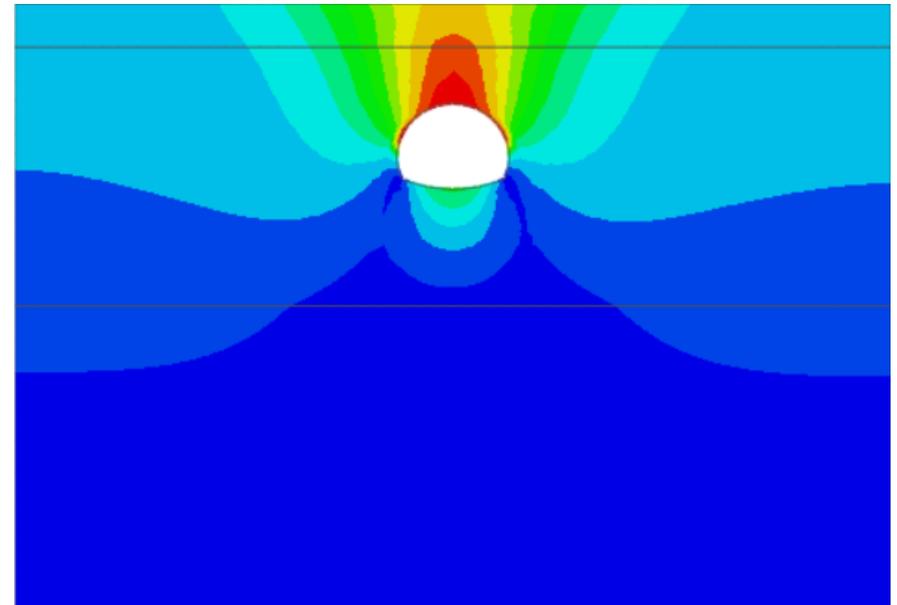
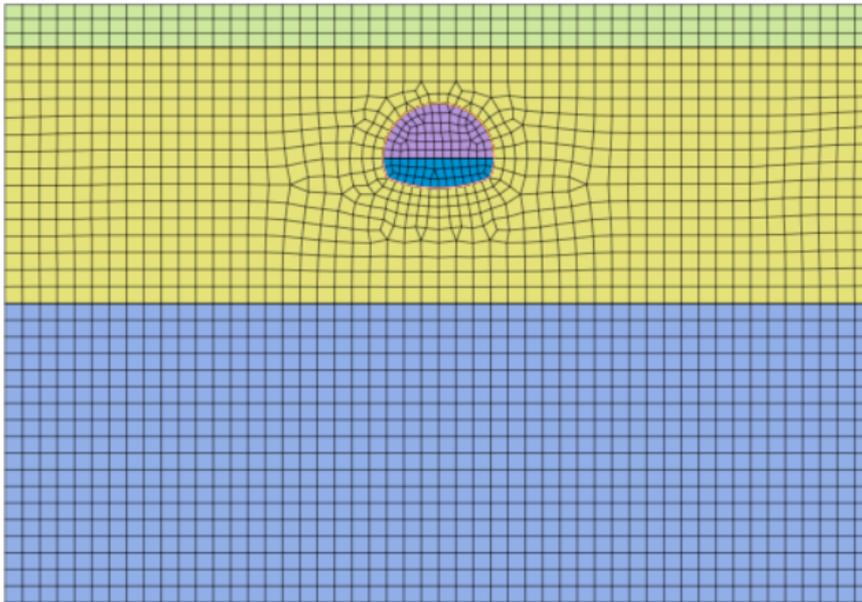


***Stress Seepage
Coupled Analysis Of a
2D NATM Tunnel***

Modelling and Analysis Summary

This tutorial summarizes the 2D stress seepage coupled analysis of the construction of a NATM Tunnel. 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 and demonstrate the ingress of water due to presence of groundwater in the tunnel vicinity.



Soil Layers

[unit : kN, m,s]

Name	Top layer	Siltstone	Sandstone
Material Model	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
General			
Elastic Modulus(E) [kN/m²]	7.5e+04	1.5e+06	2.5e+06
Poisson's Ratio(ν)	0.2	0.25	0.3
Unit Weight(γ_t) [kN/m³]	20	24	23
K0	0.5	0.5	0.5
Groundwater			
Unit Weight(γ_{sat}) [kN/m³]	22	25	24
Conductivity K_x, K_y [m/s]	1e-5	1e-7	1e-7
Drainage Parameters	Drained	Drained	Drained
Non-Linear			
Cohesion(c) [kN/m²]	10	120	150
Frictional Angle(Φ) [deg]	30	42	43
Dilatancy Angle(Φ) [deg]	0	0	0

Structure

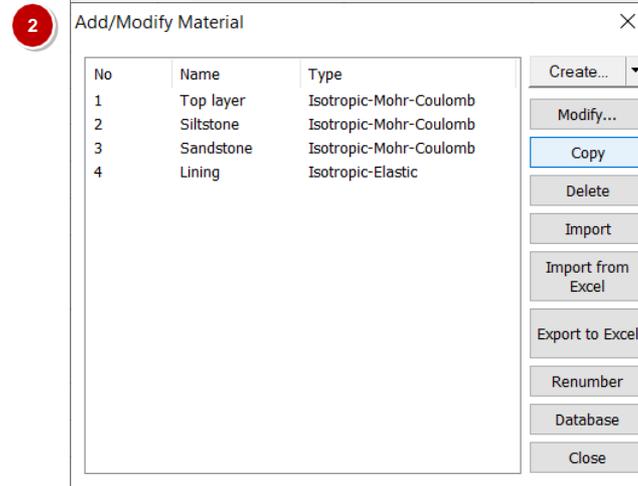
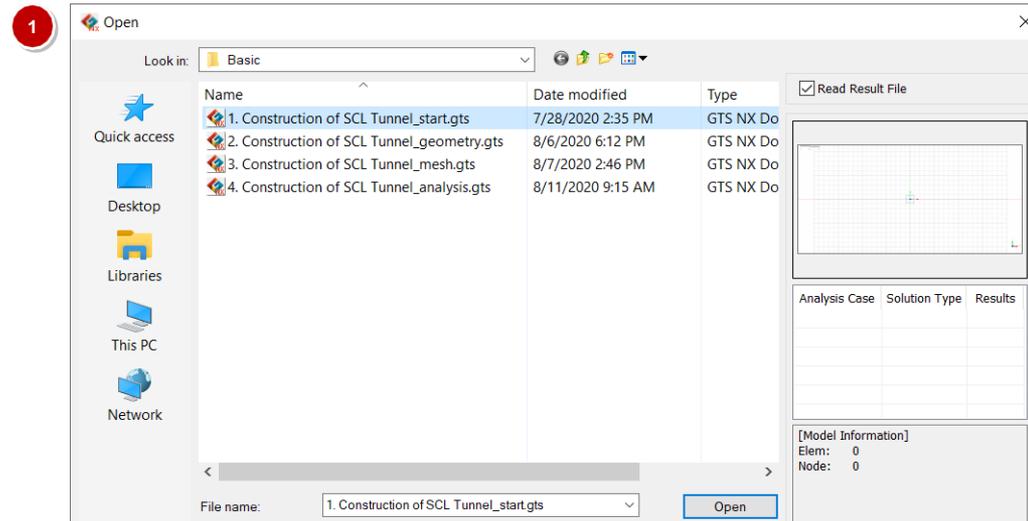
[unit : kN, m]

Name	Lining
Material Model	Elastic
Elastic Modulus(E) [kN/m ²]	3e+07
Poisson's Ratio(ν)	0.15
Unit Weight(γ) [kN/m ³]	25
Element Type	Beam
Thickness [m]	0.35

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

Tunnel Section ×

Tunnel

Tunnel Type 3 Center Circle

Section Type 3 Center Circle + Invert

Full

Dimensions

Invert

Tangential Radius Angle

R1	6.5 m	A1	60 [deg]
R2	6 m	A2	55 [deg]
R3	0 m	A3	0 [deg]
R4	0 m	A4	0 [deg]

Asymmetric Section

A1	60 [deg]		
R2	6 m	A2	55 [deg]
R3	0 m	A3	0 [deg]

Include Rock Bolts

Number of Rock Bolts

Length of Rock Bolts

Arrangement

Tangential Pitch

Rotation Angle

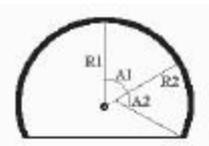
Location

Screen Snap

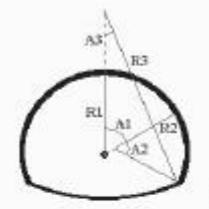
Section Center

Make wire

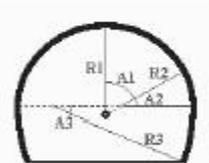
Geometry Set Geometry Set-1



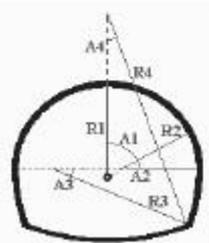
: 3 Center Circle
Create a tunnel using 3 arcs, all with different center points and diameters.



: 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: **0,7**

- OK

1
X

Tunnel Section

Tunnel Type: 3 Center Circle + Invert

Section Type: Full Left Half Right Half

Dimensions

Invert: Tangential Radius Angle

R1	<input type="text" value="6.5"/> m	A1	<input type="text" value="60"/> [deg]
R2	<input type="text" value="6"/> m	A2	<input type="text" value="55"/> [deg]
R3	<input type="text" value="15"/> m	A3	<input type="text" value="0"/> [deg]
R4	<input type="text" value="0"/> m	A4	<input type="text" value="0"/> [deg]

Asymmetric Section

R2'	<input type="text" value="6"/> m	A2'	<input type="text" value="55"/> [deg]
R3'	<input type="text" value="0"/> m	A3'	<input type="text" value="0"/> [deg]

Include Rock Bolts

Number of Rock Bolts:

Length of Rock Bolts: m

Arrangement: Tangential Pitch Rotation Angle

Tangential Pitch: m

Rotation Angle: [deg]

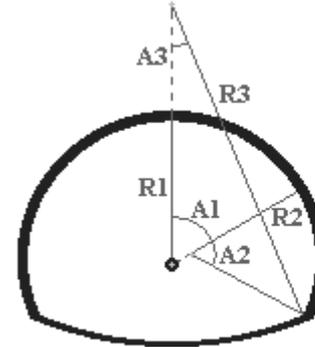
Location

Screen Snap

Section Center:

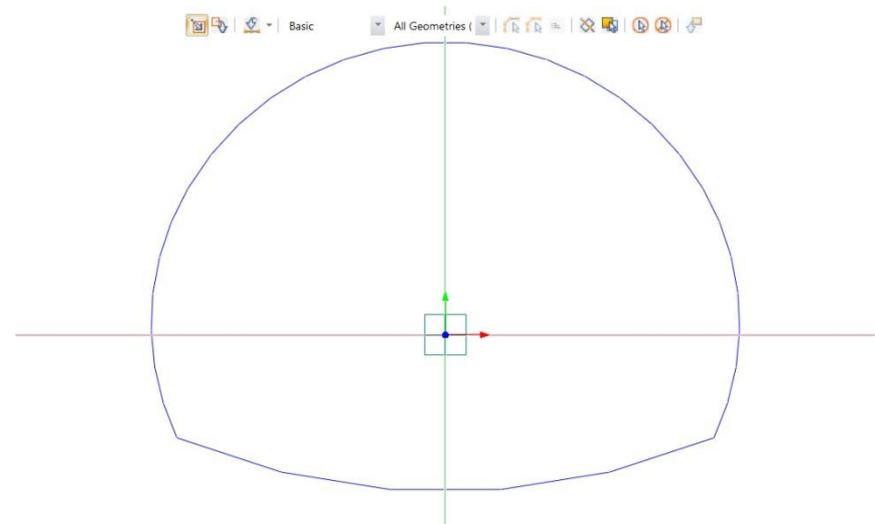
Make wire

Geometry Set: Geometry Set-1



: 3 Center Circle + Invert

Create a tunnel using 3 different arcs and an invert.

