Pile Resistance Using RSPile

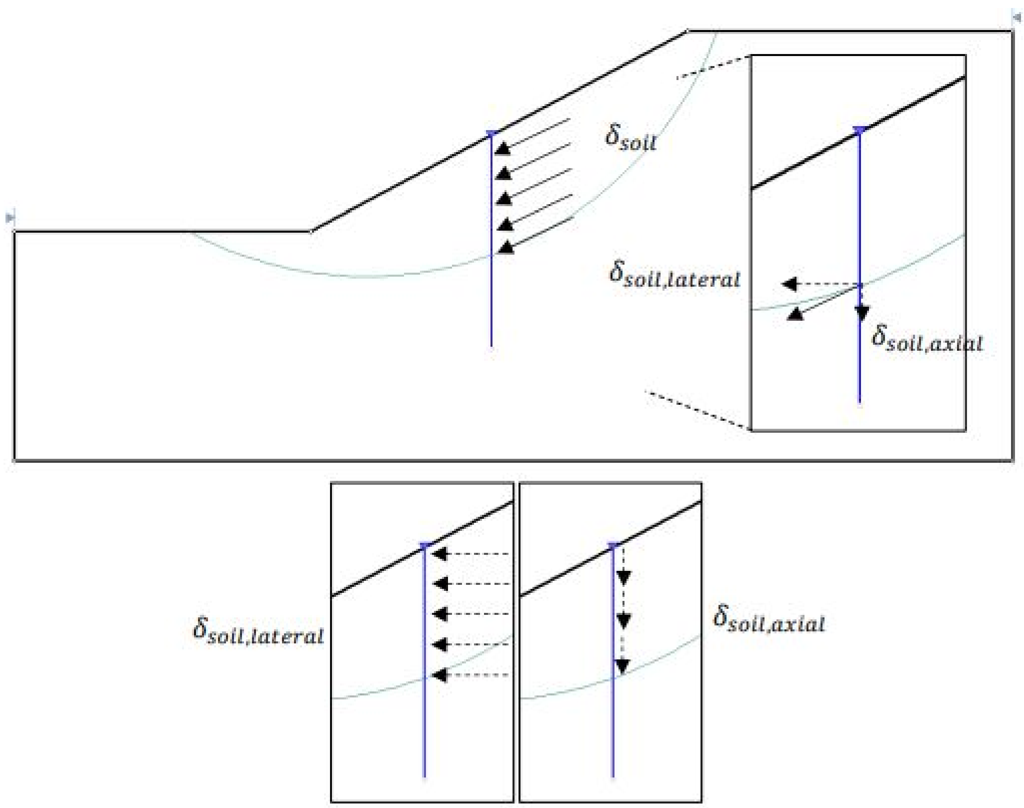
1.0 Introduction

This tutorial will demonstrate how to install a pile support into Slide2, define the pile model in RSPile, and compute the pile resistance functions against sliding to be used for slope stability analysis.

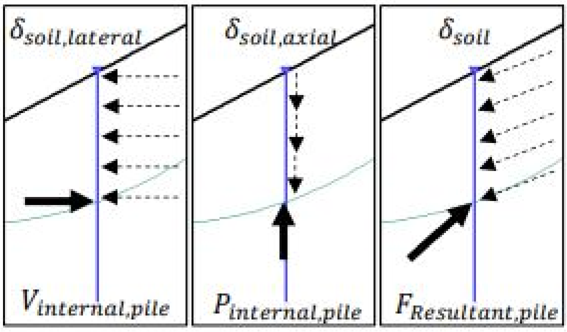
The finished product of this tutorial can be found in *Tutorial 30 Analyzing Pile Resistance using RSPile.slmd* data file. All tutorial files installed with Slide2 can be accessed by selecting **File > Recent Folders > Tutorials** Folder from the Slide2 main menu.

PILE RESISTANCE FOR SLOPE STABILITY ANALYSIS

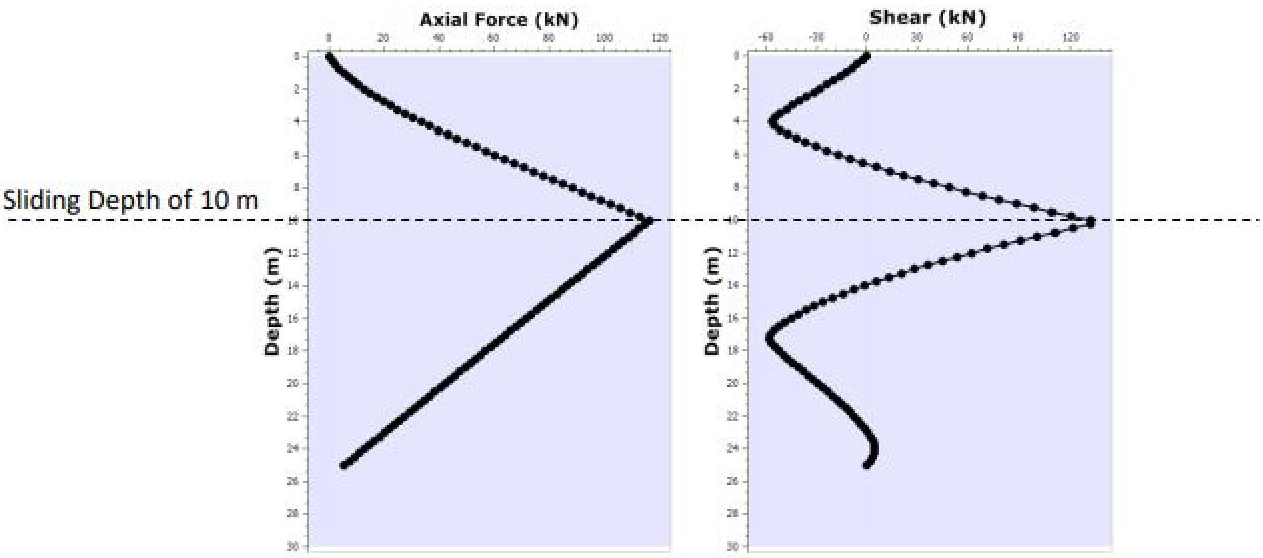
For slope stability analyses using limit equilibrium methods, the soil displacement moving along a slip surface against the pile can be used to compute the axial and lateral resistance against sliding through the principles of superposition. An assumed soil displacement is applied against the pile from the ground to the slip surface. The direction of the applied soil displacement is tangent to the slip surface at the intersection of the pile. The axial and lateral components of the applied displacement are used to compute the axial and lateral resistances separately. The resultant pile resistance force at the slip surface intersection is used to satisfy force equilibrium for the selected limit equilibrium method.



The pile internal axial force at the sliding depth in response to the applied axial soil displacement is the axial resistance against sliding for that particular slip surface. Similarly, the internal shear force at the sliding depth in response to the applied lateral soil displacement is the lateral resistance for that particular slip surface.



The pile resistance is dependent on the depth and angle of the slip surface, as this will affect the pile response from the applied displacement. Therefore, the pile resistance must be computed at a number of points along the pile, varying the depth and angle of applied displacement at each point. Linear interpolation is used to obtain resistance values of intermediate sliding depths. The user may specify the maximum allowable soil displacement moving along any slip surface based on design tolerances to obtain the pile resistances. Alternatively, an ultimate pile resistance can be obtained by increasing the assumed soil displacement independently in the axial and lateral directions until the maximum resistances are reached.



The figure above illustrates a typical axial force and shear diagram along the pile depth for an applied displacement from the ground to the sliding depth of 10 m. The axial force and shear at a sliding depth of 10 m are the axial and lateral resistances respectively for one tested sliding configuration

RSPILE

To compute the pile resistances using the methodology outlined above, the support properties for installed pile supports in Slide2 are defined using the dedicated pile analysis software RSPile. The software is capable of modelling complex pile models using the load transfer curve method (better known as the p-y method for laterally loaded piles and the t-z method for axially loaded piles).

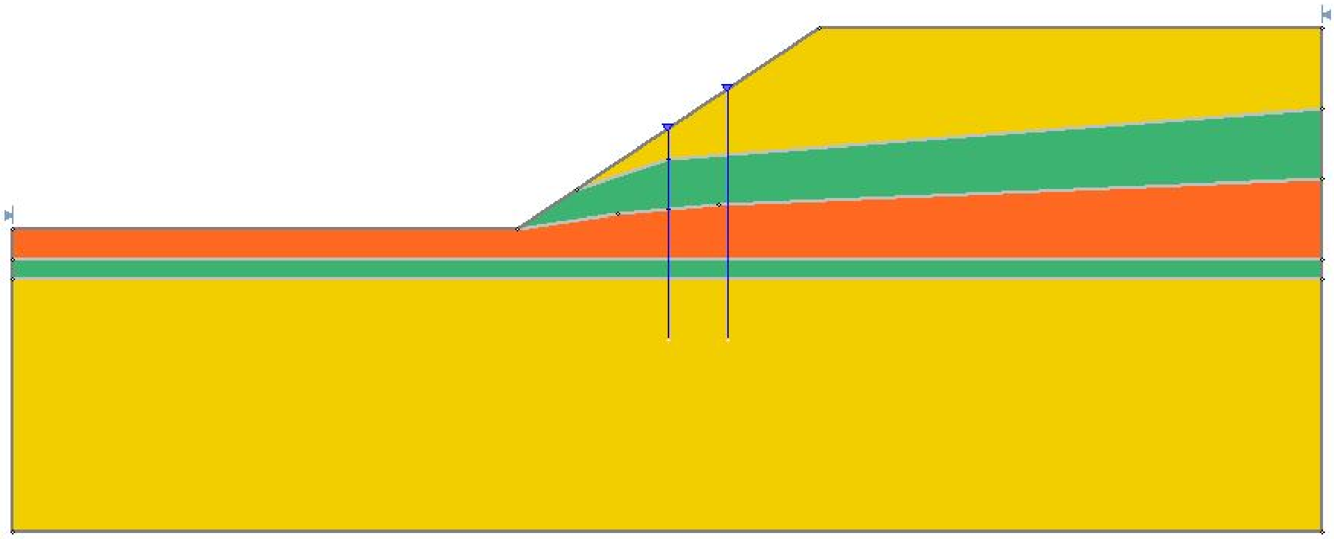
The soil load transfer curves capture the non-linear soil-pile behavior by relating the soil reaction forces to the soil displacement at each depth. Various recommended load transfer curves are available in RSPile and are presented in the RSPile theory manual. For axially loaded piles, the load transfer curves are known as t-z curves for soil skin friction and q-z curves for soil end bearing resistance. For laterally loaded piles, the load transfer curves are known as p-y curves for soil lateral resistance.

