

5

Phased excavation of a shield tunnel [GSE]

5.1 | Introduction

A lining of a shield tunnel is often constructed using prefabricated concrete ring segments, which are bolted together within the tunnel boring machine to form the tunnel lining.

During the erection of the tunnel lining the tunnel boring machine (TBM) remains stationary. Once a tunnel lining ring has been fully erected, the excavation is resumed until enough soil has been excavated to erect the next lining ring. As a result, the construction process can be divided into construction stages with a length of a tunnel ring, often about 1.5 m long. In each of these stages, the same steps are repeated over and over again.

In order to model this, a geometry consisting of slices (or sections) each 1.5m long can be used. The calculation consists of a number of *Plastic* phases, each phase modelling the same parts of the excavation process, as displayed as follows:

1. The *support pressure* at the tunnel face needed to prevent active failure at the face.
2. The *conical shape of the TBM shield*.
3. The *excavation* of the soil and pore water within the TBM.
4. The *installation of the tunnel lining*
5. The *grouting* of the gap between the soil and the newly installed lining.

In each phase the input for the calculation phase is identical, except for its location, which will be shifted by 1.5m each phase.

Objectives

- Modelling of the tunnel boring process with a TBM.
- Modelling of the cone shape of the TBM.
- Using **Tunnel designer** to define geometry, trajectory and sequencing of the tunnel.

5.2 | Geometry

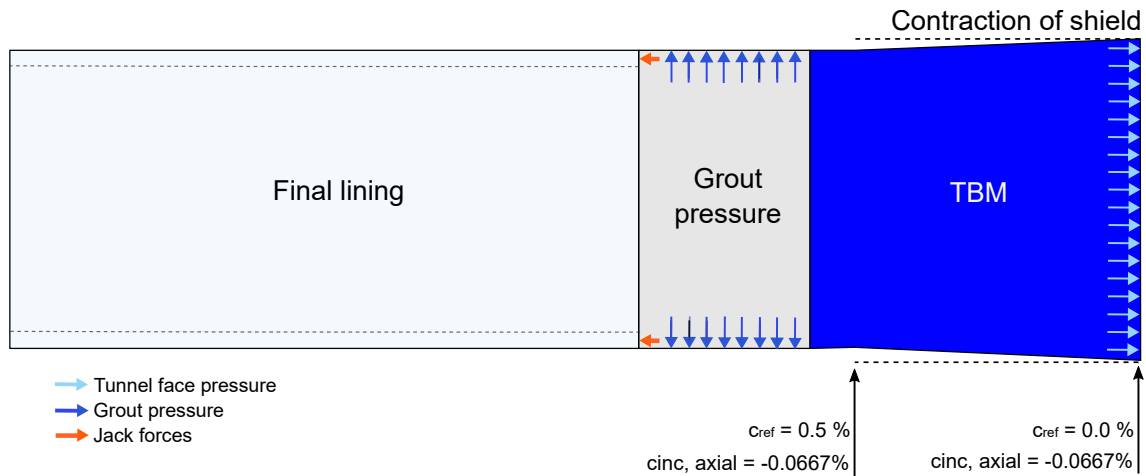


Figure 5–1: Construction stages of a shield tunnel model

5.3 | Create a new project

In the model, only one symmetric half is included. The model is 20 m wide, it extends 80 m in the y-direction and it is 20 m deep. These dimensions are sufficient to allow for any possible collapse mechanism to develop and to avoid any influence from the model boundaries.

- 1 Start the Input program and select **Start a new project** from the **Quick select** dialog box.
- 2 In the **Project** tabsheet of the **Project properties** window, enter an appropriate title.
- 3 Keep the default units and set the model dimensions to
 - a. $x_{\min} = -20$ and $x_{\max} = 0$,
 - b. $y_{\min} = 0$ and $y_{\max} = 80$.

5.4 | Define the soil stratigraphy

The subsoil consists of three layers. The soft upper sand layer is 2m deep and extends from the ground surface to Mean Sea Level (MSL). Below the upper sand layer, there is a clay layer of 12m thickness and this layer is underlain by a stiff sand layer that extends to a large depth. Only 6m of the stiff sand layer is included in the model. Hence, the bottom of the model is 18m below MSL.

Soil layers are assumed to be horizontal throughout the model and so just one borehole is sufficient to describe the soil layers. The present groundwater head corresponds to the MSL.

- 1 Press the **Create borehole** button  and click at the origin of the system of axis to create a borehole at (0 0 0). The **Modify soil layers** window will open.
- 2 Define 3 layers: Upper sand with the top at 2m and the bottom at 0m, Clay with the bottom at -12m and Stiff sand with the bottom at -18m.

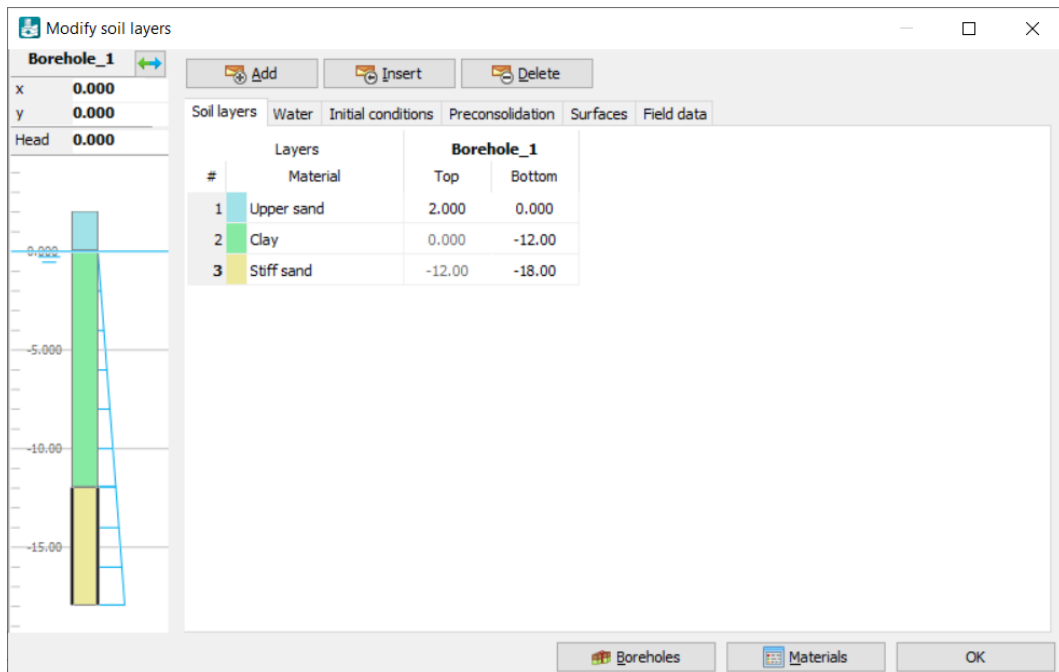


Figure 5-2: Soil layer distribution

5.5 | Create and assign the material data sets

The material properties for the data sets are shown in [Table 5-1 \(p. 84\)](#).

Table 5-1: Material properties for the soil layers

Property	Name	Upper sand	Clay	Stiff sand	Concrete	Unit
General						
Soil model	Model	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Linear elastic	-
Drainage type	Type	Drained	Drained	Drained	Non porous	-
Unsaturated unit weight	γ_{unsat}	17.0	16.0	17.0	27.0	kN/m ³
Saturated Unit weight	γ_{sat}	20.0	18.0	20.0	-	kN/m ³
Mechanical						
Young's modulus	E'_{ref}	$1.3 \cdot 10^4$	$1.0 \cdot 10^4$	$7.5 \cdot 10^4$	$3.1 \cdot 10^7$	kN/m ²
Poisson's ratio	$\nu(nu)$	0.3	0.35	0.3	0.1	-
Cohesion	c'_{ref}	1.0	5.0	1.0	-	kN/m ²
Friction angle	$\varphi'(phi)$	31	25	31	-	°
Dilatancy angle	$\psi(psi)$	0	0	0	-	°
Interfaces						
Strength determination	-	Rigid	Rigid	Rigid	Rigid	-
Initial						
K ₀ determination	-	Automatic	Automatic	Automatic	Automatic	-

- 1 Open the materials database by clicking the **Materials** button  and create the data sets for the soil layers and the final concrete lining in the tunnel as specified in the [Table 5-1 \(p. 84\)](#).
- 2 Assign the material data sets to the corresponding soil layers ([Figure 5-2 \(p. 83\)](#)) and close the **Modify soil layers** window. The concrete data set will be assigned later.

5.6 | Definition of structural elements

The tunnel excavation is carried out by a tunnel boring machine (TBM) which is 9.0m long and 8.5m in diameter.

The TBM already advanced 25m into the soil. Subsequent phases will model a segment advancement of 1.5m each.

Note:

- The segments of the tunnel considered in the present tutorial do not have a specific meaning, as the tunnel lining is homogeneous and the tunnel will be constructed at once.

In general, the meaning of segments becomes significant when:

- It is desired to excavate or construct the tunnel (lining) in different stages.
- Different tunnel segments have different lining properties.
- One would consider hinge connections in the lining (hinges can be added after the design of the tunnel in **Staged construction mode**, [Reference Manual - Chapter 7 - Definition of connections.](#))
- The tunnel shape is composed of arcs with different radii (e.g. NATM tunnels).
- A tunnel interface is nothing more than a curved interface.

To model the TBM a plate element whose material properties are displayed in [Table 5-2 \(p. 85\)](#).

Table 5-2: Material properties of the plate representing the TBM

Property	Name	TBM	Unit
General			
Material type	-	Elastic	-
Unit weight	γ	247	kN / m ³
Mechanical			
Isotropic	-	Yes	-
Young's modulus	E_1	$200 \cdot 10^6$	kN / m ²
Poisson's ratio	ν_{12}	0	-
Thickness	d	0.17	m
Shear modulus	G_{12}	$100 \cdot 10^6$	kN / m ²

Note:

A tunnel lining consists of curved plates (shells). The lining properties can be specified in the material database for plates. Similarly, a tunnel interface is nothing more than a curved interface.

5.6.1 | Create tunnel cross section

In the **Structures mode** both the geometry of the tunnel and the TBM will be defined.

- 1  Click on the **Start designer** button in the side toolbar.
- 2  Click on the **Create tunnel** button from the list.
- 3 Click anywhere on the drawing area to define the insertion point. The **Tunnel designer** window pops up.
- 4 While keeping the **Tunnel designer** window open. Go to the PLAXIS **Selection explorer**. In the newly created tunnel object set the insertion point to (0 0 -13.25) as shown in [Figure 5–3 \(p. 86\)](#) .

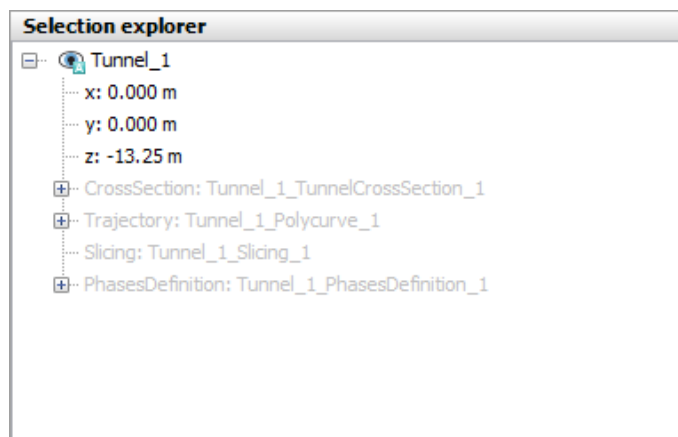


Figure 5–3: Insertion point of the tunnel

- 5 On the **Tunnel designer** window go to the **Cross section** > **General** tabsheet. From the **Shape type** drop-down menu select *Circular*.

- 6 The left half of the tunnel is generated for this example. Hence, from the **Whole or half tunnel** drop-down menu select *Define left half*.

Note:

With the *Offset to begin point* option it is possible to move the insertion point of the tunnel taking the local axes as reference.

A screenshot of the **General** tabsheet after the proper assignment is given in [Figure 5-5 \(p. 88\)](#).

