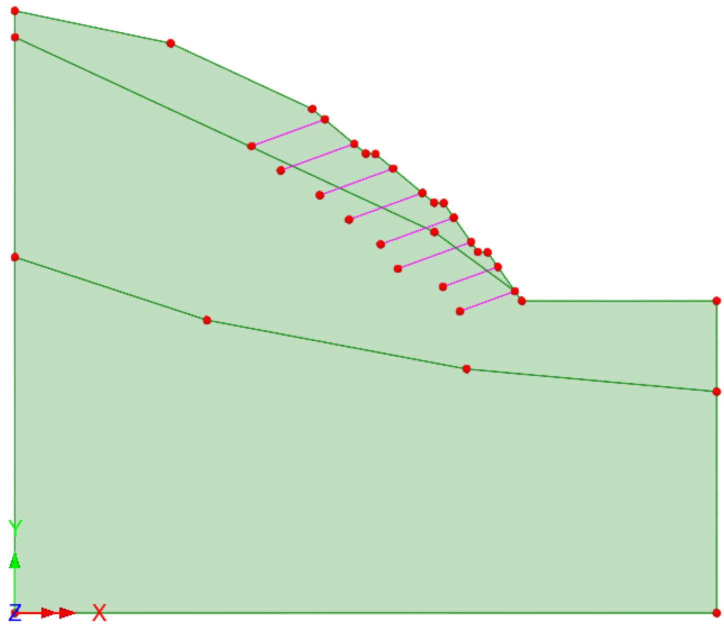
Stability Analysis for Reinforced Slope

For LUSAS version:	24.0
For software product(s):	LUSAS Bridge plus or LUSAS Civil&Structural plus
With product option(s):	Geotechnical, Nonlinear

Problem Description

This overview example demonstrates the modelling of reinforcement slope support in LUSAS. The slope consists of three layers as shown below, namely: sedimentary rock, moderately weathered rock and weathered rock. The total height of the slope is 74.4m.



Geological conditions modelled

Keywords

Slope Stability, Embedded Bar, Interface, Nails, Phi-c Reduction.

Associated Files

Associated files can be downloaded from the user area of the LUSAS website.

- **stability_analysis_for_reinforced_slope.lvb** carries out automated modelling of the example.

- Use **File > New** to create a new model of a suitable name in a chosen location.
- Use **File > Script > Run Script** to open the lvb file named above that was downloaded and placed in a folder of your choosing.

Objectives

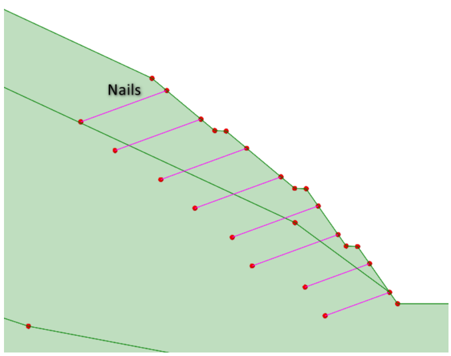
The objective is to find out the safety factor for the reinforced slope.

Modelling overview

The model is created using an analysis category of **2D Inplane** and model units of **kN,m,t,s,C**.

Feature Geometry

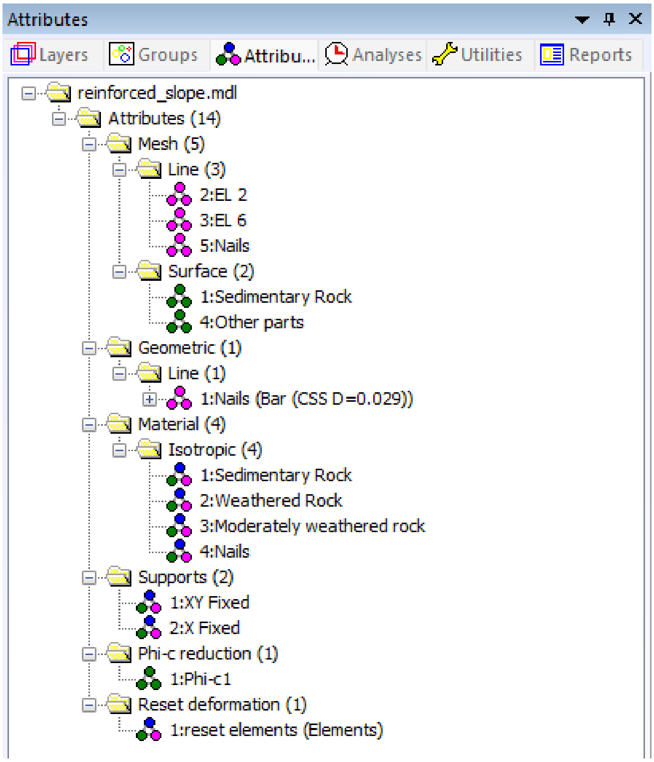
The model is developed using point and line features which are then used to form the surfaces representing the soil mass. In the discretisation of the model, embedded bars with interface elements are used to represent the nails.



