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New eXperience of Geo-Technical analysis System

Construction of Segmental Tunnel Lining

MIDAS

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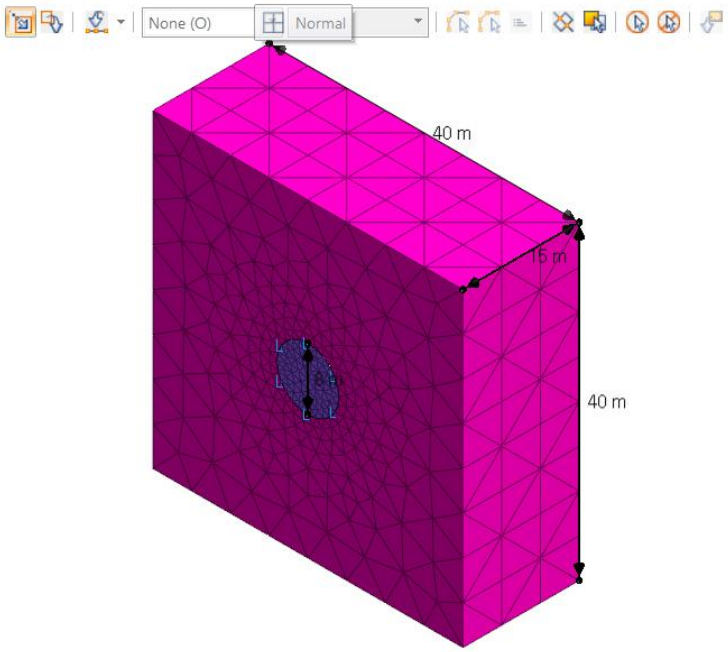
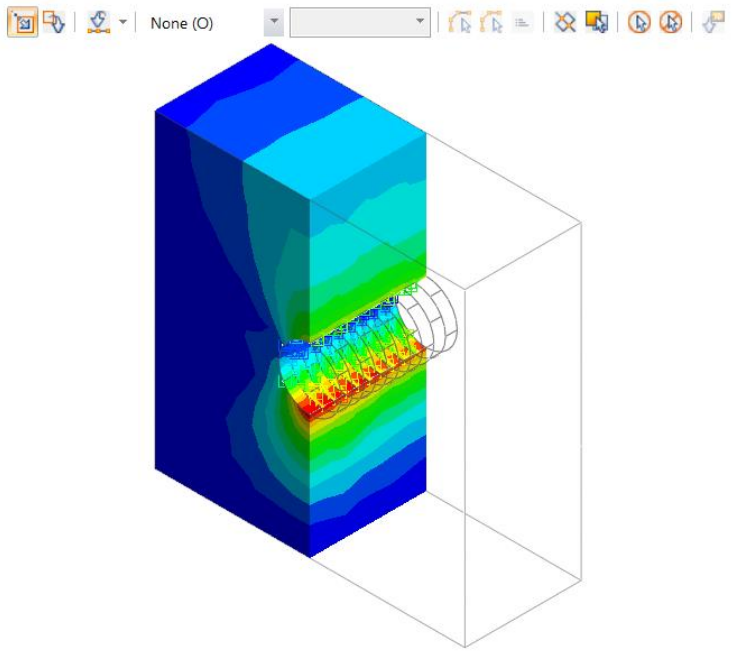
Modelling and Analysis Summary

This tutorial demonstrates the 3D simulation of the construction of a segmental tunnel lining. The tunnel consists of ten rings with six segments each. For the placement of each ring, the slice of soil is excavated and the ring with segments is installed simultaneously. Nonlinear line interfaces with Janssen model are available for the bending stiffness of the joints between the segments.





)0), [UNIT] kN, m

Soil Layers

[unit : kN, m]

Name	Soil
Material Model	Mohr-Coulomb
General	
Elastic Modulus(E) [kN/m^2]	1e+06
Poisson's Ratio(v)	0.3
Unit Weight(γ_t) [kN/m^3]	20
K0	0.5
Groundwater	
Unit Weight(γ_{sat}) [kN/m^3]	21
Drainage Parameters	Drained
Non-Linear	
Cohesion(c) [kN/m^2]	10
Frictional Angle(Φ) [deg]	30
Dilatancy Angle(Φ) [deg]	0
Tensile Strength [kN/m^2]	0

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Structure

[unit : kN, m]

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

Connection

[unit : kN, m]

Name	Segment connection
Model Type	Shell Interface
Normal Stiffness Modulus (K_n) [kN/m^3]	1e+09
Shear Stiffness Modulus (K_t) [kN/m^3]	1e+09
Thickness [m]	0.2

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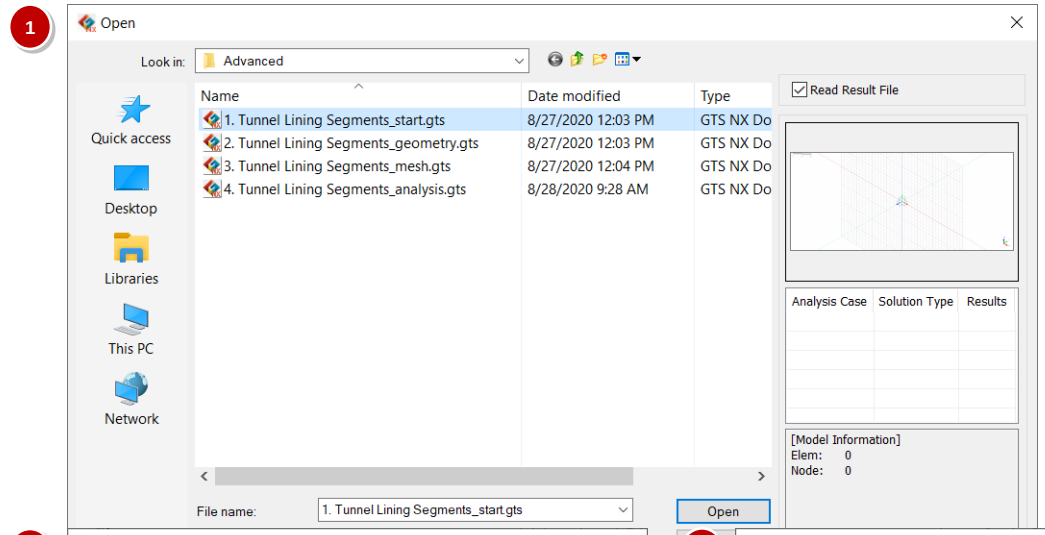
Procedure

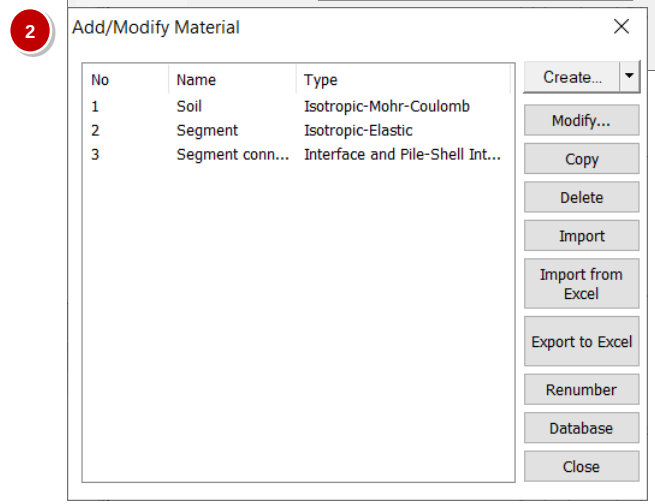
Start the tutorial by opening the start file in which the materials and properties have already been predefined.

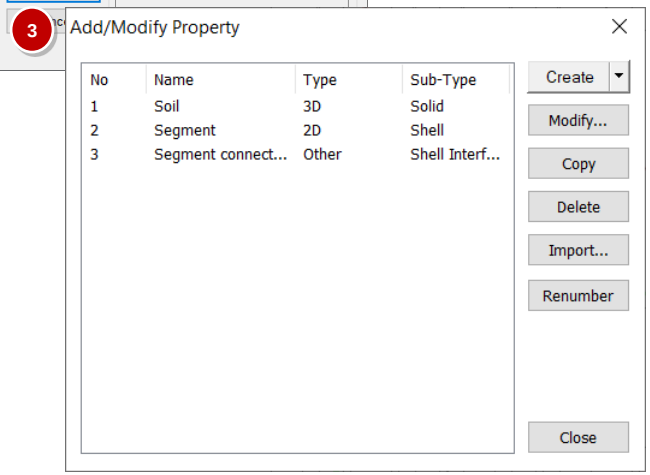
1. **File > Open**
   - Select **'1. Tunnel Lining Segments_start.gts'**
   - Open

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

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







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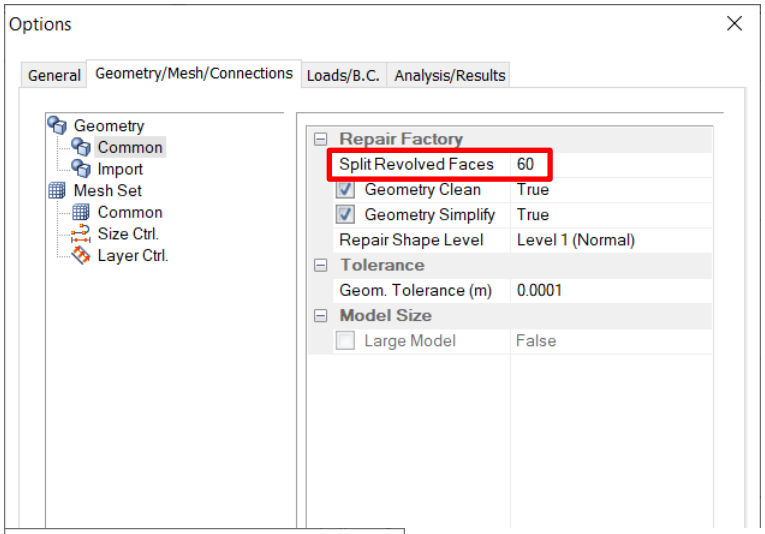
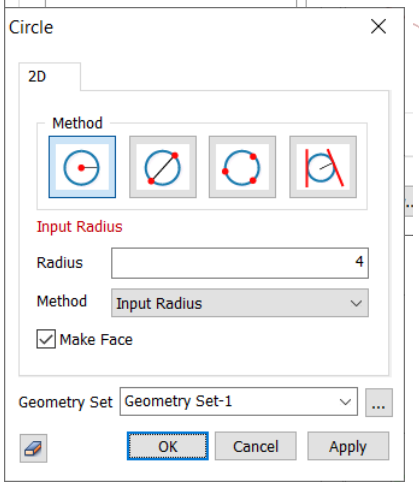
Procedure

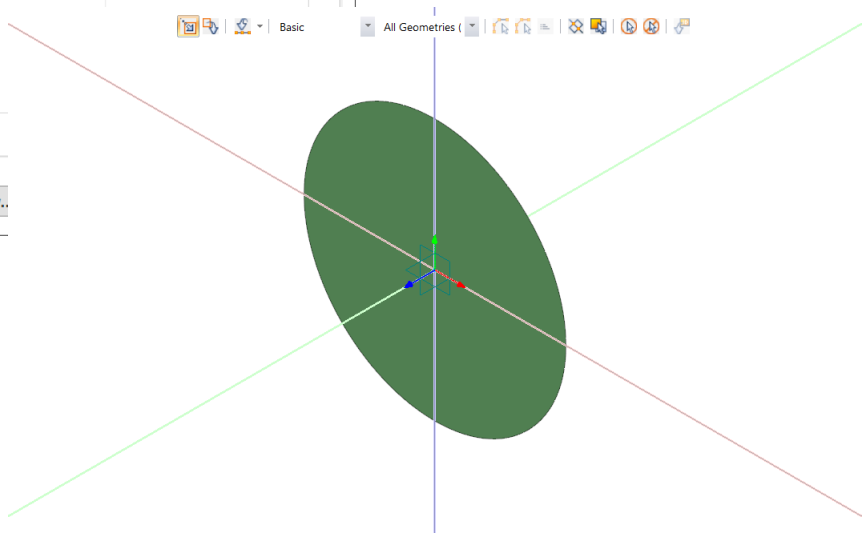
Create a tunnel section considering six segments.