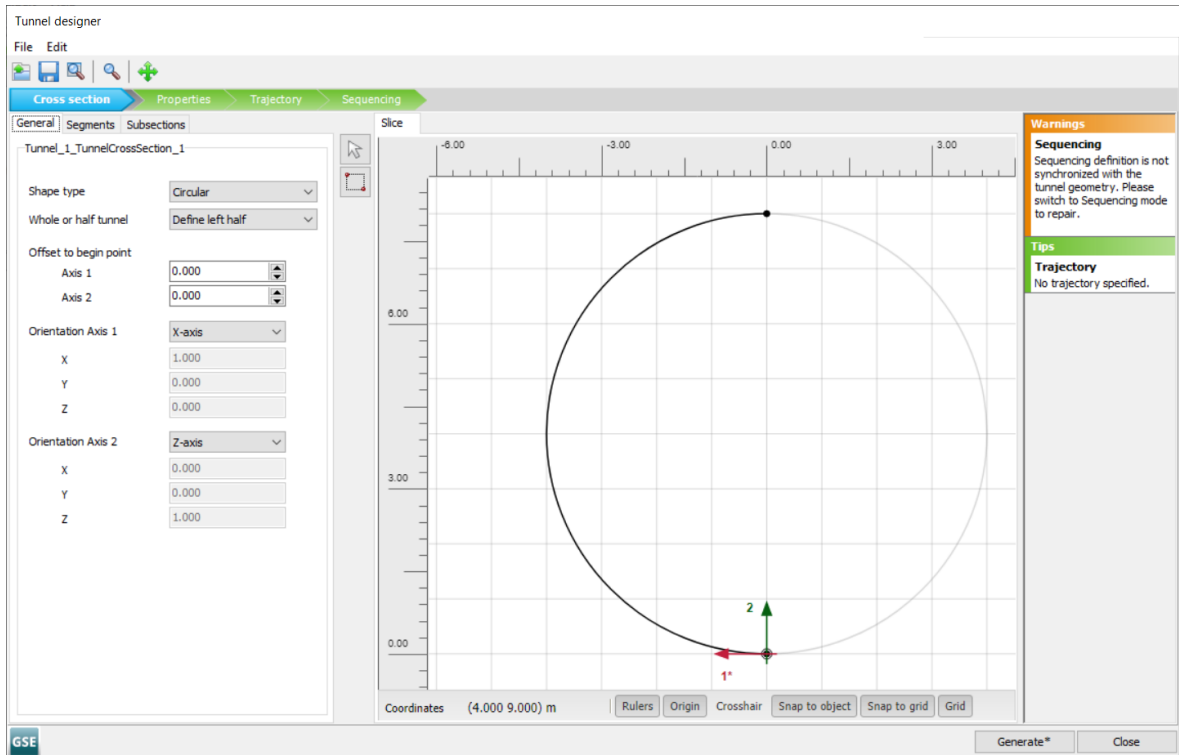


Figure 5-4: General tabsheet of the Tunnel designer

- 7 Proceed to the **Segments** tabsheet to define the radius of the TBM and the thickness of the final lining.

Note:

Notice that the segment created is shown on the *Display area*. Also a new box is now visible in the segment list. By clicking on *Segment[0]* a tunnel *Selection Explorer* gets activated that contains the corresponding editable properties of the segment.

- 8

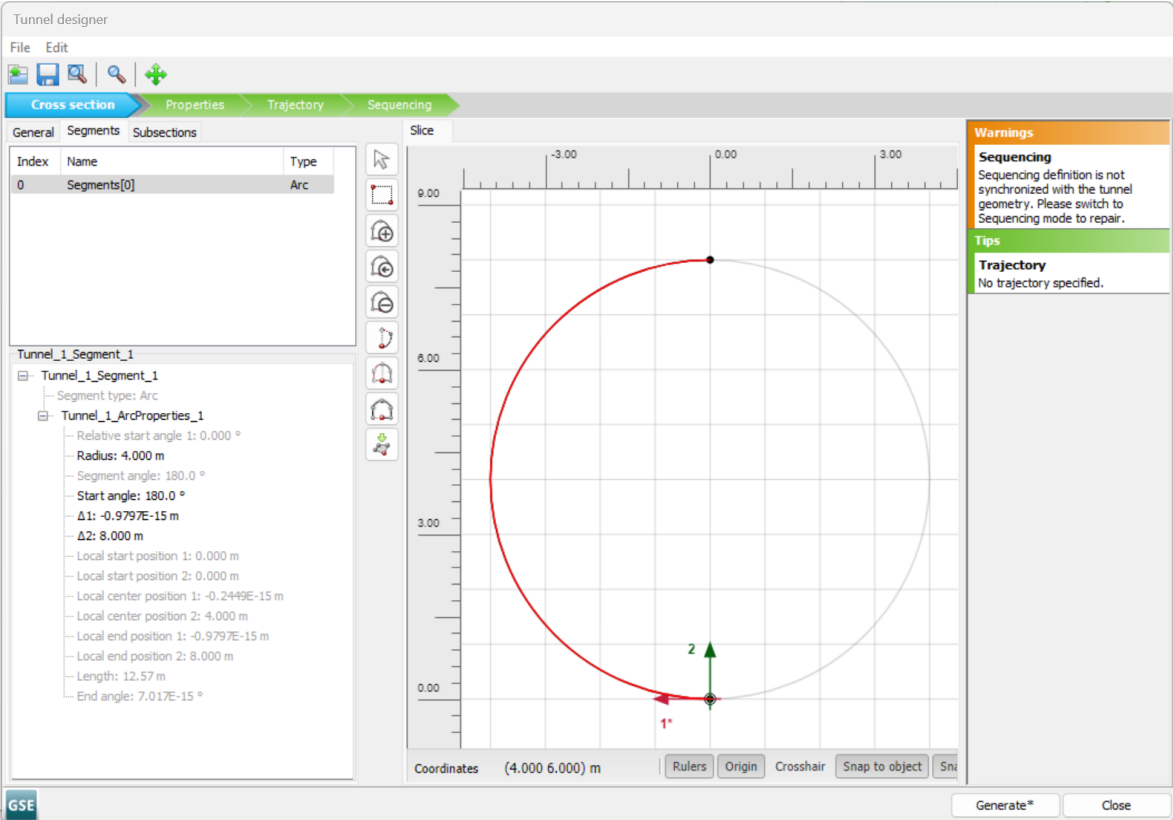


Figure 5-5: Definition Tunnel Radius

- 9 Click on the **Subsections** tabsheet.
- 10  Click on the **Generate thick lining** button on the side toolbar. The **Generate thick lining** window pops up.
- 11 Assign a value of 0.25 m and click **OK**.

The generated lining is displayed on the *Drawing area* in [Figure 5–6 \(p. 89\)](#).

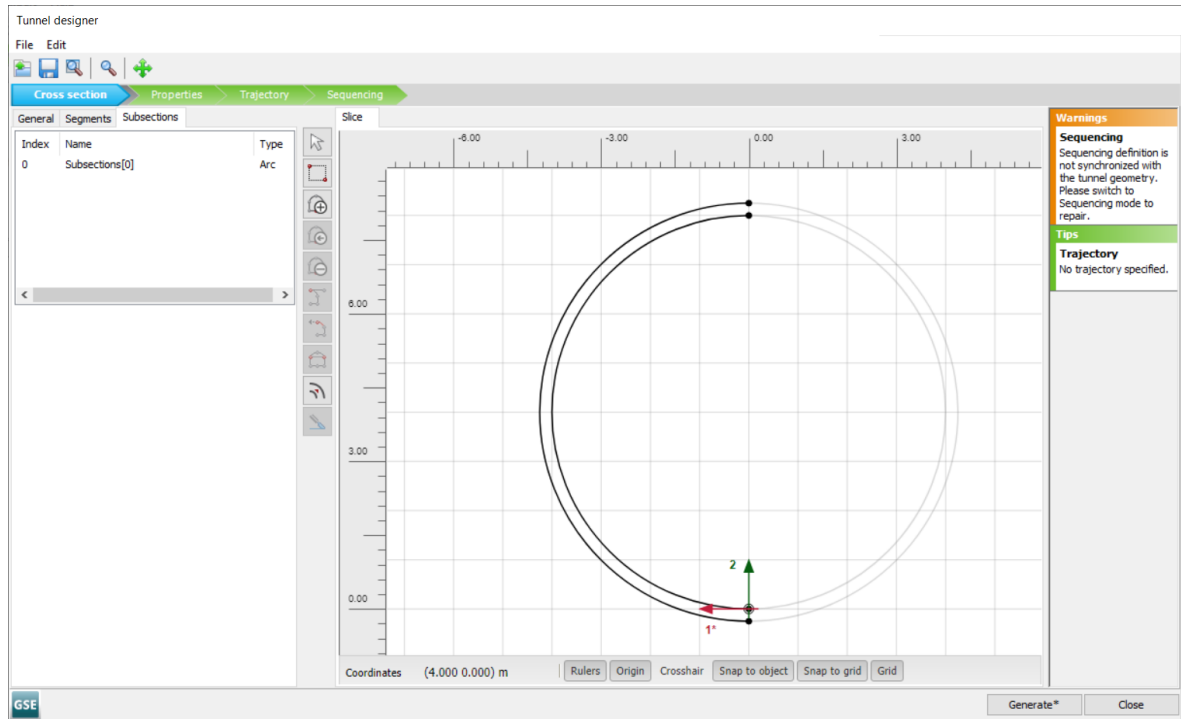


Figure 5–6: Generated thick lining

5.6.2 | Definition of Tunnel properties

Some of the properties for the tunnel definition are:

- The TBM modelling
- The surface contraction
- The grout pressure
- The Jack forces
- The tunnel face pressure

5.6.2.1 | TBM shield definition

As previously mentioned to model the TBM a plate will be used.

- 1 Click on the **Slice** tab (above the *Drawing area*) and right-click on the outer surface of the TBM. From the appearing menu select **Create > Create plate** (see [Figure 5-7 \(p. 90\)](#)).

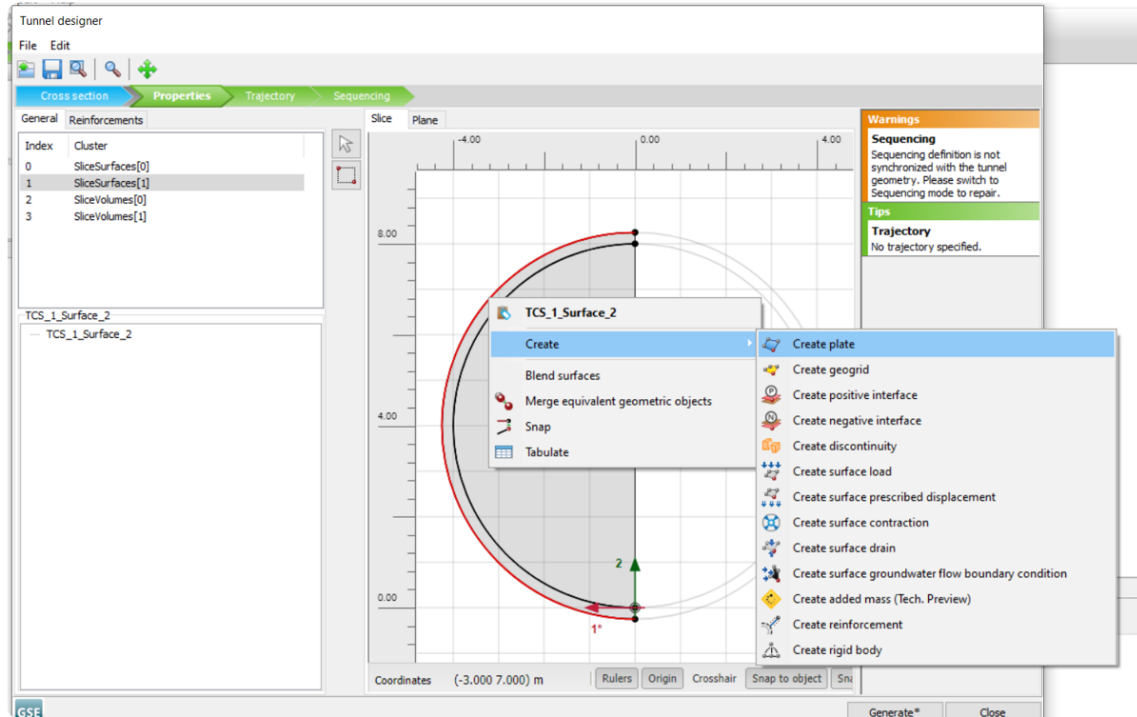


Figure 5-7: Tunnel designer - Plate creation

- 2 With the plate selected, go to the tunnel **Selection Explorer**, click on the **Material** drop down list and create the material dataset for the TBM according to [Table 5-2 \(p. 85\)](#).
- 3 Assign the created material to the plate.

5.6.2.2 | Surface contraction

A soil-structure interaction must be added on the outside of the tunnel due to the slight cone shape of the TBM. Typically, the cross-sectional area at the tail of the TBM is about 0.5% smaller than the front of the TBM. The reduction of the diameter is realised over the first 7.5m length of the TBM (5 slices) while the last 1.5m to the tail has a constant diameter.

This means the section at the tail has a uniform contraction of 0.5% and the other 5 sections have a linear contraction with a reference value $C_{ref} = 0.5\%$ and an increment $C_{inc,axial} = -0.0667\%$. Take into account that:

- The reference is set on the front surface of the excavated slice in the tunnel during the tunnel construction.
- The surface contraction is applied while defining the tunnel [5.6.4 Sequencing \(p. 95\)](#).
- The $C_{inc,axial} = -0.0667\%/m$ and remains the same in every step (see [5.6.4 Sequencing \(p. 95\)](#) <Step_1_1> to <Step_1_5>).

Note:

For further information on **Surface contraction** refer to the [Reference Manual](#).

- 1 Right-click on the outer slice surface and from the appearing menu select **Create negative interface** to create a negative surface around the entire tunnel.
- 2 To create **Surface contraction** for the tunnel, right-click again on the outer surface and select **Create > Create surface contraction**.
- 3 While keeping selected the outer surface, in the **Selection explorer** of the tunnel designer select **Surface contraction > Distribution > Axial increment**. Also define $C_{ref} = 0.5\%$ and $C_{inc,axial} = -0.0667\%/m$.

Note:

- A surface contraction of the tunnel contour of 0.5% corresponds approximately to a volume loss of 0.5% of the tunnel volume (applicable only for small values of surface contractions).
- The entered value of contraction is not always fully applied, depending on the stiffness of the surrounding clusters and objects.
- The increment $C_{inc,axial}$ must be a negative number to account for the volume loss with respect to the front of the excavation.

The created interface and the surface contraction is displayed in [Figure 5–8 \(p. 91\)](#).

