

Tunnel Excavation Accounting for Stress Deconfinement

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

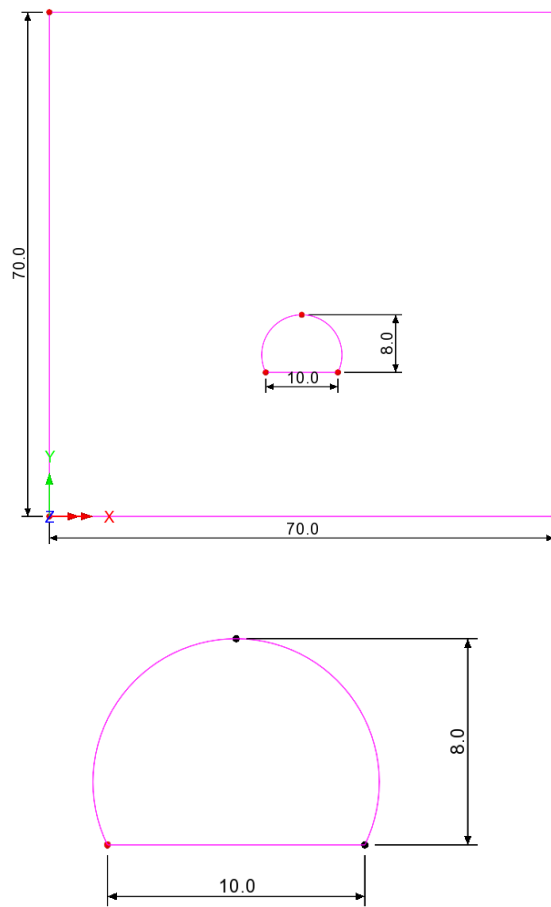
Problem Description

Among numerical approaches used to simulate stress deconfinement during rock tunnel excavation, three ways can be used:

- ❑ **Internal pressure:** This method applies a controlled internal pressure on the tunnel boundary, which is gradually reduced to represent progressive stress relaxation in the surrounding rock mass prior to support installation. The pressure reduction factor (β) ranges from 1.0 (full confinement, pre-excavation condition) to 0.0 (fully released condition).
- ❑ **Gap parameter:** This approach introduces a prescribed physical or numerical gap between the excavation boundary and the support system. The support is activated only after the surrounding rock has undergone deformation equal to the defined gap, thereby simulating delayed support installation. This can be implemented using interface elements or joints models, such as smooth joint model.
- ❑ **Progressive internal force redistribution:** This method simulates excavation by deactivating elements representing the excavated material and progressively

redistributing their internal forces to the surrounding rock mass. This captures the gradual stress transfer and redistribution that occurs as the excavation advances.

In this example, where the third approach is adopted, we simulate tunnel excavation in a rocky stratification. The tunnel excavation is accompanied by the installation of tunnel lining and rock bolts. The lining has a thickness of 160mm, and the rock bolts are 4m long. The construction process is divided into a series of stages that simulate the excavation and support installation. The tunnel has a horseshoe-shaped cross-section with a height of 8m and a width of 10m, as depicted in the two-dimensional model as shown in the following image.



Tunnel shape

Keywords

Tunnel, Bolts, Lining, Deactivate, Construction Stages

Associated Files

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



☐ **tunnel_stress_deconfinement.mdl** is the model file for this example.

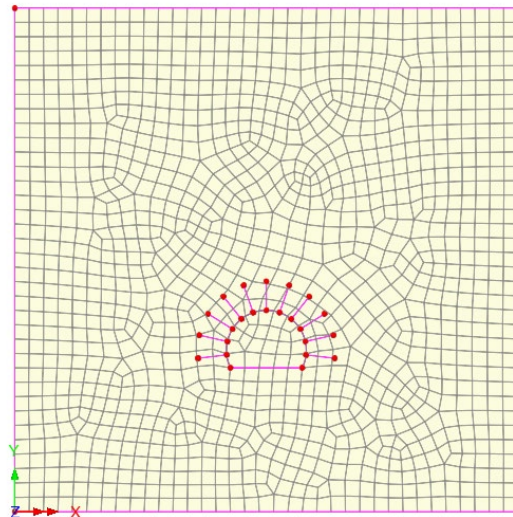
- Use **File > Open** to open the file named above that was downloaded and placed in a folder of your choosing.

