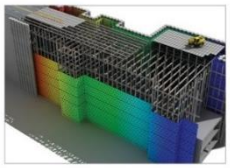
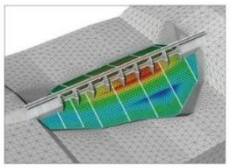
2D & 3D Semi Coupled Analysis
Seepage-Stress-Slope

GTS NX
Geo-Technical analysis System New eXperience





MIDASoft Inc.

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Integrated Solver Optimized for the next generation 64-bit platform

Finite Element Solutions for Geotechnical Engineering

MIDAS

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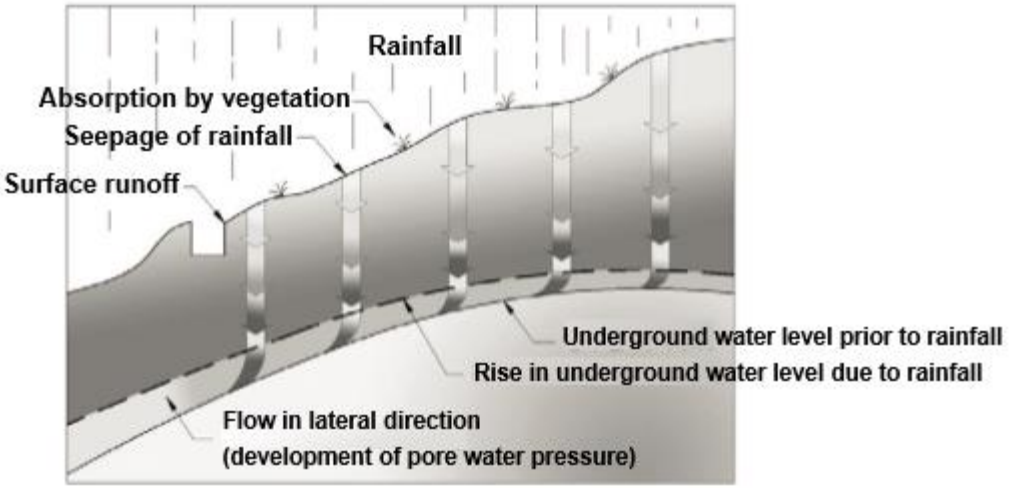
Overview of Seepage-Slope Coupled Analysis

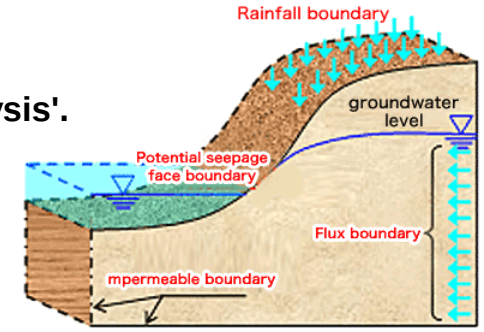
• **Instability of a slope in unsaturated soils is closely related to rainfall**. The slope instability increases with the **reduction in shear strength caused by the increase in water content** in the unsaturated soils due to rainfall. Therefore, the presence of **negative pore water pressure and its magnitude are very important for the stability of an unsaturated slope**.

• Unlike common belief that **slope failure under rainfall** is attributed to global sliding in the slope due to an increase in pore water pressure caused by a rise in the underground water level, research and failure cases mainly point to **shallow slope fai lure**. It has been identified that a rise in underground water level under concentrated torrential rainfall is not significant. Rathe r the **wetting front due to seepage reaches the critical depth (wetting depth) causing the shallow slope failure**. Accordingly, **stability analysis for the surface layer part in the slope due to rainfall seepage becomes necessary**.



[Schematic diagram of developing wetting front due to rainfall]

Overview



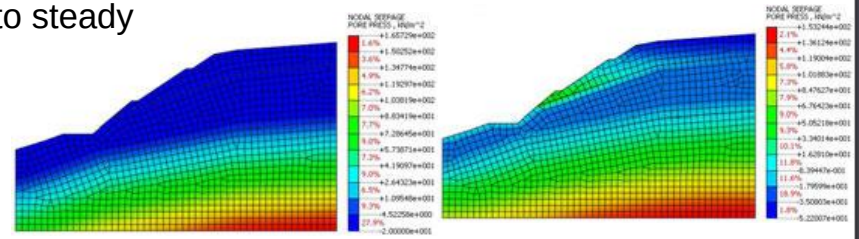
•Seepage analysis can be divided into **'Steady state analysis'** and **'Transient analysis'.**

•Steady State

The boundary conditions within and outside of the ground remain constant with time

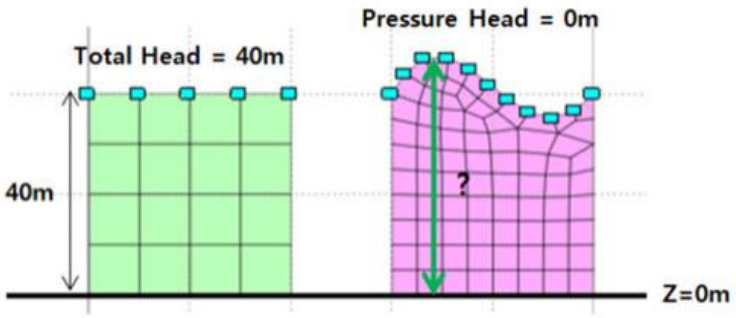
•Transient

Assumes that the boundaries vary according to time. Generally, the ground is in unsaturated status, and time is different for seepage to get into steady state according to moisture content and porosity.

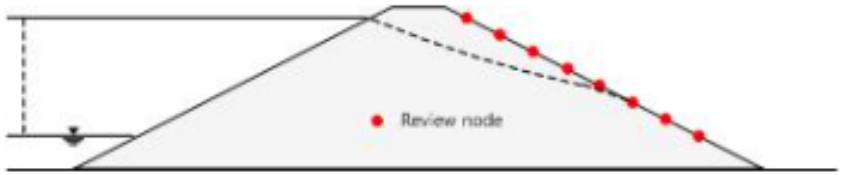


Time = 0 hr Time = 72 hrs

Nodal water head: water heads at nodes are specified (total water head, pressure water head).
Nodal flux/Surface flux: water flow quantities at nodes or surfaces are specified.
Review boundary based on seepage condition: when the line of saturation is unknown.



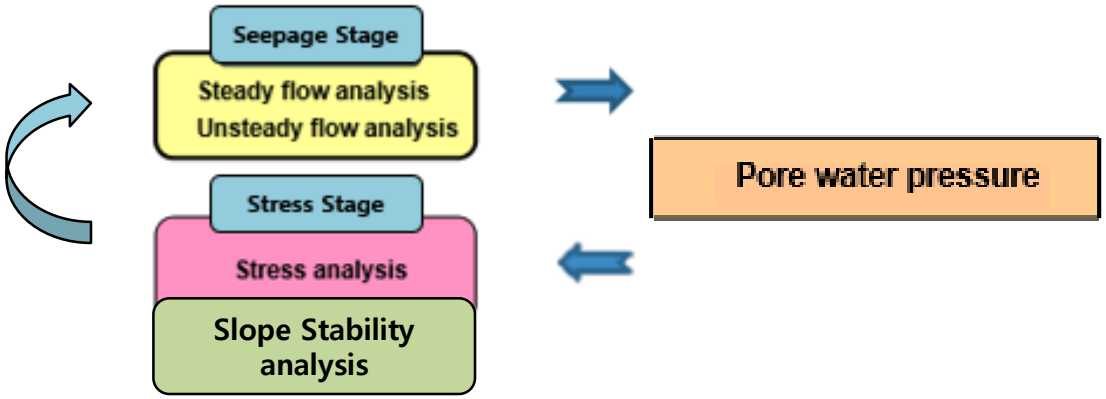
<Application of Nodal Head(ex.)>



<Specify Review boundary node (ex.) >

Sequential Seepage-Stress analysis and Slope stability analysis during the construction stage process.

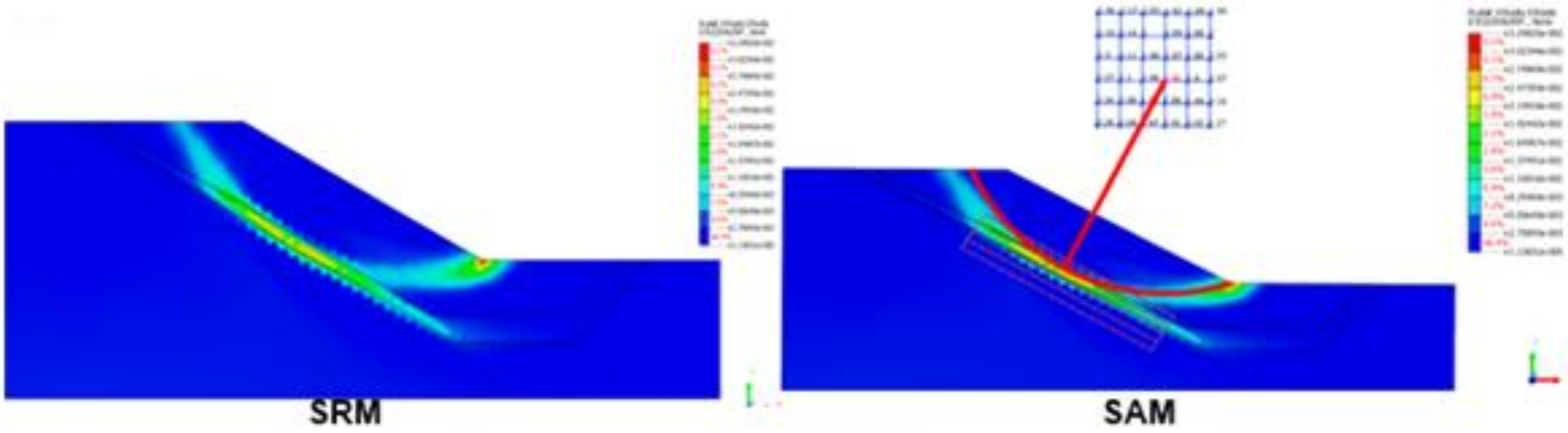
Seepage analysis and stress/slope analysis are independently performed, and then pore water pressure can be reflected through the in the following stress stage automatically.



Overview

The following slope stability analysis methods can be used on the GTS NX.

- **Strength Reduction Method (SRM):** The strength reduction method gradually decreases the shear strength and friction angle until the calculation does not converge, and that point is considered to be the failure point of the slope.
- **Stress Analysis Method (SAM):** This method first uses the finite element method to perform stress analysis on the slope and the safety factor for each various virtual slip surface, created from the assumptions of the limit equilibrium theory, is calculated based on the stress analysis results



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GTS NX

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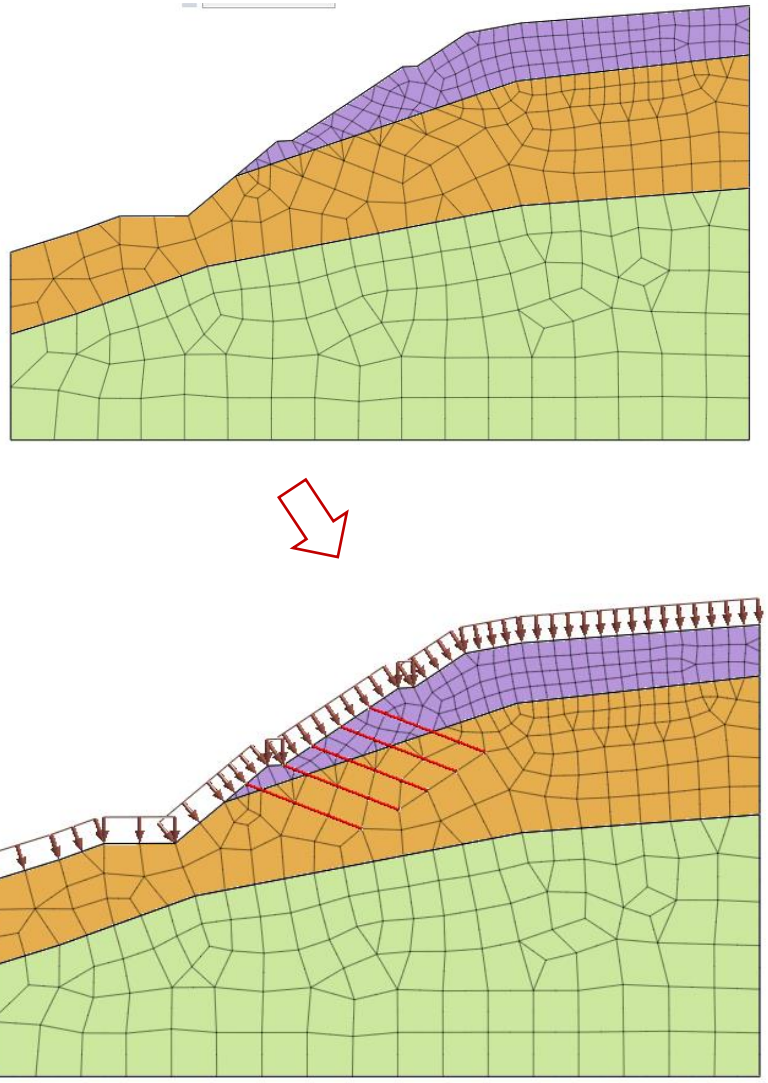
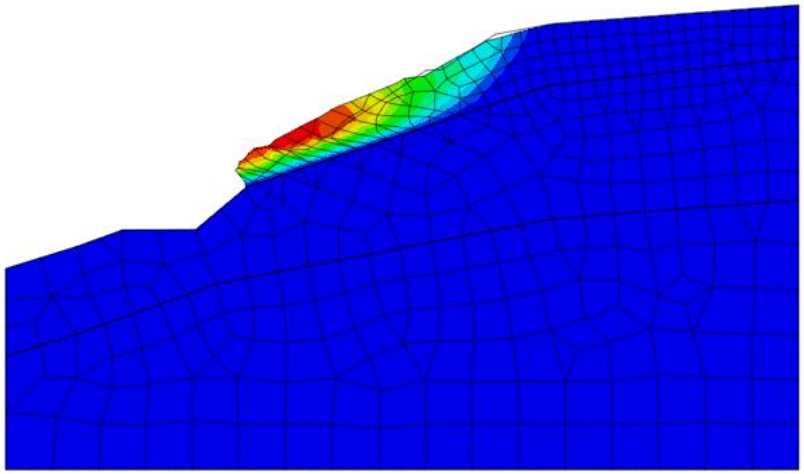


Overview

• 2D Slope Stability analysis during rain

•The stability of slopes is greatly affected by ground water, external loadings, earthquake, etc. Shear stress inside the slope develops due to the self weight and external loadings like pore pressure from rain accumulation. If the shear stress exceeds the shear strength, shear failure will take place. Using the various proposed methods, numerical analysis is performed to check the stability, and appropriate reinforcement is introduced.

Higher order elements will be used for better accuracy, and the safety factor will be examined to determine the need for reinforcement.



FEM offers accurate approximate solutions that satisfy force equilibrium, compatibility, constitutive equations and boundary conditions at each point of the slope, which enables simulation of close to real failure shapes and reflect the site conditions to find the minimum safety factor against failure. Moreover, failure planes need not be assumed in advance, and the failure process can be automatically investigated.

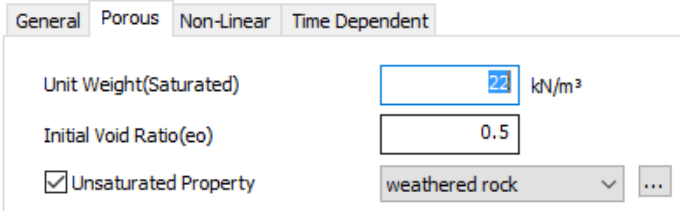
Name	Weathered Soil	Weathered Rock	Bed Rock	Nail
Material	Isotropic	Isotropic	Isotropic	Isotropic
Model Type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Elastic
General				
Elastic Modulus (E) (kN/m2)	36,500	150,000	1,850,000	20,0000,000
Poisson's Ratio(v)	0.3	0.25	0.28	0.26
Unit Weight(r) (kN/m3)	18.5	21	24	78
Ko	1	1	1	
Porous				
Unit Weight(Saturated) (kN/m3)	19.5	22	25	
Permeability Coe. (m/day)	0.504	0.00254	3.86e-005	
Non-Linear				
Friction Angle	20	25	38	
Cohesion (kN/m2)	5	40	100	

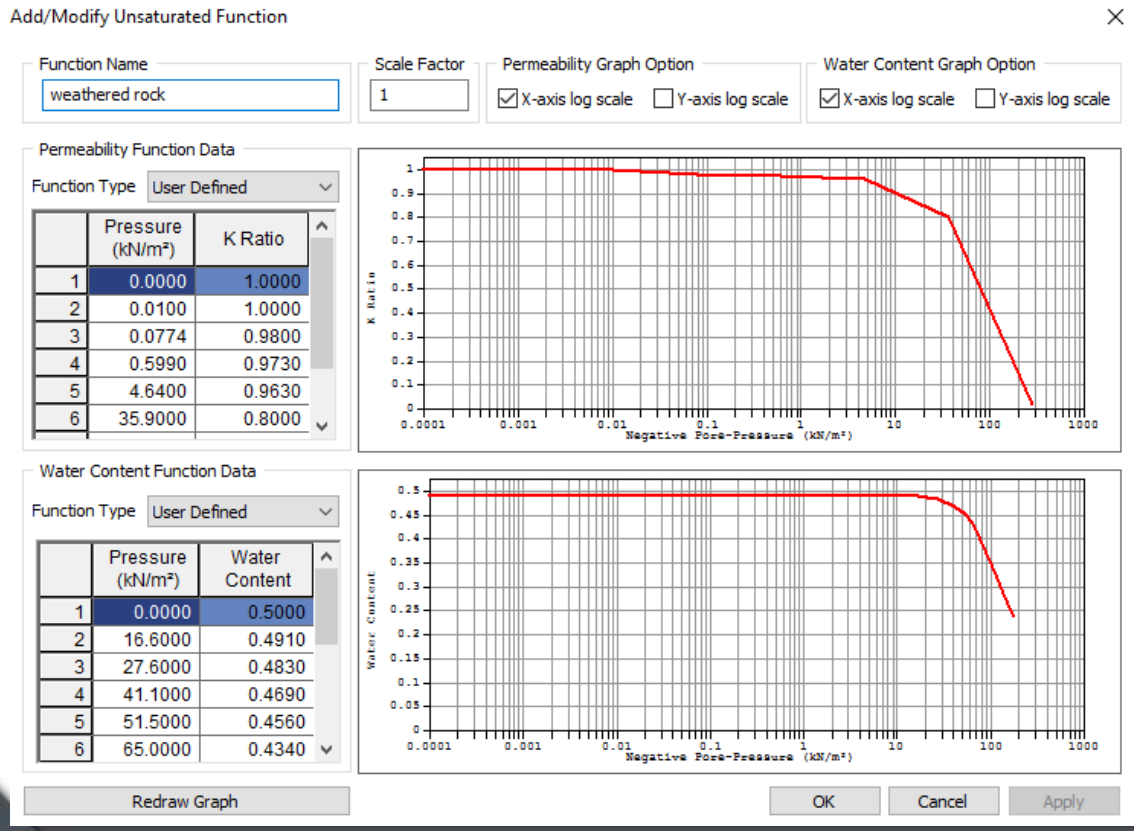
GTS NX

Unsaturated Properties

Permeability Function Type: select 'User-defined' and copy the data from the Excel sheet.

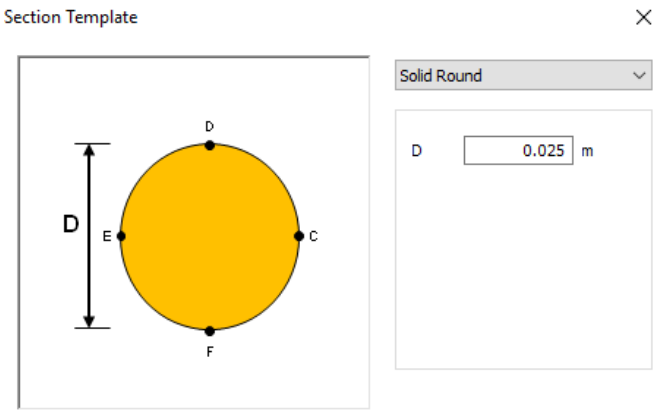
Water Content Function: select 'User-defined' and copy the water content data from the Excel sheet.





