GTS NX

New eXperience of Geo-Technical analysis System

Construction of Sprayed Concrete Lining Tunnel

MIDAS

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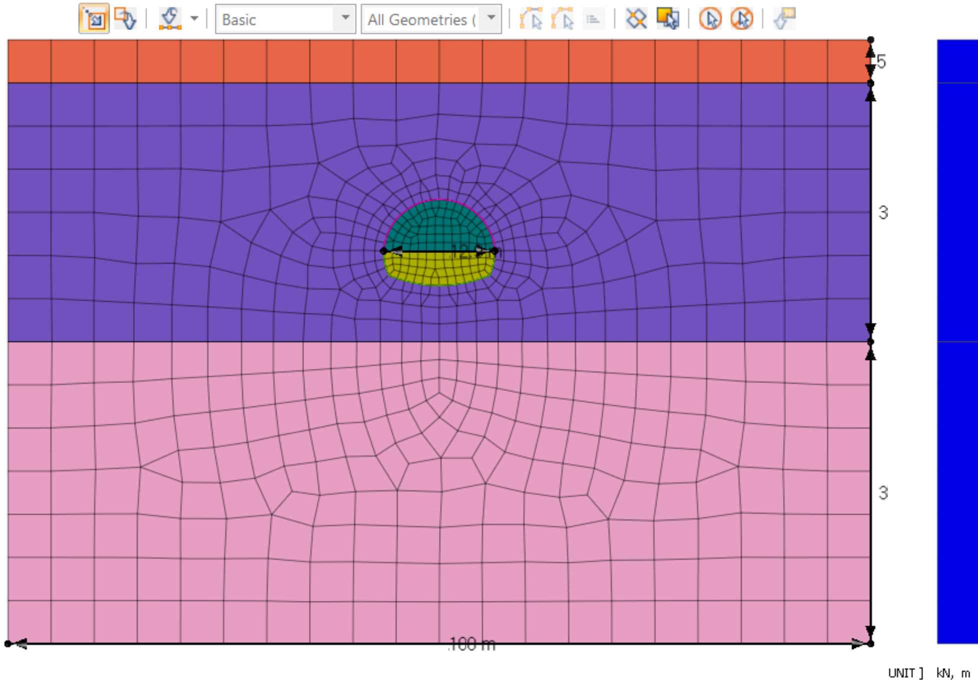
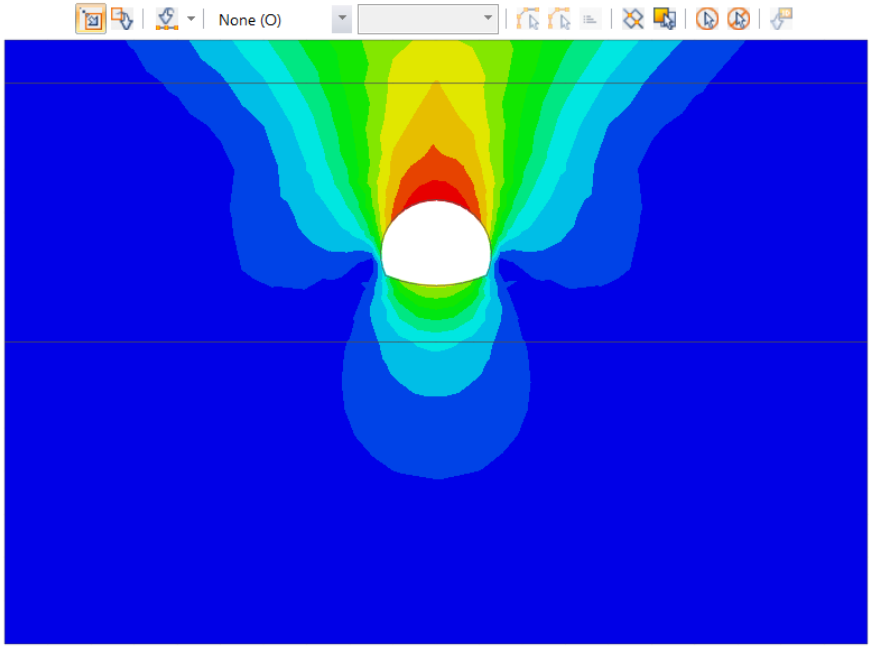
Modelling and Analysis Summary

This tutorial is aiming on performing the 2D analysis of the construction of a Sprayed Concrete Lining (SCL) tunnel. The SCL method is a soft ground application of the New Austrian Tunnelling Method (NATM). Support is provided as soon as possible by the application of sprayed concrete (shotcrete). The objective is to model the construction of a SCL tunnel using the convergence-confinement method to consider the 3D arching effect in 2D model.





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Soil Layers

[unit : kN, m]

Name	Top layer	Siltstone	Sandstone
Material Model	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
General			
Elastic Modulus(E) [kN/m^2]	4e+04	1e+06	2.5e+06
Poisson's Ratio(v)	0.2	0.25	0.25
Unit Weight(γ_t) [kN/m^3]	20	24	23
K0	0.5	0.5	0.5
Groundwater			
Unit Weight(γ_{sat}) [kN/m^3]	22	25	24
Drainage Parameters	Drained	Drained	Drained
Non-Linear			
Cohesion(c) [kN/m^2]	10	30	100
Frictional Angle(Φ) [deg]	30	33	43
Dilatancy Angle(Φ) [deg]	0	0	0
Tensile Strength [kN/m^2]	0	0	0

Structure

[unit : kN, m]

Name	Lining
Material Model	Elastic
Elastic Modulus(E) [kN/m^2]	3e+07
Poisson's Ratio(v)	0.15
Unit Weight(γ) [kN/m^3]	25
Element Type	Beam
Spacing [m]	1
Thickness [m]	0.2

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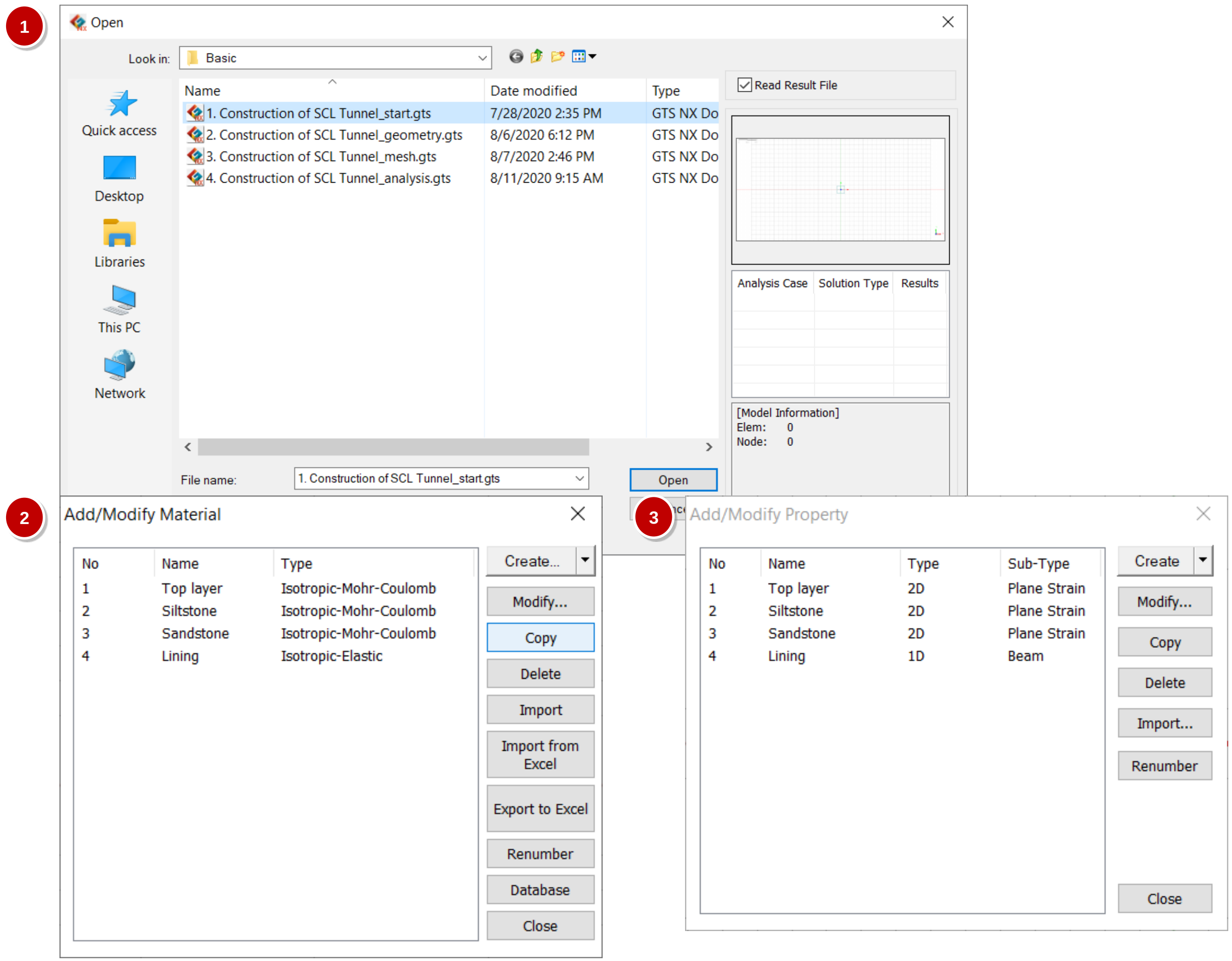
Procedure

Start the tutorial by opening the start file in which the materials and properties have already been predefined.

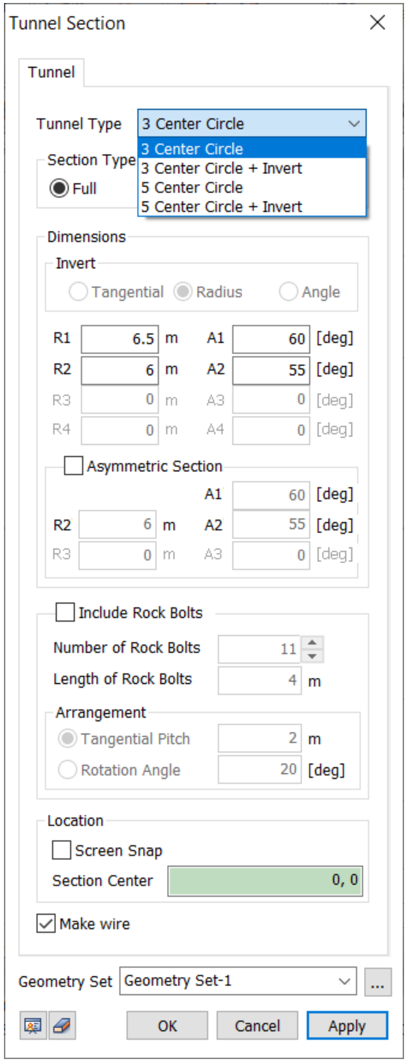
1. **File > Open**
   - Select **'1. Construction of SCL Tunnel_start.gts'**
   - Open

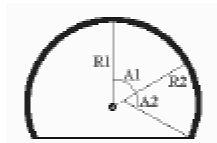
2. **Mesh > Prop./CSys./Func. > Material**
   - Check materials

3. **Mesh > Prop./CSys./Func. > Property**
   - Check properties



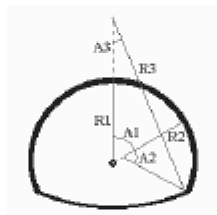
Tunnel section modelling





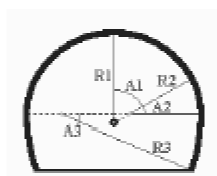
: 3 Center Circle

Create a tunnel using 3 arcs, all with different center points and diameters.



