



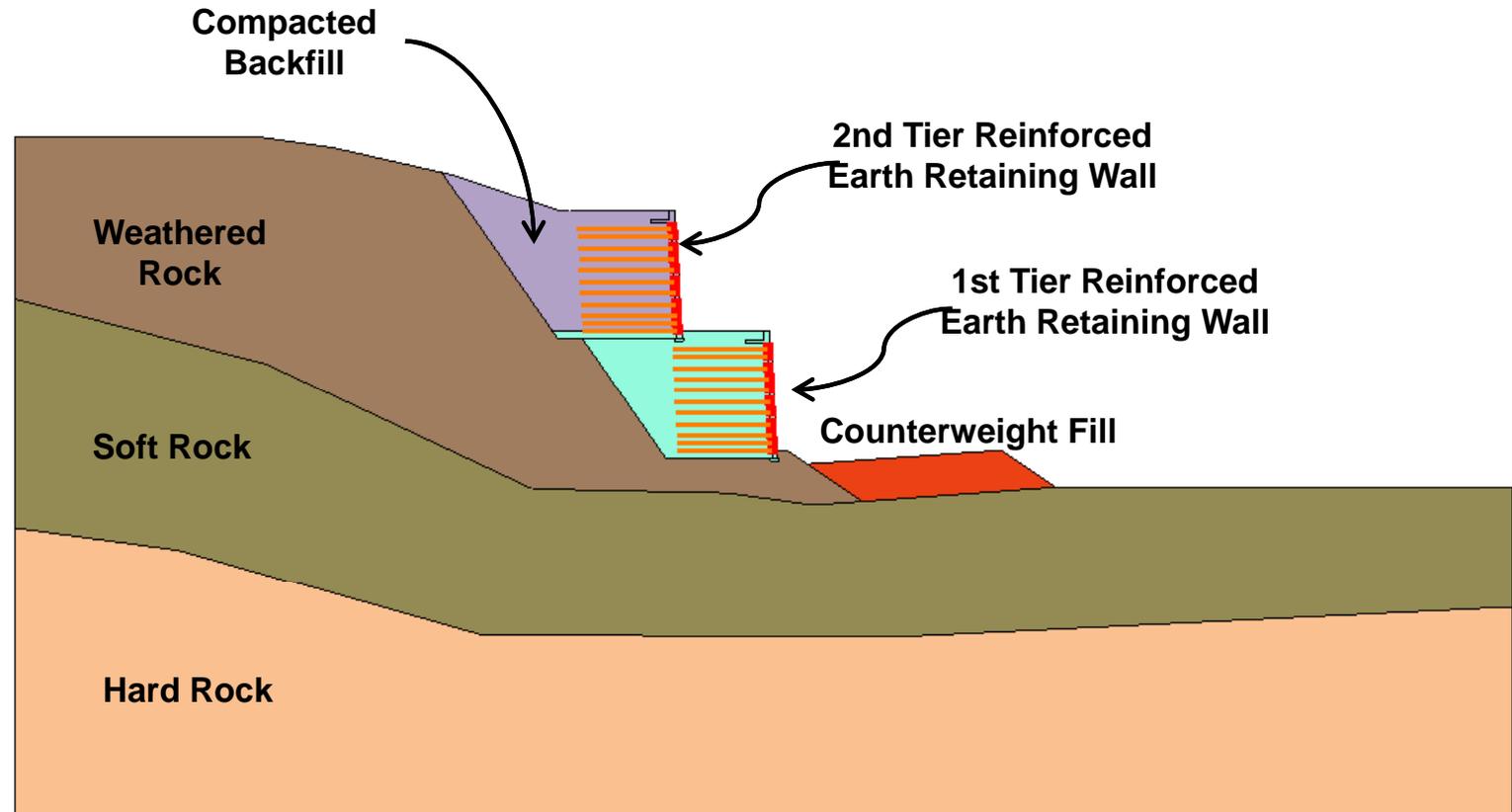
# Stability Analysis of Reinforced Earth Retaining Walls - LEM

Slope Module Tutorial

# Stability Analysis of Reinforced Earth Retaining Walls - LEM

## Overview

- Limit Equilibrium Method (LEM) is used to check the stability of the reinforced earth retaining walls. LEM assumes the ground as a unit soil mass within which equilibrium of forces and moments at a specific failure surface is considered. LEM is widely used for stability analysis of cohesive slopes.
- SoilWorks provides LEM by Fellenius, Bishop and Janbu. These methods present some discrepancies depending on the strength parameters and the accuracy in slope geometry.
-  SoilWorks can perform LEM analysis with construction stages reflecting cutting and embankment.



**Ground Properties**

No	Ground Type	Unit Weight [kN/m <sup>3</sup> ]	Saturated Unit Weight [kN/m <sup>3</sup> ]	Cohesion [kN/m <sup>2</sup> ]	Internal Friction Angle [deg]
1	Weathered rock	20	21	35	30
2	Soft rock	23	24	150	35
3	Hard Rock	24	25	200	37
4	Backfill	18.5	19.5	14	32
5	Counterweight Fill	18.6	19.6	15	25
6	Concrete Block	20	21	980	40

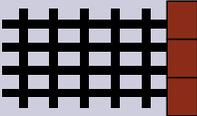
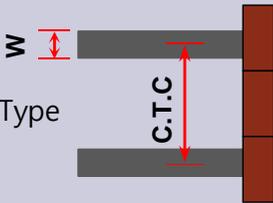
- Ground and structural properties must be defined within the model of “(LEM)” .
- In case the **limit earth pressure (pl)** and the **horizontal ground modulus of elasticity (KsB)** are defined as the structural properties, ‘Strip(LEM)’, analysis results are not affected.

**Structural Properties**

No	Name /Member Type	Reinforcement Spacing [m]	Initial Diffusion Width [m]	Initial Diffusion Angle [deg]	Tensile Force [kN]	Width [m]	Backfill Unit Weight [kN/m <sup>3</sup> ]	Friction Coefficient
1	Geogrid /Strip(LEM)	1	2	15	150	1	19.5	0.3

**Points to consider in entering reinforcement property data**

- **Reinforcement Spacing:** in the (transverse) direction of the section thickness
- **Initial Diffusion Width:** to account for the effective width of stress transfer  
Generally the width of bearing plate is used. In case of no bearing plate, the diameter of Strip may be specified. Even 0 may be specified.
- **Initial Diffusion Angle:** to account for the angle of stress distribution by Strip  
The angle is obtained from tests, or generally 10 to 15 degrees are used.
- **Tensile Force:** maximum tensile strength of Strip
- **Width:** width of Strip
- **Friction Coefficient:** between the backfill and Strip

Reinforcement Type	Spacing	Tensile Force	Width
Grid Type 	1m	Tensile Force/m	1m
Mat Type 	1m	Tensile Force/m	1m
Strip Type 	C.T.C	Tensile Force/m	W (m)