Slope stabilisation using nails

Model Attributes

Model attributes (mesh, material, geometric properties, etc.) are defined and assigned to the model.



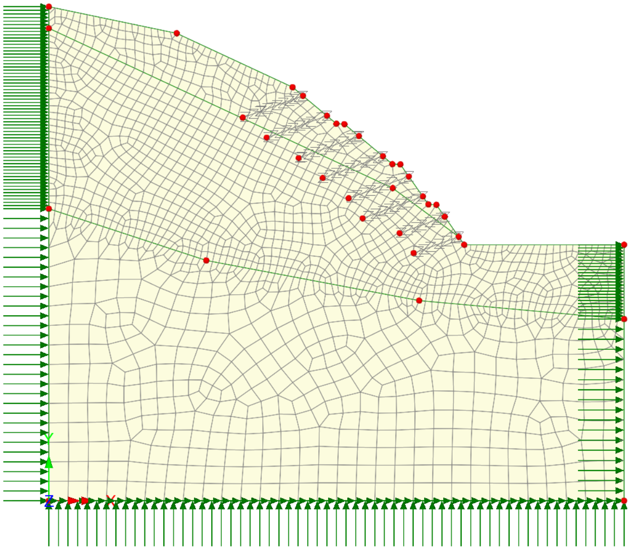
Model Attributes

Mesh

An embedded bar with interface (BAR3) attribute is used to model the anchors elements.

An embedded joint is defined and assigned to the anchors tops.

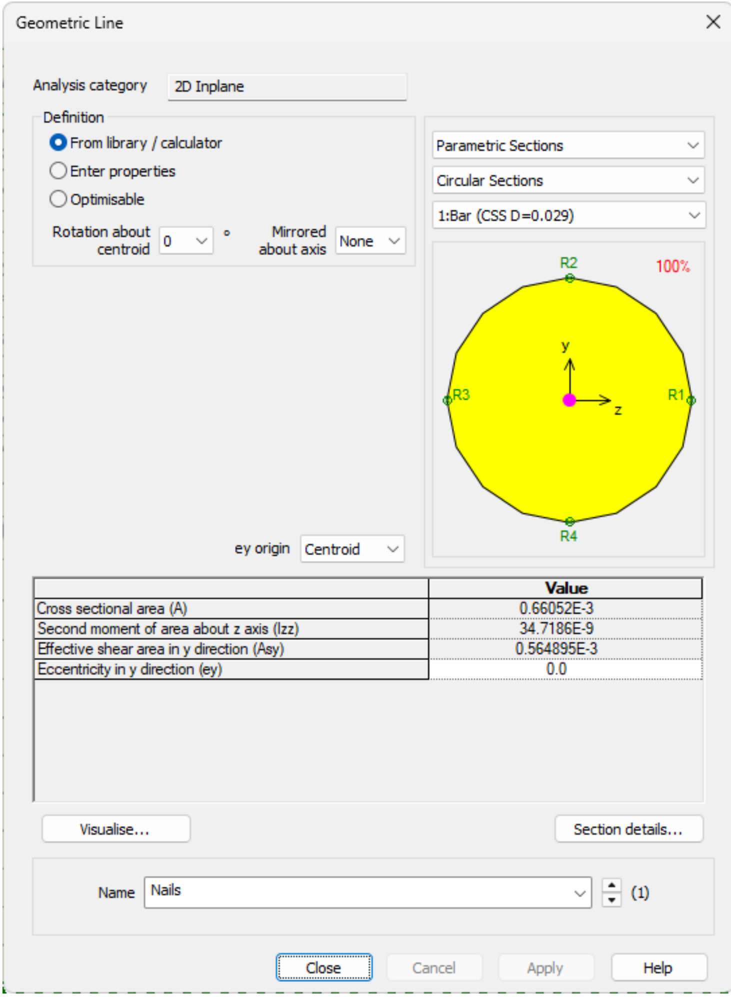
The surface is meshed with plane strain, quadrilateral, quadratic elements (QPN8) of various sizes.