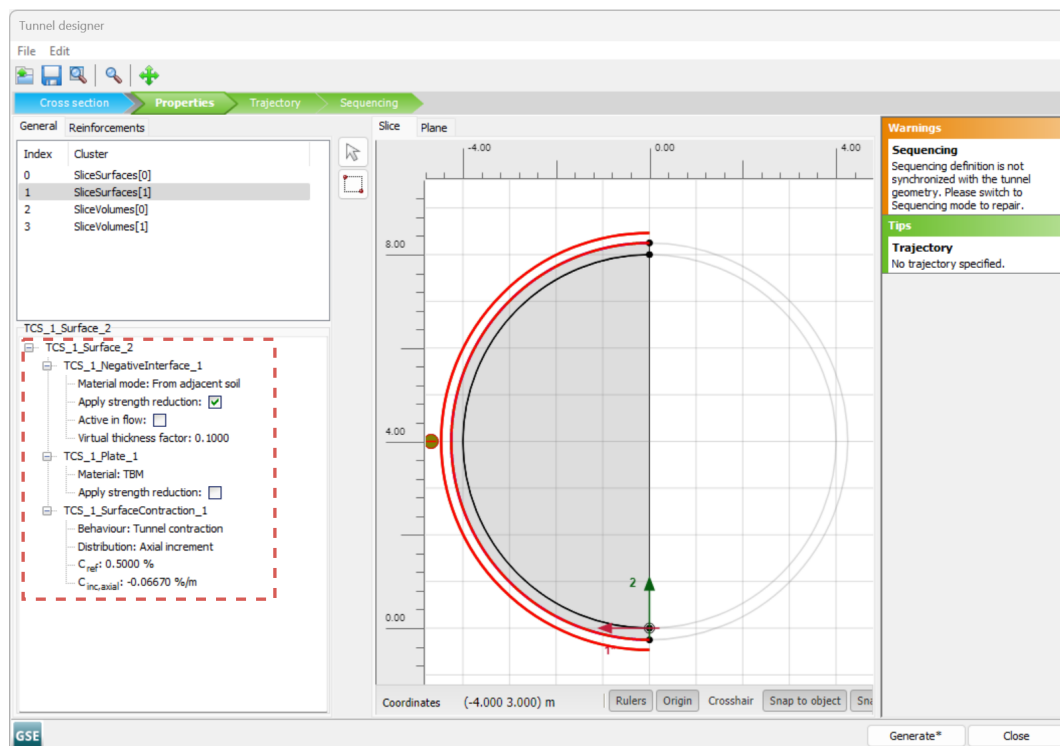


Figure 5–8: Created negative interface and surface contraction on the tunnel outer slice surface

5.6.2.3 | Grout pressure

The surface load representing the grout pressure is constant during the building process. In the specifications of the tunnel boring process, it is given that the grout pressure should be -100 kN/m^2 at the top of the tunnel ($z = -4.75 \text{ m}$) and should increase with $-20 \text{ kN/m}^2 / \text{m}$ depth. To define the grout pressure:

- 1 Click on the **Slice** tab.
- 2 Right-click on the outer slice surface and select **Create > Create surface load** from the appearing menu to create a surface load around the entire tunnel.
- 3 In the **Selection explorer** of the tunnel designer, from the drop-down menu select **Surface load > Distribution > Perpendicular, vertical increment**.
- 4 As shown in [Figure 5–9 \(p. 92\)](#) define:
 - a. $\sigma_{n,ref}$ to -100 and $\sigma_{n,inc}$ to -20 .
 - b. $(0 \ 0 \ -4.75)$ as the reference point for the load by assigning the values to x_{ref} , y_{ref} and z_{ref} .

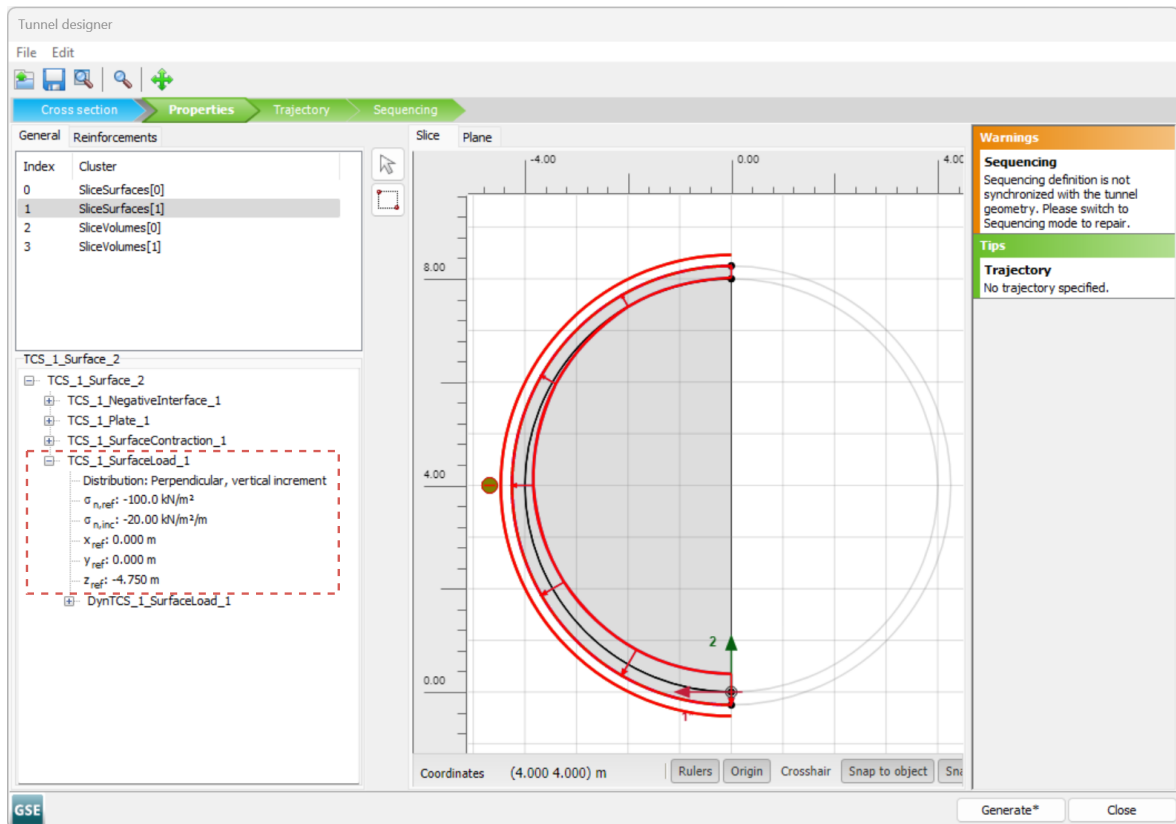


Figure 5–9: Slice tab Tunnel designer - Grout pressure definition

5.6.2.4 | Tunnel face pressures

The tunnel face pressure is a bentonite pressure (Bentonite Slurry, BS) or an earth pressure (Earth Pressure Balance, EPB) that increases linearly with depth. For the initial position of the TBM and the successive four positions when simulating the advancement of the TBM, a tunnel face pressure has to be defined.

- 1 Click on the **Plane** tab located above the Display area with the tunnel cross section.
- 2 Select both face surfaces (see [Figure 5-10 \(p. 93\)](#)), followed by pressing right click. Then from the appearing menu select **Create** > **Create surface load** to create a surface load on the TBM face.
- 3 In the **Selection explorer** go to **Selection** > **Surface Load** and from the drop-down menu select **Distribution** > **Perpendicular, vertical increment**.
- 4 As shown in [Figure 5-10 \(p. 93\)](#) set:
 - a. $\sigma_{n,ref}$ to -90 kN/m^2 and $\sigma_{n,inc}$ to $-14 \text{ kN/m}^2/\text{m}$.
 - b. (0 0 -4.75) as the reference point for the load by assigning the values to x_{ref} , y_{ref} and z_{ref} .

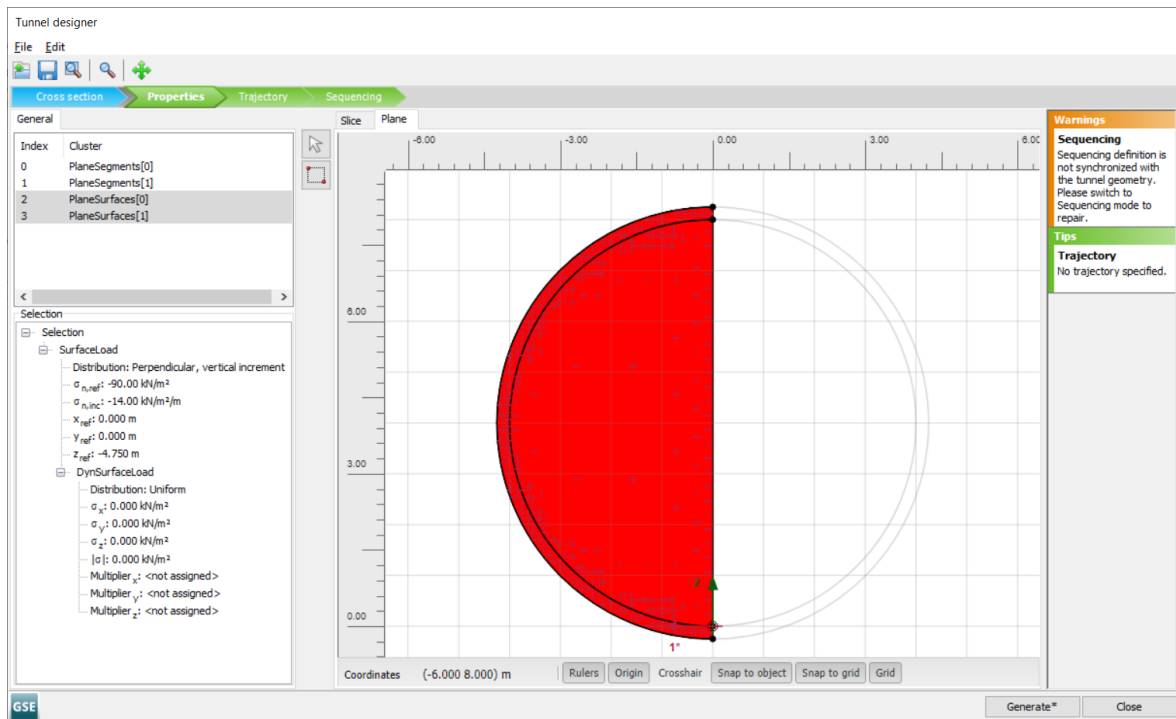


Figure 5-10: *Plane* tab Tunnel designer - Definition of TBM face pressure

5.6.2.5 | Jack forces

Note:

In order to move forward during the boring process, the TBM has to push itself against the existing tunnel lining. This is done by hydraulic jacks. The force applied by the jacks on the final tunnel lining has to be taken into account. This will be assigned to the tunnel lining in the <Step_1_7> of the tunnel [5.6.4 Sequencing](#) (p. 95).

5.6.3 | Trajectory

The next step is to create the path of the boring process. As mentioned before, the TBM already advanced 25m into the soil and then proceeds from 25m to 41.5m excavating slices of 1.5m each:

- 1 Click on the **Trajectory** tabsheet to proceed to the corresponding window.
- 2  In the **Segments** tab, click on the **Add segment** on the left toolbar to create the first segment.
- 3 In the **Selection explorer** set the length to 25 (see [Figure 5-11](#) (p. 94)).

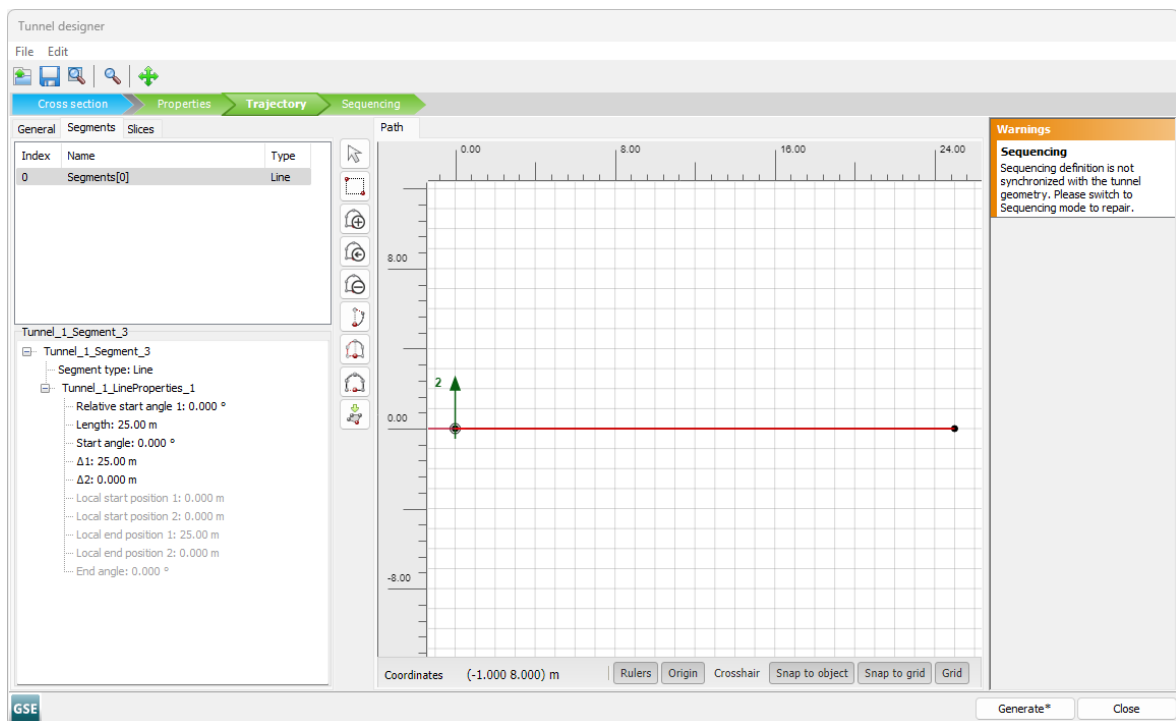


Figure 5-11: Trajectory tabsheet on Tunnel designer-Adding a trajectory segment

- 4  Add a second segment and set the *length* to 16.5.
- 5 Go to the **Slices** tab to create the tunnel slices till 41.5 m. Selected the created second segment.
- 6 In the **Selection explorer**, go to the **Slicing method**, chose *Length* and set the **Slice length** as 1.5m ([Figure 5-12](#) (p. 95)).