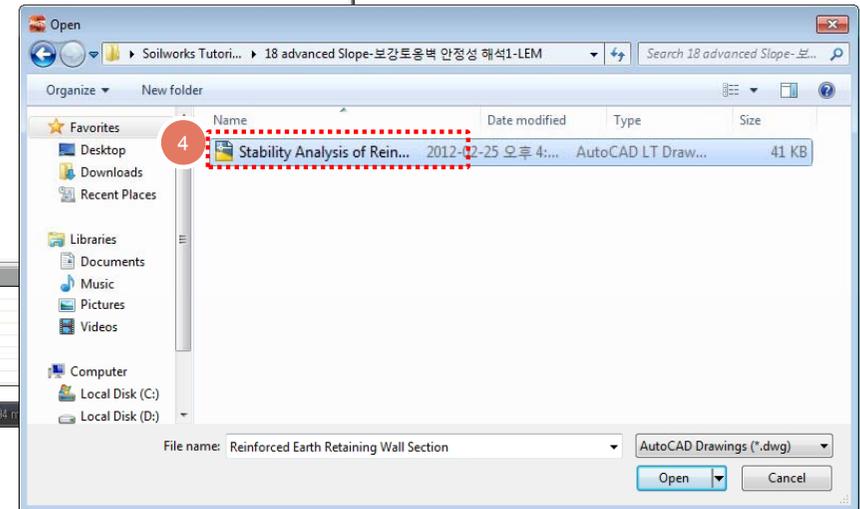
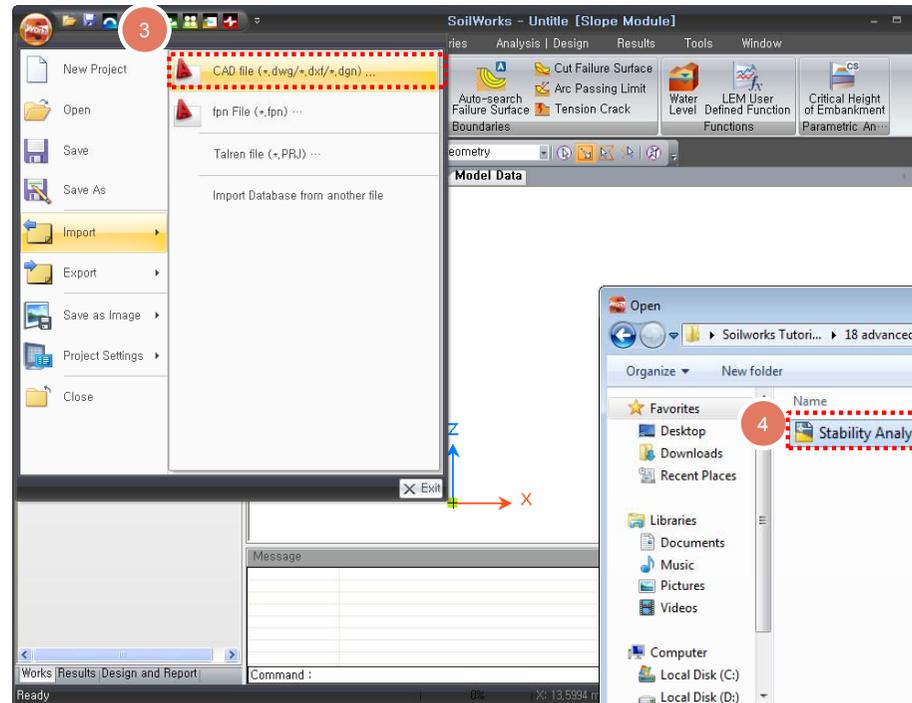
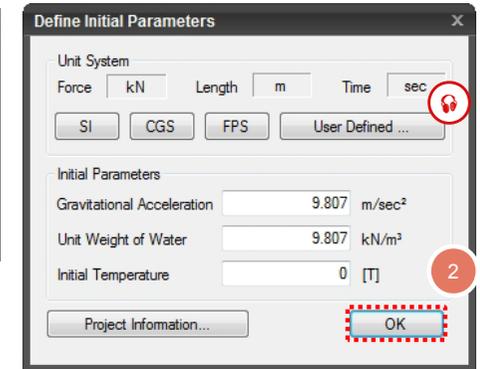
**Procedure**

Select the SoilWorks execution icon from the Desktop.

- 1 Project Manager > click Slope.
- 2 Define Initial Parameters: click OK.
- 3 Main Icon > Import > select CAD File.
- 4 Select 'Reinforced Earth Retaining Wall Section.dwg' and click Open.

The user can change the default units for 'Force', 'Length' & 'Time', 'kN', 'm' & 'sec'.

The user can also directly copy the object from the CAD program screen & paste it into SoilWorks.



**Procedure**

- 1 From the Main Menu, select **Limit Equilibrium Method > Ground Material Property (command: gm)**
- 2 Refer to **Step 01**. to enter the ground material properties and click **Add**.
- 3 Click **Close**.

SoilWorks permits ground material properties used in projects to be compiled in a database. The database is created by editing the gdb file in SoilWorks/Dbase in the Install folder.

**Define Ground Material Property**

ID	Name
1	Weathered rock
2	Soft rock
3	Hard Rock
4	Backfill
5	Counterweight...
6	Concrete Block

**General**

ID: 1 Name: Weathered rock

Model Type: Mohr-Coulomb (LEM)

**General Parameters**

Unit Weight (Yt)	20	kN/m <sup>3</sup>
Saturated Unit Weight (Ysat)	21	kN/m <sup>3</sup>
Cohesion (c)	35	kN/m <sup>2</sup>
Internal Friction Angle (Φ)	30	[deg]

**Additional Parameters**

Variation in Cohesion	0	kN/m <sup>2</sup>
<input type="checkbox"/> Anisotropic Function		...
<input type="checkbox"/> Nonlinear Function		...
<input type="checkbox"/> No Water Level considered		
<input type="checkbox"/> Pore Pressure Coefficient	0	
<b>Nail/Pile(LEM)</b>		
qs Value for Nail	200	kN/m <sup>2</sup>
Limit Soil Pressure (pl)	100	kN/m <sup>2</sup>
Horizontal Subgrade Reaction (ksB)	1000	kN/m <sup>2</sup>

Database ...

Add Modify Delete Close

**Procedure**

- 1 From the **Main Menu**, select **Limit Equilibrium Method > Structural Property (command: sp)**

Define Geogrid.

- 2 Refer to **Step 01**. to enter the structural properties and click **Add**.
- 3 Click **Close**.

1 Define Structural Property

ID	Name
1	Geogrid

2

General

ID 11 Name Geogrid

Element Type Strip/Fabric (LEM)

Stiffness

**General**

Spacing	1 m
Initial Diffusion Width	2 m
Initial Diffusion Angle	15 [deg]
Adjust Reinf. Effect by FS	Independent
Reinforcement Vector	0

**Reinforcement Load**

Tensile Force	150 kN
Consider Pullout Force	Simplified Method
Width	1 m
No. of Contact	Side2
Unit Weight of Backfill	19.5 kN/m <sup>3</sup>
Friction Coefficient	0.3