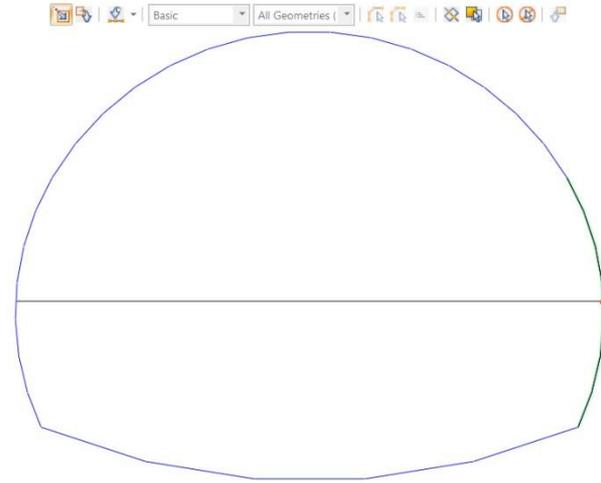
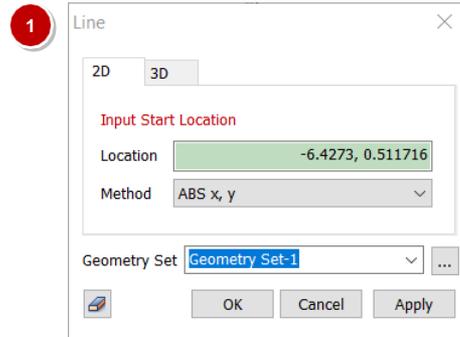


Procedure

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

1 Geometry > Point & Curve > Line

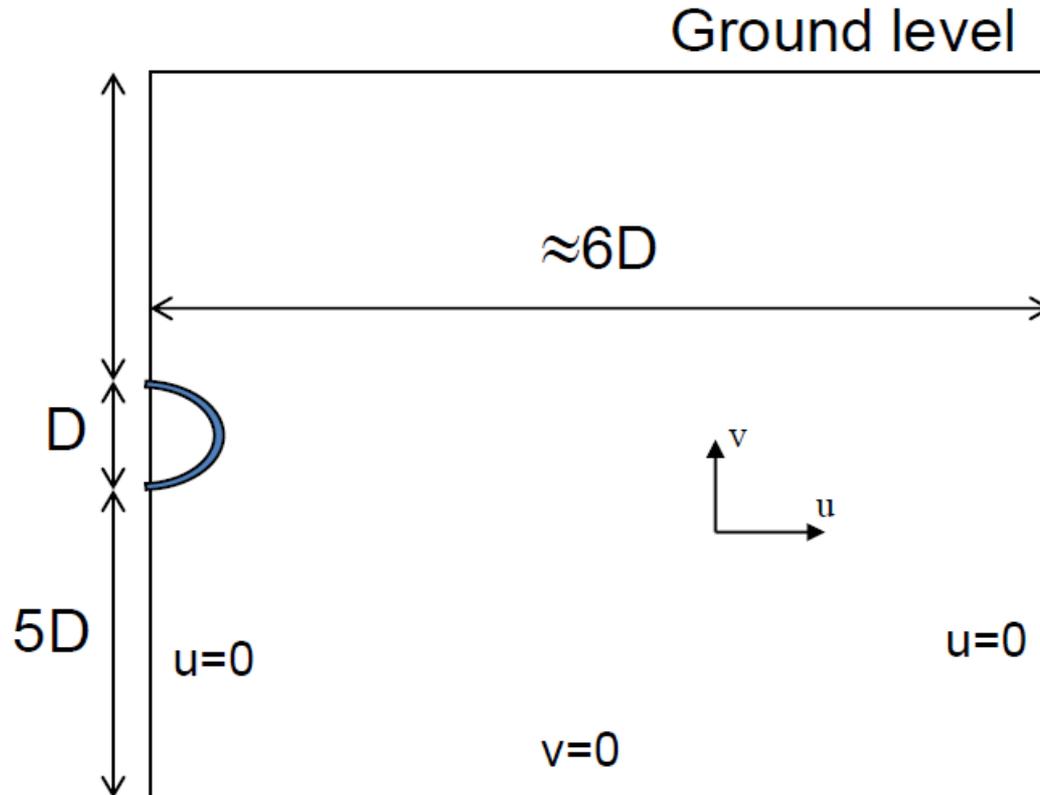
- Click the **Start Location at the middle of bottom-left** tunnel section.
- Click the **End Location at the middle of bottom-right** tunnel section.
- OK



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.

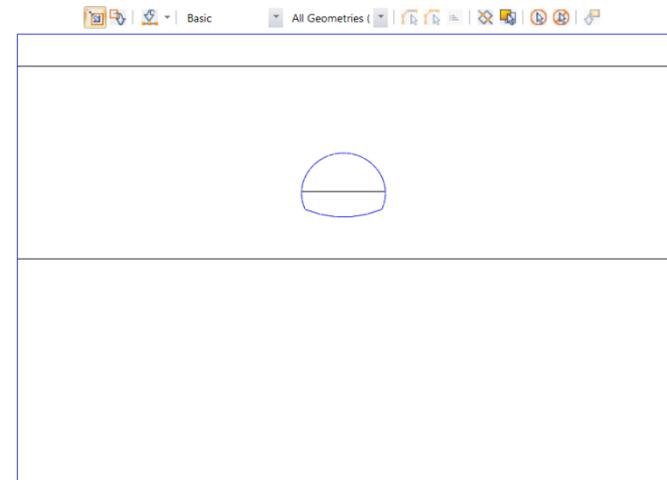
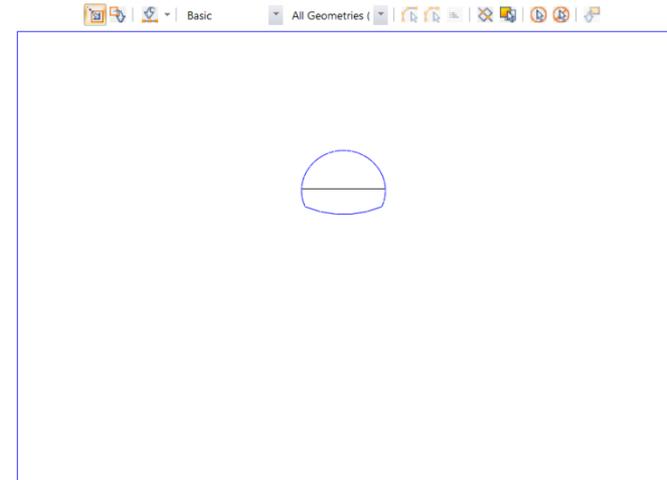
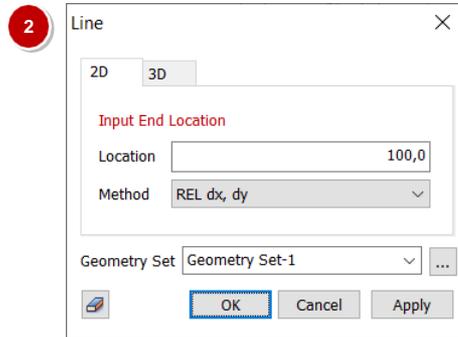
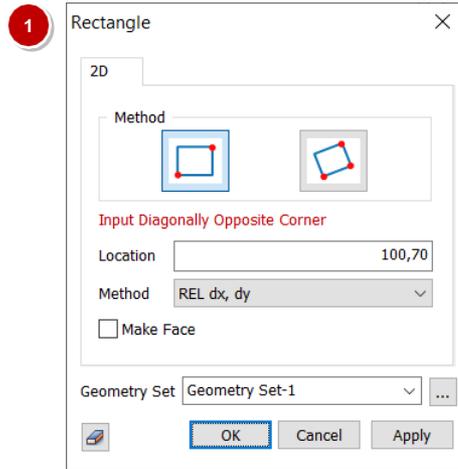
1 Geometry > Point & Curve > Rectangle

- 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.

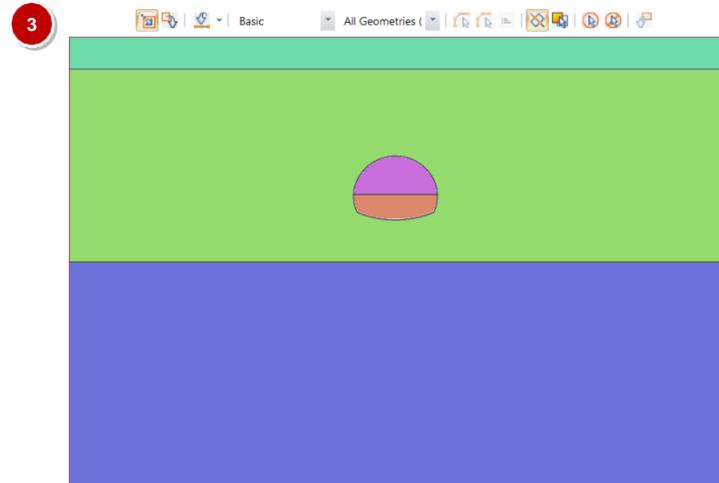
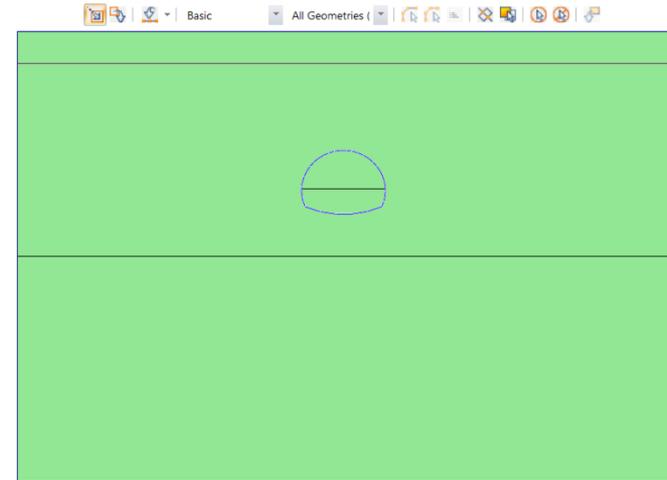
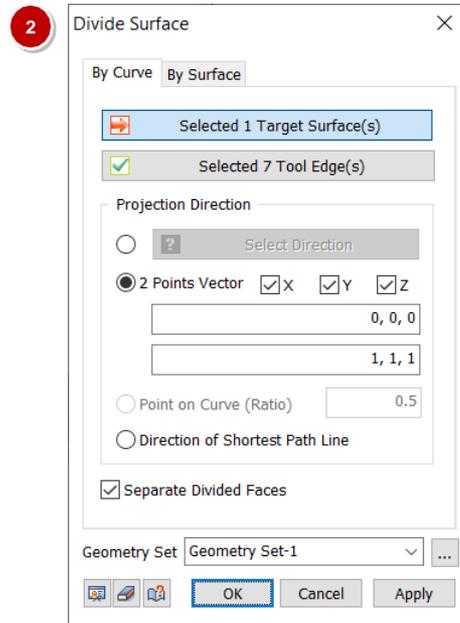
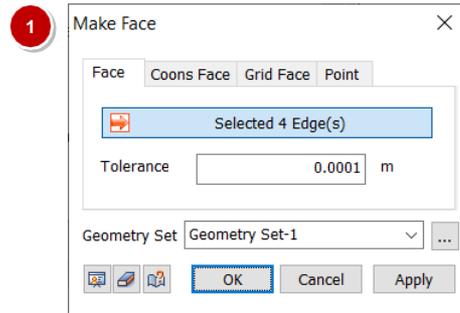
1 Geometry > Surface & Solid > Make Face