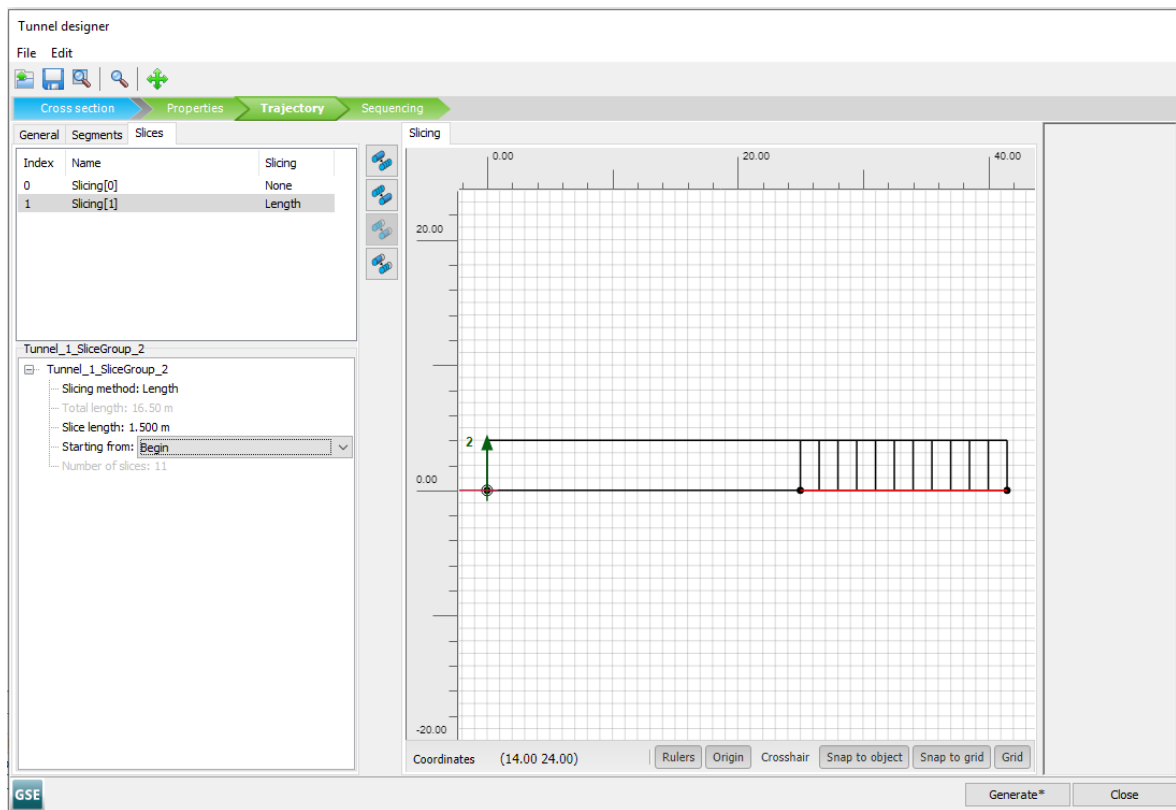


Figure 5–12: *Trajectory* tabsheet of tunnel designer-Slicing a trajectory segment

5.6.4 | Sequencing

In order to simplify the definition of the phases in the **Staged construction** mode, the sequencing of the tunnel is defined. The soil in front of the TBM will be excavated, a support pressure will be applied to the tunnel face, the TBM shield will be activated and the conicity of the shield will be modelled. Then at the back of the TBM, the pressure due to the grouting will be modelled. Subsequently, given that it is also required to model a driving force applied by hydraulic jacks on the already installed TBM lining. Finally, a new lining ring will be placed.

- 1 Click on the **Sequencing** tabsheet to proceed to the corresponding window.
- 2 In the **Sequencing** tabsheet, under the **General** submenu set the **Excavation method** as **TBM**.

a. Step_1_1 **Face excavation**

- Click on the **Slice** tab. Notice that below the **General** submenu a first step (i.e., **Step_1_1**) is now available by default.
- Select the volumes inside the tunnel and in the **Selection explorer**, deactivate the soil volumes and set the **WaterConditions** to **Dry** as displayed in [Figure 5–13 \(p. 96\)](#) .

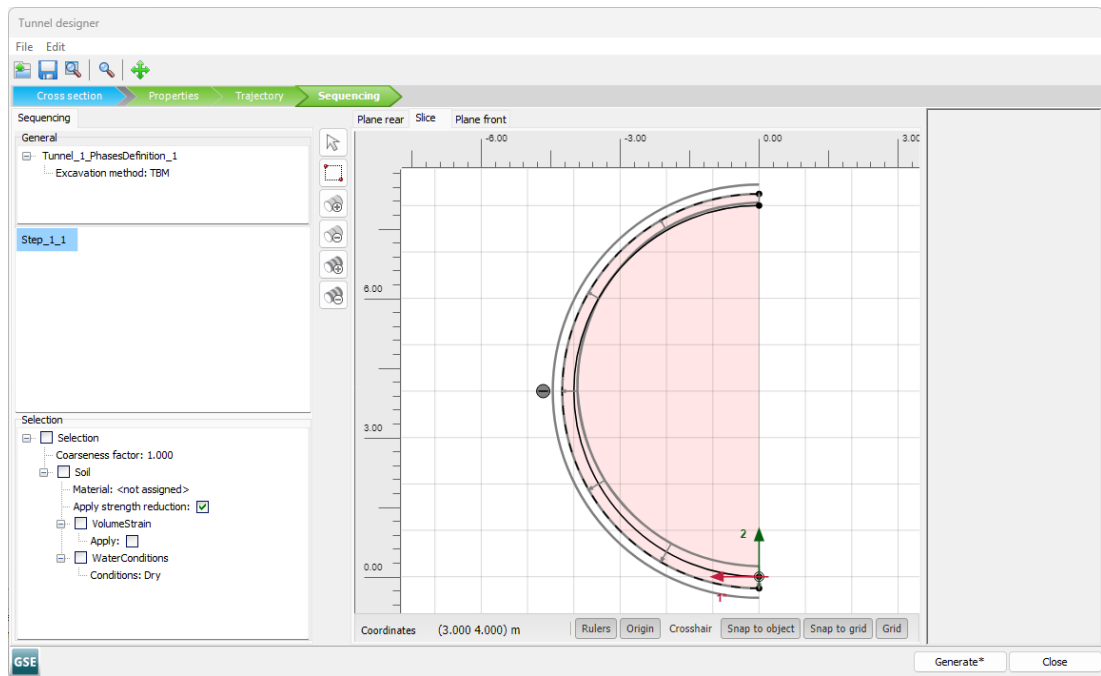
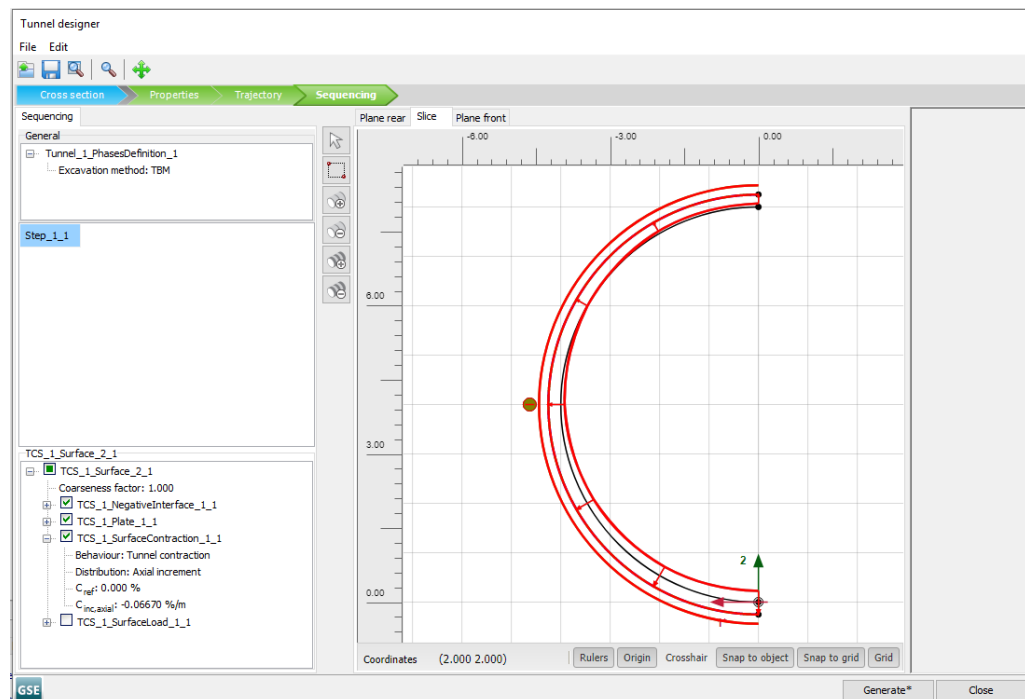


Figure 5–13: Slice from the face excavation - Deactivated soil volumes

- Staying on the **Slice** tab, select the outer surface (shield). Then, go to the **Selection explorer** and activate: the negative interface, the plate and the surface contraction (Figure 5–14 (p. 96)).
- For the surface contraction C_{ref} set a value of 0% (since this is on the front of the excavation).



**Figure 5–14: Slice tab Tunnel designer <Step_1.1>
TBM activation and definition of surface contraction**

- Click on the **Plane Front** tab and select all the surfaces (front TBM). In the **Selection Explorer**, activate the **Surface load** corresponding to the TBM face pressure ([Figure 5-15 \(p. 97\)](#)).

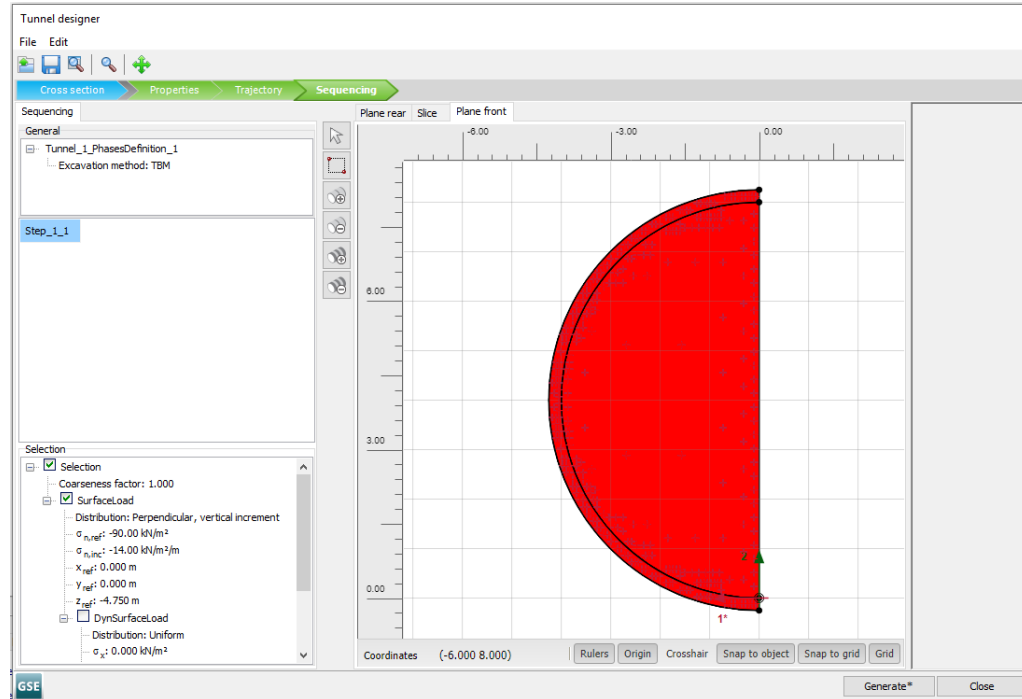


Figure 5-15: Plane front tab Tunnel designer- <Step_1_1> Definition of face pressure

Note: If the face pressures were correctly applied, by unselecting the front surfaces the markers (representing those pressures) will appear colored.

b. **Step_1_2** *TBM with conicity*

- Continue in the **Plane front** tab.
-  Click on the **Add Step** button to add a new step.

Note: The difference with the previous step is that the load corresponding to face pressure gets deactivated by default (Face pressures are only considered in the front of the TBM).