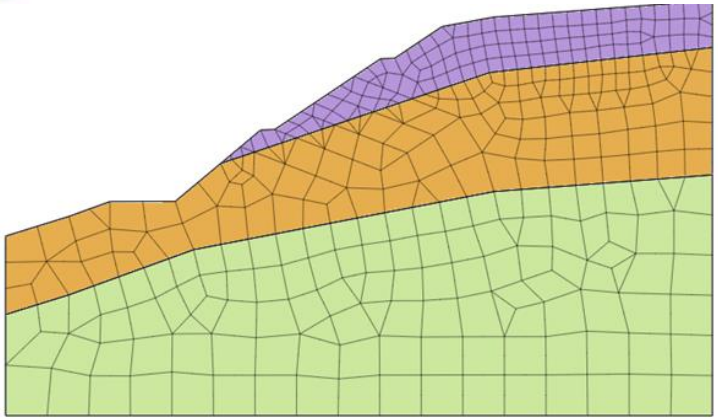
	A	B	C	D	E	F
1						
2	Weathered Soil		Weathered Rock		Soft Rock	
3	Pressure Load (kN/m²)	K Ratio	Pressure Load (kN/m²)	K Ratio	Pressure Load (kN/m²)	K Ratio
4	0	1.00E+00	0	1.00E+00	0	1.00E+00
5	0.01	1.00E+00	0.01	1.00E+00	0.01	1.00E+00
6	0.0774	1.00E+00	0.0774	9.80E-01	0.0373	6.39E-01
7	0.599	1.00E+00	0.599	9.73E-01	0.139	3.51E-01
8	4.64	9.61E-01	4.64	9.63E-01	0.518	1.84E-01
9	35.9	2.14E-03	35.9	8.00E-01	1.93	9.46E-02
10	278	5.15E-06	278	1.75E-02	7.2	4.29E-02
11					26.8	1.64E-02
12					100	3.74E-03
13					373	7.37E-04
14	Pressure Load (kN/m²)	Water Content	Pressure Load (kN/m²)	Water Content	Pressure Load (kN/m²)	Water Content
15	0	3.80E-01	0	0.5	0	0.35
16	1.55	3.79E-01	16.6	0.491	0.45	0.349
17	5.83	3.74E-01	27.6	0.483	10.4	0.344
18	6.59	3.65E-01	41.1	0.469	42.6	0.331
19	7.05	3.48E-01	51.5	0.456	80	0.321
20	7.6	3.18E-01	65	0.434	127	0.311
21	8.45	2.85E-01	105	0.342	200	0.299
22	10.5	2.35E-01	134	0.285		
23	13.8	1.98E-01	150	0.264		
24	19.5	1.71E-01	179	0.24		
25	27.9	0.159				
26	48	0.14				
27	169	0.122				
28						

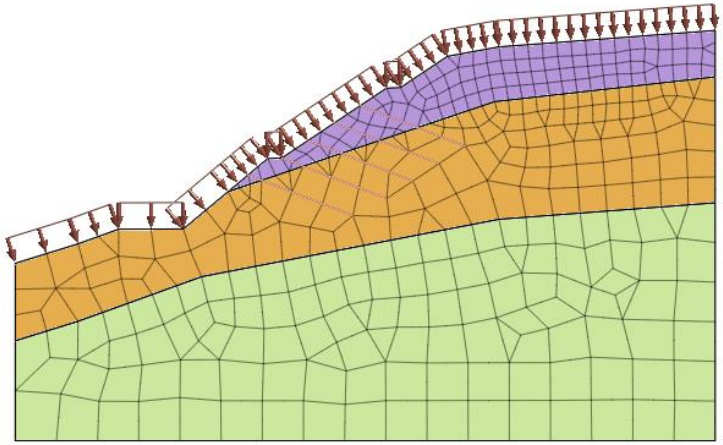
Name	Weathered Soil	Weathered Rock	Bed rock	Nail
Property	2D	2D	2D	1D
Model Type	Plain Strain	Plain Strain	Plain Strain	Truss
Material	Weathered Soil	Weathered Rock	Bed rock	Nail (Steel)
Size (m)				D= 0.025



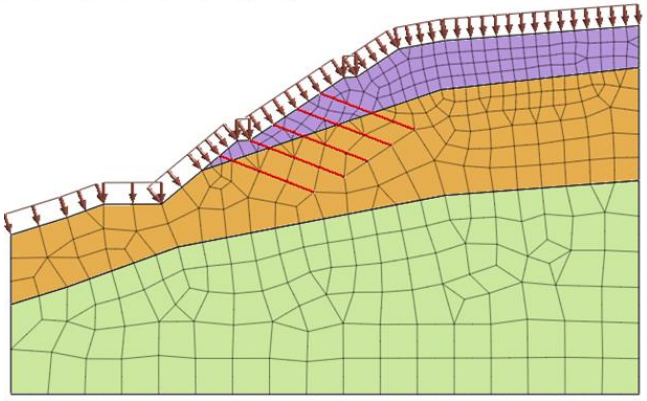
04 Construction Sequence

GTS NX





1. Initial state of dry slope
2. Rain
3. Reinforcement with Nails

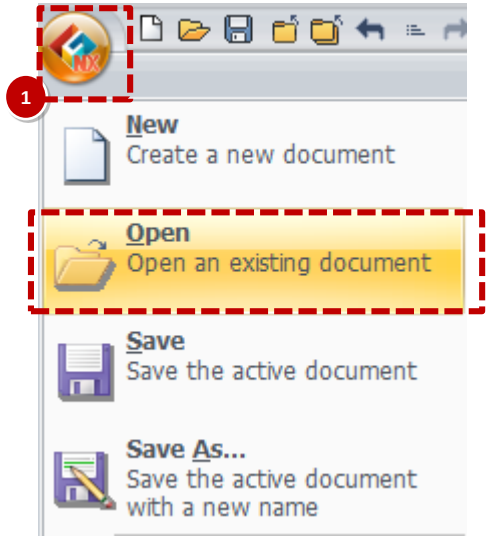


01 Open Project

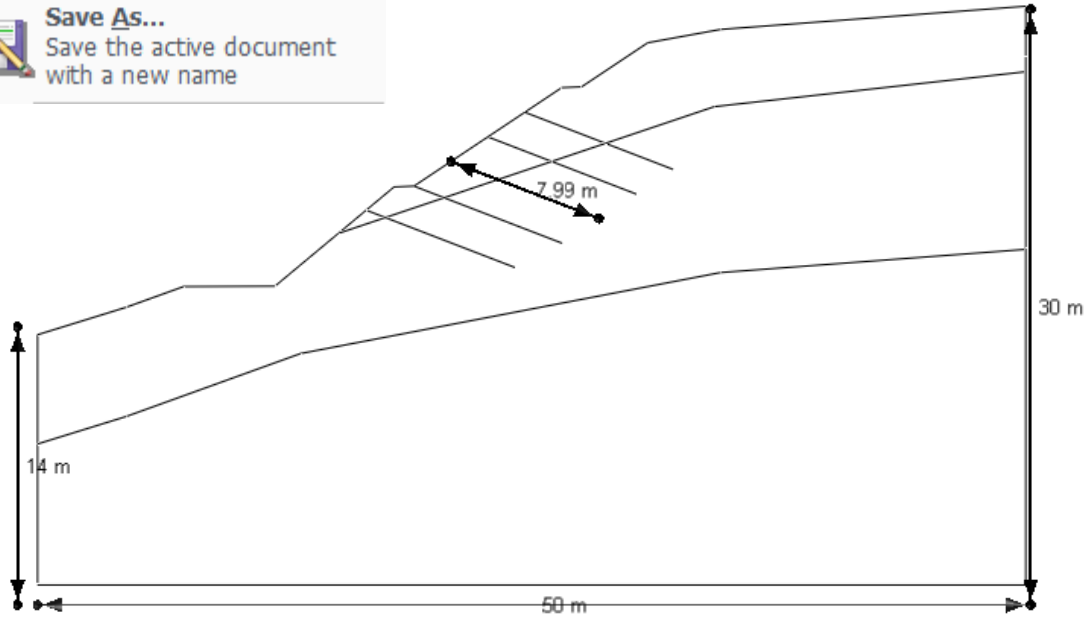
GTS NX

Overview

1. Main Menu > Open
2. Select 2D slope rain with nails start



2 2d slope rain with nails start



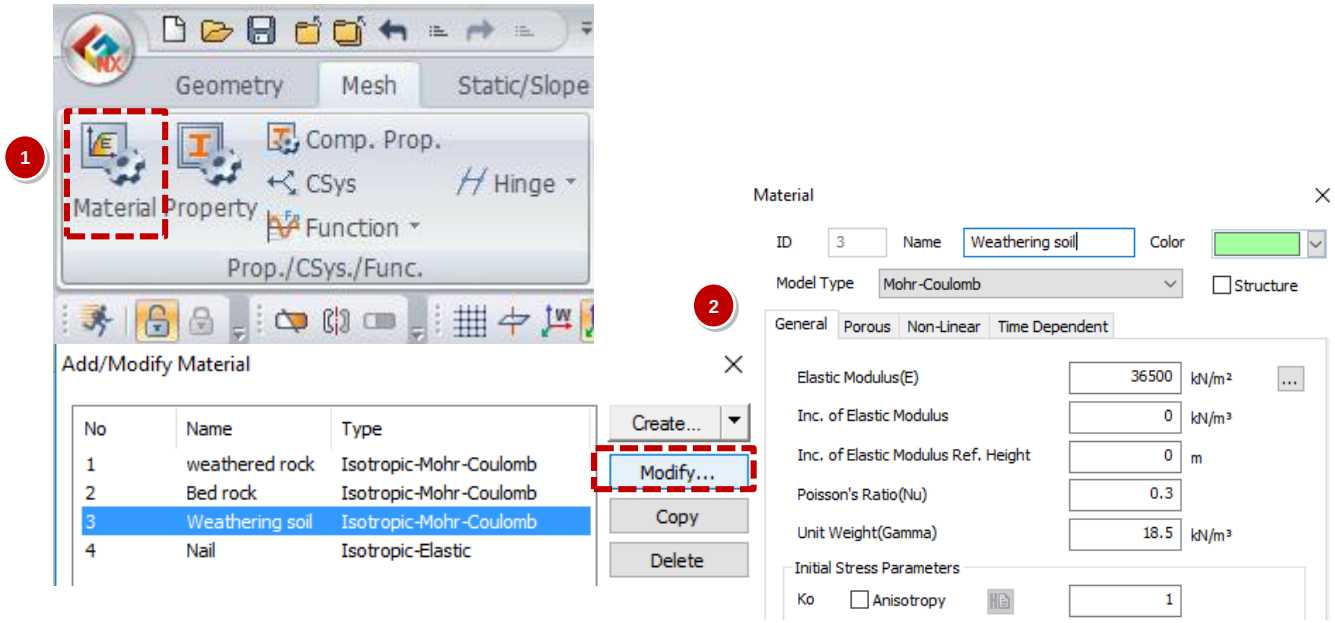
02 Inspect Material for Soil & Structures

GTS NX

Procedure

* You can inspect and modify Material / Property from start files

1. Mesh > Prop. > Material
2. Select weathering soil material and click modify to inspect



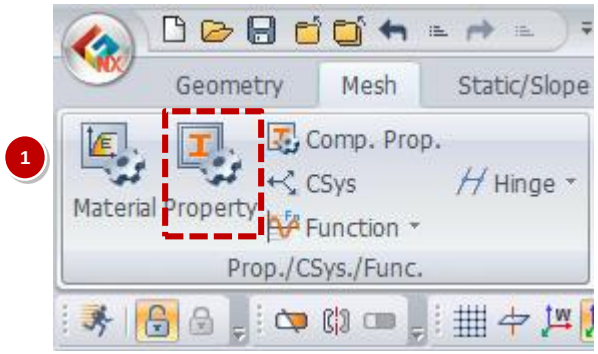
03 Inspect Property for Soil & Structures

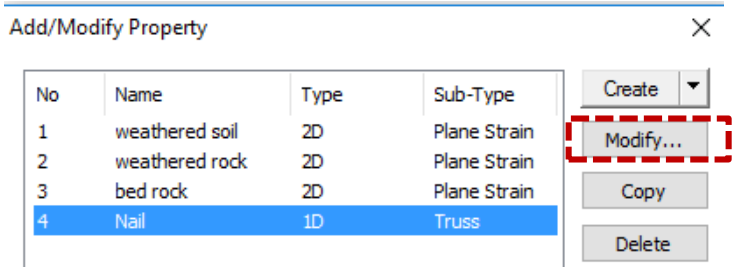
GTS NX

Procedure

* You can inspect and modify Material / Property from start files

1. Mesh > Prop. > Property
2. Select nail property and click modify to inspect





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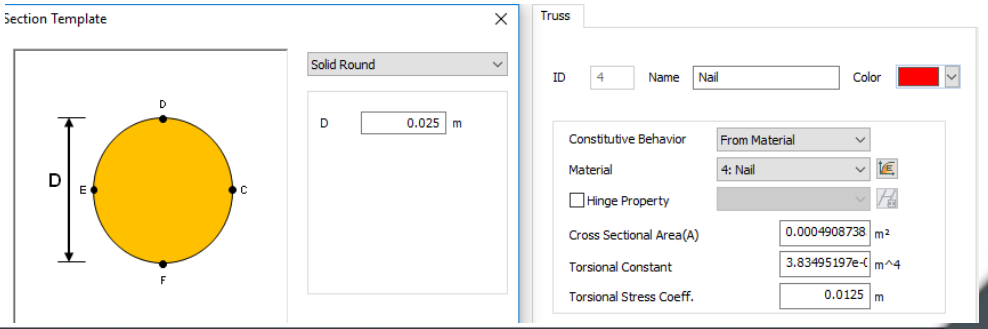
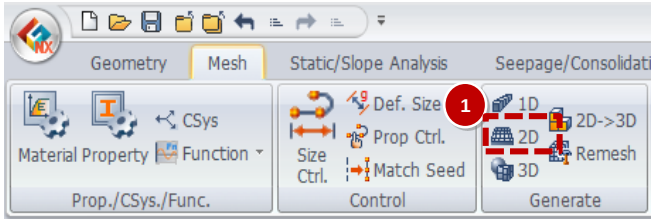


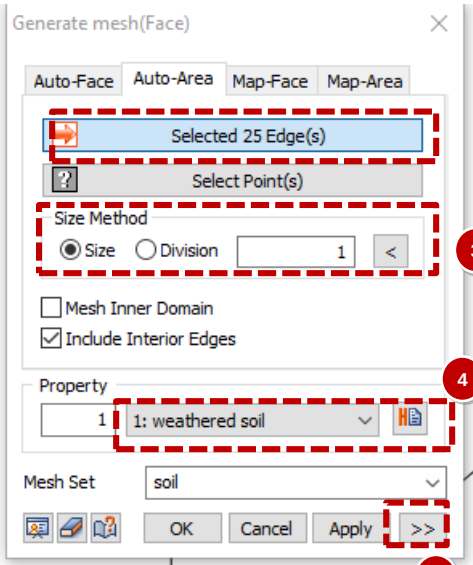
04 Generate Mesh (2D Element)

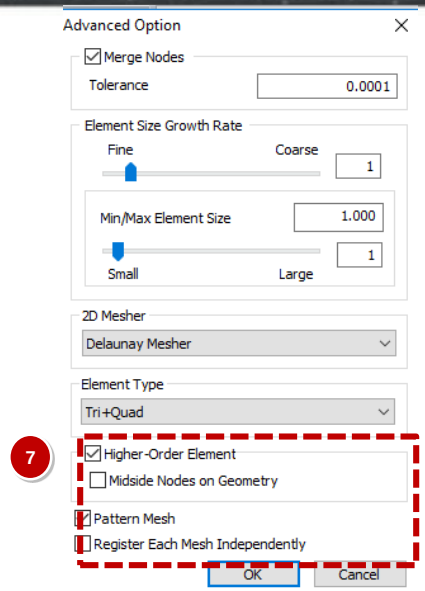
GTS NX

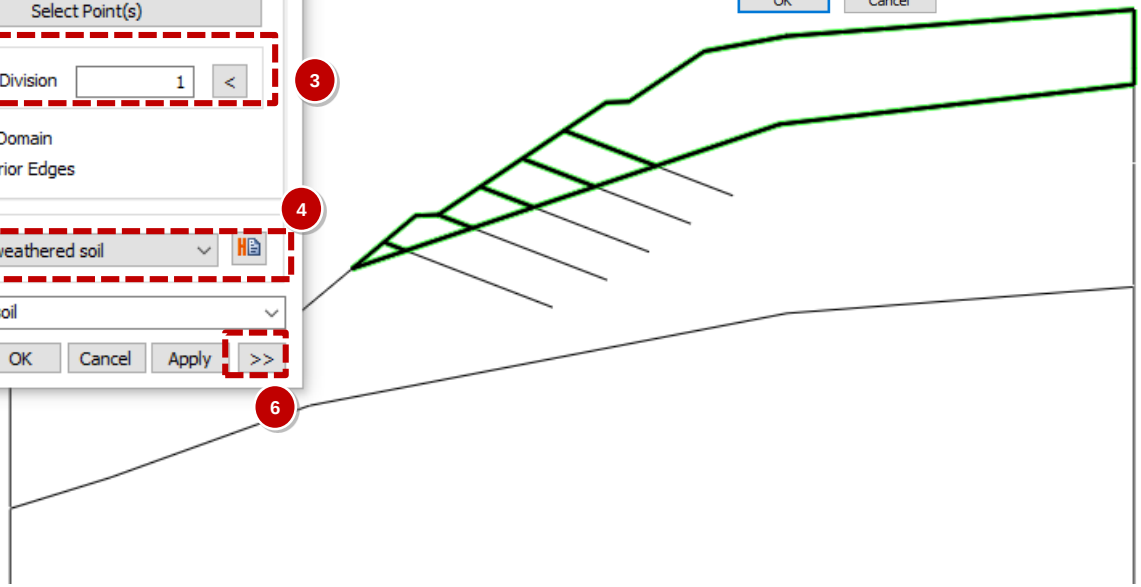
Procedure

1. Mesh > Generate > 2D > Auto - Area
2. Select Edge(s) > Select 25 edges for "Soil layer" as highlighted in the figure. (Include nails)
3. Input element Size : 1
   (1m between two nodes)
4. Select Property : weathered soil
5. Input Mesh Set Name : soil
6. Click on the >> icon to open the Advanced Option Window
7. Activate Higher Order Elements Uncheck Register each set indep.
8. Click OK , then Click Apply (by clicking apply, window keeps HOE option on)







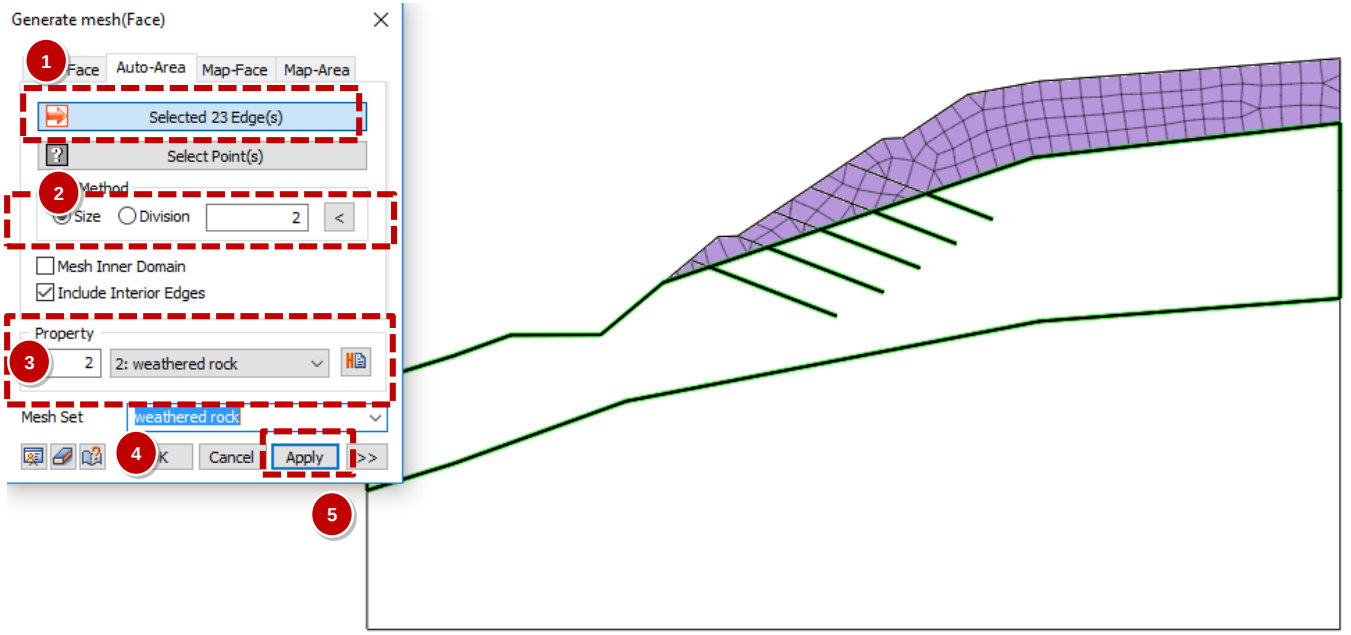


04 Generate Mesh (2D Element)

GTS NX

Procedure

1. Select Edge(s) > Select edges for “Weathered Rock” as highlighted in the figure.
2. Input element Size : 2
   (2 m between two nodes)
3. Select Property : Weathered Rock
4. Input Mesh Set Name : Weathered Rock
5. Click Apply (by clicking apply, window keeps Higher Order Elements option on)