- 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

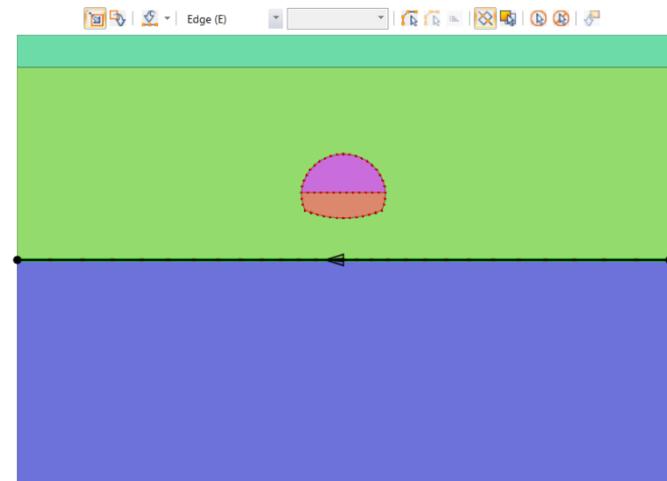
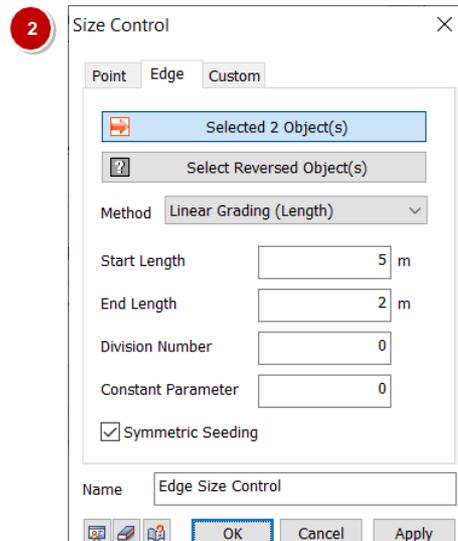
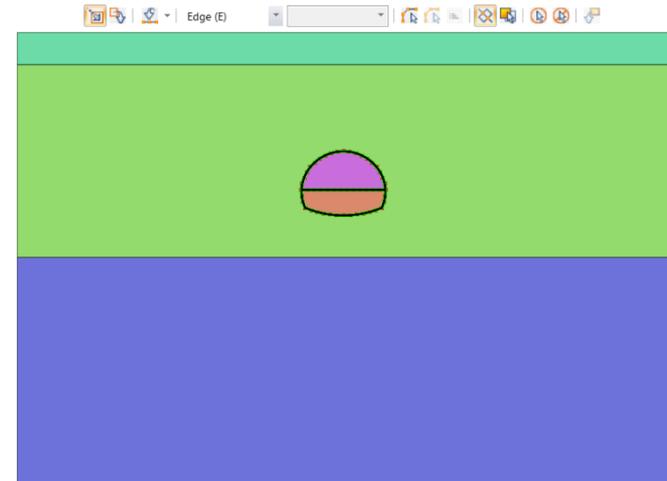
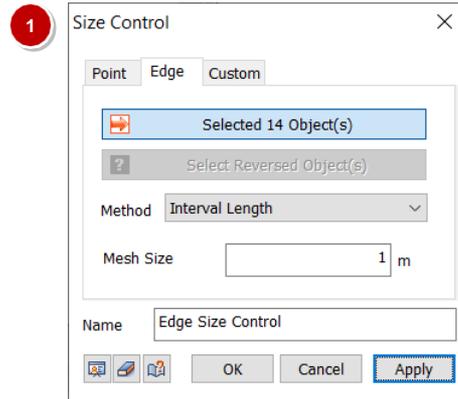
3 Tools > Geometry > Random Color



Procedure

Specify size of elements for the tunnel and soil layer.

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



Procedure

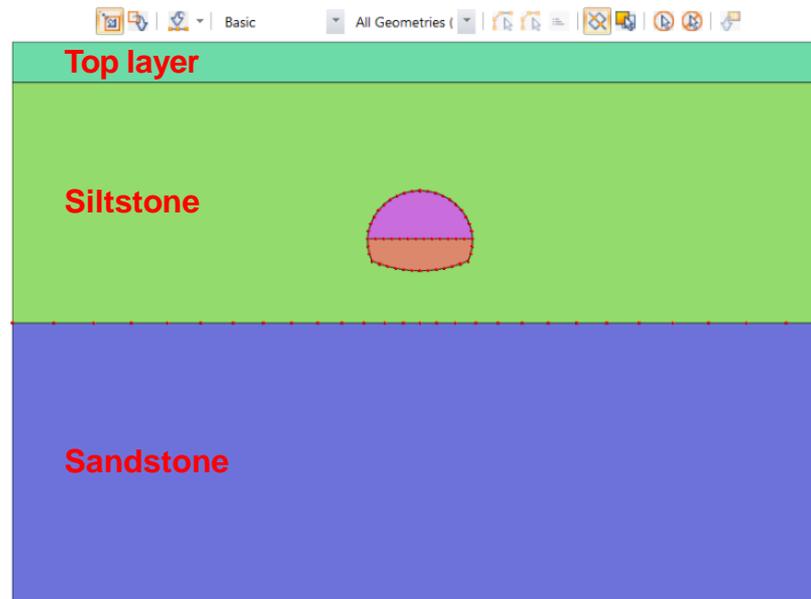
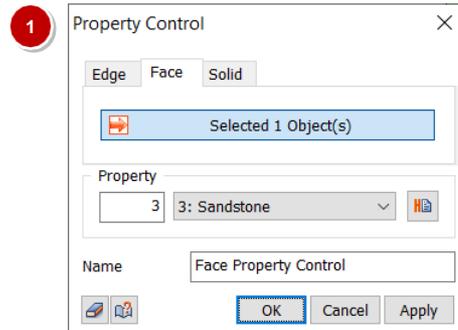
Pre-assign the soil properties before mesh generation.

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

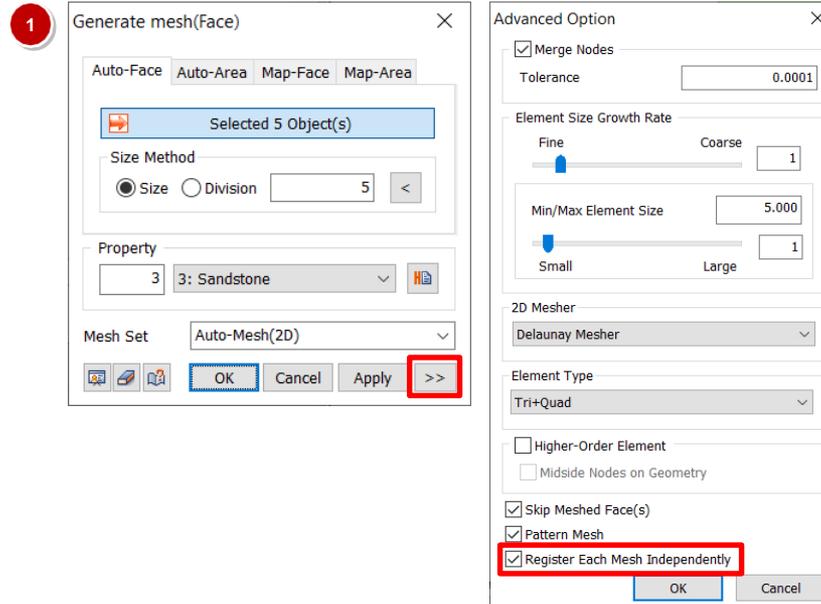
- Select: **Sandstone (1 surface)**
- Property: **3: Sandstone**
- OK



Procedure

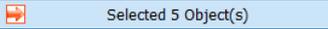
Generate mesh for soil layers.

- 1 **Mesh > Generate > 2D**
 - Auto-Face tab
 - Click **Advanced Option**
 - Check on: **Register Each Mesh Independently**
- Mesh Independently**
- OK
-
- Select: **all surfaces**
 - Size: **5 (m)**
 - OK



1 Generate mesh(Face) ×

Auto-Face Auto-Area Map-Face Map-Area

 Selected 5 Object(s)

Size Method
 Size Division <

Property
 3: Sandstone 

Mesh Set Auto-Mesh(2D) ▾

   **OK** Cancel Apply **>>**

Advanced Option ×

Merge Nodes
Tolerance

Element Size Growth Rate
Fine Coarse

Min/Max Element Size
Small Large

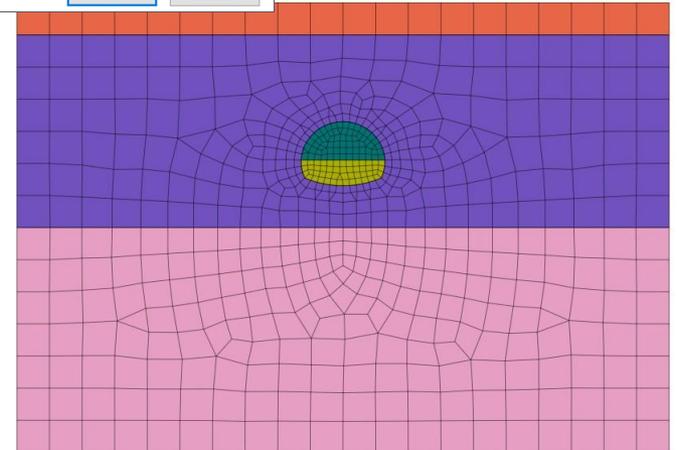
2D Mesher
Delaunay Mesher ▾

Element Type
Tri+Quad ▾

Higher-Order Element
 Midside Nodes on Geometry

Skip Meshed Face(s)
 Pattern Mesh
 Register Each Mesh Independently

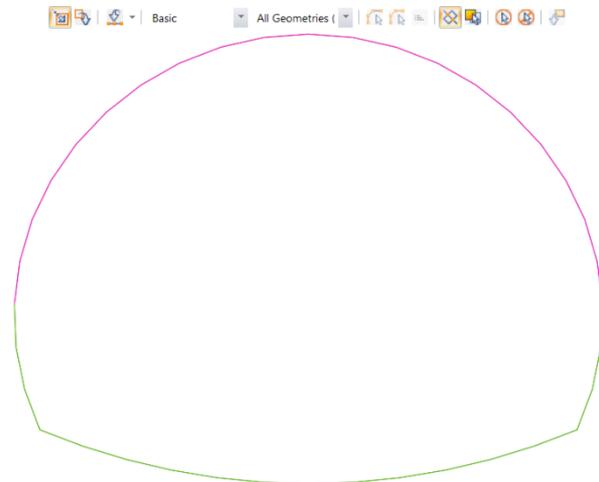
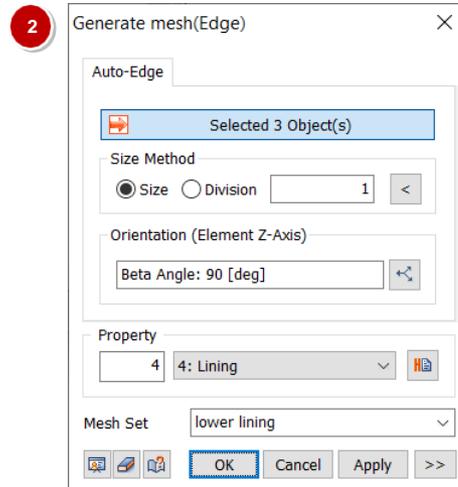
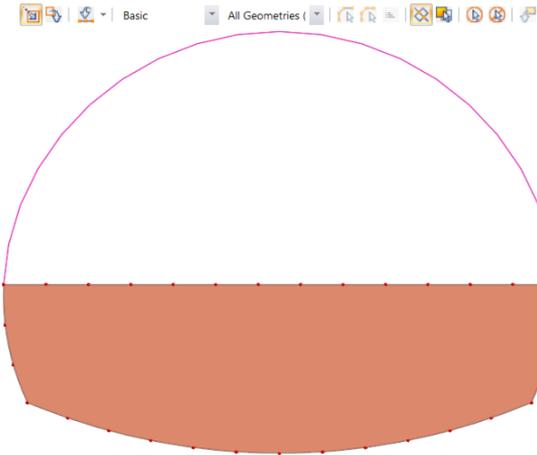
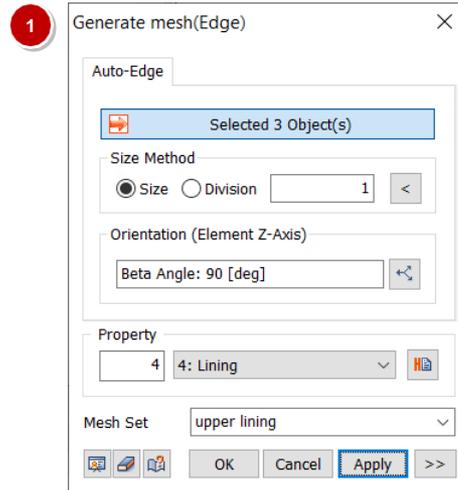
OK Cancel



Procedure

Generate mesh for lining.