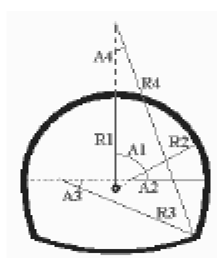
: 3 Center Circle + Invert

Create a tunnel using 3 different arcs and an invert.



: 5 Center Circle

Create a tunnel using 5 arcs, all with different center points and diameters.



: 5 Center Circle + Invert

Create a tunnel using different 5 arcs and an invert.

Procedure

Create a tunnel section.

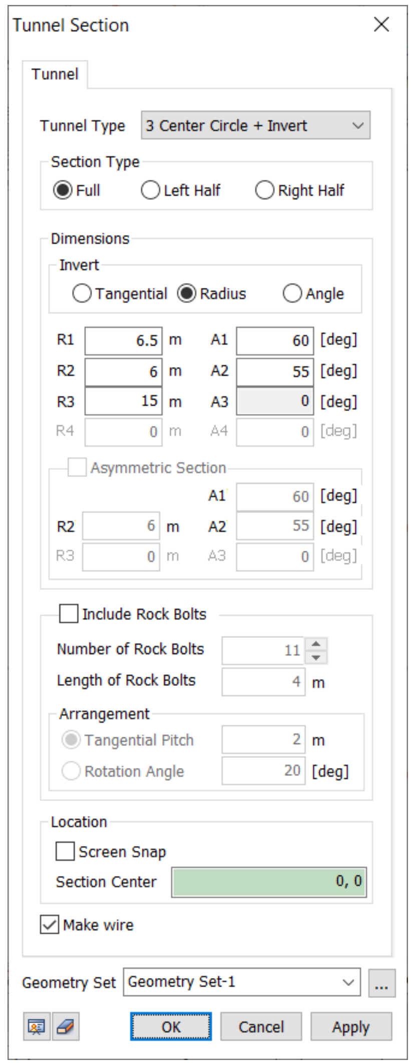
1 **Geometry > Point & Curve > Tunnel**

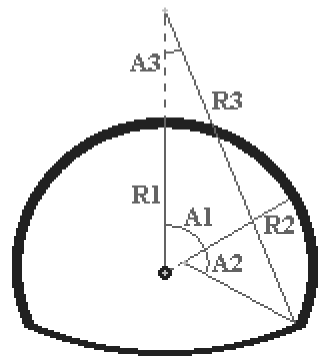
- Tunnel Type: **3 Center Circle + Invert**
- Section Type: **Full**
- Dimensions

R1: 6.5	**A1: 60**
R2: 6	**A2: 55**
R3: 15	**A3: 0**

- Section Center: **0, 0**
- OK

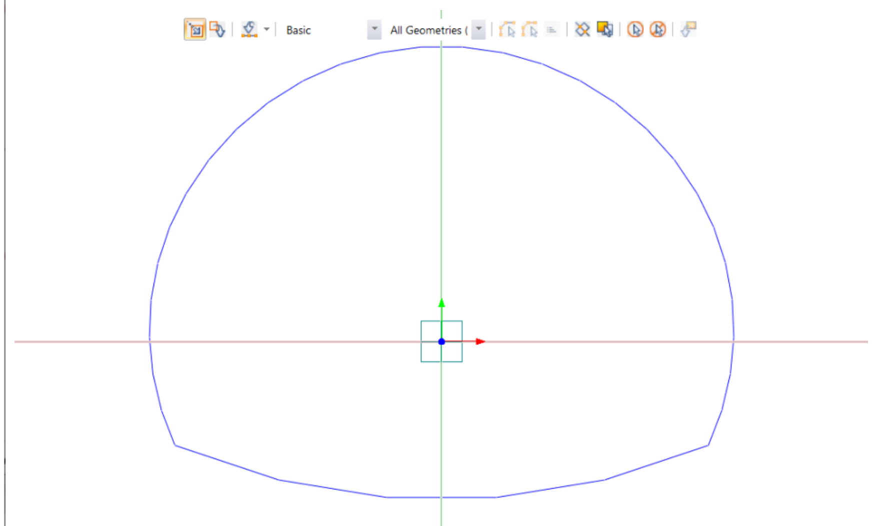
1





: 3 Center Circle + Invert

Create a tunnel using 3 different arcs and an invert.

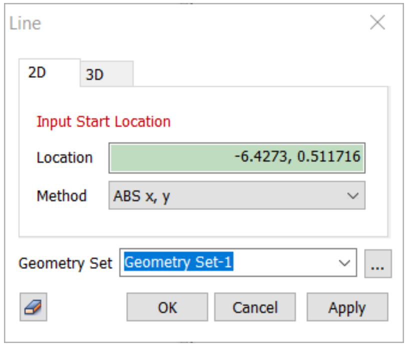


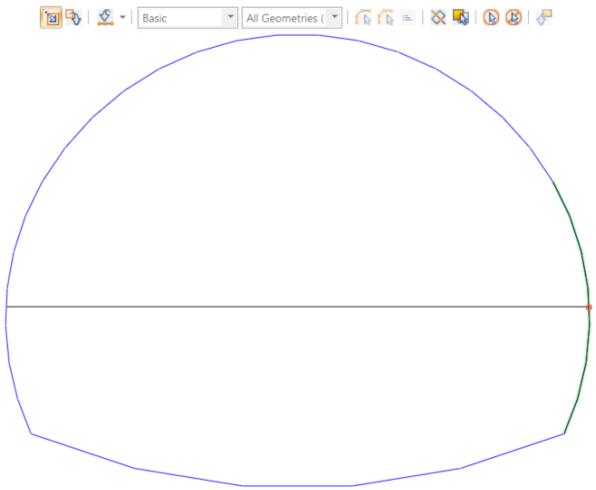
Procedure

Create a line to separate the top heading (upper excavation) from the invert (lower excavation).

1. **Geometry > Point & Curve > Line**
   - Click the **Start Location at the middle of bottom-left** tunnel section.
   - Click the **End Location at the middle of bottom-right** tunnel section.
   - OK

1

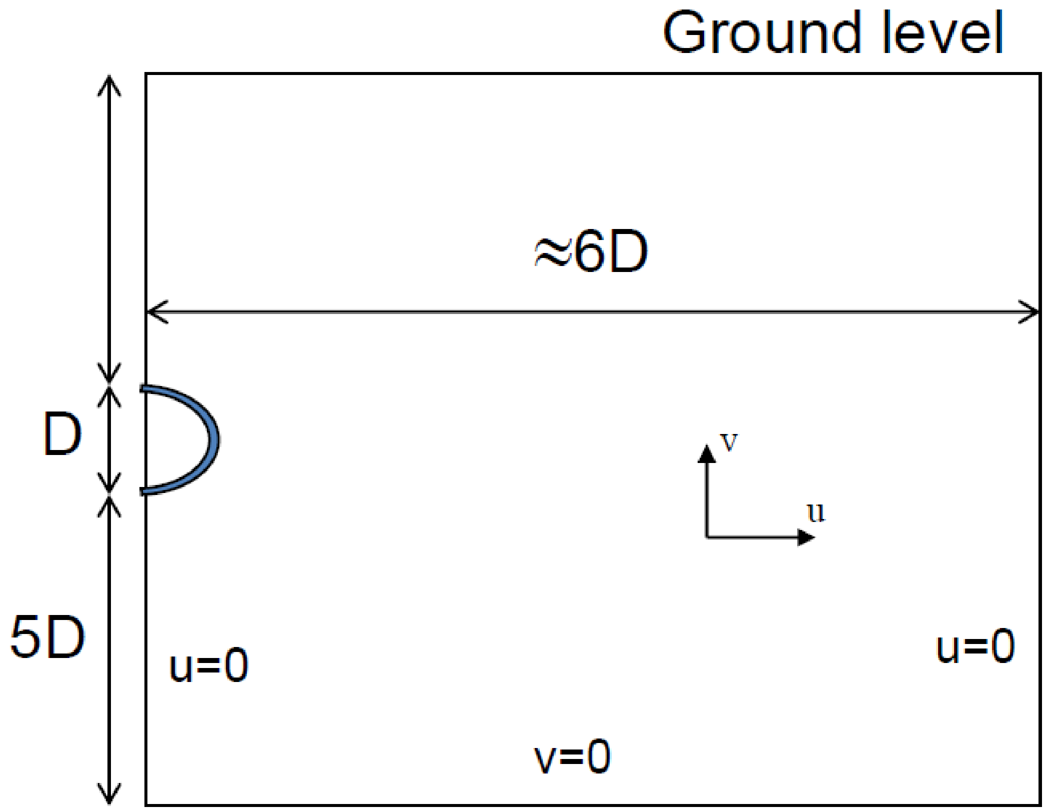




Model boundaries of tunnel

The stress arching that occurs around the tunnel is related to its depth and, accordingly, the dimensions of the mesh area should typically extend to a depth of around 5D beneath the tunnel invert, and should include the entire height of soil above the crown. Laterally, the dimension of the mesh area should be extended to about 6D from the tunnel axis as illustrated in the figure below.

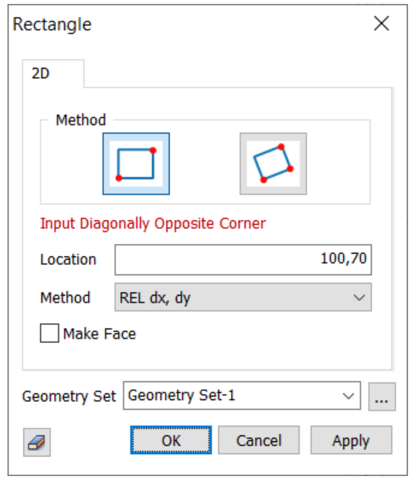
Obviously, these dimensions only represent a guideline, and the engineer must always seek a compromise between reliable predictions in terms of stress-strain distribution, and cost.