- Go to the **Slice** tab, select the outer surface and set $C_{ref} = 0.1\%$, see [Figure 5-16 \(p. 98\)](#).

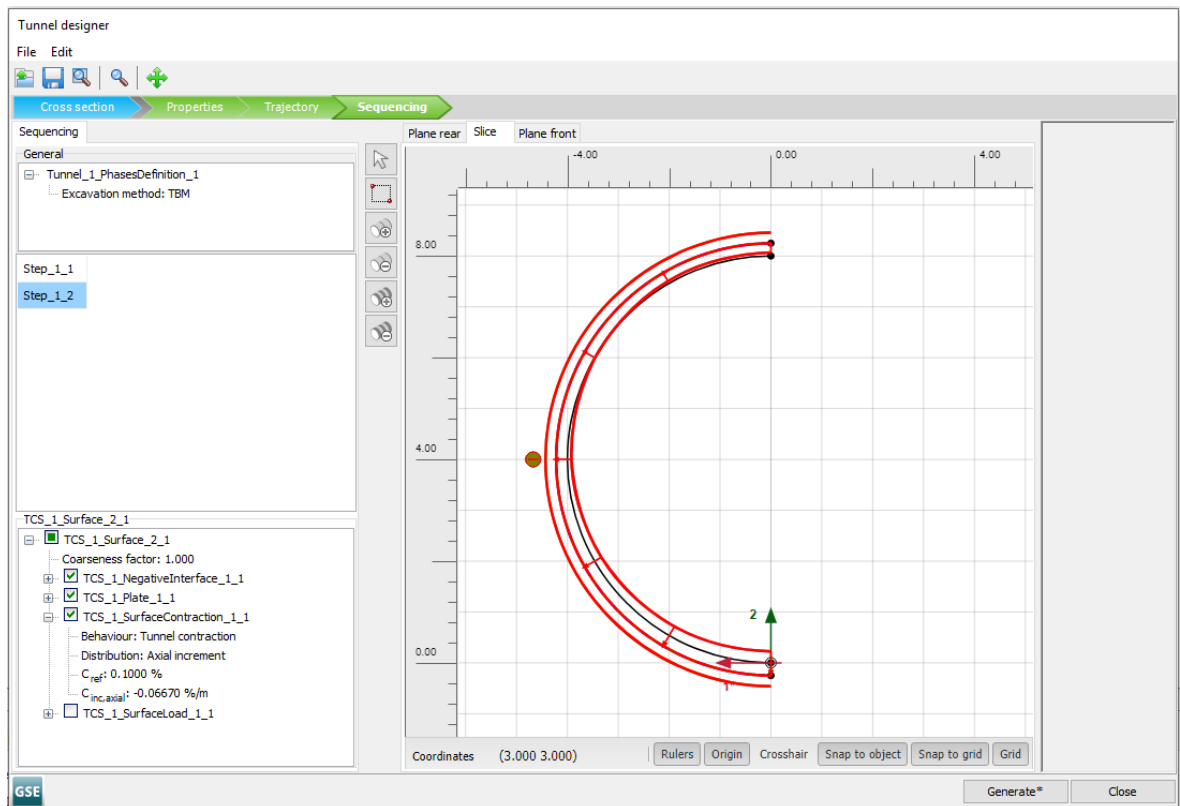


Figure 5-16: Slice tab Tunnel designer - <Step_1_2>Definition of Surface contraction

c. **Step_1_3 to Step_1_5** *TBM with conicity*

-  Click on the **Add Step** button three times to add three new steps. These steps are necessary to define the remaining cone part of the TBM shield ([Figure 5-17 \(p. 99\)](#)).
- For each step verify the **Slice** tab is chosen, select the outer surface and in the **Selection explorer** set the following values for the surface contraction:
 Step_1_3: $C_{ref} = 0.2\%$
 Step_1_4: $C_{ref} = 0.3\%$
 Step_1_5: $C_{ref} = 0.4\%$, see [Figure 5-17 \(p. 99\)](#)

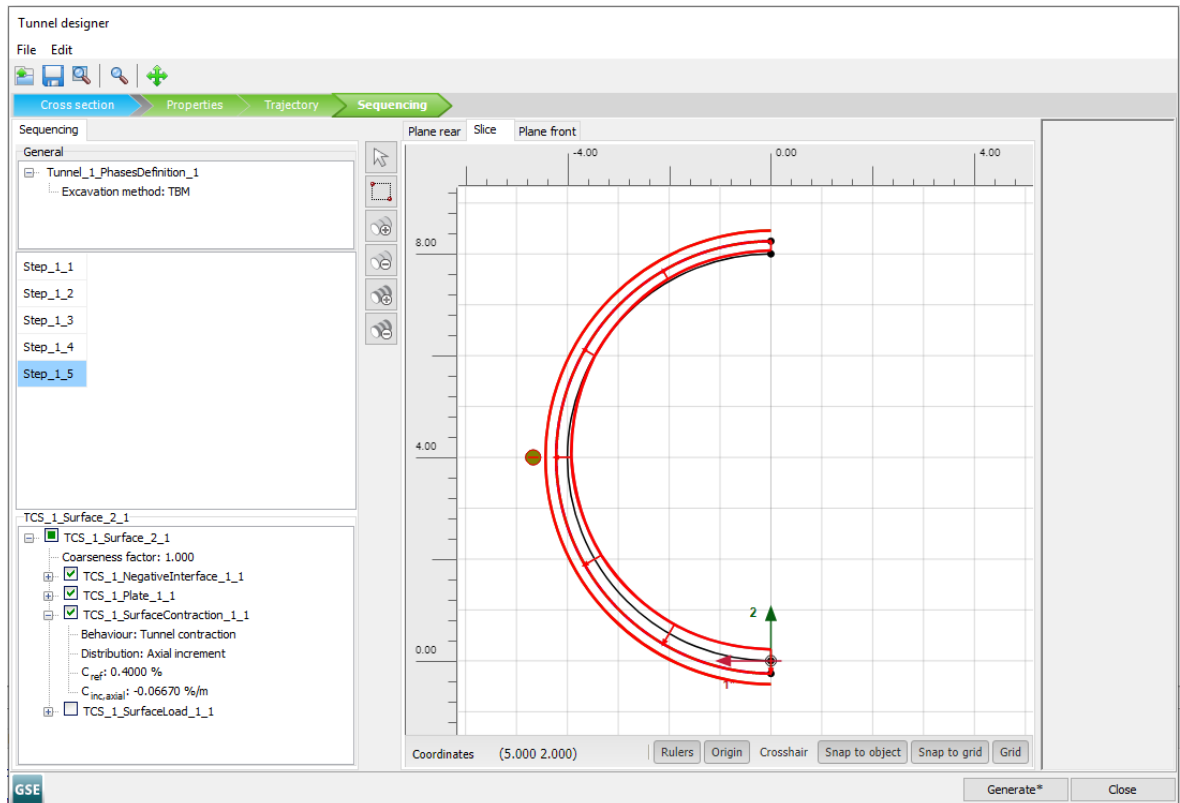


Figure 5-17: Slice tab Tunnel designer <Step_1_3 to Step_1_5>Definition of surface contraction

d. **Step_1_6** *Tail of the shield*

- Click on the **Add Step** button.
- The last slice of the shield has a constant diameter. From the **Slice** tab select the outer surface.
- In the **Selection explorer** select the **Surface contraction** > **Distribution** > **Uniform** option with $C_{ref} = 0.5\%$ (Figure 5–18 (p. 100)).

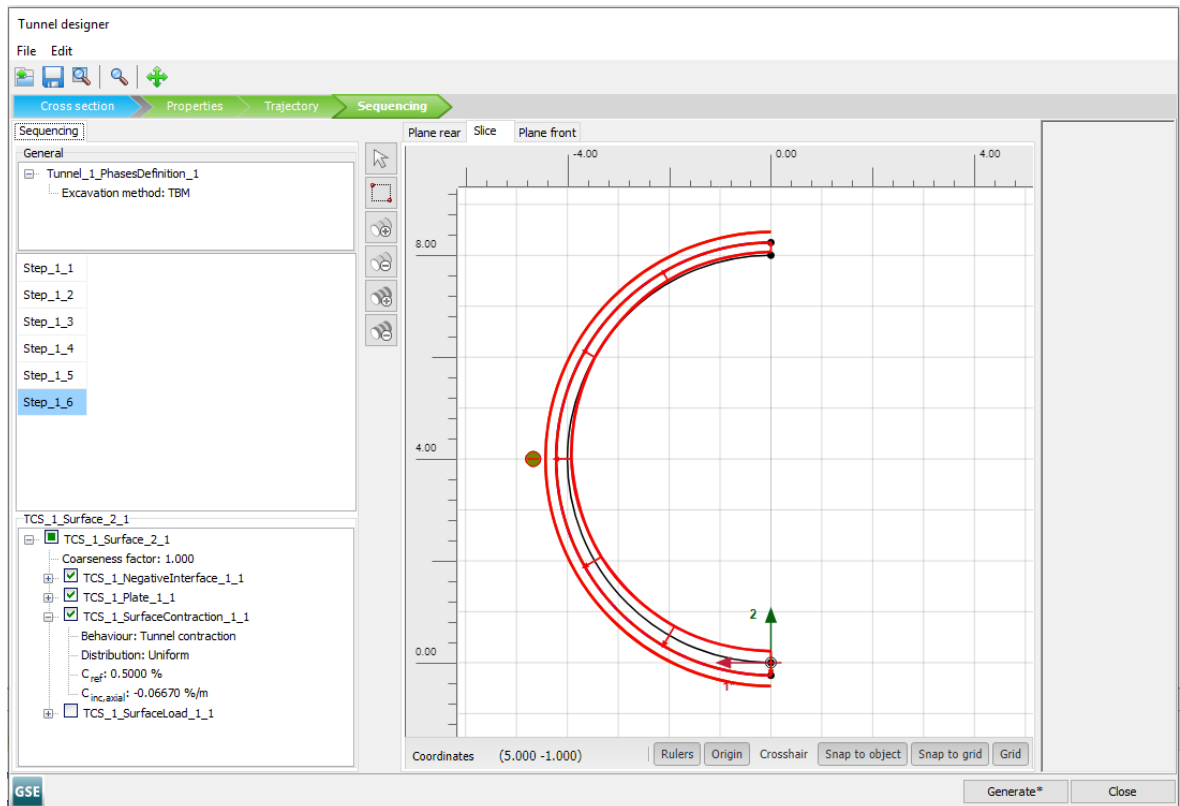


Figure 5–18: *Slice* tab Tunnel designer <Step_1_6> Definition of surface contraction

e. **Step_1_7** *Grouting and jack thrusting*

In order to move forward during the boring process, the TBM has to push itself against the existing tunnel lining. This is done by hydraulic jacks. The force applied by the jacks on the final tunnel lining has to be taken into account. Also the grout pressure is applied.

- Click on the **Add Step** button.
- From the **Slice** tab select the outer surface.
- Deactivate the negative interface, the plate and the surface contraction.
- In the **Selection explorer**, activate the **Surface load** corresponding to the *grout pressure* (see Figure 5–19 (p. 101)).

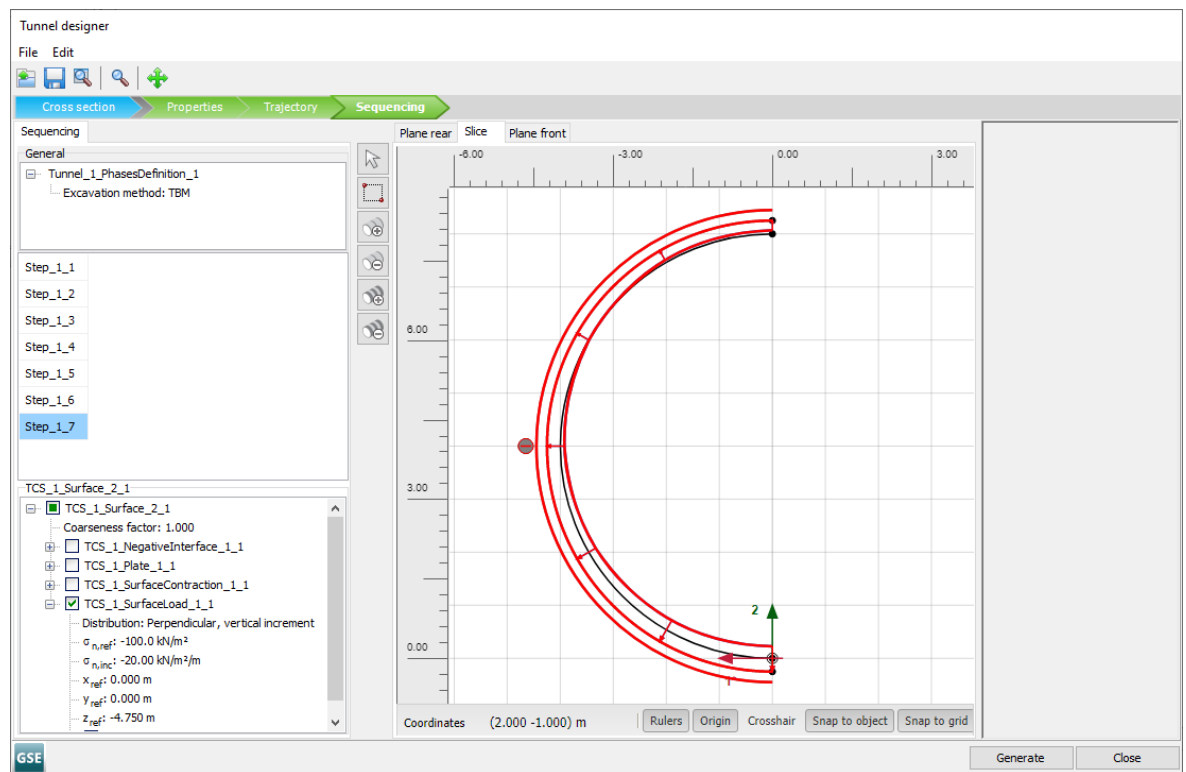


Figure 5–19: Slice tab Tunnel Designer <Step_1_7> Grout pressure TBM

- Click on the **Plane rear** tab and select the outerrear-plane surface (i.e, the created thick lining) to define the jack thrusting against the final lining.
- In the **Selection explorer**, activate the **Surface load** and select the *Perpendicular* option for the distribution with $\sigma_{n,ref} = 635.4 \text{ kN/m}^2$ (Figure 5–20 (p. 101)).

