rocscience

Statistical Correlation of Material Properties

1. Introduction

This tutorial will demonstrate the advanced statistical correlation options in Slide2, which allow you to equate or correlate material properties between different materials in a Slide2 probabilistic analysis.

This is particularly important when modelling anisotropic material properties in probabilistic analysis.

At the end of the tutorial, we will compare the results to the Anisotropic Surface option.

2. Model

Start the Slide2 model program. Select **File > Recent Folders > Tutorials Folder**, or use the dropdown arrow on the **Open** toolbar button to choose the Tutorials folder.

Select the *Tutorial 27 initial.slmd* file.

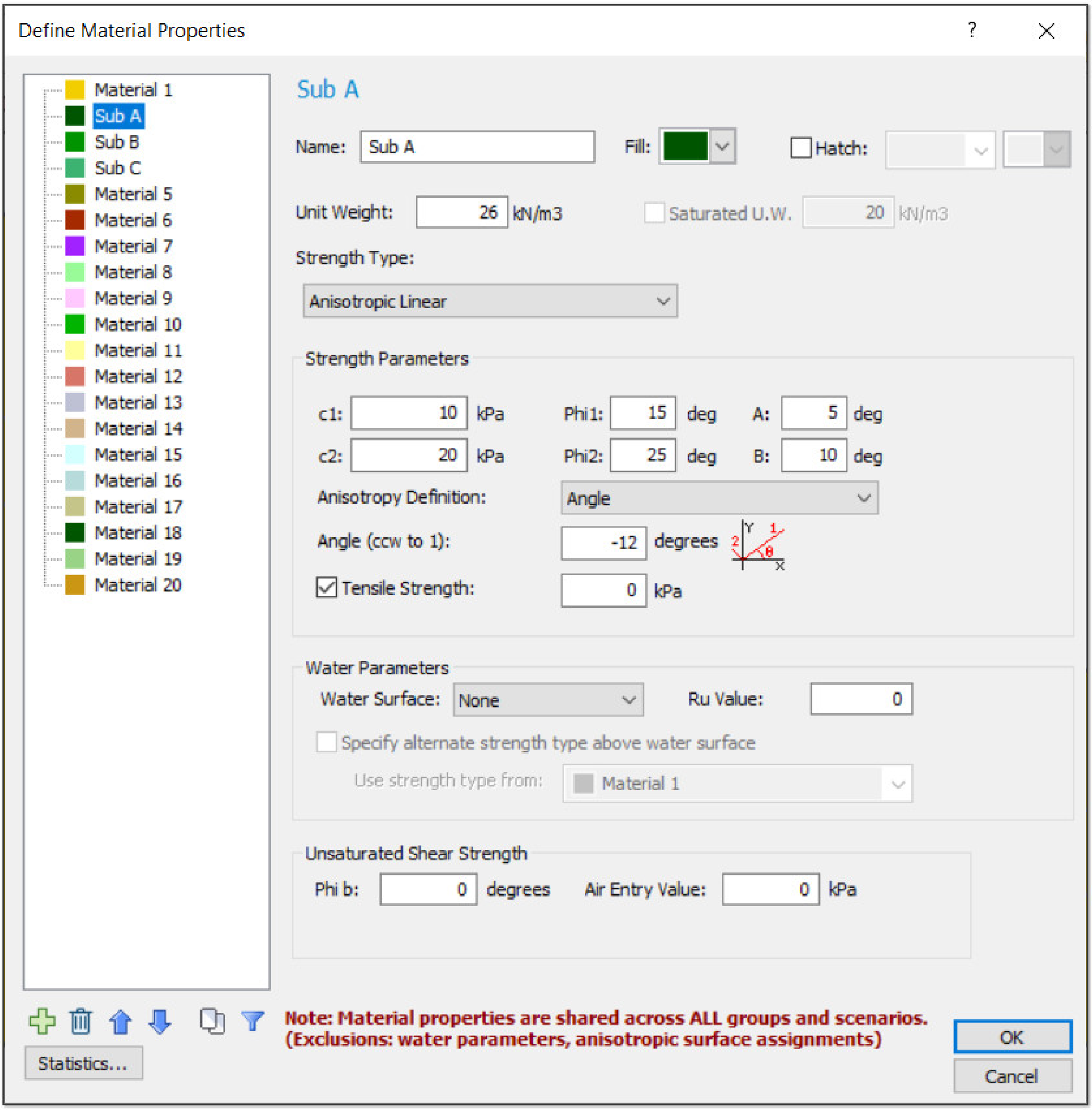
Open the **Project Settings** dialog and click on the **Statistics** tab. Notice that in this example we will be running a **Probabilistic Analysis** with **Latin-Hypercube** sampling and 10 000 samples. This means that 10 000 trials will be generated, and our random variables will have a different sampled value in each trial. We will use the Global Minimum Analysis type, such that the slip surface from the deterministic analysis will be used for each trial. Click **Cancel**.