2.0 Model

2.1 GEOMETRY

1. Start the Slide2 Model program.
2. Select **File > Recent Folders > Tutorials** Folder from the Slide2 main menu and open the *Tutorial 30 Analyzing Pile Resistance using RSPile (initial).slmd* file.

You should see the following model.



The material properties for this model have been defined and two support elements have been added. The support properties, though, have not yet been defined.

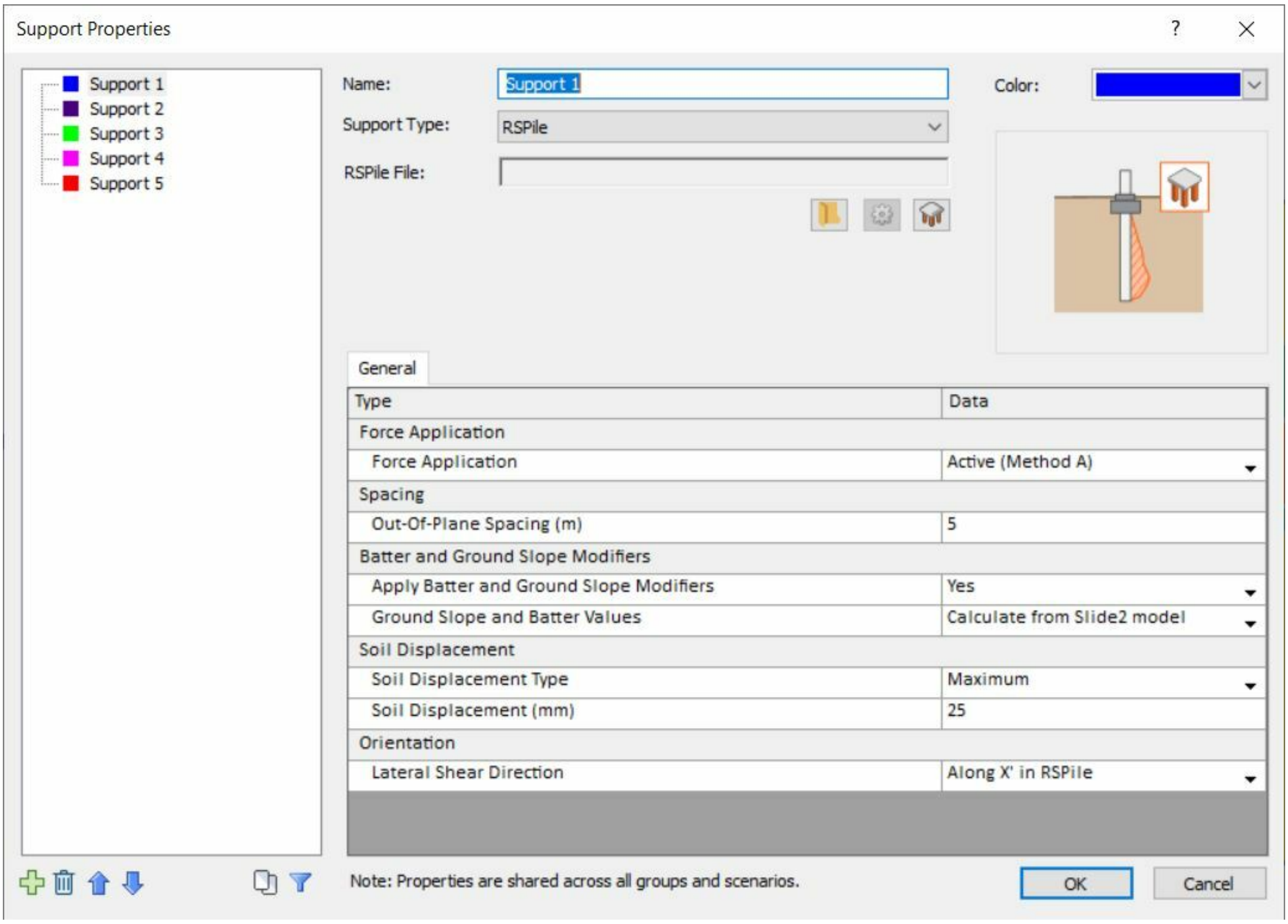
2.2 SUPPORT PROPERTIES

We will now define the pile support properties using the RSPile utility.

1. Select **Properties > Define Support**
2. The **Define Support Properties** dialog should appear. Define the properties as follows:
    - Name = RSPile Model 1
    - Support Type = RSPile
3. In the **General tab** select:

- Force Application = Active (Method A)
- Out-of-Plane Spacing = 5 m
- Apply Batter and Ground Slope Modifiers = Yes
- Ground Slope and Batter Values = Calculate from Slide2 model
- Soil Displacement Type = Maximum
- Soil Displacement = 25 mm
- Lateral Shear Direction = Along X' in RSPile

For more information about what these settings do, please see the Support help page here.



3.0 RSPile

1. Now you will open the RSPile utility by clicking on the **RSPile** icon underneath the **RSPile File** field at the top of the dialog.

> **Note**
>
> This tutorial assumes that you have **RSPile 3.008** or later installed. If you do not have the latest version, download it via the Program Downloads page.

Alternatively, you can run the RSPile Model program by double-clicking on the **RSPile** icon in your installation folder.

The finished product of the RSPile model file can be found in the *Tutorial 30 Analyzing Pile Resistance using RSPile.rspile2* data file. All tutorial files installed with Slide2 can be accessed by selecting **File > Recent Folders > Tutorials** Folder from the Slide2 main menu. Below, we will make the RSPile file from scratch.

3.1 RSPILE MODEL - PROJECT SETTINGS

1. In RSPile, select **Home > Project Settings**
2. In the **General** tab, make sure the **Units** are set to **Metric** and **Program Mode Selection** is set to **Pile Analysis.**
3. Click on the **Pile Analysis Type** tab. By default, the program will open with the Laterally Loaded option selected.
4. Change the **Individual Pile Analysis** mode to **Axially/Laterally Loaded**.
5. Click **OK** to close the dialog.

3.2 SOIL PROPERTIES

1. Select **Soils > Define Soil Properties**

We will now define the soil properties. Notice that each soil property has an Axial and Lateral tab. Some soil properties are common between laterally or axially loaded piles, for example, names, unit weights, and colours. Other properties that may be common within one base type, such as friction angle for any sand, are not copied between modes because the material models are different and usually contain unique property values depending on the problem.

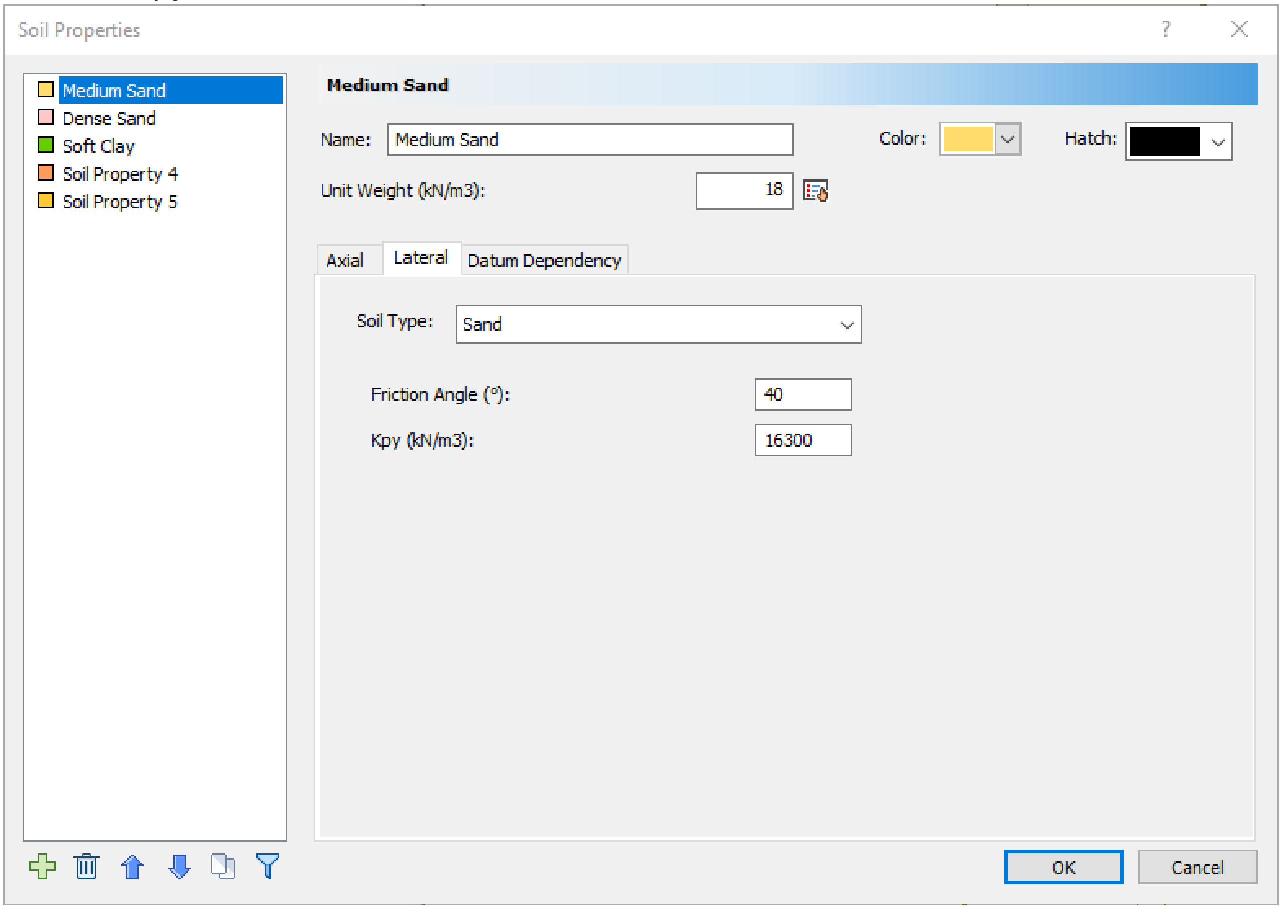
Begin by defining the soil material properties in the **Soil Properties** dialog. You do not need to define the layer thicknesses because these values will be initialized according to the soil profile of the installed pile support in Slide2. As such, we can use one RSPile model file to define the soil and pile properties for multiple piles of various embedment lengths and soil layer configurations.