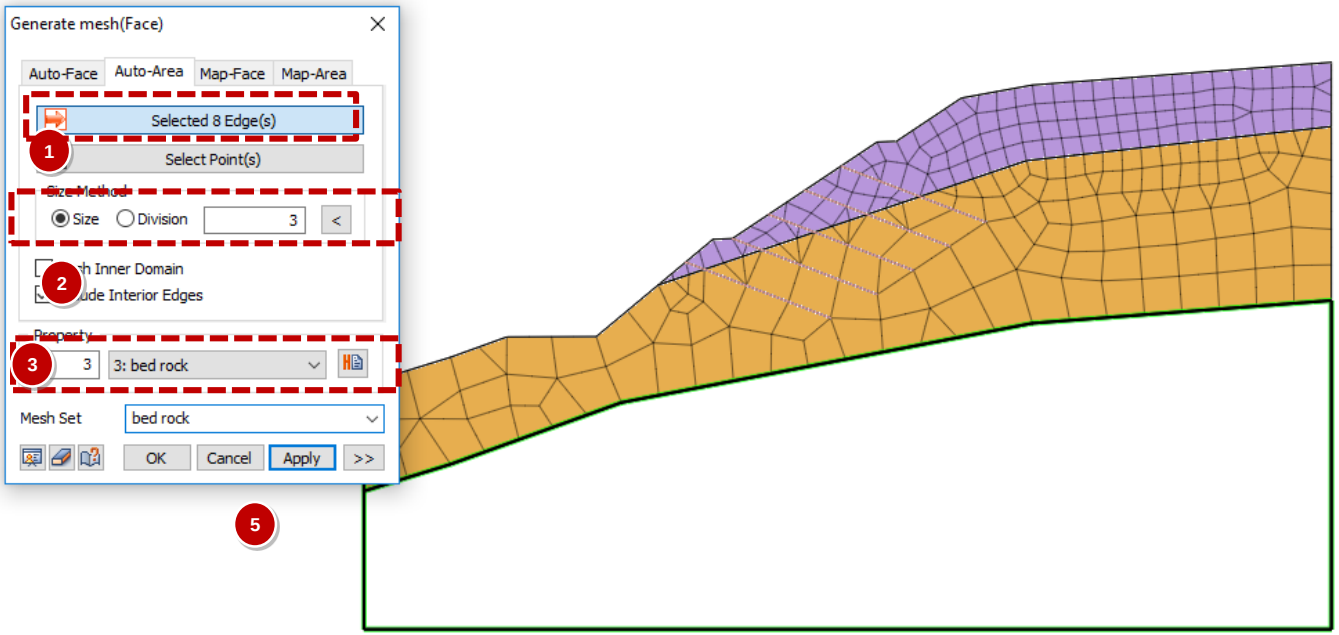


04 Generate Mesh (2D Element)

GTS NX

Procedure

1. Select Edge(s) > Select edges for “Bed Rock” as highlighted in the figure.
2. Input element Size : 3
   (3 m between two nodes)
3. Select Property : Bed Rock
4. Input Mesh Set Name : Bed Rock
5. Click OK

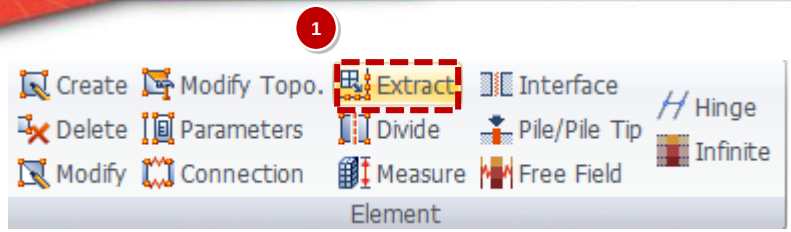


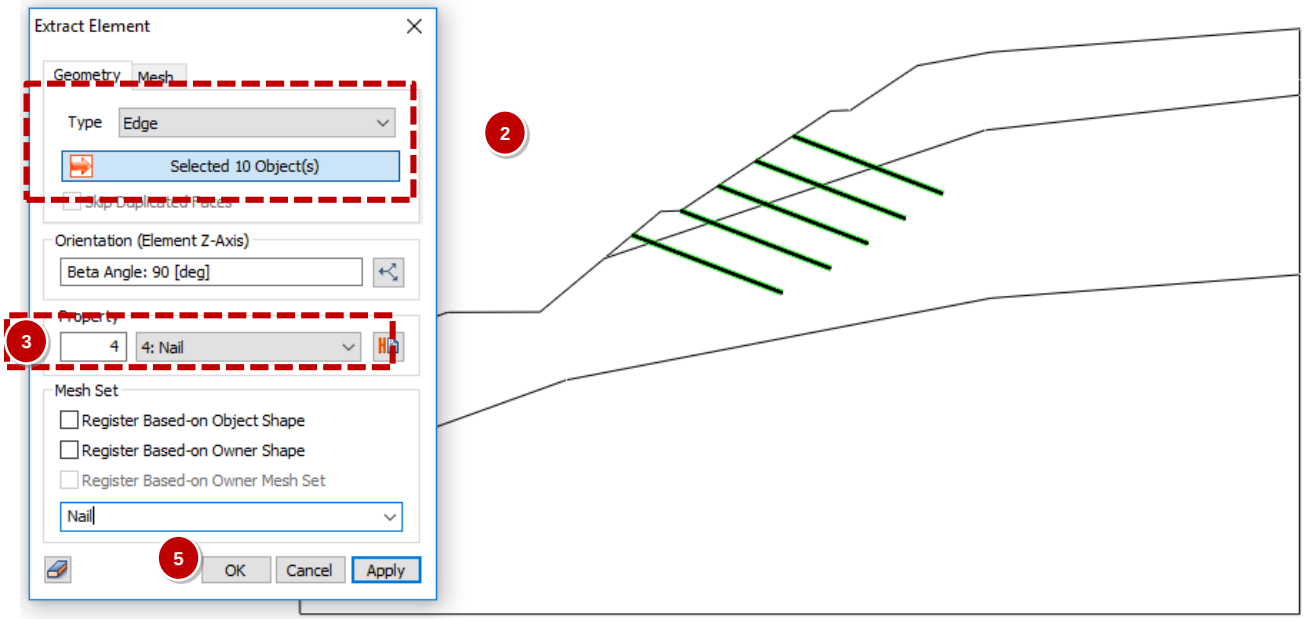
04 Generate Mesh (Extract 1D Element)

GTS NX

Procedure

1. Mesh > Element > Extract
2. Select the TYPE: Edge(s) > Select 10 edges for “nails” as highlighted in the figure.
3. Select Property : Nail
4. Input Mesh Set Name : Nails
5. Click OK





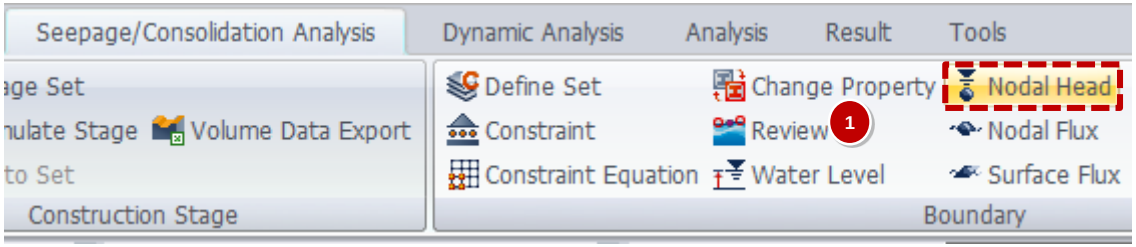
05 Define Boundary Condition (Seepage)

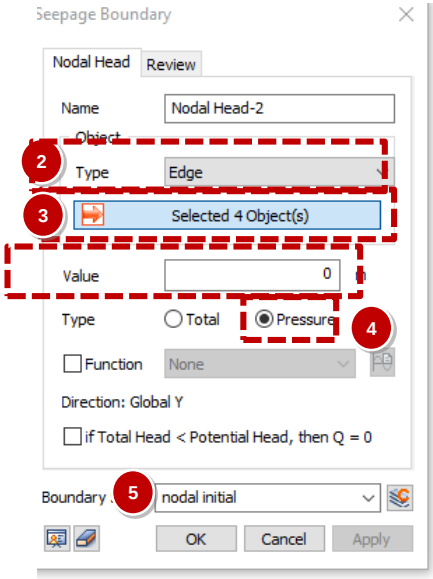
GTS NX

Procedure

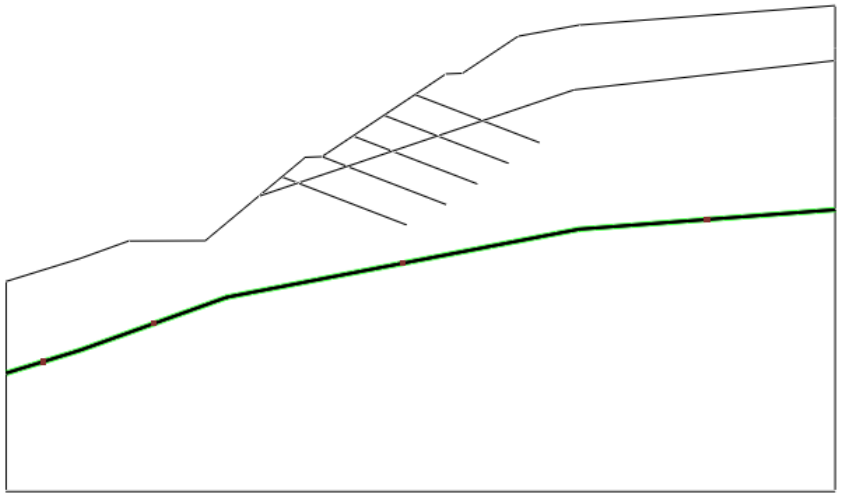
* Nodal Seepage will be defined.

1. Seepage Analysis > Boundary > Nodal Head
2. Select Target Edge(s) > Select edges to define water level as highlighted in the figure. (Do not need to select Vertical edges)
3. Value = 0 m
4. Type: Pressure
5. Boundary Set: Nodal Initial





Nodal Head: Initial Water Level



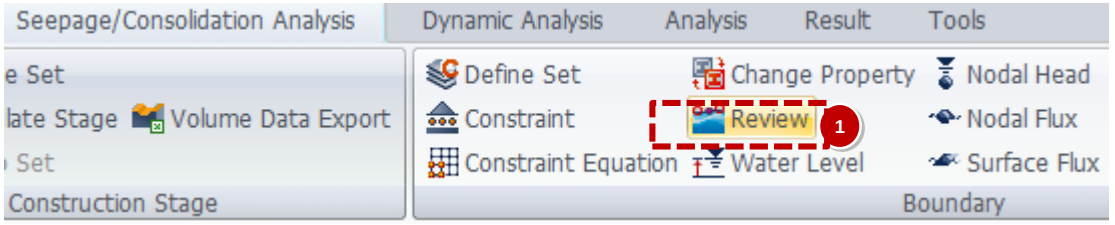
05 Define Boundary Condition (Seepage)

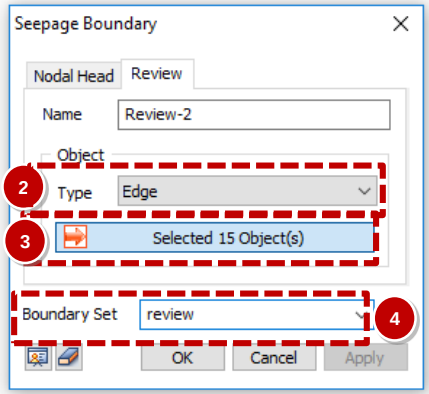
GTS NX

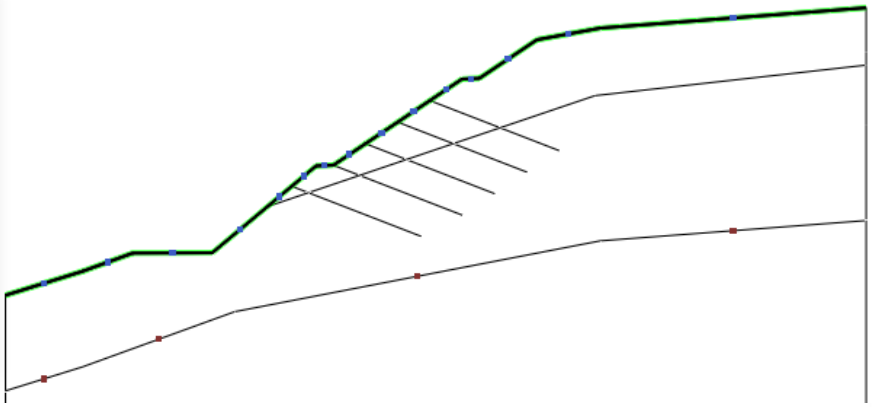
Procedure

* Review Boundary will be defined.

1. Seepage Analysis > Boundary > Review
2. Select Target Edge(s)
3. Select top Surface edge
4. Boundary Set: Review







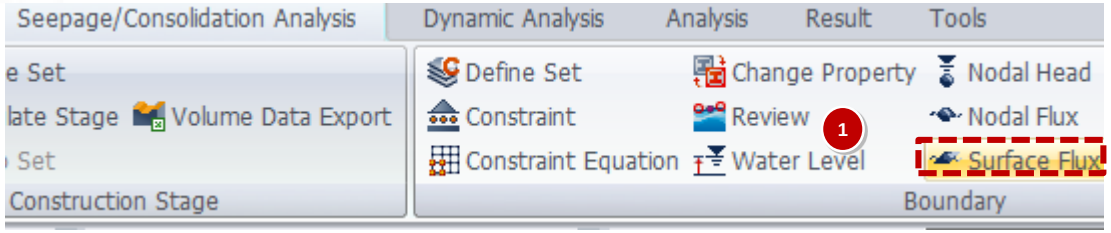
05 Define Boundary Condition (Seepage)

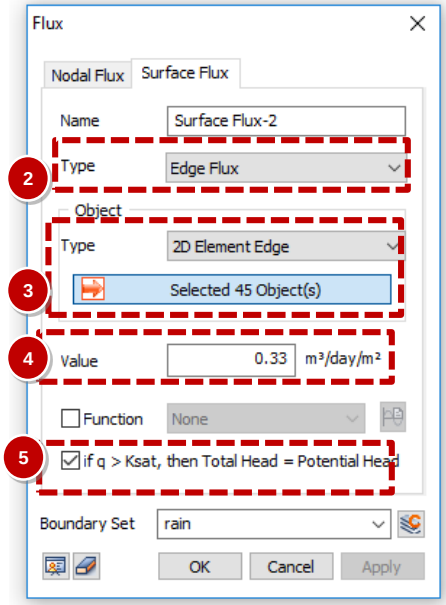
GTS NX

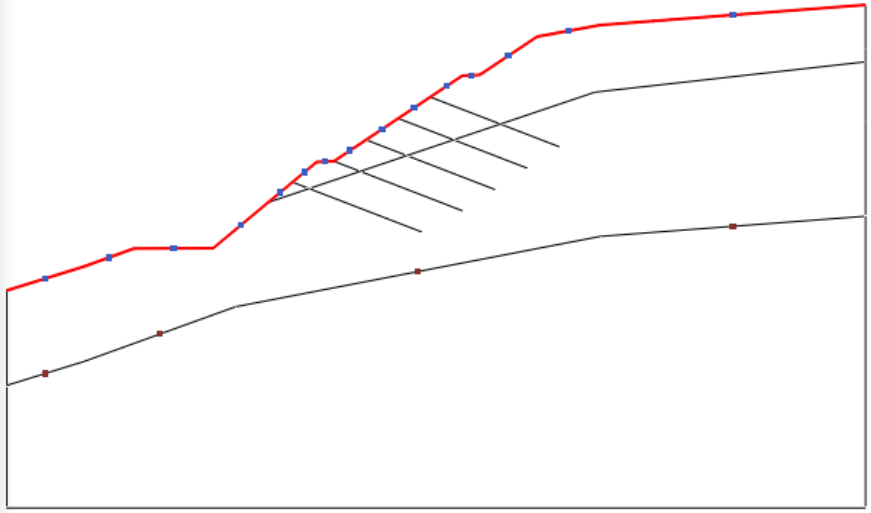
Procedure

* **Surface Flux** will be defined.

1. Seepage Analysis > Boundary > Surface Flux
2. Type: Edge Flux
3. Type: 2D Element Edge
   Select top edges
4. Value: 0.33 m^3/day/m^2
5. Turn on if q > Ksat, then Total Head = Potential Head







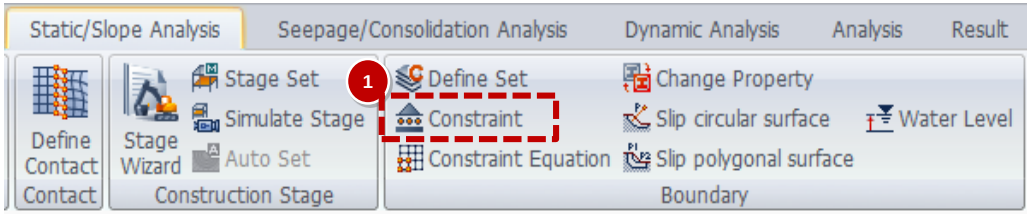
If the rainfall intensity is larger than the absorption capability, the ground surface is in a saturated state during rainfall, as if the groundwater level existed above the surface. Hence, the area of rainfall needs to be changed to a water level line. Use the [If q > Ksat, then Total Head = Pressure Head] option to automatically change the ground surface boundary from the existing rainfall intensity inflow condition to a water level condition for analysis.

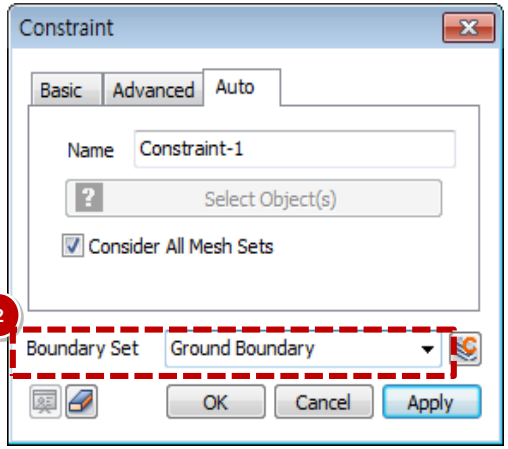
05 Define Boundary Condition (Ground)

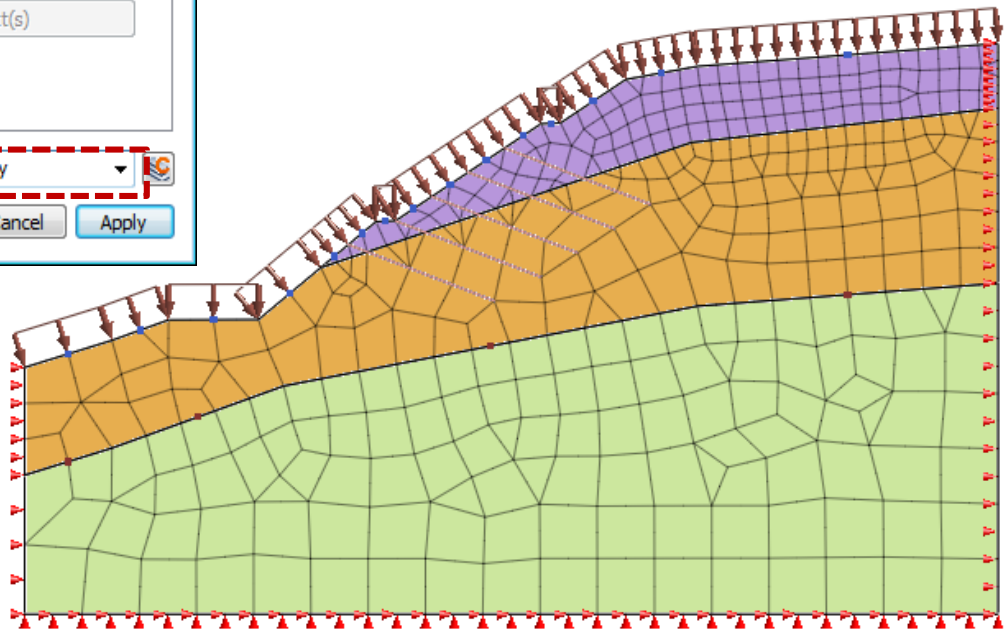
GTS NX

Procedure

1. Static / Slope Analysis > Boundary > Constraint > Auto
2. Boundary Set Name : Ground Boundary





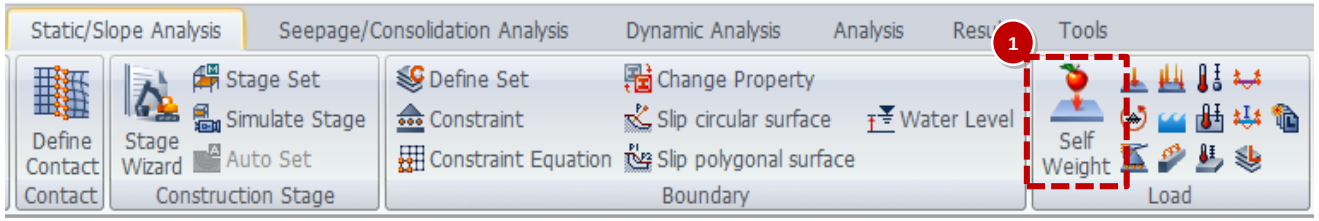


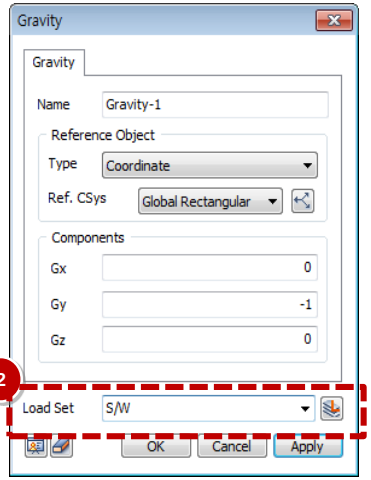
06 Load Condition (Self Weight)