Objectives

Modelling of the tunnel boring process, accounting for stress deconfinement and the installation of the tunnel lining and rock bolts.

Modelling overview

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



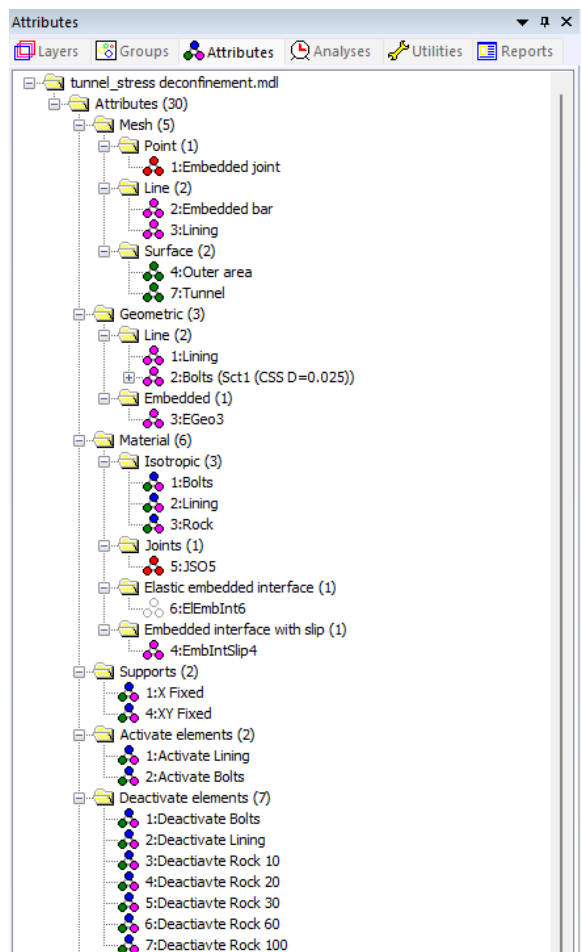
Model as provided

Feature Geometry

- The 2D end view of the model is created using point and line features.
- The tunnel shape is generated using the command **Geometry > Line > Arc/Circle > From Coords/Points**.

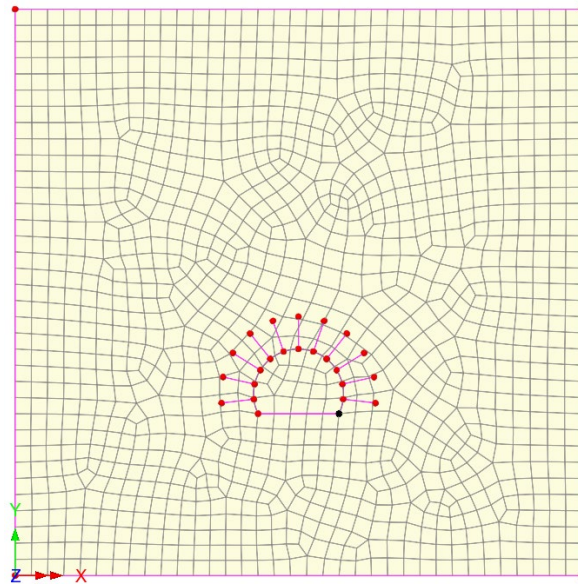
Model Attributes

Model attributes (mesh, material, geometric properties, etc.) are defined and assigned to the model. Attributes used are shown in the following image.

