

# Analysis of Tunnel Excavation

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 example investigates the stability analysis of a tunnel excavation in a rocky stratification. The excavation of the tunnel is accompanied with the installation of a tunnel lining and rock bolts, The lining has a thickness of 160mm and the bolt length is 3 m. The construction process can be divided into construction stages that simulate the excavation and supporting process, with the same steps being repeated over and over again as tunnelling progresses.

The tunnel has a horseshoe shape with a height of 8 meters and a width of 10 meters, as depicted in 2D in Figure 1.

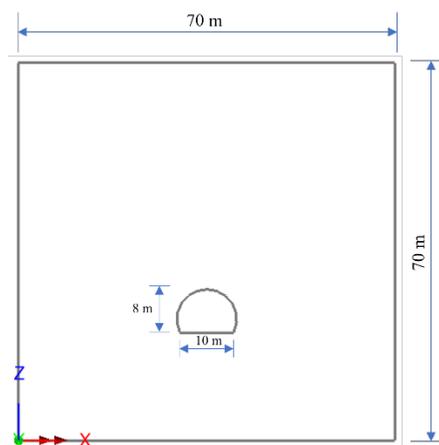


Figure 1: Tunnel shape

### Keywords

Tunnel, Bolts, Lining, Construction Stages

### Associated Files

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



- tunnel\_3d.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 with supporting structural elements; lining and rock bolts.
- Analysis of stability of the tunnel during construction stages and at the final stage.

## Preparing the Model Features

We create a new model, set the Analysis category as 3D, and specify the model units as kN,m,t,s,C.

### Feature Geometry

- The front side of the model can be created through point and line features.
- The tunnel shape is generated using the command **Geometry > Line > Arc/Circle > From Coords/Points** (figure 2).

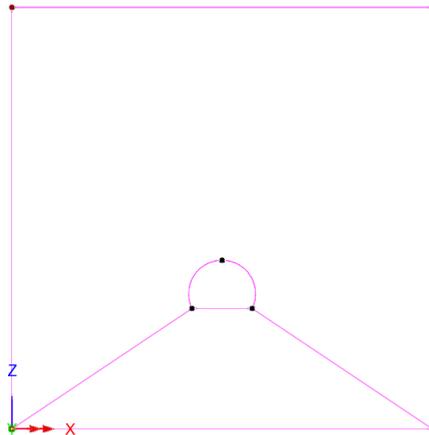


Figure 2: Front façade of the tunnel

- Points on the tunnel representing the starting of bolts are created via the command **Geometry > Line > By Splitting > In Equal Divisions**. Figure 3 shows these points of connection of the bolts with the tunnel.

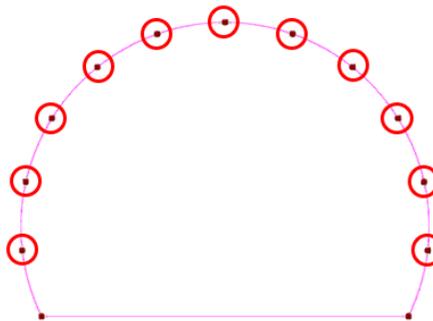


Figure 3: Splitting the tunnel curve

- To set up the bolts we offset the twelve divisions created previously, through the command **Geometry > Line > By Offsetting**. Figure 4 shows the offsetting of one segment with the dialog used for this purpose.

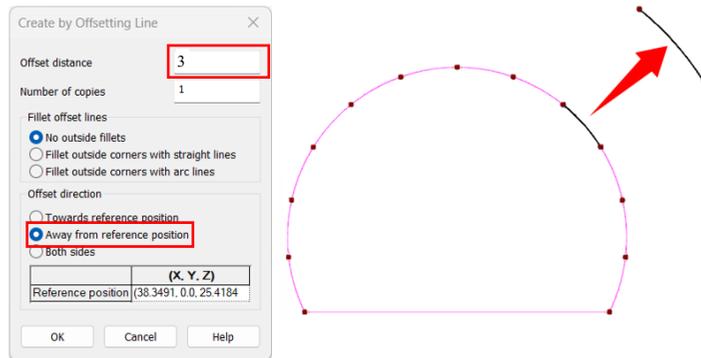


Figure 4: Offsetting one segment of the tunnel curve

- We generate a bolt by creating a line between two points as depicted in figure 5. After selecting the two edge points, we use the command **Geometry > Line > By Points**, the final shape is illustrated in figure 5 (right side).