2. Change the first Soil Property to the following (via the **Lateral and Axial tabs**, respectively):

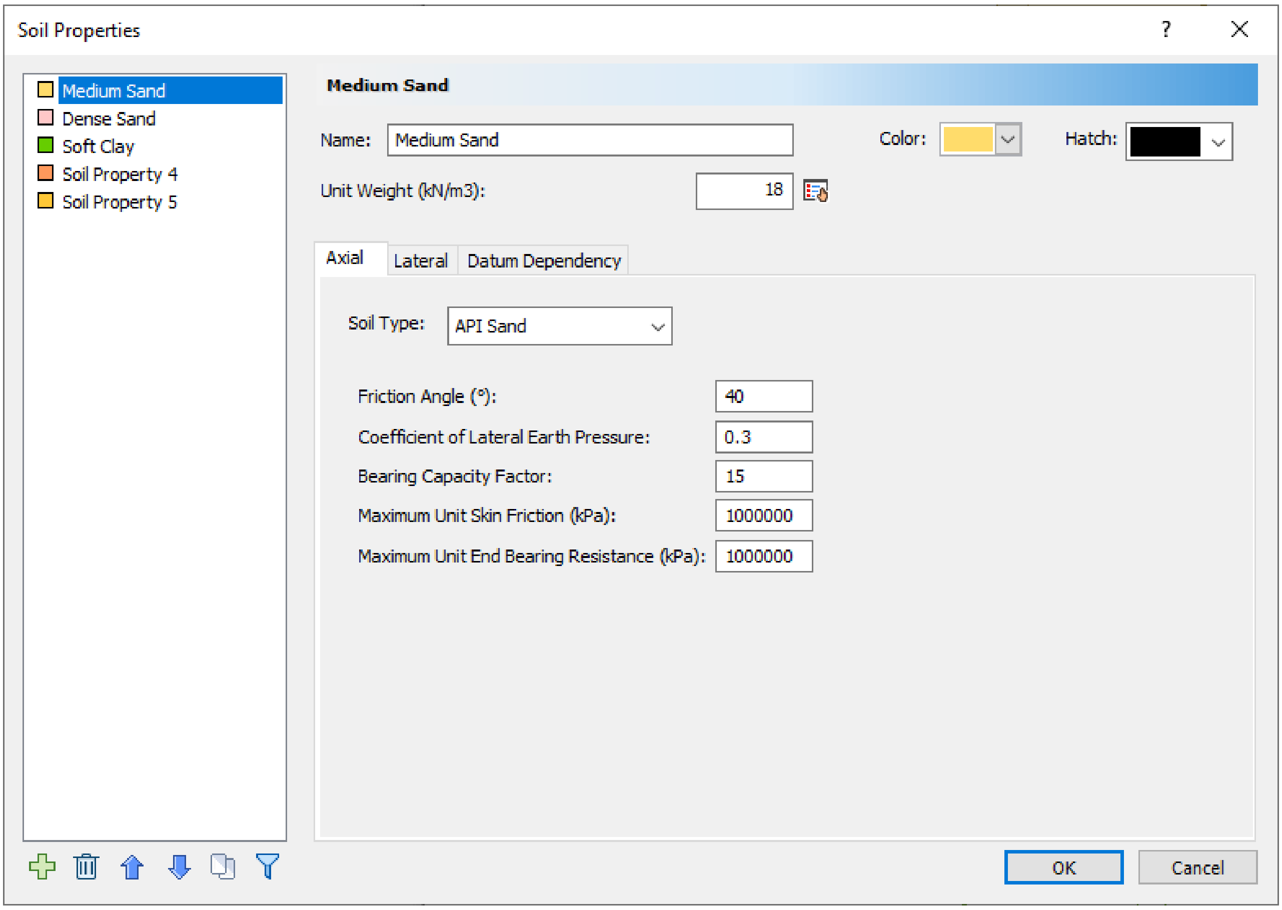
   Medium Sand

   - Name = Medium Sand
   - Unit Weight (kN/m3) = 18
   - **Lateral tab**
     - Soil Type = Sand
     - Friction Angle (degrees) = 40

- Kpy (kN/m3) = 16300



- **Axial tab**
  - Soil Type = API Sand
  - Friction Angle = 40
  - Coefficient of Lateral Earth Pressure = 0.3
  - Bearing Capacity Factor = 15
  - Maximum Unit Skin Friction = 1000000
  - Maximum Unit End Bearing Resistance = 1000000

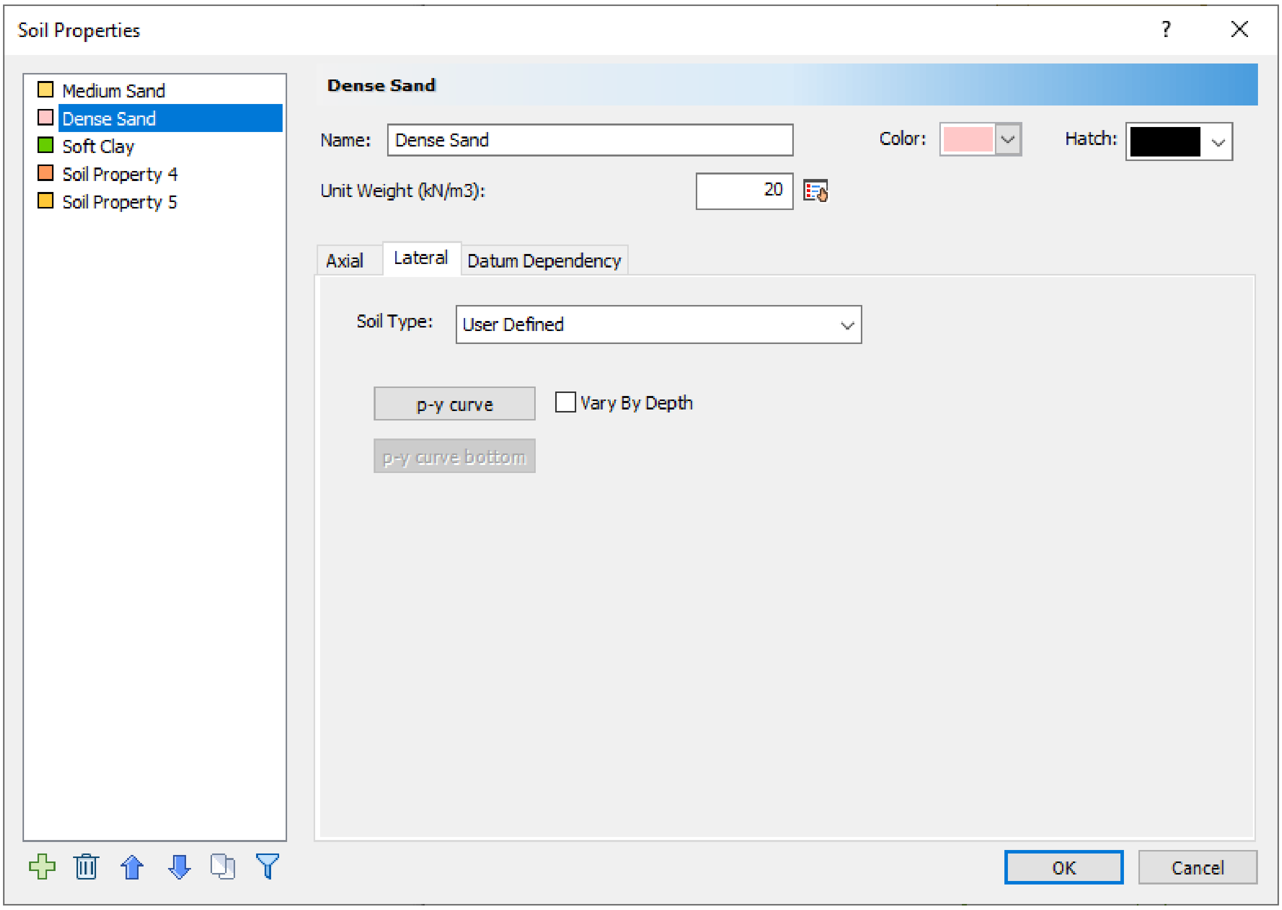


The **unit weight** entered in RSPile is the total unit weight whether the material is saturated or unsaturated and is equal to the unit weight entered in Slide2. If a groundwater table exists in the model, the program will automatically calculate effective unit weight if the material is below the groundwater table.

3. Define the **second layer** as follows:

Dense Sand

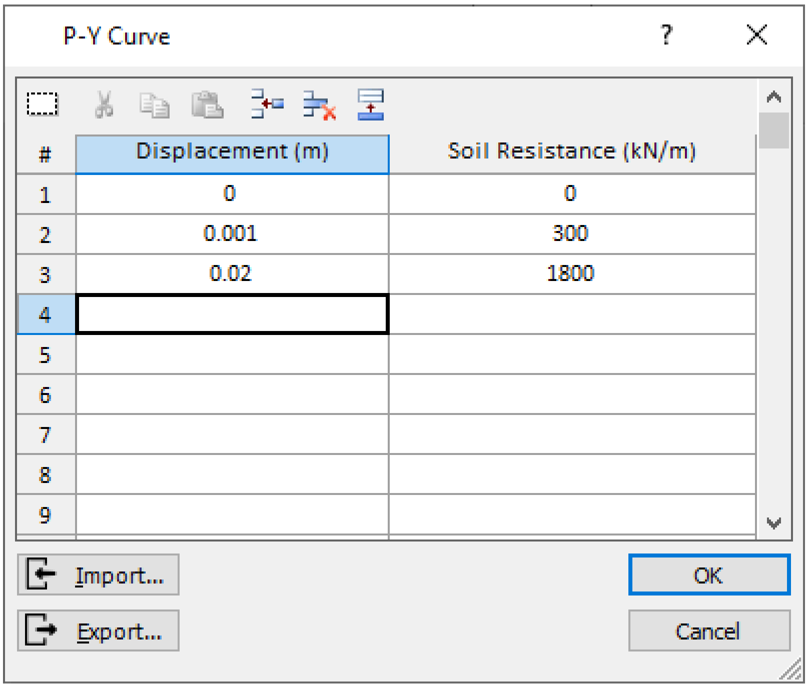
- Name = Dense Sand
- Unit Weight (kN/m3) = 20
- **Lateral tab**
  - Soil Type = User Defined