3

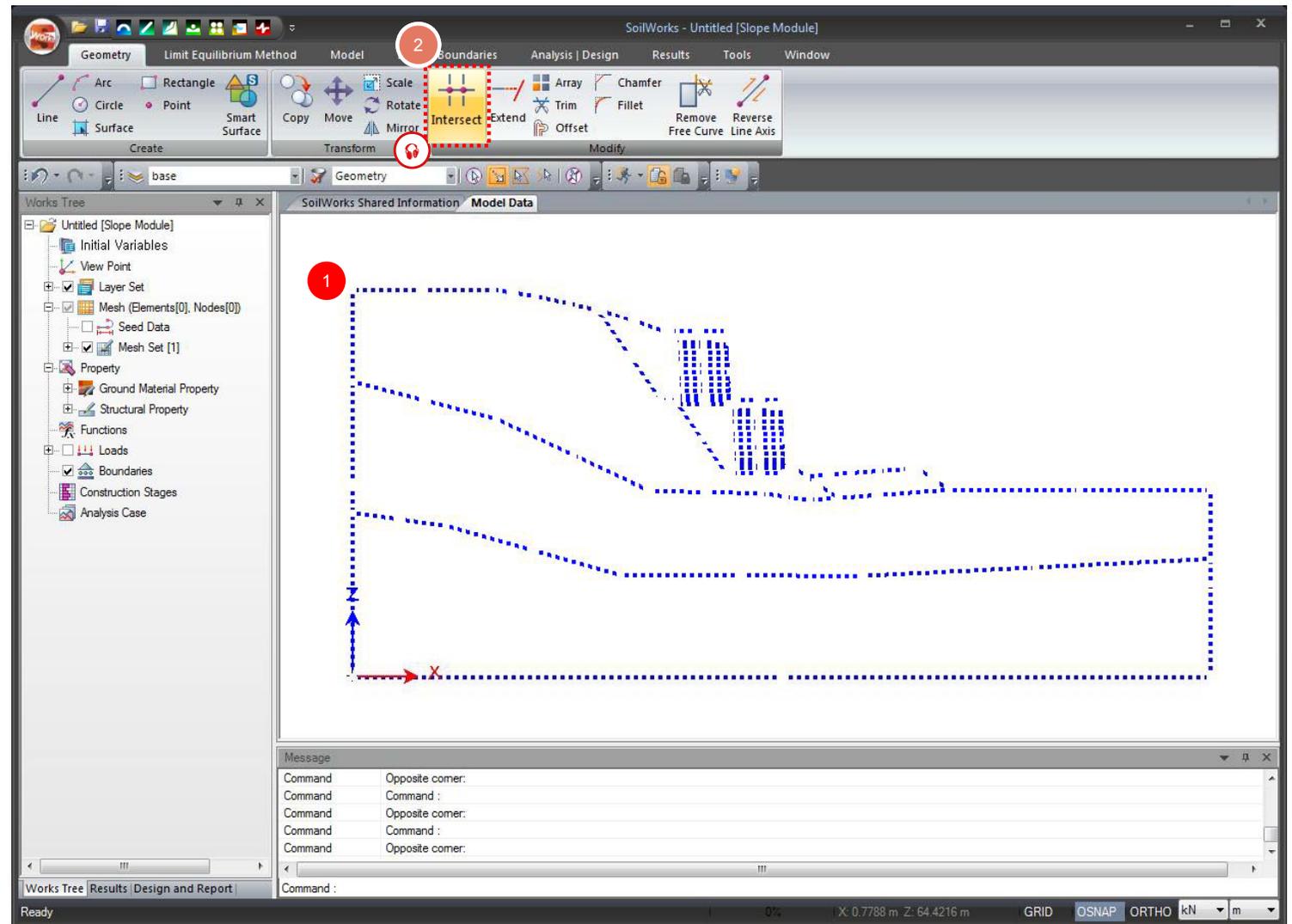
Reset Add Modify Delete Close

**Procedure**

Prior to creating surfaces for a complex section like reinforced earth retaining walls,

- 1 Select all the curves from **Model Data**.
- 2 From the **Main Menu**, select **Geometric Shape > Division at Intersection**.

 In case the objects constituting the section in the CAD file are improperly composed (ie, overlapped curves, minute offsets, etc.), errors may occur in the process of auto-generating the surfaces. **Accordingly, intersections are divided in advance.**



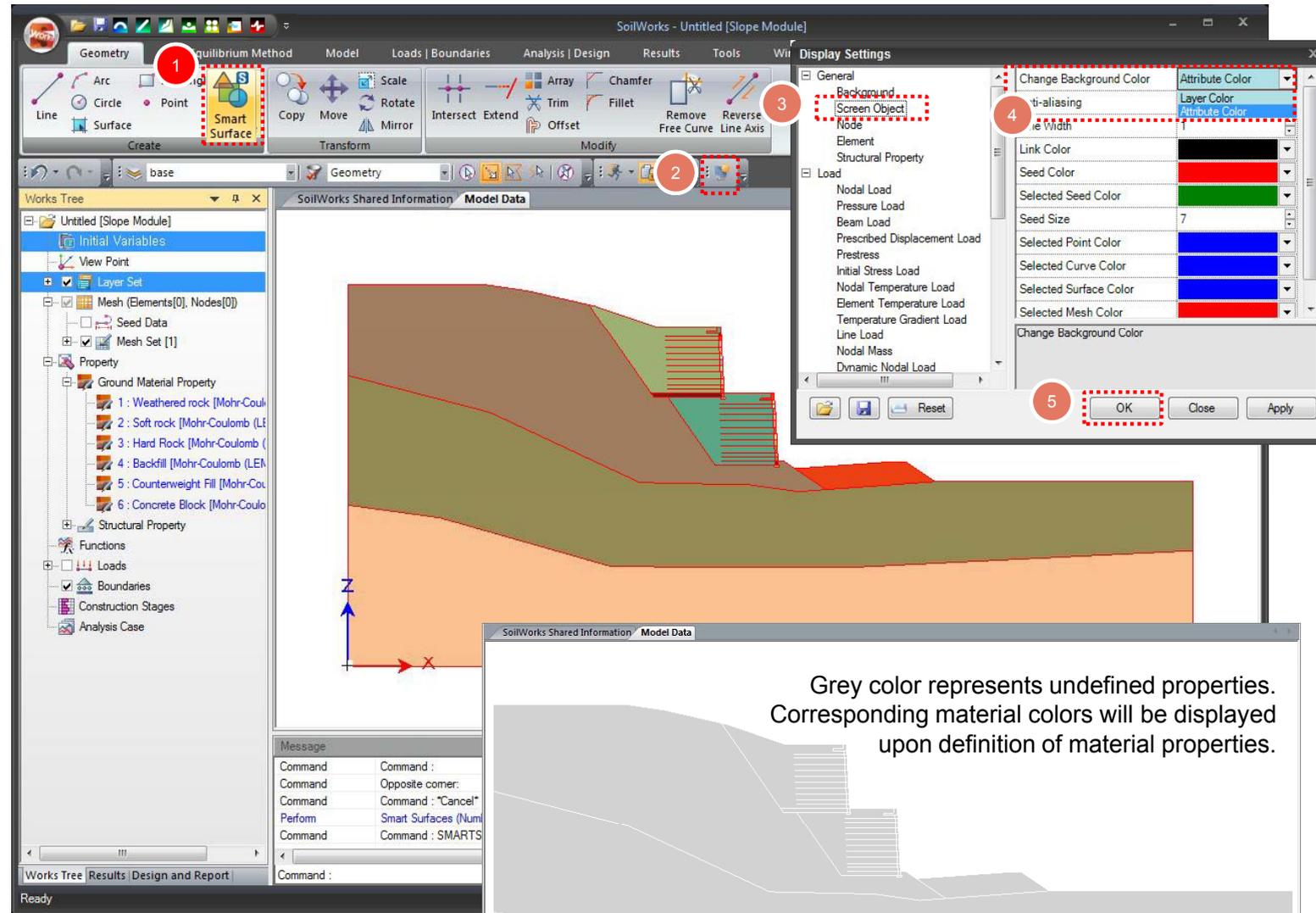
**Procedure**

In order to create surfaces to which material properties will be assigned,

- 1 From the **Main Menu**, select **Geometric Shape > Auto-generate Surfaces (command: ss)**

In order to check proper input of material properties, select **Main Menu > Window > View Setting.** (or select the icon )

- 2 material properties, select **Main Menu > Window > View Setting.** (or select the icon )
- 3 Select **Display Setting > Screen Object.**
- 4 Select **Change Background Color > Attribute Color.**
- 5 Click **OK.**



The screenshot shows the SoilWorks software interface. The toolbar at the top has a red dashed box around the 'Smart Surface' icon (1). The Works Tree on the left shows a 'Layer Set' with six material properties: 1: Weathered rock, 2: Soft rock, 3: Hard Rock, 4: Backfill, 5: Counterweight Fill, and 6: Concrete Block. The central model view shows a cross-section of a slope with a retaining wall. The Display Settings dialog box is open, with a red dashed box around the 'Screen Object' option (3). The 'Change Background Color' section has 'Attribute Color' selected (4). The 'OK' button is highlighted with a red dashed box (5). A message window at the bottom shows the command 'SMARTS' performed.