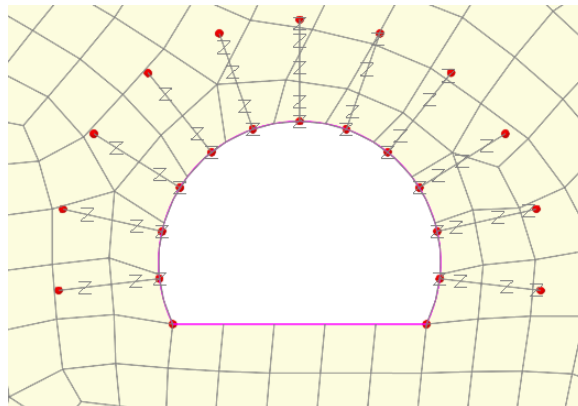


Mesh

Quadrilateral, quadratic stress elements (QPN8) are used to mesh the surface representing the rock material, while plane strain beam elements (BMI3N) are used for the tunnel lining, and quadratic embedded bar with interface elements (BAR3) are used for the bolts. An embedded point joint element is assigned to the end of the bolts that meet the tunnel lining, to model the connection with the lining.



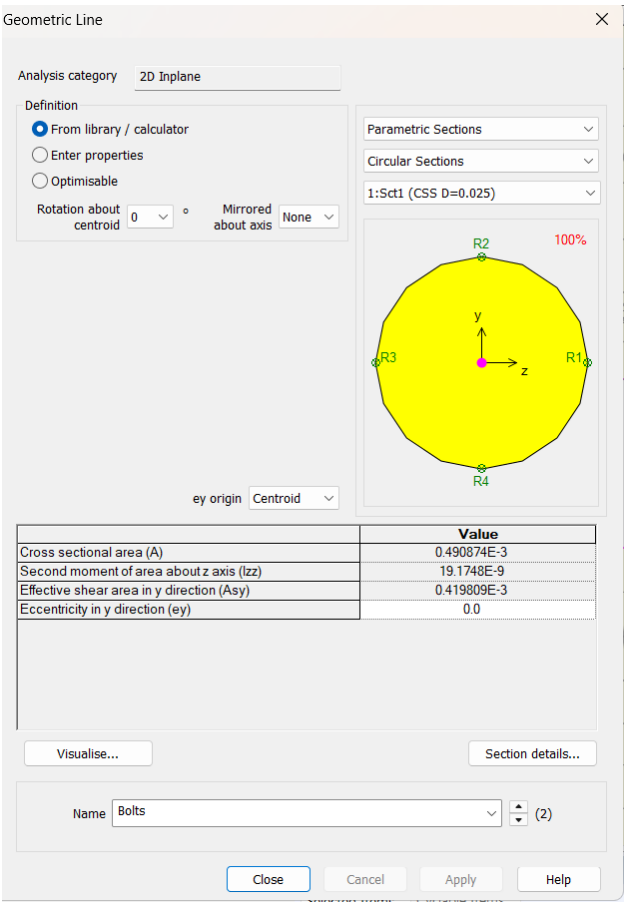
Model meshing



Embedded beam with interface elements

Geometric properties

A geometric surface attribute is assigned to the lining feature with a thickness of 160mm, while the rock bolt is given a circular section with a diameter of 25mm as shown in the following image.



Rock bolt section

An elastic embedded interface zone is assigned to the bolts with a zone diameter of the same value of the bolt diameter (but entered as 0.025 on the dialog)

Materials

The rock material is modelled using an isotropic nonlinear material with a Modified Mohr-Coulomb (HS) failure surface, while the structural elements are assumed to have elastic behaviour. The initial stress state in the soil is defined by the coefficient for lateral

earth pressure, K_0 , of the soil. All material properties are listed in table 1. Interfaces properties are listed in table 2.

Table 1: material properties

Layer	Young's modulus, E (kPa)	Poisson's ratio, ν	Mass Density (t/m^3)	Cohesion, c (kPa)	Angle of friction, φ (degrees)	K_0
Rock	300.0E3	0.25	2.24	60	33	0.6
Lining	35.0E6	0.2	2.5	-	-	-
Bolt	200.0E6	0.3	7.85	-	-	-