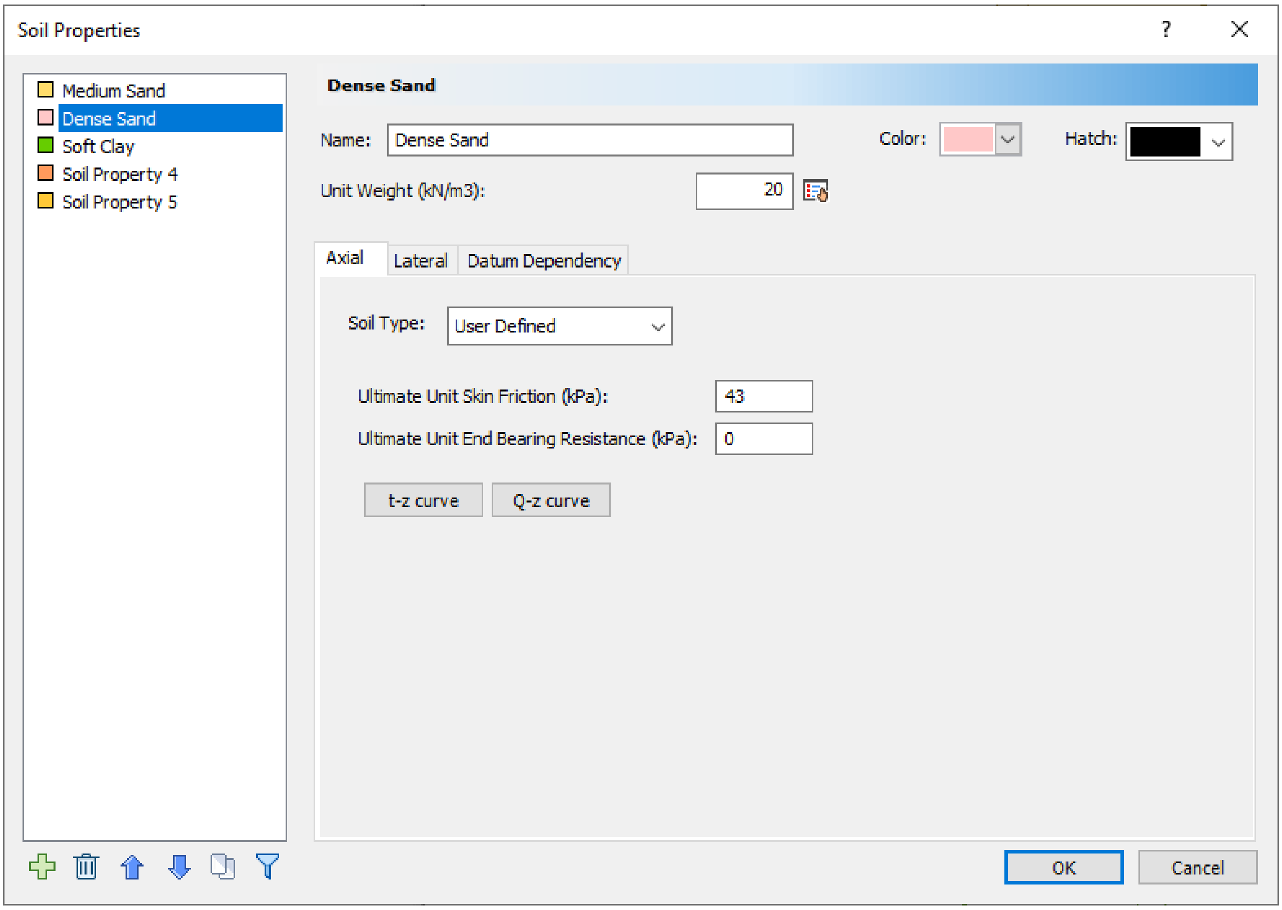
4. A user-defined material allows the user to enter the p-y curve that relates soil lateral reaction force to the soil displacement. Click on **p-y curve**.

5. The P-Y Curve dialog should appear. Enter the following values in the table and click **OK**.

Displacement (m)	Soil Resistance (kN/m)
0	0
0.001	300
0.02	1800



6. Now go to the **Axial** Tab and select:
   - Soil type = User Defined
   - Ultimate Unit Skin Friction (kPa) = 43
   - Ultimate Unit End Bearing Resistance (kPa) = 0



Similar to user defined material in laterally loaded piles, you must define the t-z curve that relates soil skin friction to soil displacement. You do not have to define the Q-z curve for this tutorial since it is assumed that this soil layer has no end bearing strength.

7. Select: **t-z curve**
8. Enter the following t-z curve data:

Displacement (m)	Stress to Max Stress Ratio
0	0
0.00028	0.4
0.000476	0.6
0.000561	0.675
0.000695	0.76
0.000854	0.83
0.0011	0.9
0.0014	0.935
0.00174	0.965
0.00195	0.972
0.00305	1

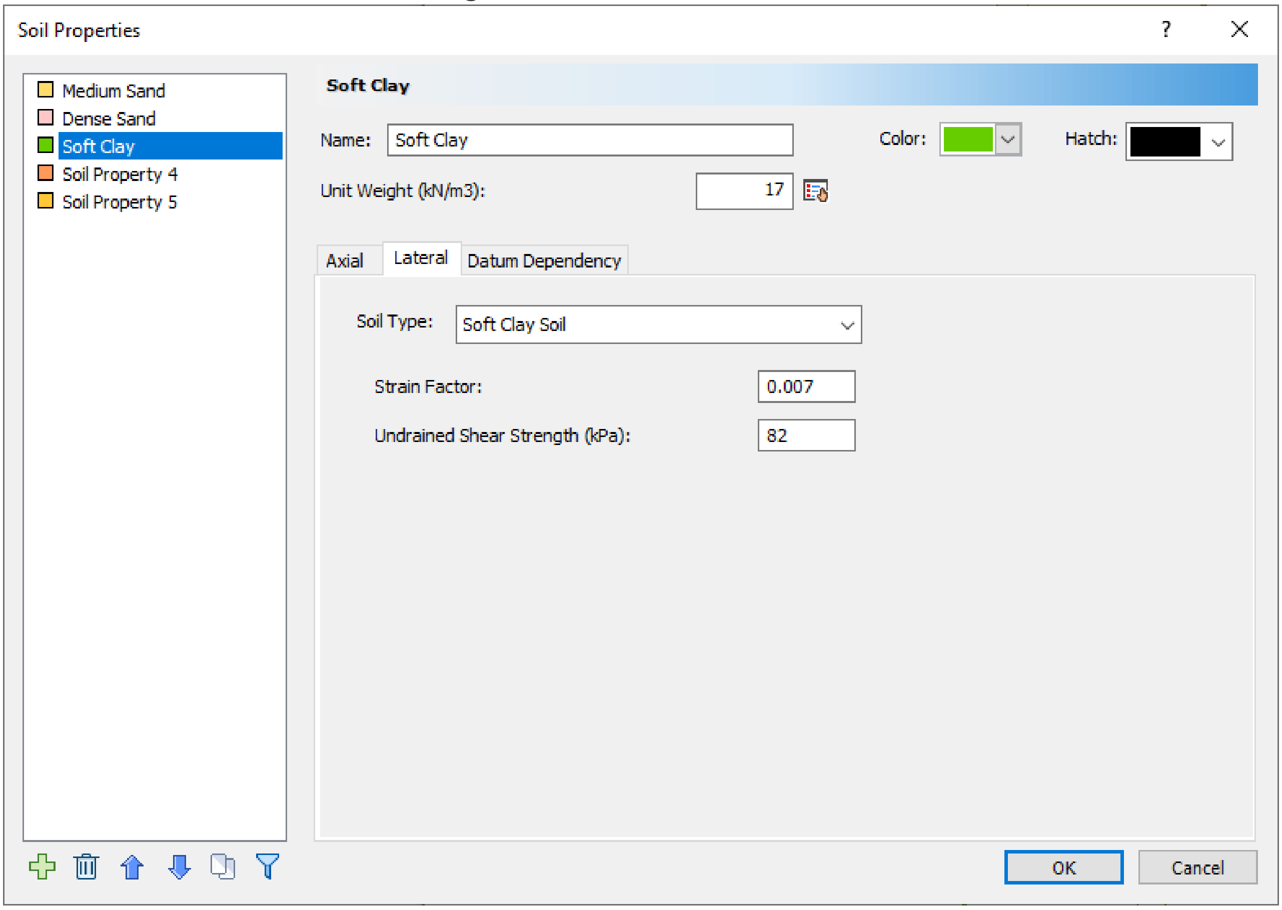
9. This is an example of a typical non-linear t-z curve based on empirical data. Select **OK**.
10. Change the third soil layer to the following properties (via the **Lateral and Axial** tabs, respectively):

    Soft Clay

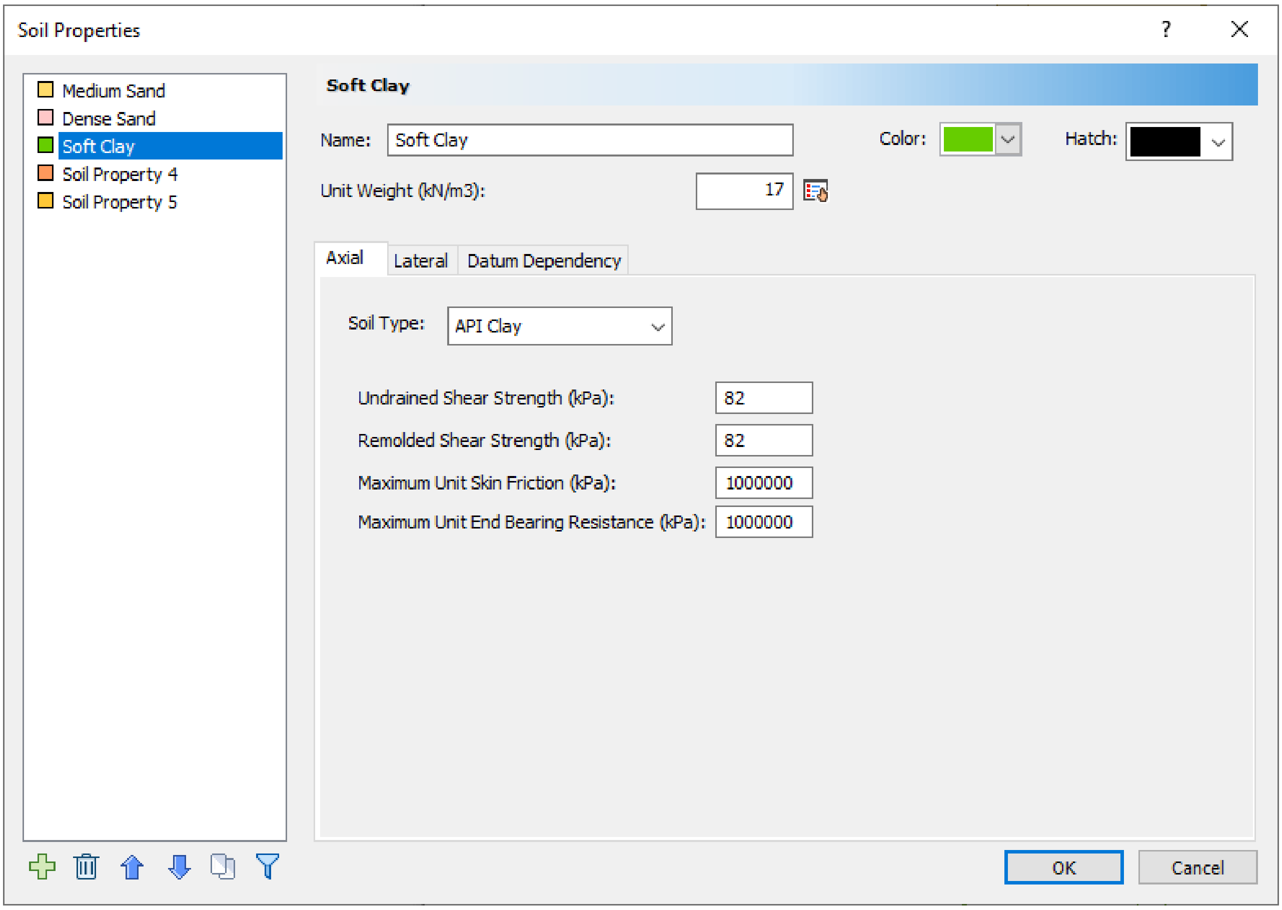
    - Name = Soft Clay

- Unit Weight = 17

- **Lateral**
  - Soil Type = Soft Clay Soil
  - Strain Factor = 0.007
  - Undrained Shear Strength = 82