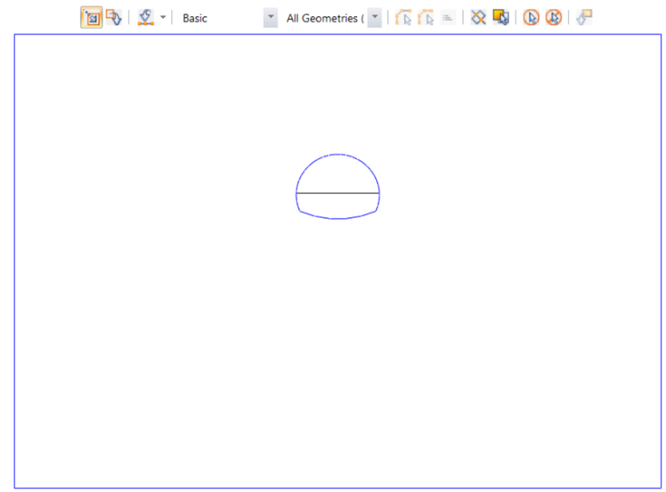


Procedure

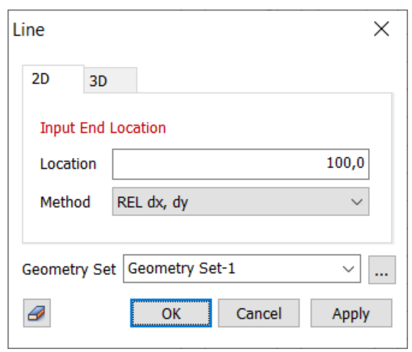
Define model boundaries and soil layers.

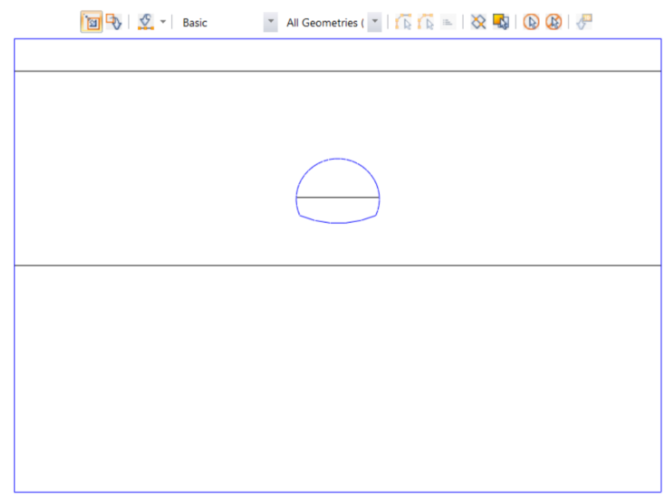
1. **Geometry > Point & Curve > Rectangle**
   - Location: **(-50,-45) <100,70>**
   - OK





2. **Geometry > Point & Curve > Line**
   - Location: **(-50,20) <100,0>**
   - Location: **(-50,-10) <100,0>**
   - OK





( ): 'ABS x, y'

< >: 'REL dx, dy'

Procedure

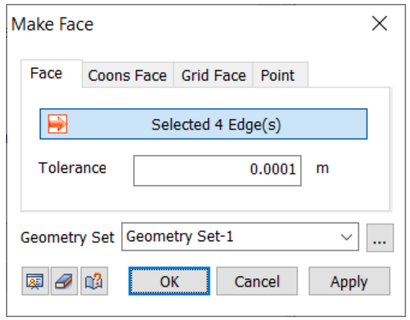
Create a surface for the model boundaries and divide the surface by tunnel section and soil layers.

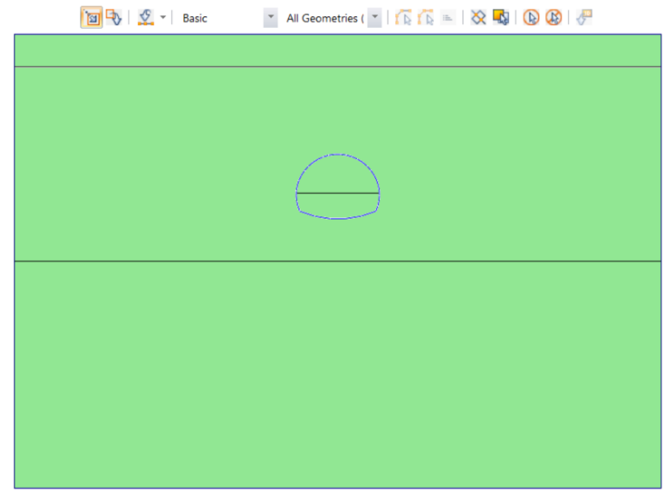
1. **Geometry > Surface & Solid > Make Face**
   - Face tab
   - Select: **4 edges**
   - OK

2. **Geometry > Divide > Surface**
   - By Curve tab
   - Target: **Surface**
   - Tool: **7 edges (tunnel and soil layers)**
   - Projection: **2 Points Vector**
   - OK

3. **Tools > Geometry > Random Color**

1





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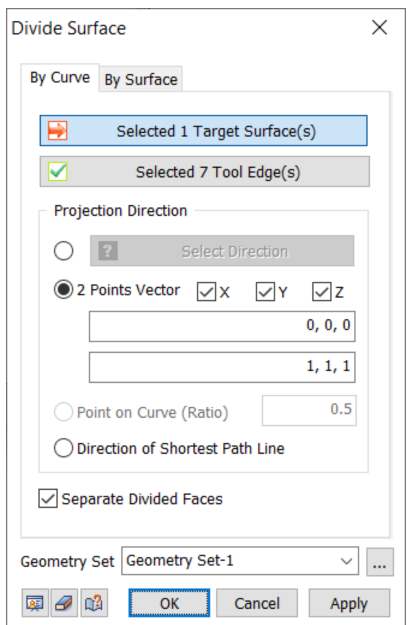

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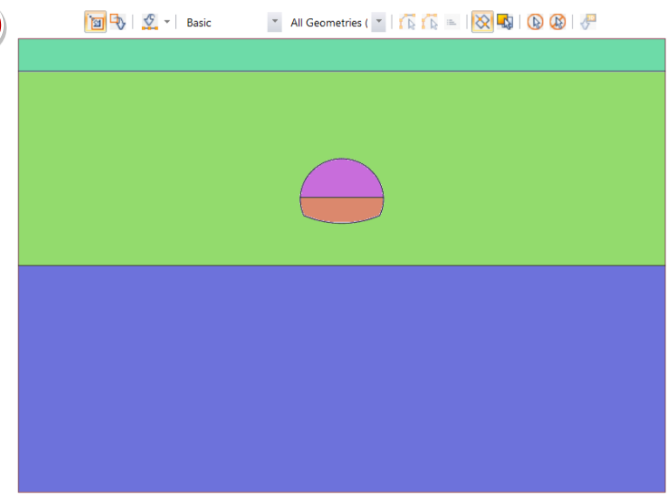


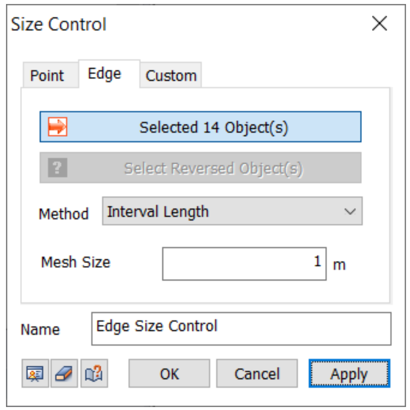
Procedure

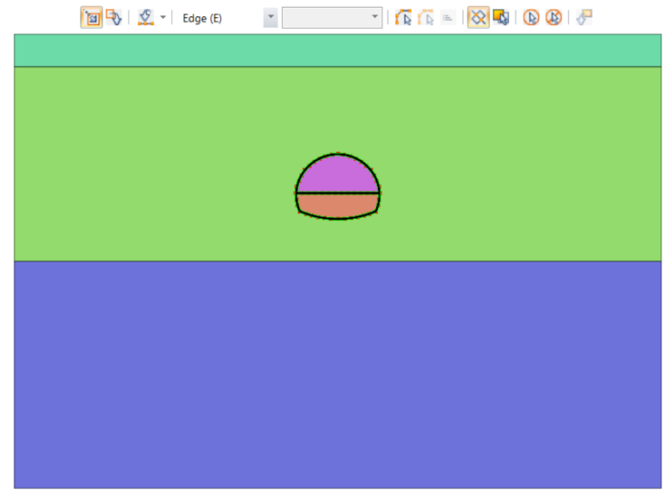
Specify size of elements for the tunnel and soil layer.

1. **Mesh > Control > Size Ctrl.**
   - Check off ‘Curve [5]’ under Geometry tree
   - Edge tab
   - Select: **14 edges (tunnel)**
   - Method: **Interval Length**
   - Mesh Size: **1 (m)**
   - Apply

2. - Method: **Linear Grading (Length)**
   - Select: **2 edges (2nd soil layer)**
   - Start Length: **5 (m)**
   - End Length: **2 (m)**
   - Check on: **Symmetric Seeding**
   - OK

1





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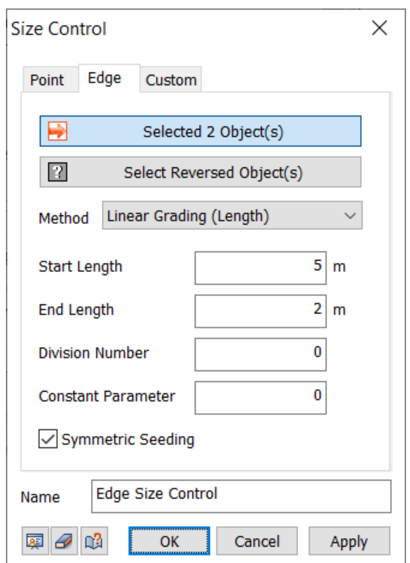
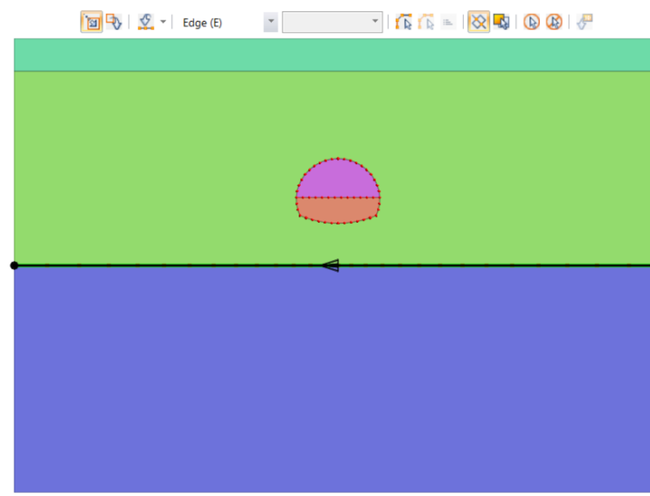




Procedure

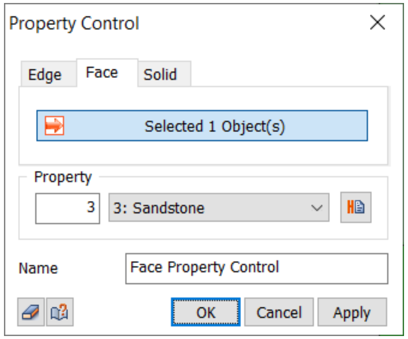
Pre-assign the soil properties before mesh generation.