1. **Tools > Options**
   - Geometry/Mesh/Connections tab
   - Split Revolved Faces: **60°**
   - OK

2. **Geometry > Point & Curve > Circle**
   - Check on: **Make Face**
   - Location: (**0,0**)
   - Radius: **4 (m)**
   - OK







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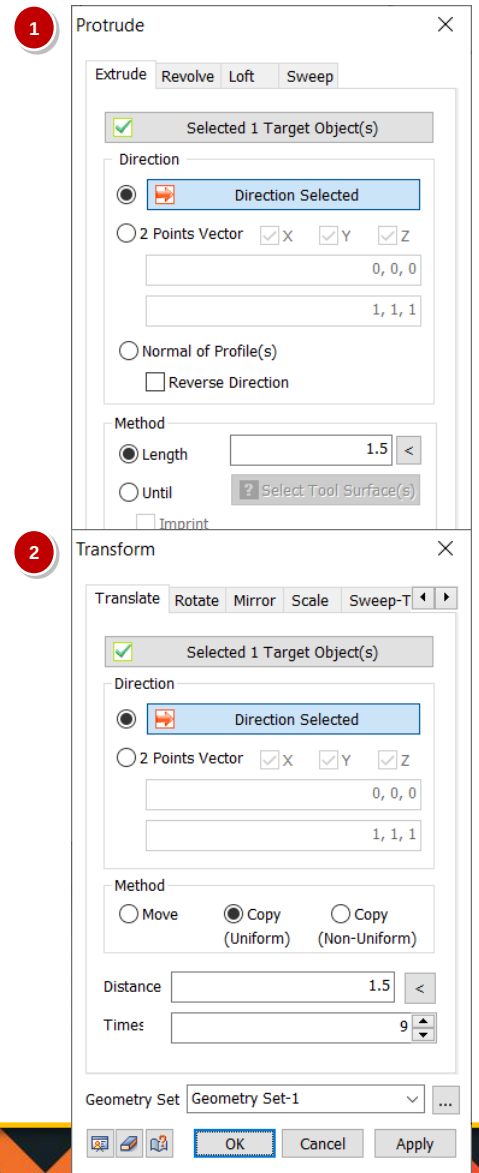
Procedure

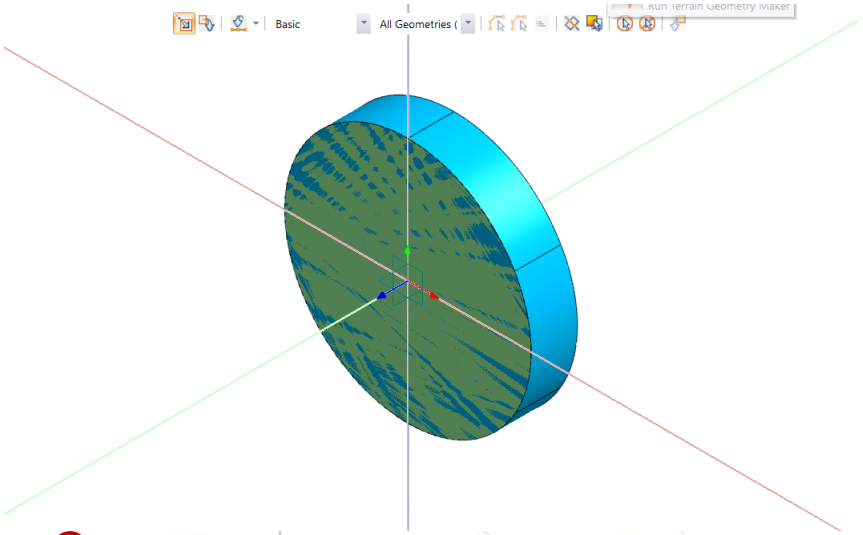
Create slices for tunnel excavation.

1. **Geometry > Protrude > Extrude**
   - Target: **1 surface**
   - Direction: **Y-axis**
   - Length: **1.5 (m)**
   - OK

2. **Geometry > Transform > Translate**
   - Target: **1 solid (slice)**
   - Direction: **Y-axis**
   - Select: **Copy(Uniform)**
   - Distance: **1.5 (m)**
   - Times: **9**
   - OK

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





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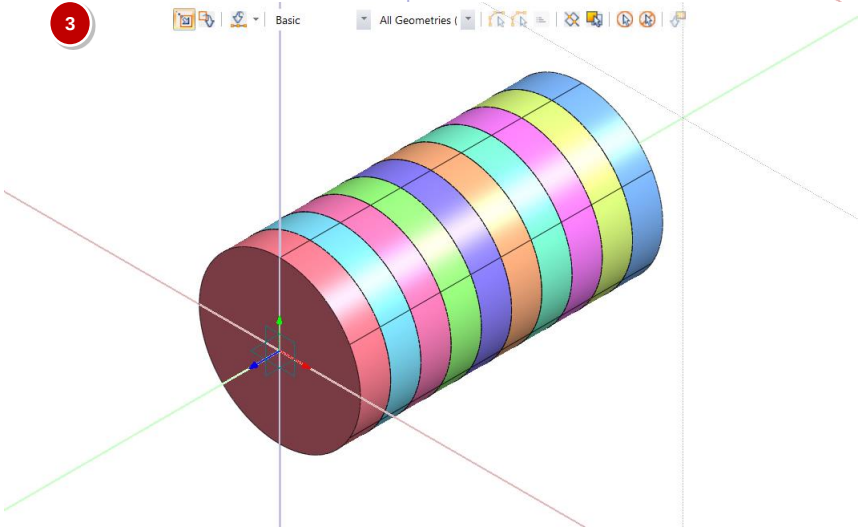
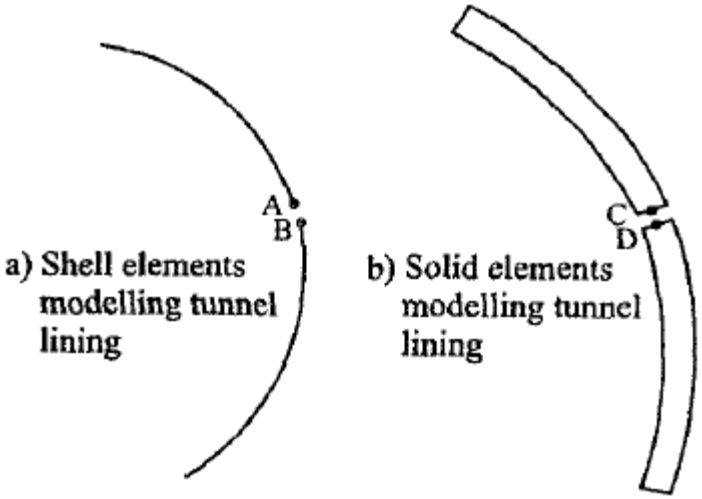
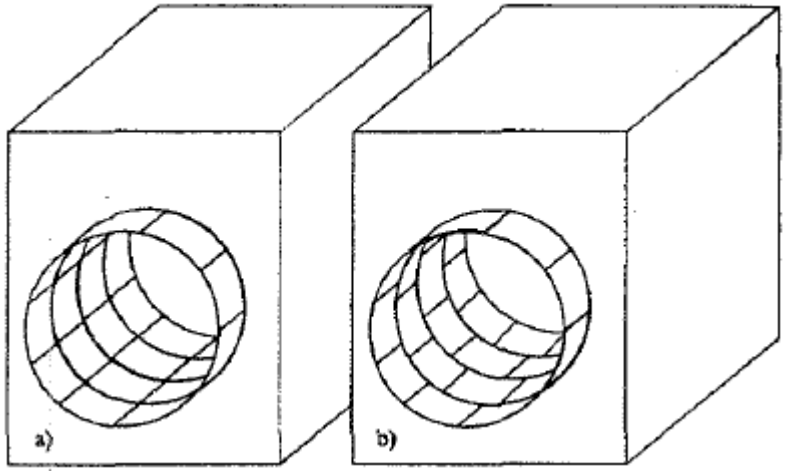


Modelling the connections between lining segments



Modelling segment connection as a moment-free joint



Unrolled and rolled tunnel lining

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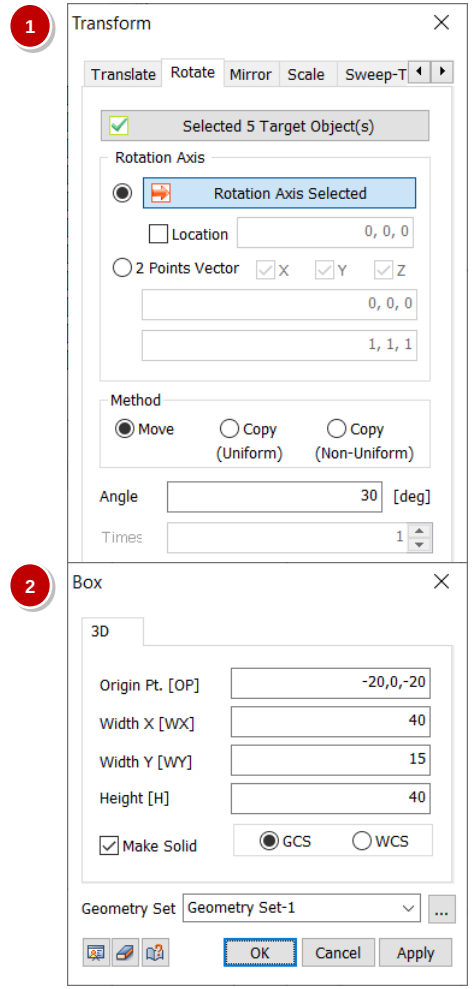
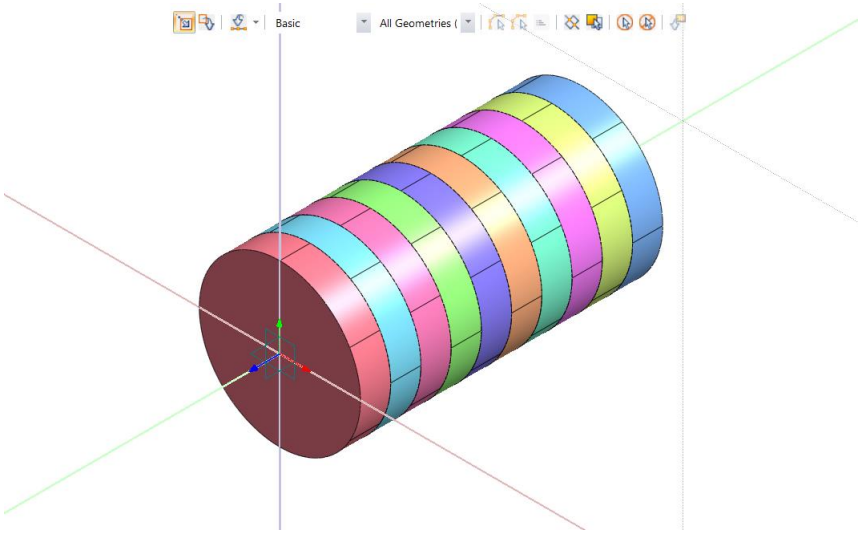
Procedure

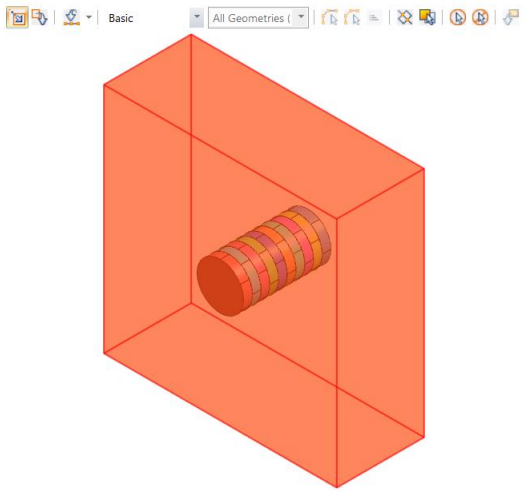
Rotate slices and create model boundaries.

1. **Geometry > Transform > Rotate**
   - Target: **5 solids (slice 2,4,6,8,10)**
   - Rotation Axis: **Y-axis**
   - Select: **Move**
   - Angle: **30°**
   - OK

2. **Geometry > Surface & Solid > Box**
   - Origin Point: **-20,0,-20**
   - Width X: **40**
   - Width Y: **15**
   - Height: **40**
   - OK







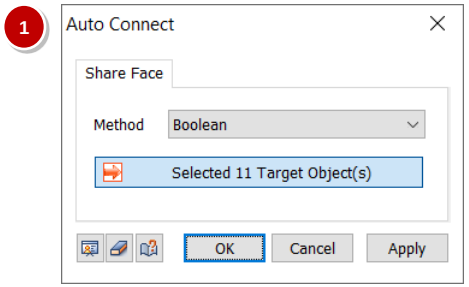
Procedure

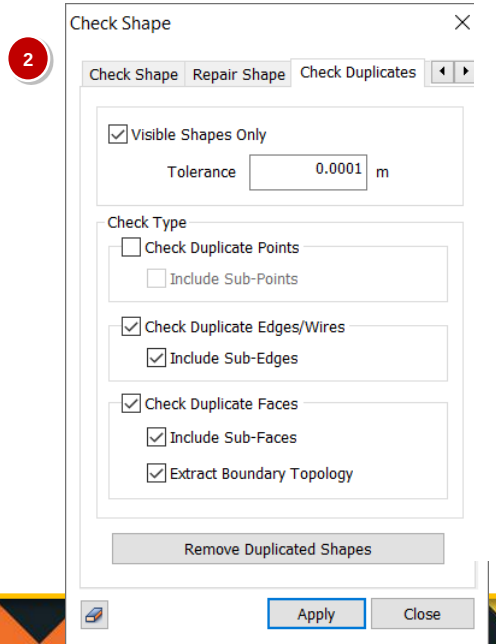
Automatically create shared faces between tunnel excavation and ground.