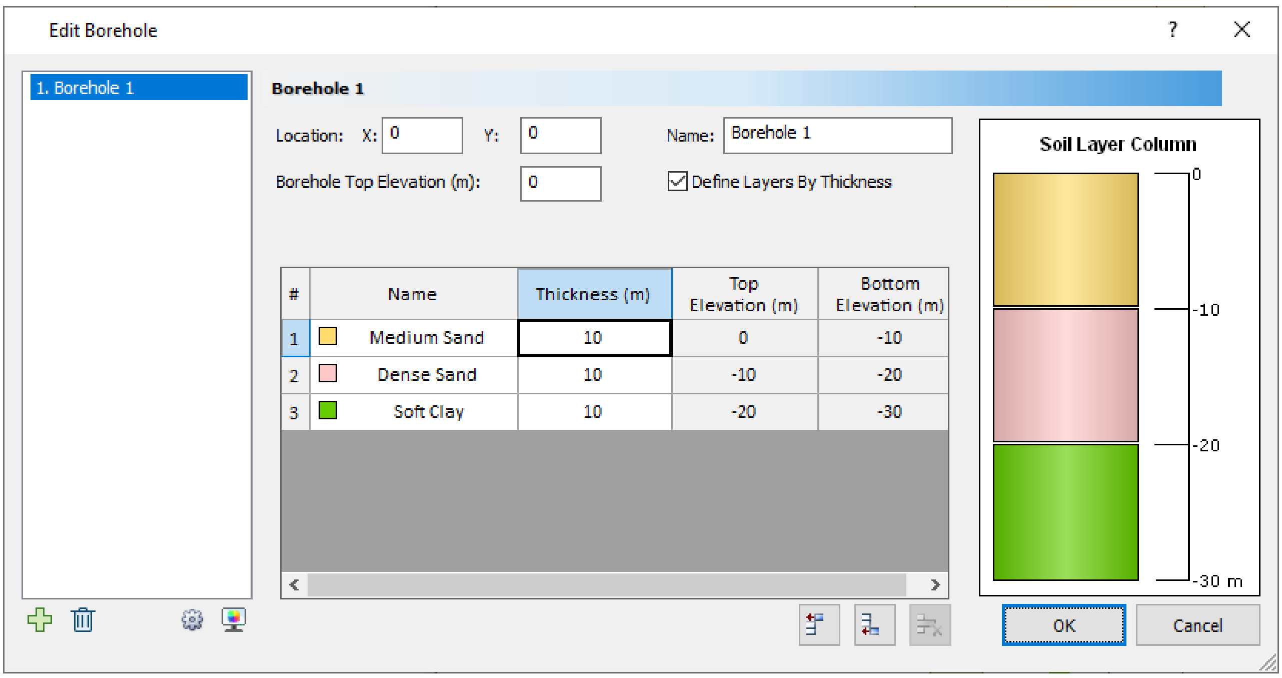
- **Axial**
  - Soil Type = API Clay
  - Undrained Shear Strength = 82
  - Remolded Shear Strength = 82
  - Maximum Unit Skin Friction = 1000000
  - Maximum Unit End Bearing Resistance = 1000000



11. Click **OK.**

12. Select **Soils > Edit All Boreholes** 

13. Click **Insert Layer Below** 2 times so you have three materials in the profile. Set each thickness to **10m**, and ensure that the layers are arranged in the following order:
    - Medium Sand = 10 m
    - Dense Sand = 10 m
    - Soft Clay = 10 m



14. Click **OK**.

A borehole will now appear in the center of the model.

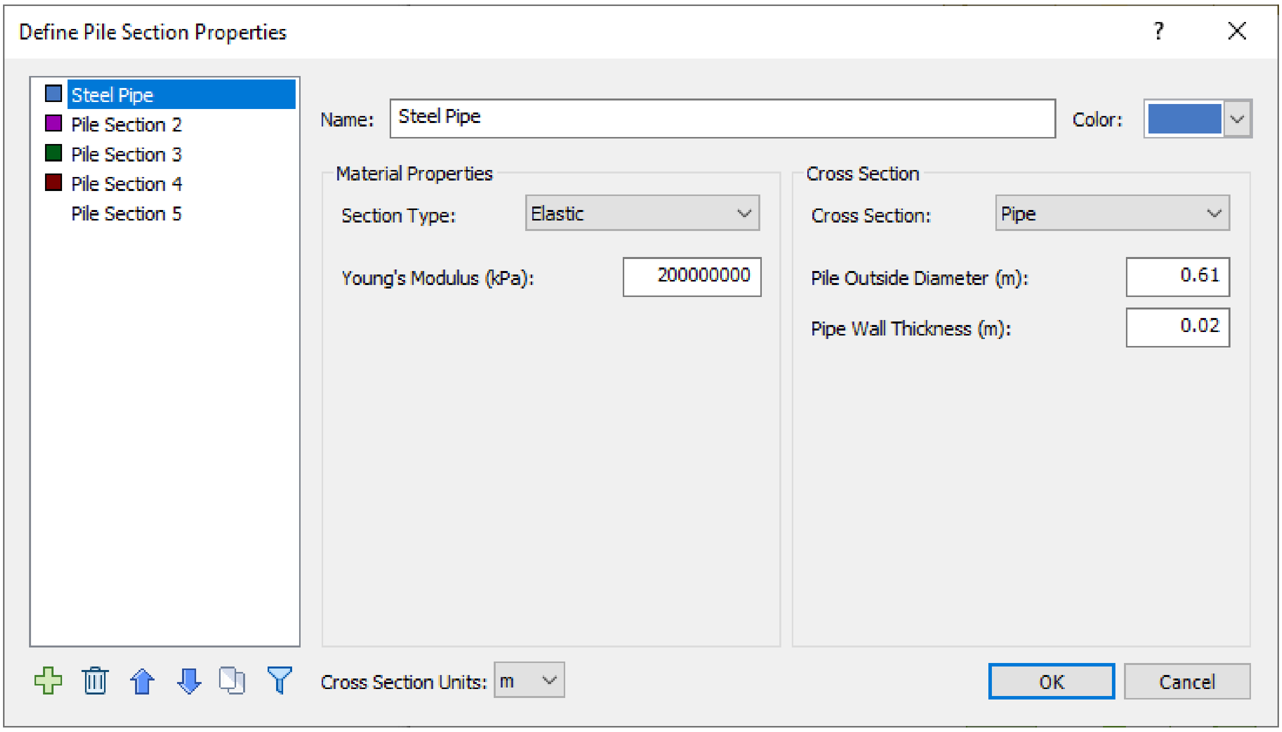
3.3 PILE SECTION PROPERTIES

You will now define the pile section properties.

1. Select **Piles > Pile Sections**

2. The **Define Pile Section Properties** dialog will appear. Enter the properties shown below.

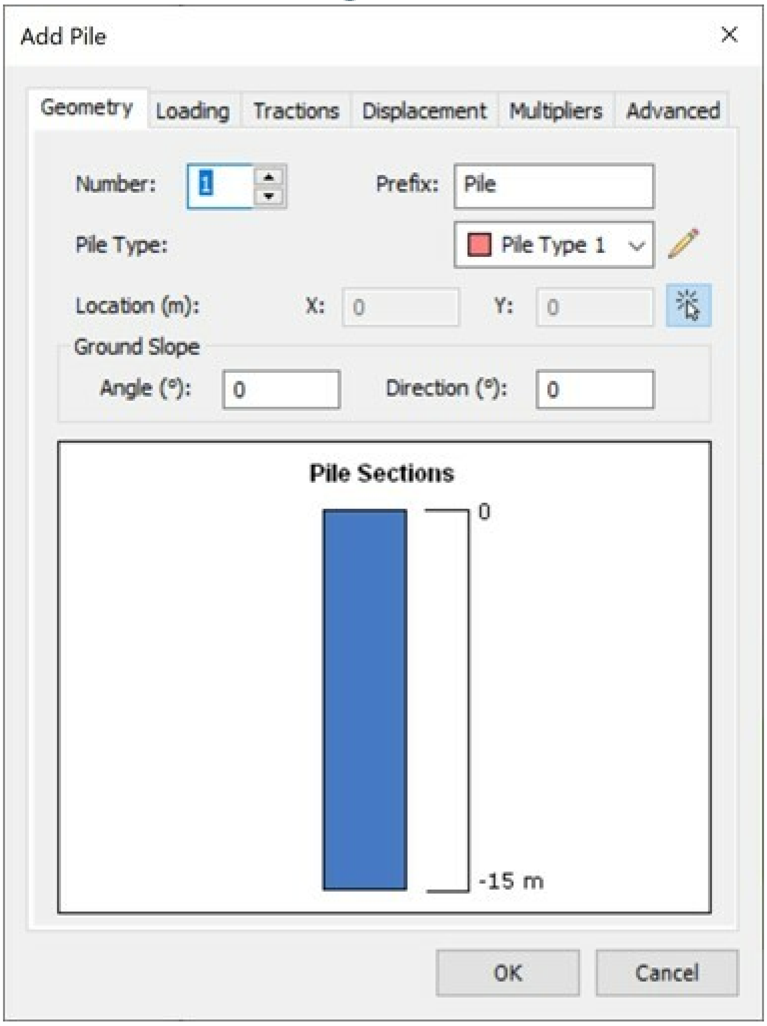
    - Name = Steel Pipe
    - Cross Section = Pipe
    - Type = Elastic
    - Pipe Outside Diameter = 0.61
    - Pipe Wall Thickness = 0.02
    - Young's Modulus = 2e8