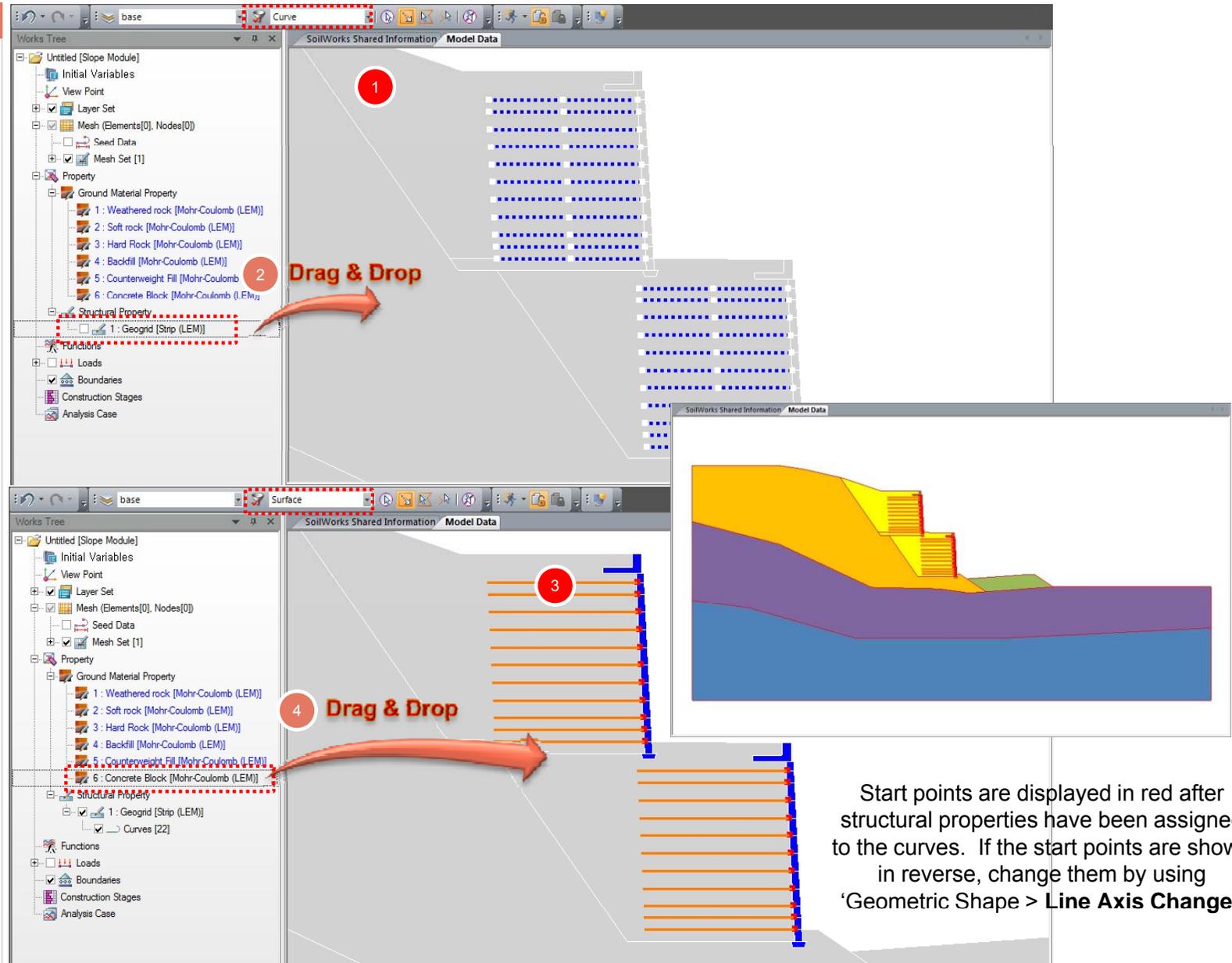
Grey color represents undefined properties. Corresponding material colors will be displayed upon definition of material properties.

# Assign Material Properties

## Procedure

First, the material properties of the reinforcement are assigned.

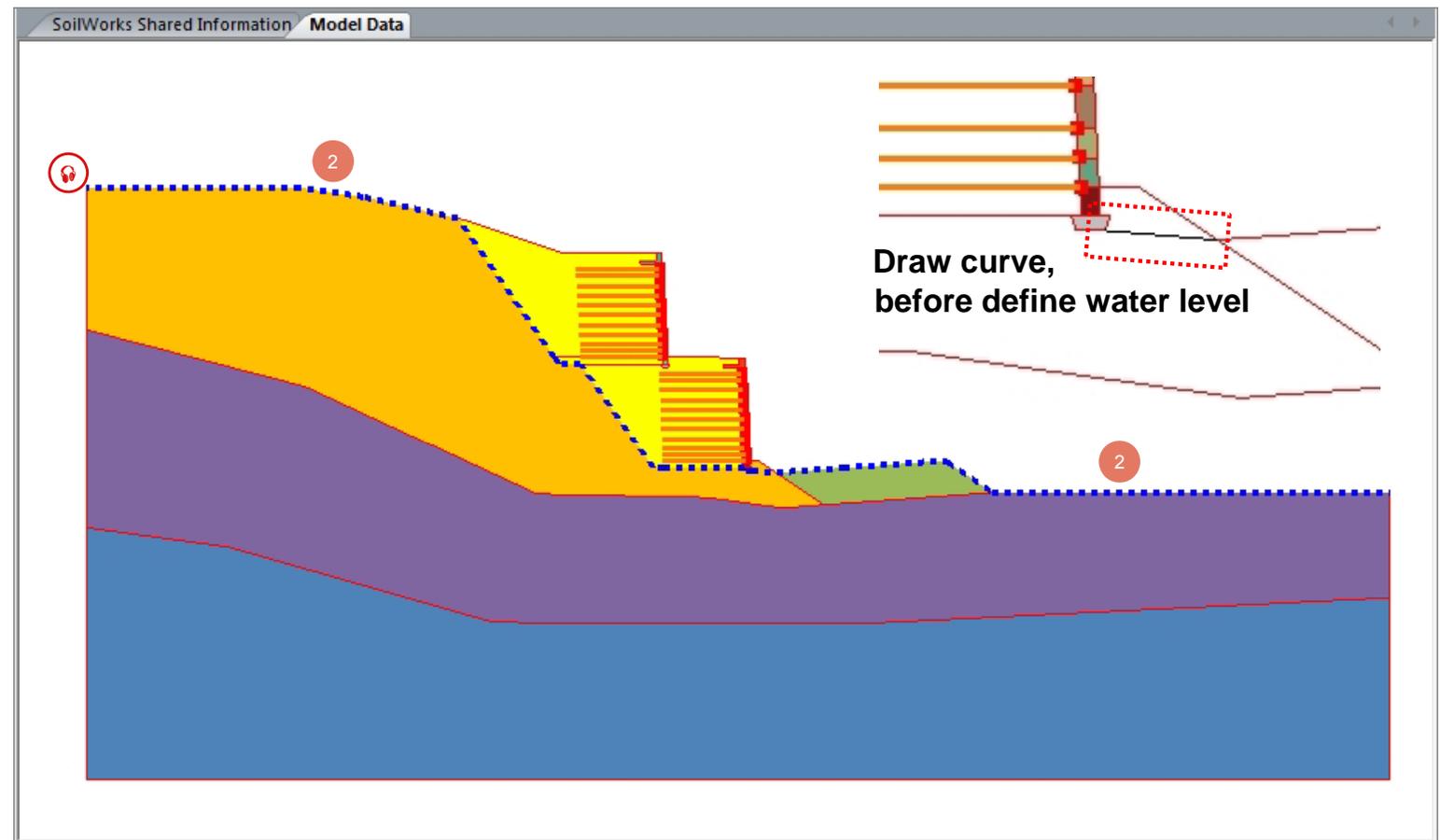
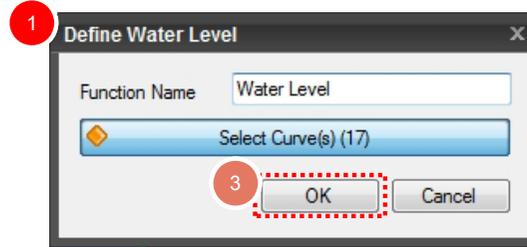
- 1 From the **Model Data**, select 22 curves corresponding to the reinforcement.
- 2 Select 'Geogrid' from the WorksTree and Drag & Drop.
- 3 From the **Model Data**, select the surfaces corresponding to block and structures.
- 4 Select 'Concrete Structure' under Ground Material Property from the WorksTree and Drag & Drop.
- 5 Similarly repeat the steps 3-4 sequentially for 'Hard Rock', 'Soft Rock', 'Weathered Rock', 'Counterweight Fill', 'Backfill' and Drag & Drop.