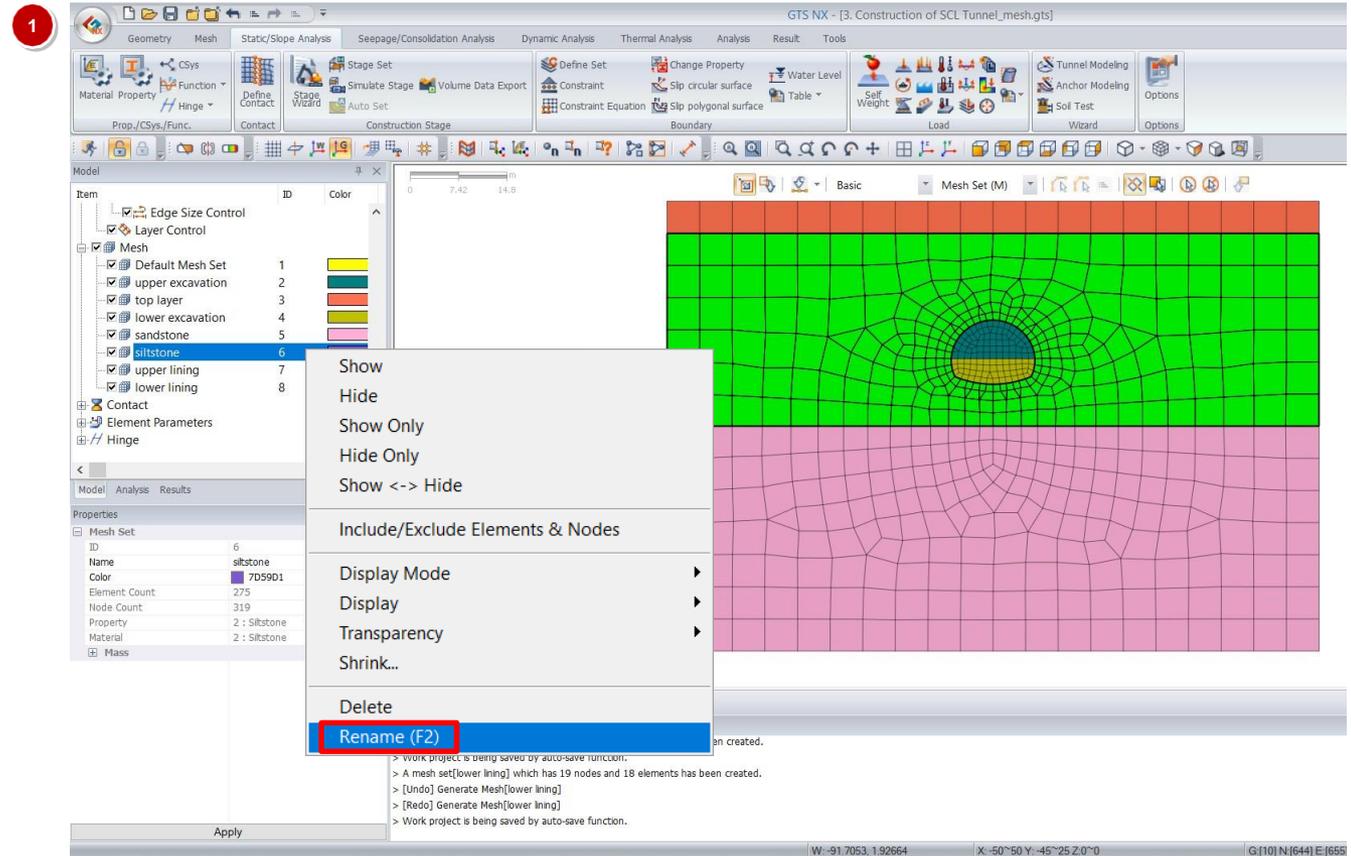
- 1 Mesh > Generate > 1D**
 - Hide all mesh sets
 - Show only tunnel surface under Geometry tree
 - Select: **3 lines (upper lining)**
 - Size: **1 (m)**
 - Property: **4: Lining**
 - Mesh Set: **upper lining**
 - Apply
- 2 - Select: 3 lines (lower lining and invert)**
 - Size: **1 (m)**
 - Property: **4: Lining**
 - Mesh Set: **lower lining**
 - OK



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

Item

ID	Color
1	Yellow
2	Green
3	Red
4	Orange
5	Purple
6	Pink
7	
8	

Properties

Mesh Set	
ID	6
Name	siltstone
Color	7DS9D1
Element Count	275
Node Count	319
Property	2 : Siltstone
Material	2 : Siltstone
Mass	

Model Analysis Results

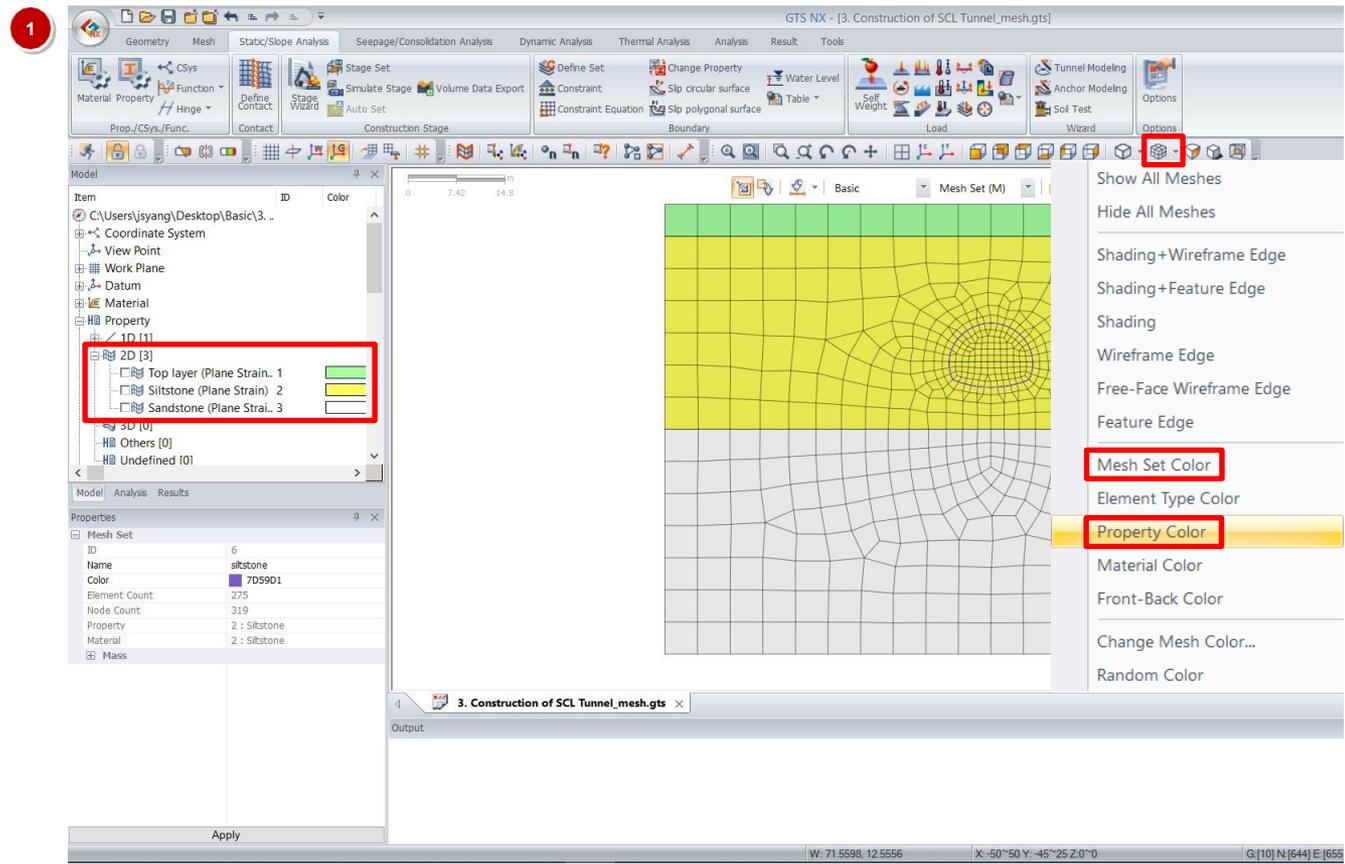
Apply

W: -91.7053, 1.92664 X: -50°50' Y: -45°25' Z: 0°0 G:[10] N:[644] E:[655]

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



Procedure

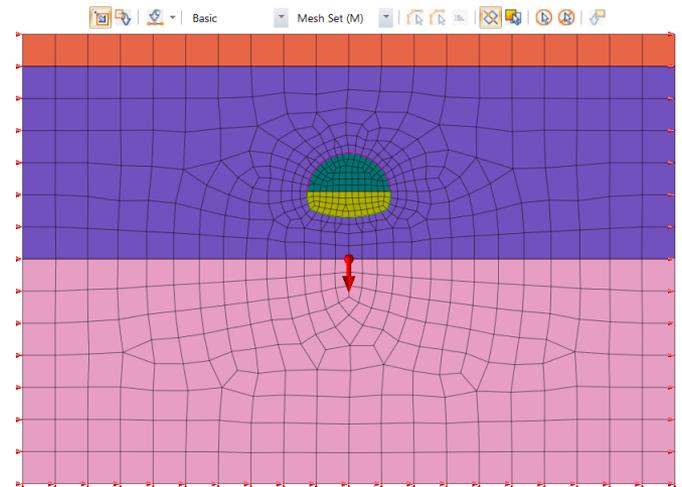
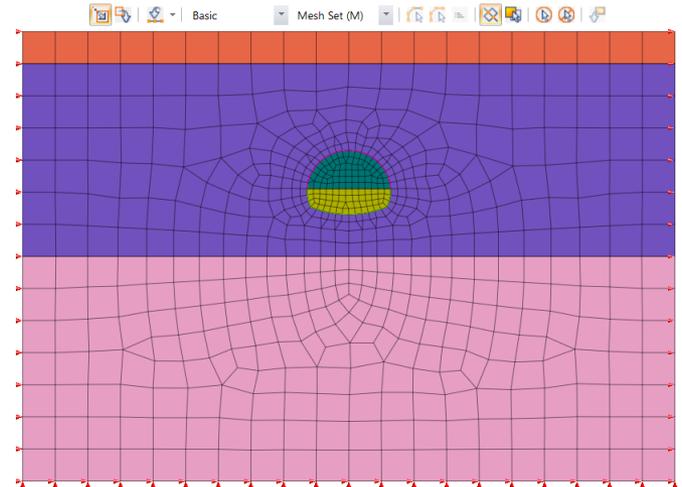
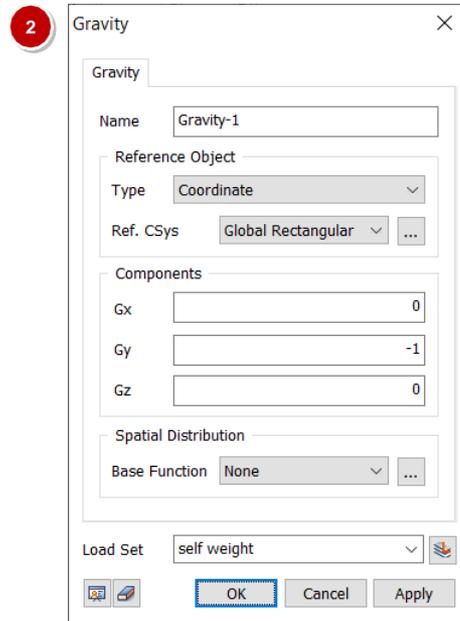
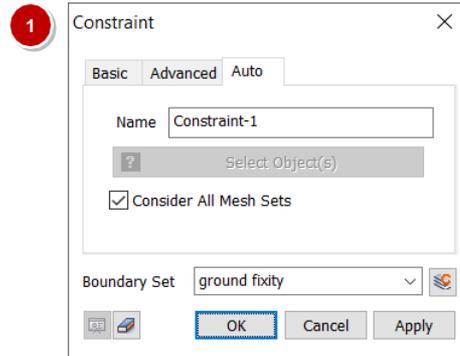
Assign constraints to model boundaries and create self weight.

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



Procedure

Assign constraints to model boundaries and create self weight.

1

Seepage/Consolidation Analysis > Boundary > Nodal Head

Object Type – Node

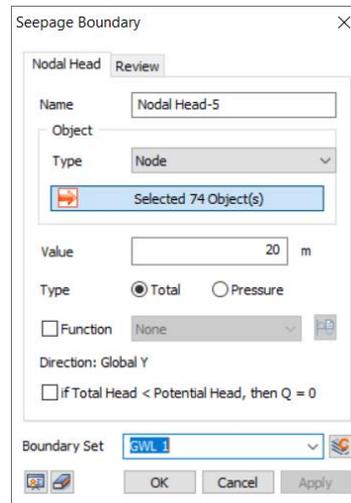
Select all the nodes on the vertical edges of the model.