MATERIAL PROPERTIES

The geometry has already been set up in this tutorial. Select Define Materials from the toolbar or the **Properties** menu. We will keep the pre-defined values of Material 1.

The pre-defined gray material boundaries in our model will represent an anisotropic material, with linear bedding. This is based on the Mohr-Coulomb criterion and assumes that the minimum shear strength occurs in the direction of the bedding planes. This means that the cohesion and friction angle will be the same for the three areas, but the angle of bedding plane orientation (theta) from the horizontal will be different in each case. As such the anisotropic material will be defined with three sub-materials materials: Sub A, Sub B, and Sub C.

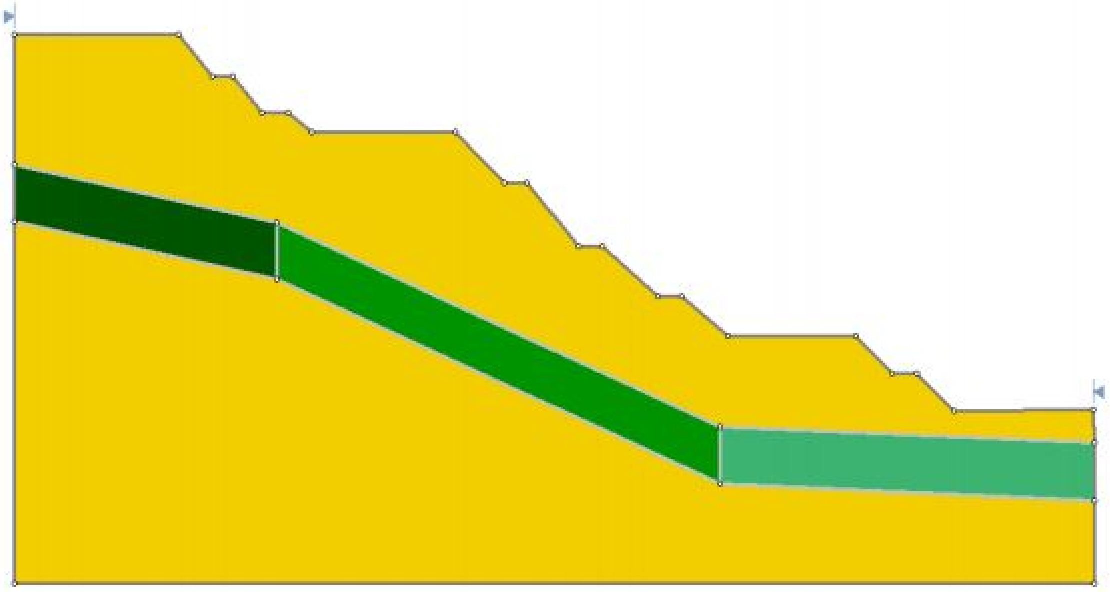
Click on material **Sub A** on the left panel. The material properties have already been defined, and the **Strength Type is** Anisotropic Linear, as shown. Sub A, Sub B, and Sub C are identical.



For more information on what each parameter represents, click on the question mark at the top right corner of the dialog to go to the Anisotropic Linear Online Help topic.

We will now modify the angle of bedding plane orientation. Click on **Sub B** and change the angle from -12 to -25 degrees. Click on **Sub C** and change the angle to -2 degrees. Click **OK** to close the Material Properties dialog.

Right-click on the first anisotropic region and select **Assign Material > Sub A**. Similarly, define the second and third anisotropic regions as Sub B and Sub C, respectively. Your model should look as follows:



3. Material Statistics

Select **Statistics > Materials** from the menu. Click the **Show All** button. Notice that the random variable parameters have already been defined for our materials. All parameters follow a normal distribution.