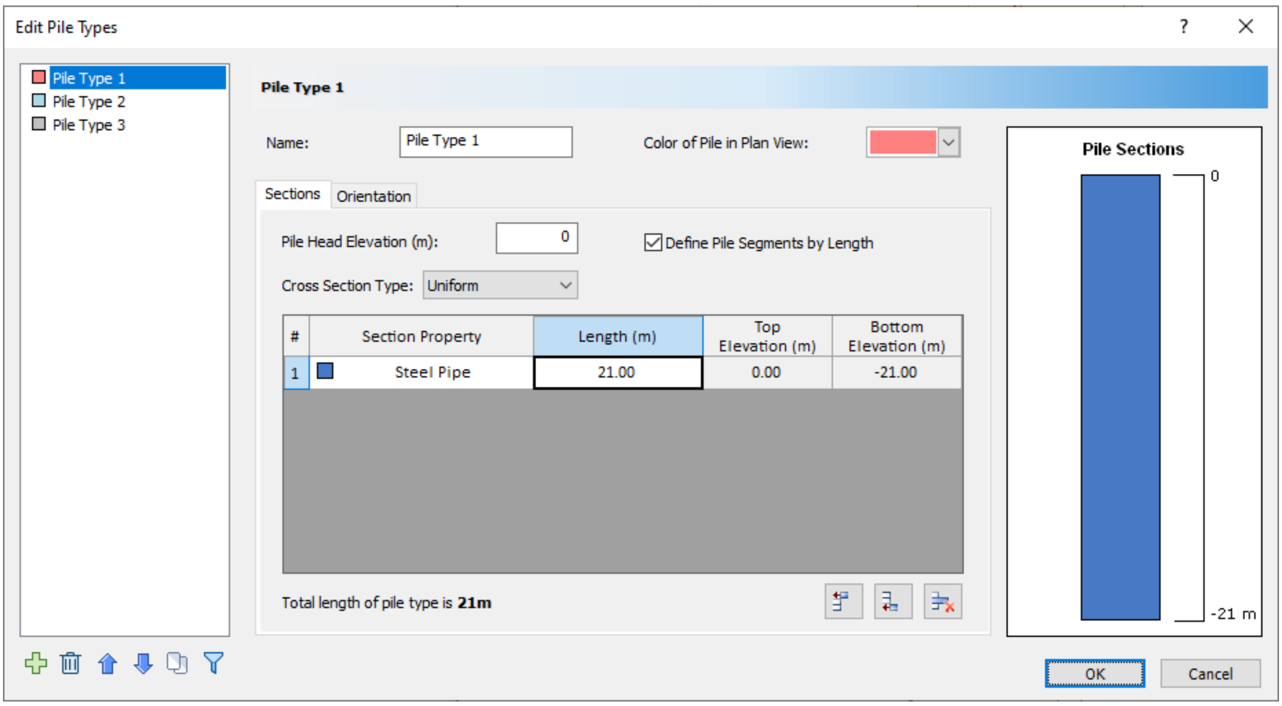
3. Click **OK.**

3.4 PILE LENGTH

1. Select **Piles > Single** to bring up the Add Pile dialog.



2. In the **Geometry** tab, click on the **Edit Pile Type** button.



3. Change the Length to **21m** and click **OK** to return to the Add Pile dialog.

Important! In this RSPile model, the pile length is set to 21 m. However, when this pile is read into Slide2, the length of the pile drawn on the slope in Slide2 may differ. During the analysis of pile resistance in such a case, the RSPile will automatically be extended or truncated to the lengths specified in Slide2 (whichever is appropriate). In other words, you can define any length of the pile in Slide2 for the analysis.

Note

If the RSPile contains multiple section properties defined along the length of the pile, it will also simply be truncated or extended to match the length in Slide2 without scaling the extents of the cross-sections. If the pile is extended, then the bottom-most cross-section defined in the RSPile will be extended to match the length in Slide2.

Note

When choosing the RSPile file, Slide2 does not accept piles containing tapered or bell sections.

4. Go to the **Loading** tab of the Add Pile dialog. You may specify loads in the RSPile file, which will be additional to the soil displacements during the analysis. These will affect the axial and/or shear force diagrams for the pile, and thus also the reaction of the pile on the slip surface. These loads are applied in the global axis directions. We will not apply loads in this case.
5. Click **OK** to close the Add Pile dialog and place the pile at **0,0.**
6. Before you import the RSPile model into Slide2, save it as a file called *Tutorial 30 Analyzing Pile Resistance using RSPile.rspile2*. (RSPile version 2 and above file names use the extension ".rspile2").
7. Select **File > Save As.**
8. Use the Save As dialog to save the file.

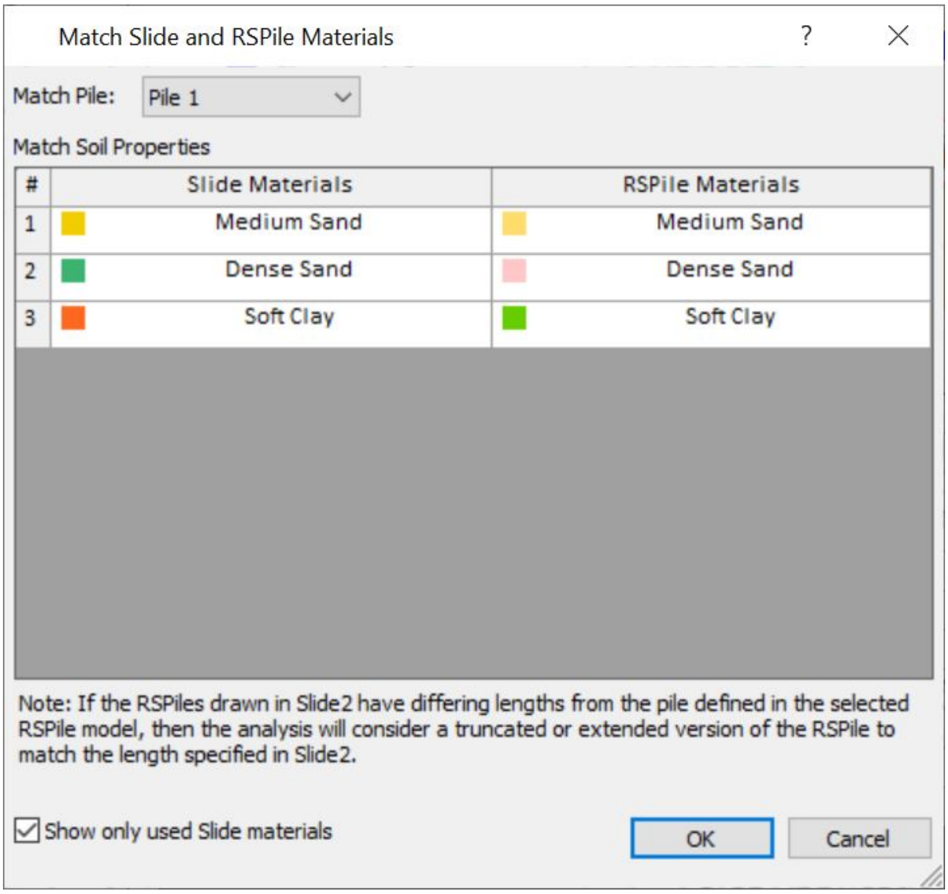
3.5 IMPORTING RSPILE MODEL INTO SLIDE2

1. Navigate back to the Slide2 modeller.

   Now you will import the soil and pile properties specifically for the pile model. You can do this from the **Define Support Properties** dialog. If it is not open, navigate back to the Define Support Properties dialog, and set up the support using the instructions at the beginning of the tutorial.

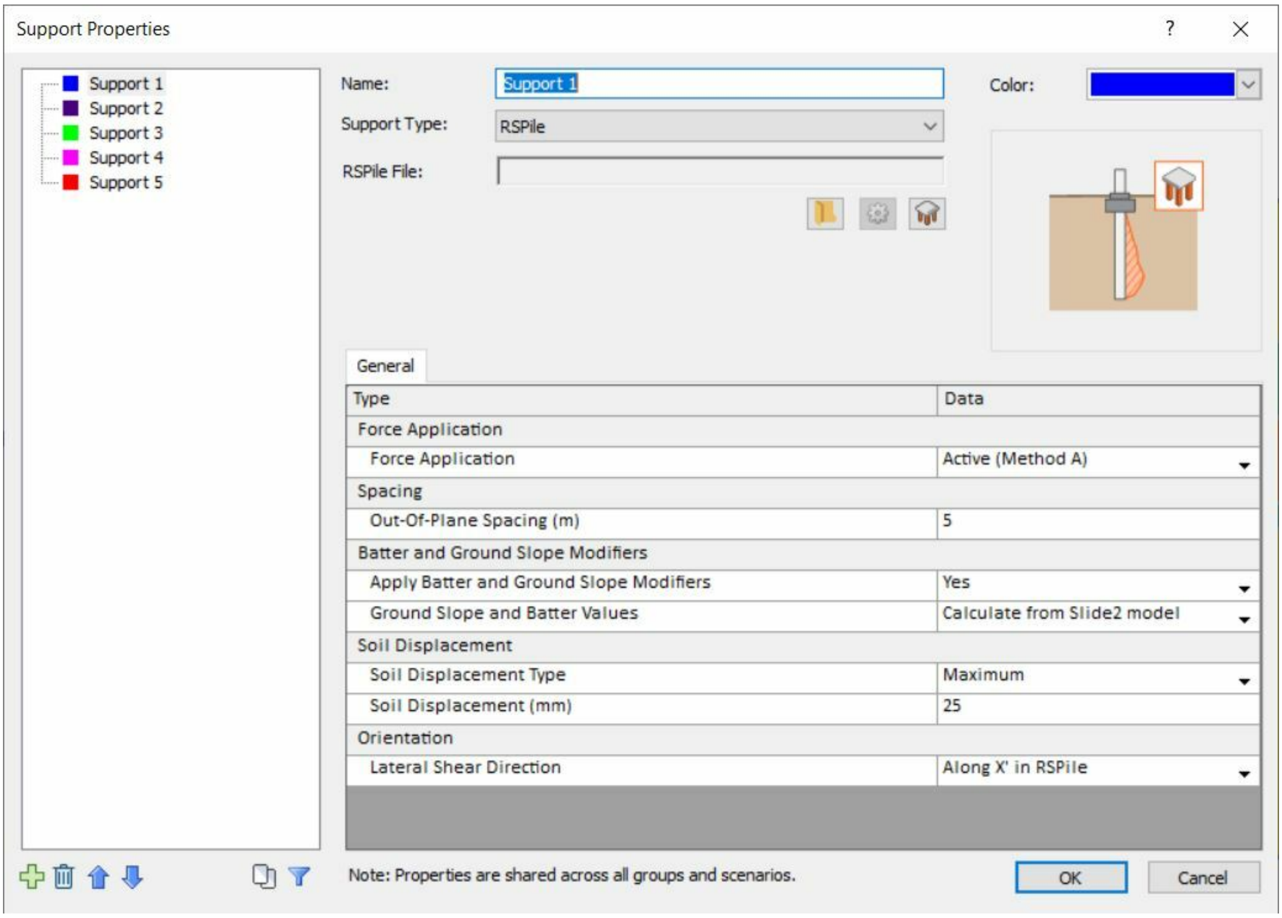
2. In the RSPile File section, select the folder icon to import the RSPile model you have just created.
3. Locate the RSPile model file *Tutorial 30 Analyzing Pile Resistance using RSPile.rspile2.* Select **Open**.