**Procedure**

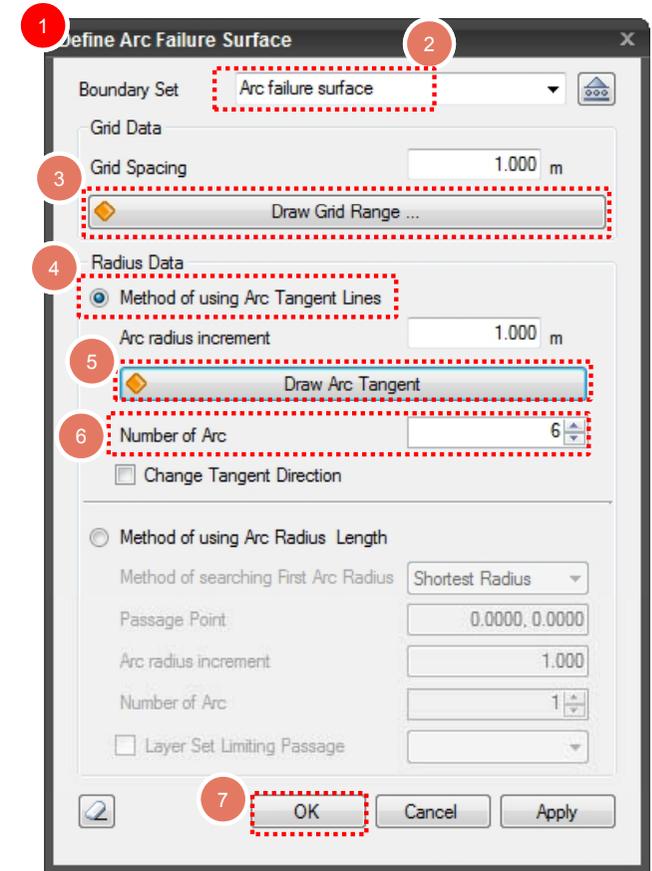
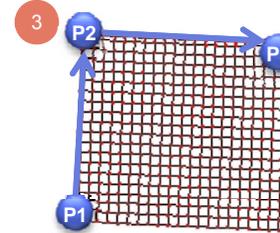
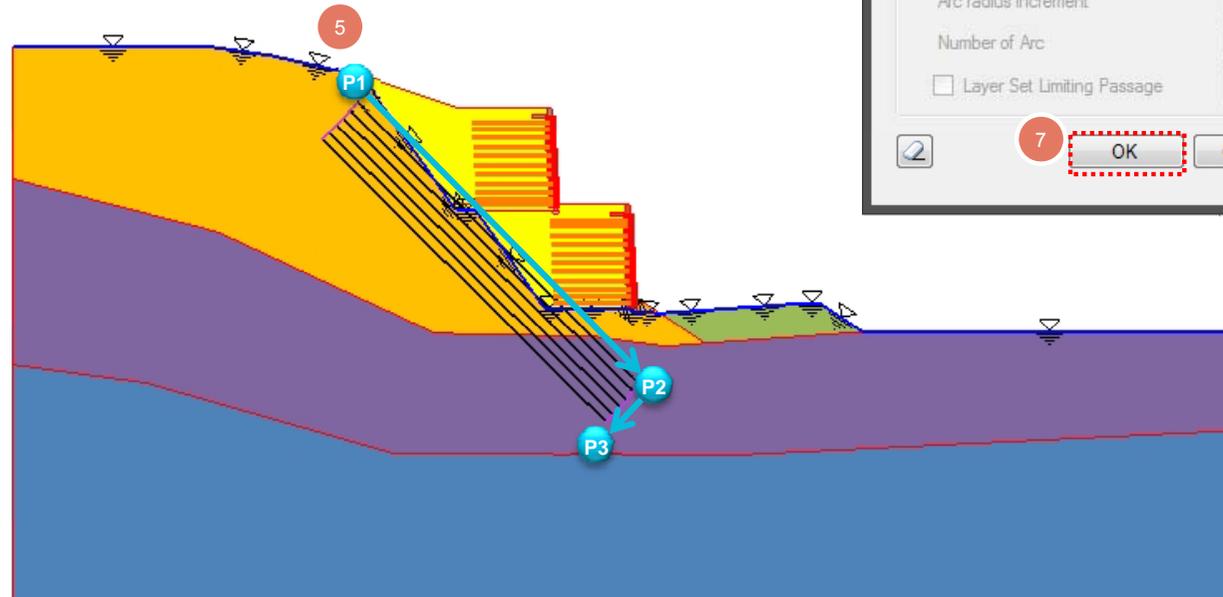
- 1 From the **Main Menu**, select **Limit Equilibrium Method > Water Level**.
- 2 From the **Model Data**, select the curves by which the water level will be defined (water level is set to the rainy season)
- 3 Click **OK**.

-  Saturated Unit Weight ( $\gamma_{sat}$ ) of Ground Material Properties is used for the ground below the water level, and Wet Unit Weight ( $\gamma_t$ ) is used for the ground above the water level.



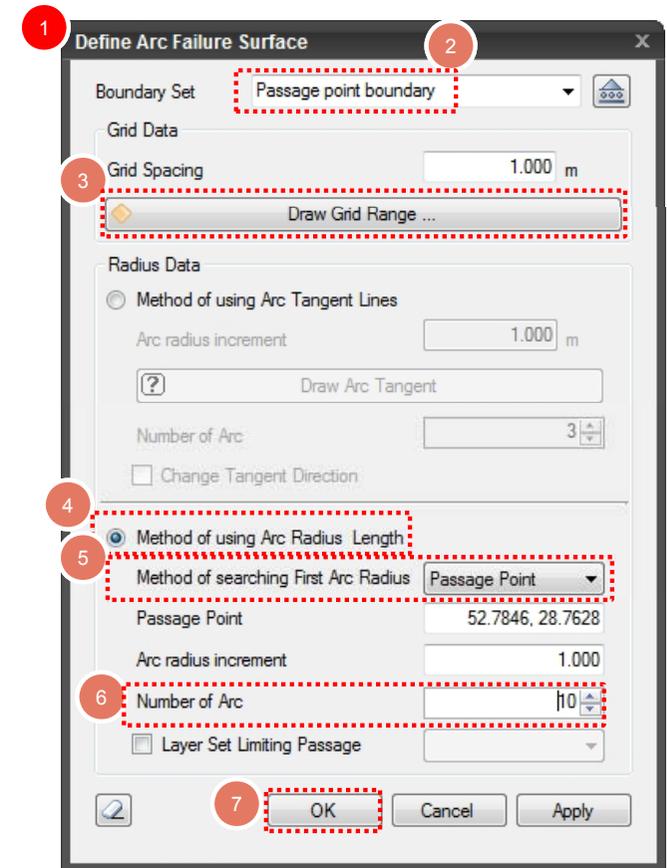
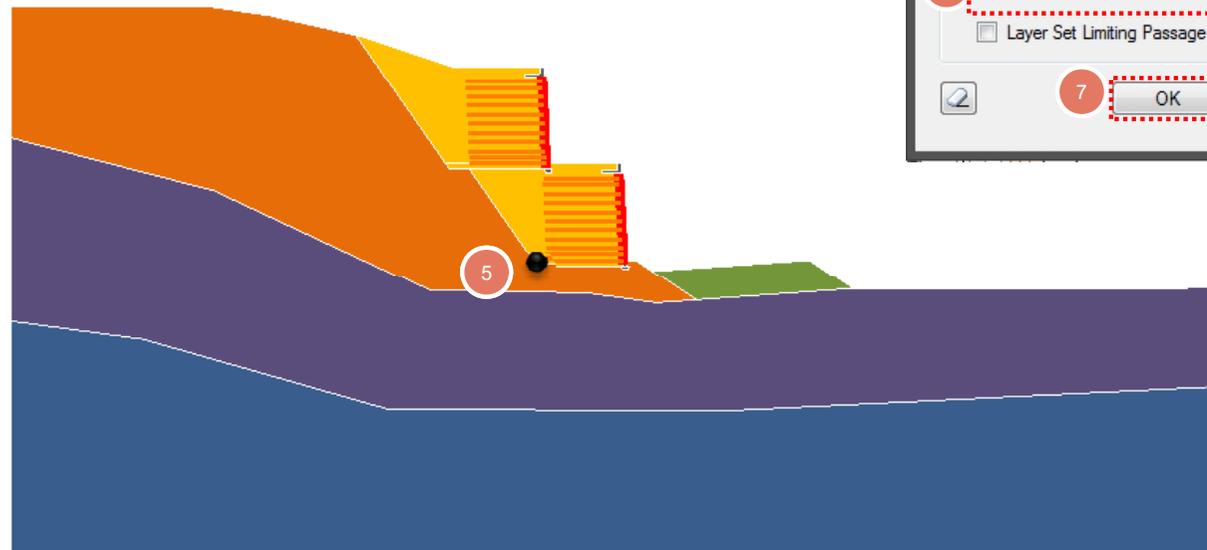
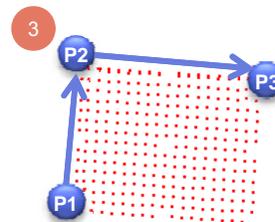
**Procedure**

