Material = Soil Mass
- Anisotropy Definition = Surface

19. And input the following row in the grid:
    - Surface = Anisotropic Surface 1
    - A = 10
    - B = 40
    - Material = Bedding

The dialog should look as follows:



This can be interpreted in the same way as our previous function. Instead of inputting the angle ourselves, the program will locate the point on the anisotropic surface that is closest to each slice base, and use the angle of the surface instead. A and B will then be used in the same way as before. Our anisotropic surface is horizontal, so the angle will be 0 for all slice bases.

20. Click **OK**. In the Define Material Properties dialog, ensure the Generalized Function is set to "**Surface, A, B**". Click **OK**.
21. Right-click on the slope and select **Assign Material > Surface, A, B**.
22. **Compute** the model and select **Analysis > Interpret** to view the results.

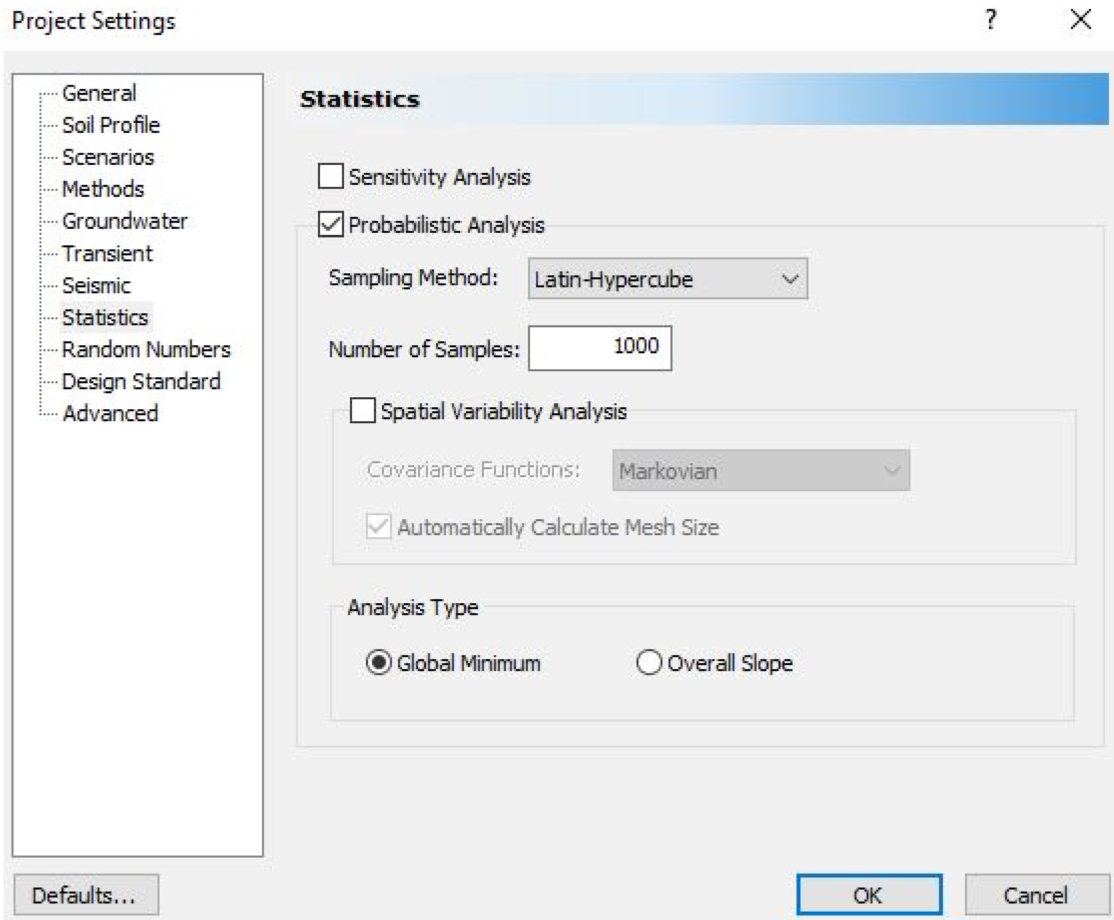
As expected, the slip surface and factor of safety are identical to the previous scenario.

9. Probabilistic Analysis

Go back to the Slide2 Model program and select the master scenario in the Document Viewer (the orange slope). We now assume that the friction angle of the bedding orientation is not well known, and we will determine the probability of failure for a given distribution of friction angles for the bedding.

1. Open the **Project Settings** dialog from the **Analysis** menu.
2. On the left side click on **Statistics**. Check the box for **Probabilistic Analysis**. Leave the analysis type as **Global Minimum**.

