

Tunnel Shaft

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

Tunnel shafts are vertical channels that link the surface of the ground to the upper part of a tunnel during the tunnel's construction (Figure 1). There exist various techniques for supporting shafts. When dealing with groundwater, it is recommended to employ a watertight support system. Such systems eliminate the need for dewatering to reduce the groundwater level, which can be costly. Discharging the water can be particularly challenging, especially in urban areas.

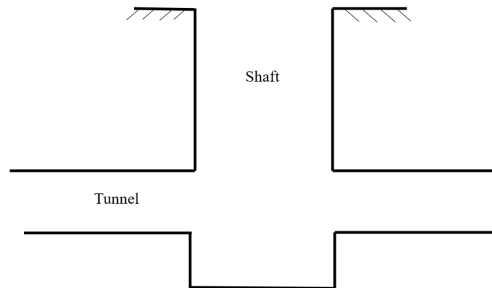


Figure 1: Sketch of tunnel shaft

The example shaft has a width of 28 meters and a height of 39 meters. It is excavated through layers of made ground and London clay, with the made ground being 6 meters thick. To provide support, sheet piles supported by beams are used in the upper portion of the shaft, while sequential linings are utilized in the lower portion (Figure 2). The water table is at 6m depth. Axial symmetry is assumed.

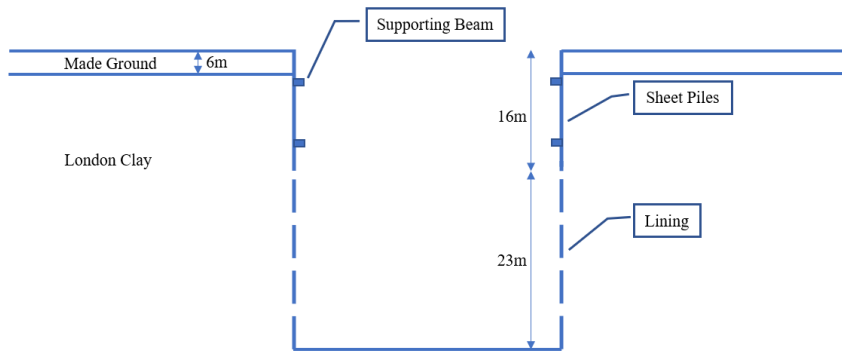


Figure 2: Tunnel shaft details

Keywords

Two Phase Elements, Interface Elements, Excavation, Pore Pressure, Structural Elements, Drained, Undrained.

Associated Files

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



□ **tunnel_shaft.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

Through this example, we demonstrate how different functions of LUSAS can be employed to develop the model, including construction stages of the supporting system comprising sheet piles, lining, and supporting beams.

Preparing the Model Features

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

Feature Geometry

The model is created by entering point coordinates using the command **Geometry > Point > By Cords**, these points define the excavation pit shape, as shown in figure 3 and then by connecting lines between these points to form surfaces through the command **Geometry > Surface > By Lines**. The user has a variety of options and facilities to use,

which enables them to construct the model with ease. We advise the use of the **Copy** command to reduce the time needed to develop the model.

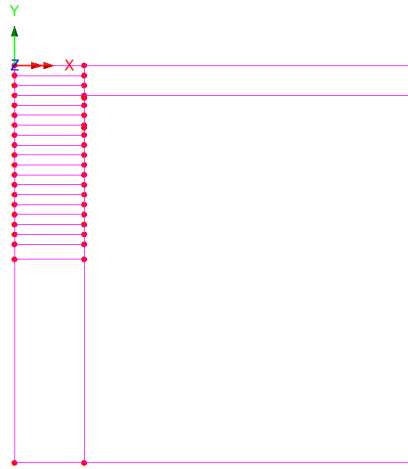


Figure 3: Model geometry

An interface is defined and assigned to both sides of the sheet piles/linings. Figure 4 shows the interface along the excavation.