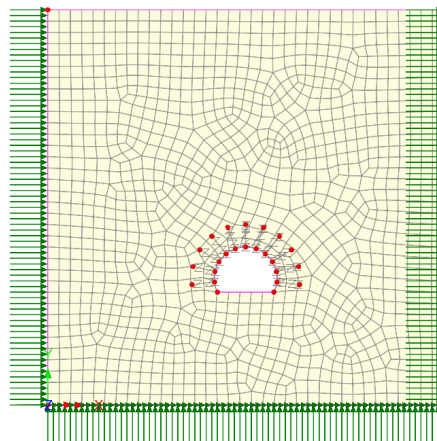
Table 2: Interfaces properties

	Normal stiffness factor	Tangential stiffness factor	Cohesion, c (kPa)	Angle of friction, φ
Embedded interface with slip	10.0E6	0.15	60	33

An embedded point joint with an elastic spring stiffness value of 1E12 kN/m is also defined.

Supports

The sides of the model are restrained in the X direction and the base is restrained in the Z and Y directions.



Boundary conditions

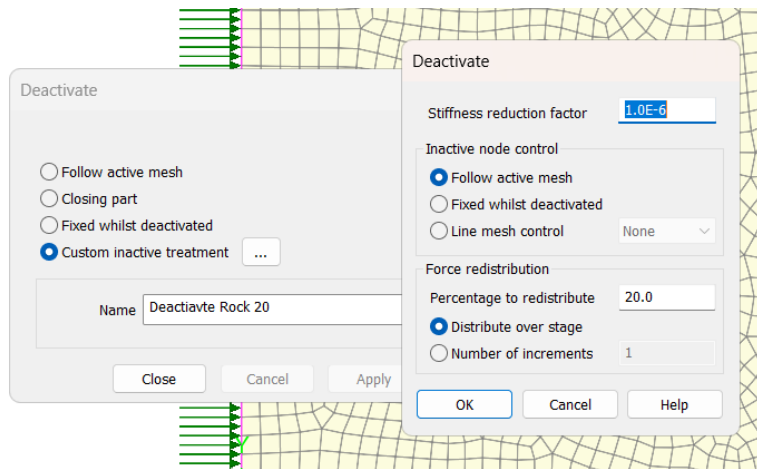
Loads

Gravity load is the only load considered.

Other Attributes

Deactivate and Activate attributes are used to simulate the excavation phases of the tunnel and the installation of the lining and bolts.

Stress deconfinement is accounted for through the percentage of force redistribution at each of construction stage.



Force redistribution percentage (Deactivate attribute)

Analyses considered

The following construction stages are considered.

Initial Phase

During this stage, the simulation replicates the starting conditions in which the only load applied is the gravity. The nonlinear analysis control characteristics are established, with all parameters remaining at their default settings.

Excavation Phases

The excavation phases model the percentage force redistribution in the relevant deactivation attribute. This captures the gradual stress transfer and redistribution that

occurs as the excavation advances. They have the following names: **Ex10**, **Ex20**, **Ex30**, **EX60** and **Ex 100** where the number represents the redistribution percentage.

Running the Analysis



Ensure all analyses are selected and press **OK** to solve.

Viewing the Results

Analysis loadcase results are presented in the Analyses treeview.

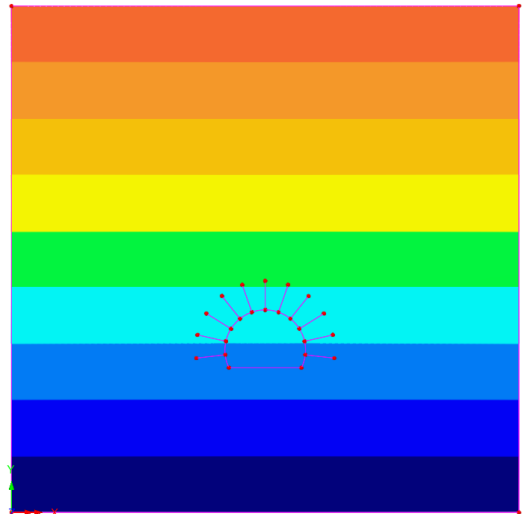
Stress

- Ensure that display of the **Mesh** and **Deformed mesh** layer and **Supports** are turned off.
- With the **Initial Phase** set active, add the **Contours** layer to plot contours of entity **Stress – Plane Strain** and component **SY**