4. The following **Match Slide2 and RSPile Materials** dialog should appear. Check the "Show only used Slide2 materials," ensure that each material in Slide2 is matched with the same material in RSPile, and select **OK**.



Note

At the bottom of this dialog are written any warnings generated during the import process. As shown earlier, the chosen RSPile file, in this case, contains a length of **21 m**. However, the piles defined in Slide2 for this example have lengths **21 m** and **25 m**. Specifically for the analysis of the 25 m long pile, the RSPile will be extended to **25 m**.



Note

Under the **Soil Displacement** section we have a choice between **Maximum** and **Ultimate** modes. The Maximum mode assumes that a maximum allowable soil displacement of 25 mm in the direction tangent to the tested slip surface is used to compute the axial and lateral resistance against sliding. The Ultimate mode increases the applied soil displacement in the axial and lateral direction until a maximum resistance is reached.

In Slide2, a uniform soil displacement is applied from the ground surface to each of the tested slip surface intersections to the pile. The magnitude of the applied displacement is constant with depth. When using RSPile for a stand-alone pile analysis, the user may define more complex soil displacement profiles to apply to the model. However, due to the variability of slip surfaces that could intersect a pile in Slide2, more complex soil displacement profiles cannot be defined for a Slide2 analysis of imported RSPile files. We will use the default **Maximum Soil Displacement** settings.

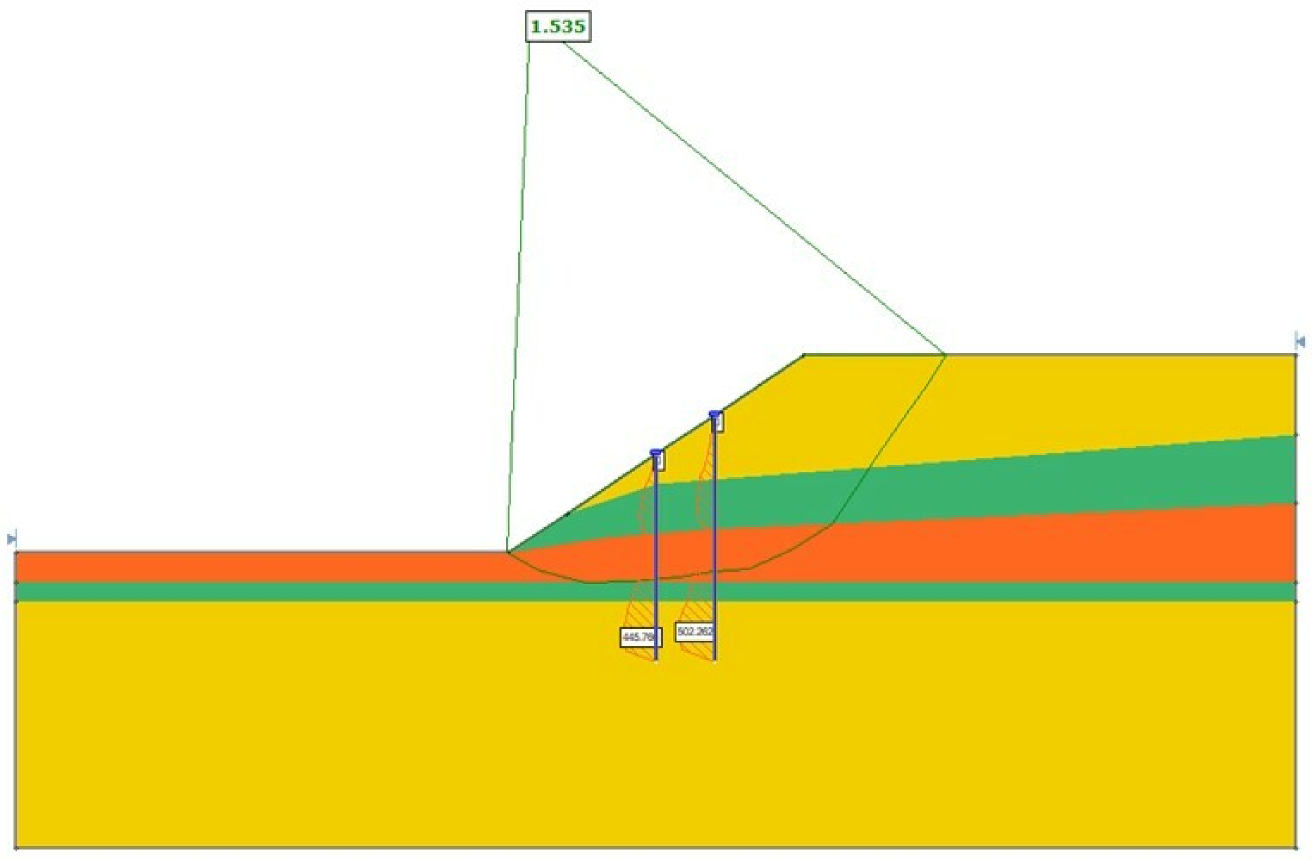
5. Ensure that the lateral shear direction is set to **Along X′ in RSPile**. This means that the soil displacement analysis will be carried out along the X′ direction of the RSPile. For piles that are not radially symmetric, you can change this setting to apply the lateral displacement along either of the major axes (X′ or Y′) of the pile.
6. Click **OK**.
7. Save and Compute the file.

4.0 Interpret

To view the results of the analysis:

1. Select **Analysis > Interpret**
   This will start the Slide2 Interpret program.
2. Ensure **Show Support Force diagram** is toggled on by selecting **Data > Show Support Force Diagram**

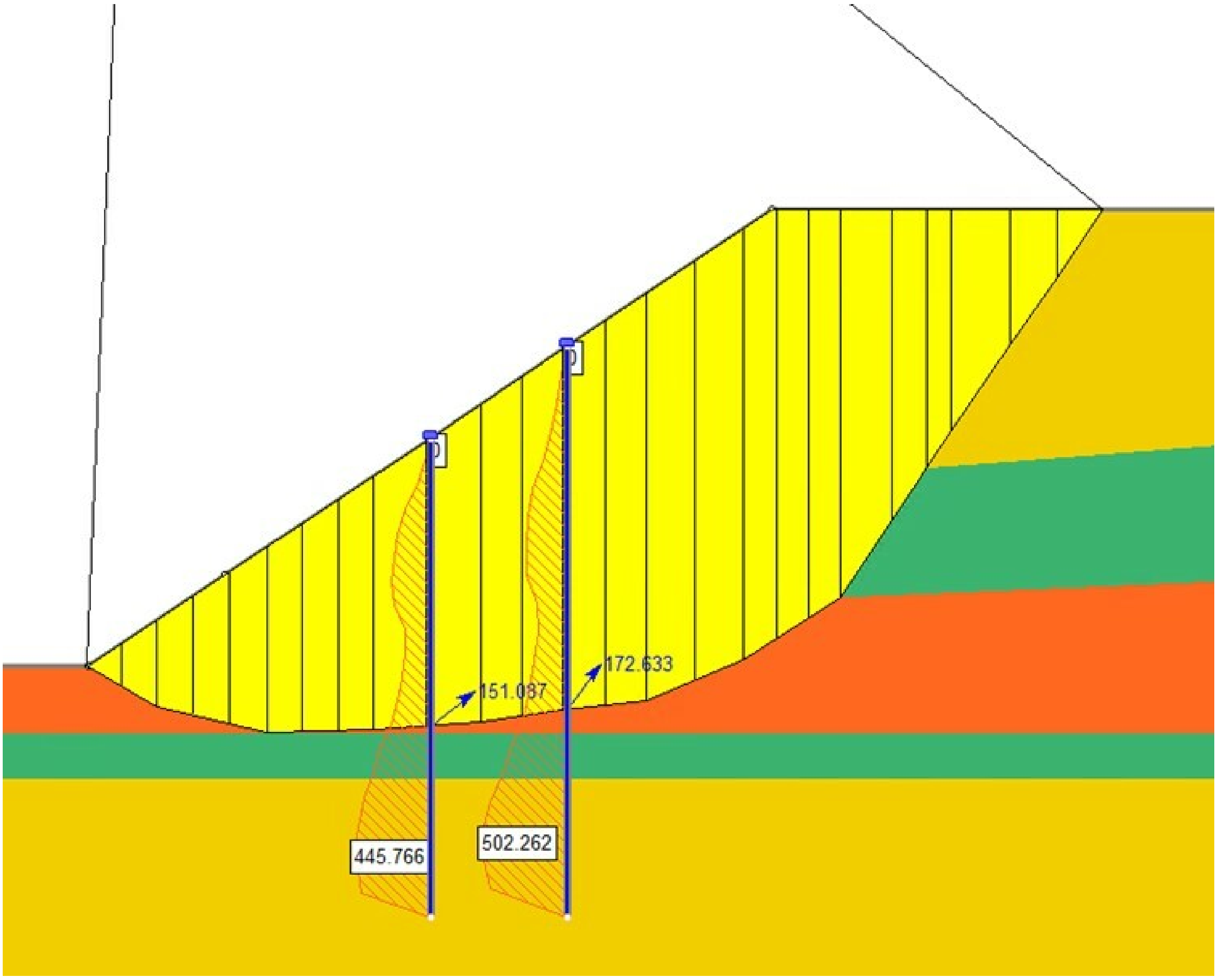
You should see the following figure for the Spencer FS analysis.



4.1 PILE RESISTANCE

To view the pile resistance force, select **Show Slices** from the **Query** menu.

1. Select **Query > Show Slices**



The pile resistance is indicated by the blue arrow with its origin located at the intersection of the pile and slip surface. Notice that the direction of pile resistance is always opposite to the direction of sliding although it may not always be tangent to the slip surface. Each slip surface will have a different pile resistance depending on the depth and angle of intersection. The forces in the left and right piles are 151.1 kN and 172.6 kN, respectively. Note that because the pile out of plane spacing is 5 m, the actual force for each pile is 5 times higher.

This part of the tutorial is now complete.

To compare the results from Slide2 to an analysis done completely in RSPile, proceed with this tutorial.

