Excavation of a NATM tunnel

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

Problem Description

This analysis considers the installation of a tunnel in rock below a slope of rock and soil. The geology consists of 3 layers (Figure 1). The base layer is a clayey limestone. The next layer, in which the tunnel lies, is a clayey siltstone whilst the top layer of the slope is made from a slightly cohesive frictional soil. The tunnel is 9.9m high and 11.25m wide at its widest point.

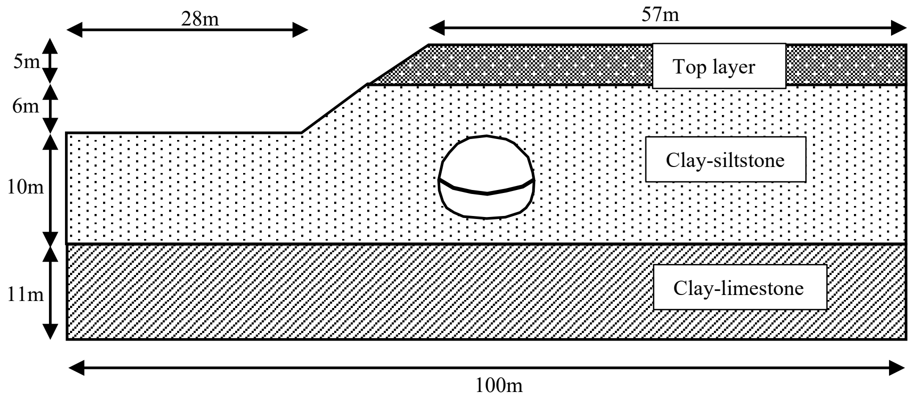

Figure 1: Problem geometry

The tunnel is excavated in two sections. The upper section first with shotcrete applied to form the tunnel liner. A temporary floor of shotcrete is installed at this time. In the second excavation phase, the temporary floor is removed, and the bottom of the tunnel is dug.

Finally, a shotcrete liner is installed to form the floor of the tunnel. The liner is a uniform 20cm thick.

Keywords

2D continuum elements, manually assigned interface elements, displacement reset, interface material properties, Hoek-Brown material model, activation/deactivation of elements.

Associated Files

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

- **NATM_tunnel_construction.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.

Discretisation

The 2D problem is meshed with quadrilateral plane strain elements (QPN8) and the liner with quadratic plane strain beams (BMI3N). The bottom of the model is fully restrained and the lateral sides are restrained in the x-direction only.

Figure 2 shows the problem geometry, mesh and boundary conditions.

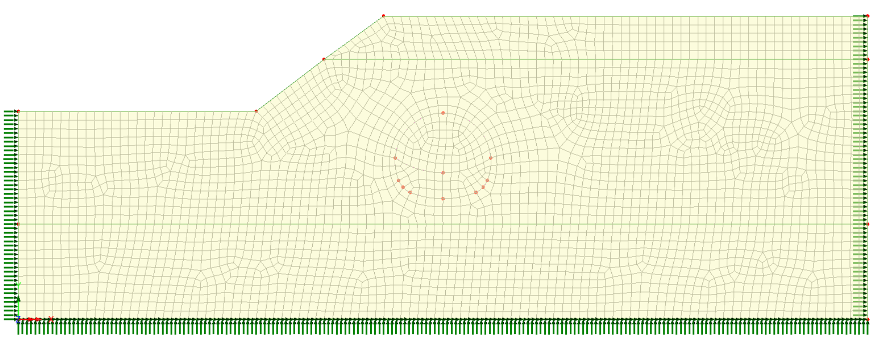

Figure 2. 2D Problem geometry and mesh

Material Properties

The rock, soil and tunnel liner properties are listed in tables 1,2 and 3.