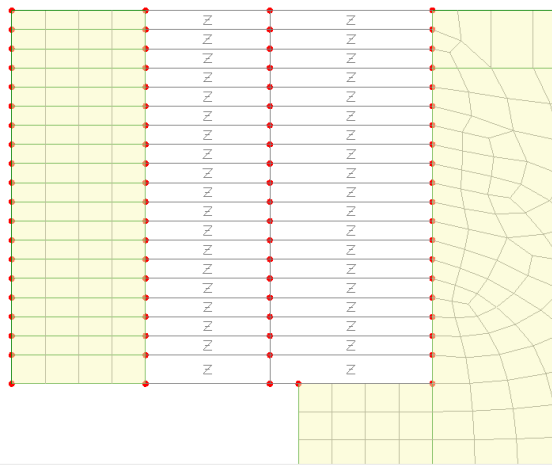


Figure 4: Interface along the sheet piles and linings

Preparing the Model Attributes

Model attributes (mesh, material, geometric properties, etc.) now need to be defined and assigned to the model (Figure 5).

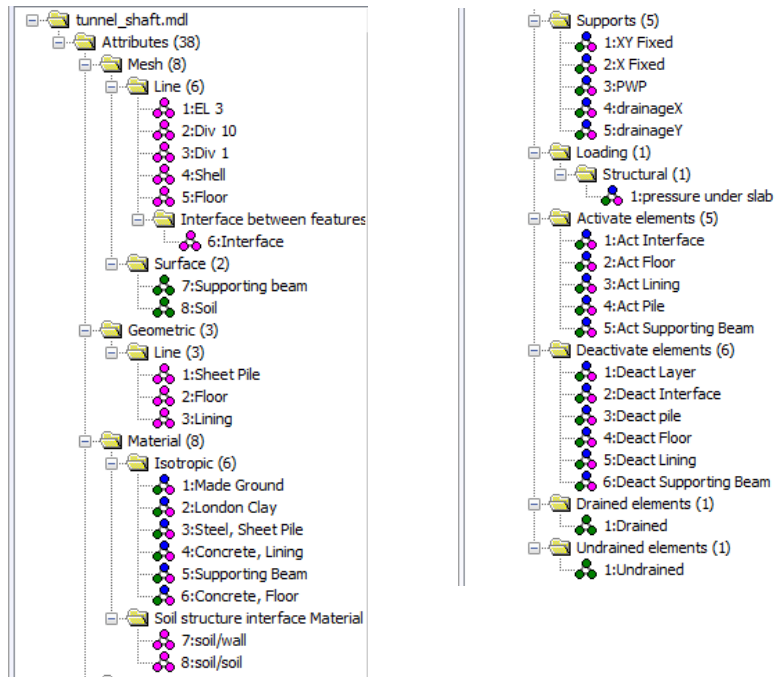


Figure 5: Model Attributes

Defining the Mesh

- The surface features are meshed using quadrilateral axisymmetric two-phase elements (QAX8P) as illustrated in figure 6.
- The sheet piles and floor are meshed with quadratic axisymmetric shell elements (BXS13).
- The supporting beams are meshed using quadrilateral axisymmetric elements (QAX8)
- And finally, the interface is meshing with axisymmetric two-phase interface elements (IAX6P).

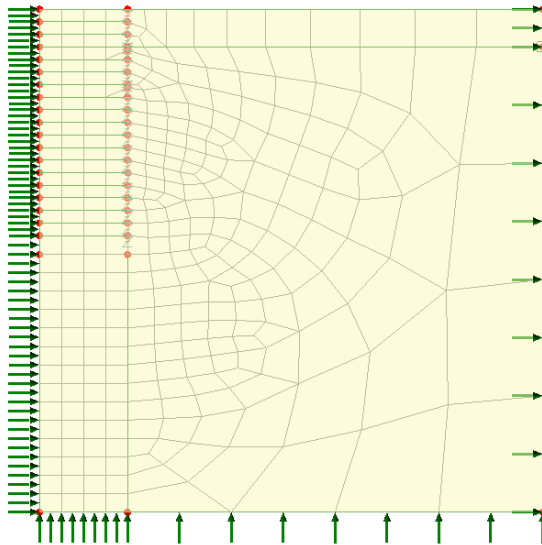


Figure 6: Model meshing

Defining the Geometric Properties

All the geometric attributes are created using the command **Attributes > Geometric > Line**.

The table 1 lists the geometric properties for structural elements as follows.

Table 1. Geometric properties for structural elements

Feature	Thickness (m)
Sheet Pile	0.02
Lining	0.5
Floor	0.5

Defining the Materials

The Made Ground and London clay are modelled by the Modified Mohr-Coulomb (MMC) with Rankine cut-off material. The sheet piles, linings, supporting beams and the floor by linear elastic (LE) materials. Properties are given in table 2.