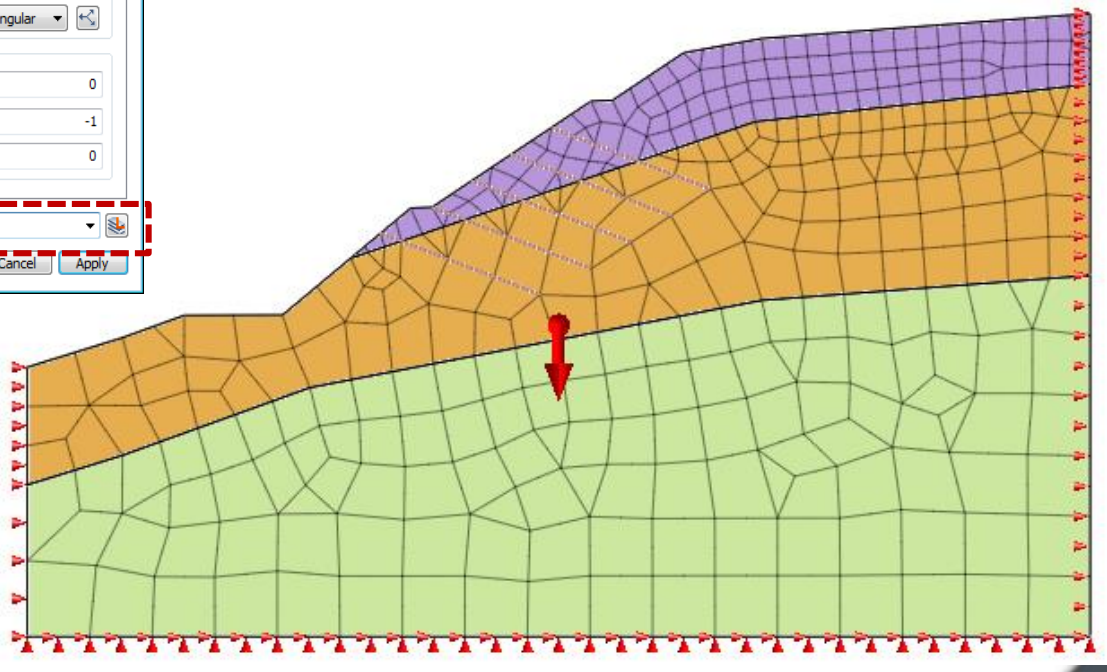
GTS NX

Procedure

1. Static / Slope Analysis > Load > Self Weight
2. Load Set Name : S/W







07 Define Construction Stage (Create Stage Set)

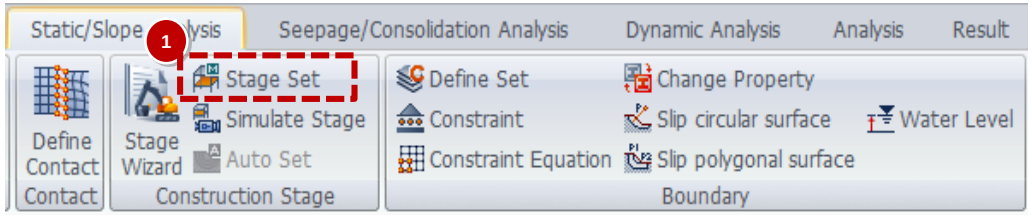
GTS NX

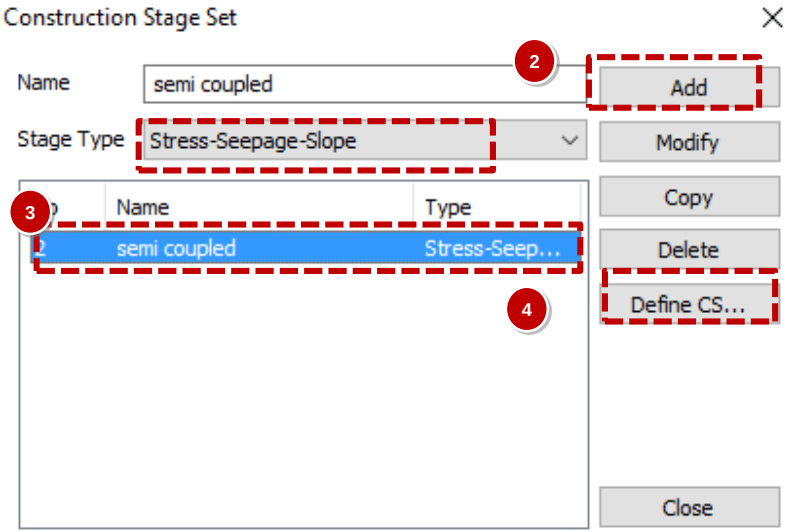
Procedure

* 5 Construction stage will be defined for this project.

1. Static / Slope Analysis > Construction Stage > Stage Set
2. Stage Type > Stress – Seepage Slope
3. Select Add
4. Select Created Stage Set

   Select Define CS...



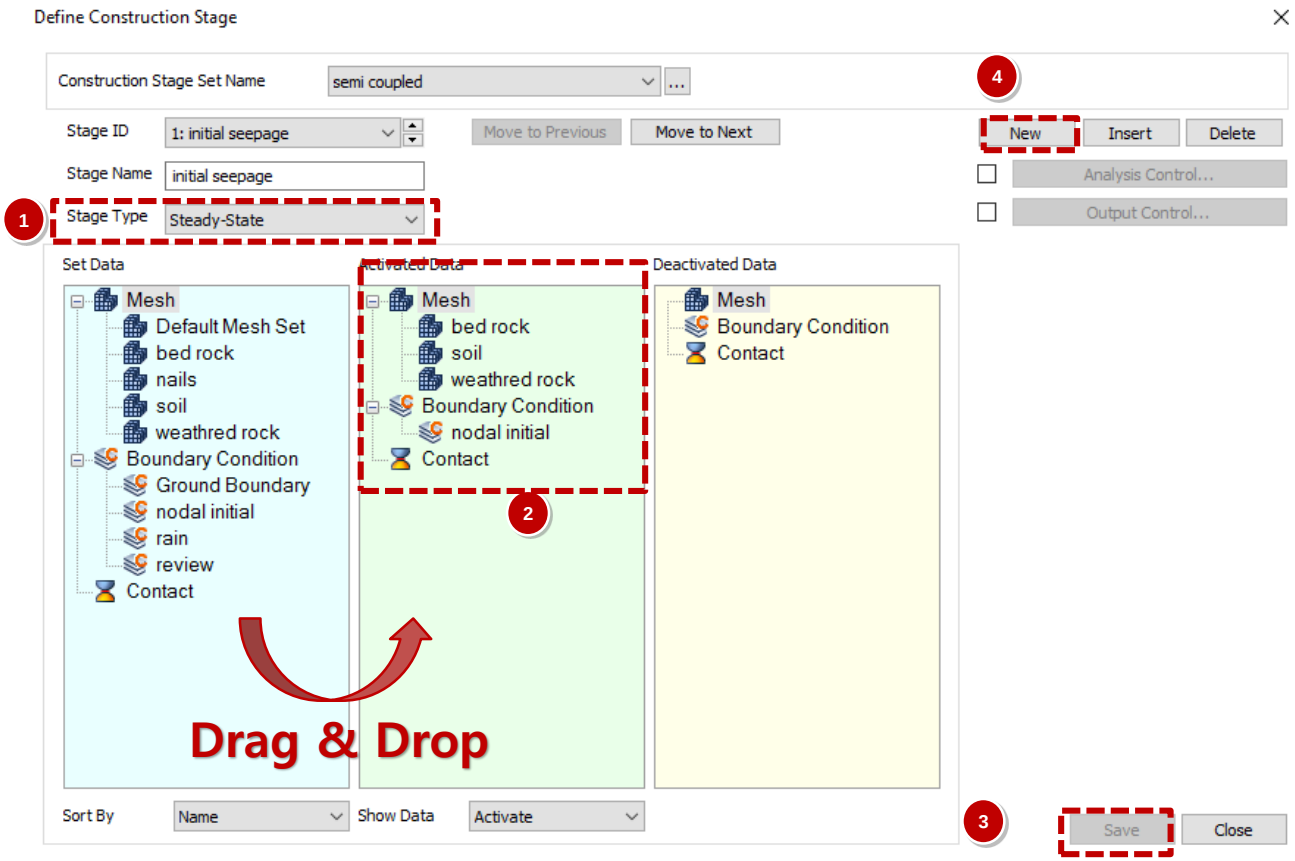


08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 1 Type : Seepage Steady State
2. Activated Data : All Mesh Sets for initial state of ground (2D elements), and Nodal Initial seepage boundary
3. Select Save
4. Select New

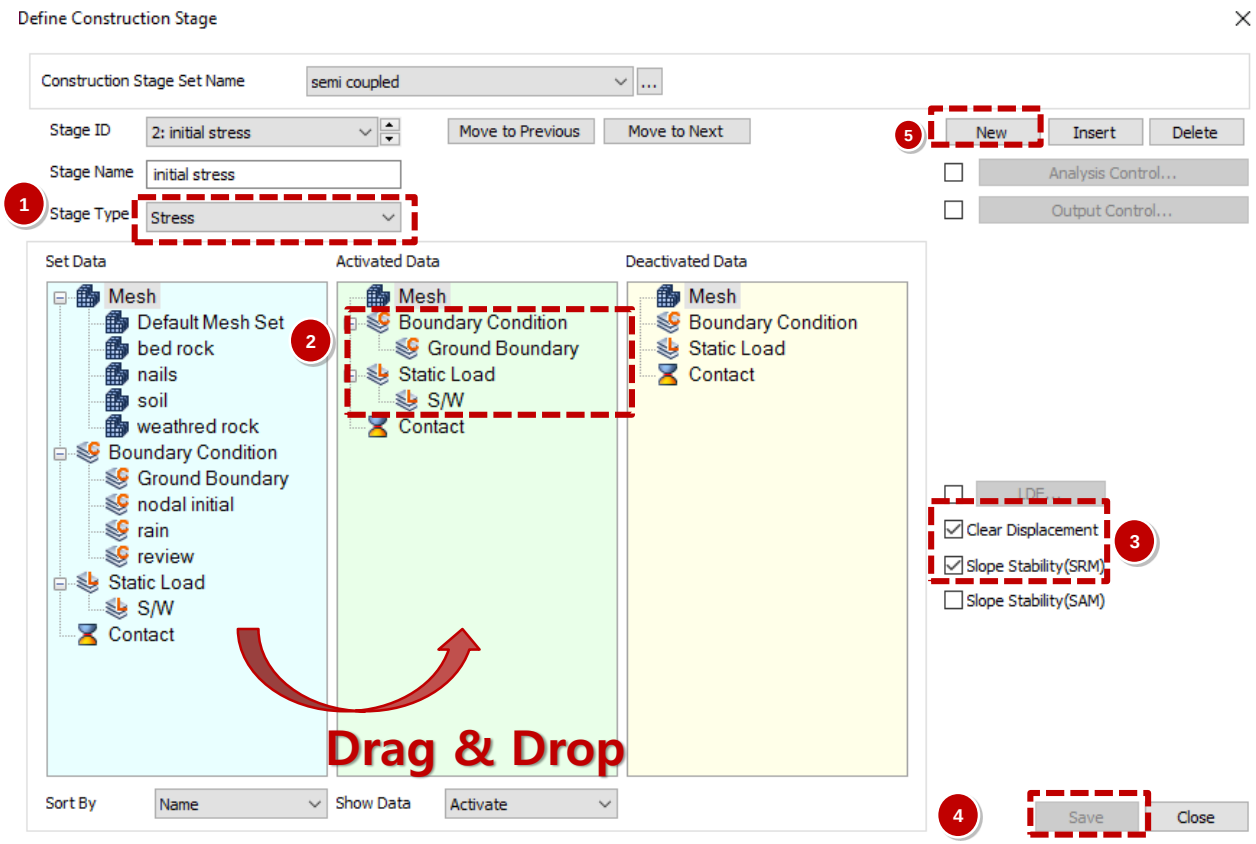


08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 2 Type : Stress
2. Activated Data : Boundary and Load Sets for Ground Boundary and Self Weight
3. Activate Clear Displacements and SRM
4. Select Save
5. Select New



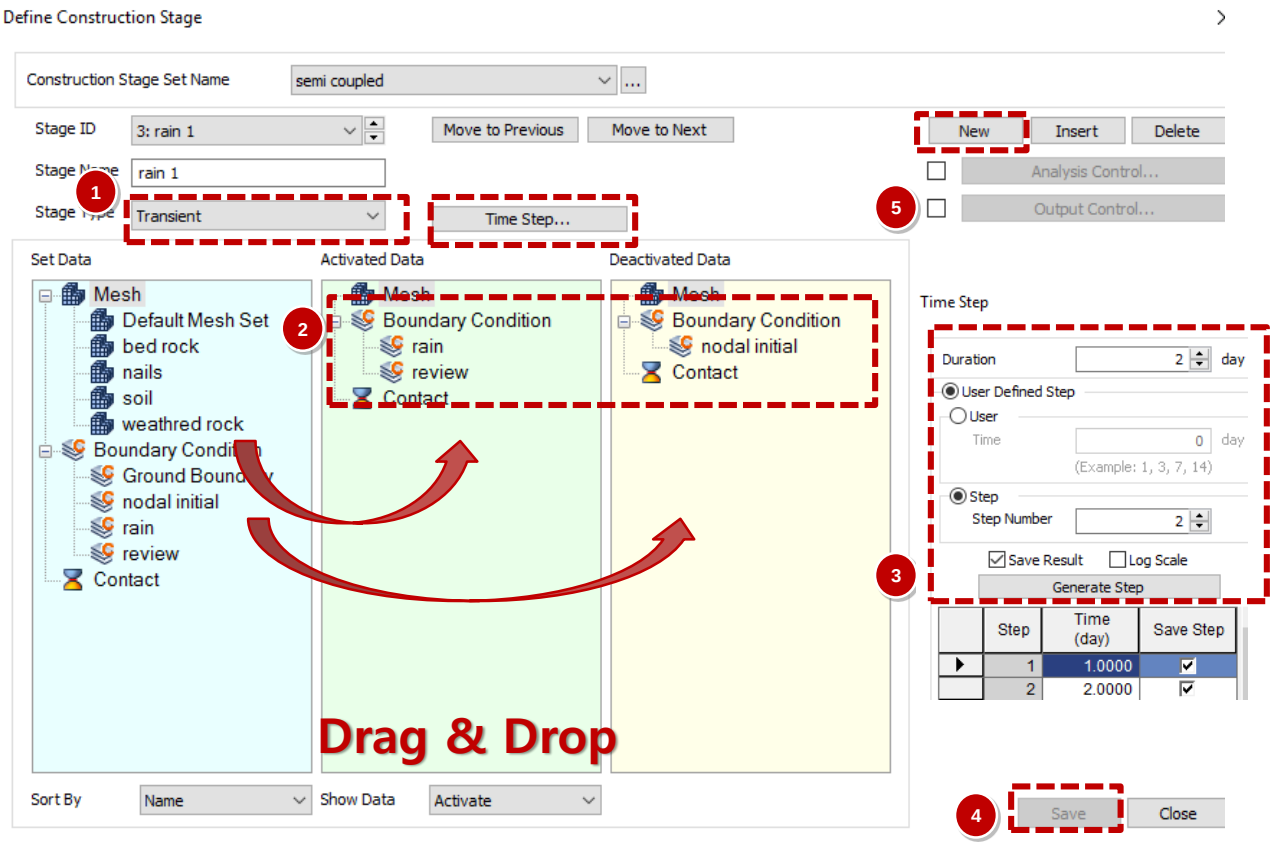
08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 3 Type : Seepage
   Transient (rain)
2. Activated Data : Boundary Sets
   Rain and Review

   Deactivate Data: Boundary Set
   nodal review
3. Click Time Step
   2 days 2 Steps
   Save Result / Generate Step
4. Select Save
5. Select New

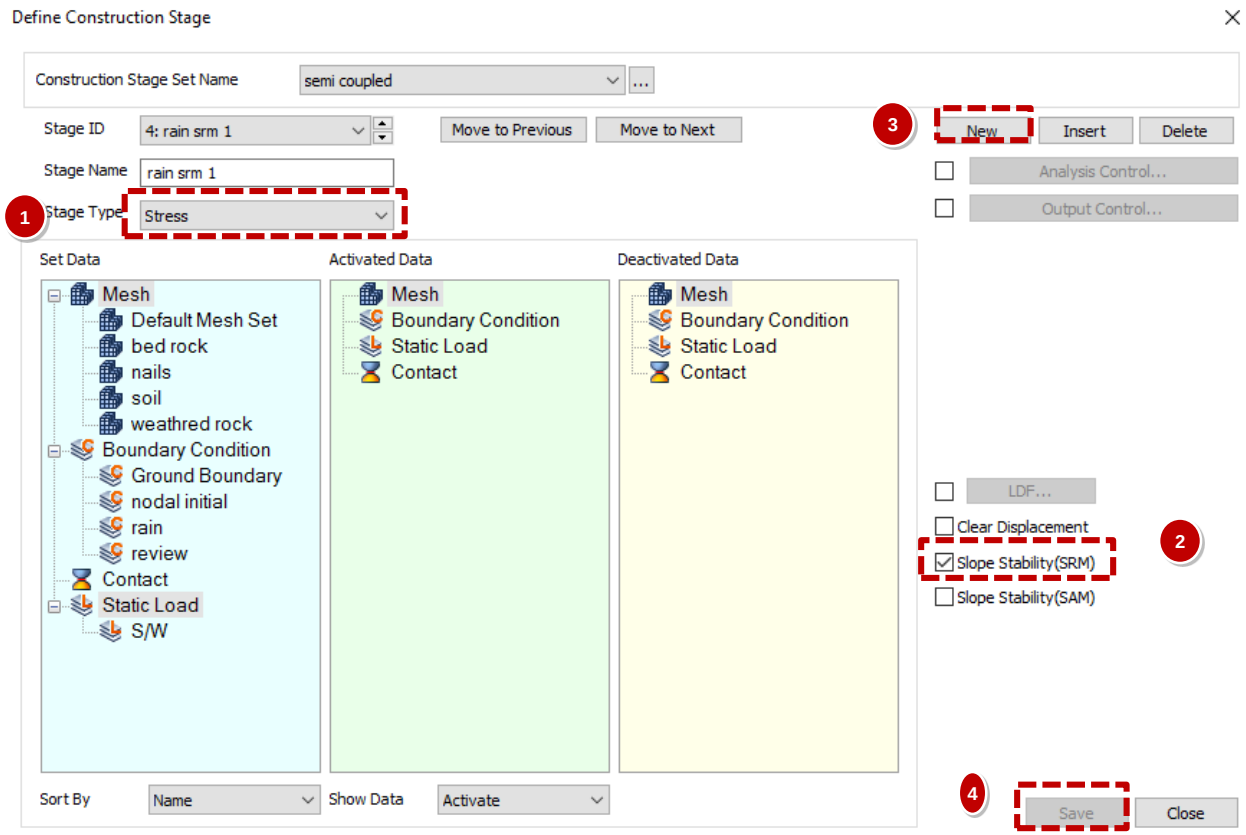


08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 4 Type : Stress
2. Check on Slope Stability SRM
3. Select Save
4. Select New

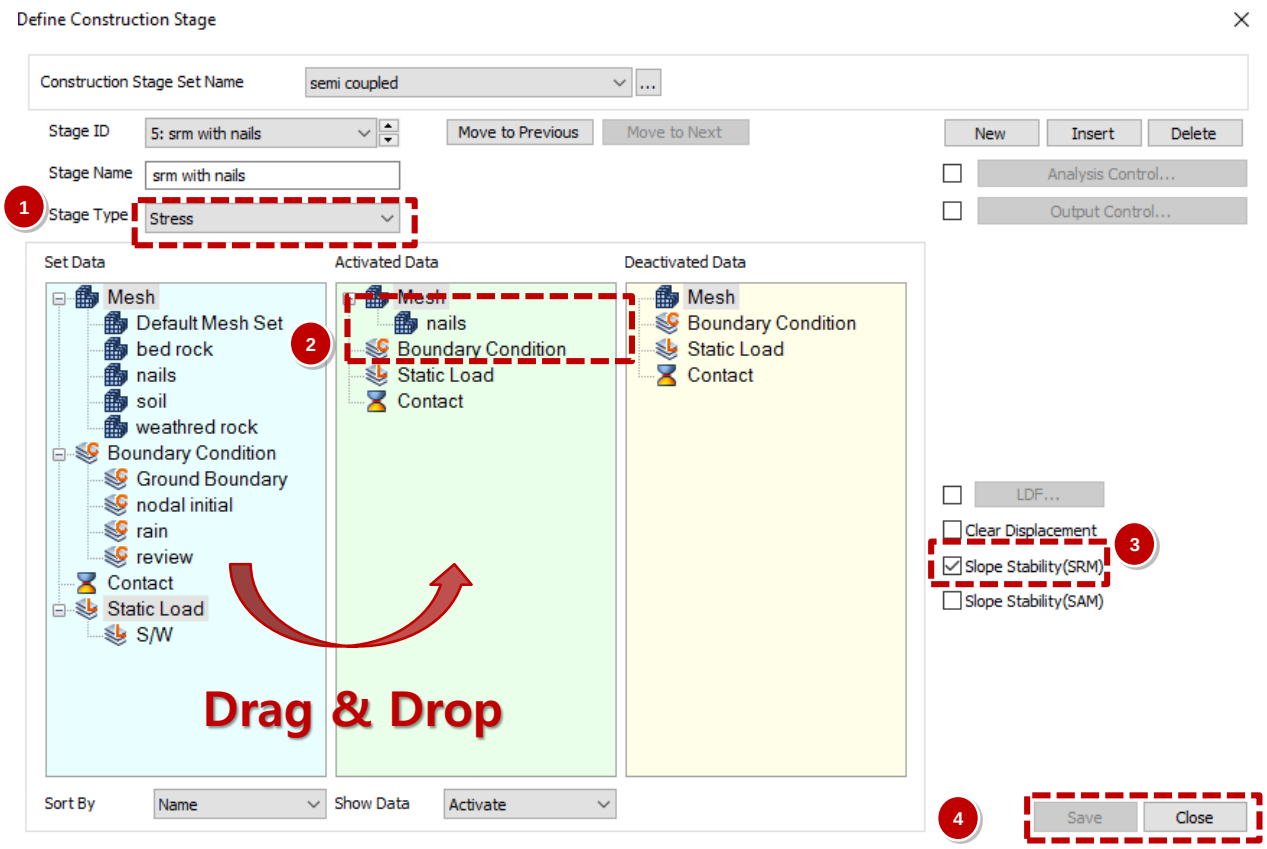


08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 5: Type : Stress
2. Activated Data : Nails mesh set
3. Activate SRM
4. Select Save and Close