- Value: **20 m**
- Boundary Set: **GWL 1**

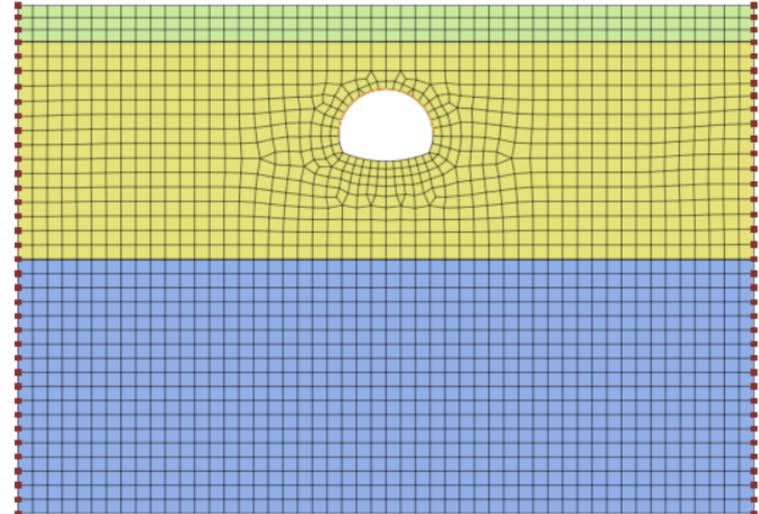
2

- OK

1



2



Procedure

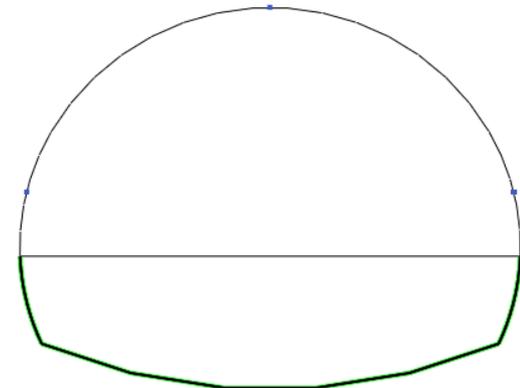
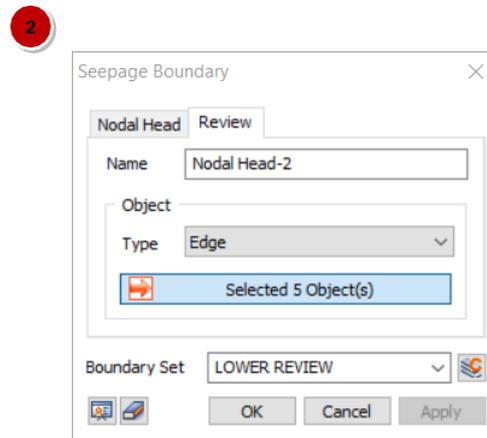
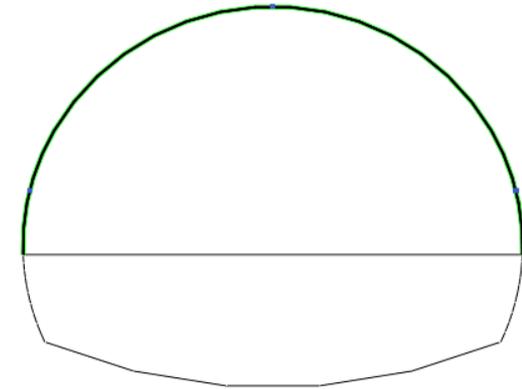
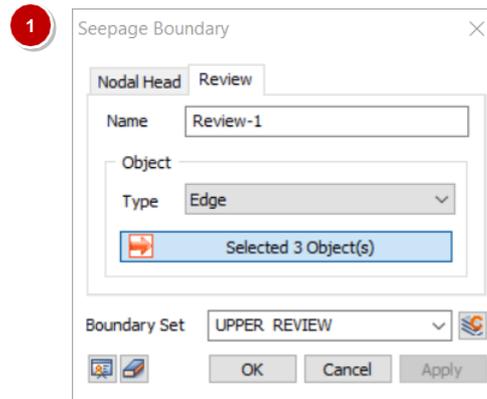
Assign constraints to model boundaries and create self weight.

1 Seepage/Consolidation Analysis > Boundary > Review

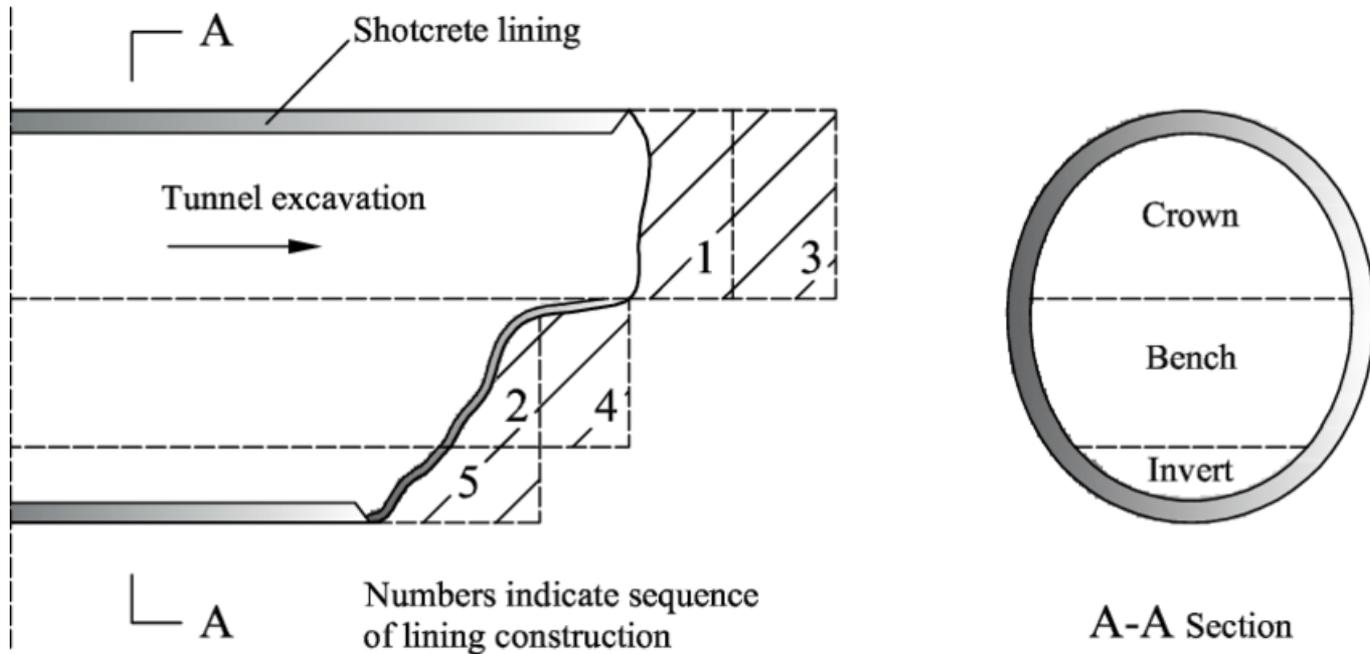
- Select the 3 edges forming the upper excavation.
- Boundary Set: **UPPER REVIEW.**
- OK

2 Seepage/Consolidation Analysis > Boundary > Review

- Select the 5 edges forming the lower excavation.
- Boundary Set: **LOWER REVIEW.**
- OK



Staged construction sequence



Tunnel built with New Austrian Tunneling Method (NATM)

06 Define Construction Stage

Procedure

Define construction stages of the SCL tunnel.

1 Static/Slope Analysis > Construction Stage > Stage Set

- Stage Type: **Stress Seepage Slope**

- Add

- Double click the

'Construction Stage Set-1'

2 - Stage Name: **IN SITU**

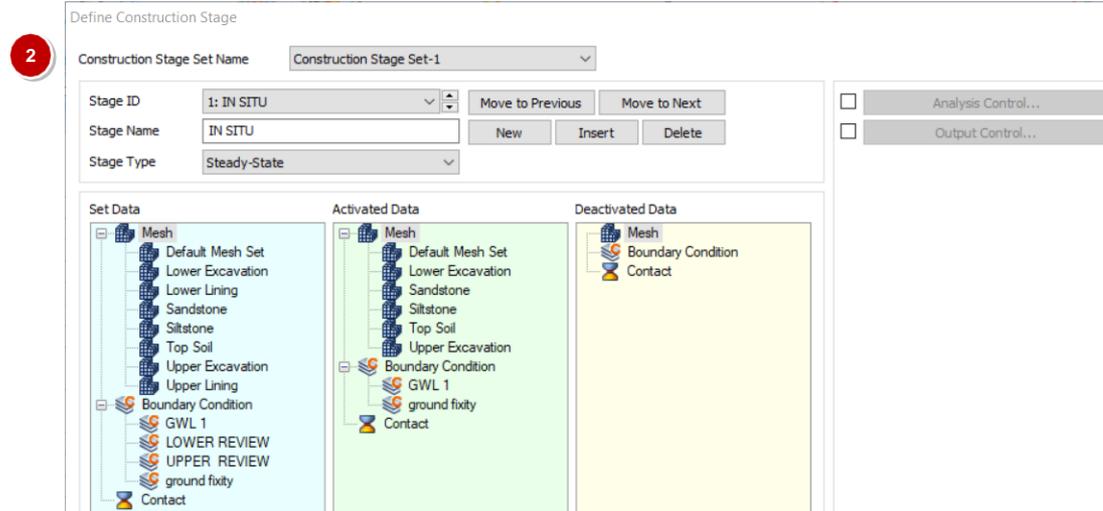
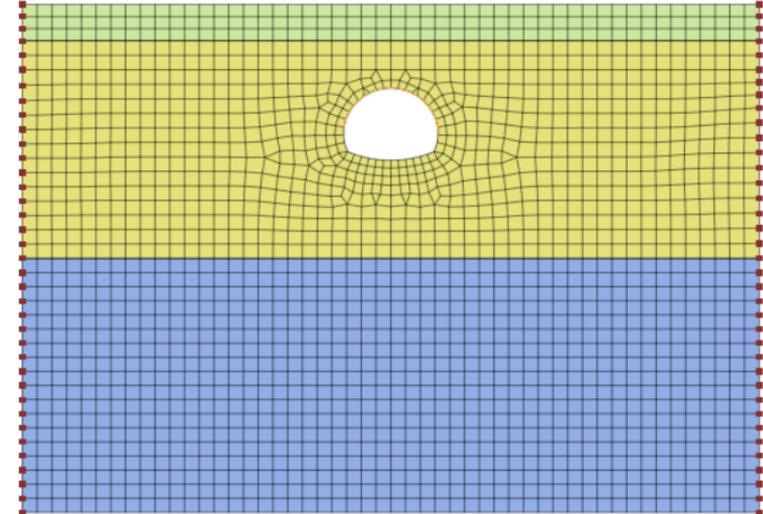
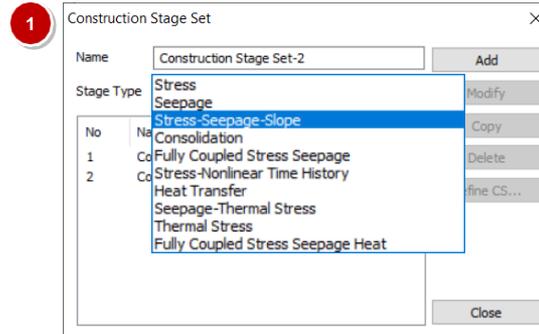
- Show Data: **Activate**

- Stage Type: **Steady State**

- Select mesh, boundary and load sets, and drag & drop them into 'Activated Data' from 'Set Data'. (as shown in the figure)

This stage is for calculating the initial seepage conditions of the ground.