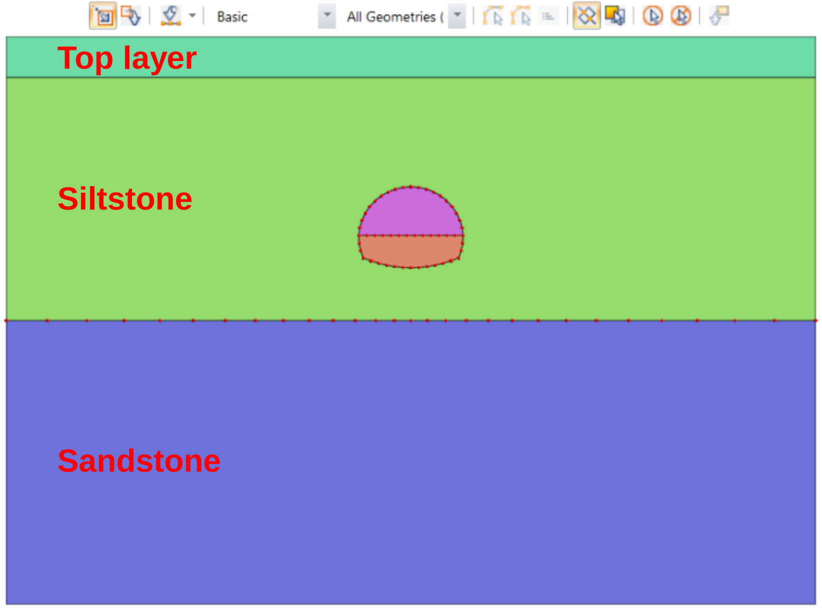
1 **Mesh > Control > Prop Ctrl.**
- Face tab
- Select: **Top layer (1 surface)**
- Property: **1: Top layer**
- Apply

- Select: **Siltstone (3 surfaces)**
- Property: **2: Siltstone**
- Apply

- Select: **Sandstone (1 surface)**
- Property: **3: Sandstone**
- OK

1





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Procedure

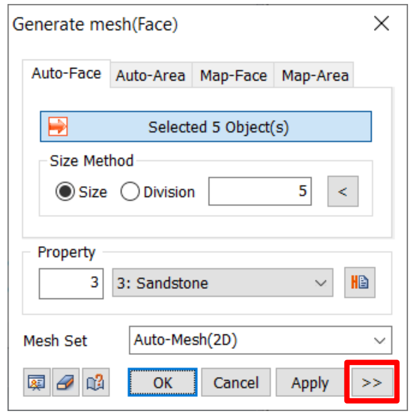
Generate mesh for soil layers.

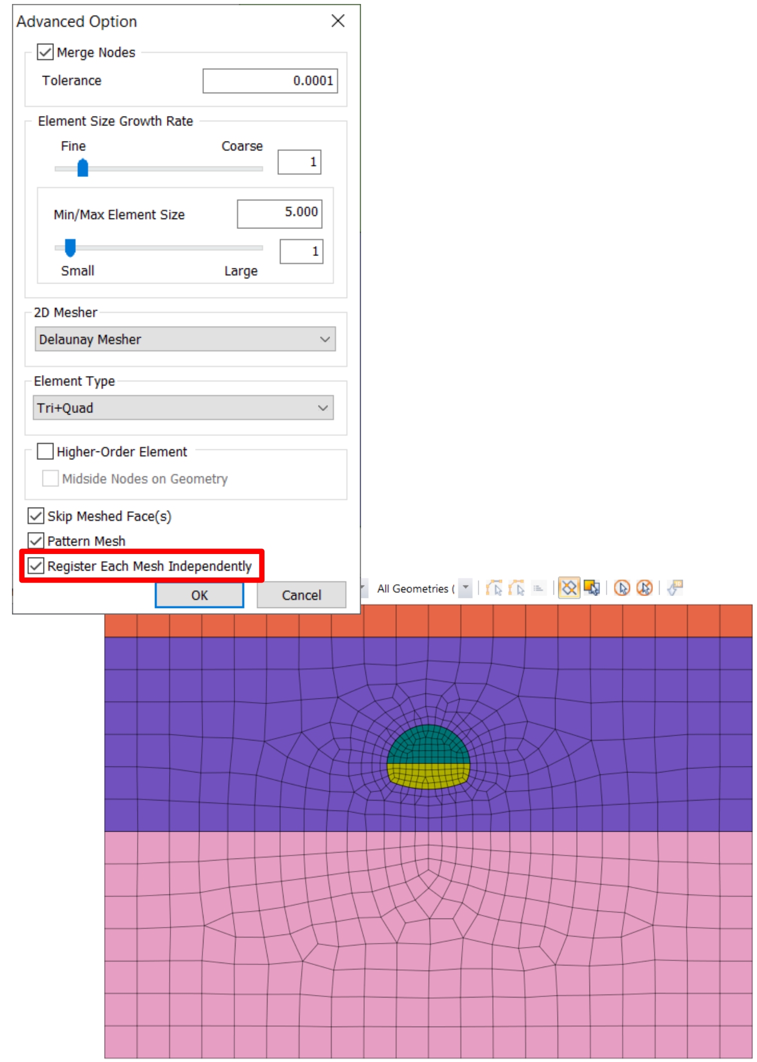
1 **Mesh > Generate > 2D**

- Auto-Face tab
- Click **Advanced Option**
- Check on: **Register Each Mesh Independently**
- OK

- Select: **all surfaces**
- Size: **5 (m)**
- OK

1





Procedure

Generate mesh for lining.

1 **Mesh > Generate > 1D**

- Hide all mesh sets
- Show only tunnel surface under Geometry tree
- Select: **3 lines (upper lining)**
- Size: **1 (m)**
- Property: **4: Lining**
- Mesh Set: **upper lining**
- Apply

2
- Select: **3 lines (lower lining and invert)**
- Size: **1 (m)**
- Property: **4: Lining**
- Mesh Set: **lower lining**
- OK

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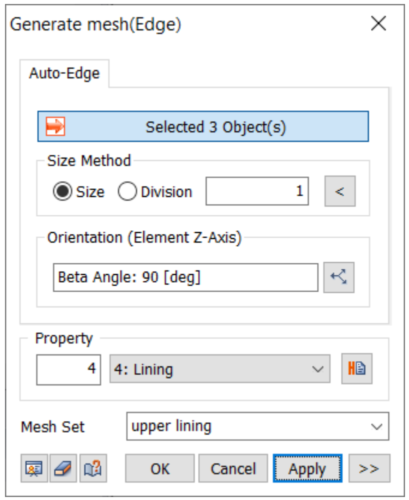

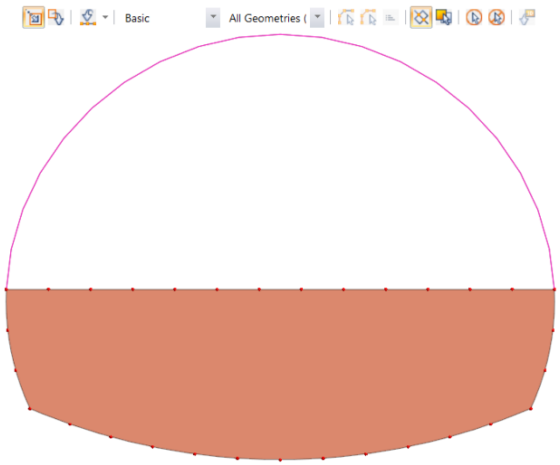

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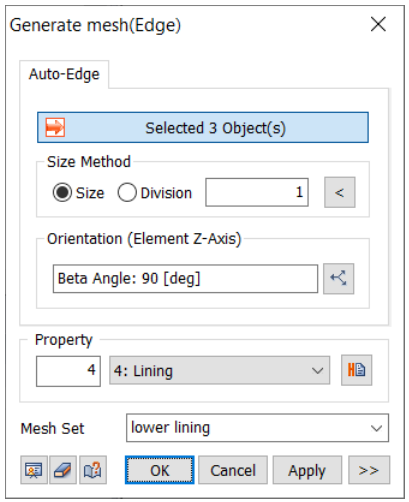
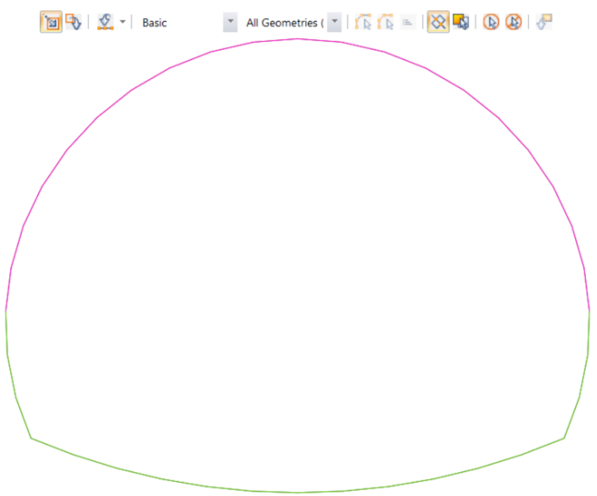




Procedure

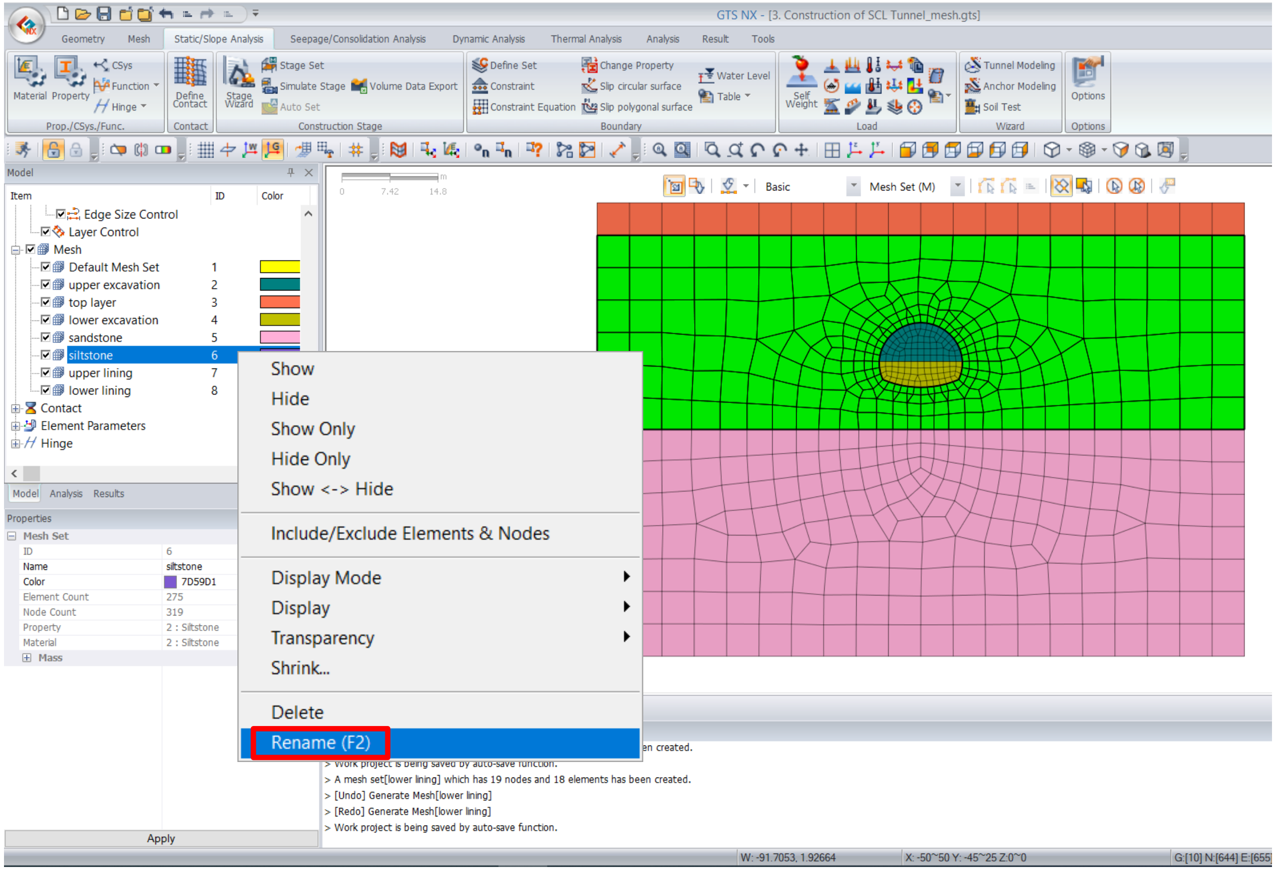
Rename soil mesh sets.