Table 1: Hoek-Brown Material properties

	Clay- limestone	Clay-siltstone
Young's modulus E (kPa)	$2.5\text{x}10^6$	$1.0\text{x}10^6$
Poisson's ratio ν	0.25	0.25
Uniaxial compressive strength σ_{ci} (kPa)	$50\text{x}10^3$	$25\text{x}10^3$
Density ρ (t/m^3)	2.5	2.5
Empirical strength parameter m_i	10	4
Geological strength index GSI	55	40
Damage coefficient D	0.0	0.2
Dilation angle ψ^o	35	30
Transition stress σ_ψ (kPa	-1000	-400
Transition rate a_ψ	0.5	0.5

Table 2: Top layer Modified Mohr-Coulomb properties

Young's modulus E (kPa)	Poisson's ratio ν	Density ρ (t/m^3)	Cohesion c (kPa)	Friction angle ϕ^o	Dilation angle ψ^o
$120\text{x}10^3$	0.2	2.0	10	30	0

Table 3: linear elastic properties

Young's modulus E (kPa)	Poisson's ratio ν	Density ρ (t/m^3)
$30\text{x}10^6$	0.15	5.0

The shotcrete sticks to the rock, so slip is highly unlikely to occur. However, the interface elements can be used to limit the tension transmitted between rock and concrete. If this is exceeded there will be a dramatic release of energy and it is unlikely a static solution will converge but the debonding may still be captured by starting a dynamic analysis at this point.

The maximum tensile stress σ_t predicted by the Hoek Brown model is

$$\sigma_t = \frac{-s\ \sigma_{ci}}{m_b}$$

The Hoek-Brown material parameters s and m_b are related to the geological parameters by [1]

$$m_b = m_i \exp\left(\frac{GSI - 100}{28 - 14D}\right)$$

$$s = \exp\left(\frac{GSI - 100}{9 - 3D}\right)$$

So, the tensile strength of the rock is 53kPa which is far less than the tensile strength of concrete. A high value of cohesion is set for the interface because we are just monitoring the tensile stress. Also, a higher shear stiffness factor than normal is used to reduce shear displacement on the interface. The interface properties are given in table 4.

Table 4: Interface properties

Normal stiffness factor K_n	Shear stiffness factor K_s	Friction angle º	Dilation angle º	Cohesion c (kPa)	Tension stress cut-off (kPa)
100	5	0.0	0.0	1×10^6	50

Loading Conditions

Gravity loading is applied.

Modelling Hints

The tunnel is formed as a hole in the surrounding surface. The surfaces of the tunnel are first defined and then selected along with the surrounding surface in which to the hole is be formed. The hole is then made by using the command **Geometry > Surface > Holes > Create…** (figure 3).

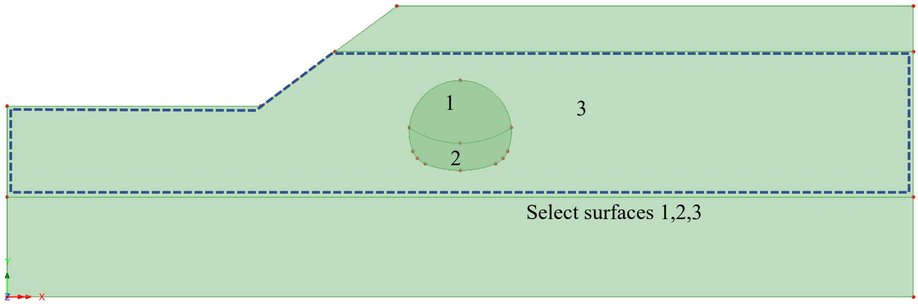

Figure 3: Formation of hole for tunnel

The lines that form the tunnel lining are then copied above the model and the interfaces assigned. The surfaces of the tunnel are hidden to ensure that the interfaces are formed correctly between the external soil and the tunnel lining (figure 4). The soil surface is the primary surface to which the interface material properties and activation/deactivation attributes are assigned.