All Material Stats

#	Name	Property	Distribution	Mean	Std. Dev.	Rel. Min	Rel. Max
1	Sub A	Cohesion	Normal	10	3	9	9
2	Sub A	Cohesion 2	Normal	20	3	9	9
3	Sub A	Phi	Normal	15	2	6	6
4	Sub A	Phi 2	Normal	25	2	6	6
5	Sub B	Phi 2	Normal	25	2	6	6
6	Sub B	Phi	Normal	15	2	6	6
7	Sub B	Cohesion 2	Normal	20	3	9	9
8	Sub B	Cohesion	Normal	10	3	9	9
9	Sub C	Phi 2	Normal	25	2	6	6
10	Sub C	Phi	Normal	15	2	6	6
11	Sub C	Cohesion 2	Normal	20	3	9	9
12	Sub C	Cohesion	Normal	10	3	9	9

OK

Click OK and Select Cancel in the Material Statistics dialog. Click the Compute button to run the analysis. Select Interpret to view the results.

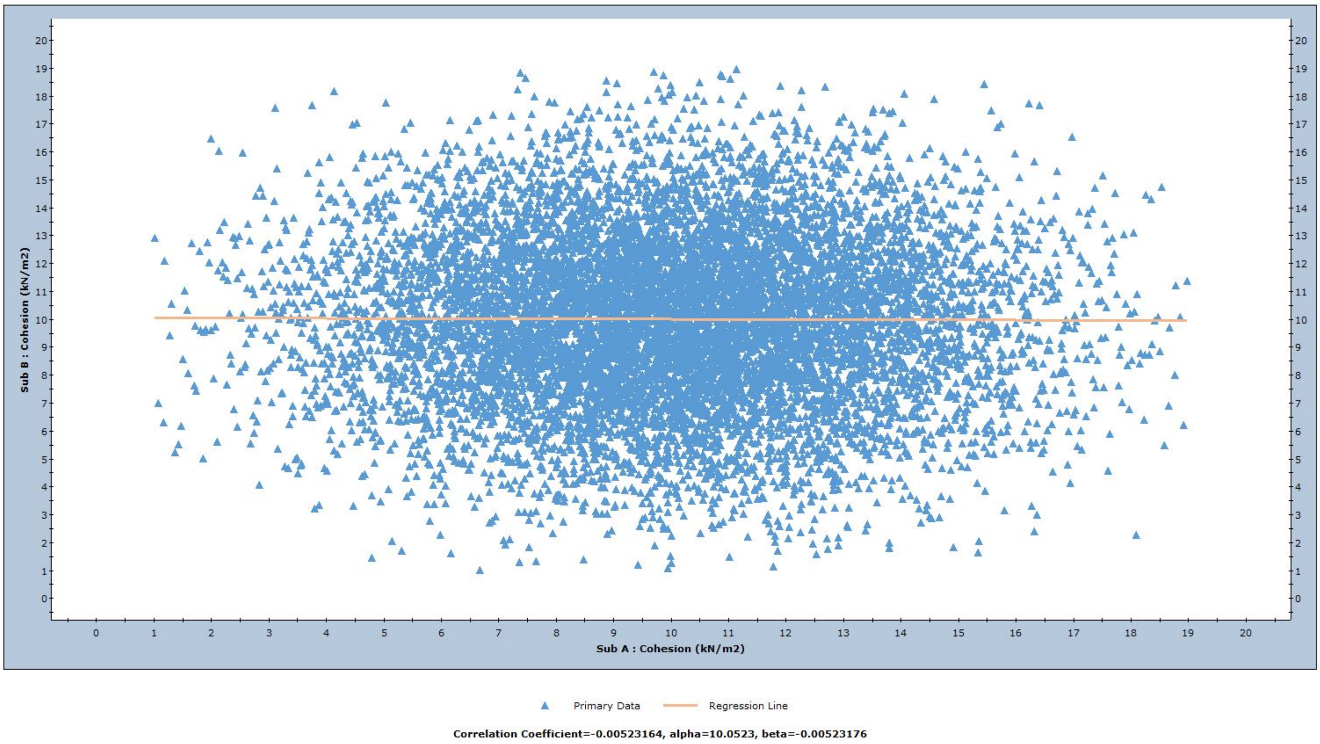
4. Results

We can see that the probability of failure for our Probabilistic Analysis is 13.33%. This indicates that the slope failed in 1333 of the 10000 trials.

We will now plot a scatter plot of the cohesion value in Sub A and Sub B.

1. Select **Statistics > Scatter Plot** or click on the **Scatter Plot** button in the toolbar.
2. Set the **Horizontal Axis** to Sub A: Cohesion and the Vertical Axis to **Sub B: Cohesion**, as shown:
3. Select **Plot**.