1 - Show **all mesh sets**

- Right click and select '**Rename (F2)**' to change mesh set name under Mesh tree.

- **top layer**
- **siltstone**
- **sandstone**
- **upper excavation**
- **lower excavation**

1



Procedure

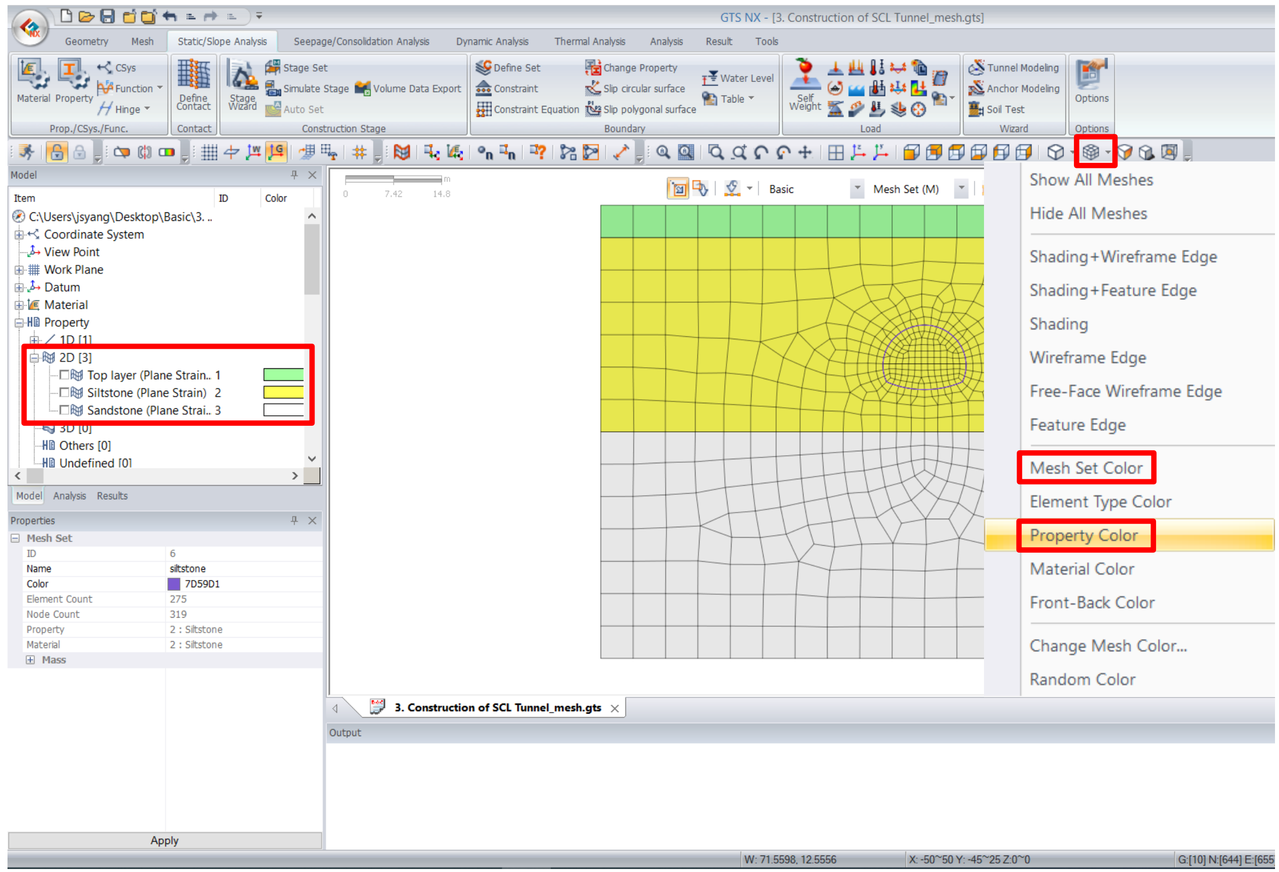
Check material property for all mesh sets.

1 - Display Mode (Mesh) > Property Color

- Check property color under Property tree

- Display Mode (Mesh) > Mesh Set Color

1



05 Load & Boundary Condition

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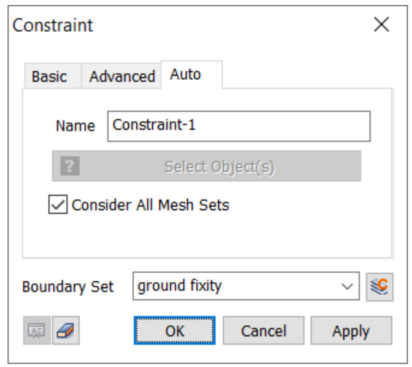
Procedure

Assign constraints to model boundaries and create self weight.

1. **Static/Slope Analysis > Boundary > Constraint**
   - Auto tab
   - Boundary Set: **ground fixity**
   - OK

2. **Static/Slope Analysis > Load > Self Weight**
   - Gy: **-1**
   - Load Set: **self weight**
   - OK

1



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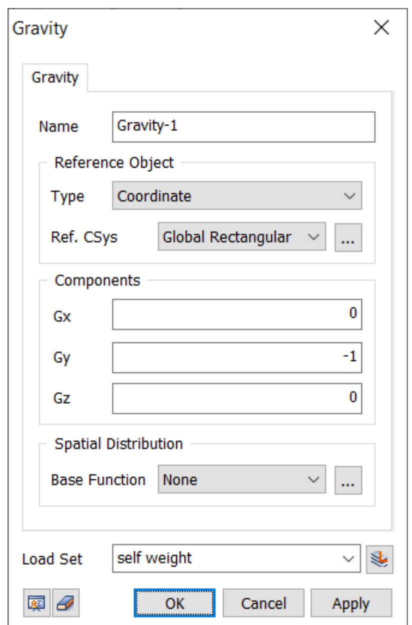
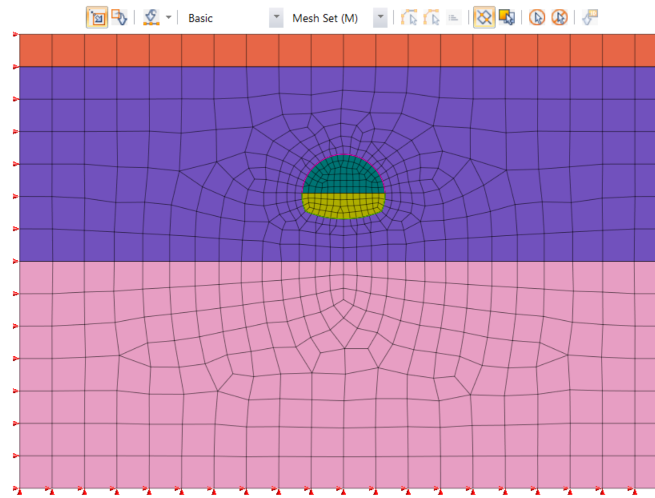
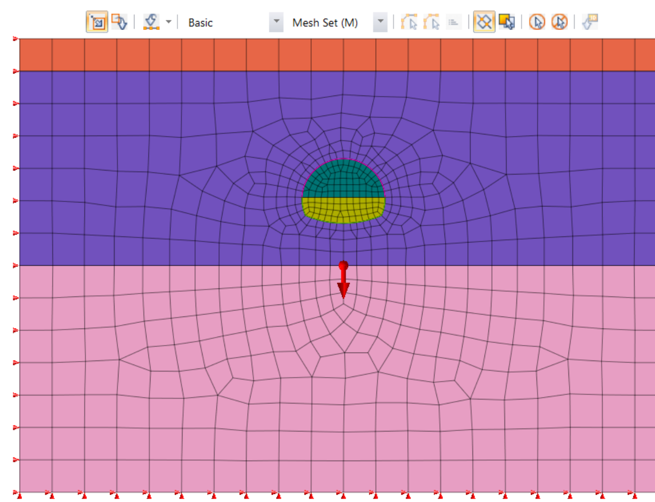
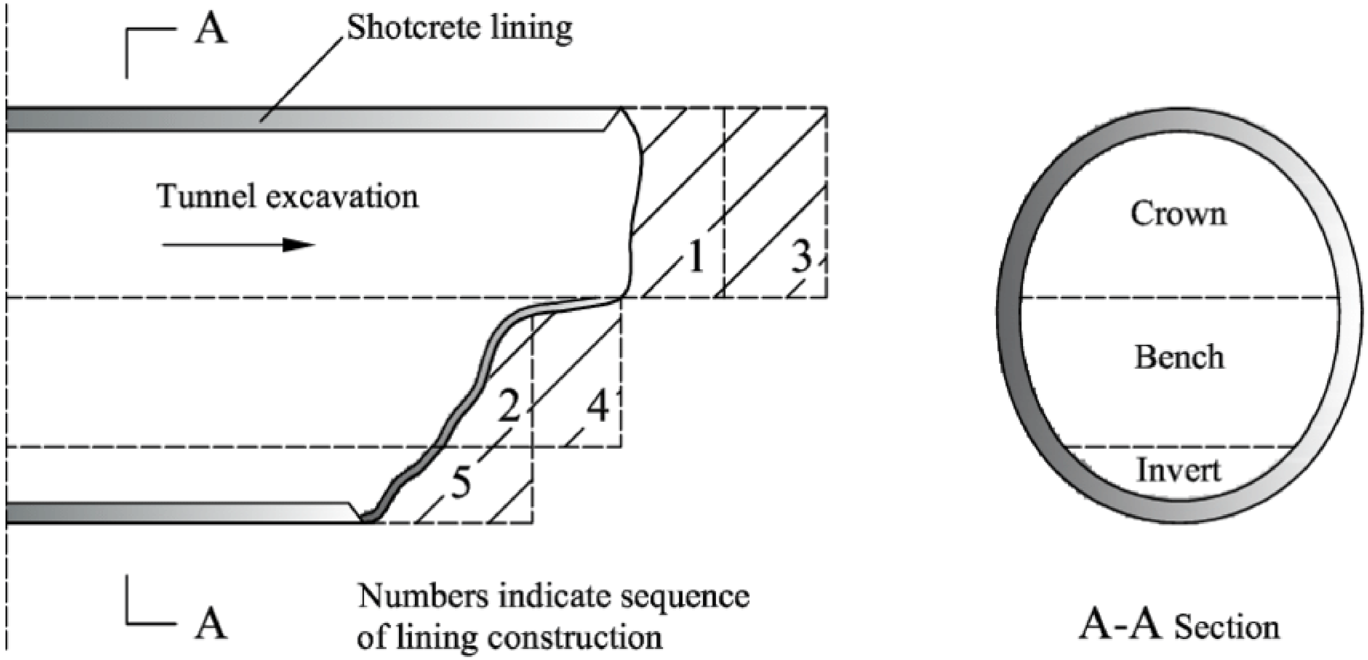