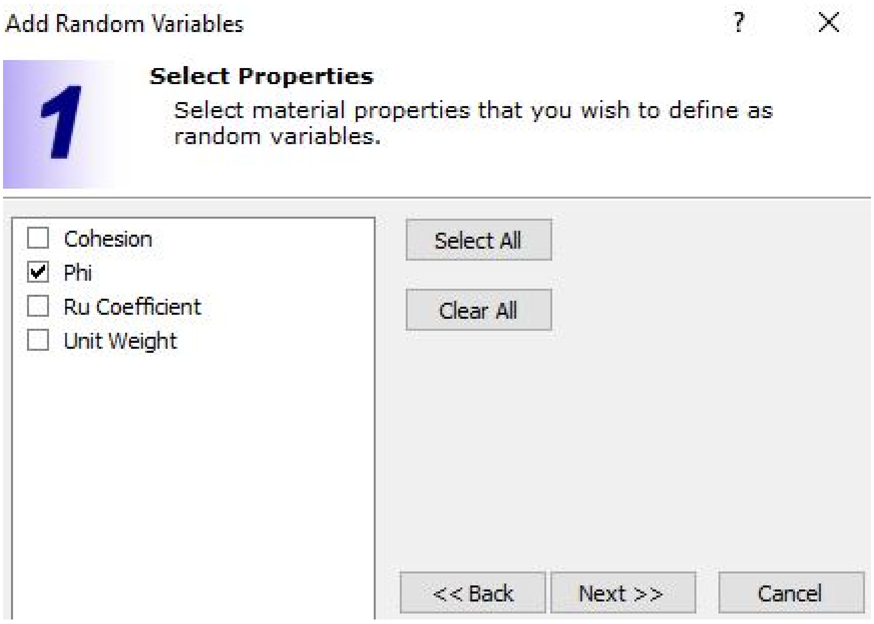
   This will find a critical surface deterministically and then will calculate the probability of failure using this surface with varying material properties. To re-compute the critical failure surface for each randomization of material properties you could choose Overall Slope. Since this takes a longer time to compute, it will be left as an additional exercise.



3. Click **OK** to close the dialog.

We are now going to define the statistical distribution of the strength of the bedding layer.

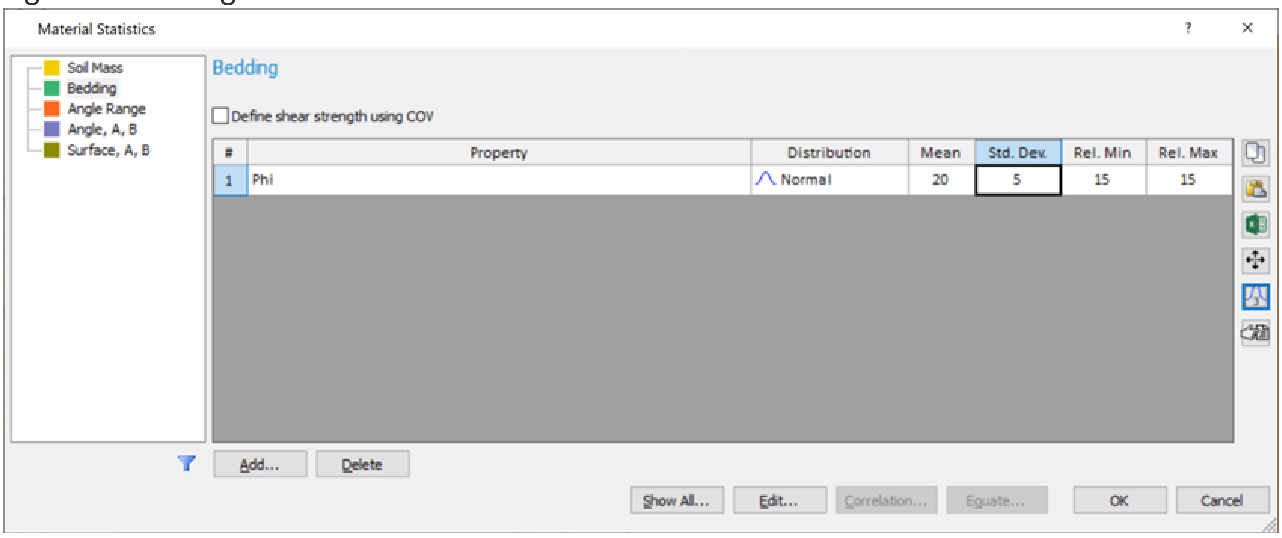
1. Go to **Statistics > Materials**.
2. We are going to vary the Bedding strength so click on **Bedding**, then click on the **Add** button.
3. The cohesion of the bedding is 0, so we will only alter the friction angle. Check the box for **Phi.**