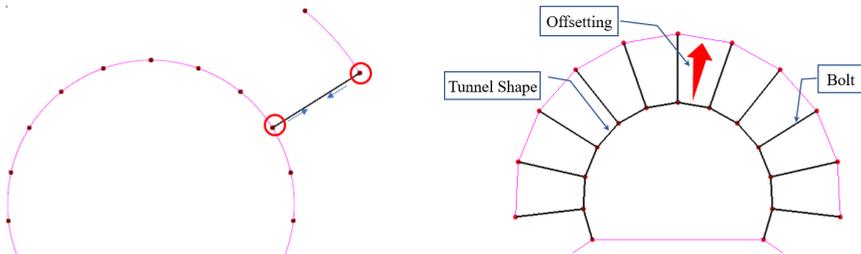


Figure 5: Creating bolts

- The resulting lines are used to create the surfaces which produces the model in figure 6.

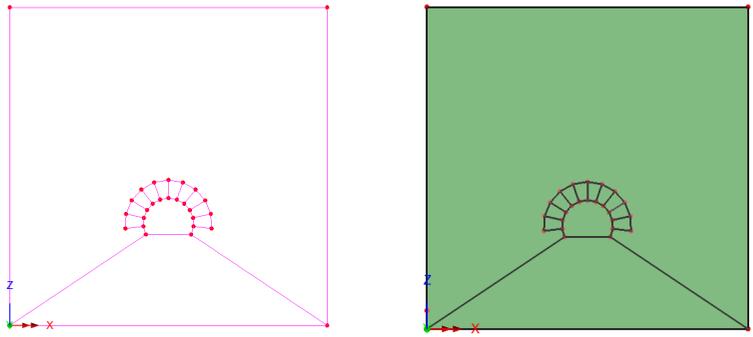


Figure 6: Converting Lines into surfaces

- Volumes are formed by sweeping the surfaces in Y direction by the command **Geometry > Volume > By Sweeping** (Figure 7)

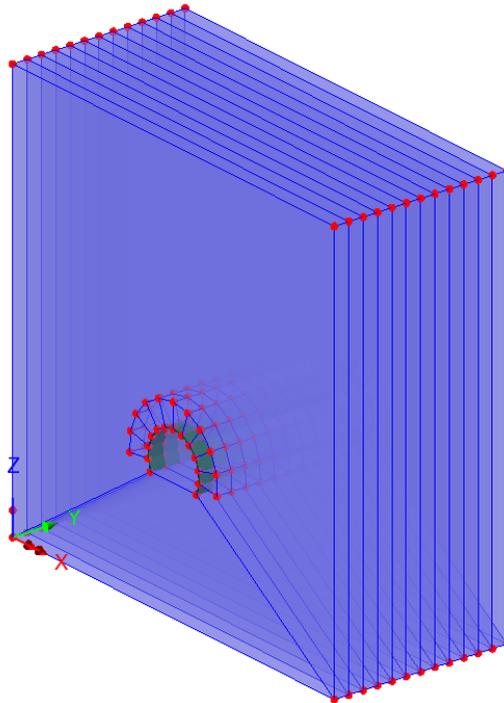


Figure 7: Sweeping surfaces to form volumes

## Preparing the Model Attributes

Model attributes (mesh, material, geometric properties, etc.) are defined and assigned to the model. Figure 8 shows the attributes of model.