1. **Geometry > Surface & Solid > Auto Connect**
   - Method: **Boolean**
   - Target: **11 solids (all slices and ground)**
   - OK

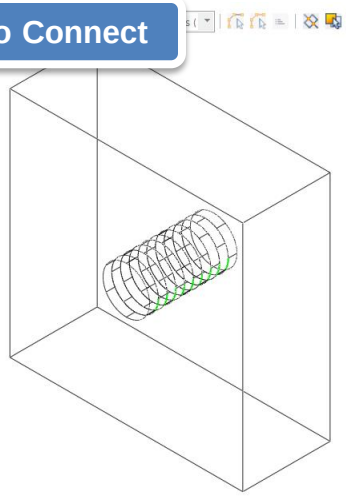
2. **Geometry > Tools > Check Duplicate**
   - Apply

Please check shared faces after creating 3D geometry objects. Free face would be created when mesh sets are generated on unshared solids, and it will cause inaccurate analysis results.

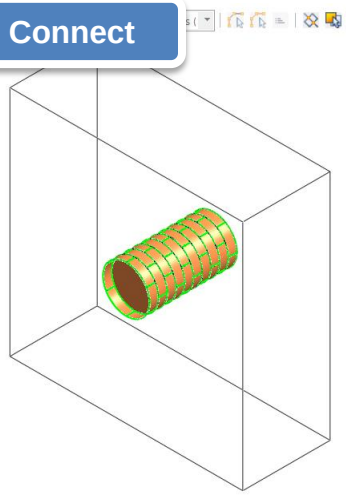




Before Auto Connect



After Auto Connect



04 Mesh Generation

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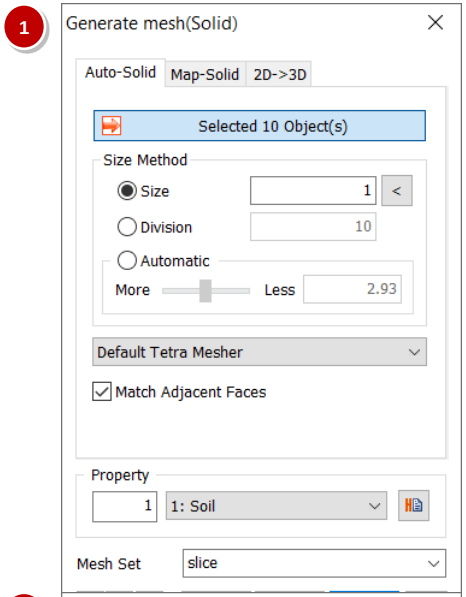
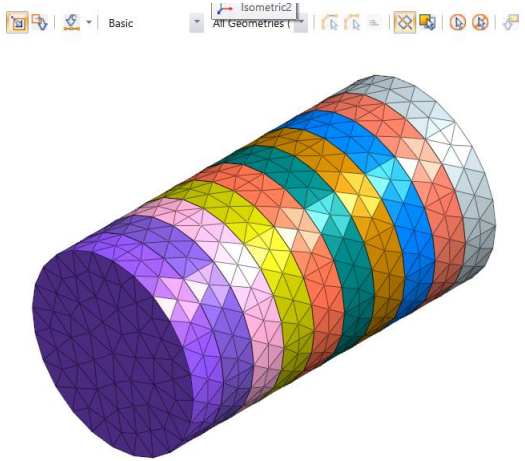
Procedure

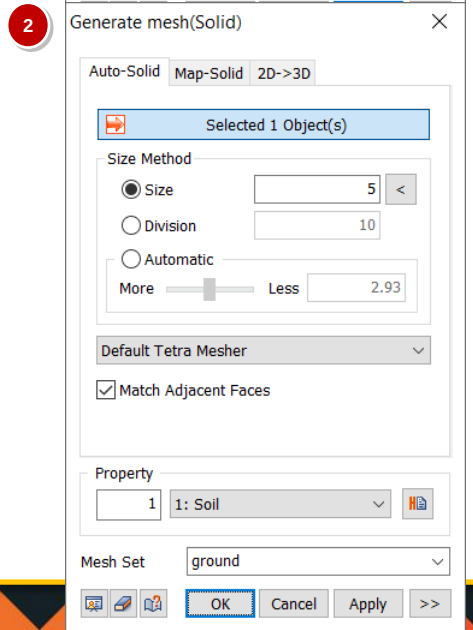
Generate mesh for tunnel excavation and ground.

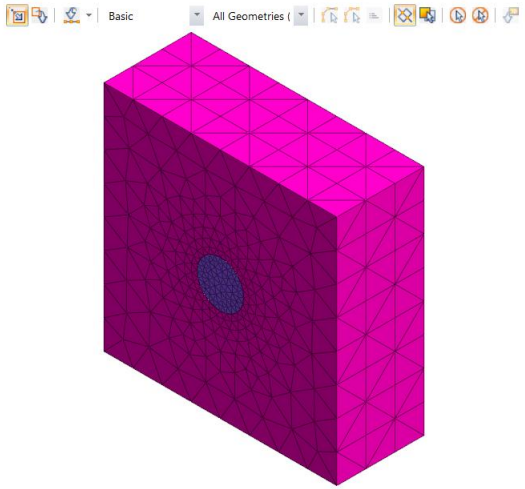
1. **Mesh > Generate > 3D**
   - Show only **slices for tunnel excavation**
   - Auto-Solid tab
   - Select: **10 solids (tunnel)**
   - Size: **1 (m)**
   - Property: **1: Soil**
   - Mesh Set: **slice**
   - Apply

2. - Show **ground box**
   - Select: **1 solid**
   - Size: **5 (m)**
   - Mesh Set: **ground**
   - OK









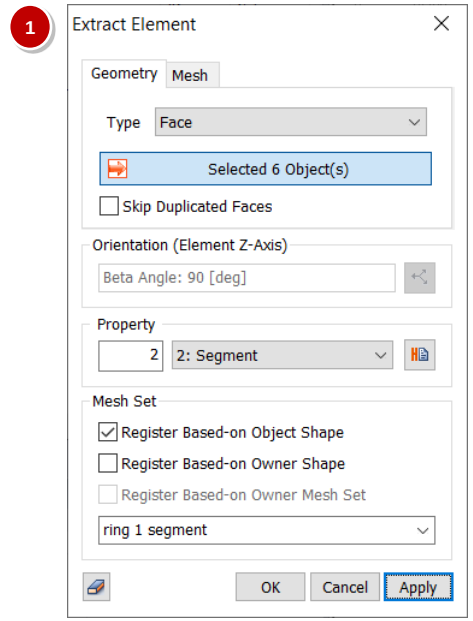
Procedure

Generate mesh for lining segments.

1. **Mesh > Element > Extract**
   - Hide **all mesh sets**
   - Show only **slices of tunnel excavation under Geometry tree**
   - View Toolbar: **Right**
   - Geometry tab
   - Type: **Face**
   - Select: **6 faces (segments)**
   - Check on: **Register Based-on Object Shape**
   - Mesh Set: **ring 1 segment**
   - Apply

2. Do the same for other slices. (slice 2~10)

Drag with Ctrl key to select all objects that are crossed by the selection rectangle (crossing selection).



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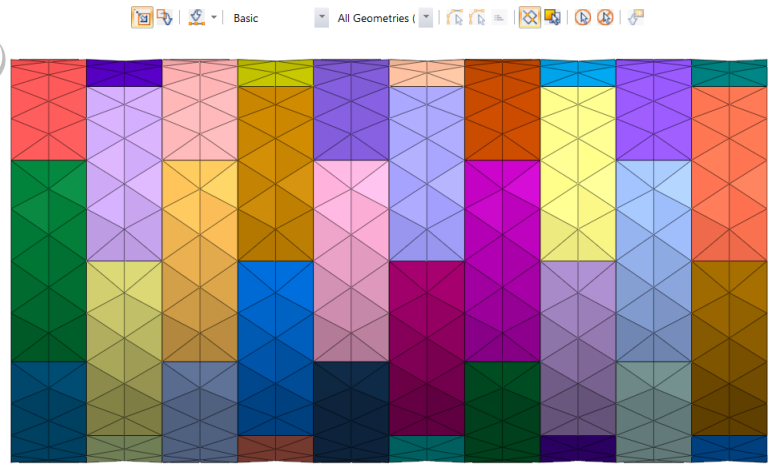
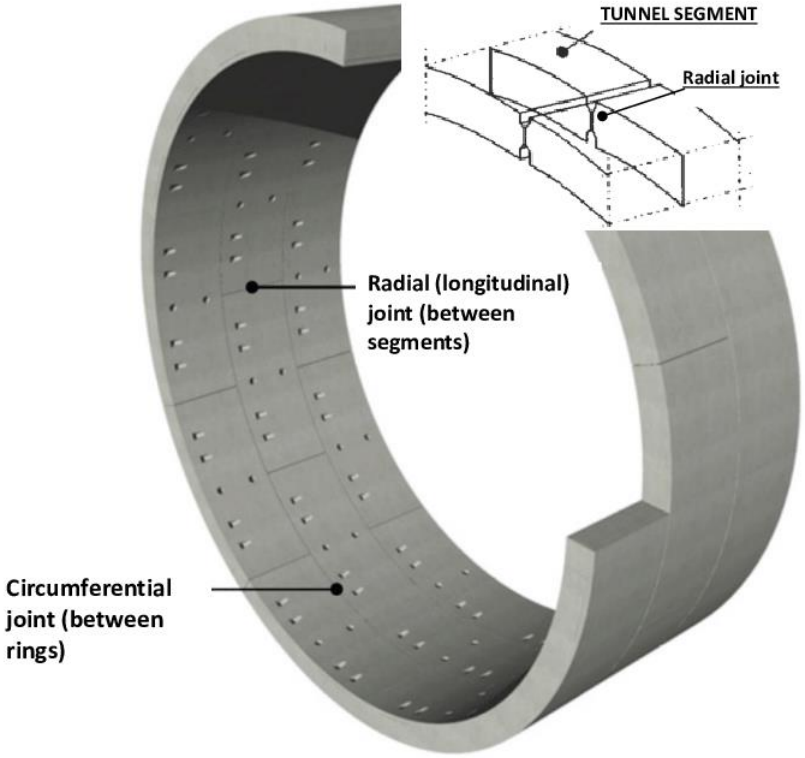
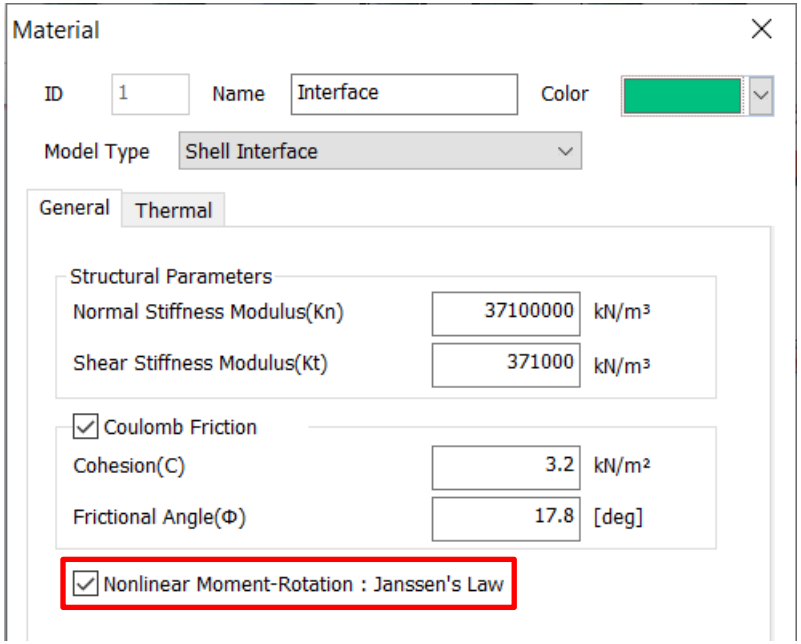


Shell interface element



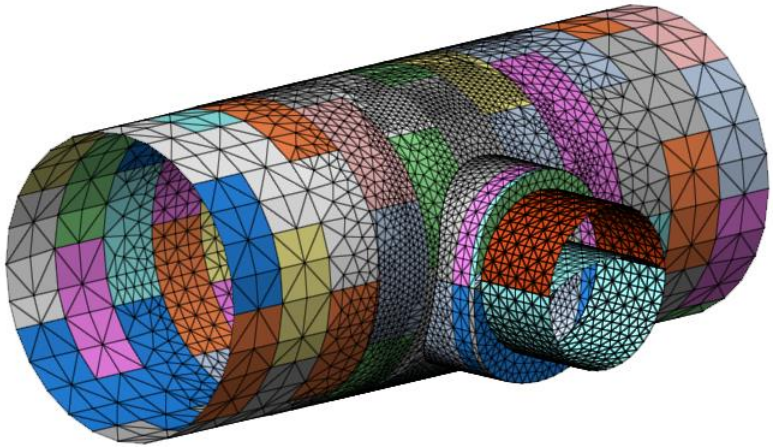


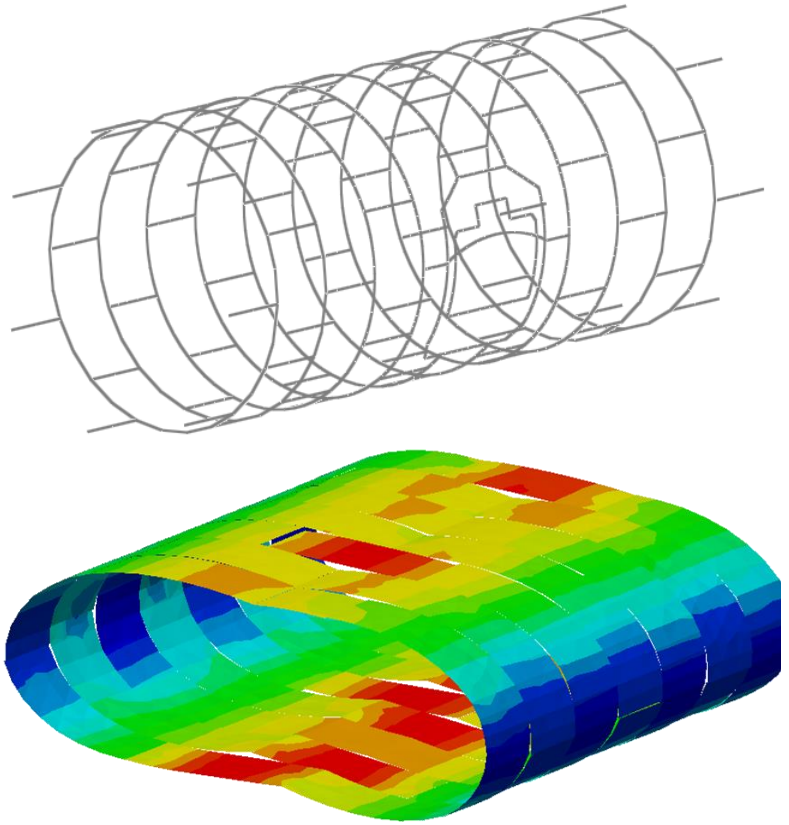
Parameters for the shell interface element

