# Stability Analysis for Reinforced Slope

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|---|---|
| For LUSAS version: | 21.0 |
| For software product(s): | LUSAS Bridge plus or LUSAS Civil&Structural plus |
| With product option(s): | Geotechnical, Nonlinear |

## Problem Description

This tutorial demonstrates the modelling of reinforcement slope support in LUSAS. The slope consists of three layers as given in figure 1; sedimentary rock, moderately weathered rock and weathered rock. The total height of the slope is 74.4 m.

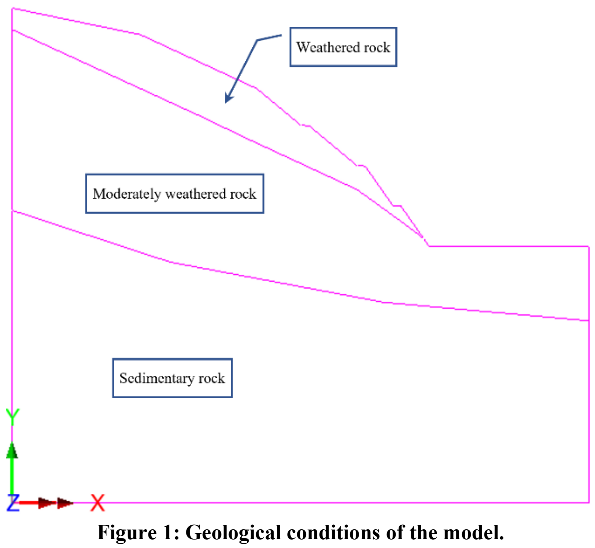



**Figure 1: Geological conditions of the model.**

## Keywords

**Slope Stability, Nails, Phi-c Reduction.**

## Associated Files

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

- ❑ **slope_reinforcement.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.

# Preparing the Model Features

We create a new model, set the Analysis category as 2D, and specify the model units as kN,m,t,s,C.

## Feature Geometry

- The model is developed using point and line features which are then used to form the surfaces. In the discretization of the model, lines are used to represent the nails. Nails that pass through two soil layers are split into two lines, each forming part of a surface, as shown in Figure 2. A well-designed model should have proper connections between surfaces and avoid any unintentional overlap.

- The model is subdivided based on the lines that represent nails as depicted in Figures 2 and 3.

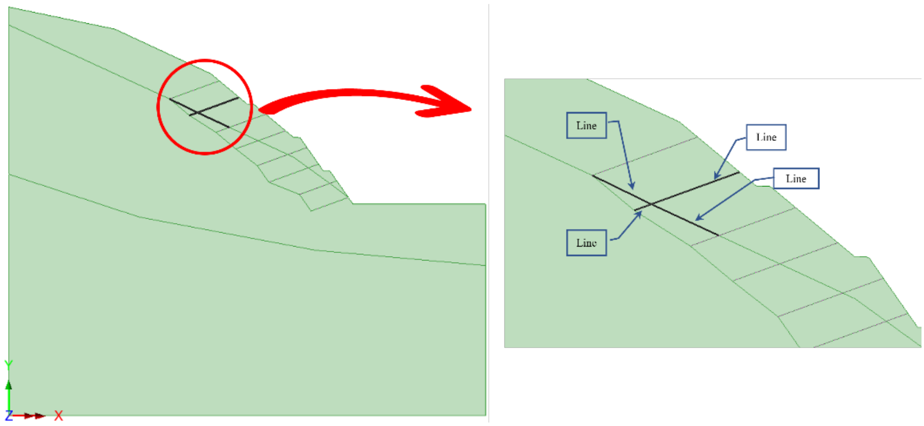



Figure 2: Decomposition of the model

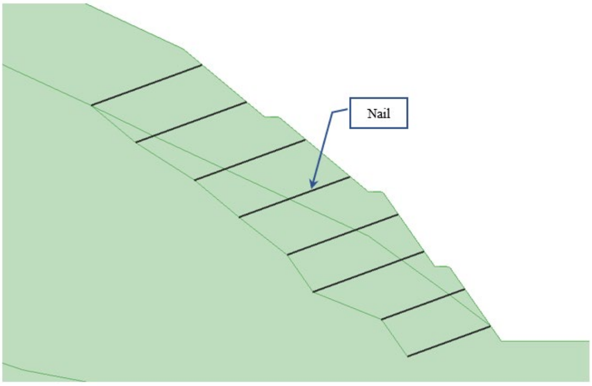



Figure 3: Slope stabilization using nails

# Preparing the Model Attributes

Model attributes (mesh, material, geometric properties, etc.) are defined and assigned to the model. (Figure 4).

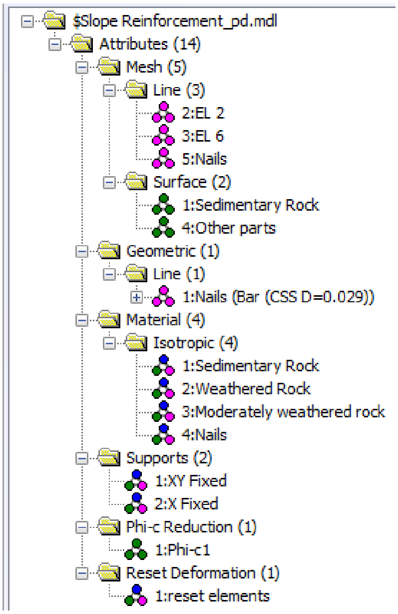



**Figure 4: Model Attributes**

## Defining the Mesh

- Line features are meshed with quadratic bar elements (BAR3) of length 2 m.
- The surface is meshed with plane strain, quadrilateral, quadratic elements (QPN8) of various sizes (Figure 5).