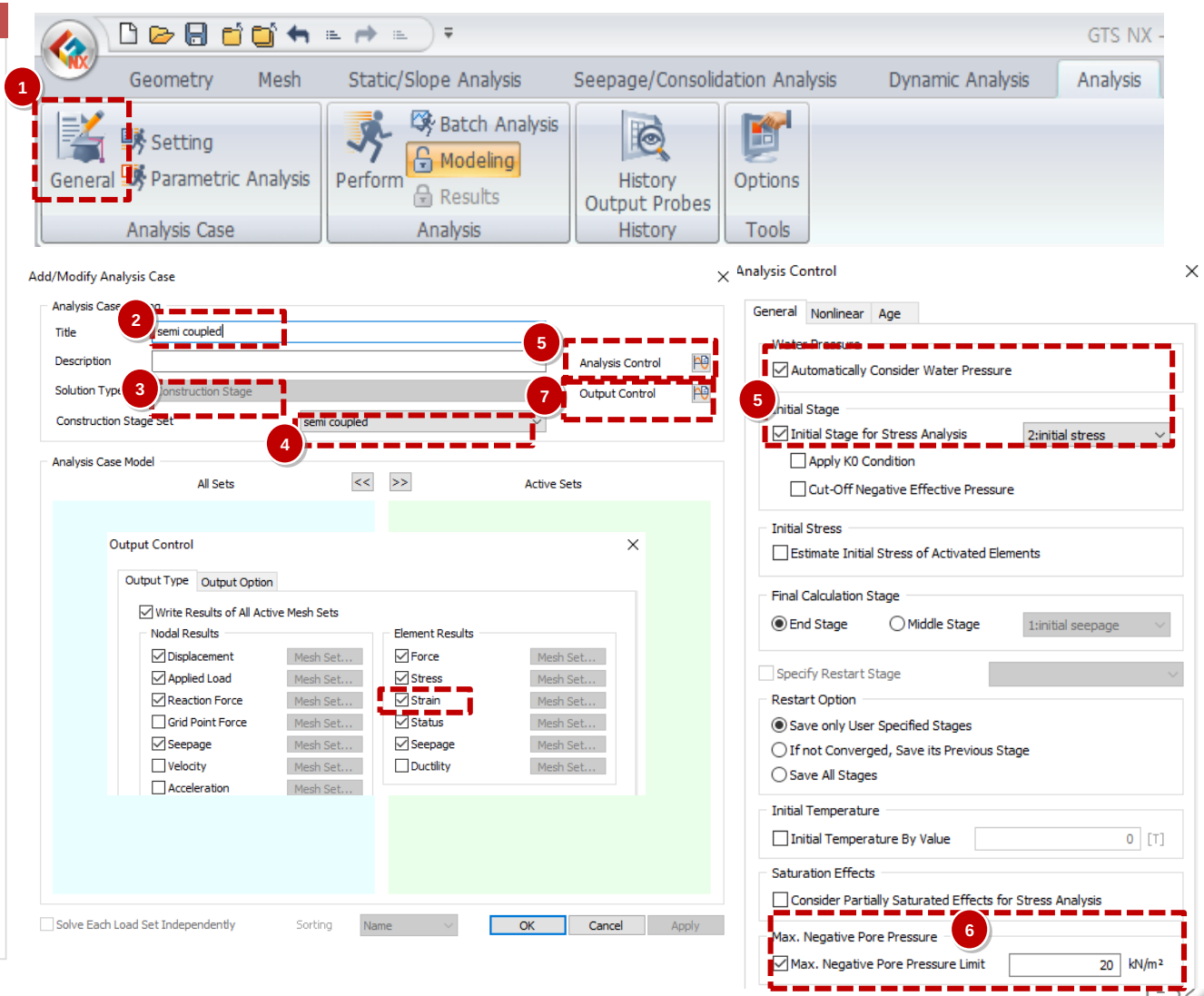


09 Analysis Case

GTS NX

Procedure

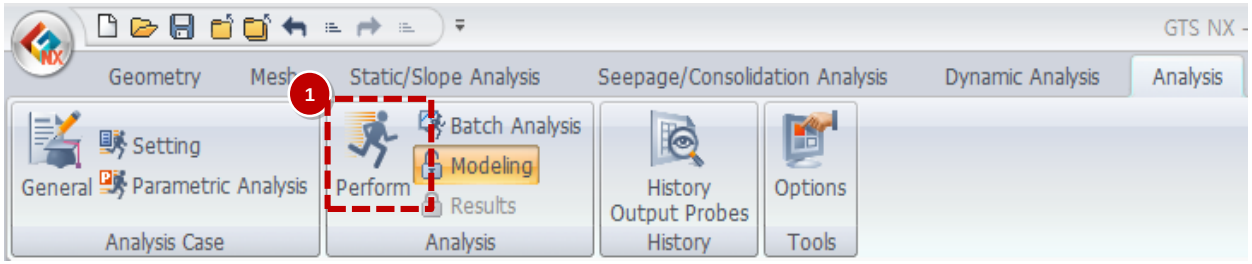
1. Analysis > Analysis Case > General
2. Title : Semi Coupled
3. Solution Type : Construction Stage
4. Select Construction Stage Set Semi coupled
5. Analysis Control : Select Initial Stage for Stress Analysis (2. Initial Stress),
   Check: Auto Consider Water Pressure
6. Check Max Negative Pore Pressure: 20kN/n^2
7. Output Control:
   Check On: Strains

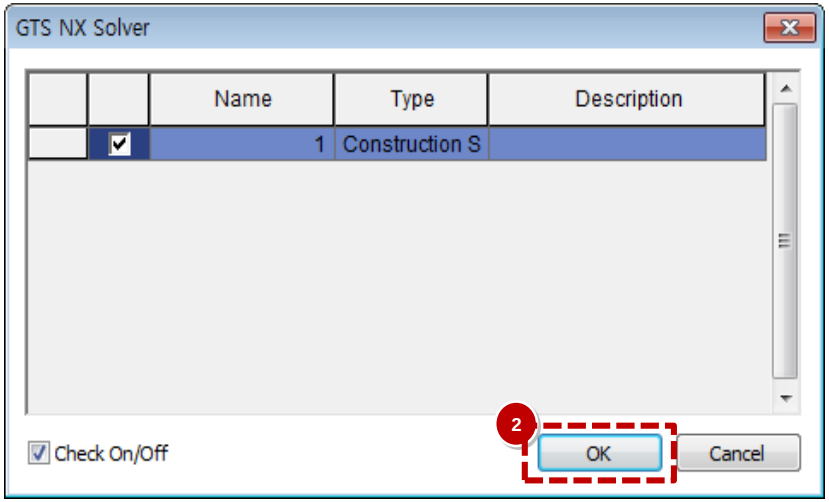


GTS NX

Procedure

1. Analysis > Analysis > Perform
2. Select OK





11 Post Processing (Pre mode vs Post mode)

GTS NX

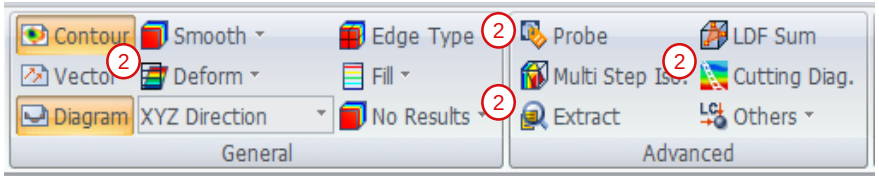
Procedure

① After analysis, model view will be converted to Post-Mode automatically, can back to Pre-Mode to change model information.

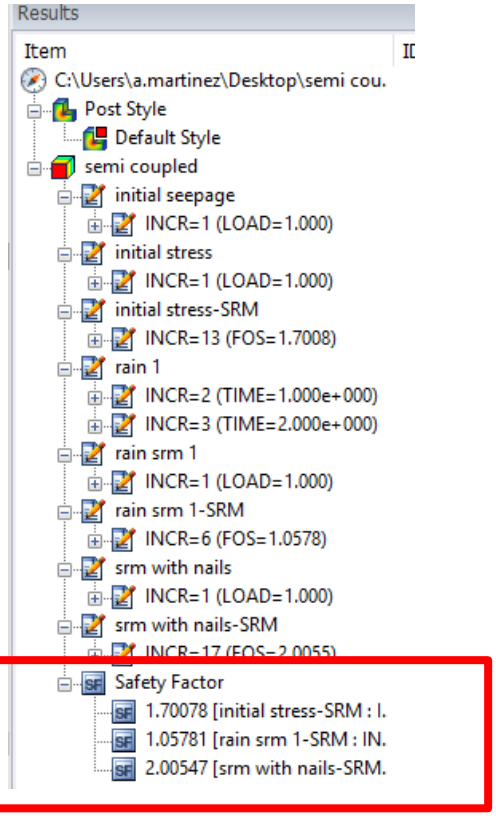
② All results will be represented by graphic based output, table, diagram and graph.

③ Results are given by stages and types of elements.

The results are set in order of the stages.
The bottom of the results tab lists the FOS for all the stages in order.



3



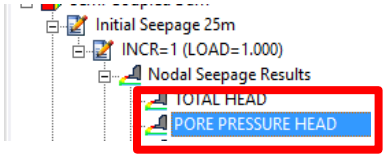
11 Post Processing (Post mode)

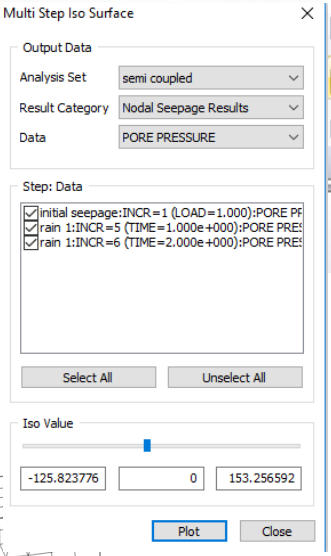
GTS NX

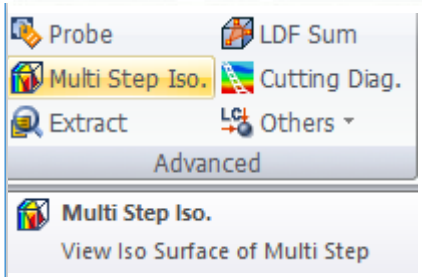
Procedure

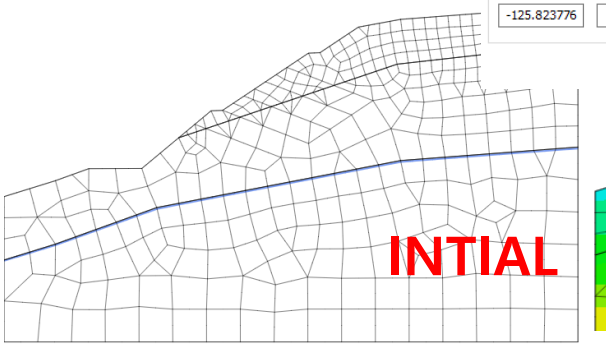
1. Expand the results for semi coupled and double click **Nodal Seepage > Pore Pressure** to verify the Pore Stress dues to change in Water Level.

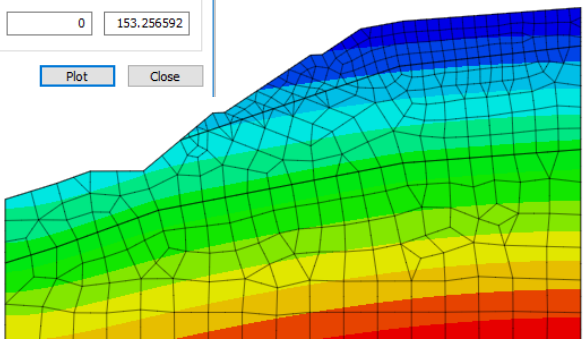
2. You can activate the water level lines by using the Multi Step Iso surface function and setting pore pressure to 0 for each stage. Click PLOT

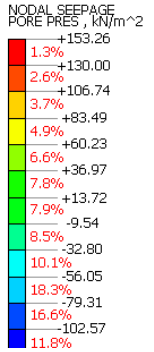


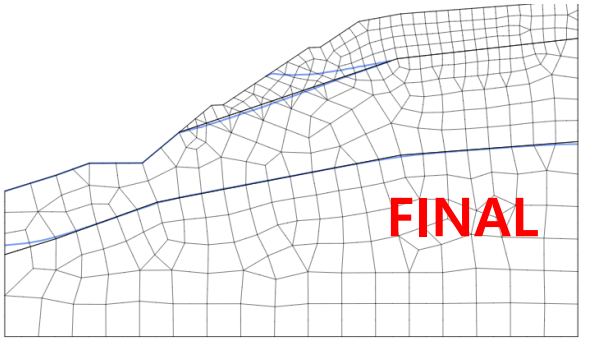


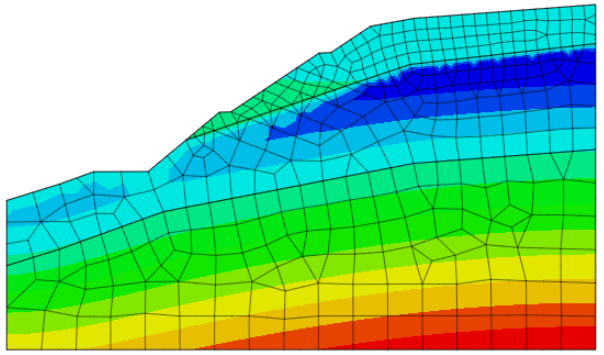


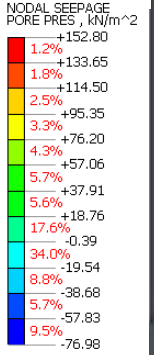












11 Post Processing (Post mode)

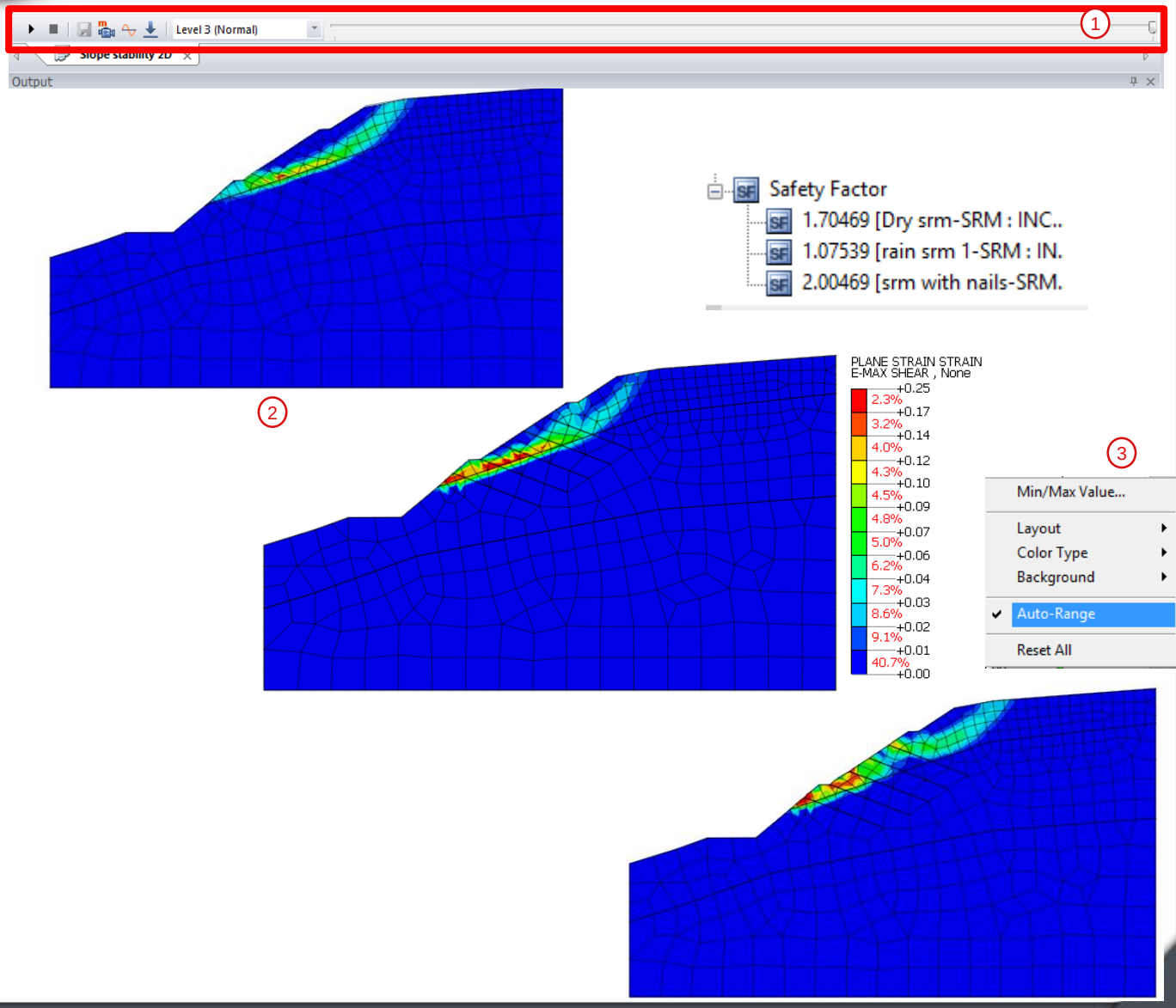
GTS NX

Procedure

1. Inspect the changes in the model by navigating the stages using the bar on the bottom of the model / above the output window. Press Right or Left key on keyboard to go forward and backward in the stages respectably.

2. Inspect the slope stability results for the last stage by selecting the Plane Strain Strains.
The images shows max shear strains for the 1st 3 stages of the analysis.