Janssen material law includes four regimes:

- No transmission of forces and bending moments for tensile direct force (loss of contact)
- Linear elasticity for small rotations and small shear stresses
- Nonlinear elasticity in the moment-rotation response for larger rotation
- Perfect sliding plasticity (Coulomb friction) for larger shear stresses

Use of shell interface element





Example of shell interface elements

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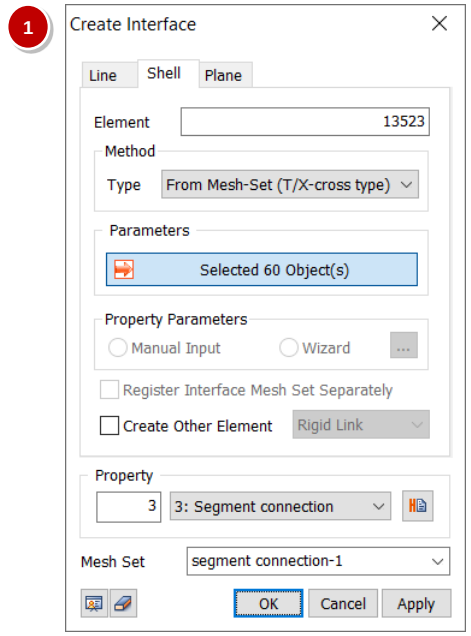
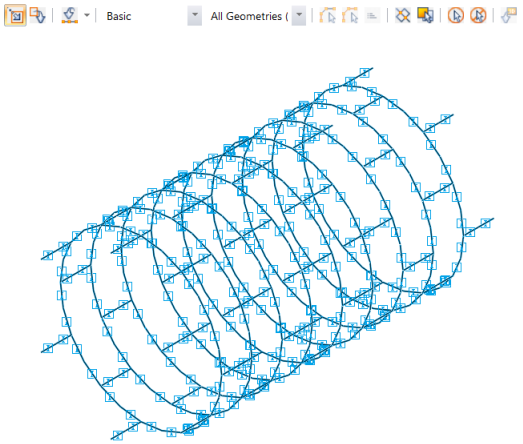
Procedure

Create line interface between segments and rings.

1. **Mesh > Element > Interface**
   - View Toolbar: **Isometric**
   - Hide **slices of tunnel excavation**
   - Shell tab
   - Type: **From Mesh-Set (T/X-cross type)**
   - Select: **60 mesh sets (all segments)**
   - Property: **3: Segment connection**
   - Mesh Set: **segment connection-1**
   - OK





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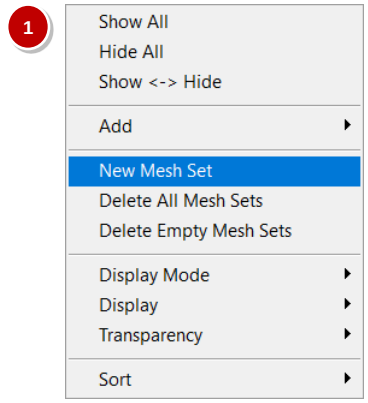
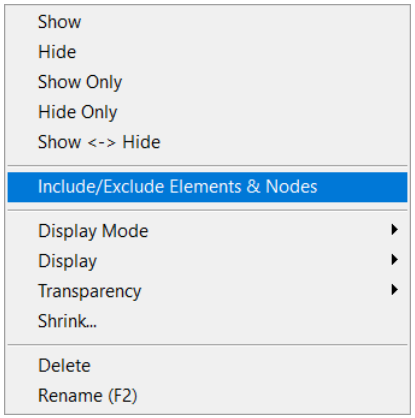
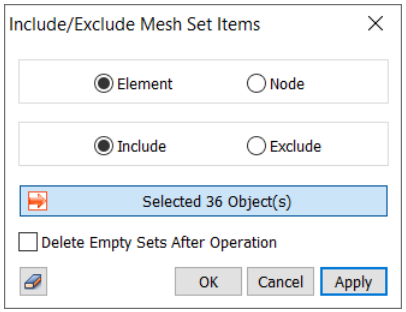
Procedure

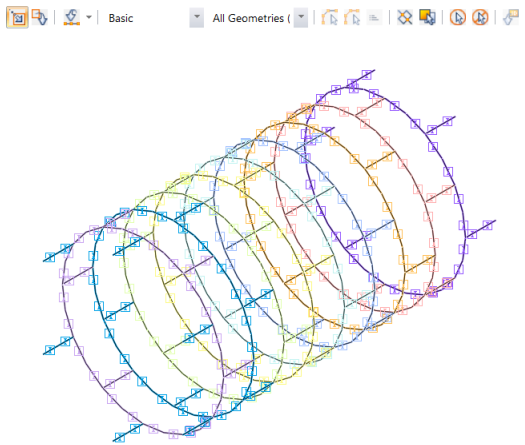
Create line interface between segments and rings.

1 - Hide **all segment mesh sets**
- Right click Mesh tree and select **'New Mesh Set'** for segment connection of each slice.
- Right click and select '**Rename (F2)**' to change mesh set name. (**segment connection-2~10**)
- Right click each connection mesh set and select **'Include Element'**. Then, drag to select each segment connection, respectively.









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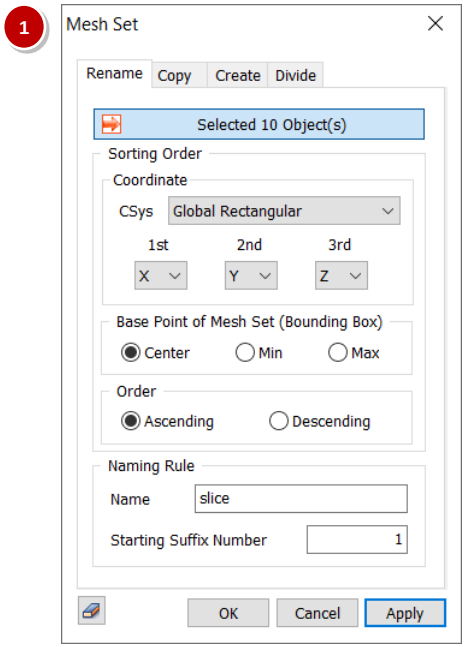
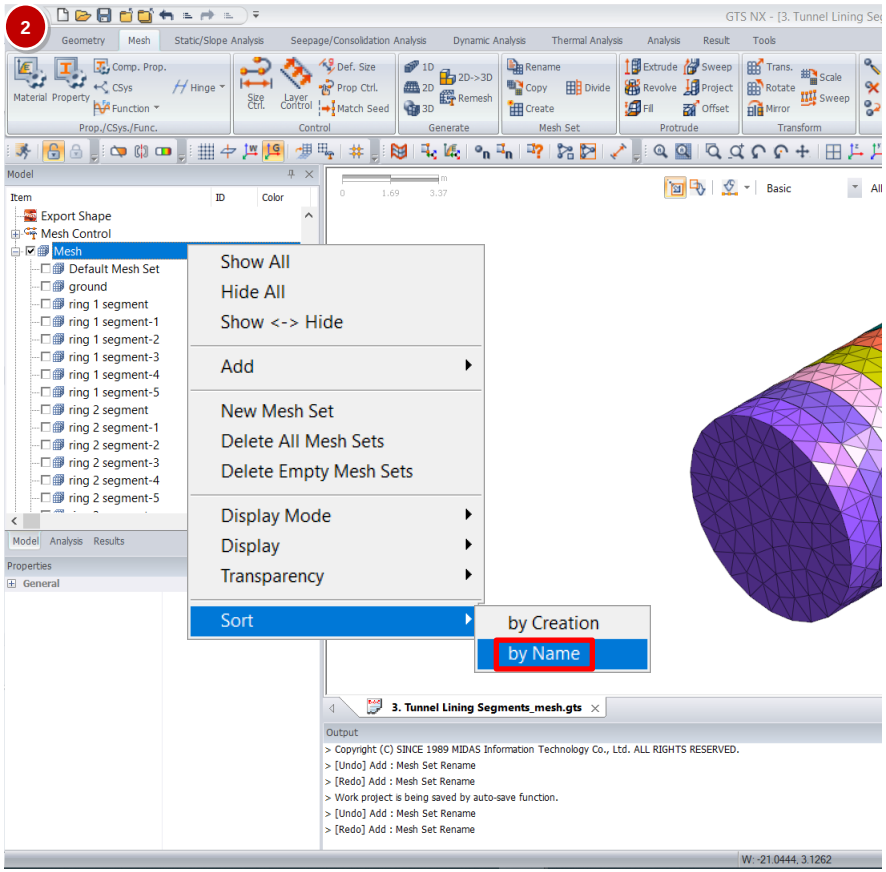
Procedure

Change the name of mesh sets to consider the construction sequence.

1. **Mesh > Mesh Set > Rename**
   - Show only **tunnel excavation**
   - Rename tab
   - Select: **10 mesh sets**
   - Name: **slice**
   - Starting Suffix Number: **1**
   - OK

2. Right click Mesh tree and select **'Sort > by Name'** to change order of mesh sets





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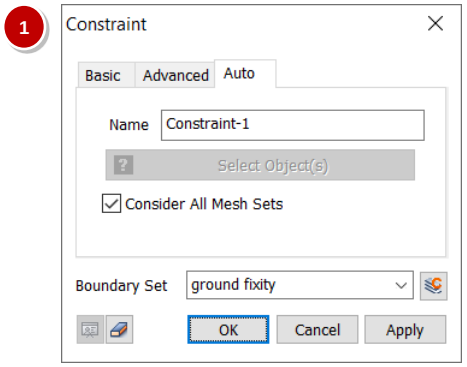
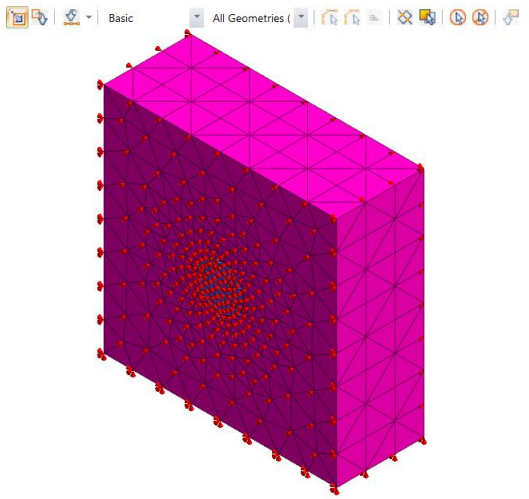
Procedure

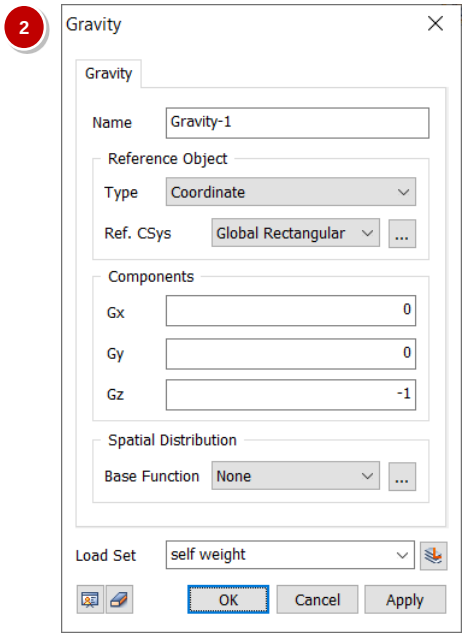
Assign constraints to model boundaries and create self weight.