Staged construction sequence

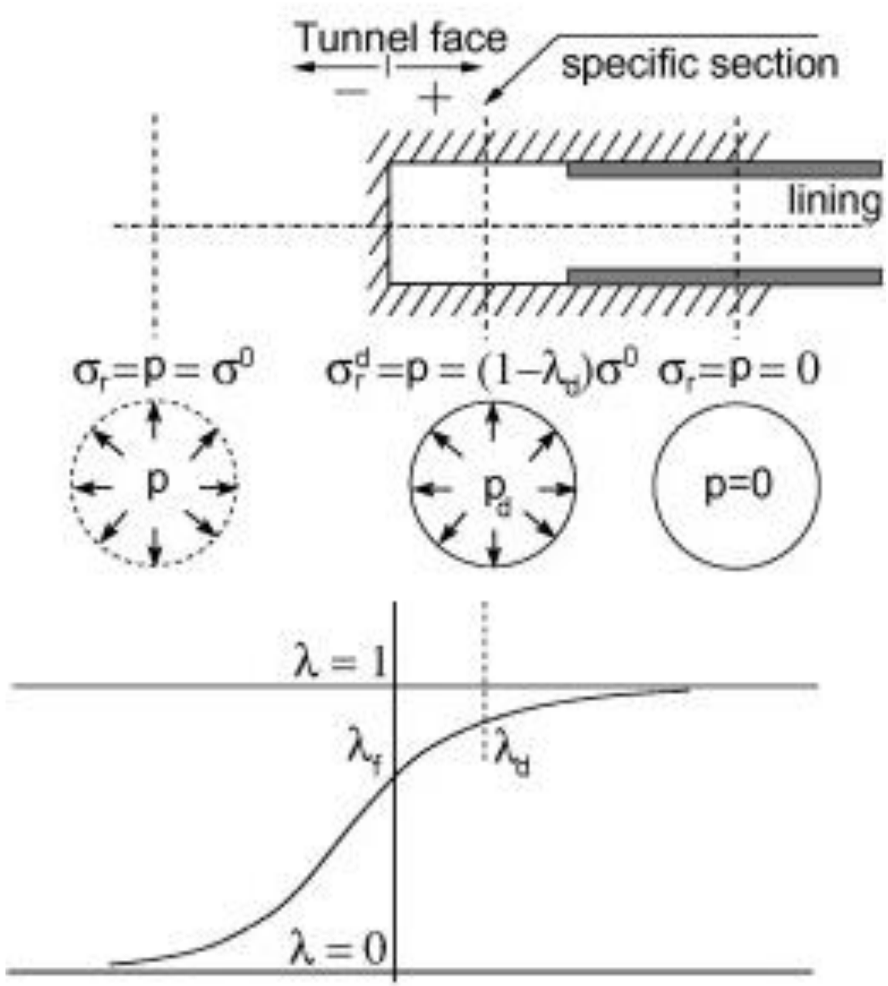


Tunnel built with New Austrian Tunnelling Method (NATM)

Convergence-confinement method

A staged construction analysis is required that the tunnel lining is activated and the soil mesh set inside the tunnel are deactivated. The main issue in this analysis is to account for the three-dimensional arching effect that occurs within the soil and the deformations that occur around the unsupported tunnel face.

The three-dimensional arching effect is simulated by using the λ or convergence-confinement method (Panet and Guenot (1982)), in which the proportion of unloading before lining construction is prescribed, so volume loss is a predicted value. An internal force vector is applied at the nodes on the tunnel boundary. λ is initially equal to 0 and is then progressively increased to 1 to model the excavation process. At a prescribed value λ_d the lining is installed, at which point the stress reduction at the boundary is $\lambda_d\{\sigma_0\}$. The remainder of the stress reduction is applied to create the lining stress. The stress reduction with the lining in place is then $(1-\lambda_d)\{\sigma_0\}$.



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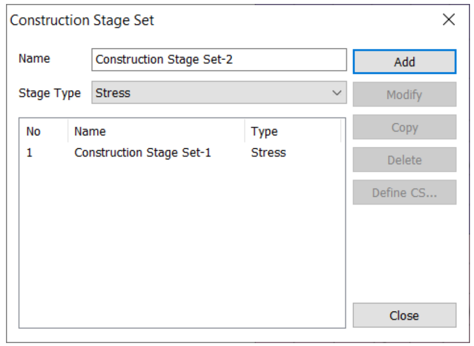
Procedure

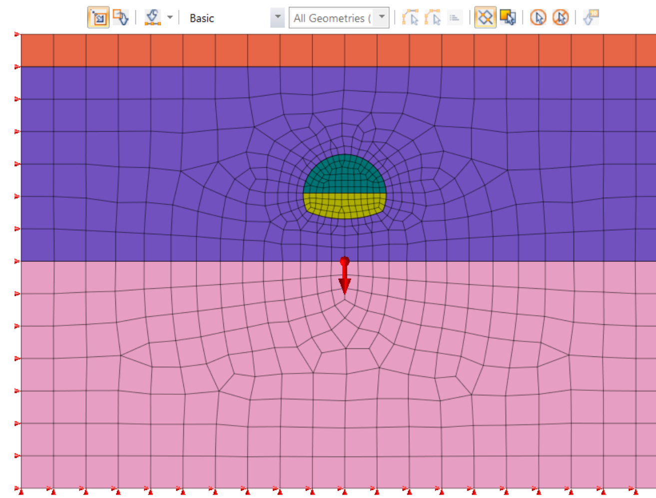
Define construction stages of the SCL tunnel.

1. **Static/Slope Analysis > Construction Stage > Stage Set**
   - Stage Type: **Stress**
   - Add
   - Double click the **'Construction Stage Set-1'**

2. - Stage Name: **initial phase**
   - Show Data: **Activate**
   - Select mesh, boundary and load sets, and drag & drop them into 'Activated Data' from 'Set Data'. (as shown in the figure)
   - Check on: **Clear Displacement**
   - Save

1





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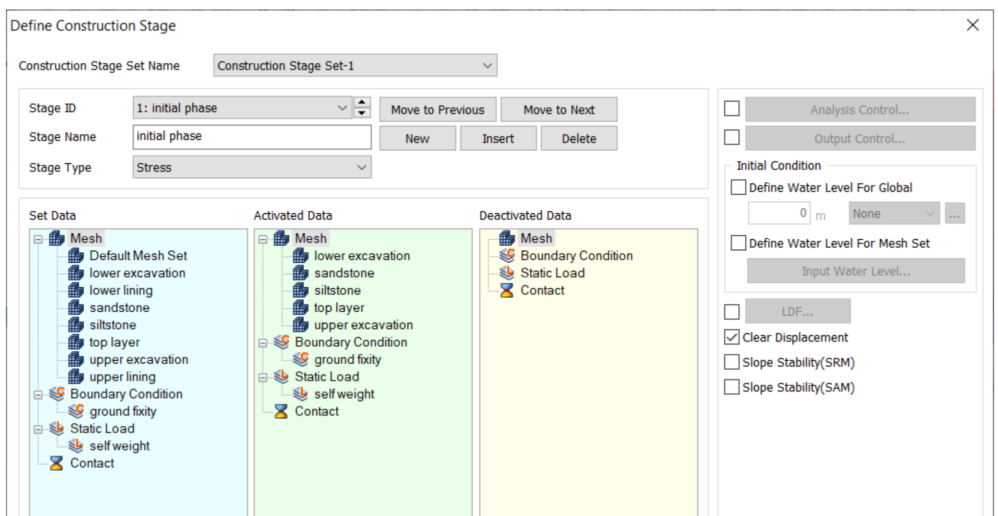

06 Define Construction Stage

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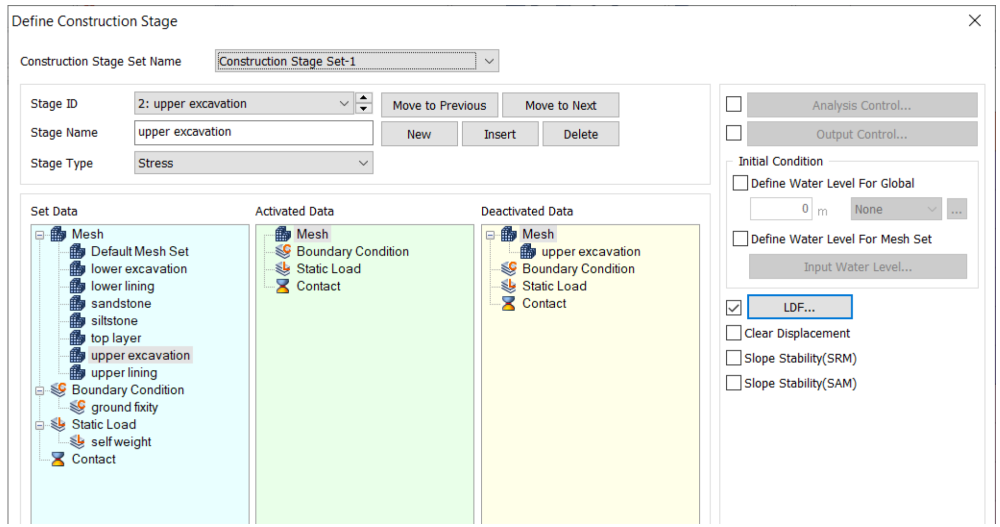
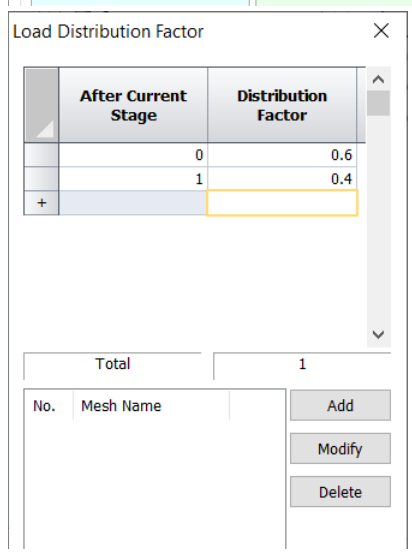
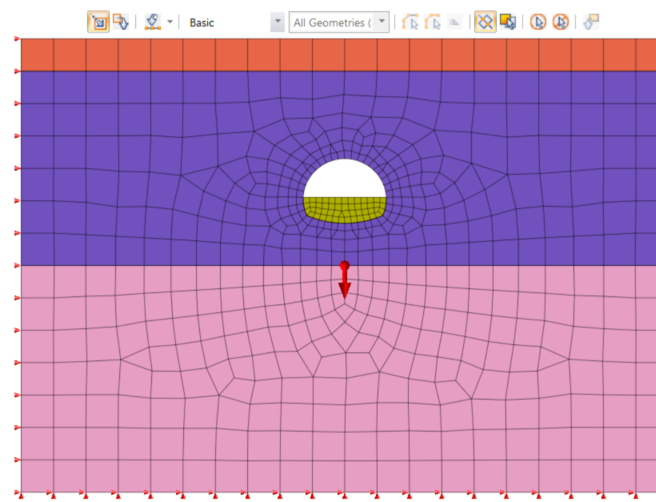
Procedure