3. Right click the legend and select AUTO RANGE to see results more clearly.
You can create a video animation of the stages by selecting **Multi Stage Animation > Select All Stages > Play > Save**



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Part 2. 2D Slope Stability SRM

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Part 4. 2D Dam Stability SAM

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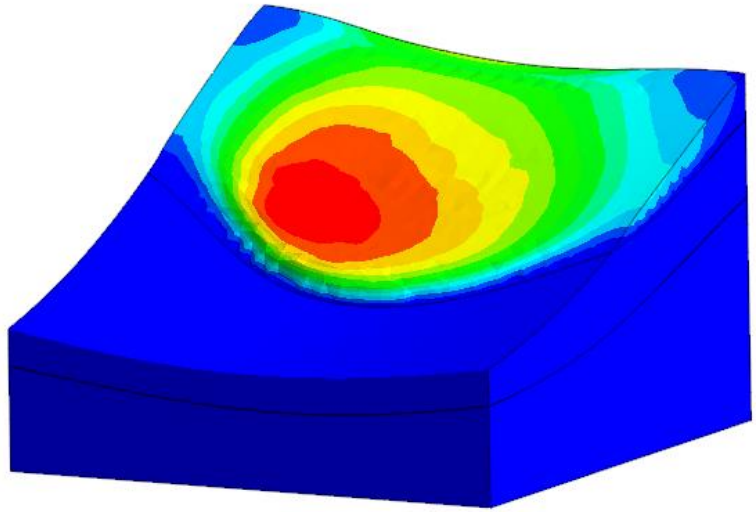
STEP 02	Define Materials
STEP 03	Mesh generation
STEP 04	Boundary Conditions
STEP 05	Load Conditions
STEP 06	Define Construction Sequence
STEP 07	Analysis Case
STEP 08	Perform analysis and check result



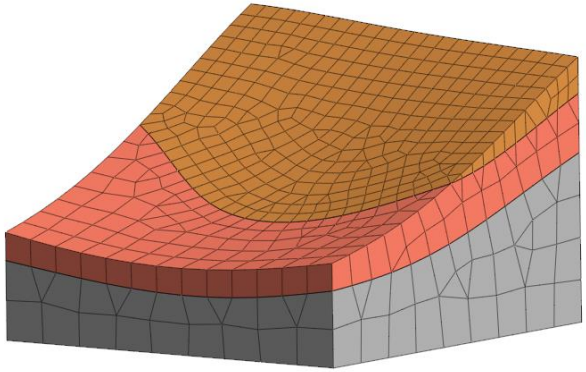
GTS NX

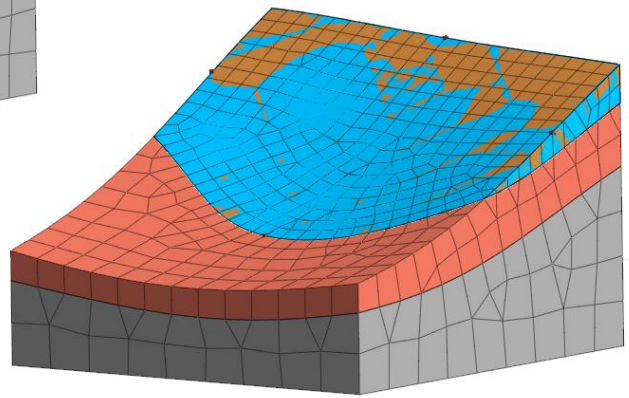
Name	Weathered Soil	Weathered Rock	Bed Rock
Material	Isotropic	Isotropic	Isotropic
Model Type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
General			
Elastic Modulus (E) (kN/m^2)	40,000	150,000	1,850,000
Poisson's Ratio(v)	0.3	0.25	0.28
Unit Weight(r) (kN/m^3)	18	21	24
Ko	1	1	1
Porous			
Unit Weight(Saturated) (kN/m^3)	19	22	25
Permeability Coe. (m/day)	0.504	0.00254	3.86e-005
Non-Linear			
Friction Angle	21	25	38
Cohesion (kN/m^2)	9	40	100

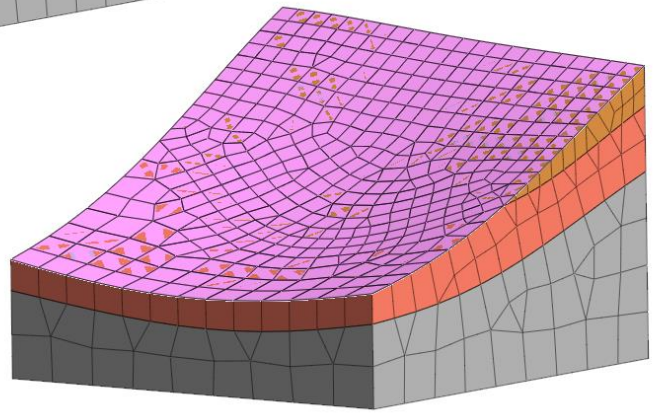
Geogrid
Orthotropic
Geogrid
Elastic Modulus 1
550000 kN/m^2
Elastic Modulus 2
475000 kN/m^2
Shear Modulus
375000 kN/m^2
Weight
7 kN/m^3

GTS NX

Name	Weathered Soil	Weathered Rock	Bed rock	Geogrid
Property	3D	3D	3D	2D
Model Type	Solid	Solid	Solid	Geogrid
Material	Weathered Soil	Weathered Rock	Bed rock	Geogrid
Size (m)				Thickness = 0.01



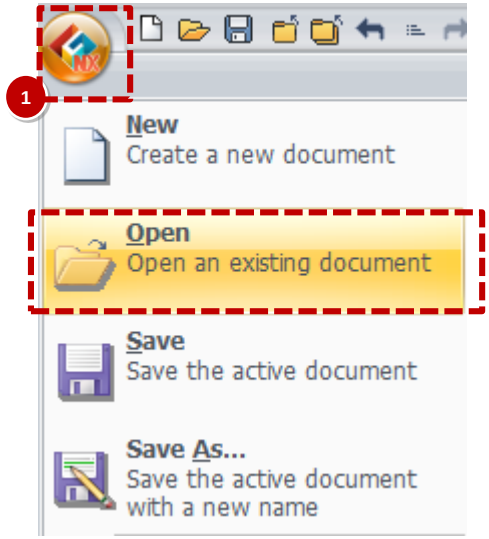


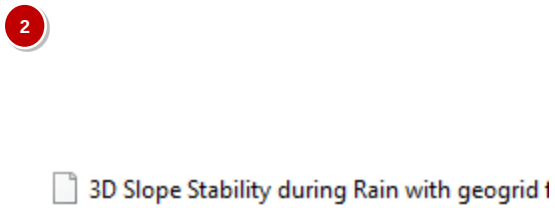


1. Initial state of dry slope
2. Rain
3. Reinforcement with geogrid

Overview

1. Main Menu > Open
2. Select 3D Slope Stability during Rain with geogrid start





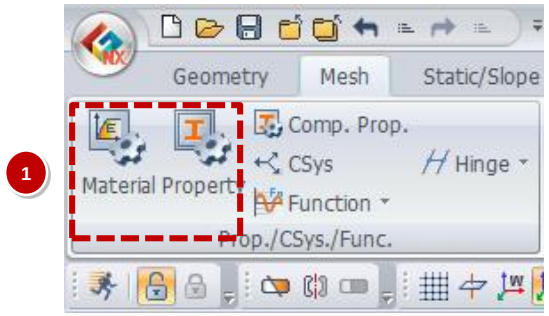
02 Inspect Material / Property for Soil & Structures

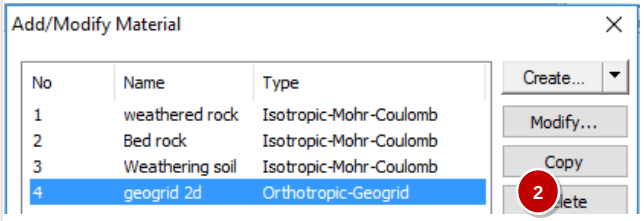
GTS NX

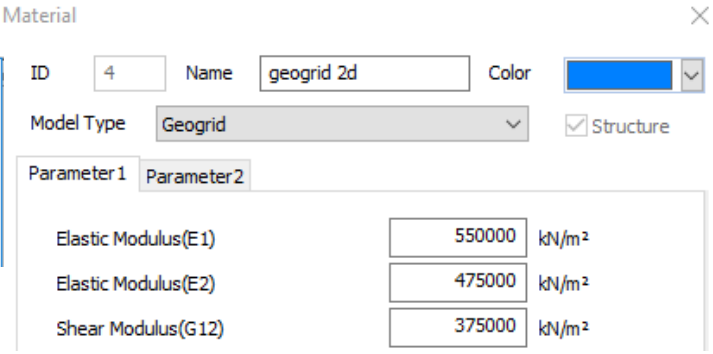
Procedure

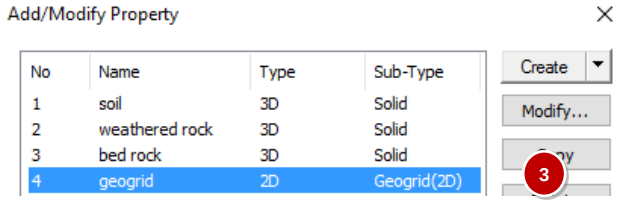
* You can inspect and modify Material / Property from start files

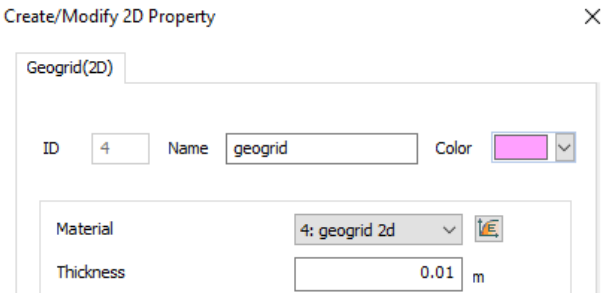
1. Mesh > Prop. > Material or Property
2. Select geogrid material and click modify to inspect
3. Select geogrid property and click modify to inspect









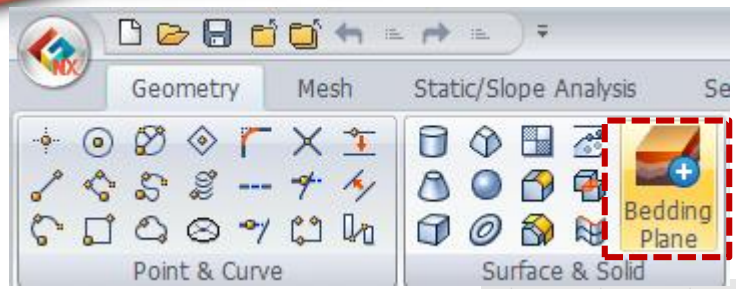


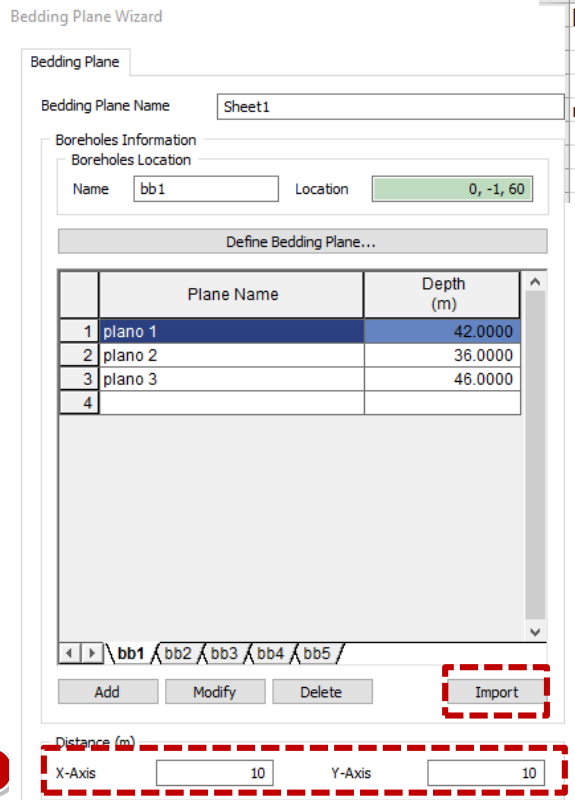
03 Geometry works (Create or Import from Excel)

GTS NX

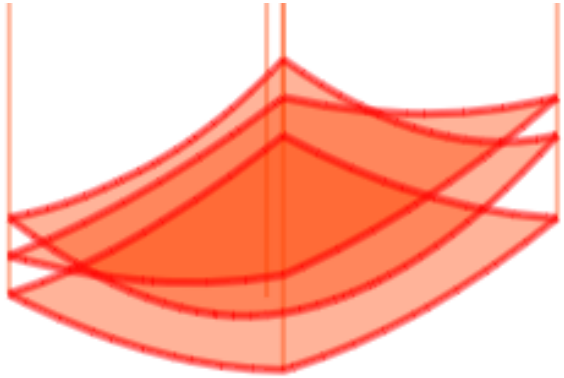
Procedure

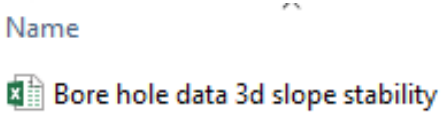
1. Geometry > Surface Solid > Bedding Plane
2. Select Import > Excel file ''Bore Hole data 3D Slope Stability''
3. X and Y = 10
4. Click OK





	A	B	C	D	E	F	G
1	[m]						
2		Bore Hole	bb1	bb2	bb3	bb4	bb5
3		Location	10,5,60	10,55,60	35,27,50	60, 5, 60	60, 55, 60
4							
5	no.	plane	Depth				
6	1	plane 1	42.0	42.0	25.0	20.0	17.0
7	2	plane 2	36.0	36.0	30.0	26.0	23.0
8	3	plane 3	48.0	48.0	37.0	35.0	36.0



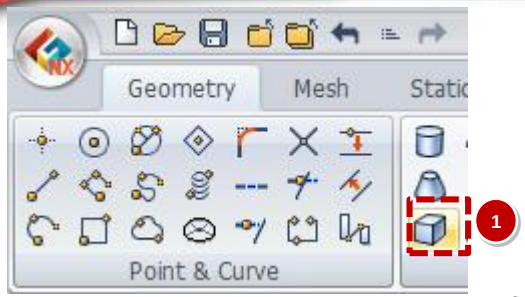


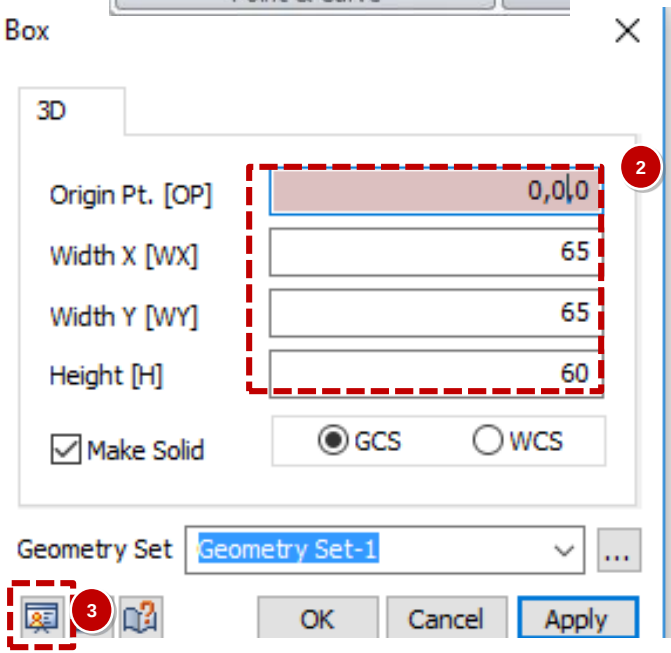
03 Geometry works

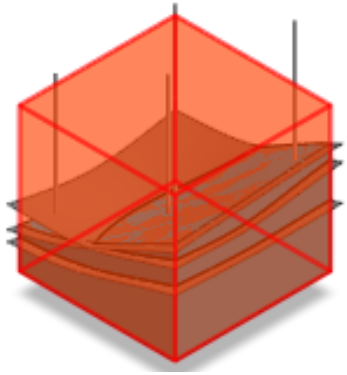
GTS NX

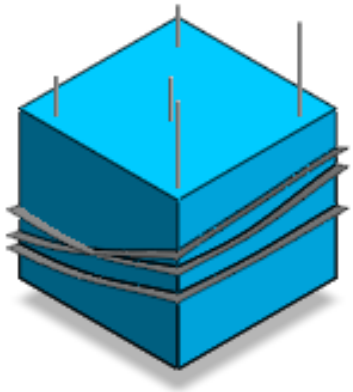
Procedure

1. Geometry > Surface Solid > Box
2. Enter dimensions as shown
3. Click Preview, Click OK







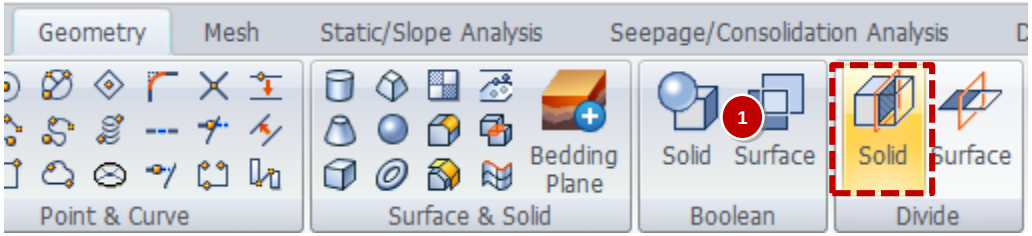


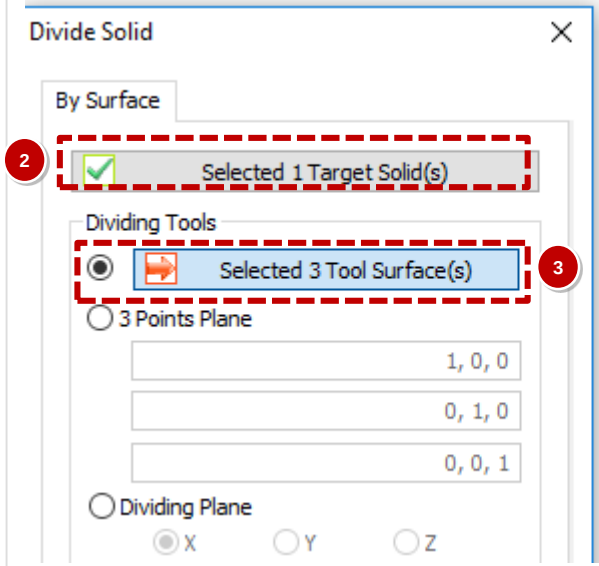
03 Geometry works

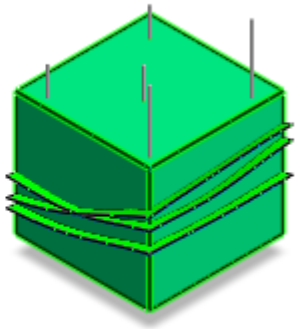
GTS NX

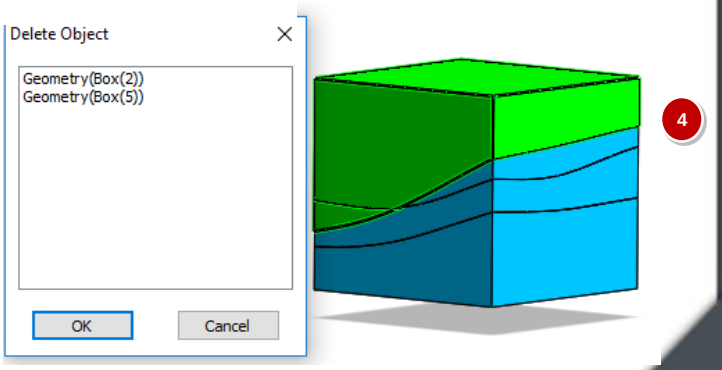
Procedure

1. Geometry > Surface Divide > Solid
2. Target: 1 Solid Box
3. Dividing tools: 3 surfaces Click OK
4. Delete 2 geometries shown by selecting and pressing DELETE on keyboard









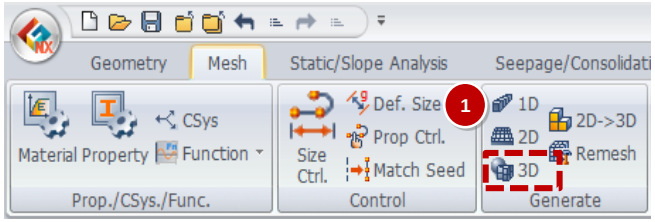
04 Generate Mesh (3D Element)

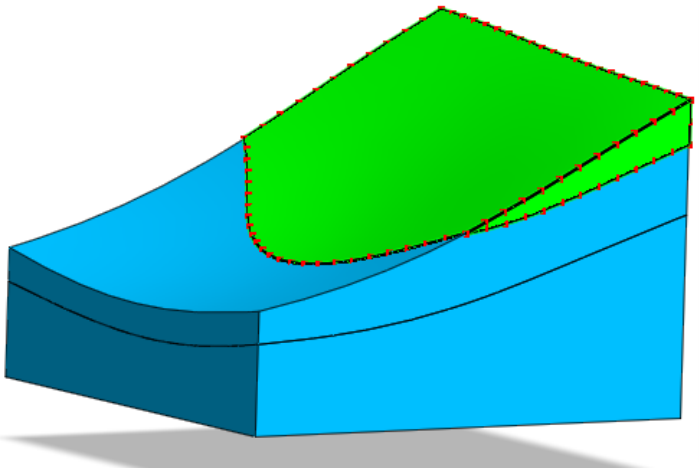
GTS NX

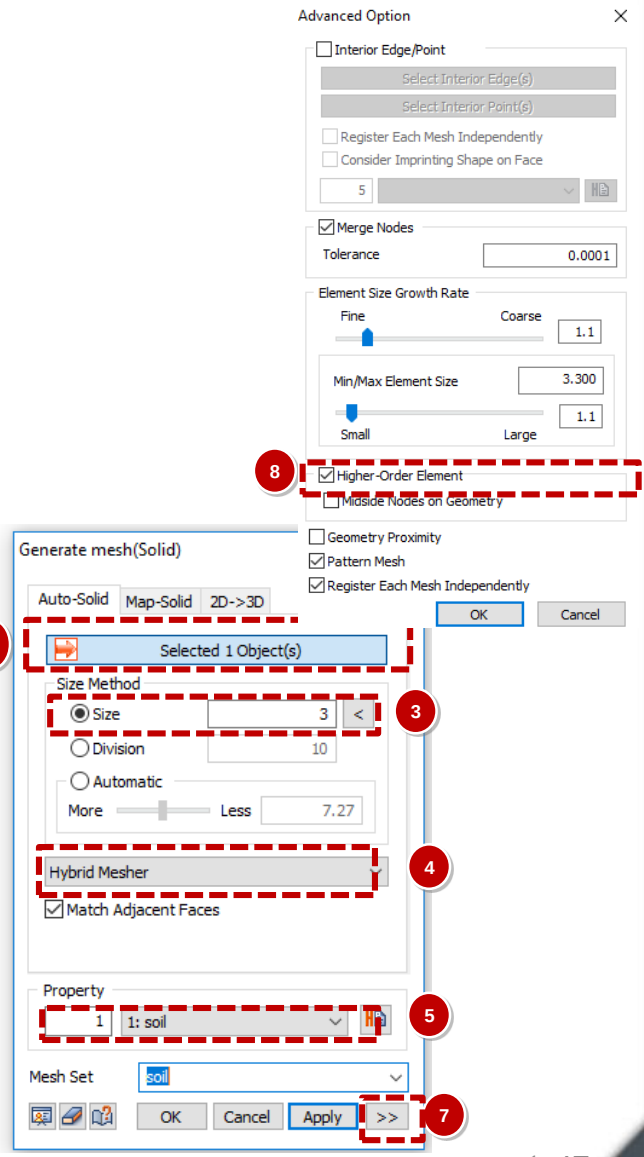
Procedure

1. Mesh > Generate > 3D > Auto solid
2. Select object > Select solid for “Soil layer” as highlighted in the figure.
3. Input element Size : 3
   (3m between two nodes)
4. Select Hybrid mesh
5. Select Property : soil
6. Input Mesh Set Name : soil
7. Click on the >> icon to open the Advanced Option Window
8. Activate Higher Order Elements