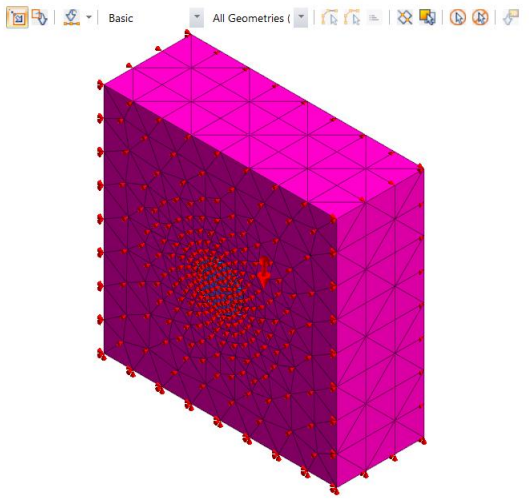
1. **Static/Slope Analysis > Boundary > Constraint**
   - Show **all mesh sets**
   - Auto tab
   - Boundary Set: **ground fixity**
   - OK

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









05 Load & Boundary Condition

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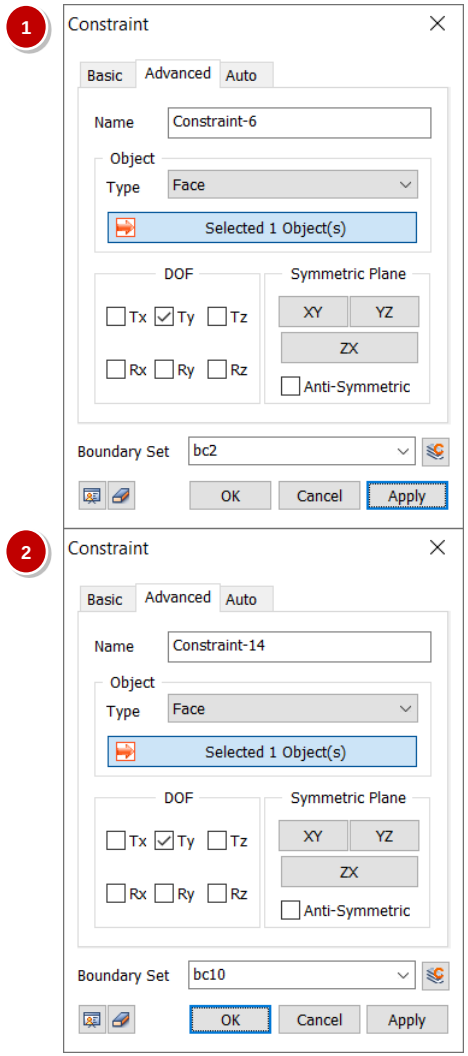
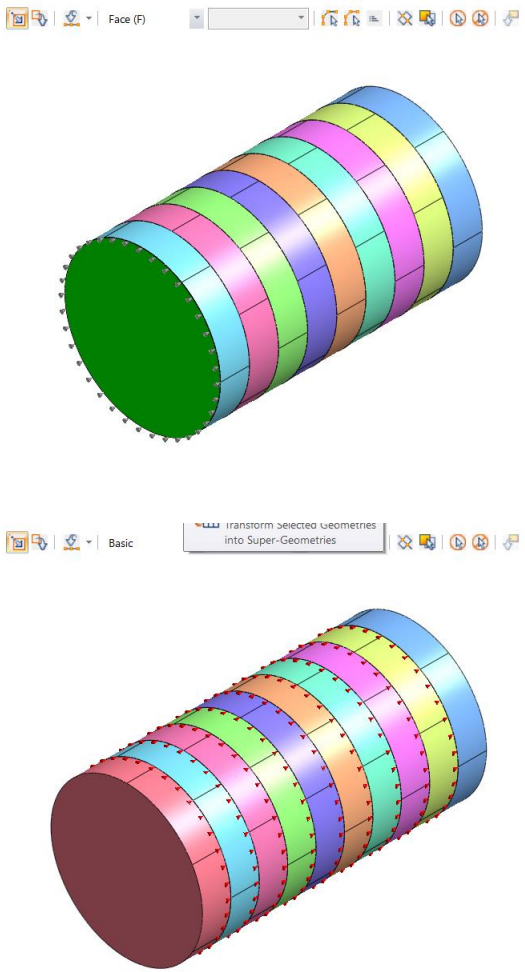
Procedure

Assign boundary conditions to simulate the effect of support by the tunnel boring machine.

1. **Static/Slope Analysis > Boundary > Constraint**
   - Hide **all mesh sets**
   - Show only **9 slices (except 1st slice) of tunnel under Geometry tree**
   - Advanced tab
   - Type: **Face**
   - Select: **1 face (front face of slice)**
   - DOF Check on: **Ty**
   - Boundary Set: **bc2 (referring to the tunnel slice, respectively)**
   - Apply

2. Do the same for other slices. (slice 3~10)





06 Define Construction Stage

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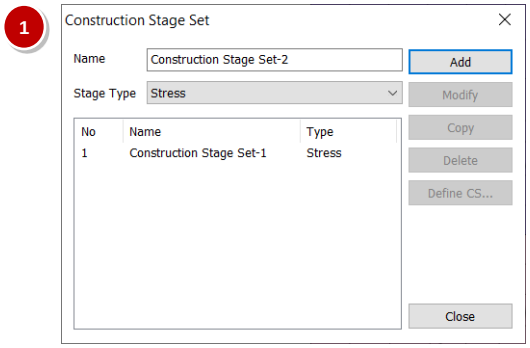
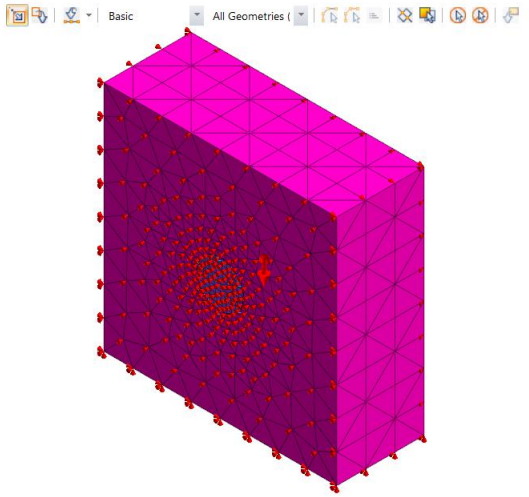
Procedure

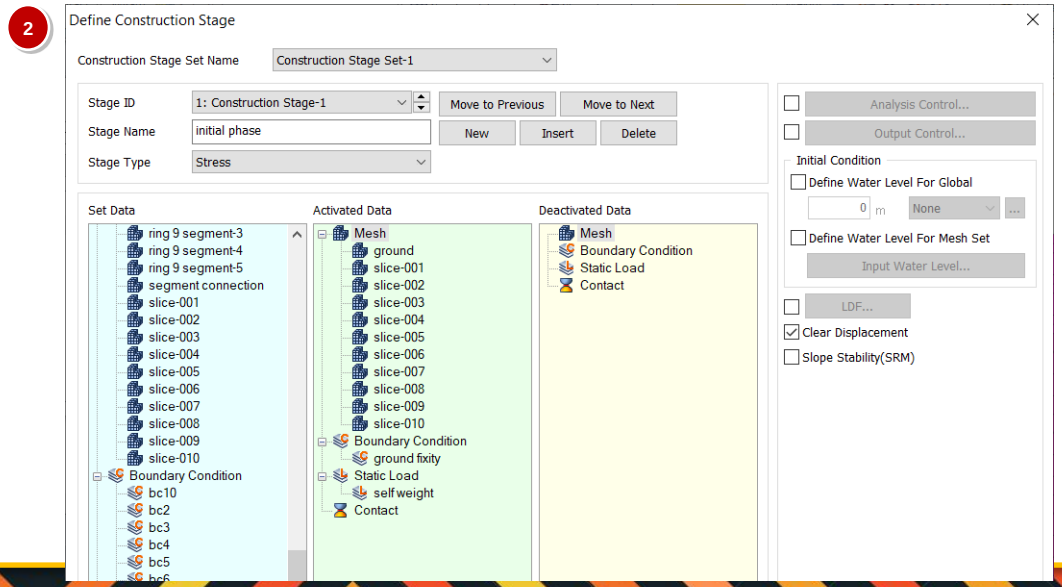
Define construction stages of the tunnel lining segments.

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





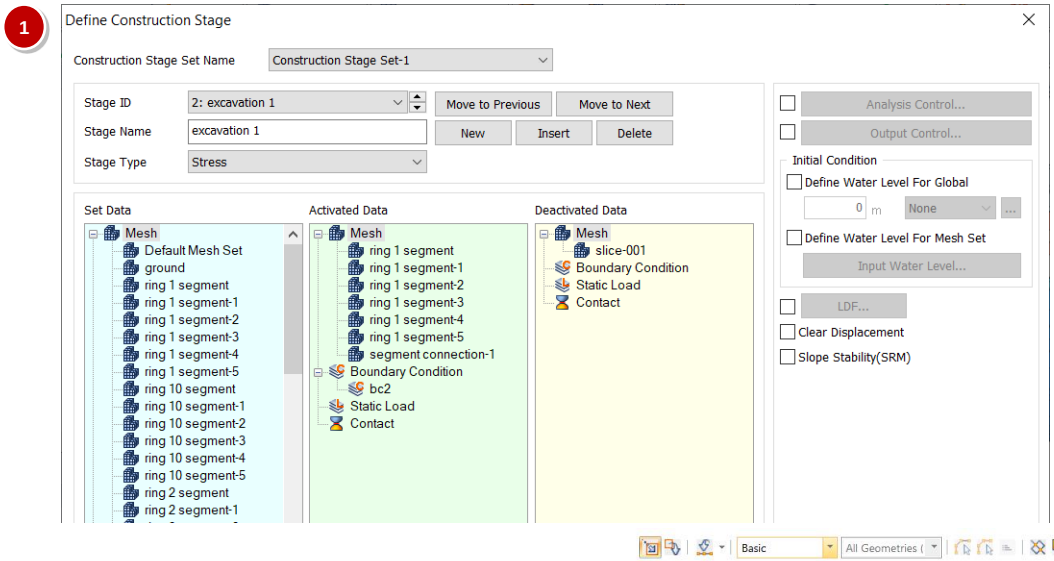


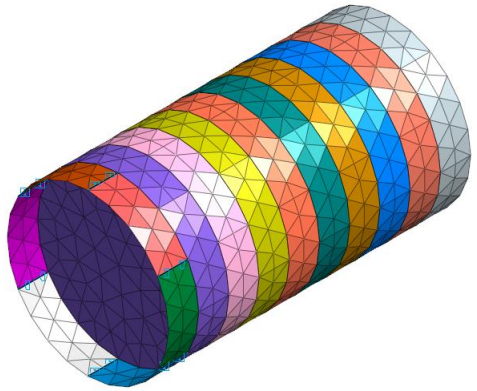
06 Define Construction Stage

GTS NX

Procedure

1. - New
   - Stage Name: **excavation 1**
   - Activated: **ring 1 segments, segment connection-1 and bc2**
   - Deactivated: **slice 1**
   - Save



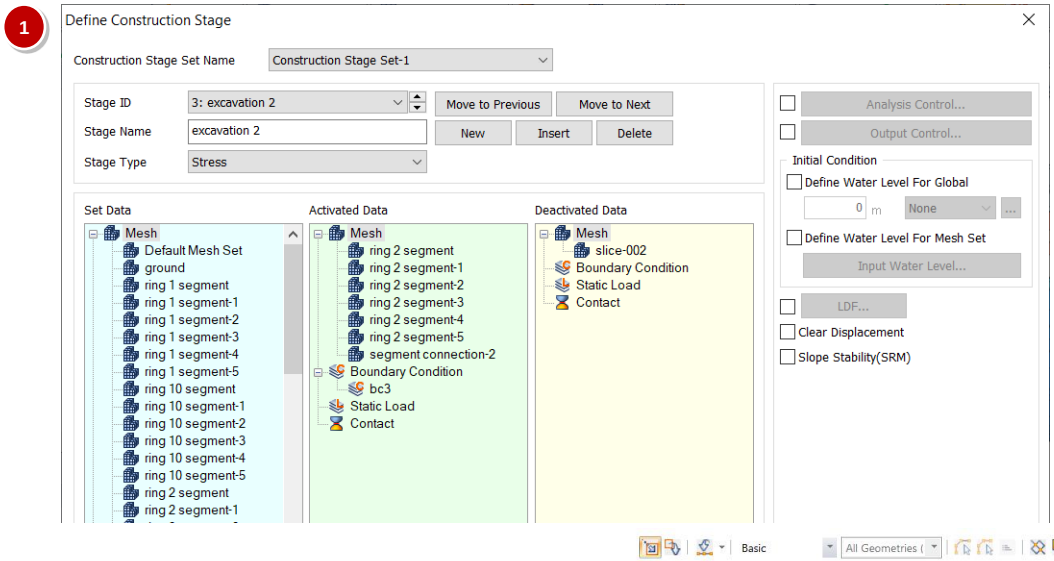


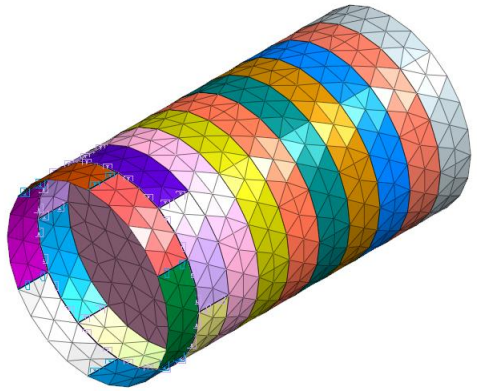
06 Define Construction Stage

GTS NX

Procedure

1. - New
   - Stage Name: **excavation 2**
   - Activated: **ring 2 segments, segment connection-2 and bc3**
   - Deactivated: **slice 2**
   - Save