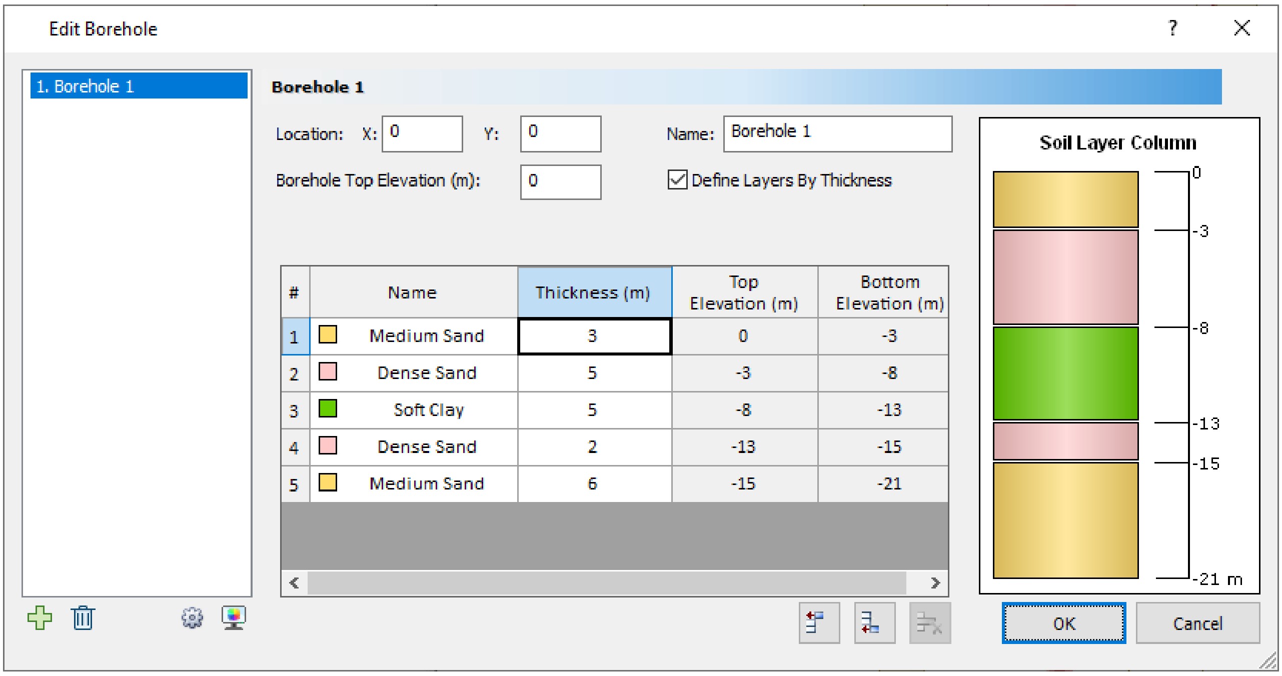
5.0 Verifying Pile Resistance using RSPile

You can verify the pile resistance results from Slide2 by using the same pile length and soil layer configuration for the RSPile model. For this tutorial, we will be verifying the pile resistance of the downslope, shorter pile.

The finished product of the RSPile model file for verification can be found in the *Tutorial 30 (Verification).rspile2* data file. All tutorial files installed with Slide2 can be accessed by selecting **File > Recent Folders > Tutorials** Folder from the Slide2 main menu.

1. Return to the RSPile Model program and open the *Tutorial 30 Analyzing Pile Resistance using RSPile.rspile2* file if it is not already open.
2. Go to **Soils > Edit All Boreholes** and change the soil layer thicknesses to the following.

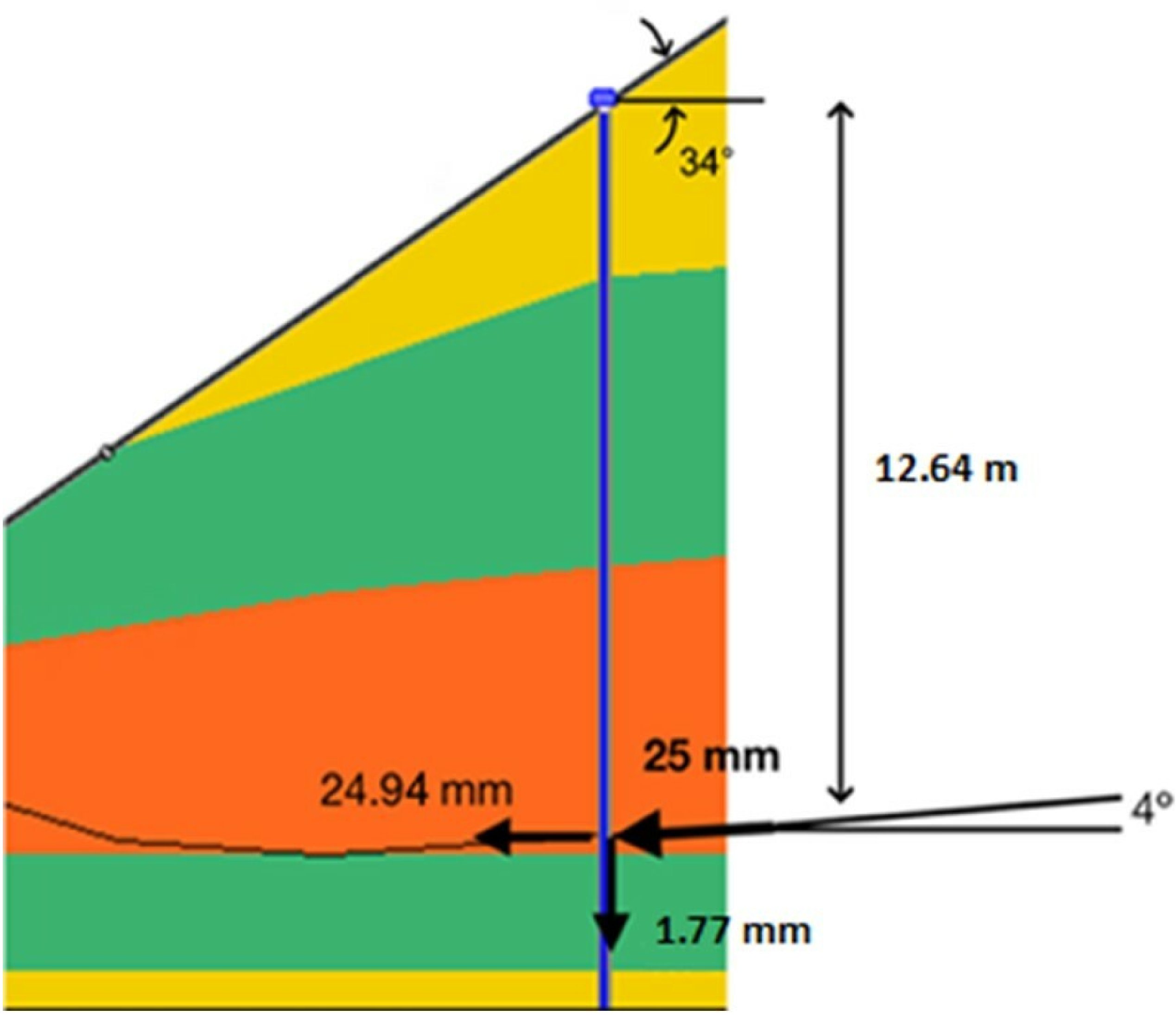
Name	Thickness
Medium Sand	3
Dense Sand	5
Soft Clay	5
Dense Sand	2
Medium Sand	6



3. Click **OK**.

5.1 PILE RESISTANCE

The maximum soil displacement entered in Slide2 to calculate pile resistance is 25 mm. Since the critical slip surface intersects the pile at approximately 4 degrees to the horizontal, the components of soil displacement for the axial and lateral direction are 1.77 mm and 24.94 mm respectively. The depth was found to be 12.64 m. This information was found with the **Query Slice Data** feature in Slide2, by selecting the slice containing the pile, as well as with the measuring tools.



In RSPile:

1. Right-click on the pile in the **Plan view** and select **Edit Pile.** Go to the **Displacement** tab in the **Edit Pile** dialog:
2. Ensure you have selected the **Displacement Profile** radio button
3. Select **Profile = Displacement Profile 1**
4. Click on the **Pencil** icon and specify the following profile:

#	Depth (m)	X Displacement (mm)	Y Displacement (mm)	Z Displacement (mm)
1	0	-24.99	0	-1.77
2	12.64	-24.99	0	-1.77
3	12.65	0	0	0
4	21	0	0	0

5. Click **OK** to return to the **Edit Pile** dialog, and then switch back to the **Geometry** tab.

6. Change the Ground Slope angle to +**34°** and direction to **270°**. The direction of the ground slope is measured clockwise from the Y-axis in RSPile, and a positive ground slope angle is downwards sloping. Click **OK**
7. Recalculate by selecting **Home > Compute**
8. Right-click on the pile and select **Graph Pile** .
9. Change the graph and table data so that you can see both Beam Shear Force X′ and Beam Axial Force. This is done as follows for the graph and table, respectively:
10. Select **Chart > Edit Charts**. Click on the second input and select Beam Shear Force X′ from the dropdown. Click on the third input and select Beam Axial Force. Click OK.
11. Select **Chart > Edit Table Columns**. Click on Beam Shear Force X′ on the right and click the left arrow to add it to the table view. Do the same for Beam Axial Force. Click OK.

The slip surface intersected the pile at approximately 12.64 m in Slide2 so we will look at the two depths of 12.583 m and 12.792 m and interpolate.

At a depth of 12.583 m, we see a shear force of 560.7 kN and axial force of 463.4 kN. The resultant force is 727.4 kN. At a depth of 12.792 m, the resultant of a 554.9 kN shear force and 462.4 kN axial force is 722.3 kN. Interpolating the results from RSPile gives a force of 724 kN.

Slide2's pile force is 151.1 kN but recall that due to the 5 m spacing, the actual pile force is multiplied by 5, yielding **755 kN**. This results in approximately 4% difference.

The discrepancies are due primarily to linear interpolation of the resistance at two locations. In Slide2, the resistance functions are constructed for the number of sliding depths as set in RSPile and the soil displacement is varied at each sliding depth to account for the unknown slip surface angle of intersection. First, linear interpolation must be done to compute the resistance function for the exact component of soil displacement produced by the slip surface based on the closest tested soil displacements. Secondly, linear interpolation is done to compute the resistance for the exact sliding depth since the tested sliding depths are unlikely to align exactly with the actual slip surface intersection with the pile.

In RSPile, you have more control over the exact soil displacement and sliding depth since you are verifying one known slip surface. However, repeating this resistance computation for every slip surface would be rather tedious, hence the necessity for an automated process in Slide2. Even with a relatively low Number of Intervals, the resultant pile resistance computed in RSPile is within 4% of the value from Slide2 which is within typically accepted tolerances.

Before you exit RSPile, save this file as *Tutorial 30 (verification).rspile2*.

- Select **File > Save As**

This concludes this tutorial.