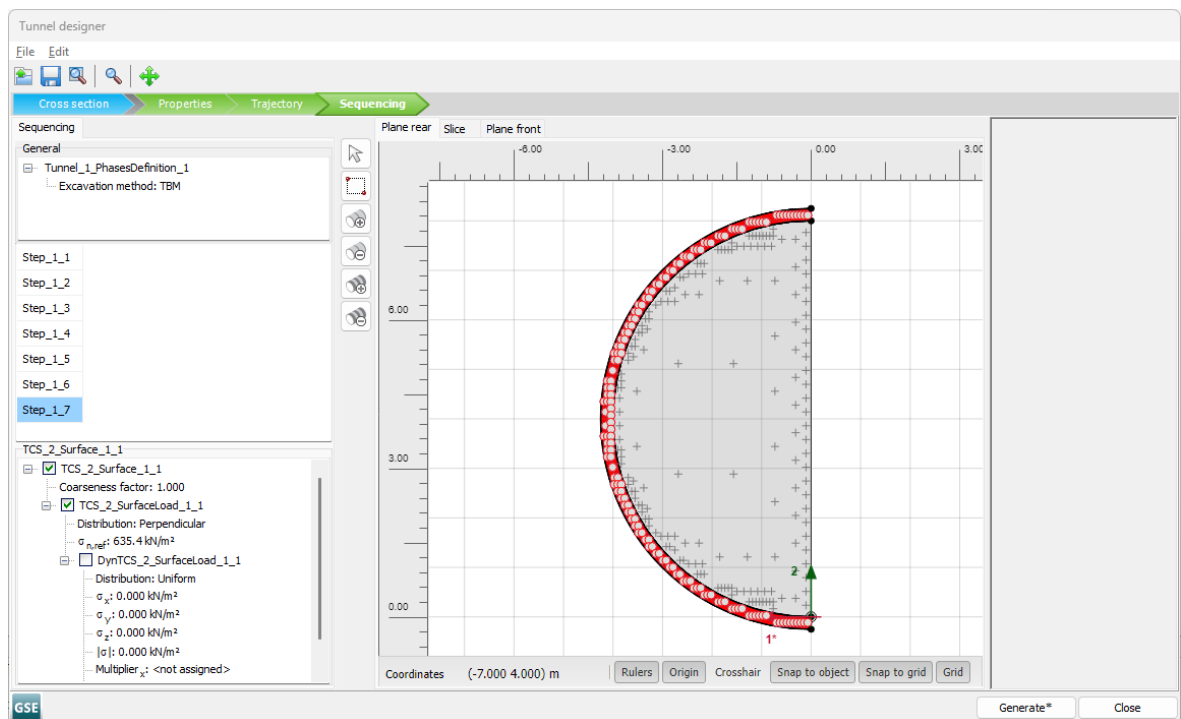


Figure 5–20: Plane Rear tabsheet Tunnel designer <Step_1_7> Application of jack forces

f. **Step_1_8** *Final lining*

- Click on the **Add Step** button.
- Go to the **Slice** tab and select the 0.25m outer surface.
- In the **Selection explorer**, deactivate the surface load corresponding to grout pressure and activate the negative interface.
- Continuing in the **Slice** tab, select the outer volume (or lining). Activate it, then in the **Selection explorer** click on the **Material** drop-down list and select the *Concrete* option (Figure).

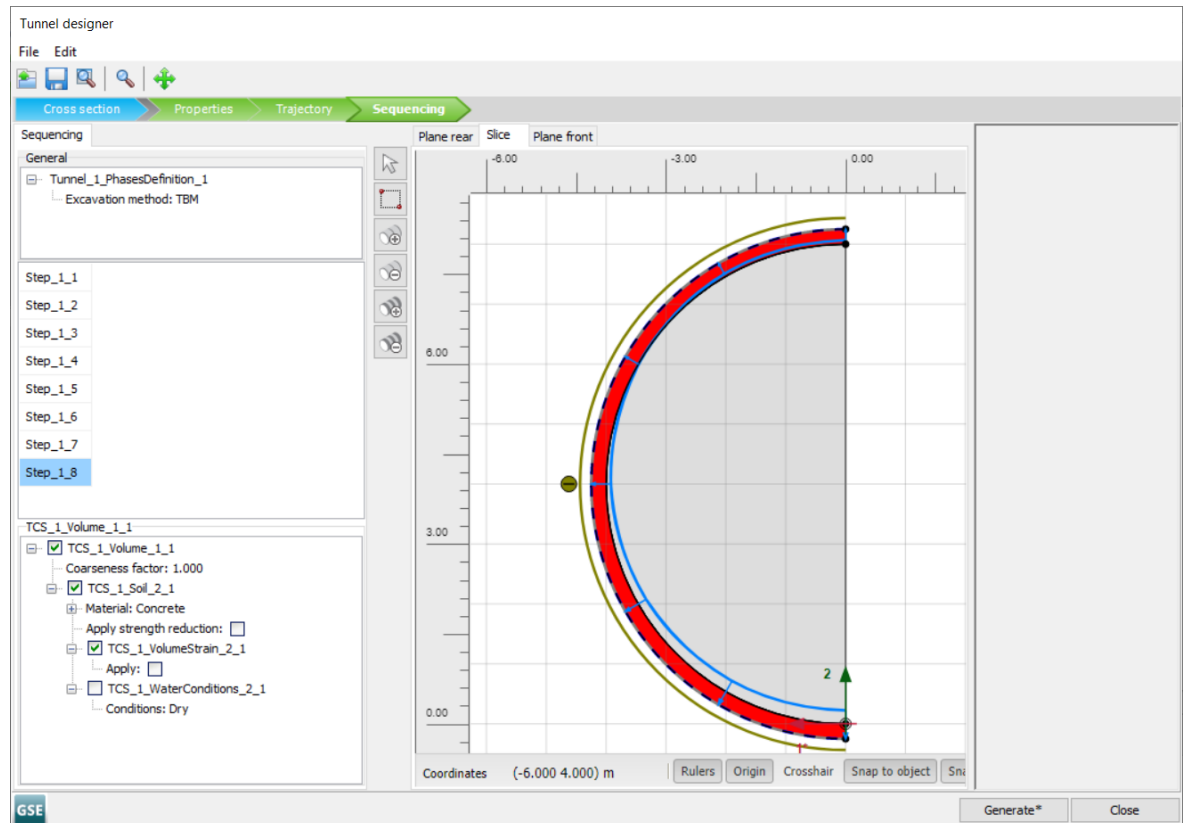


Figure 5–21: Slice tab Tunnel designer <Step_1_8> Material definition for final lining

- Click on the **Plane rear** tab and select the rear outer plane surface (or back area of the lining).
- In the **Selection explorer**, deactivate the surface load corresponding to the thrusting jacks (Figure 5–22 (p. 103)).

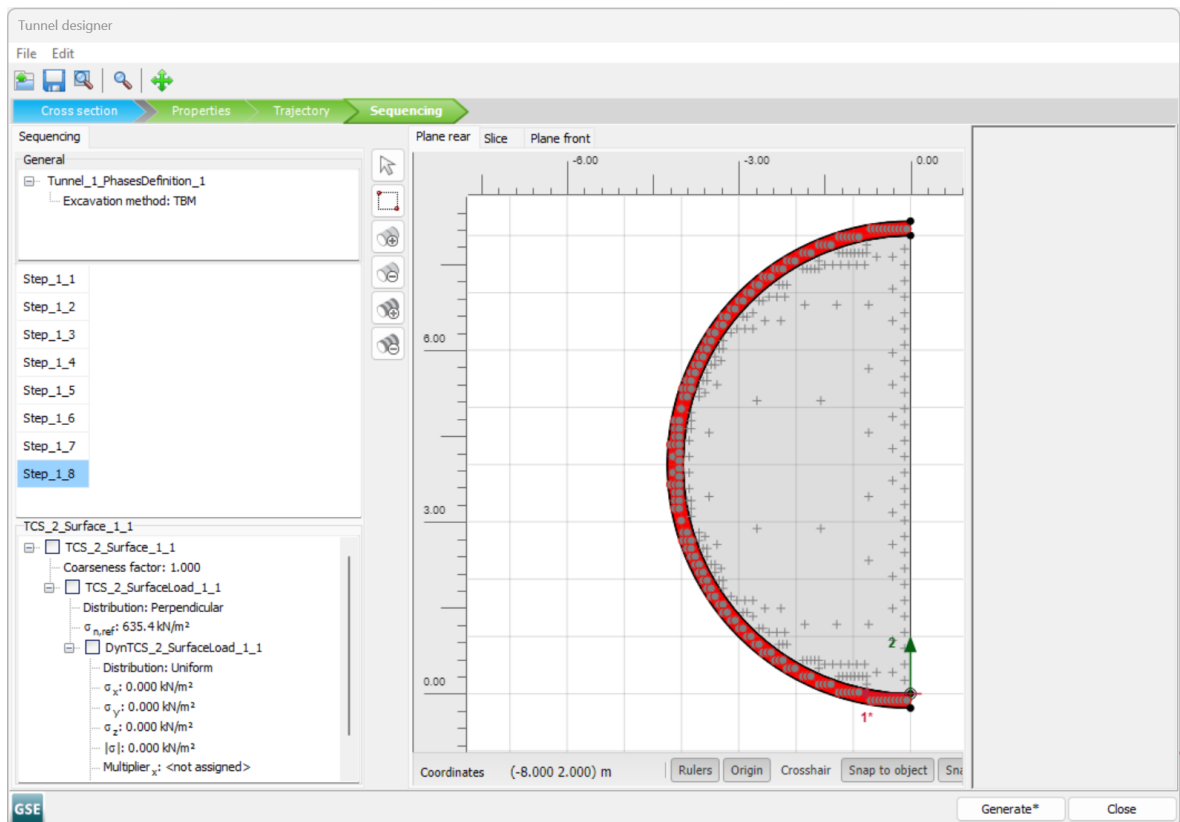


Figure 5–22: Plane rear tab Tunnel designer <Step_1_8> Deactivation of jacks forces

Note: For the steps *Step1_1* to *Step1_5* keep in mind that the contraction increment $C_{inc,axial}$ has to be -0.0667%.

- 3 Click on **Generate** to include the defined tunnel in the model.
- 4 Close the **Tunnel designer** window.

>The model is created in the **Structures mode**. Click on the **Options** menu and then select **Show local axes on surfaces with structures** this is shown on [Figure 5–23 \(p. 104\)](#).

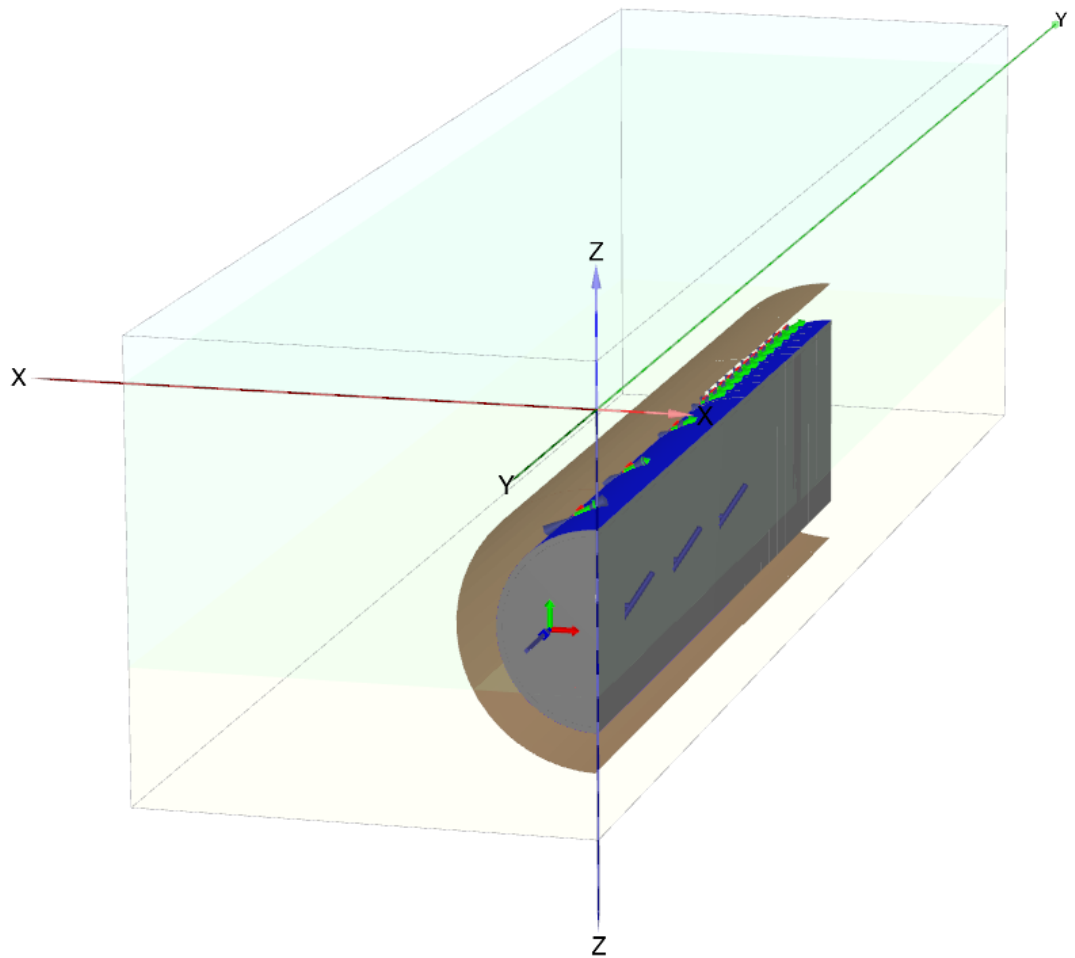


Figure 5–23: The created tunnels with local axes in the Structures mode

Note:

It is possible to edit the tunnel after being generated. To do this, in the **Structures** mode go to the **Model Explorer**, expand the *Tunnels tree*, do right click on the tunnel of interest, and from the pop up menu select the **Edit** option.