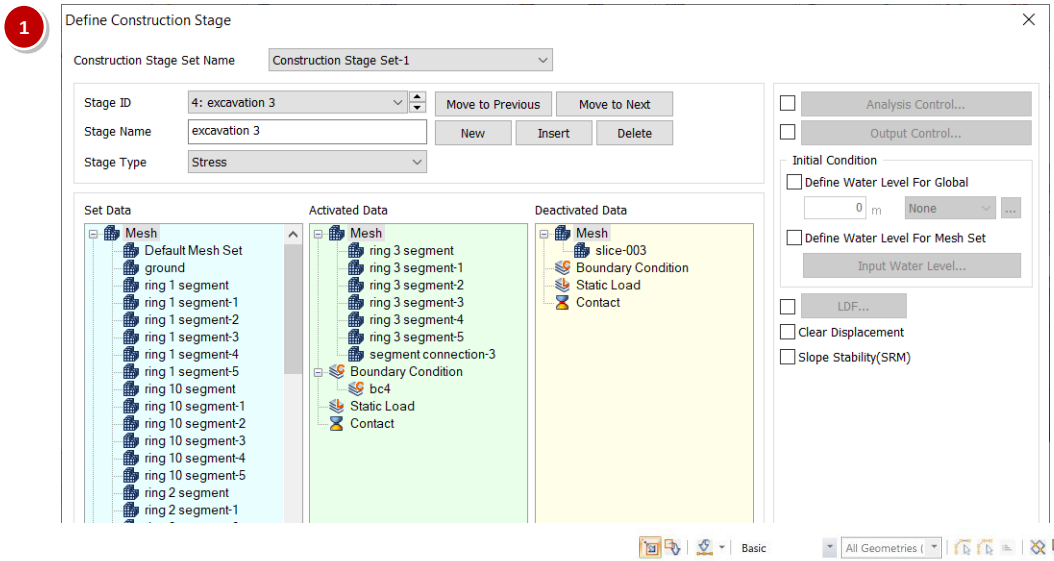


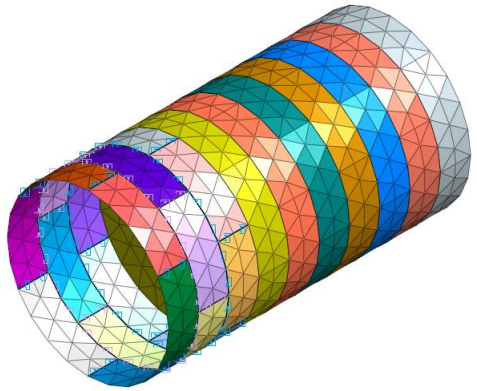
06 Define Construction Stage

GTS NX

Procedure

1. - New
   - Stage Name: **excavation 3**
   - Activated: **ring 3 segments, segment connection-3 and bc4**
   - Deactivated: **slice 3**
   - Save



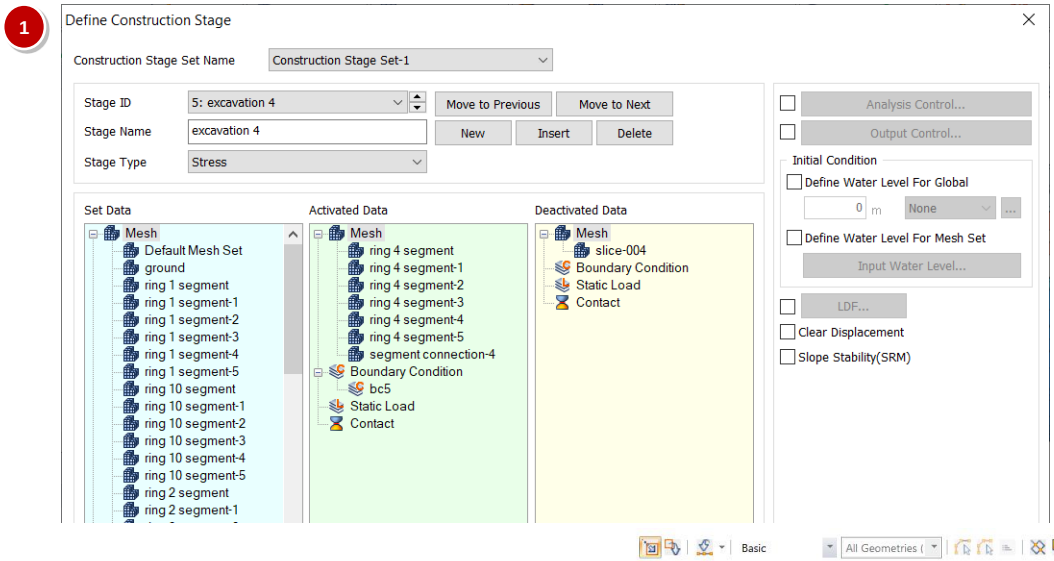


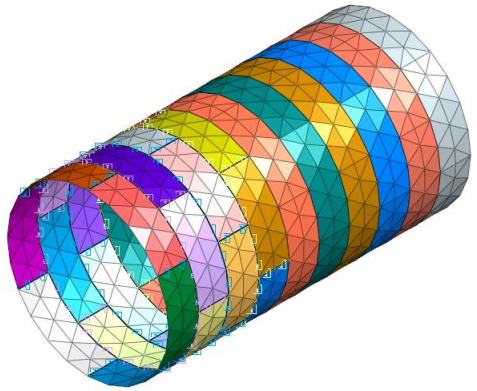
06 Define Construction Stage

GTS NX

Procedure

1. - New
   - Stage Name: **excavation 4**
   - Activated: **ring 4 segments, segment connection-4 and bc5**
   - Deactivated: **slice 4**
   - Save



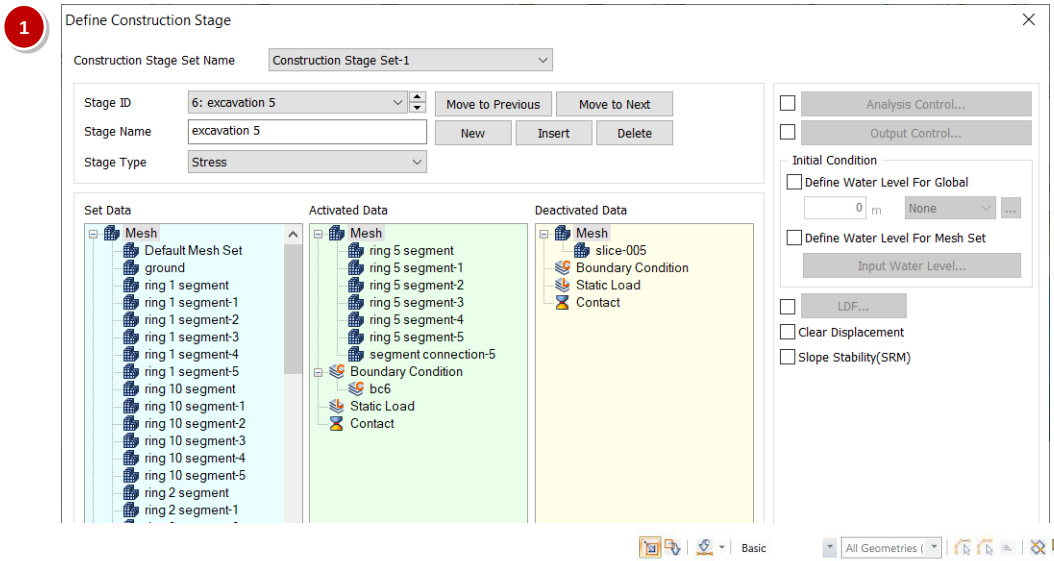


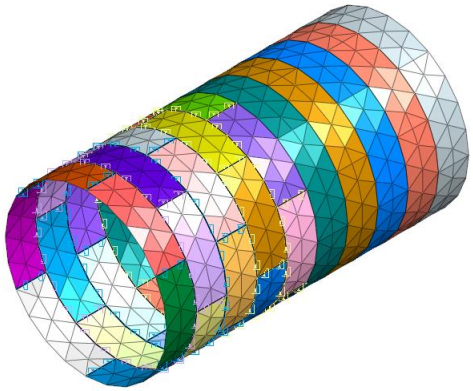
06 Define Construction Stage

GTS NX

Procedure

1. - New
   - Stage Name: **excavation 5**
   - Activated: **ring 5 segments, segment connection-5 and bc6**
   - Deactivated: **slice 5**
   - Save



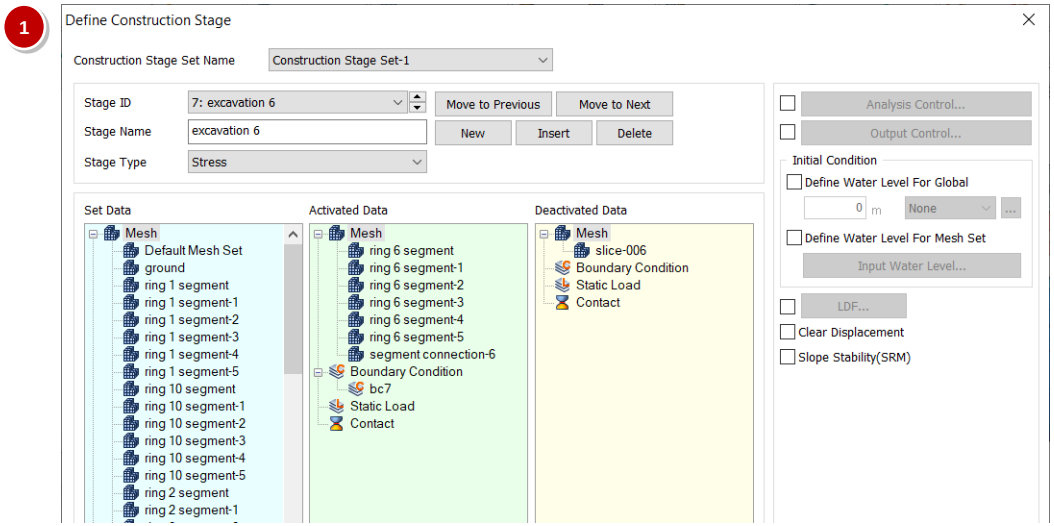


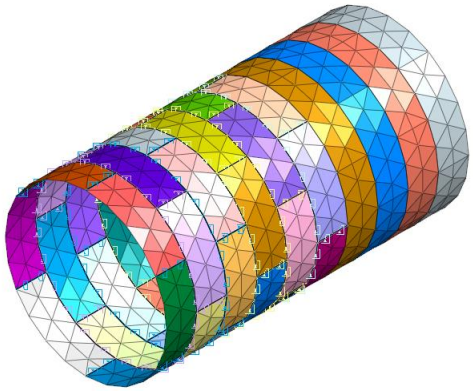
06 Define Construction Stage

GTS NX

Procedure

1. - New
   - Stage Name: **excavation 6**
   - Activated: **ring 6 segments, segment connection-6 and bc7**
   - Deactivated: **slice 6**
   - Save



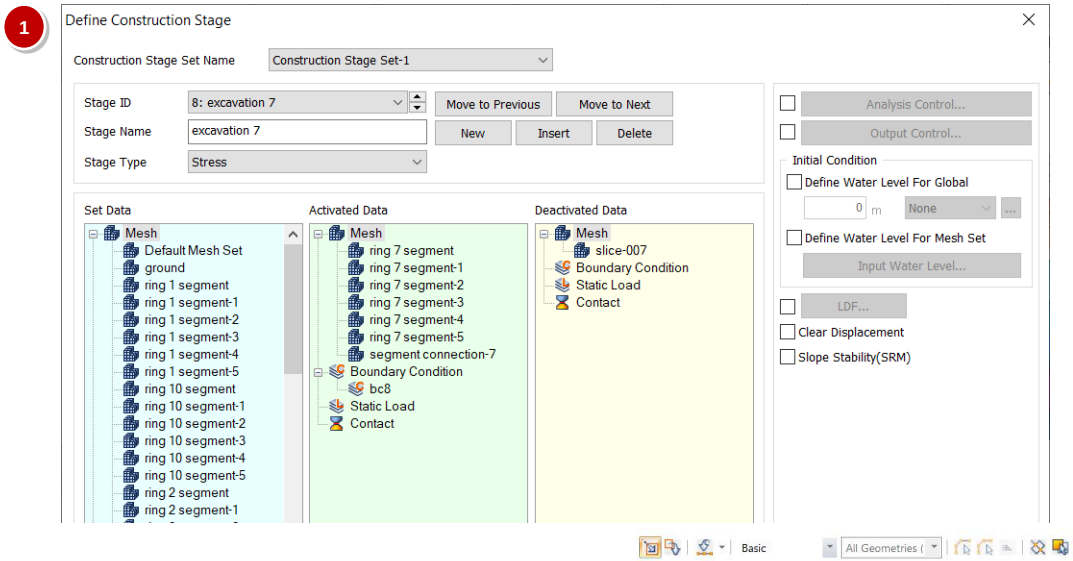


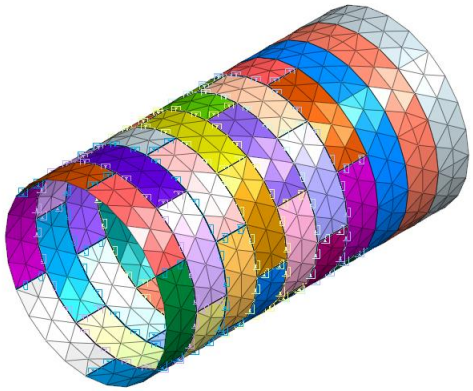
06 Define Construction Stage

GTS NX

Procedure

1. - New
   - Stage Name: **excavation 7**
   - Activated: **ring 7 segments, segment connection-7 and bc8**
   - Deactivated: **slice 7**
   - Save