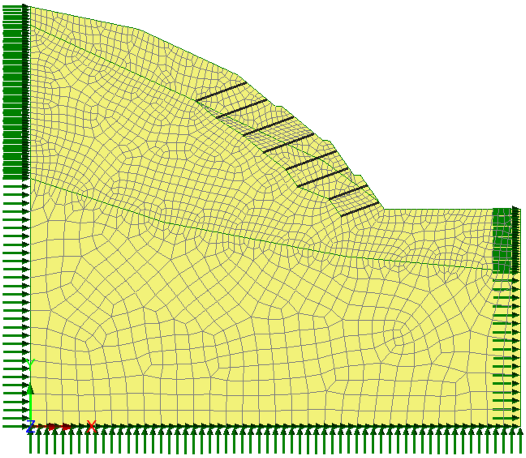


**Figure 5: Model mesh with boundary conditions**

## Defining the Geometry

The only geometry that needs to be defined is the nail section. Figure 6 shows the adopted section.

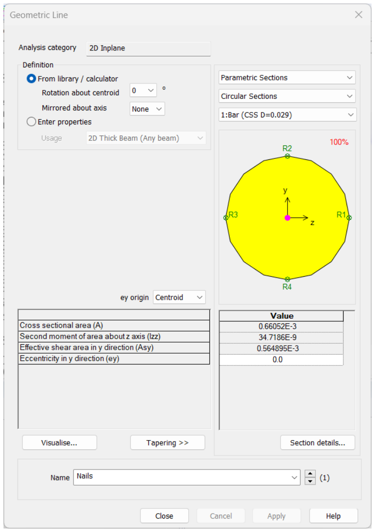



**Figure 6: Nail's Section**

## Defining the Materials

An isotropic elastic material will be used for the nail's material 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.

**Table 1: Material properties**

| Layer | Mass Density | Young's modulus, E | Poisson's ratio, ν | Angle of friction, $\varphi$ | Angle of dilation, $\psi$ | 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 |

## Defining the Supports

Fully fixed supports are assigned to the base, while the lateral sides are fixed in the horizontal direction as shown in the figure 5.

## Defining the Loads

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

## Defining Other Attributes

In addition to the previous attributes, we need to define a **Phi-c Reduction** attribute and assign it to the model so we can calculate the factor of safety (Figure 7)

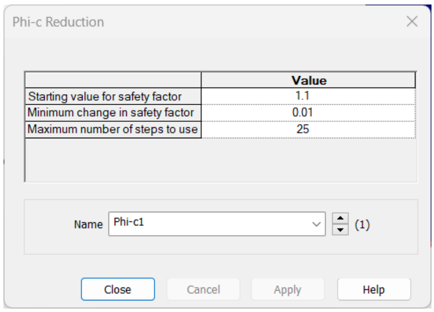



**Figure 7: Ph-c reduction parameters**

# Running the Analysis

We consider one stage for the calculation.

## 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.

## Initial Phase > Phi-c Reduction Branch

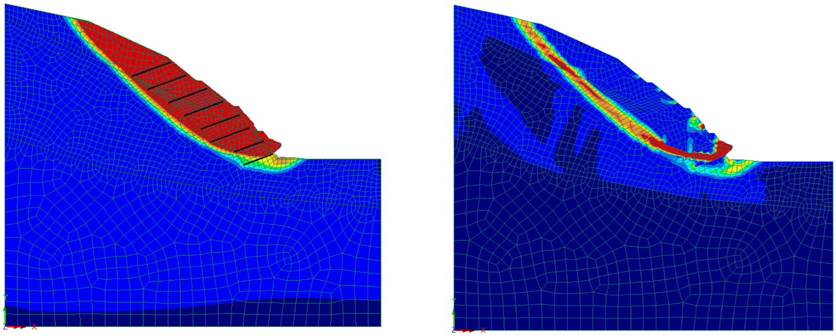
The Phi-c reduction attribute can be assigned to relevant features in the model for a specified analysis allowing the safety of a slope to be evaluated. By its very nature a Phi-c reduction analysis will always lead to failure, so it is best used in an analysis 'branch' where it can be used to study 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.

# Viewing the Analysis

Analysis loadcase results are present in the Treeview.

## Loading Stage Results

Figure 8 illustrates 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 1.34. In order to illustrate how soil nails help to improve the stability of slopes, we run the file after deactivating the nails elements, and we get a factor of safety of 1.05 which shows a critical state of the original slope.



Deformed mesh at final stage of safety factor calculation

Effective shear strain

**Figure 8: Results obtained based on Phi-c reduction calculation**

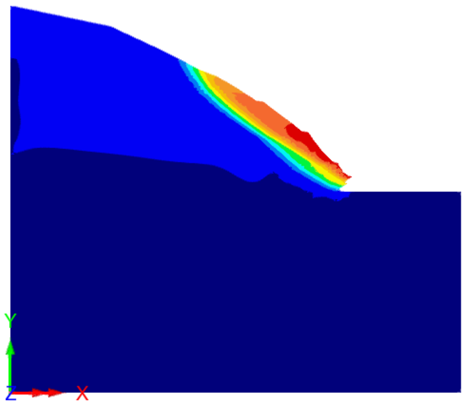



**Figure 9: Results obtained based on Phi-c reduction calculation (no nails)**