Tunnel Shaft

Table 2: Material properties

Parameter	Made Ground	London Clay	Concrete	Steel
Model	MMC	MMC	LE	LE
Density	1.8 t/m ³	1.9 t/m ³	2.4 t/m ³	7.8 t/m ³
Young's Modulus	30.0E3 kPa	80-150 kPa*	14.0E6 kPa	210.0E6 kPa
Poisson's ratio	0.3	0.2	0.2	0.3
Friction angle	35°	25°	-	-
Dilatancy angle	0°	0°	-	-
Cohesion	15 kPa	130 kPa	-	-
K ₀	0.4264	0.5774	-	-

* Young's modulus varies linearly with depth from 80 kPa to 150 kPa.

Additional two-phase properties are given in table 3. It is important to note that the London Clay is modelled with fully saturated two-phase properties. During excavation, the pore water pressure drops temporarily and goes negative. If we use partially saturated material properties, the negative pressure is interpreted as degree of saturation with the soil losing water as the negative pressures increase. Partially saturated properties are used in the Made Ground to automatically account for the water content of the soil above and below the phreatic surface.

Table 3: Additional hydraulic properties

Partially saturated parameters	Bulk modulus water	Hydraulic conductivity	Density fluid	Saturation at residual water content	Saturation at full water content
Made Ground	2.1E6 kPa	1.0E-5 m/s	1 t/m ³	0.0	1.0
London Clay		1.0E-11 m/s		-*	-*

In addition, we need the properties at the interface between the soil and sheet piles/linings. Prior to installing the sheet pile and lining, the soil to be excavated and that outside of the shaft are held together by interface elements with very high shear and normal stiffnesses, and a large cohesion to ensure that the soil blocks displace together without slip or excessive normal penetration of the surfaces. After installation of the shaft, the interface shear stiffness as well as the angle of friction and cohesion are reduced to model the slip conditions between the London clay and shaft.

Table 3: Tangential slip interface properties

	Angle of friction	Cohesion	Kn	Ks	Hydraulic conductivity
Interface before installing support system*	45.0°	1E20 kPa*	1E9 kN/m	1E9 kN/m	1.0 m/s
Interface after installing support system	18.0°	95 kPa	10 Kn factor	0.15 Ks factor	0.0 m/s

*Cohesion is set to a high value to prevent slip.

Defining the Supports

- The base of the model is constrained in both X and Y directions, while the lateral sides are limited in the X direction (Figure 6).

- In order to take into account the water table situated at a depth of -6m, we utilize the command **Attributes > Support > Pore Pressure** to assign the value **Open** to the point depicted in Figure 7.

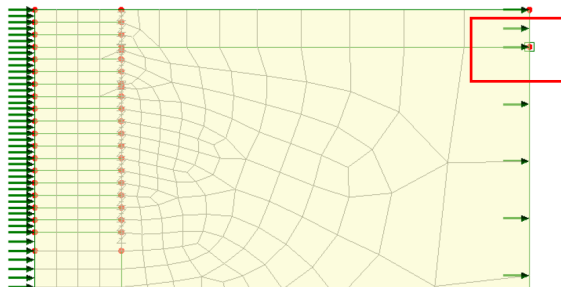


Figure 7: Pore pressure support at point 45

Defining the Loads

Gravity is the only load considered in the model.

Defining Other Attributes

The activation and deactivation functions are used to model the removal of soil and the installation of the supporting system. The excavation and installation of the supporting system is completed in a series of load cases or stages.

Other attributes:

- Activate attributes are used for activating specific beams, floor and linings at specific stages. The command is **Attributes > Activate and Deactivate**.

- Deactivate attributes are used for deactivating soil layers and adjacent interfaces to simulate the excavation process, as well as for the beams and linings that are to be installed as the shaft construction progresses. The command is **Attributes > Activate and Deactivate**.
- Drained and undrained conditions are defined at specific stages using the command **Attributes > Pore Water Pressures > Drained/Undrained**.

Running the Analyses

Two analyses are run. In the first, the excavation and installation of the lining is done in a single stage. In the second, the excavation is performed in one stage and the lining installed in the second.

We consider the following construction stages.

Initial Phase

The first stage establishes the initial stress and water pressure distributions. The supporting beams, floor, and linings are not present during this stage and so are deactivated. To deactivate any element, we first select the element and then assign the deactivate attribute to them.