The scatter plot should look as shown:



It is important to understand the significance of this scatter plot. During the Probabilistic Analysis, the cohesion and phi values used in each trial were sampled from the random variable distributions defined previously. This means that in Trial 1 (for example) the cohesion in Sub A may have had a value of 1 kPa, while the cohesion in Sub B may have had a value of 19 kPa. Because Sub A, Sub B, and Sub C are the same material, this is clearly something that would likely not occur in the field.

That is, although the cohesion may vary according to a normal distribution, the cohesion values in all three sub-materials should be relatively similar in any given trial run.

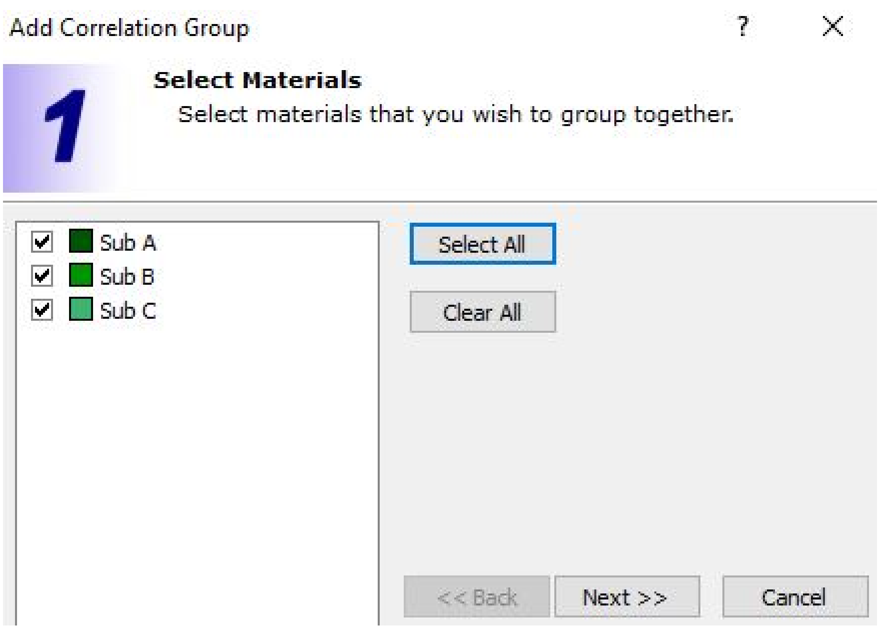
To correct this, we need to correlate the random variables between the three sub-materials. Return to the Slide2 modeller.

5. Equating Materials

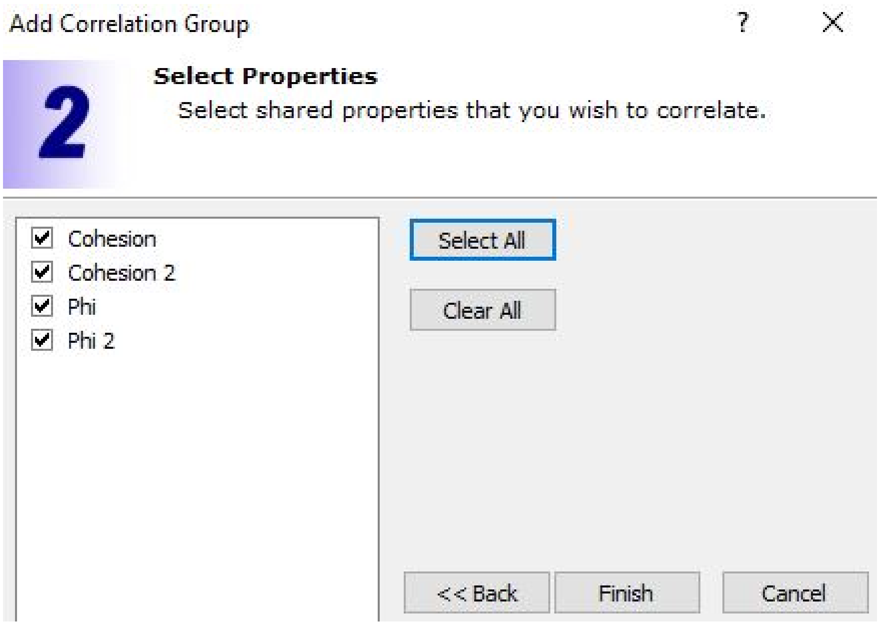
Select **Statistics > Materials** from the toolbar. In the Material Statistics dialog, select the **Equate** button at the bottom.