5.7 | Generate the mesh

In the **Mesh mode** it is possible to specify global and local refinements and generate the mesh. The default local refinements are valid for this example.

- 1  Click the **Generate mesh** button in order to generate the mesh. The **Mesh options** window appears.
 - The default option (*Medium*) will be used to generate the mesh.
- 2  Click the **View mesh** button to inspect the generated mesh ([Figure 5–24 \(p. 105\)](#)).

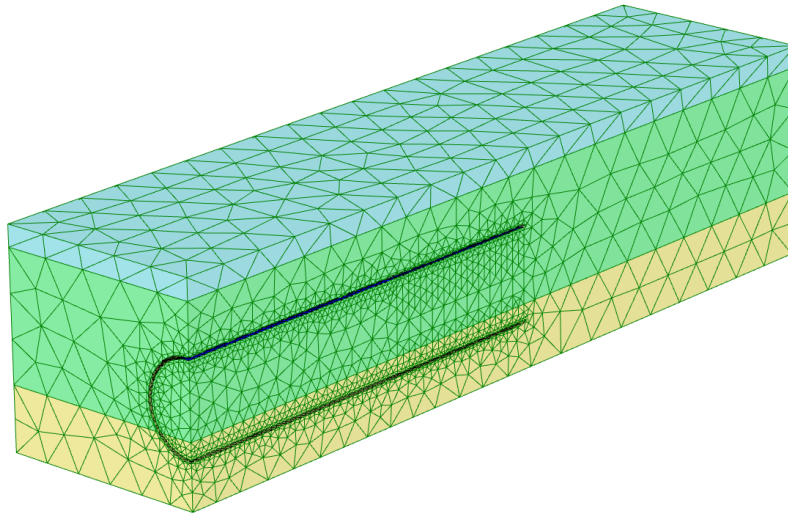


Figure 5–24: The generated mesh

After inspecting the mesh, the output window can be closed. Mesh generation has now been finished, and so creating all necessary input for defining the calculation phases has been finished.

5.8 | Define and perform the calculation

The excavation of the soil and the construction of the tunnel lining will be modelled in the **Staged construction** mode. Since water levels will remain constant the **Flow conditions** mode can be skipped. It should be noted that due to the mesh generation the tunnel effectively has been split into an upper part, located in the clay, and a lower part located in the stiff sand. As a result, both the lower and the upper part of the tunnel should be considered.

The first phase differs from the following phases, as in this phase the tunnel is activated for the first time. This phase will model a tunnel that has already advanced 25 m into the soil. Subsequent phases will model an advancement by 1.5 m each.

5.8.1 | Initial phase

The initial phase consists of the generation of the initial stresses using the K_0 procedure. The default settings for the initial phase are valid.

From the Menu toolbar select **View > Default views > Right view** to reorientate the model and obtain a clearer perspective of the of the tunnel as displayed in [Figure 5–25 \(p. 106\)](#).

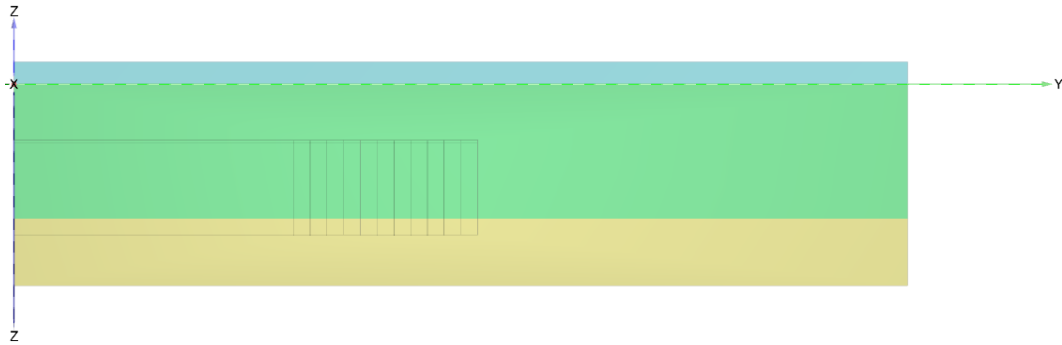


Figure 5-25: Pre-excavated Tunnel contour

5.8.2 | Phase 1: Initial position of the TBM

In the first phase, it is assumed that the TBM has already advanced 25 m. The section next to the first 25 m (section 25 m - 26.5 m) will represent the area directly behind the TBM where grout is injected in the tail void. In the next 6 sections (26.5 m - 35.5 m) the TBM will be modelled.

1. Add the first calculation phase
2. In the **Model explorer** expand *Tunnels* and then expand *Tunnel_1*. Scroll down until the option **Advancement step** and set it to 7 in order to simulate the advancement of the first 25 m. Notice that the final lining is automatically activated (see [Figure 5-26 \(p. 106\)](#)).

Note:

An Advancement step with a value of -1 represents the soil without tunnel excavation (Initial phase). In turn, for this tutorial, the Advancement step 7 represents the position of the rear of the TBM at 25 m; in this position the jack forces will be applied on the ring lining installed between 23.5-25 m).

From the Advancement step 8, the front of the TBM will advance another 1.5 m, leaving a new 1.5m lining ring installed(between 25 - 26.5 m) next to the rear of the TBM.

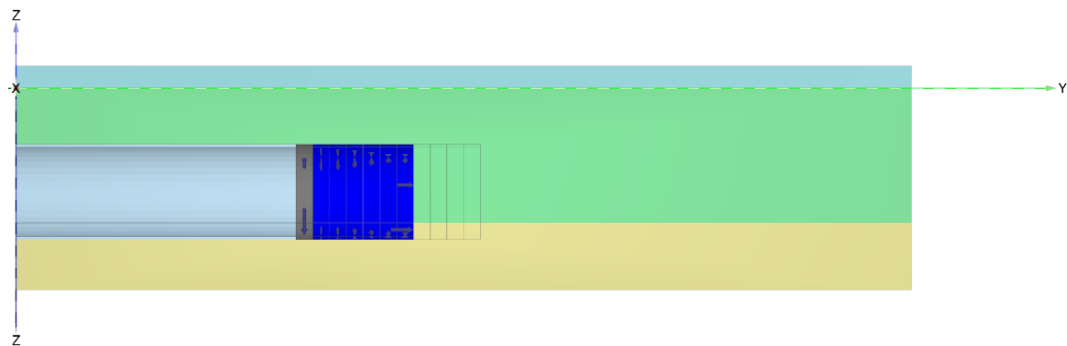


Figure 5-26: Advancement tunnel after the first 25m

3. In order to consider the conicity of the TBM for the first 25 m, it is necessary to: deactivate the final lining clusters, activate the plates representing the TBM, and apply a surface contraction of 0.5%.

- a. In the drawing area select the soil volumes representing the final lining of the first 25 m of tunnel and deactivate them ([Figure 5-27 \(p. 107\)](#))

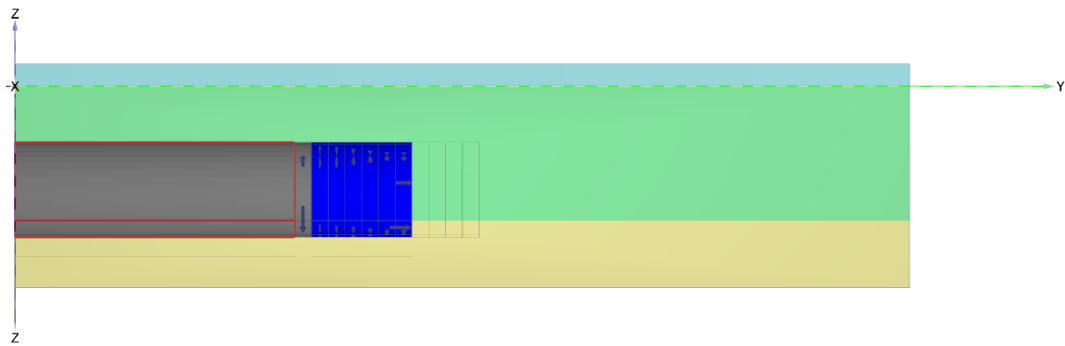


Figure 5-27: Deactivated soil volumes corresponding to final lining (0 m - 25 m), wireframe view

Notice that the lining is switched off, but the wireframe representing the deactivated volume is still coloured red as the deactivated lining is still selected.

Note: An object that is deactivated will automatically be hidden as a volume or surface, but a wireframe representing the hidden object will remain. The visibility of a non-active object can be adjusted in the **Visualization settings** window (see [Reference Manual- Modifying the display settings.](#))

- 4 Select the outer tunnel surfaces between 0 m and 25 m (inside the wireframe lines) as shown in [Figure 5-28 \(p. 107\)](#).

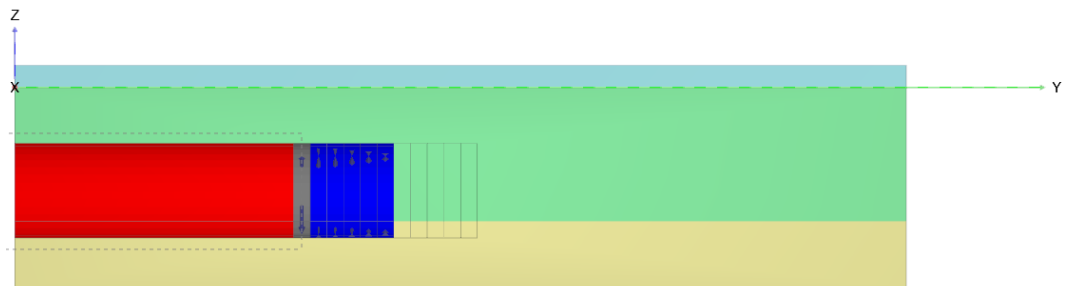


Figure 5-28: Selection of plate (0 m - 25 m)

- 5 In the **Selection explorer**:
 - a. Check that the interface around the tunnel is activated. Notice that this is done by default.

Tip: If necessary, for a better visualisation of the active interfaces hide the clay and sand soil volumes.

- b. Activate the **Plate** and the **Surface Contraction** by clicking on the corresponding check boxes (see [Figure 5-29 \(p. 108\)](#)).

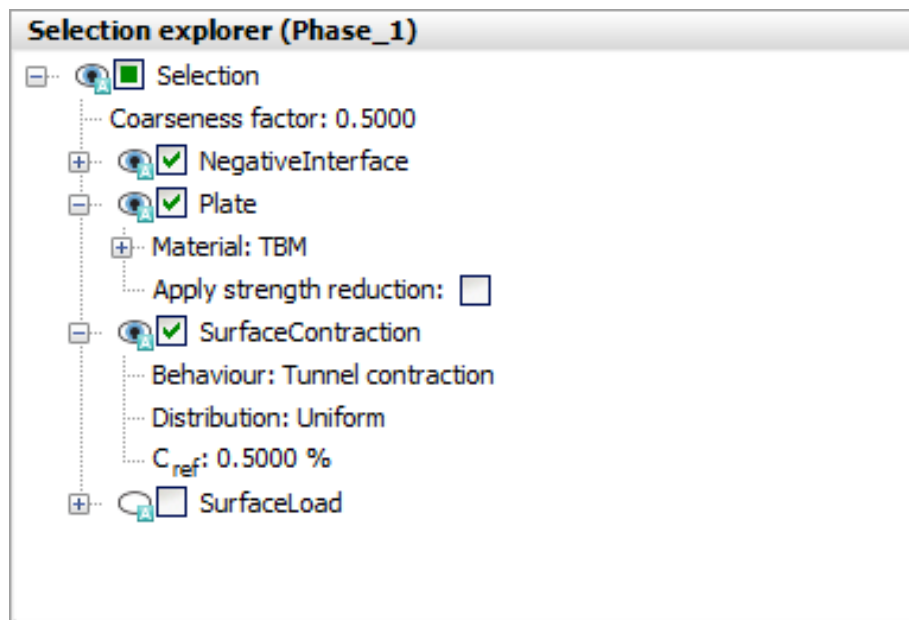


Figure 5–29: Phase 1 - Activation of plate and surface contraction in the tunnel 0 - 25 m

- 6 In the drawing area select the lateral surfaces the rear of the TBM lining as displayed in [Figure 88](#). Then in the **Selection explorer**, deactivate the **Surface load** by deselecting the corresponding check box.