- 1 From the **Main Menu**, select **Limit Equilibrium Method > Arc Failure Surface**.
- 2 **Boundary Set:** enter 'Arc failure surface'.
- 3 Click **Draw Grid Range** and draw the range of grid on Model Data (in the order of P1→P2→P3)
- 4 Select **Method of using Arc Tangent Lines**.
- 5 Click **Draw Arc Tangent** and draw the range of tangent lines on Model Data.  
(in the order of P1→P2→P3)
- 6 **Number of Arc** : enter '6'.
- 7 Click **OK**.



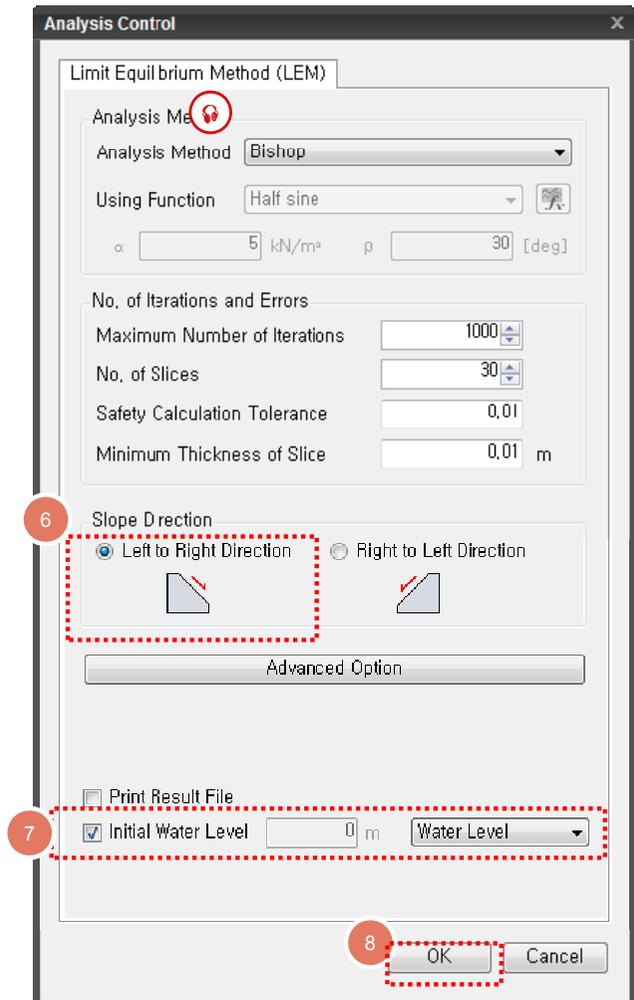
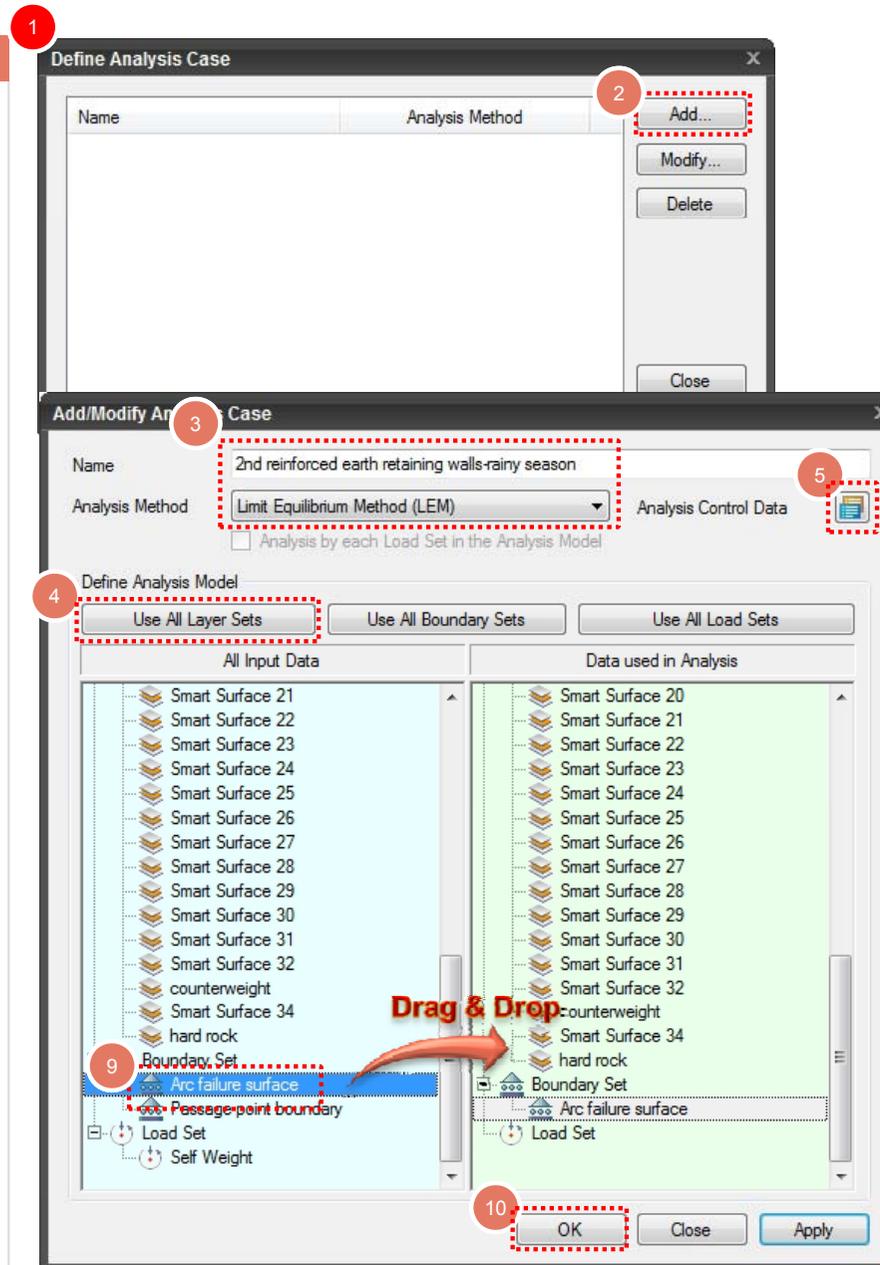
**Procedure**

- 1 From the **Main Menu**, select **Limit Equilibrium Method > Circular Failure Surface**.
- 2 **Boundary Set:** enter 'Passing point boundary'.
- 3 Click **Drawing Grid Range** and draw the range of grid on Model Data (in the order of P1→P2→P3)
- 4 Select **Method of using Arc Radius Length**.
- 5 Select **Method of Searching First Arc Radius & Define Passing Point**, and enter '52.7846, 28.7628' in **Passing Point**. (or, click the **Passing Point** entry field and click the passing point on Model.)
- 6 **Number of Arc** : enter '10'.
- 7 Click **OK**.



### Procedure

- 1 From the **Main Menu**, select **Analysis/Design > Analysis Case**.
  - 2 Click **Add**.
  - 3 **Name**: enter '2nd Tier Reinforced Earth-Rainy Season', and select **Analysis Method: Slope Stability (LEM) Analysis**.
  - 4 Click **Use all Layer Sets &**
  - 5 Click **Analysis Control Data**.
  - 6 **Slope Direction**: select 'Left to Right'.
  - 7 Check on **Initial Water Level** and select 'Water Level'.
  - 8 Click **OK**.
  - 9 Drag & Drop 'Arc failure surface' into Data used in Analysis
  - 10 Click **OK**.
- Analysis methods are 'Bishop', 'Fellenius' and 'Janbu'.