Select Add Group on the bottom left of the Equate Materials dialog.

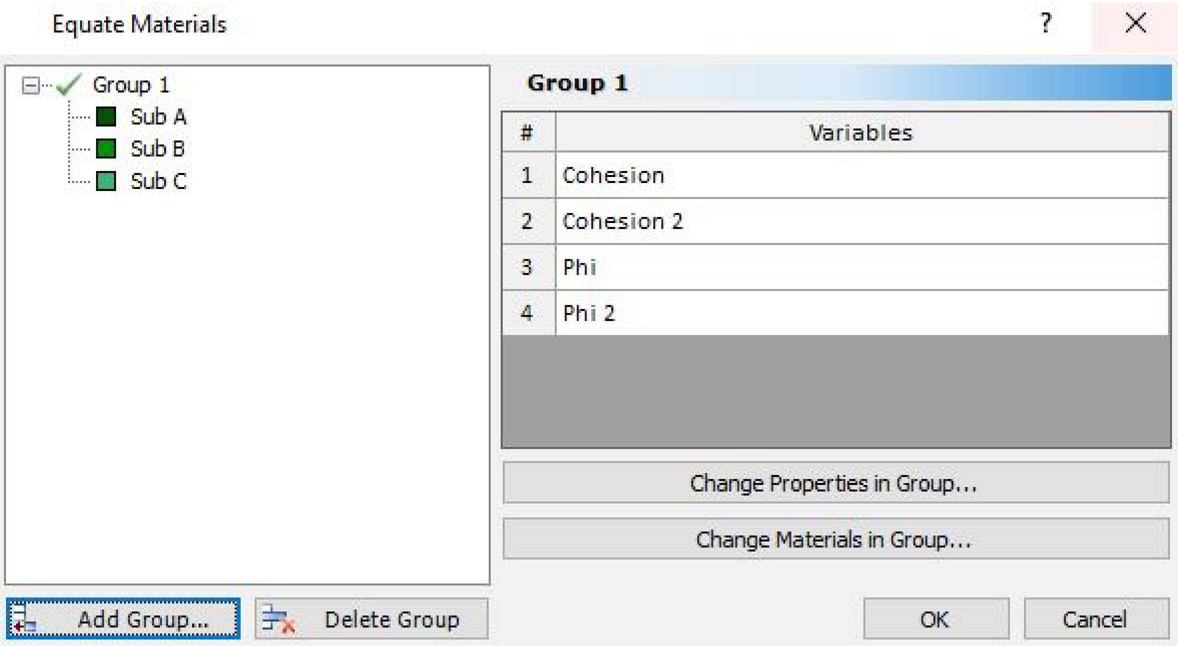
Click the **Select All** button to select all three sub-materials, as shown:



Click **Next.** We want to equate cohesion, cohesion 2, phi, and phi 2 for all three sub-materials. Click **Select All** and then **Finish.**



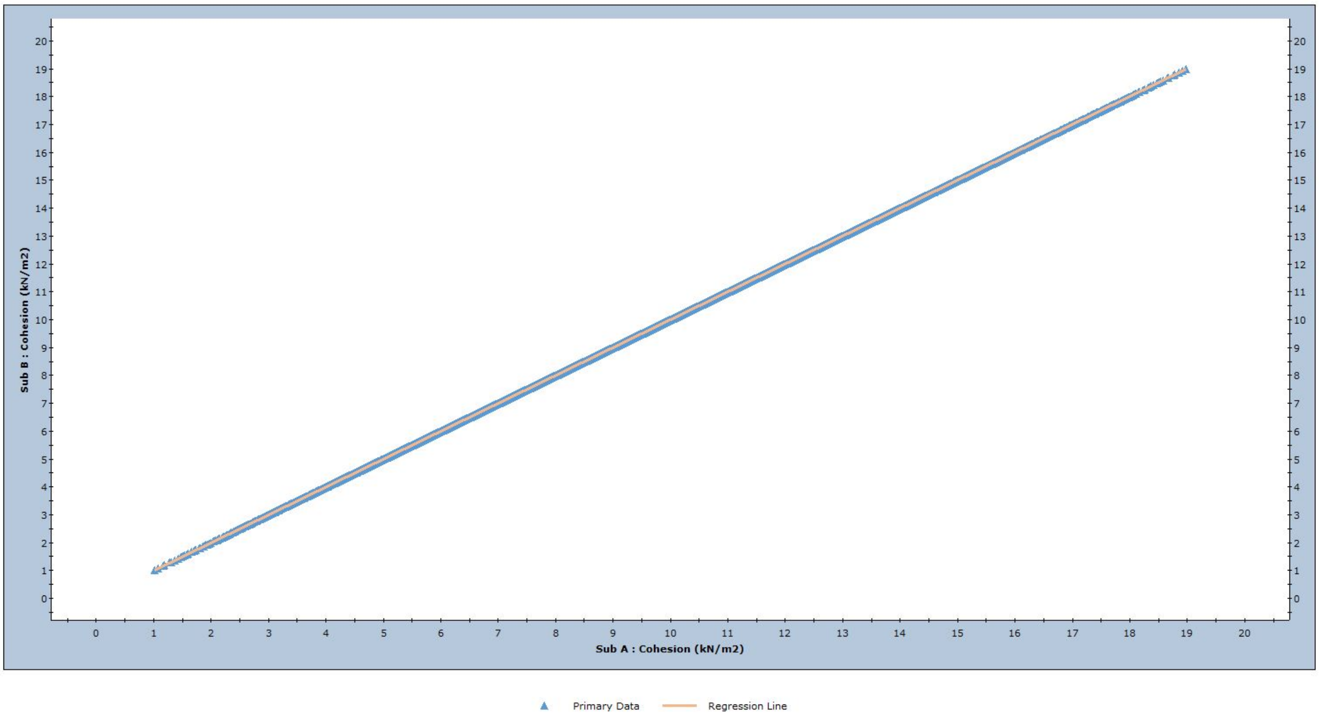
The Equate Materials Dialog should look as shown:



Click **OK** in the Equate Materials dialog, and the Material Statistics dialog.

Click the **Compute** button to run the analysis. Select Interpret to view the results.

As before, plot a scatter plot of Sub B Cohesion vs. Sub A Cohesion. The scatter plot will look as shown:



Correlation Coefficient=1, alpha=4.13891e-13, beta=1

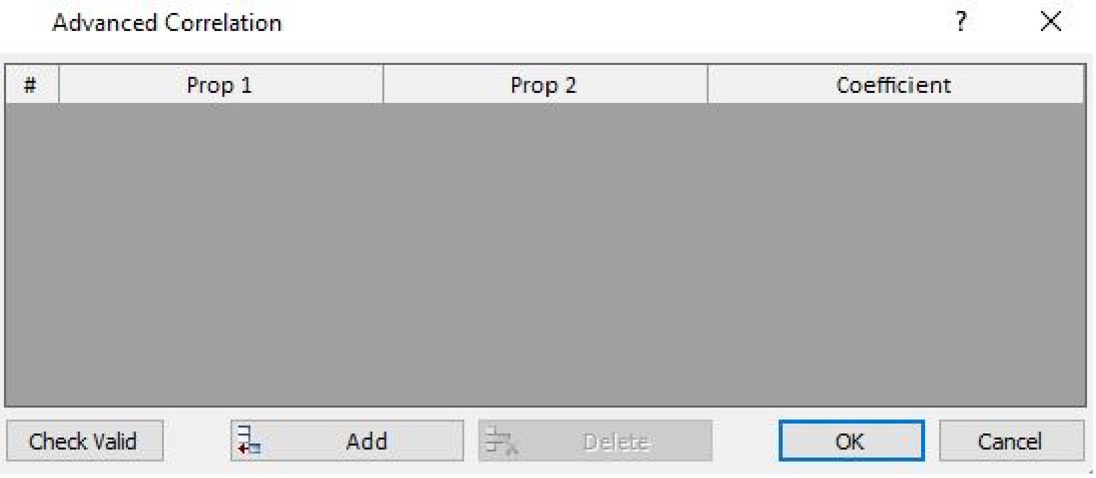
As expected, the cohesion in Sub A and Sub B is equated. This means that if in Trial 1, say, the cohesion sampled for Sub A is 10 kPa, the cohesion in Sub B (and Sub C) will also be 10 kPa, for that trial. Close the scatter plot view.

Notice that the probability of failure has now increased to 20.29%, almost double the previous value. Now that the materials have been equalized, the lower strength cases, where cohesion is 1 kPa in Sub A, for example, also mean that the cohesion is 1 kPa in Sub B and Sub C, resulting in an overall weaker anisotropic material. As such the slope is more likely to fail.

This is perhaps an idealistic case, as field parameters will likely not be exactly equal in all three sub-materials. We will now correlate the materials instead of equating them completely. Return to the Slide2 modeller.