### Defining the Mesh

Hexahedral, quadratic stress elements (HX20) are used for meshing the volume parts, while we use quadrilateral thick shell elements for the lining (QTS8) and quadratic thick beams with an element length of 3 m for the bolts (Figures 9 and 10)

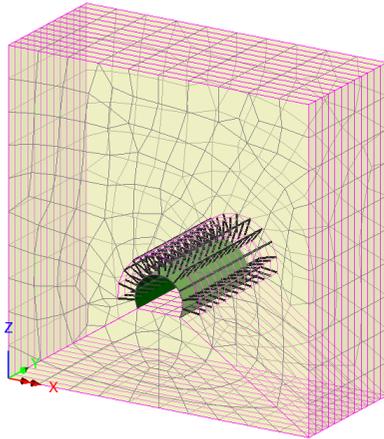


Figure 9: Model meshing

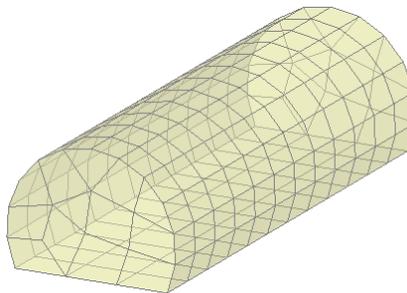


Figure 10: Tunnel meshing

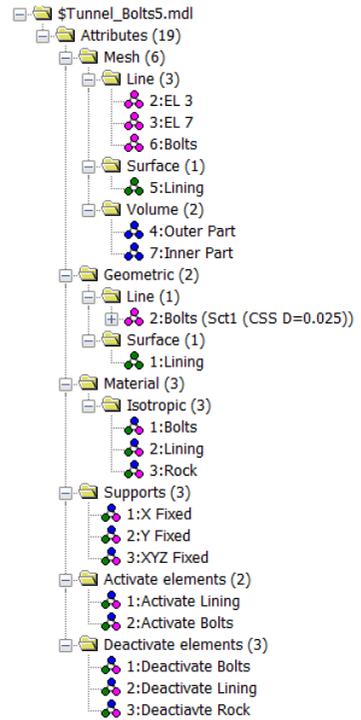


Figure 8: Model Attributes

## Defining the Geometrics

- A **Geometric Surface** attribute is assigned to the lining feature with a thickness of 160 mm, while the rock bolt is given the section displayed in figure 11, with a diameter of 25 mm.

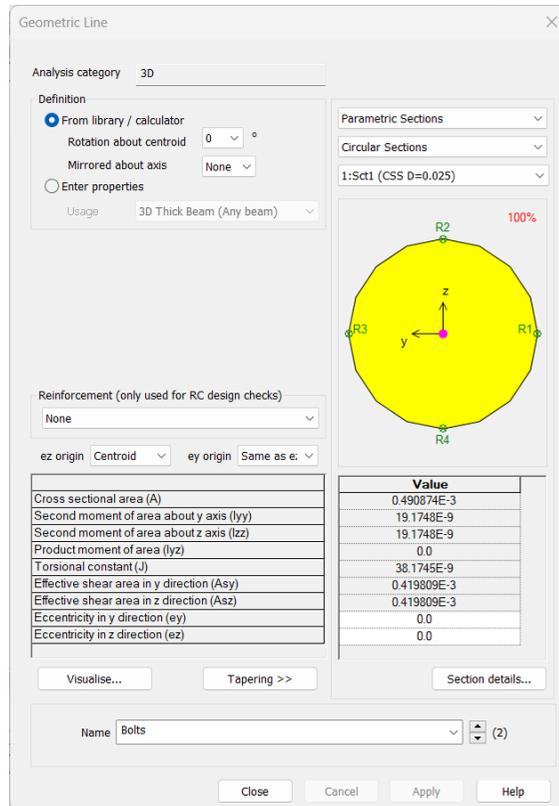


Figure 11: Rock bolt section

## Defining the Materials

The rock material will be modelled using an isotropic nonlinear material with a Modified Mohr-Coulomb failure surface, while the structural elements will be 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.