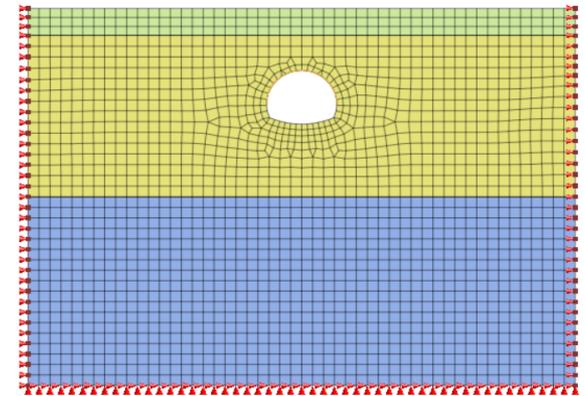
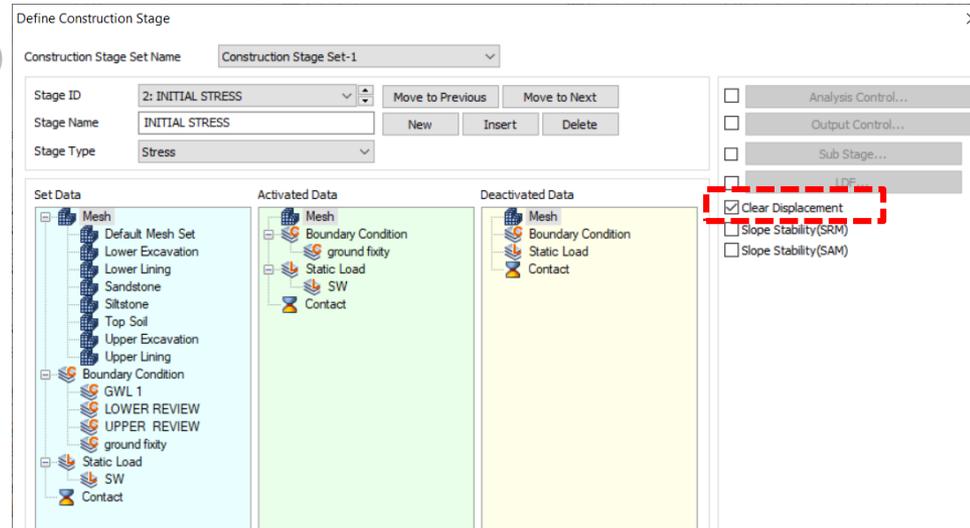
- Save



06 Define Construction Stage

Procedure

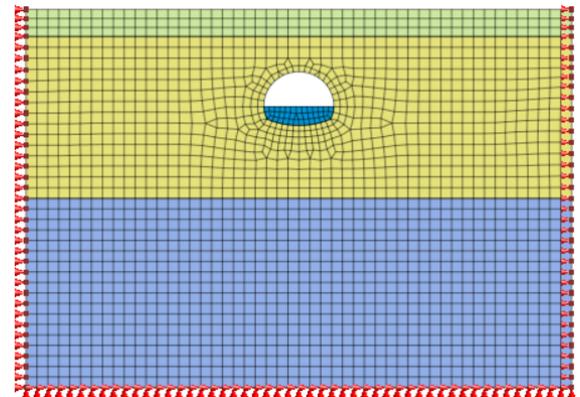
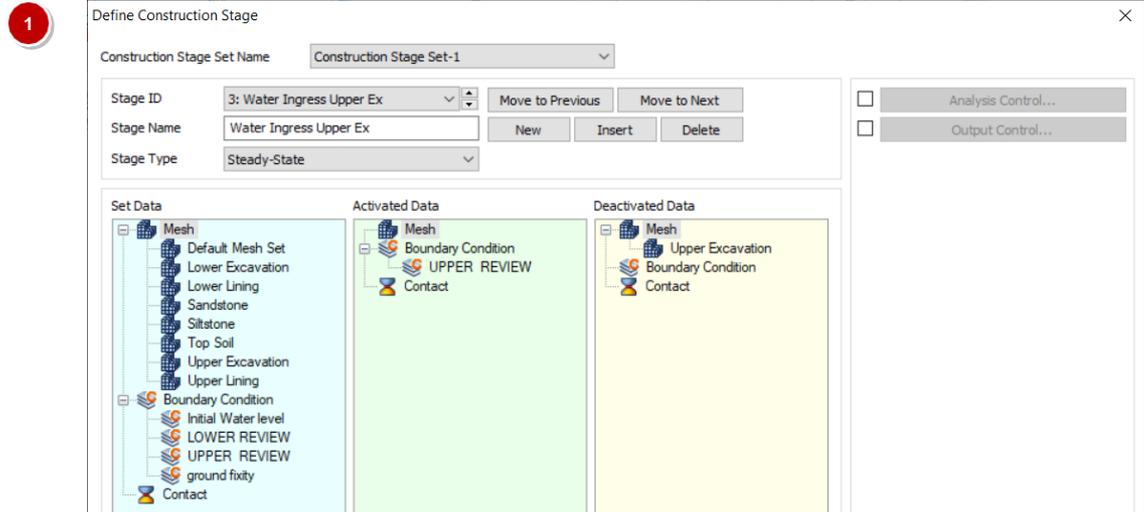
- 1 - New
-Stage Name: **Initial Stress**
-Stage Type: **Stress**
-Select ground boundary condition, and Loading condition and drag & drop it into 'Activated Data' from 'Set Data'. (as shown in the figure)
-Click on "**Clear Displacement**".
-This stage calculates the initial stress in the pre existing ground.
- Save



06 Define Construction Stage

Procedure

- 1 - New
- Stage Name: **Water Ingress Upper Ex**
- Stage Type: **Steady State**
- Select "UPPER REVIEW" and drag & drop it into 'activated Data' from 'Set Data' and Upper excavation into 'deactivated data' (as shown in the figure)
- Save

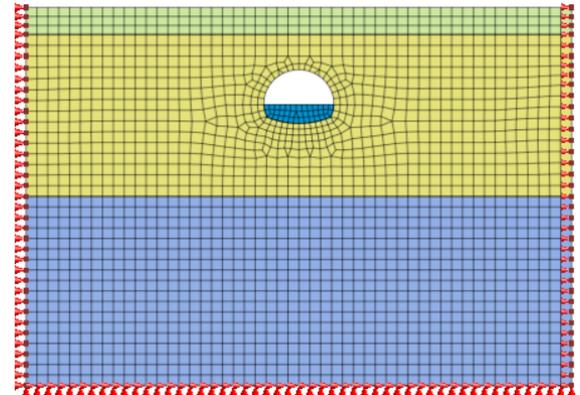
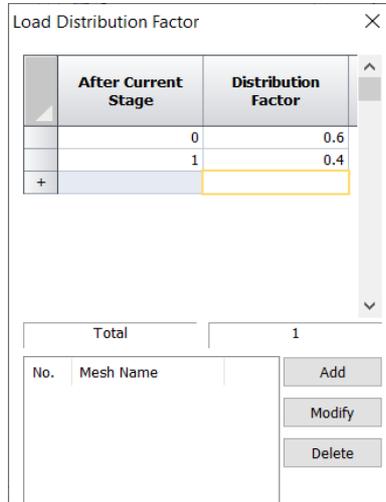
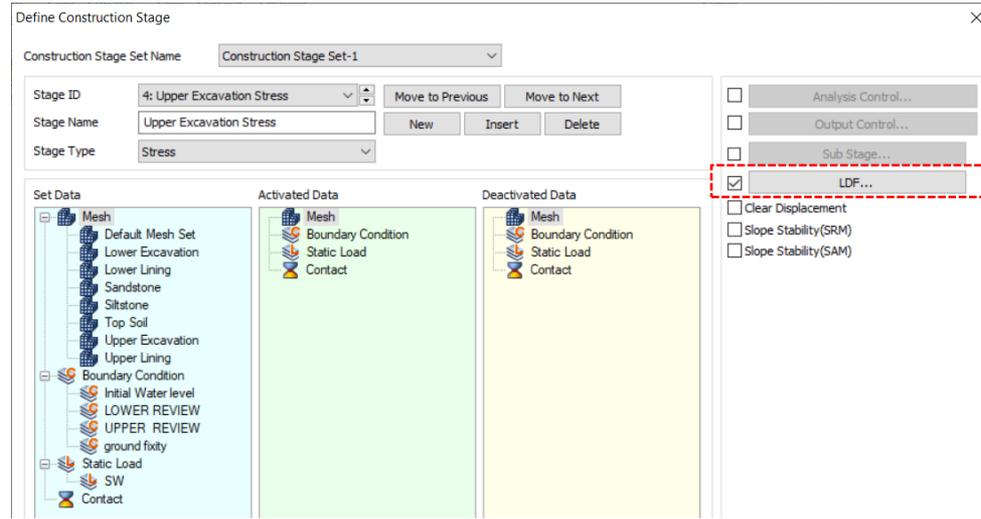


06 Define Construction Stage

Procedure

- 1 - New
- Stage Name: **Upper Excavation Stress**
- Stage Type: **Stress**
- Check on: **LDF**
- Load Distribution Factor
- Current stage: 0.6**
- Next stage: 0.4**
- OK
- Save

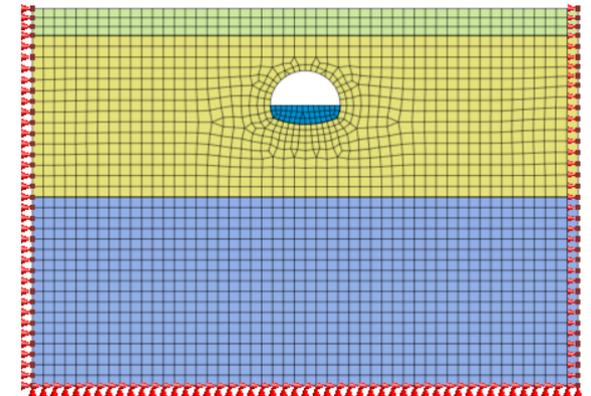
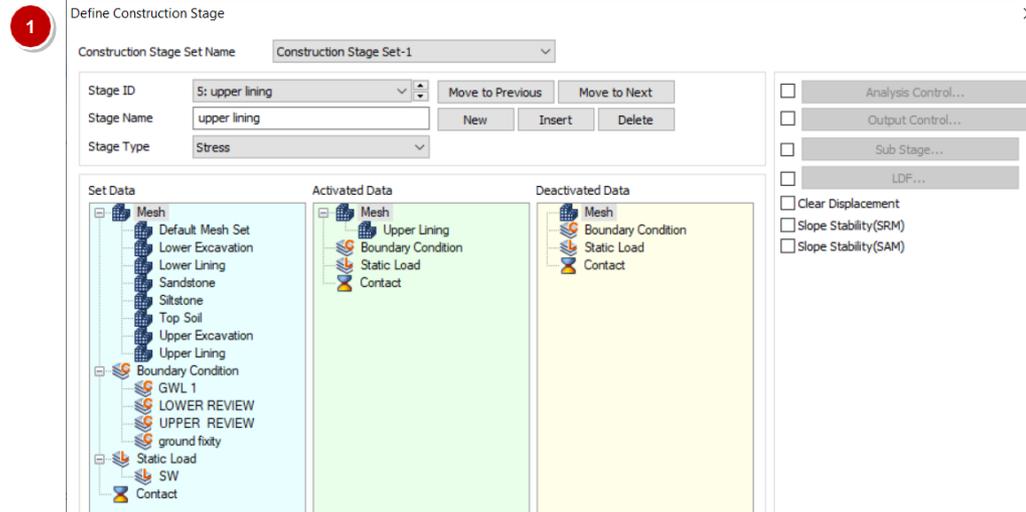
1



06 Define Construction Stage

Procedure

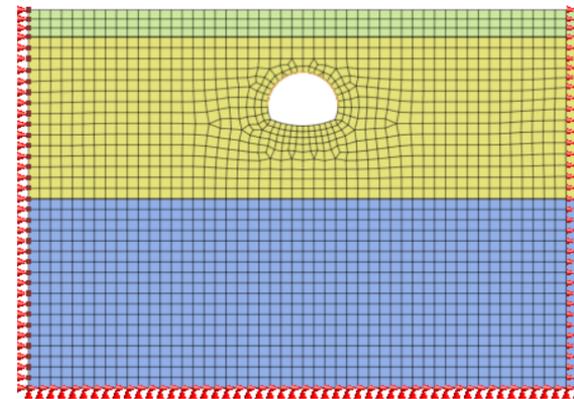
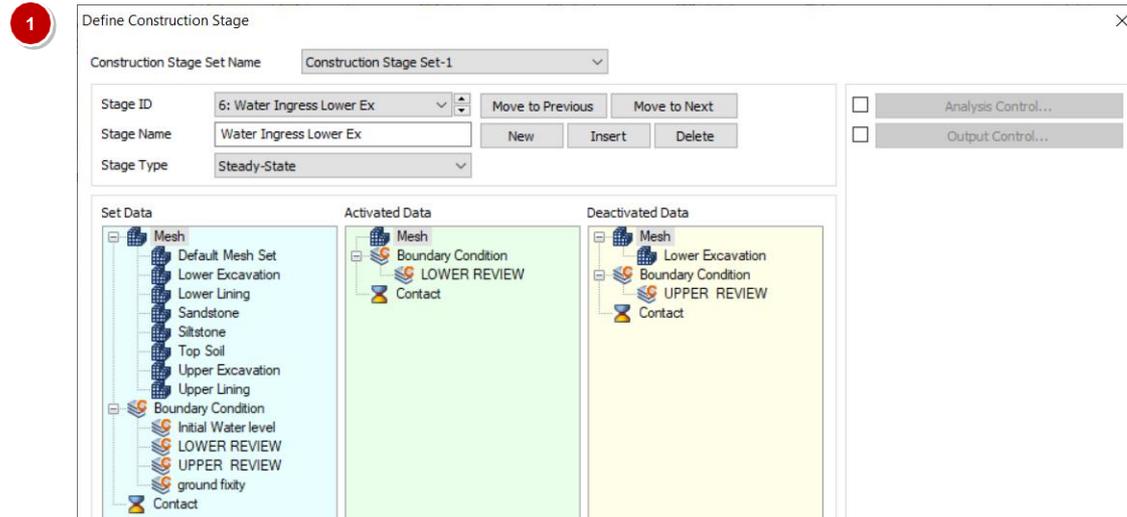
- 1 - New
- Stage Name: **upper lining**
- Stage Type: **Stress**
- Select Upper Lining, and drag & drop it into 'Activated Data' from 'Set Data'. (as shown in the figure)
- Save