Model mesh with boundary conditions

Geometry

The menu item **Attributes > Geometric > Line** is used to define the soil nail properties.



Section properties for soil nail

Materials

An isotropic elastic material will be used for the soil nail while an isotropic nonlinear material utilising the Mohr-Coulomb failure surface will be used for the different types of rock. Material properties are listed in Table 1.

An elastic embedded interface was used as the interface model for the bar interfaces. The adopted stiffness values were K_n=K_s=1×10^9 kN/m^2. The embedded joint stiffness was set to 1×10^{12} kN/m.

Table 1: Material properties

Layer	Mass Density	Young's modulus, E	Poisson's ratio, ν	Angle of friction, φ	Angle of dilation, ψ	Cohesion, c
Nail	2.5 t/m^3	200E6 kPa	0.3	-	-	-
Weathered Rock	1.9 t/m^3	30E3 kPa	0.35	29	29	18 kPa
Moderately weathered rock	2 t/m^3	300E3 kPa	0.3	33	33	25 kPa
Sedimentary Rock	2.3 t/m^3	1.0E6 kPa	0.25	40	40	70 kPa

Supports

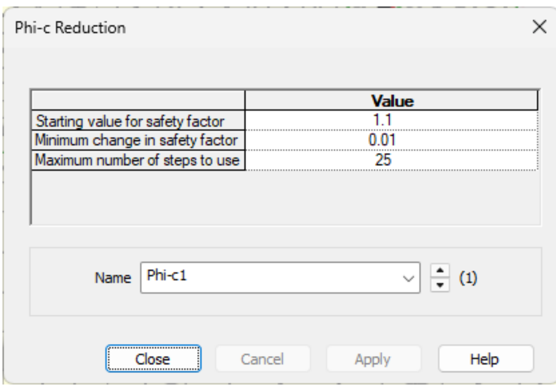
Fully fixed supports are assigned to the base, while the lateral sides are fixed in the horizontal direction as shown in the previous image titled 'Model mesh with boundary conditions'.

Loads

The soil weight due to gravity is the only load applied on the slope.

Other Attributes

In addition to the previous attributes, a **Phi-c Reduction** attribute is defined and assigned to the model so that the factor of safety can be calculated.



Phi-c reduction parameters

Analyses considered

Initial Phase

In this phase we calculate the initial stress conditions under gravity loading. The mesh is reset before proceeding to the factor of safety calculation.

Phi-c Reduction Branch

The Phi-c reduction attribute can be assigned to relevant features in the model for a specified analysis allowing the safety of a slope to be evaluated. By its very nature a Phi-c reduction analysis will always lead to failure, so it is best used in an analysis ‘branch’ where it can be used to study safety factors independent of the main solution. No loading should be applied as it maintains the load from the main analysis. Nonlinear analysis control properties are defined for this phase as well.

Running the Analysis

 Ensure all analyses are selected and press **OK** to run the analysis.

Viewing the Results

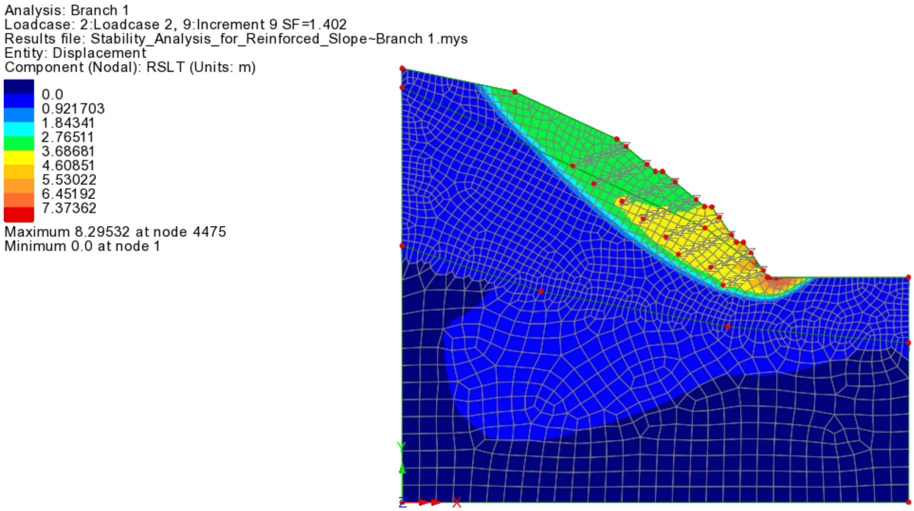
Analysis loadcase results are present in the Treeview.