   Click OK , then Click Apply (by clicking apply, window keeps HOE option on)







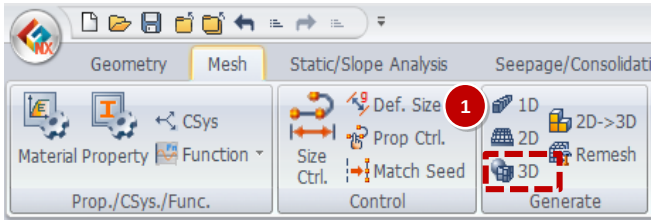
04 Generate Mesh (3D Element)

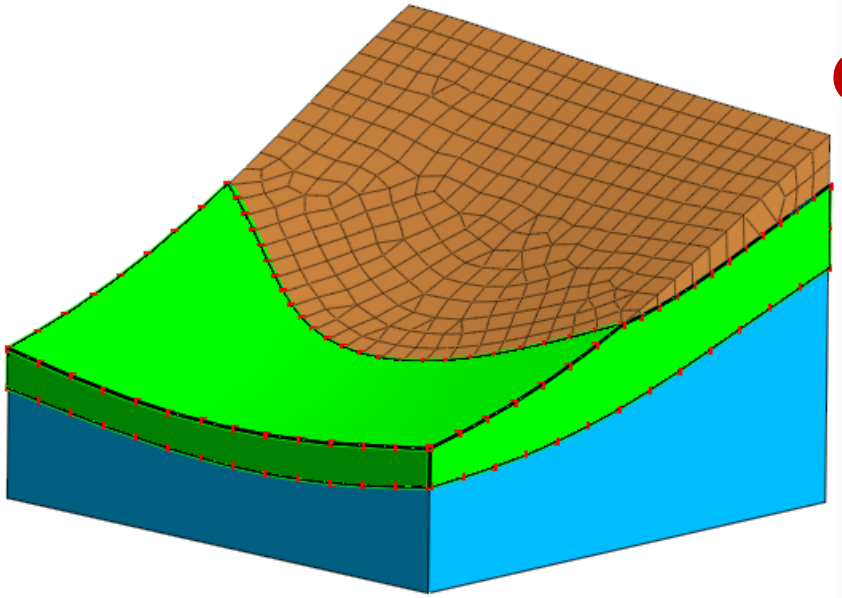
GTS NX

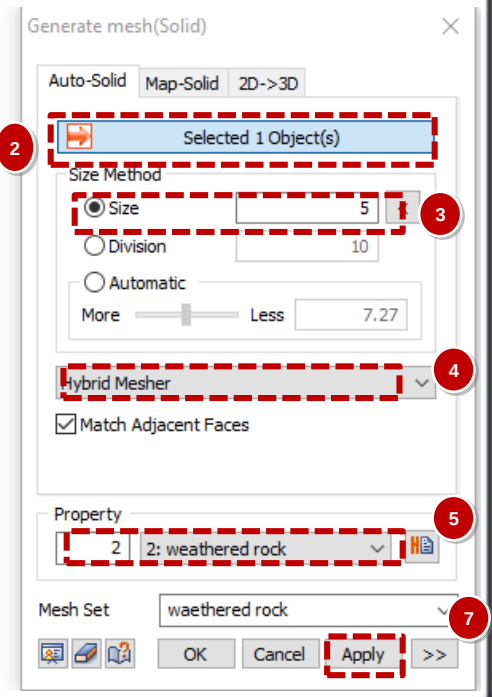
Procedure

1. Mesh > Generate > 3D > Auto solid
2. Select object > Select solid for “weathered rock” as highlighted in the figure.
3. Input element Size : 5
   (5m between two nodes)
4. Select Hybrid mesh
5. Select Property : weathered rock
6. Input Mesh Set Name : weathered rock

   Activate Higher Order Elements should still be on.
7. Click Apply







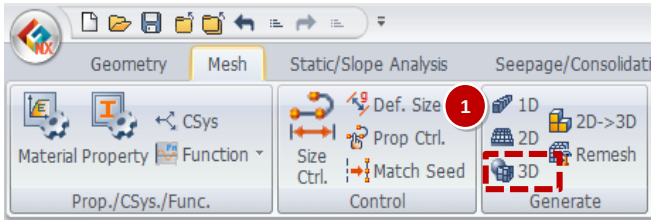
04 Generate Mesh (3D Element)

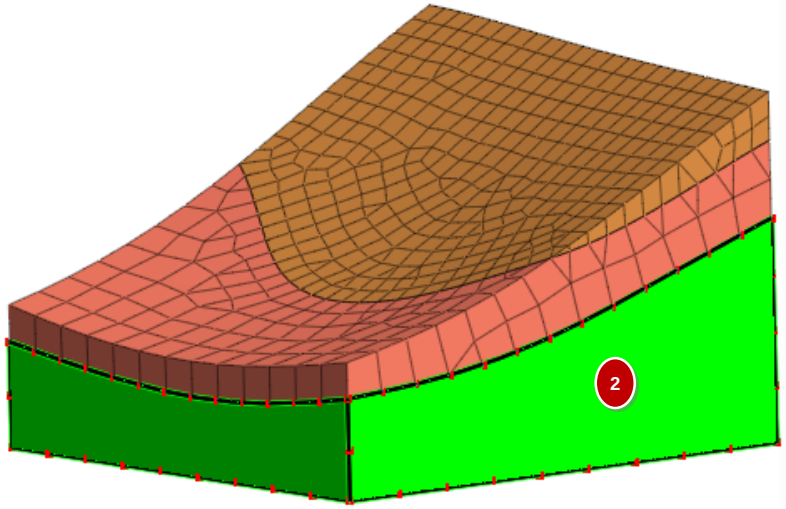
GTS NX

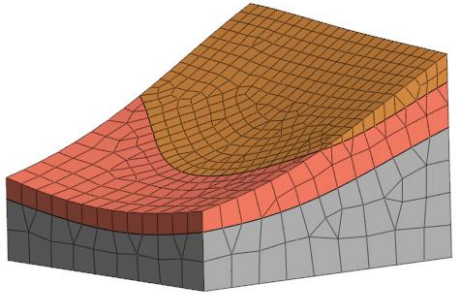
Procedure

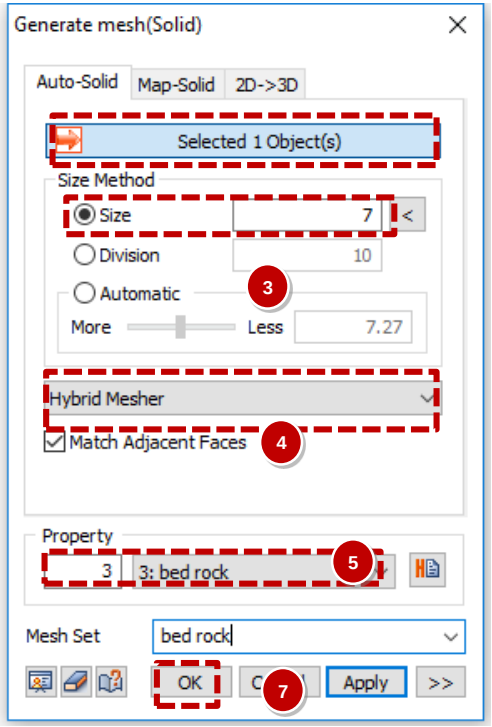
1. Mesh > Generate > 3D > Auto solid
2. Select object > Select solid for “Bed rock” as highlighted in the figure.
3. Input element Size : 7
   (7 m between two nodes)
4. Select Hybrid mesh
5. Select Property : bed rock
6. Input Mesh Set Name : bed rock

   Activate Higher Order Elements should still be on.
7. Click OK







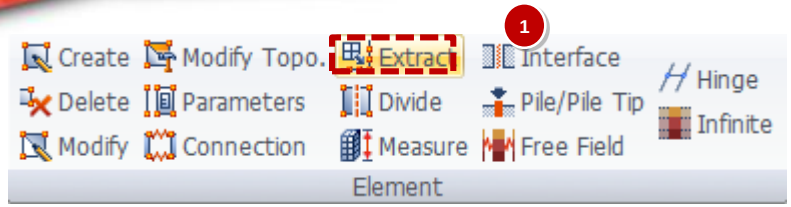


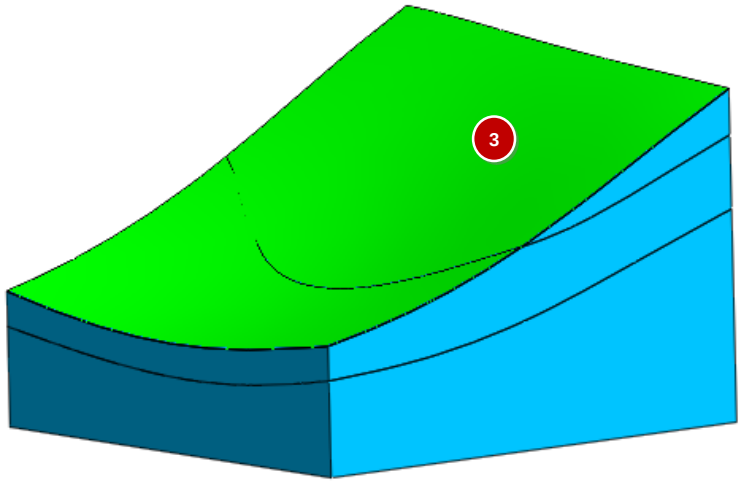
04 Extract Mesh (2D Element)

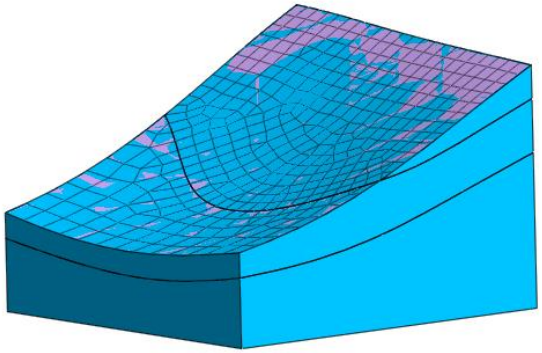
GTS NX

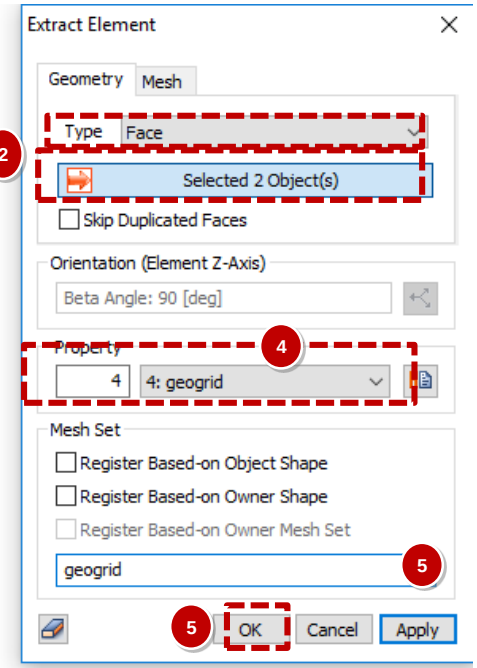
Procedure

1. Mesh > Element > Extract
2. Type: Geometry > Face
3. Re activate solid geometries >Select object > Select top faces as shown
4. Select Property : geogrid
5. Input Mesh Set Name : geogrid
6. Click OK









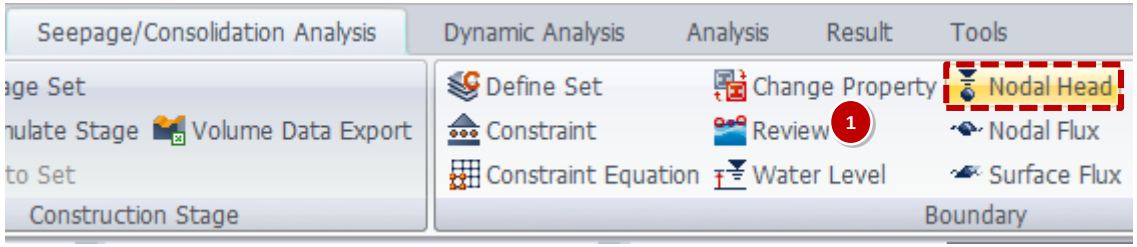
05 Define Boundary Condition (Seepage)

GTS NX

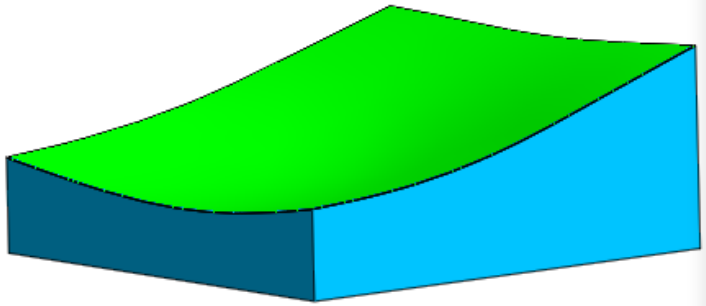
Procedure

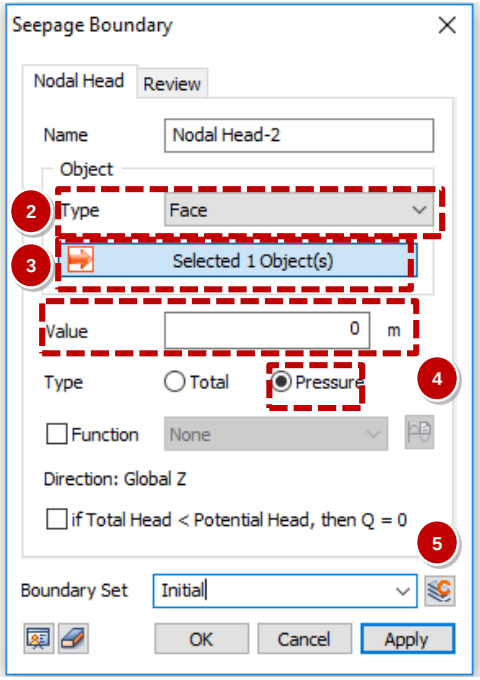
* Nodal Seepage will be defined.

1. Seepage Analysis > Boundary > Nodal Head
2. Select Target Face > Select top face of bottom solid to define water level as highlighted in the figure.
3. Value = 0 m
4. Type: Pressure
5. Boundary Set: Nodal Initial



Nodal Head: Initial Water Level





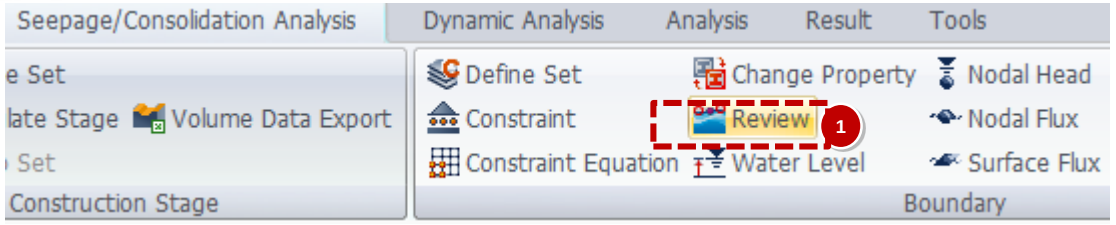
05 Define Boundary Condition (Seepage)

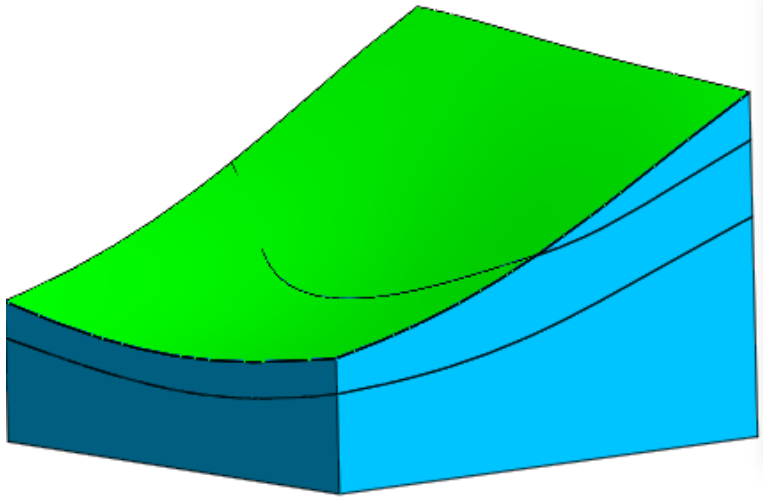
GTS NX

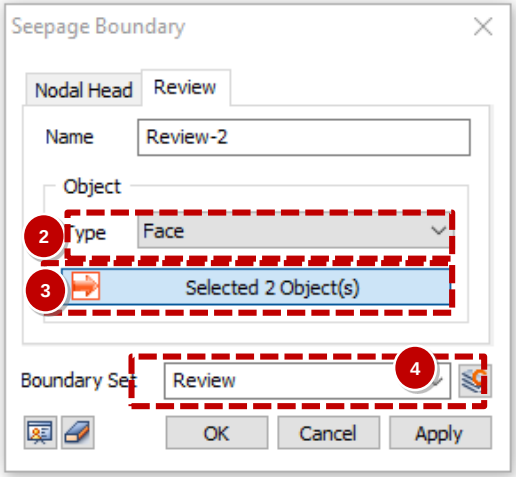
Procedure

* Review Boundary will be defined.

1. Seepage Analysis > Boundary > Review
2. Select Target Face(s)
3. Select top 2 faces of slope
4. Boundary Set: Review







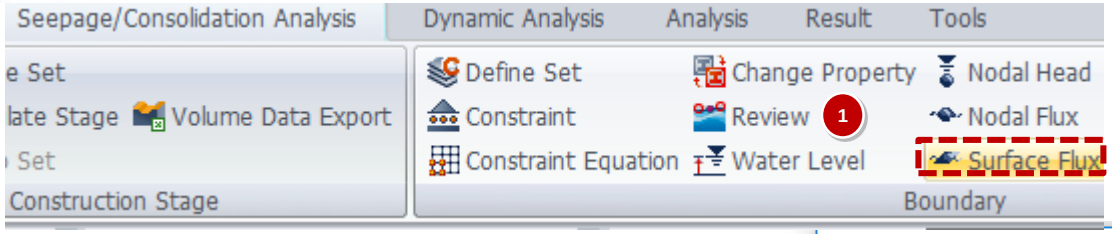
05 Define Boundary Condition (Seepage)

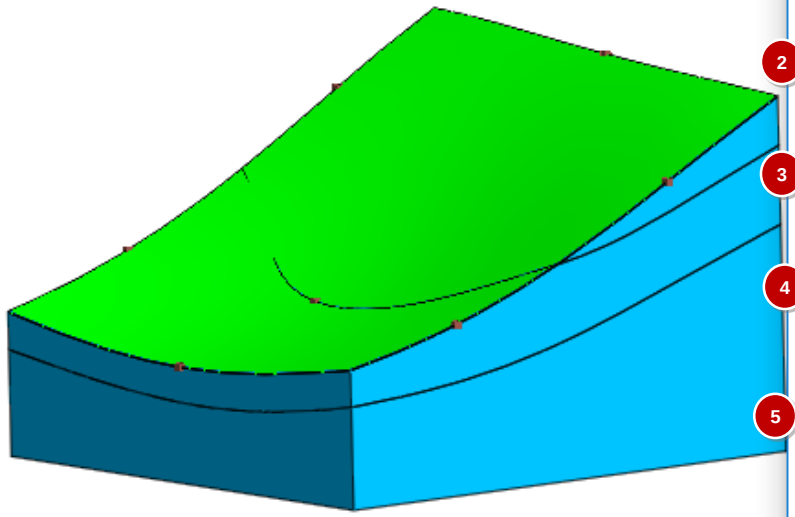
GTS NX

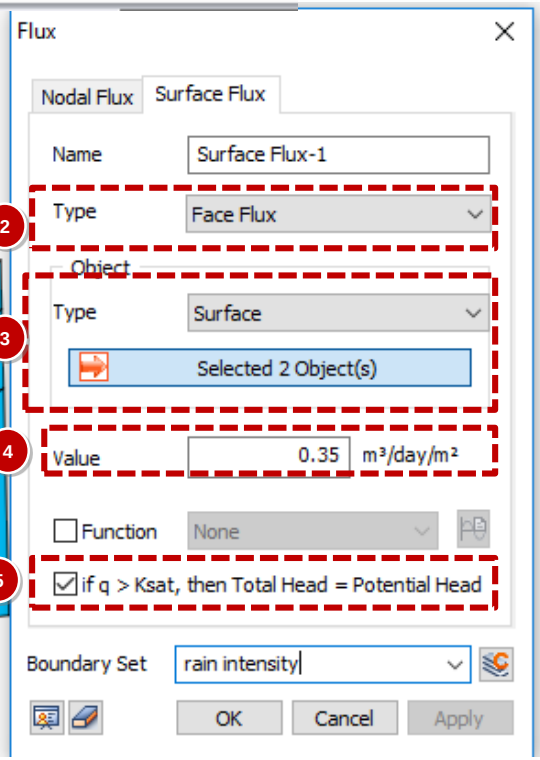
Procedure

* **Surface Flux** will be defined.