4. Click **Next** for **Statistical Distribution**, choose **Normal.**

5. Now click **Finish**.

6. You now need to enter the **Mean** and **Standard Deviation** for the distribution. The Mean is automatically set to a deterministic value from the previous analysis (20o), so we only need to set the standard deviation. Enter **5**. Now you can automatically set the maximum and minimum to 3 standard deviations by clicking the **3x Std Deviation** button on the right. The dialog should look like this:



7. Click **OK** to close the dialog.

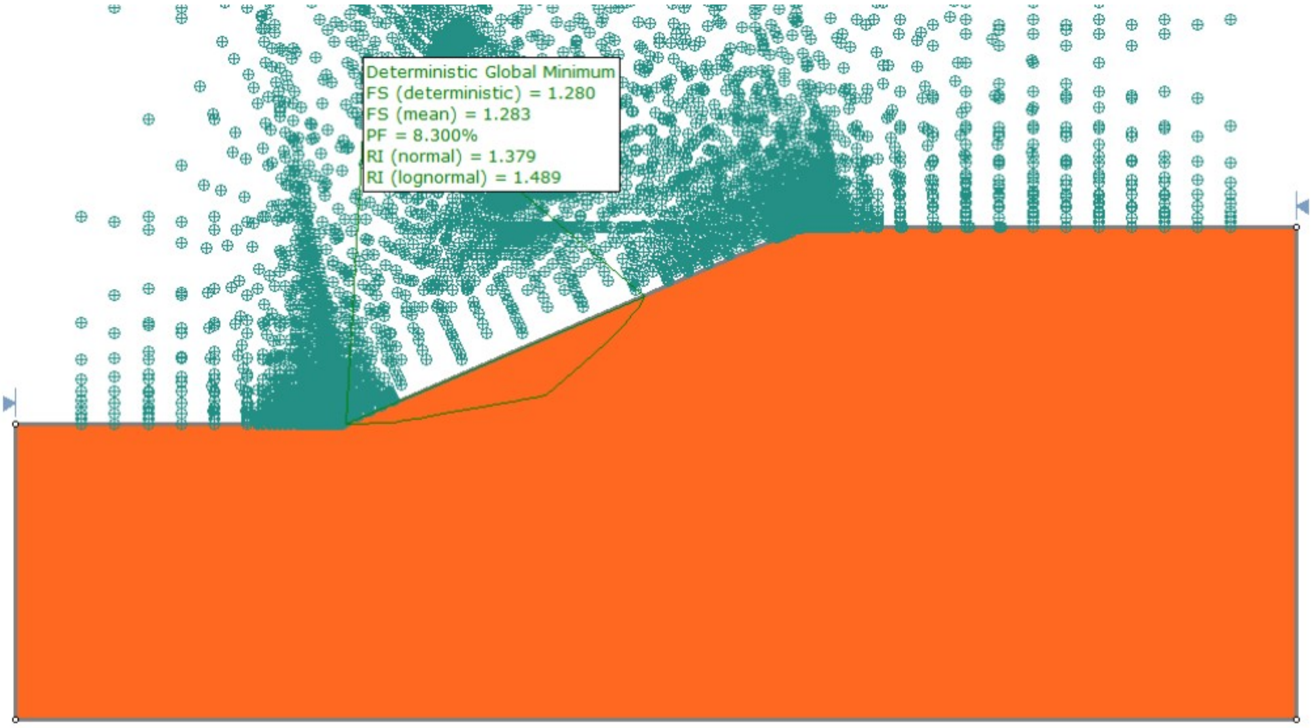
10. Compute

1. Save the model and then select **Analysis > Compute**.

2. Select **Analysis > Interpret** to view the results.

11. Interpret

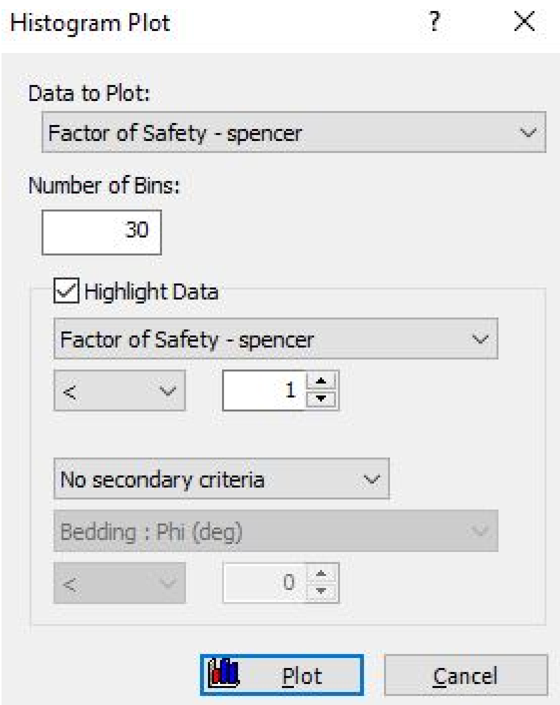
You will now see the deterministic global minimum failure surface along with some statistical data.