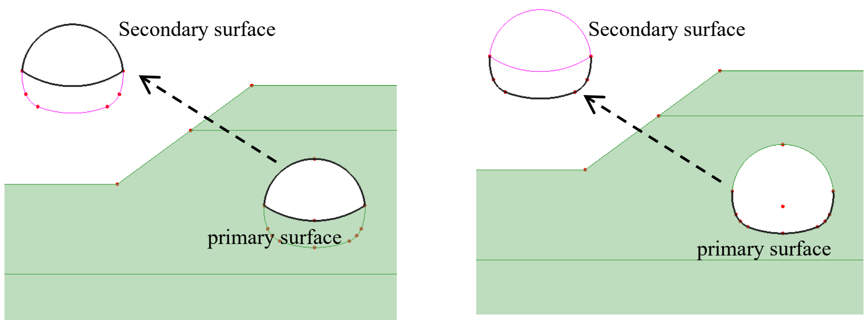

Figure 4: Assignment of interface mesh attribute

The tunnel lining and the connecting interfaces are present in the solution, although with a much reduced stiffness, and will displacement from their original positions during the excavation. To ensure that no small gaps have opened-up between the soil and the lining, the lines representing the lining and soil edges are selected and a nodal displacement reset applied at the point of activation. This has no effect on the stresses in the soil.

Running the analysis

Setting initial conditions

The tunnel lining and interface elements are deactivated. Gravity loading is then applied to generate the initial stresses in the soil. The displacements are then reset to restore the original geometry.

Excavation of upper section

The upper excavated section of the tunnel is deactivated and the residual forces reduced by 60%. The displacements of the upper tunnel lining and the corresponding edges of the excavated soil are reset to their starting geometry after the residual forces have been reduced.

Installation of upper tunnel liner

The upper tunnel liner and the corresponding interfaces are activated.

Transfer of remaining residual forces to upper tunnel liner

The remaining 40% of the residual forces from the first excavation are transferred to the liner.

Excavation of lower section

The lower section and the temporary floor are deactivated and the residual forces reduced by 60%. The displacements of the lower tunnel lining and the soil at the excavated edges are reset to their starting geometry after the residual forces have been reduced.

Installation of the lower tunnel liner

The lower tunnel liner and the corresponding interfaces are activated.

Transfer of remaining residual forces to lower tunnel liner

The remaining 40% of the residual forces from the second excavation are transferred to the liner.

Results

The resultant displacements at the end of construction are shown in figure 5 as well as the bending moments in the tunnel liner in figure 6.

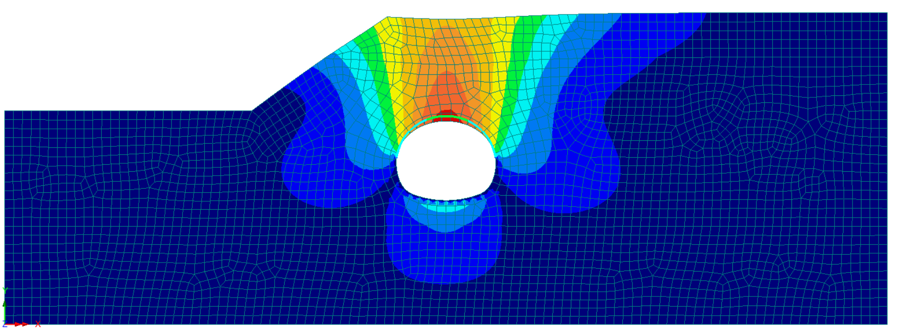

Figure 5: Resultant displacements at end of construction

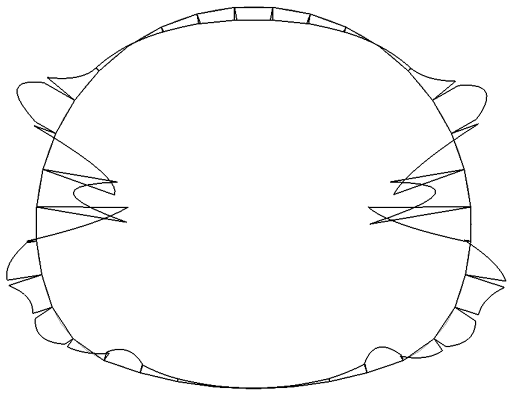

Figure 6: Bending moments in liner at end of construction

References

[1] Hoek, E., Carranza-Torres, C. and Corkum, B. (2002). Hoek-Brown failure criterion – 2002 edition. Proceedings of the 5th North American Rock Mechanics Symposium and the 17th Tunnelling Association of Canada Conference, Toronto.