06 Define Construction Stage

Procedure

- 1 - New
- Stage Name: **Water Ingress Lower Ex**
- Stage Type: **Steady State**
- Select “LOWER REVIEW” and drag & drop it into ‘activated Data’ and Select “UPPER REVIEW” and “Lower Excavation” and drag & drop it into ‘deactivated Data’ from ‘Set Data’. (as shown in the figure)
- Save



06 Define Construction Stage

Procedure

- 1 - New
- Stage Name: **Lower Excavation Stress**
- Stage Type: **Stress**
- Check on: **LDF**
- Load Distribution Factor
- Current stage: 0.6**
- Next stage: 0.4**
- OK
- Save

1

Define Construction Stage

Construction Stage Set Name: Construction Stage Set-1

Stage ID: 7: Lower Excavation Stress | Move to Previous | Move to Next

Stage Name: Lower Excavation Stress | New | Insert | Delete

Stage Type: Stress

Set Data

- Mesh
 - Default Mesh Set
 - Lower Excavation
 - Lower Lining
 - Sandstone
 - Siltstone
 - Top Soil
 - Upper Excavation
 - Upper Lining
- Boundary Condition
 - Initial Water level
 - LOWER REVIEW
 - UPPER REVIEW
- Static Load
 - ground fixity
- SW
 - Contact

Activated Data

- Mesh
- Boundary Condition
- Static Load
- Contact

Deactivated Data

- Mesh
- Boundary Condition
- Static Load
- Contact

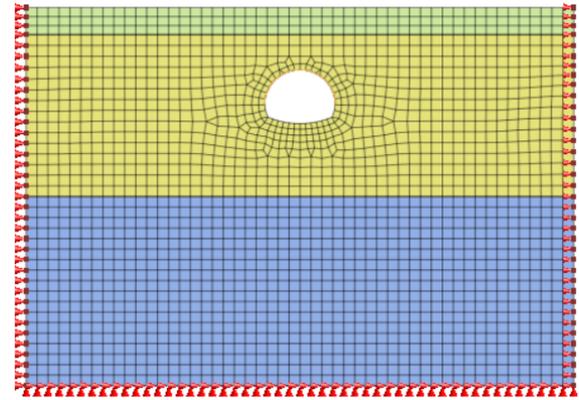
Analysis Control...
 Output Control...
 Sub Stage...
 LDF...
 Clear Displacement
 Slope Stability(SRM)
 Slope Stability(SAM)

Load Distribution Factor

After Current Stage	Distribution Factor
0	0.6
1	0.4
+	

Total: 1

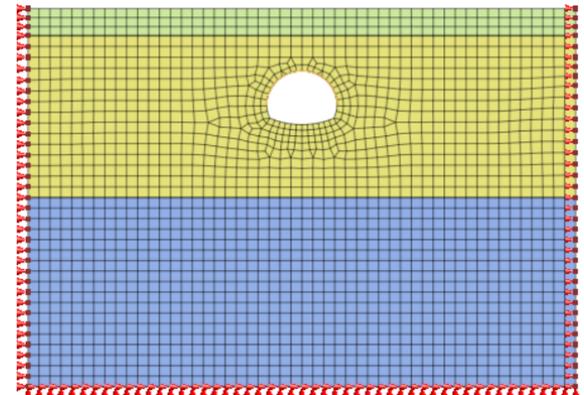
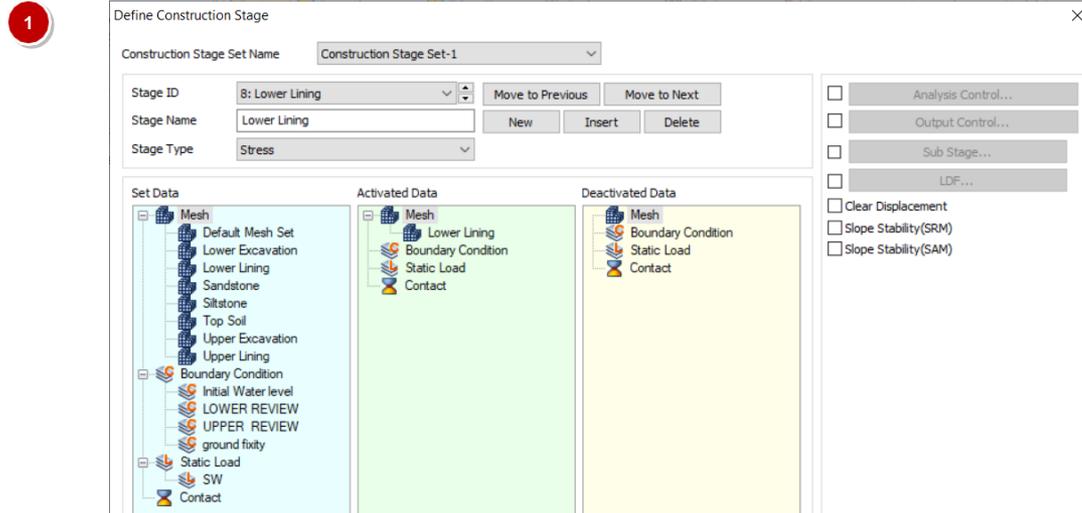
No.	Mesh Name
Add	
Modify	
Delete	



06 Define Construction Stage

Procedure

- 1 - New
- Stage Name: **lower lining**
- Stage Type: **Stress**
- Select Lower Lining and drag & drop it into 'Activated Data' from 'Set Data'. (as shown in the figure)
- Save
- Close



Procedure

1 Analysis > Analysis Case > General

- Title: **SCL tunnel**
- Solution Type: **Construction Stage**
- Analysis Control
- Check on: **Initial Stage for Stress Analysis**
- Initial Stage: **2:initial stress**
- Check on: **Apply K0 Condition & Cut Off Negative Effective Pressure.**
- OK
- OK

2 Analysis > Analysis > Perform

- Check on: **Analysis Case**
- OK

1

2

	Name	Type	Description
<input checked="" type="checkbox"/>	SCL tunnel	Construction Stage	

Procedure

Check displacement of ground.

- 1 lower lining > Displacement > TOTAL TRANSLATION (V)

Result > General > Smooth: Fringe

Result > General > Deform: Undeformed

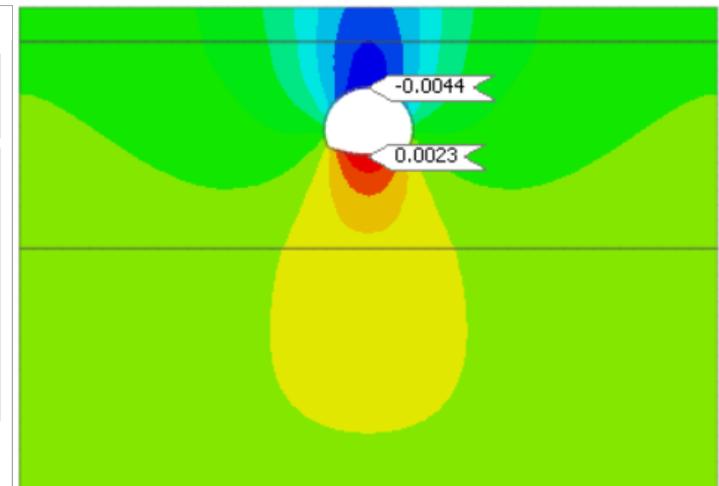
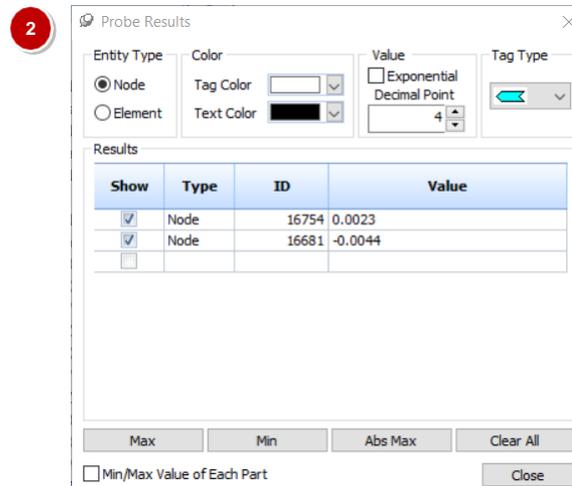
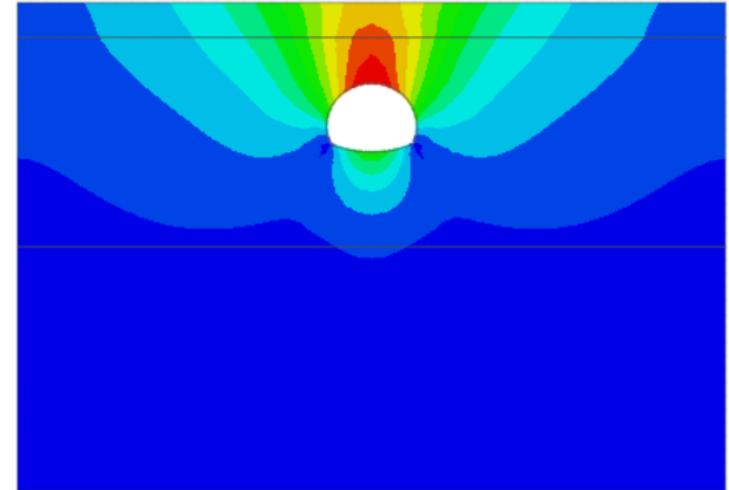
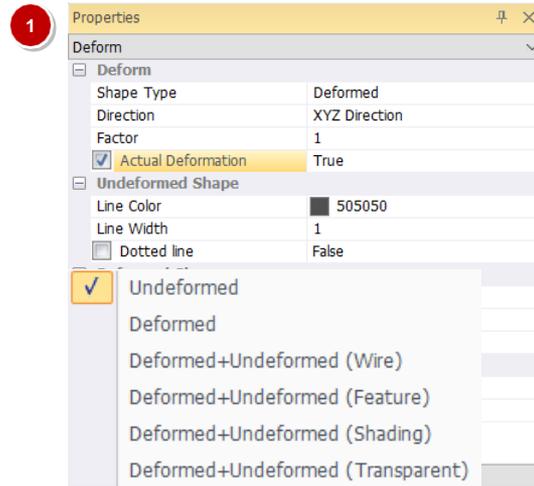
Result > Show/Hide > Actual Deformation

Properties > Deform

- 2 lower lining > Displacement > TY TRANSLATION (V)

Result > Advanced > Probe

- Max
- Min



Procedure

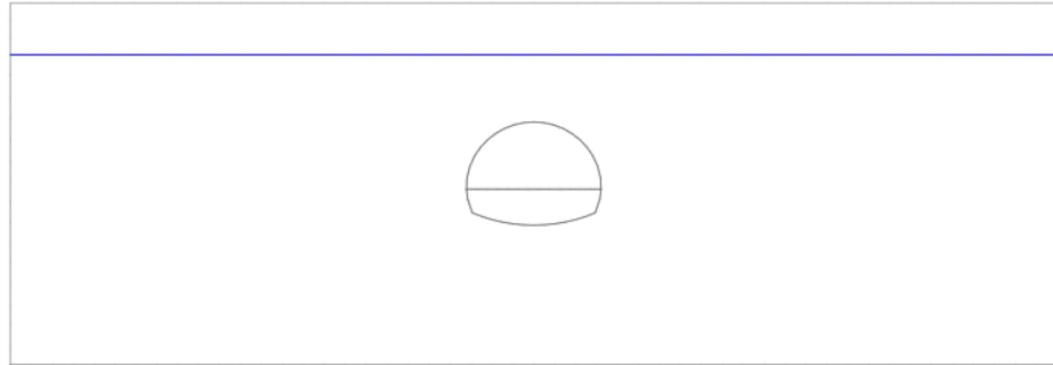
Check phreatic line inside the ground.