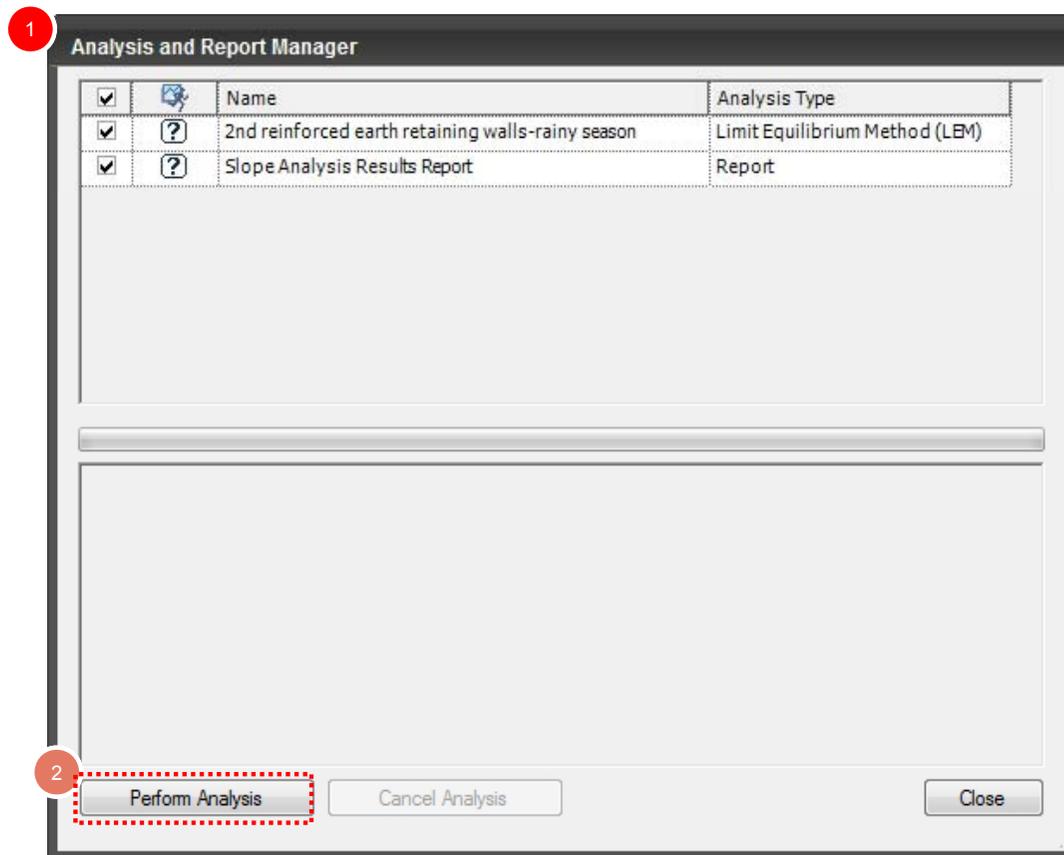
**Procedure**

- 1 From the **Main Menu**, select **Analysis/Design > Design Option**.
- 2 Select **Embankment Slope**.
- 3 Enter '**1.3**'
- 4 Click **OK**.

The screenshot shows a software dialog box titled "Design Options" with a close button (X) in the top right corner. The dialog is divided into a "Slope" section. Under "Factor of Safety for Slope", there are two radio buttons: "Embankment Slope" (which is selected) and "Cut Slope". Below these, there are three input fields: "Embankment Slope" with the value "1.300", "Cut Slope (Dry)" with the value "1.500", and "Cut Slope (Wet)" with the value "1.200". At the bottom right of the dialog, there are two buttons: "OK" and "Cancel". Red dashed boxes and numbered circles (1-4) highlight the following elements: 1. The "Design Options" title bar; 2. The "Embankment Slope" radio button; 3. The "Embankment Slope" input field containing "1.300"; 4. The "OK" button.

**Procedure**

- 1 From the **Main Menu**, select **Analysis/Design > Analysis & Report**.
- 2 Click **Perform Analysis**.



**Procedure**

- 1 From the **Result WorksTree**, check '**Safety Factor**' of Slope Stability Analysis.
- 2 **Results > Result File** produces the results in a text file (\*.txt).
- 3 **Property Window**: select '**Legend**', '**Limit Equilibrium Method**' & '**Limit Equilibrium Method Contour**', and maneuver the detail items.
- 4 Upon double-clicking a specific slice of the arc, detail data of the slice (Free Body Diagram) can be checked.
- 5 The result data background color [**Command: BK**] can be changed from **Main menu > Window > View Setting: Background Display**.

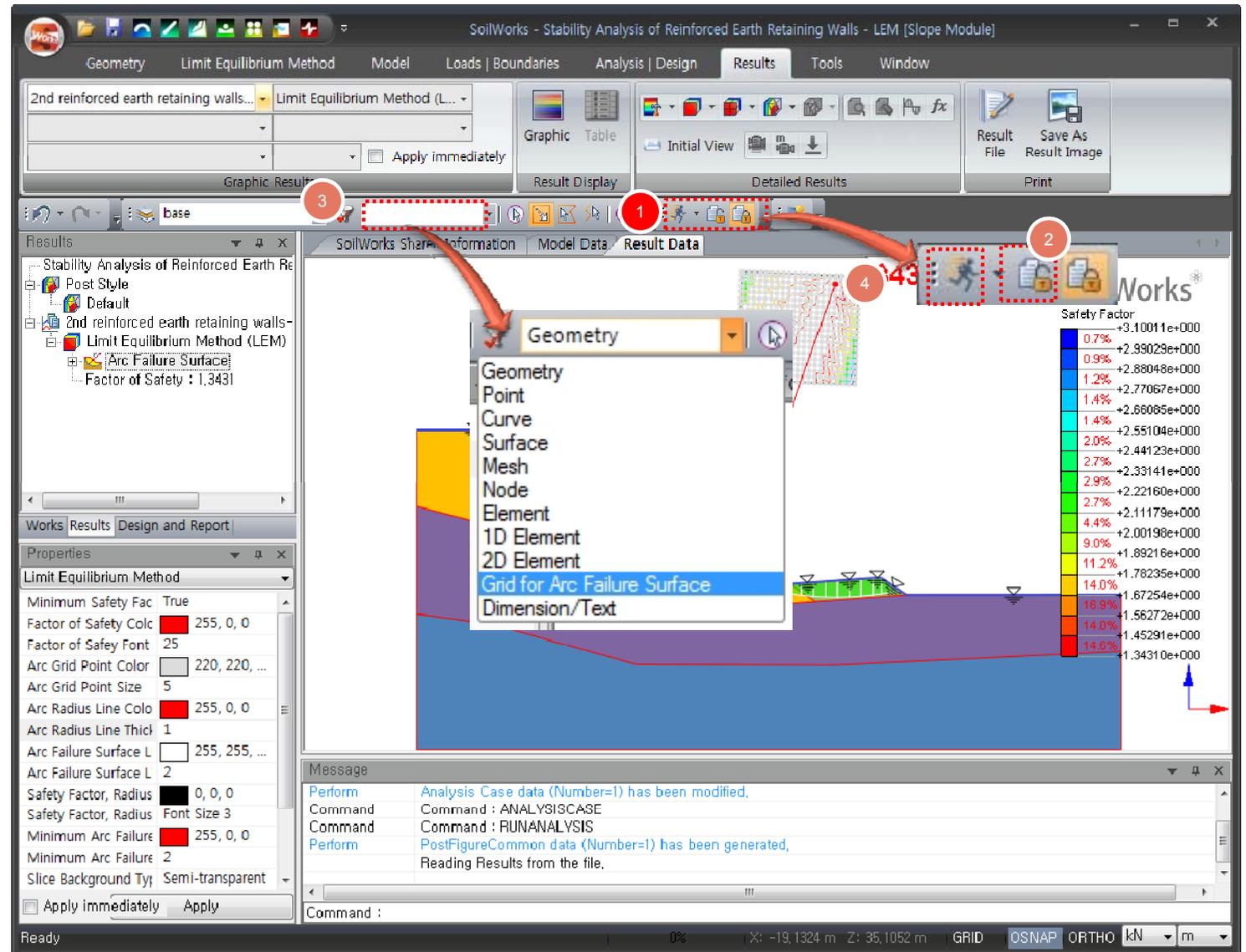
The screenshot shows the SoilWorks software interface for the 'Stability Analysis of Reinforced Earth Retaining Walls - LEM (Slope Module)'. The main window displays a cross-section of the wall and soil with a safety factor contour plot. A red arrow points to a specific slice on the failure surface, labeled '4 Double Click'. A callout window shows the 'Free Body Diagram' for that slice, including a table of forces and moments. The 'Properties' window is open, showing settings for the 'Limit Equilibrium Method' and 'Arc Failure Surface'. The 'Result Data' window shows a color-coded safety factor scale from 0.7% to 14.6%.