Analysis: Analysis 1
Loadcase: 1:Initial Phase, 1:Increment 1
Results file: tunnel_stress_deconfinement-Analysis 1.mys
Entity: Stress - Plane Strain
Component (Averaged nodal): SY (Units: kN/m²)

-1.36892E3
-1.1978E3
-1.02669E3
-855.575
-684.46
-513.345
-342.23
-171.115
0.0

Maximum 0.0 at node 276 of element 159
Minimum -1.54003E3 at node 114 of element 125

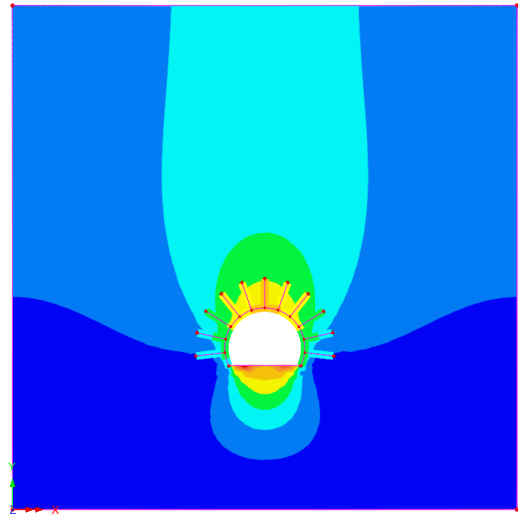


Vertical stress at the initial stage

Displacement

- Set active loadcase **Ex100**
- Change the **Contours** layer to show contours of entity **Displacement** and component **RSLT**

Analysis: Analysis 1
Loadcase: 9.Ex100, 6.Increment 6
Results file: tunnel_stress_deconfinement-Analysis 1.mys
Entity: Displacement
Component (Nodal): RSLT (Units: m)
0.0
5.87878E-3
0.0117576
0.0176363
0.0235151
0.0293939
0.0352727
0.0411514
0.0470302
Maximum 0.052909 at node 4
Minimum 0.0 at node 40



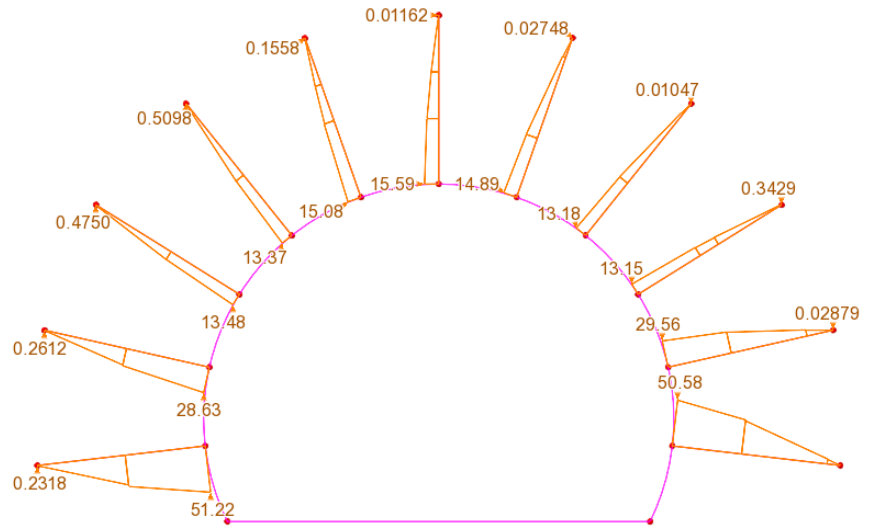
Resultant displacement

The maximum resultant displacement at the final stage is 52.9 mm.

Moments and axial forces

As well as providing results for the soil continuum, LUSAS has the capability of determining the moments and forces for structural elements.

- Add the **Diagrams** layer to plot entity **Force/Moment – Bar / Cable** and component **Fx**
- Turn off the display of the **Contours** layer and enlarge the view of the tunnel region to be as the following image.



Axial forces for rock bolts

This completes the overview example.