Loading Stage Results

The following images show the deformed shape and effective shear strain of the slope after finishing the calculation of safety factor. The slope is considered stable with a factor of safety of 1.4.

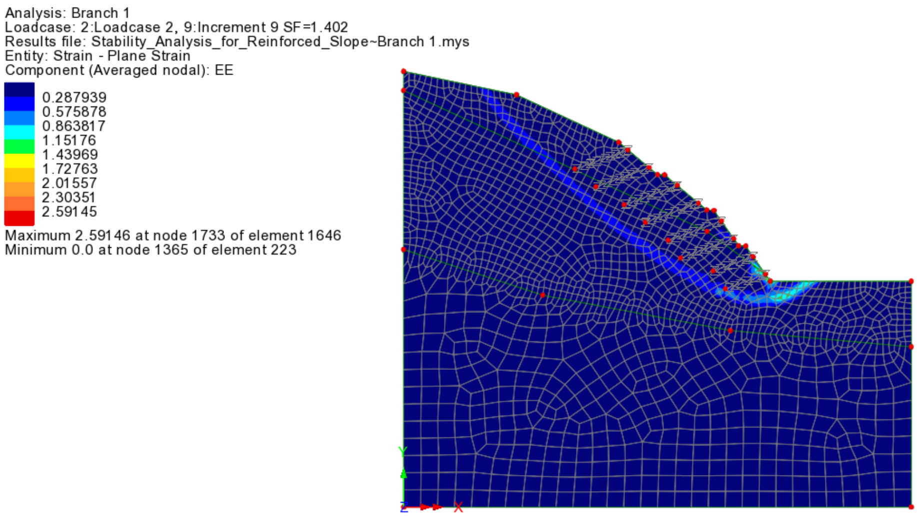
To see these plots:

- Turn off the display of the geometry and mesh layers and the supports.
- Set active loadcase 2.
- Add the contours layer to plot contours of entity **Displacement** and component **RSLT**



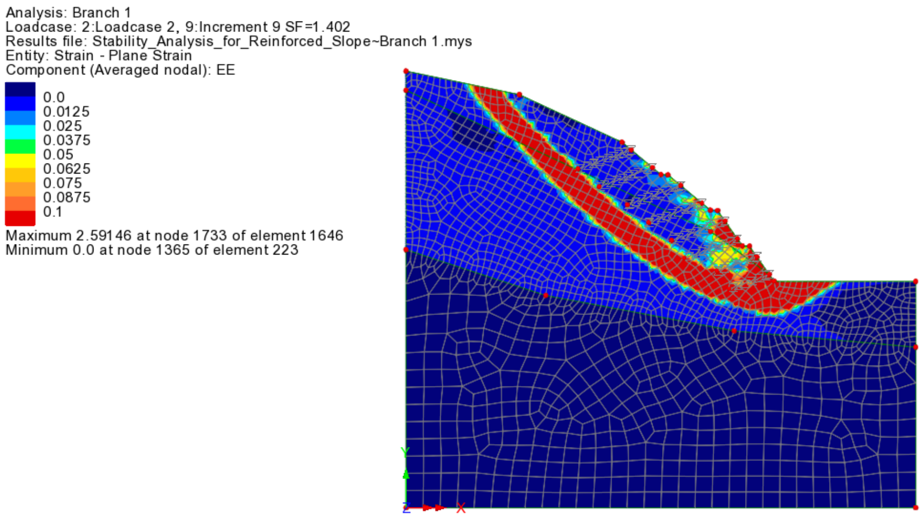
Displacements at final stage of safety factor calculation (with nails)