1 - New
- Stage Name: **upper excavation**
- Select mesh set, and drag & drop it into 'Deactivated Data' from 'Set Data'. (as shown in the figure)
- Check on: **LDF**
- Load Distribution Factor
Current stage: 0.6
Next stage: 0.4
- OK
- Save

1







06 Define Construction Stage

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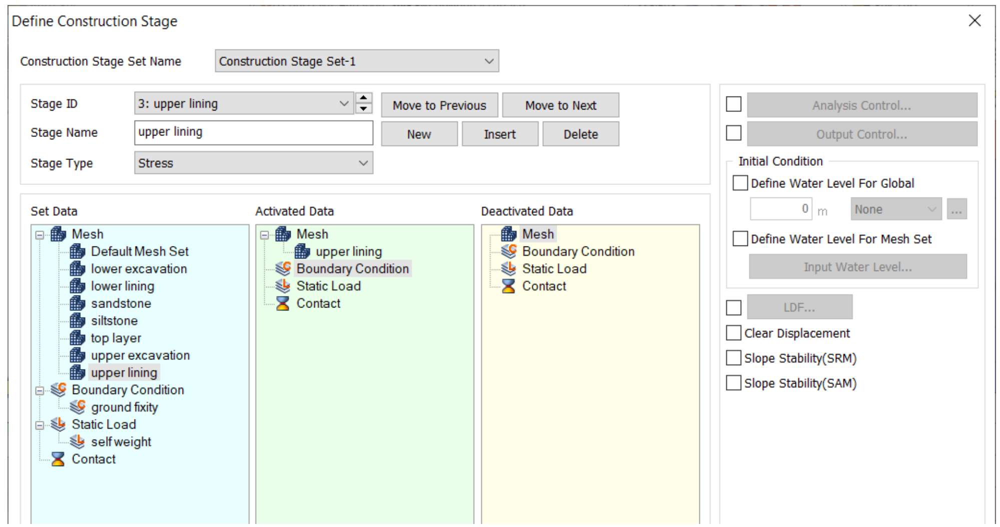
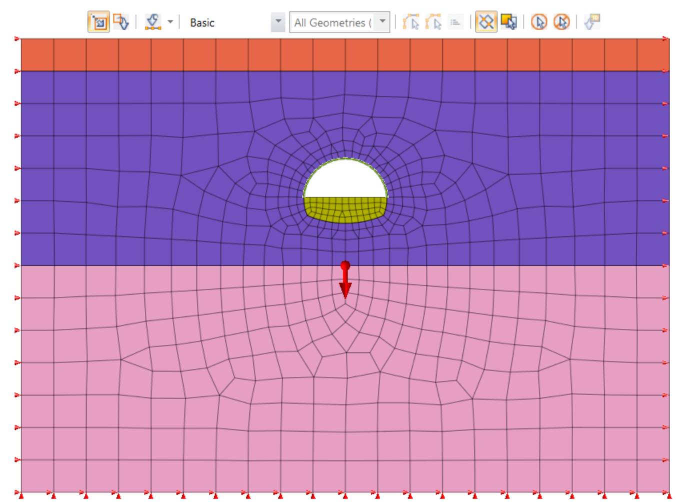
Procedure

1 - New

- Stage Name: **upper lining**
- Select mesh set, and drag & drop it into ‘Activated Data’ from ‘Set Data’. (as shown in the figure)
- Save

1





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Procedure

1 - New

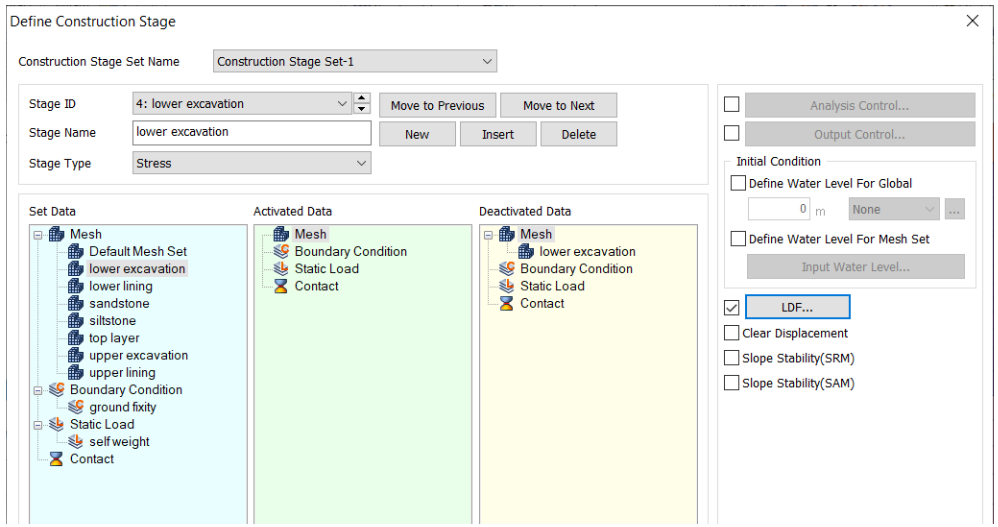
- Stage Name: **lower excavation**
- Select mesh set, and drag & drop it into 'Deactivated Data' from 'Set Data'. (as shown in the figure)
- Check on: **LDF**
- Load Distribution Factor

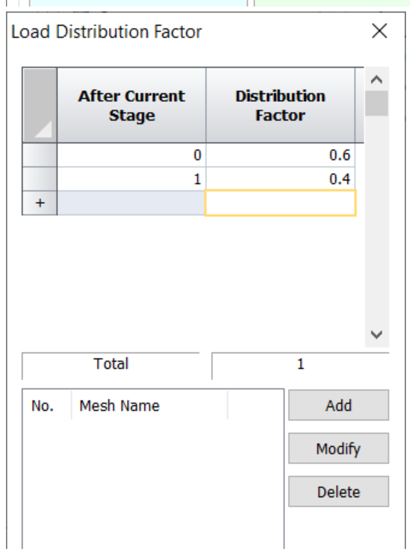
Current stage: 0.6

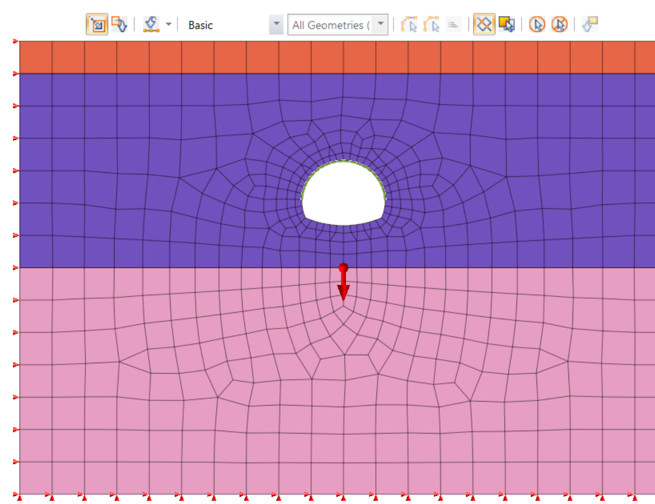
Next stage: 0.4

- OK
- Save

1







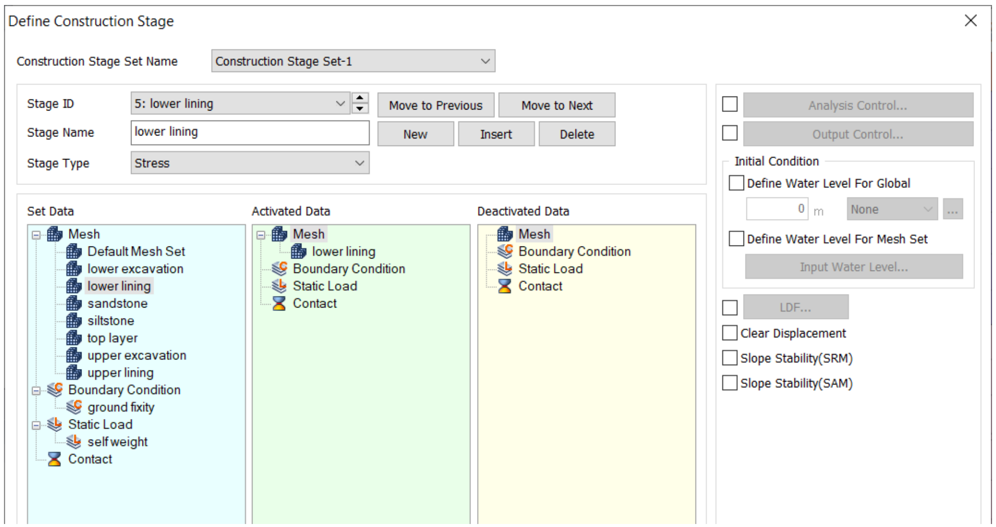
06 Define Construction Stage

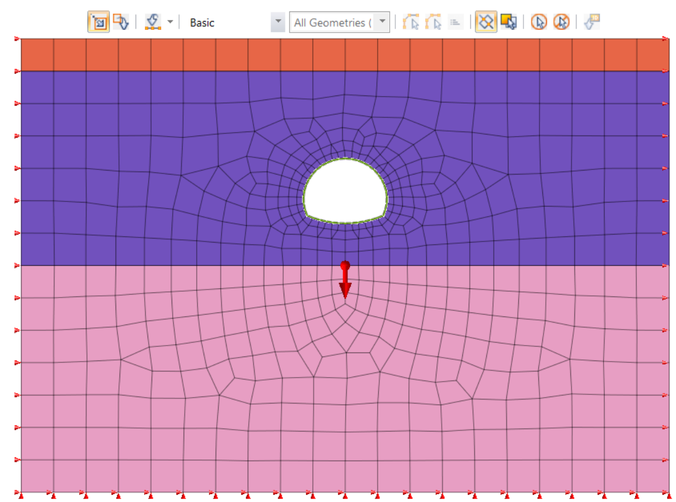
GTS NX

Procedure

1 - New
- Stage Name: **lower lining**
- Select mesh set, and drag & drop it into ‘Activated Data’ from ‘Set Data’. (as shown in the figure)
- Save
- Close
- Close