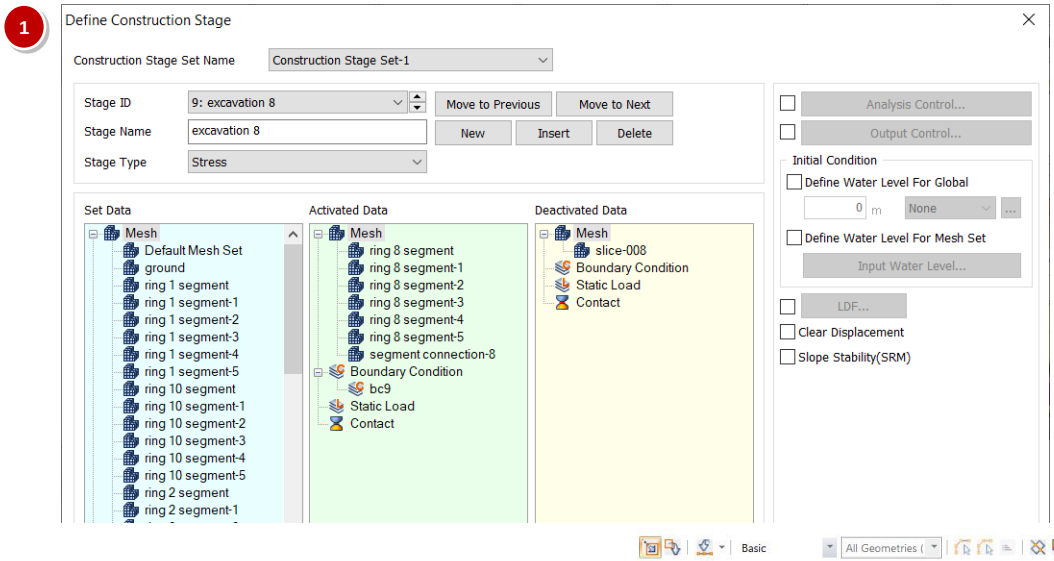


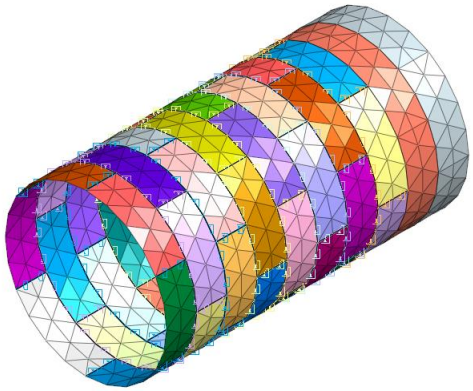
06 Define Construction Stage

GTS NX

Procedure

1. - New
   - Stage Name: **excavation 8**
   - Activated: **ring 8 segments, segment connection-8 and bc9**
   - Deactivated: **slice 8**
   - Save



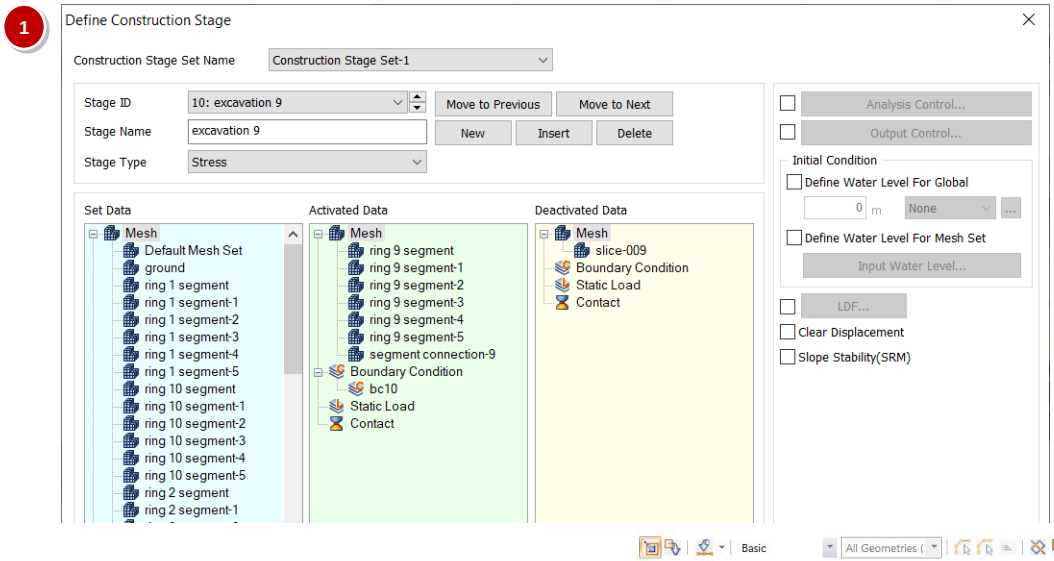


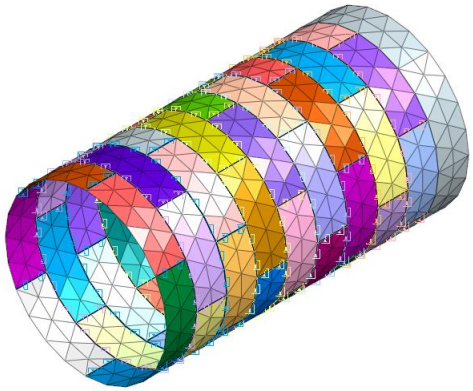
06 Define Construction Stage

GTS NX

Procedure

1. - New
   - Stage Name: **excavation 9**
   - Activated: **ring 9 segments, segment connection-9 and bc10**
   - Deactivated: **slice 9**
   - Save



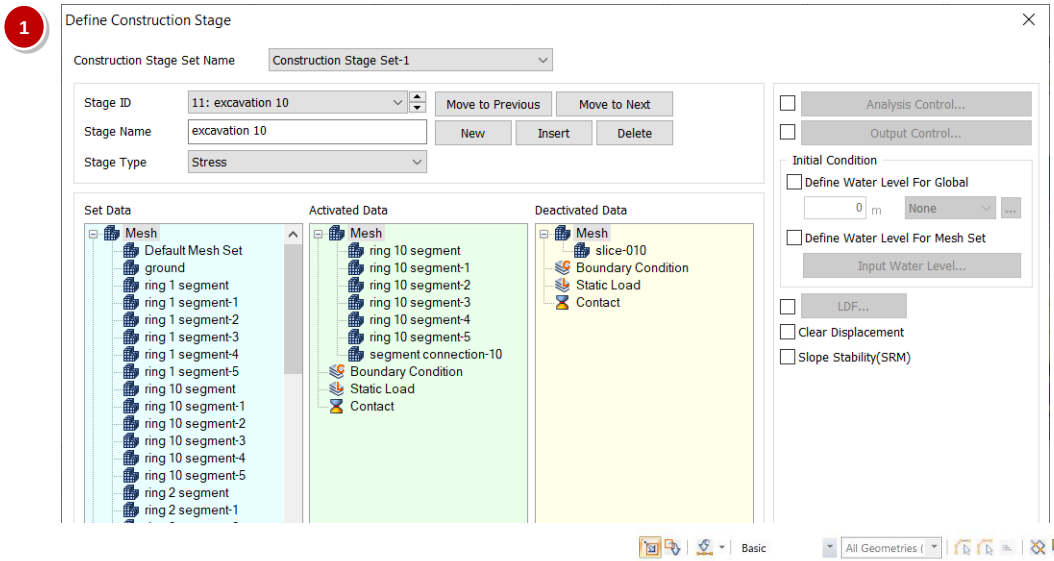


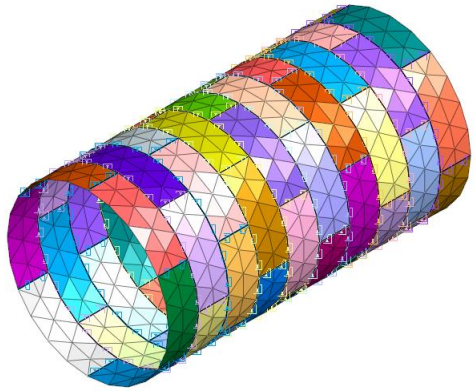
06 Define Construction Stage

GTS NX

Procedure

1. - New
   - Stage Name: **excavation 10**
   - Activated: **ring 10 segments and segment connection-10**
   - Deactivated: **slice 10**
   - Save





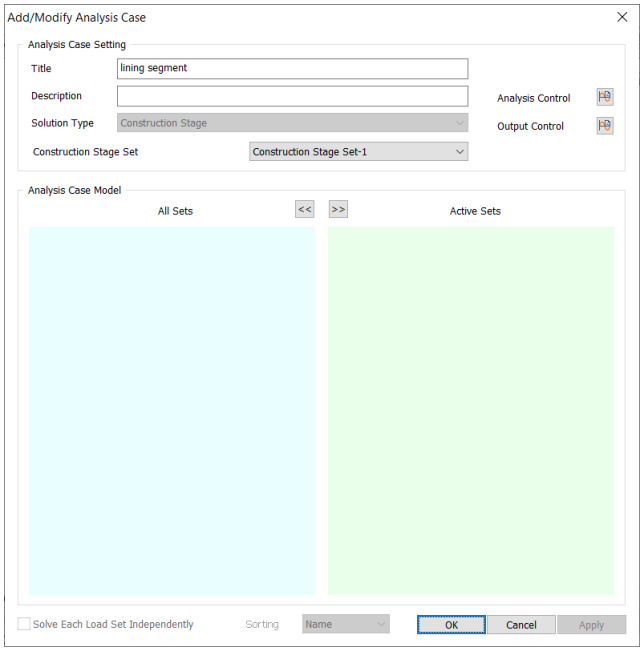
07 Analysis Setting

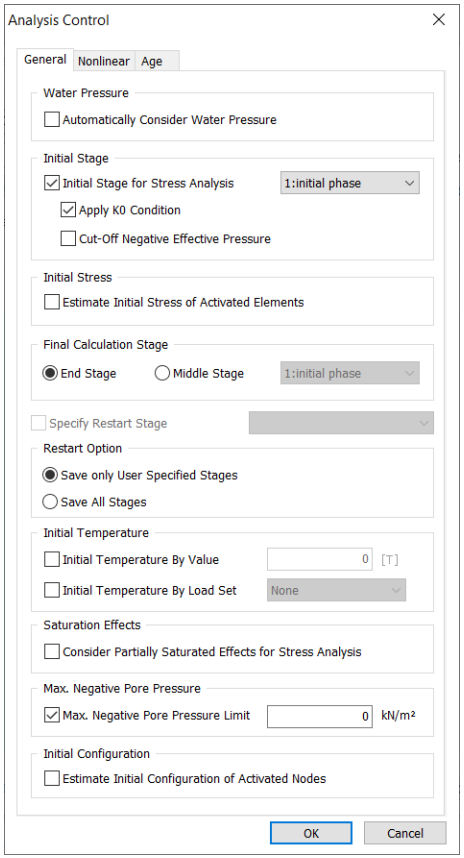
GTS NX

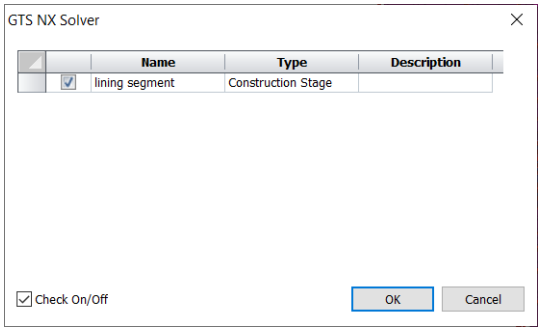
Procedure

1. **Analysis > Analysis Case > General**
   - Title: **lining segment**
   - 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







GTS NX

Procedure

Check displacement of ground.