## Analysis of Tunnel Excavation

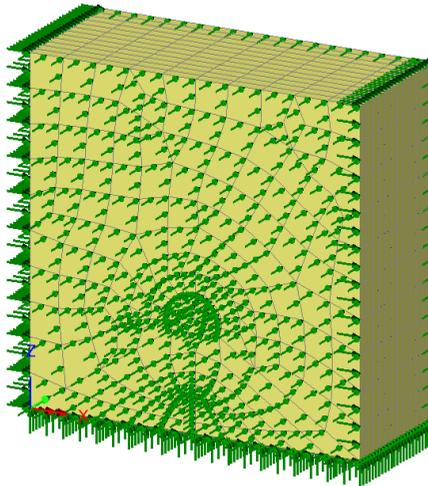
---

**Table 1: material properties**

Layer	Mass Density	Young's modulus, E	Poisson's ratio, $\nu$	Angle of friction, $\varphi$	Cohesion, c	$K_0$
Rock	2.3 t/m <sup>3</sup>	500.0E3 kPa	0.3	36°	400 kPa	0.412
Lining	2.4 t/m <sup>3</sup>	5.0E6 kPa	0.2	-	-	-
Bolt	7.85 t/m <sup>3</sup>	200.0E6 kPa	0.3	-	-	-

### Defining the Supports

The model is restrained in X and Y direction, with fully fixed supports assigned to the base (Figure 12).



**Figure 12: Boundary conditions**

### Defining the Loads

Gravity load is the only load considered.

### Defining Other Attributes

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

## Running the Analysis

We consider the following construction stages.

### 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 from 1 to 10

The phases from 1 to 10 simulate the excavation process of the tunnel. The following steps are considered:

- In stages 1, 3, 5, 7, and 9, we turn on the lining and turn off the corresponding excavated part of the tunnel rock material (Figure 13)
- In stages 2, 4, 6, 8, and 10, we turn on both the lining and bolts, and turn off the excavated part of the tunnel (Figure 14).

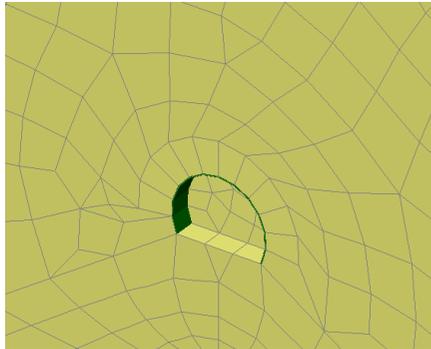


Figure 13: Stage 1

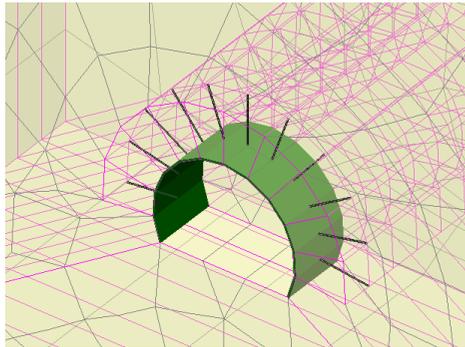


Figure 14: Stage 2

## Viewing the Analysis

Analysis loadcase results are presented in the Treeview.

### Stress

The following figure 15 shows the vertical stress at the initial stage.

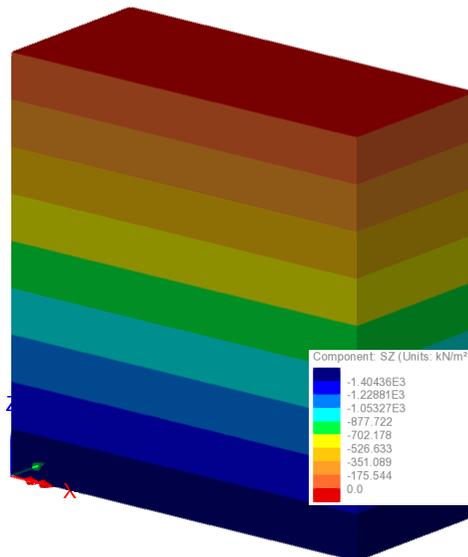


Figure 15: Vertical stress at the initial stage (kN/m<sup>2</sup>)

## Displacement

The maximum resultant displacement at the final stage is 17.4 mm. Figure 16 illustrates the displacement contours.