Gravity is included in this phase by right-clicking on the load case name and selecting gravity.

Nonlinear analysis control properties are defined for this stage, all the parameters are left at their default values.

Installing Sheet Piles

The sheet pile is activated. The interface elements adjacent to the pile are changed to allow for slip between the soil and pile.

Analysis 1

Excavation of soil adjacent to pile

The phases from 1 to 8 simulate the excavation process of soil layers adjacent to the sheet piles. In these phases we deactivate the layer in question and the corresponding interface elements. The supporting beams are activated in the appropriate excavation phase.

As London clay is highly impermeable and we are not modelling time we assign the undrained attribute to it during the excavation.

Excavation of soil and installation of lining

For the final stages of the construction, excavation phases 9 to 19 the soil is excavated and the lining installed.

Install floor

The floor at the bottom of the excavation pit is activated.

Long Term Case

During the excavation process, as the water does not have sufficient time to flow through the almost impermeable clay, the medium is treated as undrained resulting in excess pore water pressure building up in the soil. However, over the long term, the initial hydrostatic pressure distribution is restored. This leads eventually to a pore water pressure of almost 325 kPa being applied to the base of the concrete slab forming the floor. To avoid the imposition of such a large pressure the space below the slab is drained.

The long-term conditions are given by changing the soil status to ‘drained’ setting the porewater pressure below the slab to zero and restoring the porewater pressures along the boundary to their initial values by using the ‘drainage’ boundary support condition.

Analysis 2

Excavation of soil adjacent to pile

The stages 1 to 8 simulate the excavation process of soil layers adjacent to the sheet piles. In these stages we deactivate the layer in question and the corresponding interface elements. The supporting beams are activated in their own stages following the excavation of the soil.

Excavation of soil and installation of lining

During excavation below the level of the piles, the soil is excavated in one phase, followed in the next phase by the installation of the lining.

Install floor

The floor at the bottom of the excavation pit is activated.

Long Term Case

The long-term conditions are given by changing the soil status to ‘drained’, setting the porewater pressure below the slab to zero and restoring the porewater pressures along the boundary to their initial values.

Viewing the Analysis

Analysis results are present in the Treeview.

Stress

The following figure 8 shows the vertical effective stresses for the initial stage.

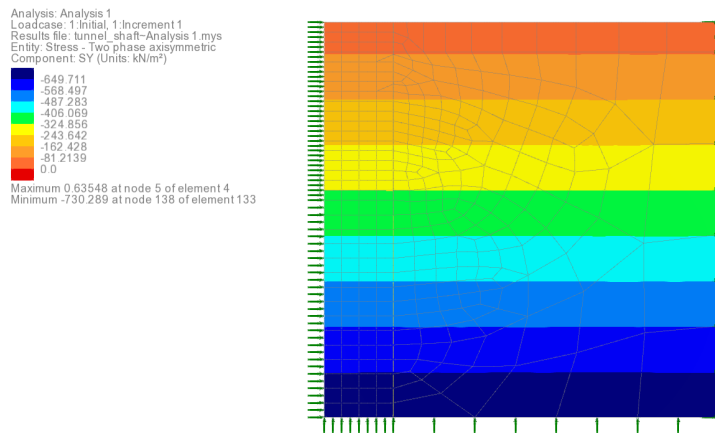


Figure 8: Vertical effective stress at initial stage (kN/m²)

Displacement

Figure 9 shows the model deformations following construction. Both analyses give similar results with a maximum resultant displacement of 73-74 mm at the bottom of the shaft.

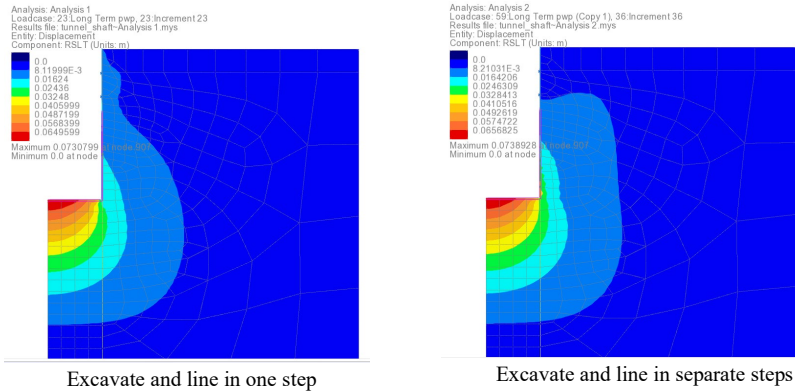


Figure 9: Model deformations at end of construction

In figure 10 the development of the sheet piles and linings deflection at the final phase is plotted. It is observed that the greatest horizontal displacement reaches 19mm for first analysis increasing to 24mm in the second.