- Change the contours layer to plot contours of entity **Strain - Plane Strain** and component **EE**



Effective shear strain (with nails)

- Revisit the **Contours** properties dialog and from the **Appearance** tab, set a maximum contour value of **0.1** to highlight how the soil failed, showing where the slip surface is located, as shown below



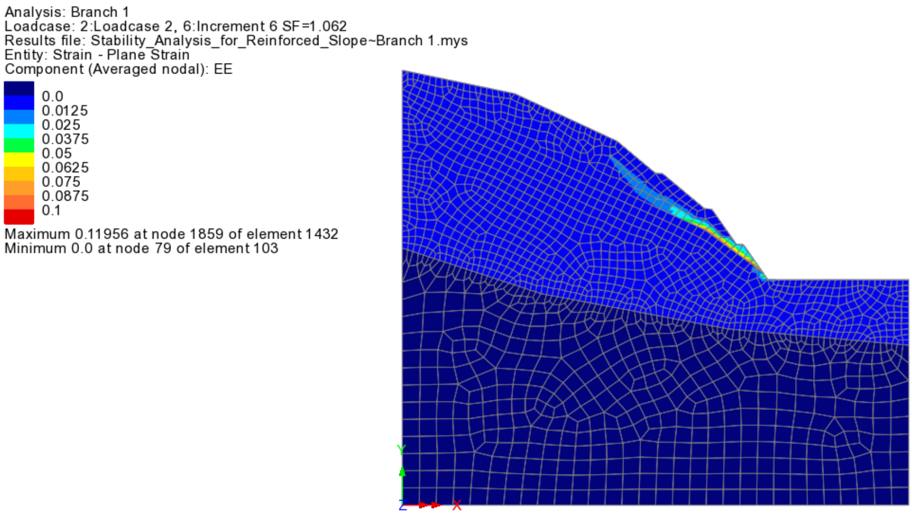
Effective shear strain (with nails) with maximum value of 0.1 set

Solving without soil nails

To illustrate how the inclusion of soil nails helps to improve the stability of the slope, the soil nails can be deactivated from the analysis by creating and assigning a deactivate attribute for loadcase 2 and the analysis then solved again. To do this:

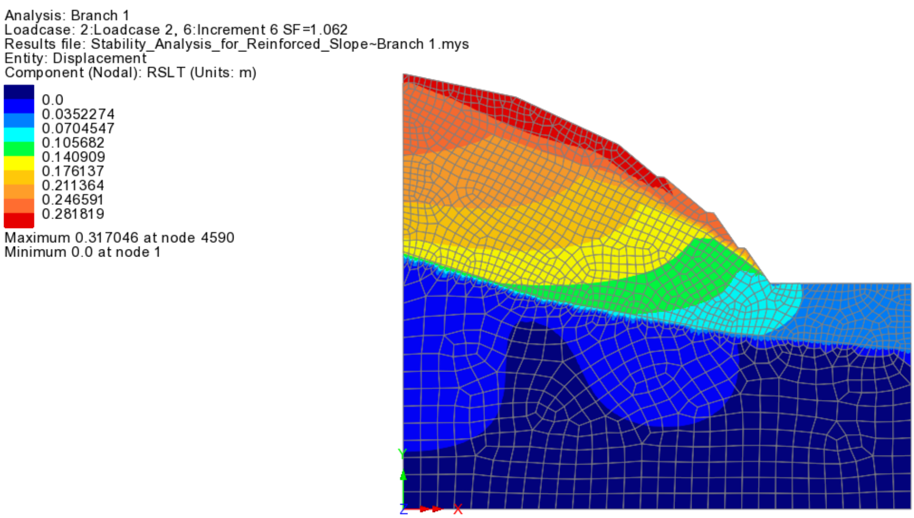
- Turn off the contours layer
- Select **Attributes > Activate and Deactivate** and create a deactivate attribute
- Select the lines representing the soil nails
- Assign the Deactivate attribute to the lines for analysis **Branch 1** and **Loadcase 2**

For this situation a factor of safety of 1.06 is obtained. which shows the critical state of the original slope.



Effective shear strain (without nails)

- Change the contours layer to plot contours of entity **Displacement** and component **RSLT** and visit the **Appearance** tab to set **Default** values.



Displacements at final stage of safety factor calculation (without nails)

This completes the example.