1



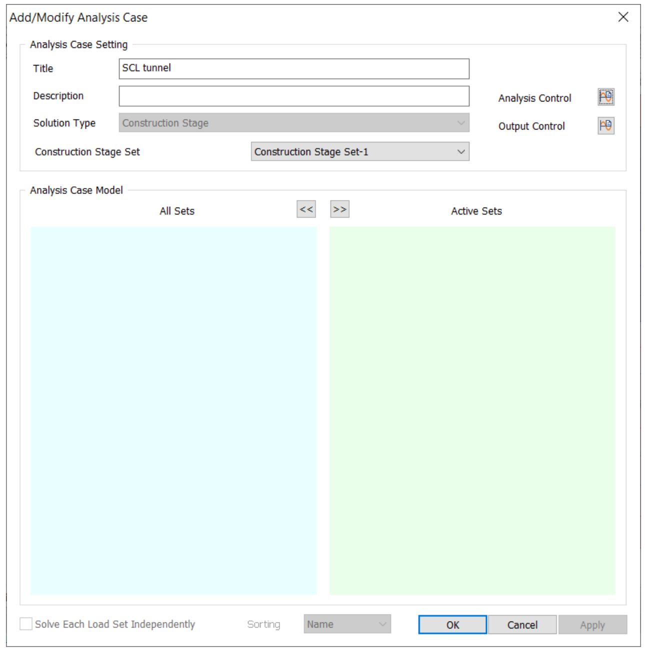


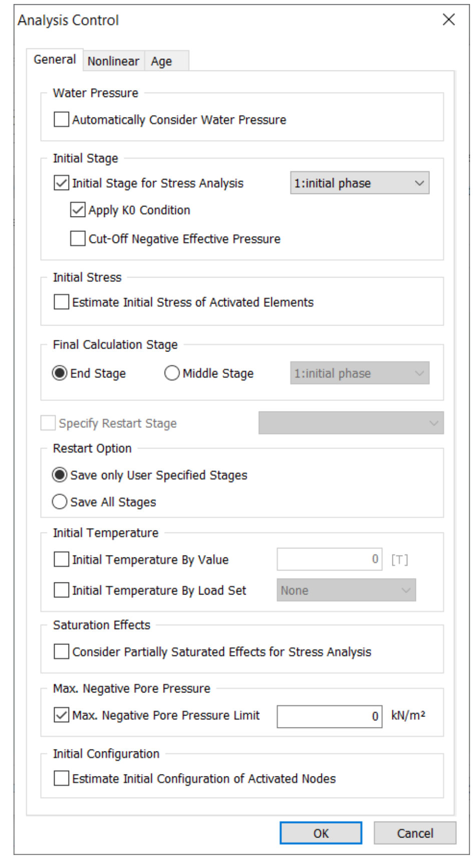
Procedure

1. **Analysis > Analysis Case > General**
   - Title: **SCL tunnel**
   - Solution Type: **Construction Stage**
   - Analysis Control
   - Check on: **Initial Stage for Stress Analysis**
   - Initial Stage: **1:initial phase**
   - Check on: **Apply K0 Condition**
   - OK
   - OK

2. **Analysis > Analysis > Perform**
   - Check on: **Analysis Case**
   - OK

1





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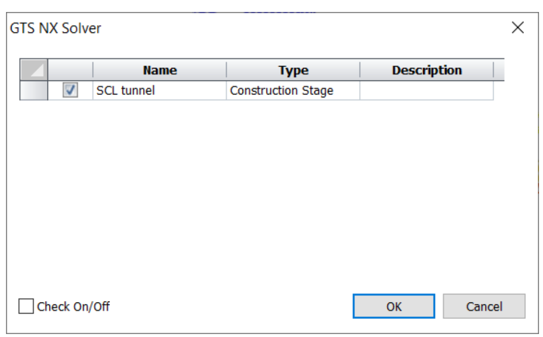


GTS NX

Procedure

Check displacement of ground.

1 lower lining > Displacement > TOTAL TRANSLATION (V)

Result > General > Smooth: Fringe

Result > General > Deform: Undeformed

Result > Show/Hide > Actual Deformation

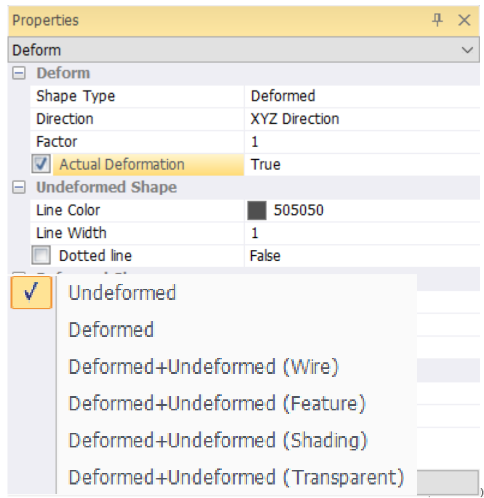
Properties > Deform

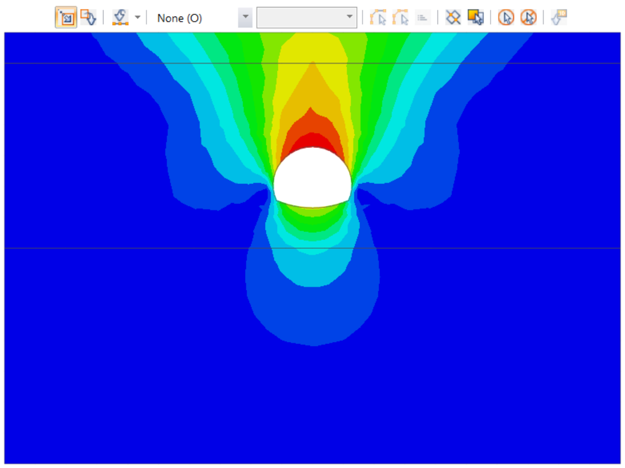
2 lower lining > Displacement > TY TRANSLATION (V)

Result > Advanced > Probe

- Max
- Min

1





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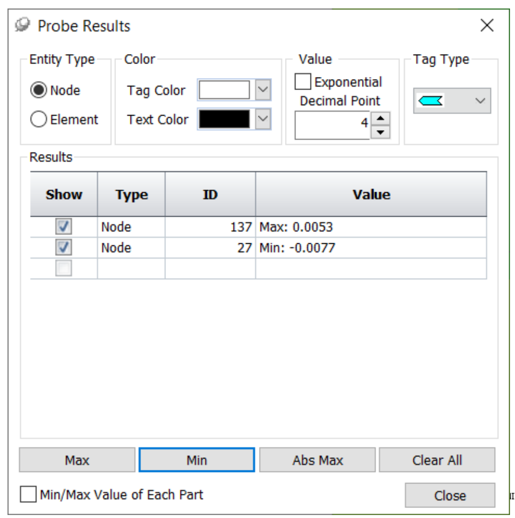
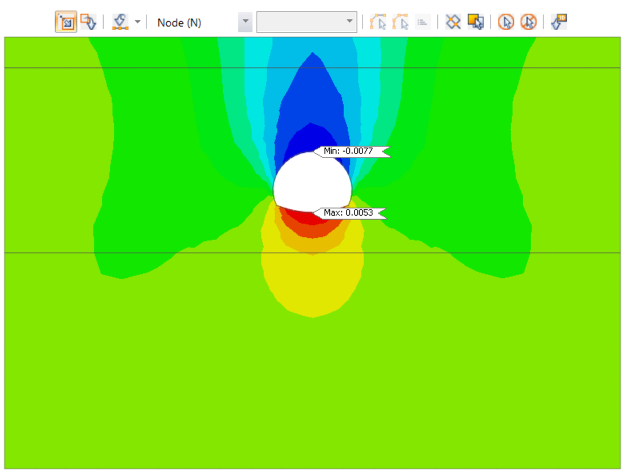


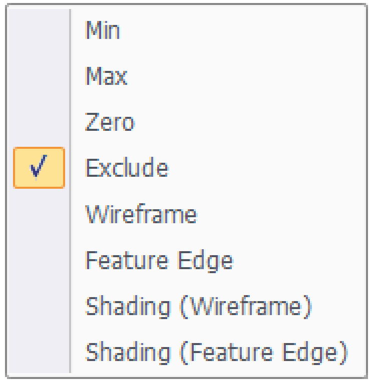


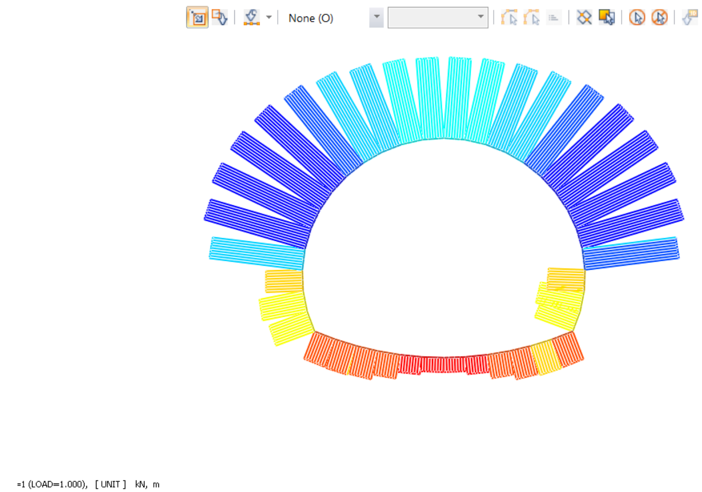
Procedure

Check member force of tunnel lining.

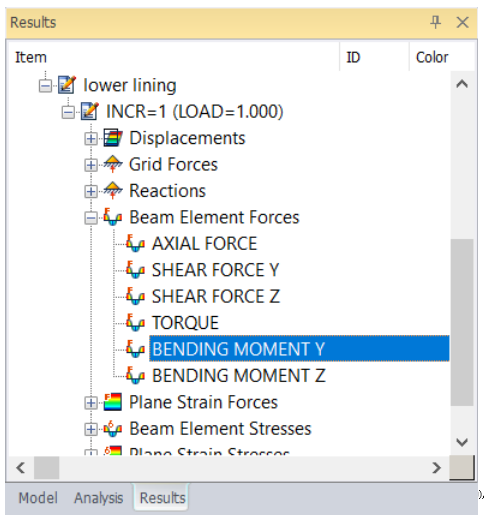
1 lower lining > Beam Element Forces > AXIAL FORCE

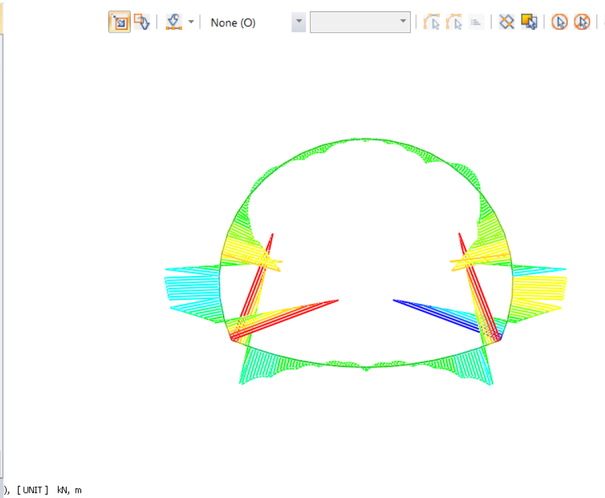
Result > General > No Results: Exclude





2 lower lining > Beam Element Forces > BENDING MOMENT YY





Thank you!

GTS NX

New eXperience of Geo-Technical analysis System

MIDAS