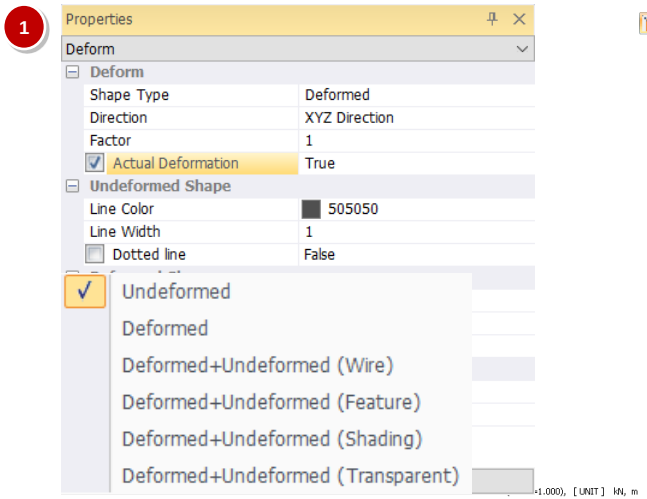
1. excavation 10 > Displacement > TOTAL TRANSLATION (V)

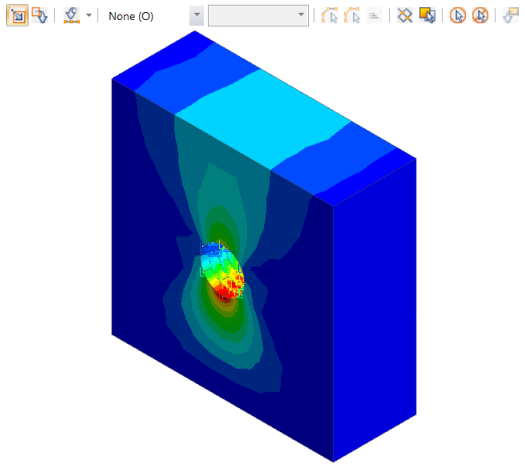
Result > General > Smooth: Fringe

Result > General > Deform: Undeformed

Result > Show/Hide > Actual Deformation

Properties > Deform





GTS NX

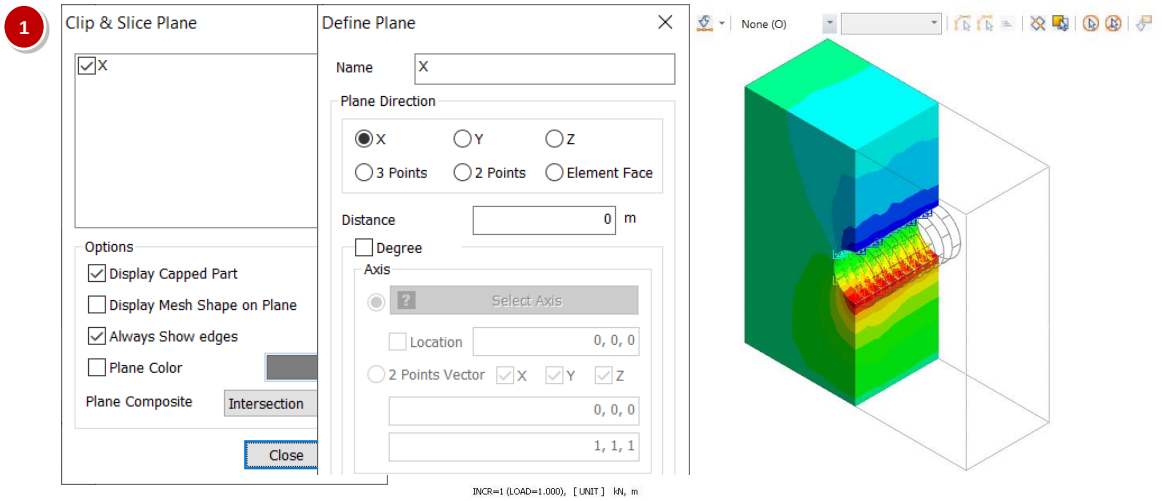
Procedure

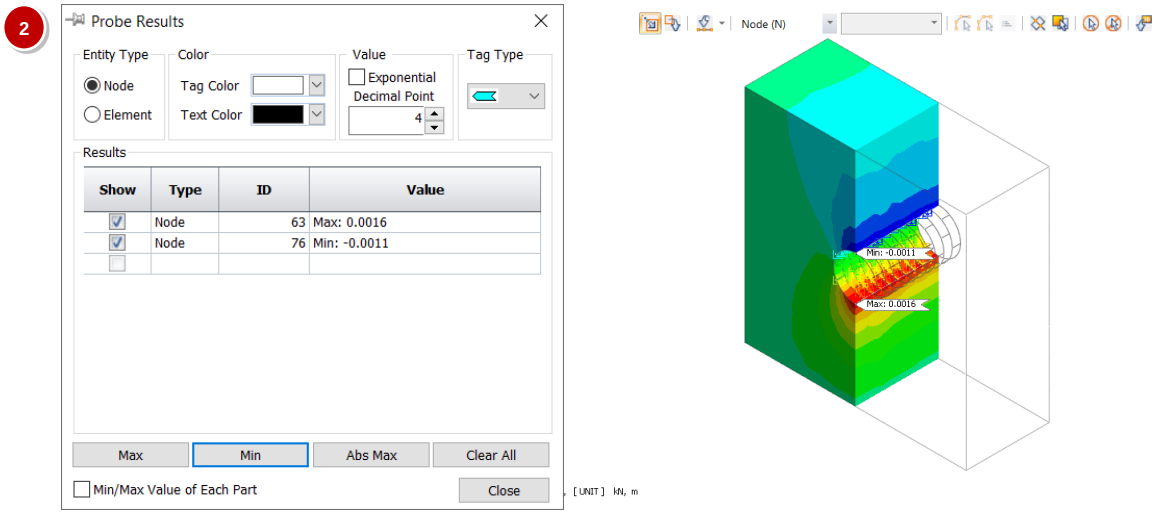
Check displacement of ground.

1. excavation 10 >
   Displacement > TZ
   TRANSLATION (V)

   Advanced View Control:
   Clipping Plane
   - Define Plane
   - X: **0 m**
   - Add
   - Close
   - Close

2. **Result > Advanced > Probe**
   - Max
   - Min





GTS NX

Procedure

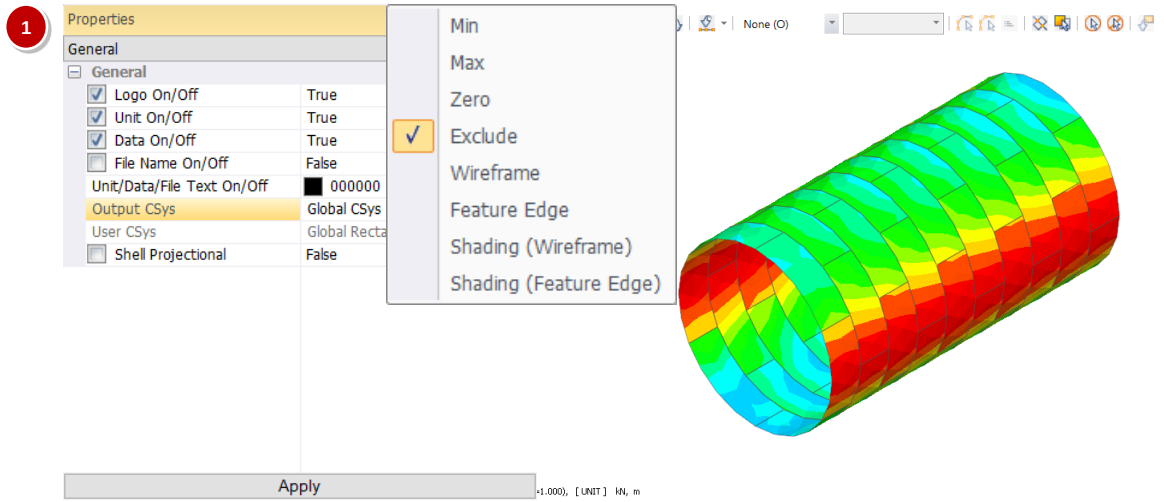
Check member force of tunnel lining in circumferential direction.

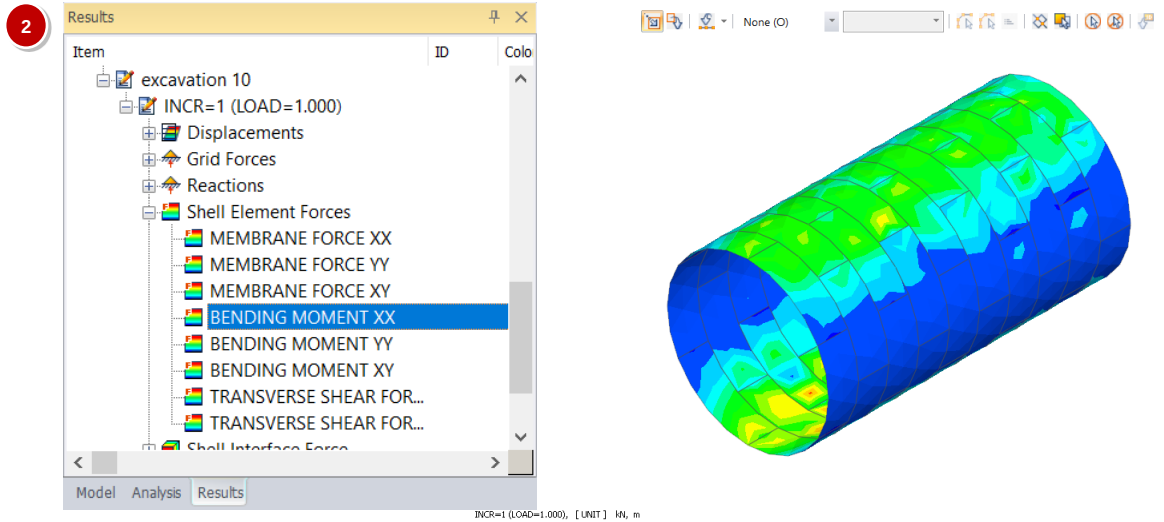
1. excavation 10 > Shell Element Forces > MEMBRANE FORCE XX

   Result > General > No Results: Exclude
   Properties > General
   - Output CSys: **Global CSys**
   - Apply

2. excavation 10 > Shell Element Forces > BENDING MOMENT XX

Because the tunnel advance is defined in the global Y direction, the global X direction is the circumferential direction.





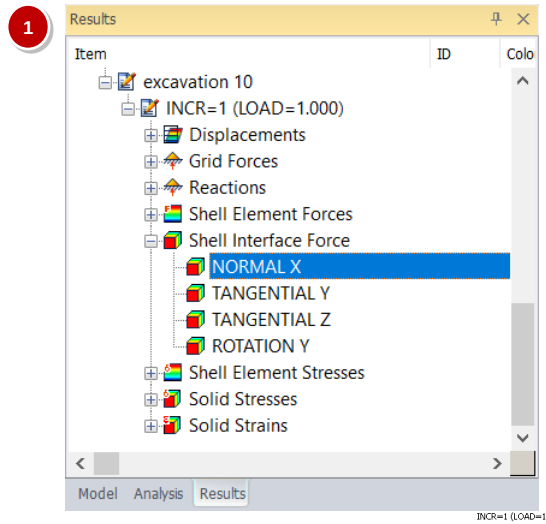
GTS NX

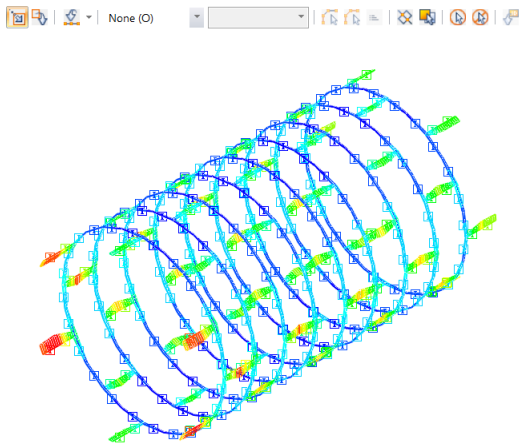
Procedure

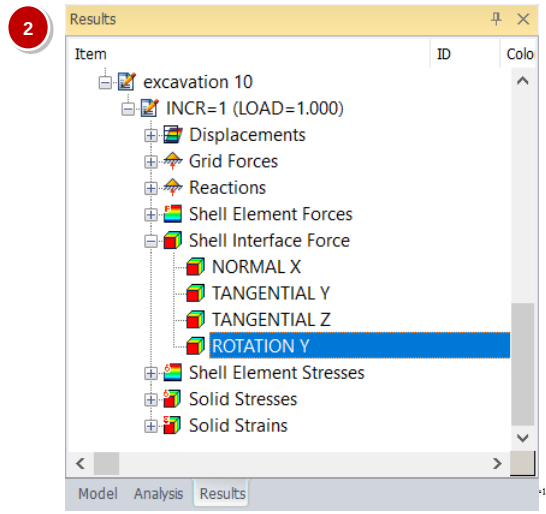
Check interface results of segment connection.

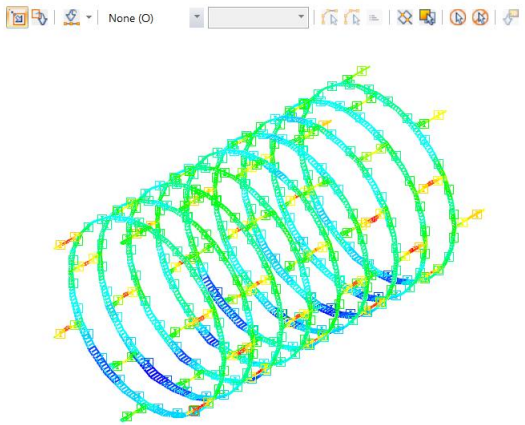
1. excavation 10 > Shell Interface Forces > NORMAL X (out of plane shear force)

2. excavation 10 > Shell Interface Forces > ROTATION Y (bending moment in the joints between segments)









GTS NX

New eXperience of Geo-Technical analysis System

Thank you!

MIDAS