Component	Value
Grid Point ID	90
Grid Point X (m)	72.2027
Grid Point Y (m)	94.1401
Radius ID	6
Radius	59.5228 m
Slice ID	9.05
Slice Width	1.4529 m
Slice Rise (m)	2.2857
Slice base Angle	39.5811 [deg]
Material ID	1
Material C	85 kN/m <sup>2</sup>
Material φ	30 [deg]
W	419.247 kN/m
Pore Pressure	0.0102 kN/m <sup>2</sup>
σ total	158.1722 kN/m <sup>2</sup>
σ (total)	5118.61 kN/m <sup>2</sup>
N (base)	414.3805 kN
T (base)	159.7433 kN
Nr (base)	0 kN
Tr (base)	0 kN
N (left Slice)	795.416 kN
T (left Slice)	0 kN
N (right Slice)	-070.6411 kN
T (right Slice)	0 kN

# 14 Result Analysis & Re-Analysis

## Procedure

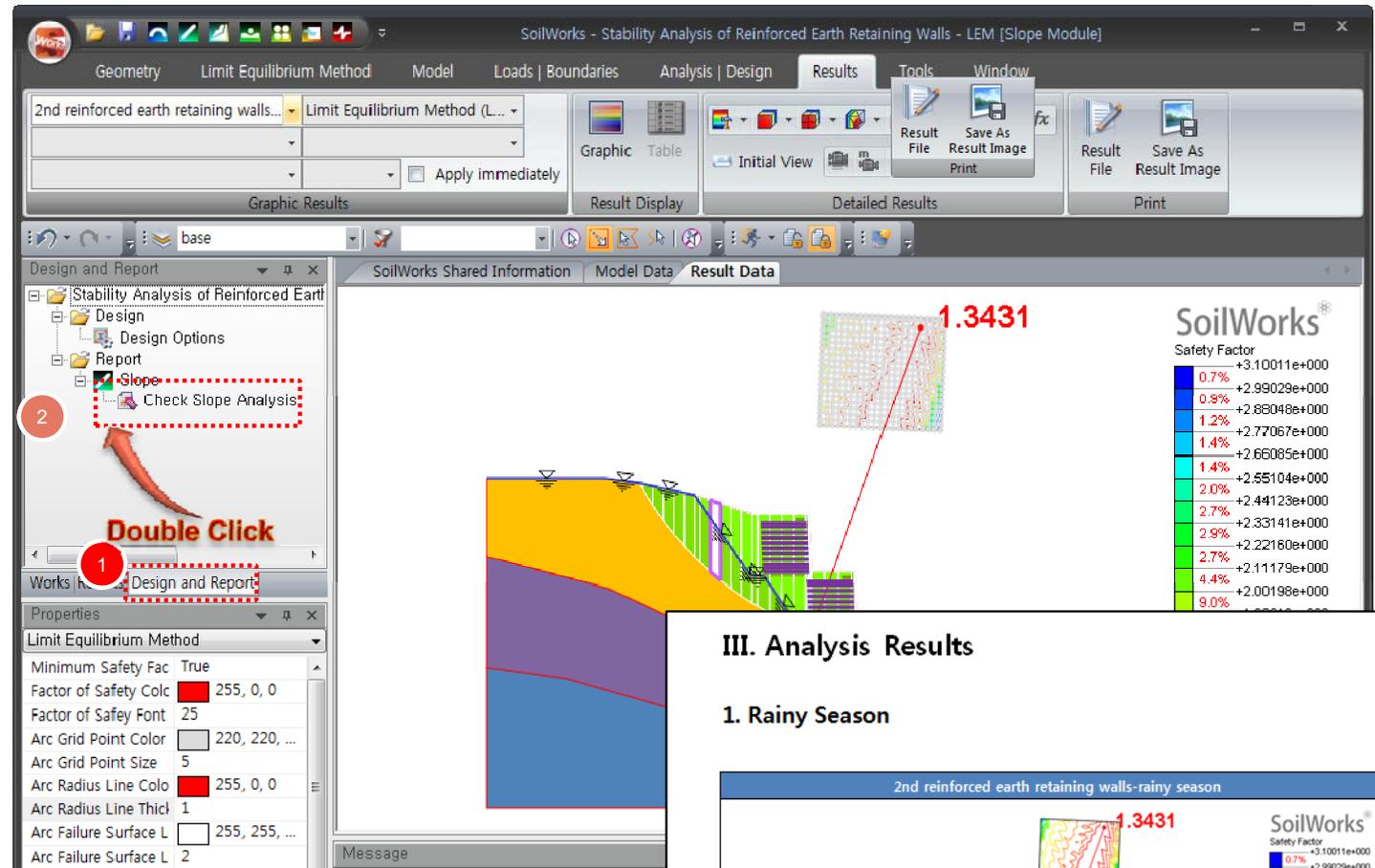
- 1 Upon execution of **Pre Mode/Post Mode** analysis, **Post Mode** automatically becomes active when results are produced.
- 2 If re-analysis is sought, any change in data such as the arc grid or arc tangents need to be revised after switching to the **Pre Mode**.
- 3 Select **Filter > Grid for Arc Failure Surface** to move or revise the **Failure Arc Center Grid**.
- 4 Once the model has been revised, repeat the **STEP 12** for re-analysis.



**Procedure**

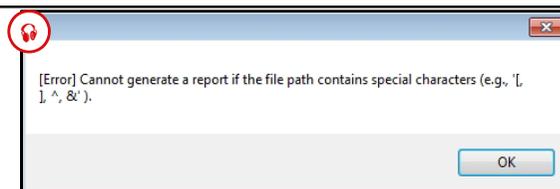
- 1 Select **Design & Report** Workstree
- 2 Double click '**Slope Analysis Check**' to check the report Word file, which is created in the folder of the model file.
- 3 The contents of the Slope Report consist of **1. Slope Stability Analysis, 2. Applied Material Properties and 3. Safety Factor Results**.
- 4 Evaluation against the safety factor reference defined in Design Option is reported in terms of **OK** (acceptable) **ING** (unacceptable).

When generating the report, the file path, file folder and file name must not include '[ ], ^, & '.



**List**

- I. Slope stability analysis.....
- II. Applied properties.....
- III. Analysis results.....



**III. Analysis Results**

**1. Rainy Season**

Standard safety factor	1.300	Evaluation
Analysis safety factor	1.343	OK

### Initial diffusion width and angle of reinforcement

When LEM is used to analyze slope stability in practice, it is not straightforward to account for the stiffness of the reinforcement. The safety factors are sensitive to the values of the diffusion width and the diffusion angle, the effects of which are often overlooked.

When reinforcement is inserted in a slope for LEM analysis, a certain increase in strength of a slice within the diffusion range needs to be reflected. The diffusion range is determined first by the diffusion width perpendicular to the reinforcement and the spread of the width by the diffusion angle, in contact with the failure arc as shown in hatch below. It is recommended that the initial diffusion width be 1.0m or 2.0m corresponding to the size of anchor plates, and the initial diffusion angle be 10 to 20 degrees.