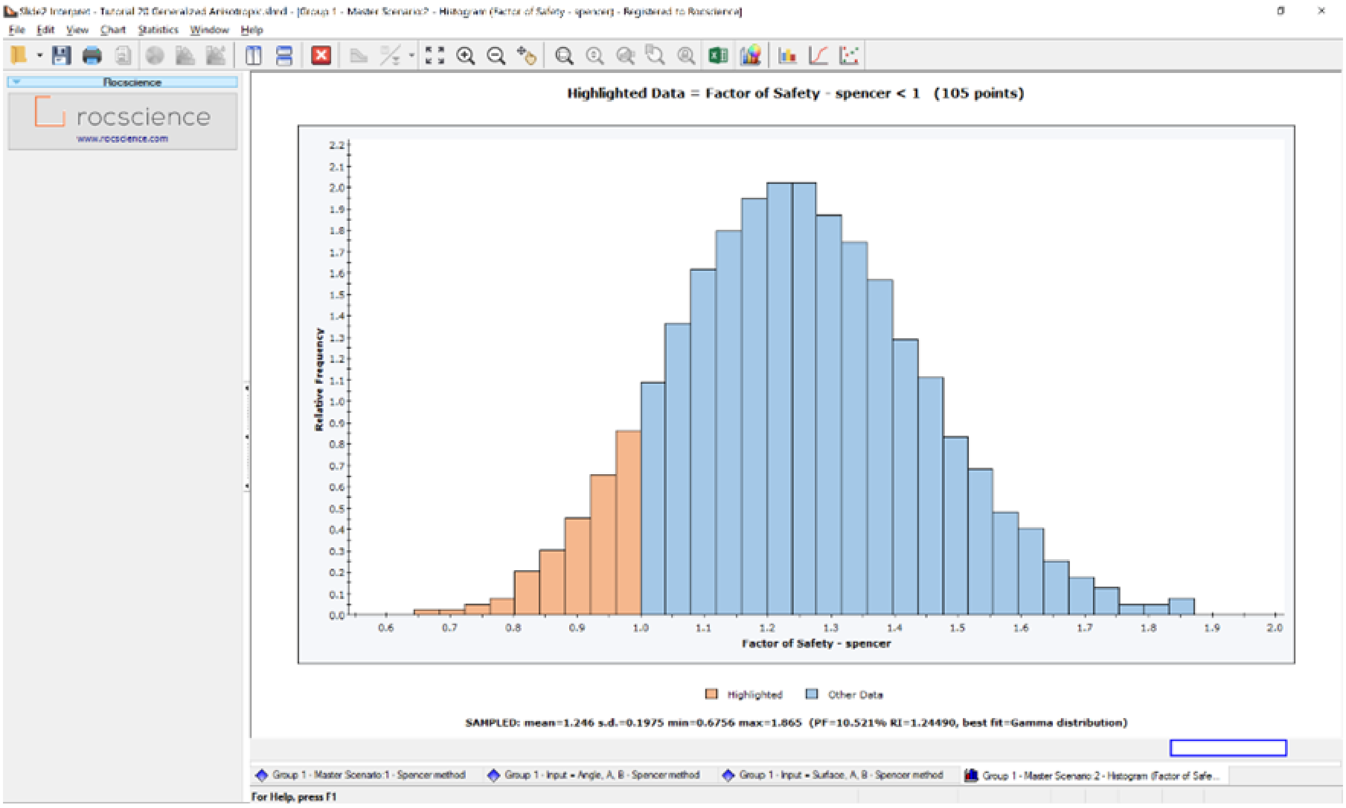
You can see that the mean factor of safety (1.25) and deterministic factor of safety (1.24) are nearly the same and that the probability of failure (PF) is 10.5%.

You can look at the distribution of safety factors by going to:

1. **Statistics > Histogram Plot**.
2. Set the **Data to Plot = Factor of Safety – spencer**.
3. Select the **Highlight Data** checkbox.
4. As the highlight criterion, select "**Factor of Safety – spencer**" and set the criterion to **< 1.**



5. Select the **Plot** button, and the **Histogram** will be generated as shown.



You can see a normal distribution of safety factors with about 10% of the area shown in red (safety factor less than 1). Because the Latin Hypercube method samples the input distributions smoothly (compared to Monte Carlo), the output, in this case, is also a relatively smooth normal distribution.

Right-click on the plot and select **Change Plot Data**. Plot the **Bedding friction angle**. As expected, the low safety factors (< 1) correspond to low sampled values of the bedding friction angle.

This concludes the tutorial.