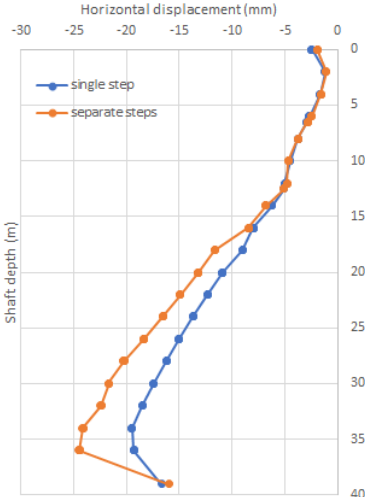


Figure 10: Displacement of shaft wall at end of construction

Pore Pressure

The contours of water pressure distribution are shown after the installation of the shaft floor and then for the long-term pressure distribution in figure 11.

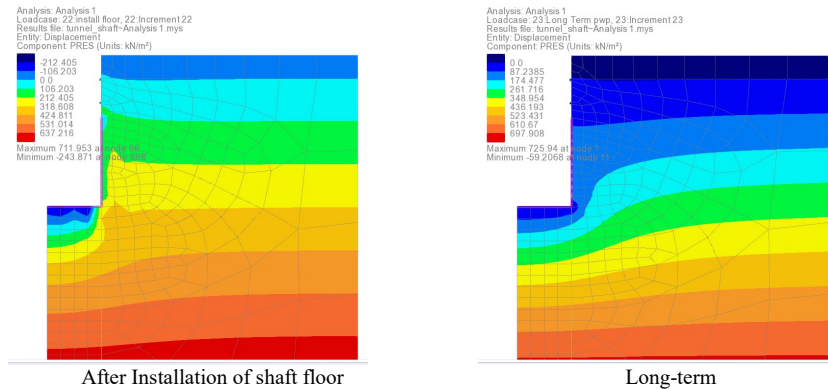
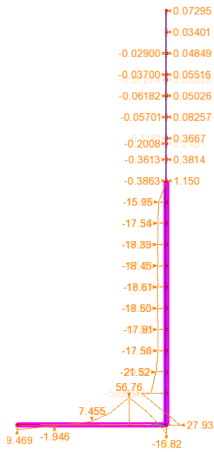


Figure 11: Pressure contours

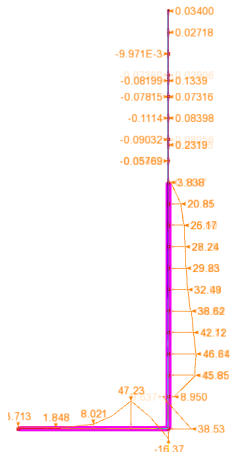
Bending Moments and Hoop stresses

Once the pile, lining and floor have been selected for display only, the bending and hoop stresses can be plotted. Right click in the display pane and then click on **Diagrams**. In the **components** field of the dialog the bending moments M_z and hoop stress N_z can be selected for plotting.

Figures 12 and 13 show the bending moments and hoop stresses respectively at the end of construction. Excavating in one step and installing the lining in the second not only leads to larger radial displacements but also larger bending moments and hoop stresses.

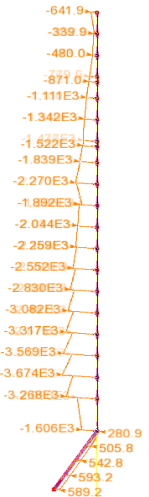


Excavate and line in one step

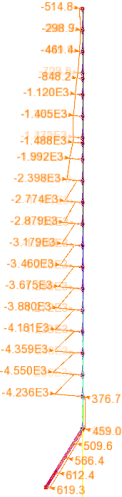


Excavate and line in separate steps

Figure 12: Bending moments at end of analysis (kN.m/m)



Excavate and line in one step



Excavate and line in separate steps

Figure 13: Hoop stresses at end of analysis (kN/m)