6. Correlating Materials

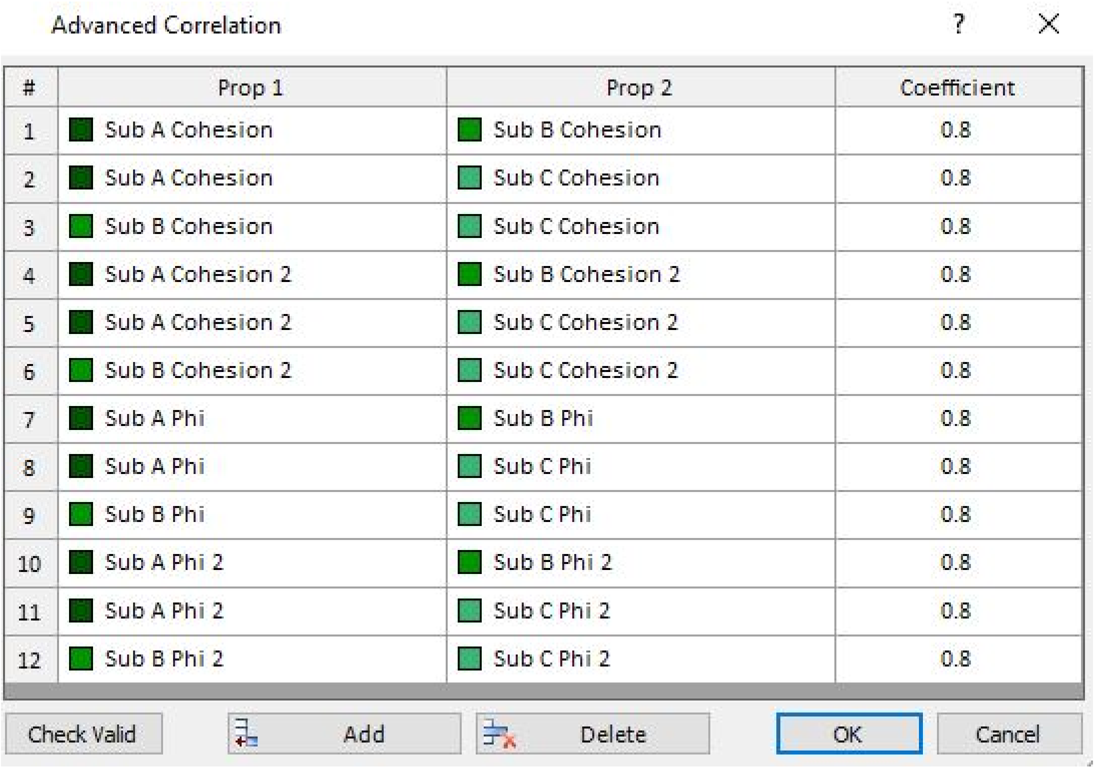
1. Select **Statistics > Materials**
2. Click on the **Equate** button and select "**Delete Group**" to remove the equating of the sub-materials.
3. Click **OK**.
4. Now select the **Correlation** button.
5. Click on **Advanced Correlation**, and select **Add**.



You will see two properties and a coefficient value. We will now correlate our parameters – for this example, we will use a correlation coefficient of 0.8.

Select **Cancel** in all dialogs. A Slide2 file with the pre-defined correlation coefficients can be found in the tutorials folder of your installation folder. It is titled *Tutorial 27 Advanced Correlation.slmd*.

Select **Statistics > Materials > Correlation > Advanced Correlation**. The Advanced Correlation dialog should look as shown:

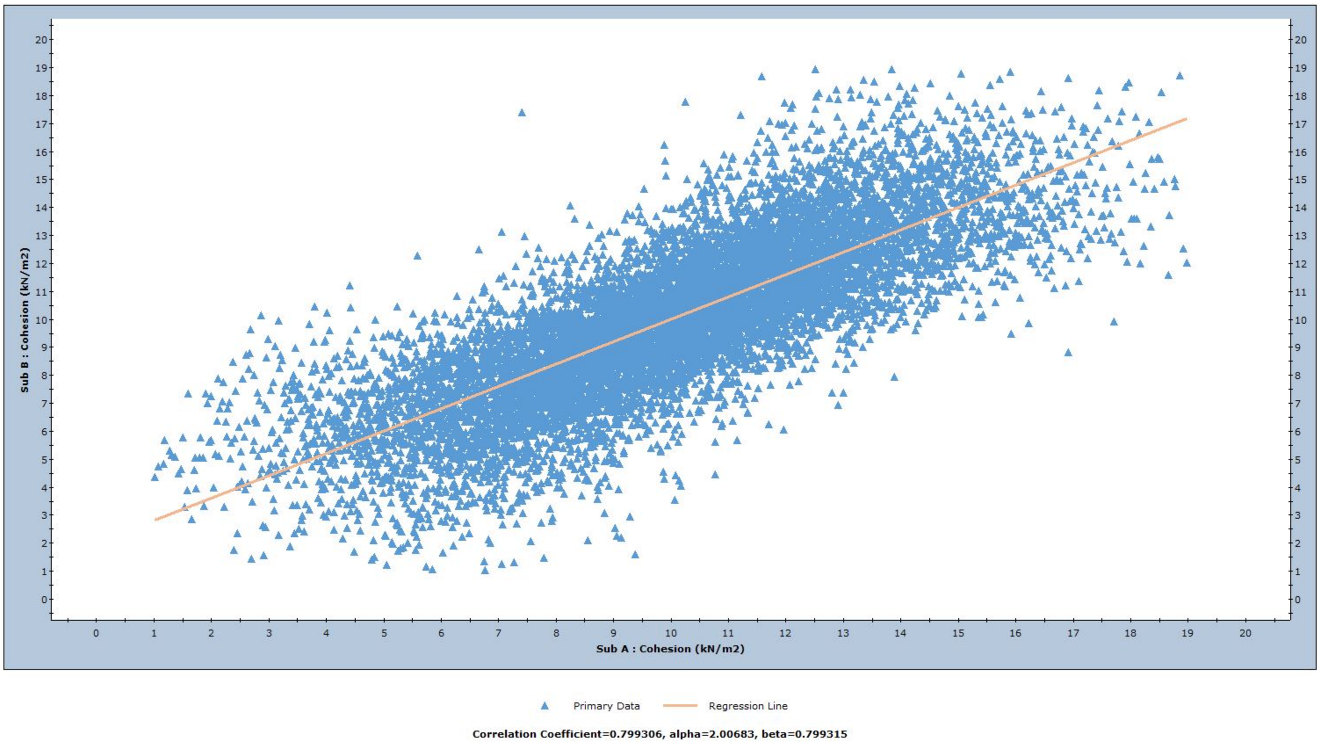

Advanced Correlation

#	Prop 1	Prop 2	Coefficient
1	Sub A Cohesion	Sub B Cohesion	0.8
2	Sub A Cohesion	Sub C Cohesion	0.8
3	Sub B Cohesion	Sub C Cohesion	0.8
4	Sub A Cohesion 2	Sub B Cohesion 2	0.8
5	Sub A Cohesion 2	Sub C Cohesion 2	0.8
6	Sub B Cohesion 2	Sub C Cohesion 2	0.8
7	Sub A Phi	Sub B Phi	0.8
8	Sub A Phi	Sub C Phi	0.8
9	Sub B Phi	Sub C Phi	0.8
10	Sub A Phi 2	Sub B Phi 2	0.8
11	Sub A Phi 2	Sub C Phi 2	0.8
12	Sub B Phi 2	Sub C Phi 2	0.8

Click **OK** in the Advanced Correlation dialog, in the Correlation dialog, and in the Material Statistics dialog.

Click the **Compute** button to run the analysis. Select Interpret to view the results.

In **Interpret,** plot a scatter plot of Sub B Cohesion vs. Sub A Cohesion as before. It will look as shown:



We can see the effect of the 0.8 correlation coefficient between Sub A and Sub B cohesion. This correlation is likely closer to the correlation values one could find in the field. Close the scatter plot tab.

Notice the probability of failure has decreased to 19.72% from the previous case. This is expected as we have reduced the correlation coefficient from 1.0 to 0.8.

It is important to note that failing to correlate the anisotropic material resulted in an unconservative (low) probability of failure.

7. Summary

In conclusion, the **Advanced Correlation** options in Slide2 allow you to **Equate or Correlate** material properties, to obtain more realistic results for probabilistic analysis. You can define correlation coefficients between almost any two variables, and between different materials.

In this example, we have only correlated cohesion and friction angle, but in general, you may define correlation coefficients between any two random variables, for any combination of materials, using the options described in this tutorial.

Slide2 comes with the addition of the **Anisotropic Surface** option. This would allow the three sub materials we defined to be defined with one material paired with an Anisotropic Surface. See Tutorial: Anisotropic Surface to run this model with an anisotropic surface.