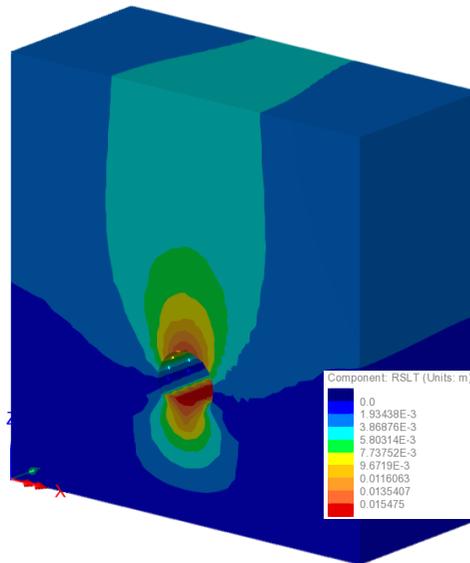


Figure 16: Resultant displacement (m)

## Moments and axial forces

LUSAS has the capability of determining the moments and forces for structural elements. Figure 17 shows the axial forces for the first row of rock bolts, where it can be seen that the bolt experiencing the highest tensile force is located at the roof of the tunnel and has a value of approximately 133 kN when first activated but which subsequently drops to 113 kN as the tunnel advances. This is in line with the deformation observed in the tunnel, as depicted in Figure 18.

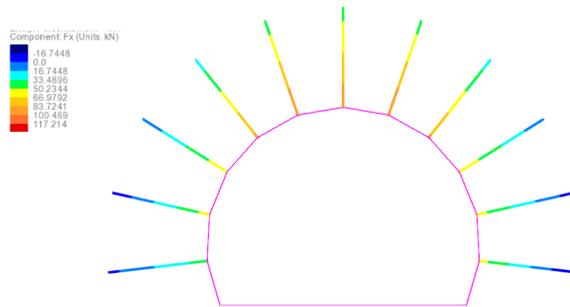


Figure 17: Axial forces for the first row of rock bolts

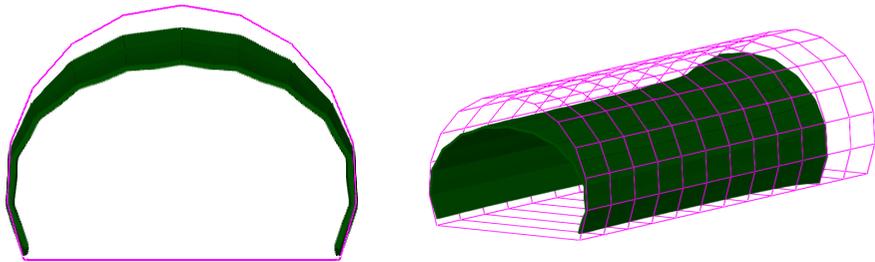


Figure 18: Tunnel deformation

We can also get the moments  $M_y$  in the lining (shell) as seen in figure 19

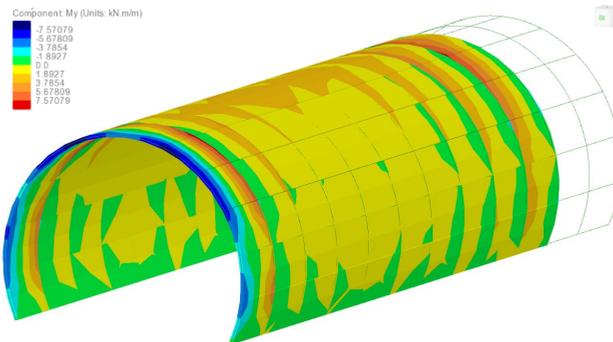


Figure 19:  $M_y$  in lining along the tunnel