Note:

Notice that this done because the TBM is only placed in this phase and it is not moving, therefore jack thrusting is not taken into account here.

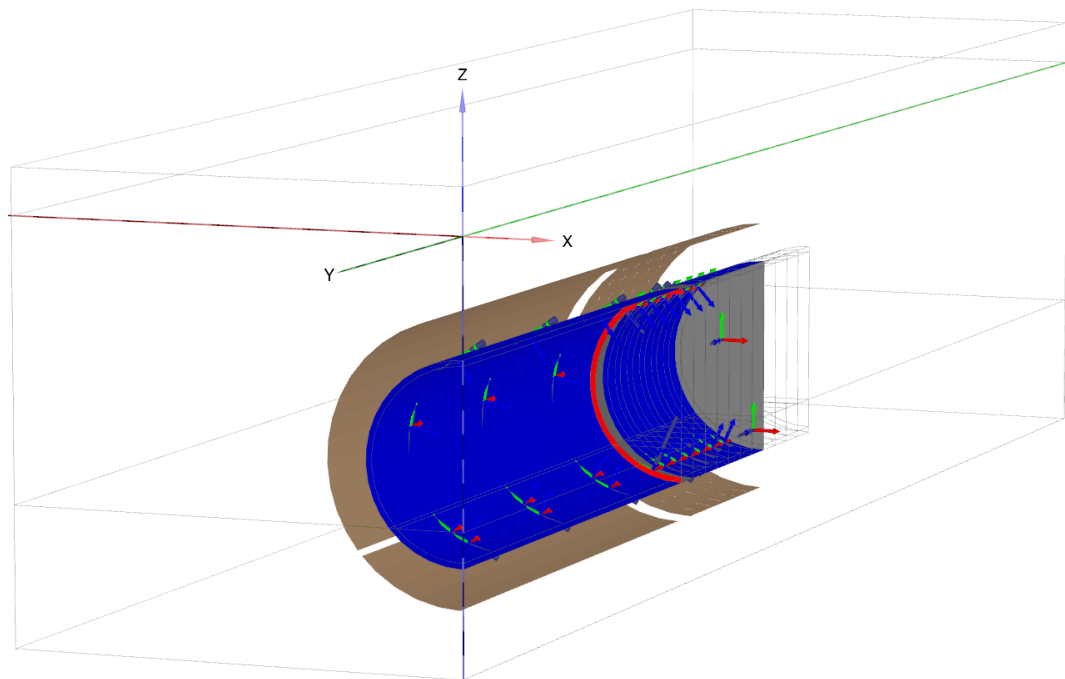


Figure 5–30: Deactivation of jack forces (25.0 m) for non-moving TBM

7

Click the **Preview** button to get a preview of the excavation up to the first 35.5 m ([Figure 5–31 \(p. 109\)](#)). Make sure that both grout pressure and tunnel face pressure are applied and that both increase from top to bottom.

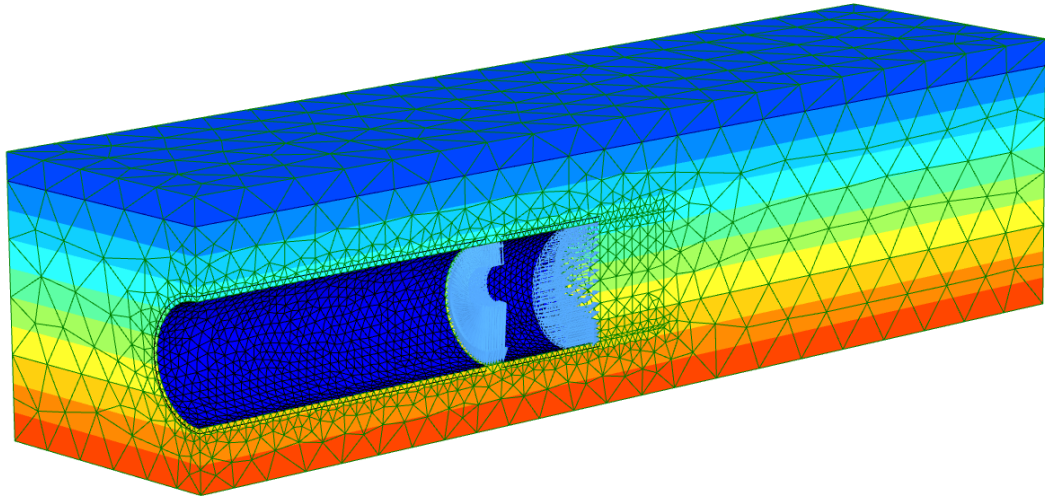


Figure 5–31: Preview of the Phase 1

Note: In the following phase, the final lining will be automatically reactivated.

5.8.3 | Phase 2: TBM advancement 1

In this phase, the advancement of the TBM by 1.5 m (from $y = 35.5$ to $y = 37$) will be modelled.

1

Add a new phase

2

In the **Model explorer** expand *Tunnels* and then expand *Tunnel_1*. Scroll down the *Model explorer* until the option **Advancement step** and set it to 8 in order to simulate the advancement of the first 26.5 m. Alternatively, the Advancement step can be executed as displayed in [Figure 5–32 \(p. 110\)](#).

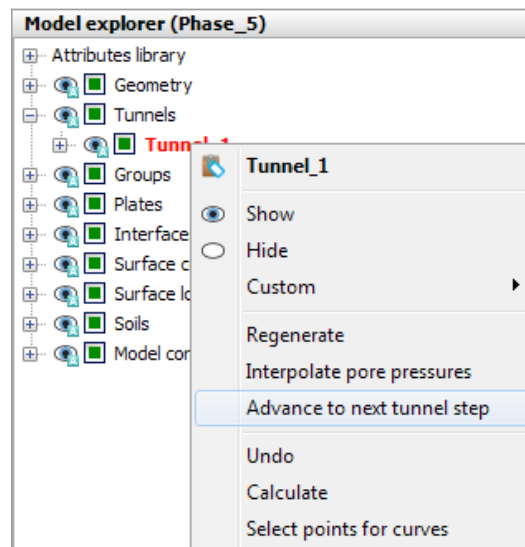


Figure 5–32: The *Advance to next tunnel step* option from *Model explorer*

Note: By default after Advancing to the next tunnel step, the final lining, in the first 25 m, gets reactivated by default while the TBM plate and the surface contraction get automatically deactivated.

At the end of this phase, the TBM will excavate between 35.5 to 37 m (in the front) and a new lining section will be installed at the TBM rear between 25 to 26.5 m (see [Figure 5–33 \(p. 110\)](#)).

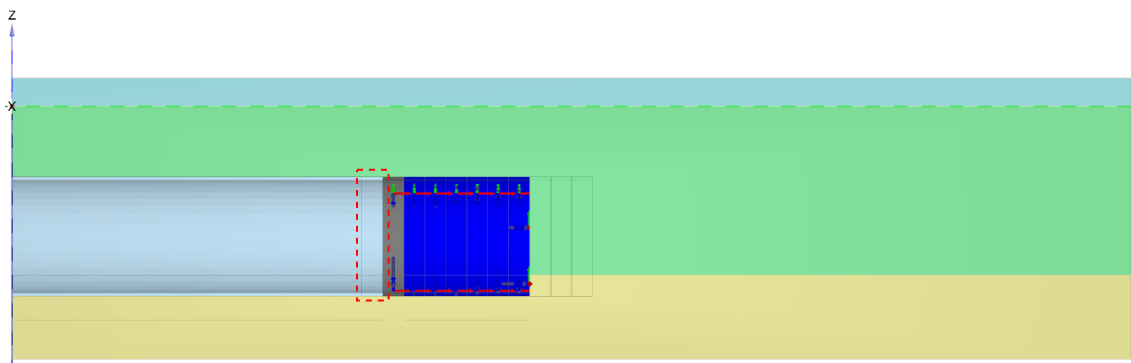


Figure 5–33: TBM advancement 35.5 to 37 m (front) - In the dotted line a new lining ring from 25 - 26.5 m (rear)

5.8.4 | Phase 3: TBM advancement 2

In this phase, the TBM advances from $y = 37$ to $y = 38.5$.

1. Add a new phase
2. In the **Model explorer** expand *Tunnels* and right-click *Tunnel_1*. Then click on **Advance to next tunnel step**.

5.8.5 | Phase 4: TBM advancement 3

In this phase, the TBM advances from $y = 38.5$ to $y = 40$.

- 1  Add a new phase
- 2 In the **Model explorer** expand *Tunnels* and right-click *Tunnel_1*. Then click on **Advance to next tunnel step**.

5.8.6 | Phase 5: TBM advancement 4

In this phase, the final advancement of the TBM is modelled (from $y = 40$ to $y = 41.5$).

- 1  Add a new phase
- 2 In the **Model explorer** expand *Tunnels* and right-click *Tunnel_1*. Then click on **Advance to next tunnel step**.
- 3 Press the **Calculate** button to start the calculation. Ignore the message "No nodes or stress points selected for curves" as no load-displacement curves are drawn in this example, and start the calculation.

5.9 | Results

Once the calculation has been completed, the results can be evaluated in the Output program. In the Output program the displacement and stresses are shown in the full 3D model, but the computational results are also available in tabular form. To view the results for the current analysis, follow these steps:

1. Select the last calculation phase (Phase 5) in the *Phases explorer*
2.  Click the **View calculation results** button. in the side toolbar to open the *Output* program. The Output program will by default show the 3D deformed mesh at the end of the selected calculation phase.
3. From the *Deformations* menu, select *Total displacements* and then u_z in order to see the total vertical displacements in the model as a shaded plot ([Figure 5-34 \(p. 112\)](#)).
4. In order to see the settlements at ground level:
 - Make a horizontal cross section by choosing the *Horizontal cross section* button.
 - In the window that appears fill in a cross section height of 1.95m.
 - In the **View** menu select **View Point > Right view**.
 - In the **Mesh** menu make the **Cluster borders** visible.
 - In the **View** menu select the **Distribution plane** option.

As a result, the window with the cross section is displayed ([Figure 5-35 \(p. 112\)](#)). The maximum settlement at ground level is about 1.9 cm.

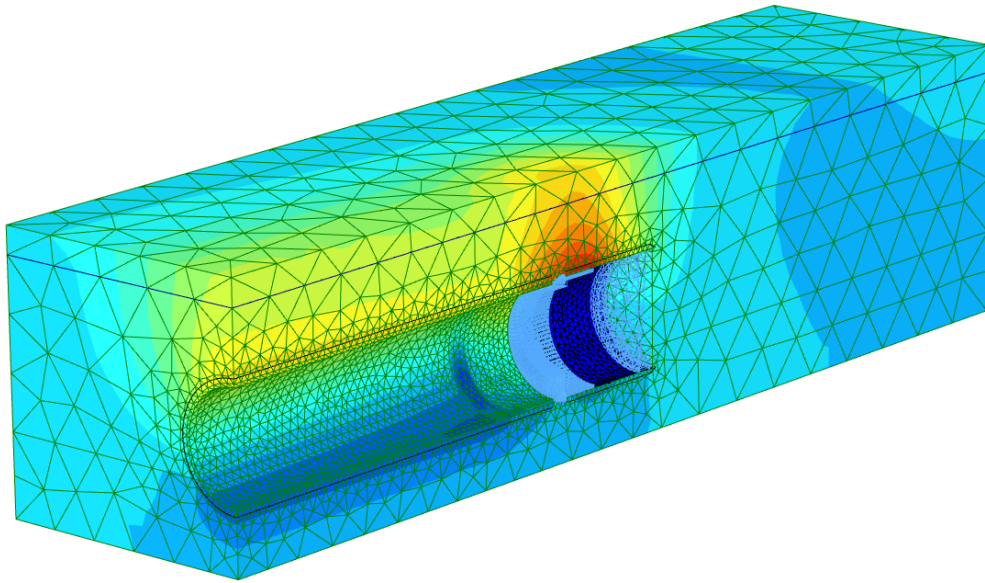


Figure 5–34: Total vertical displacements after the final phase $u_z \approx 3.1\text{cm}$

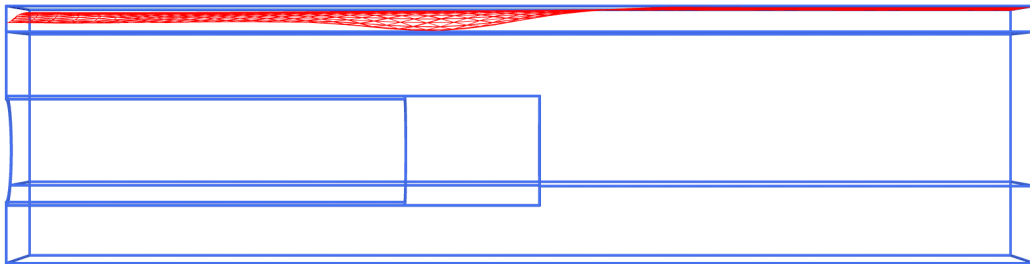


Figure 5–35: Settlement trough at ground level $u_z \approx 1.9\text{cm}$