1 IN SITU> Nodal Seepage Results> Phreatic Line/Face

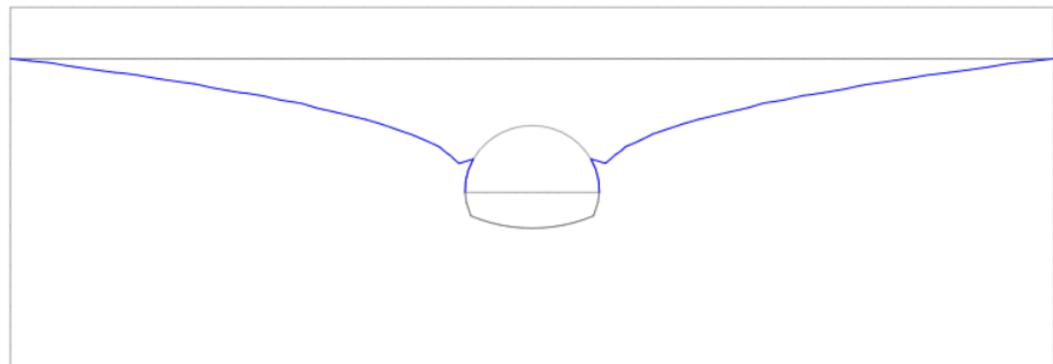
2 Water Ingress Upper Ex > Nodal Seepage Results> Phreatic Line/Face

3 Water Ingress Lower Ex > Nodal Seepage Results> Phreatic Line/Face

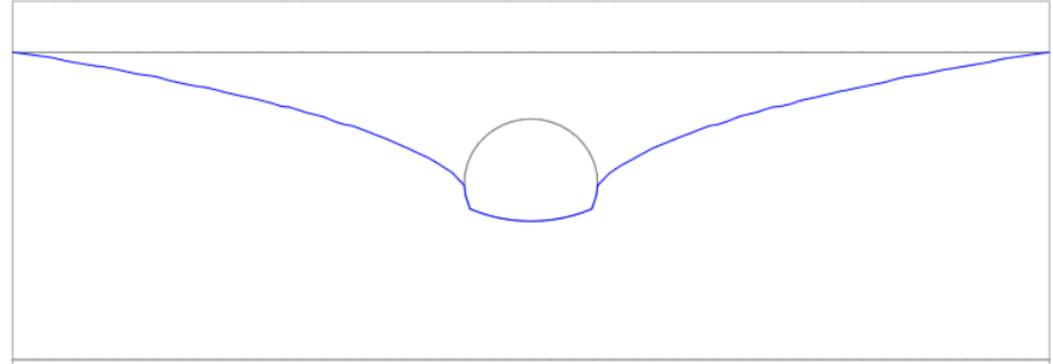
1



2



3



Procedure

Check the seepage flow of water into the tunnel.

- Water Ingress Upper Ex > Nodal Seepage Results > Flow Rate

Result > Advanced > Probe

- Abs. Max

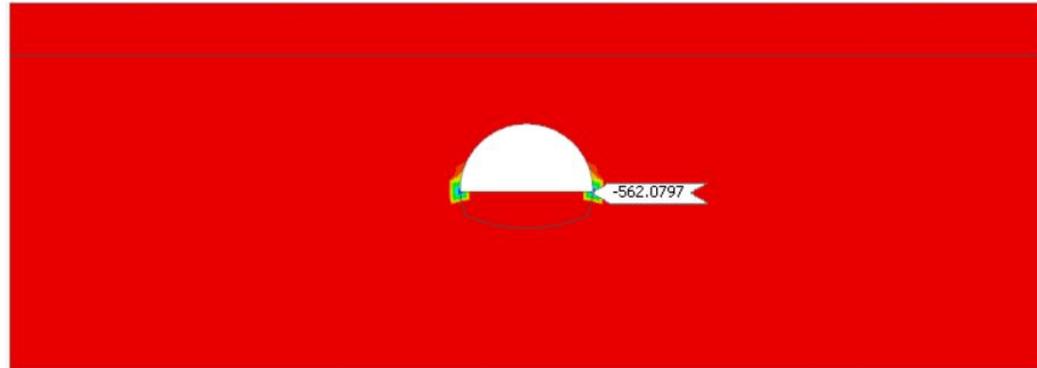
- Water Ingress Lower Ex > Nodal Seepage Results > Flow Rate

Result > Advanced > Probe

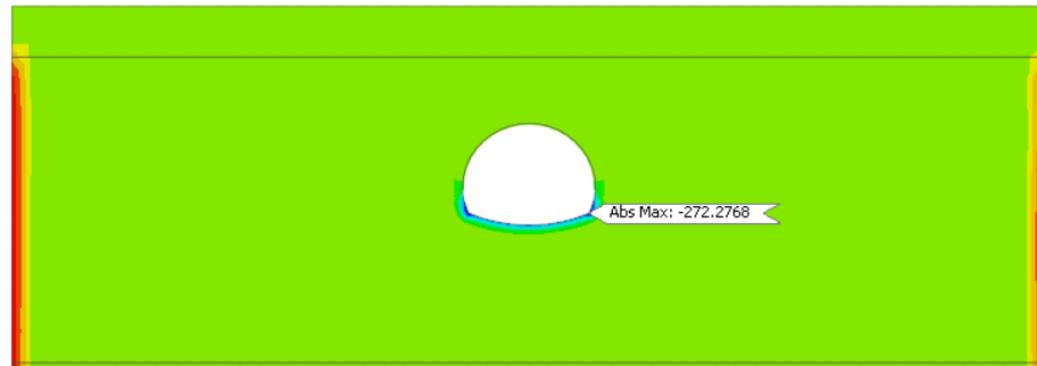
- Abs. Max

Change the unit from “m” to “mm”.

1



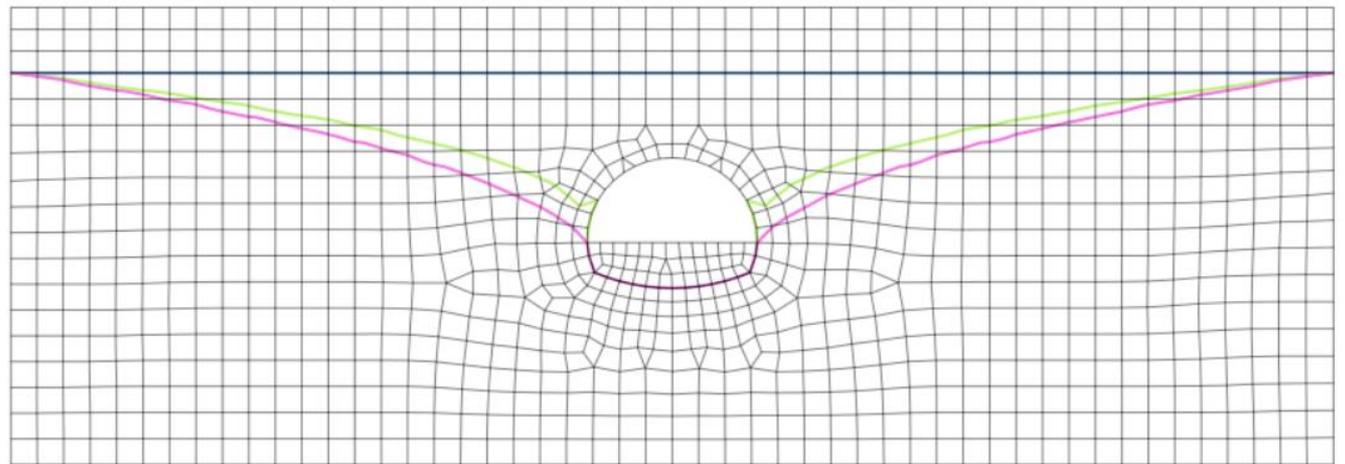
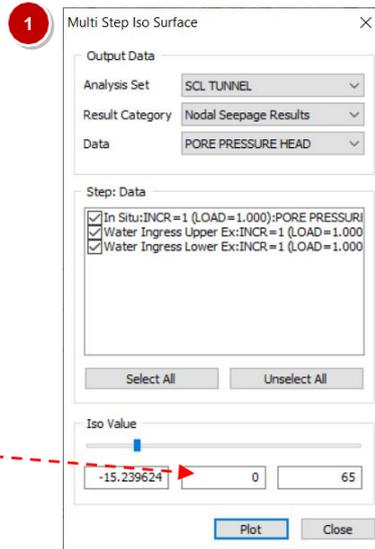
2



Procedure

1 Result > Advanced > Multi Step ISO

- Analysis Set – **SCL Tunnel**
- Result Category – **Nodal Seepage Results**
- Data – **Pore Pressure Head**
- Enter value as “0” (as shown in figure)
- Plot
- Close.



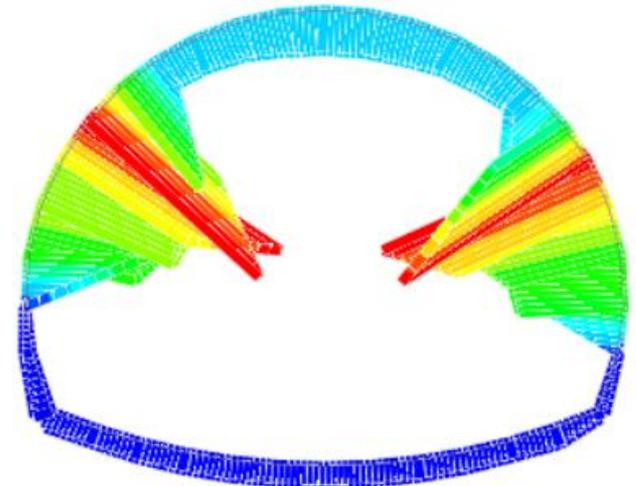
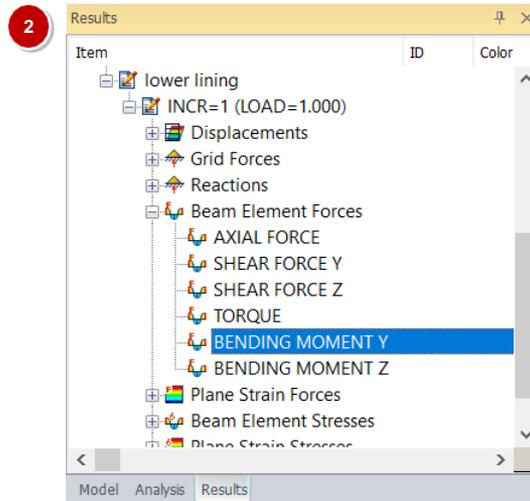
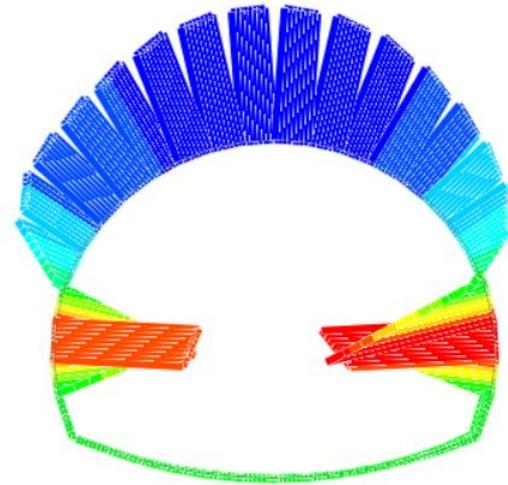
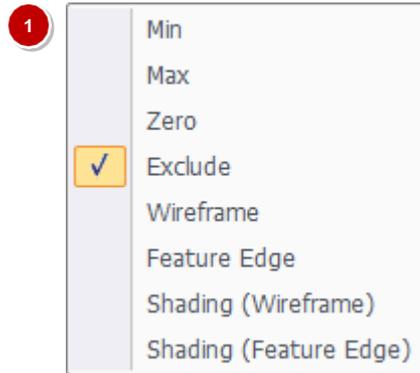
Procedure

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



CERTIFICATION TASK GUIDELINES

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MODEL DATA & TASK FILES INSTALLATION DATE – 11TH AUGUST

SUBMISSION ONLY VIA LINK, MAIL SUBMISSIONS NOT ACCEPTED

SUBMISSION DATE : 20th AUGUST

- GTS NX Certification task for participants involves submission of file (.docx or .pdf) with :
 - Generating the model as shown in tutorial.
 - Images/3D PDF report in the output.
 - Short summary of model creation, and results.

SUBMISSION DATE : 20th AUGUST

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REMAIN THE SAME THROUGHOUT ALL THE SUBMISSIONS.**