1. Seepage Analysis > Boundary > Surface Flux
2. Type: Face Flux
3. Type: Surface
   Select top faces of slope
4. Value: 0.35m^3/day/m^2
5. Turn on if q > Ksat, then Total Head = Potential Head







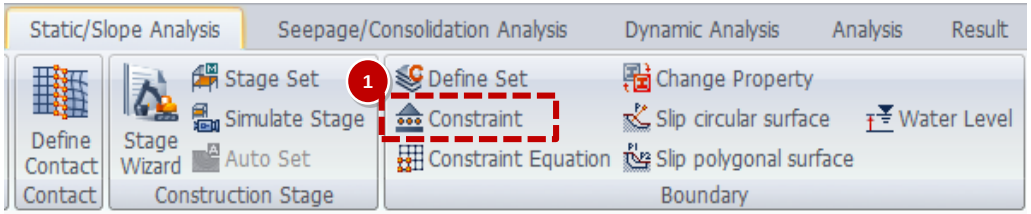
If the rainfall intensity is larger than the absorption capability, the ground surface is in a saturated state during rainfall, as if the groundwater level existed above the surface. Hence, the area of rainfall needs to be changed to a water level line. Use the [If q > Ksat, then Total Head = Pressure Head] option to automatically change the ground surface boundary from the existing rainfall intensity inflow condition to a water level condition for analysis.

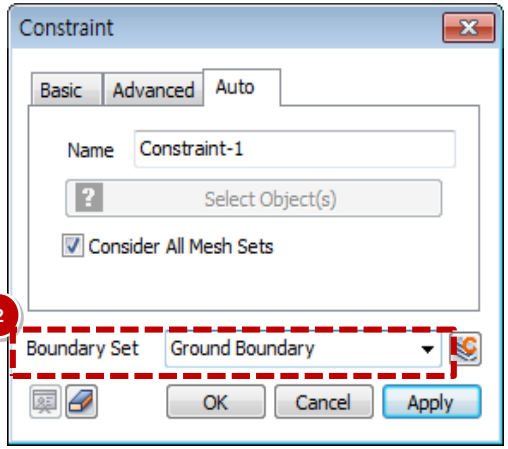
05 Define Boundary Condition (Ground)

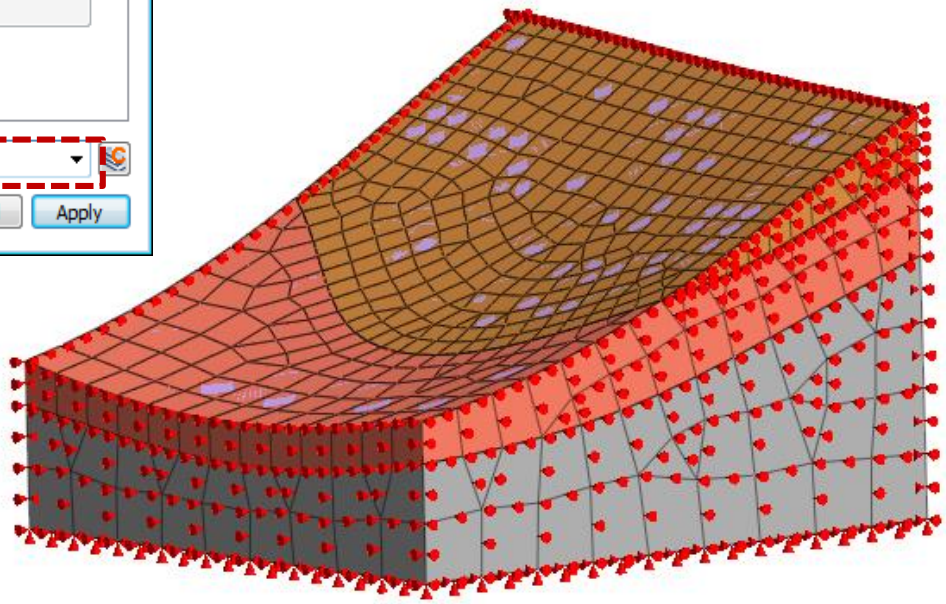
GTS NX

Procedure

1. Static / Slope Analysis > Boundary > Constraint > Auto
2. Boundary Set Name : Ground Boundary





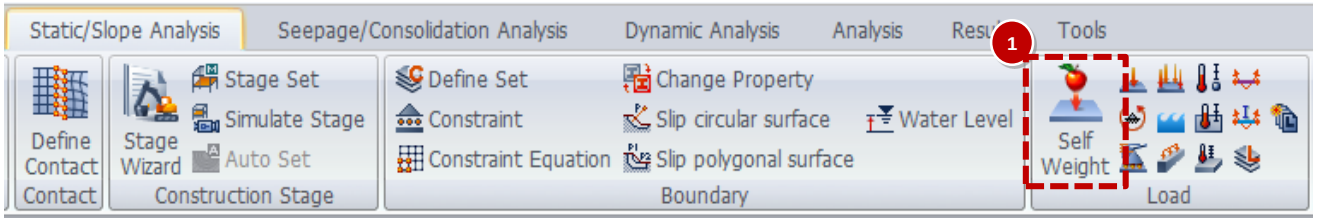


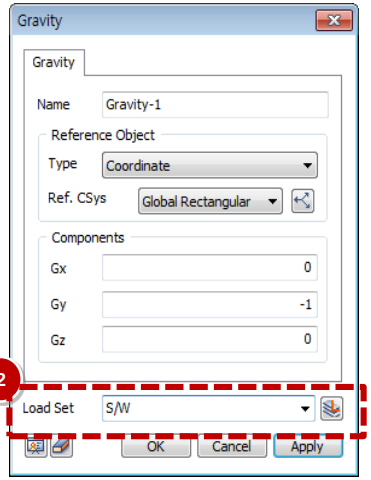
06 Load Condition (Self Weight)

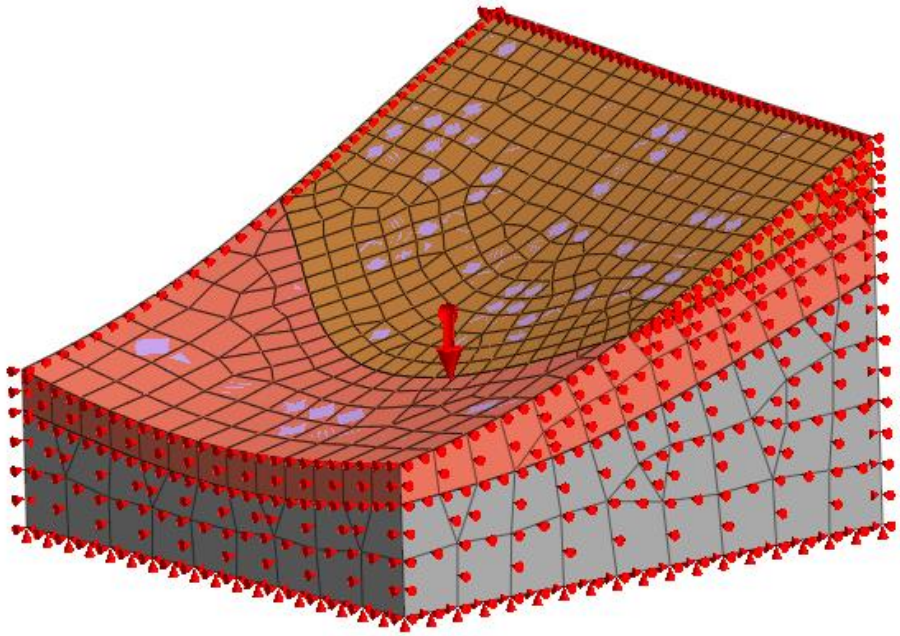
GTS NX

Procedure

1. Static / Slope Analysis > Load > Self Weight
2. Load Set Name : S/W







07 Define Construction Stage (Create Stage Set)

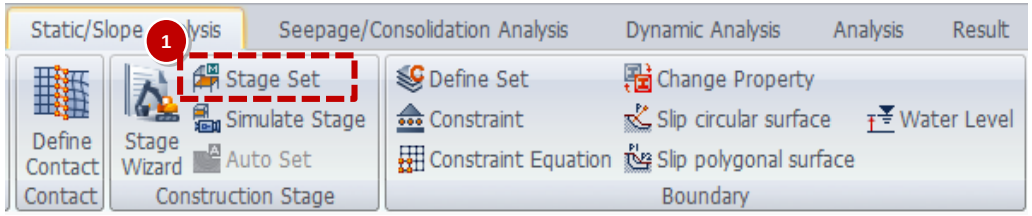
GTS NX

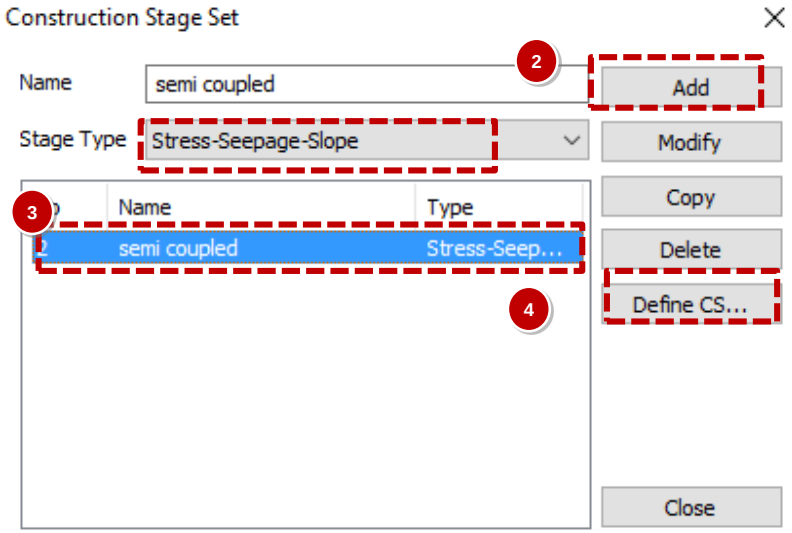
Procedure

* 5 Construction stage will be defined for this project.

1. Static / Slope Analysis > Construction Stage > Stage Set
2. Stage Type > Stress – Seepage Slope
3. Select Add
4. Select Created Stage Set

   Select Define CS...



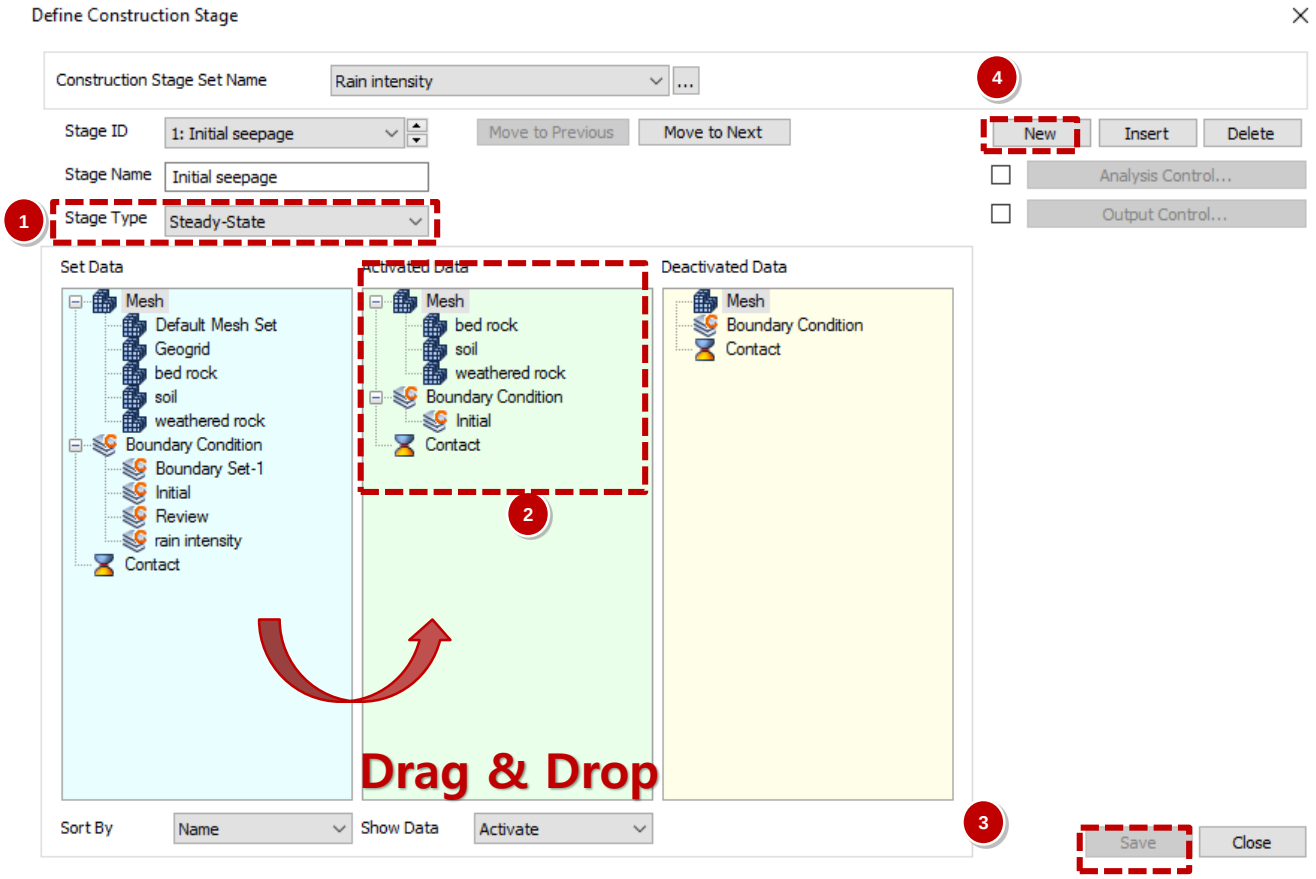


08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 1 Type : Seepage Steady State
2. Activated Data : All Mesh Sets for initial state of ground (2D elements), and Nodal Initial seepage boundary
3. Select Save
4. Select New

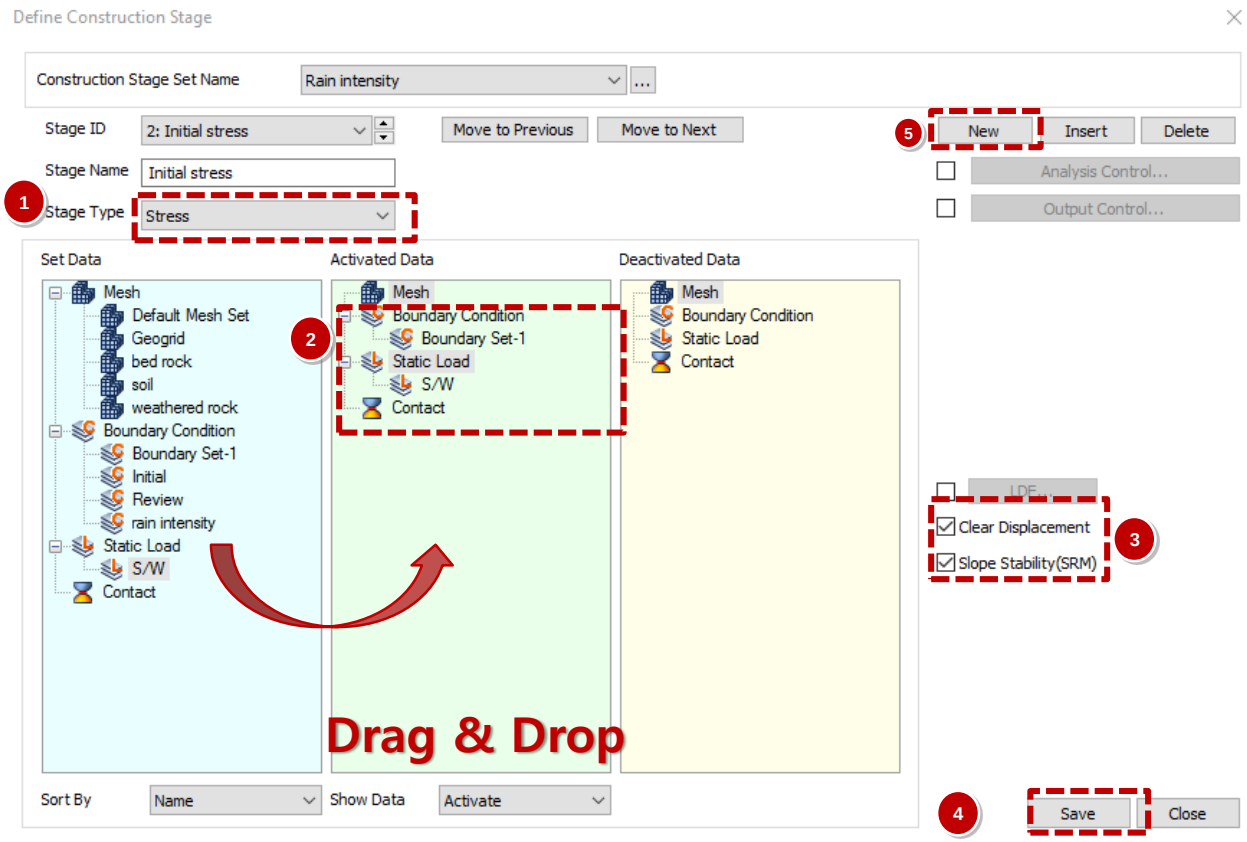


08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 2 Type : Stress
2. Activated Data : Boundary and Load Sets for Ground Boundary and Self Weight
3. Activate Clear Displacements and SRM
4. Select Save
5. Select New



08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 3 Type : Seepage
   Transient (rain)

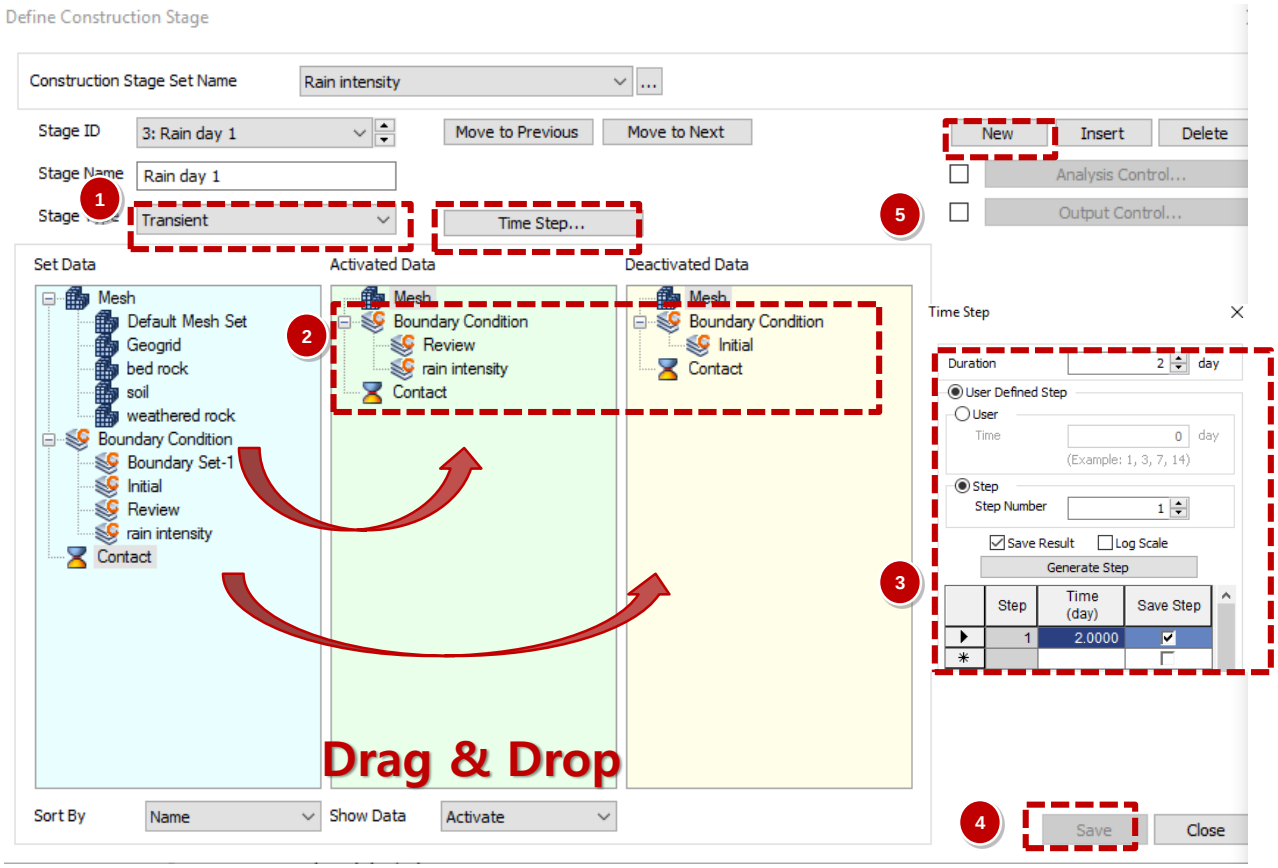
2. Activated Data : Boundary Sets
   Rain and Review

   Deactivate Data: Boundary Set
   nodal review

3. Click Time Step
   2 days 1 Steps
   Save Result / Generate Step

4. Select Save

5. Select New

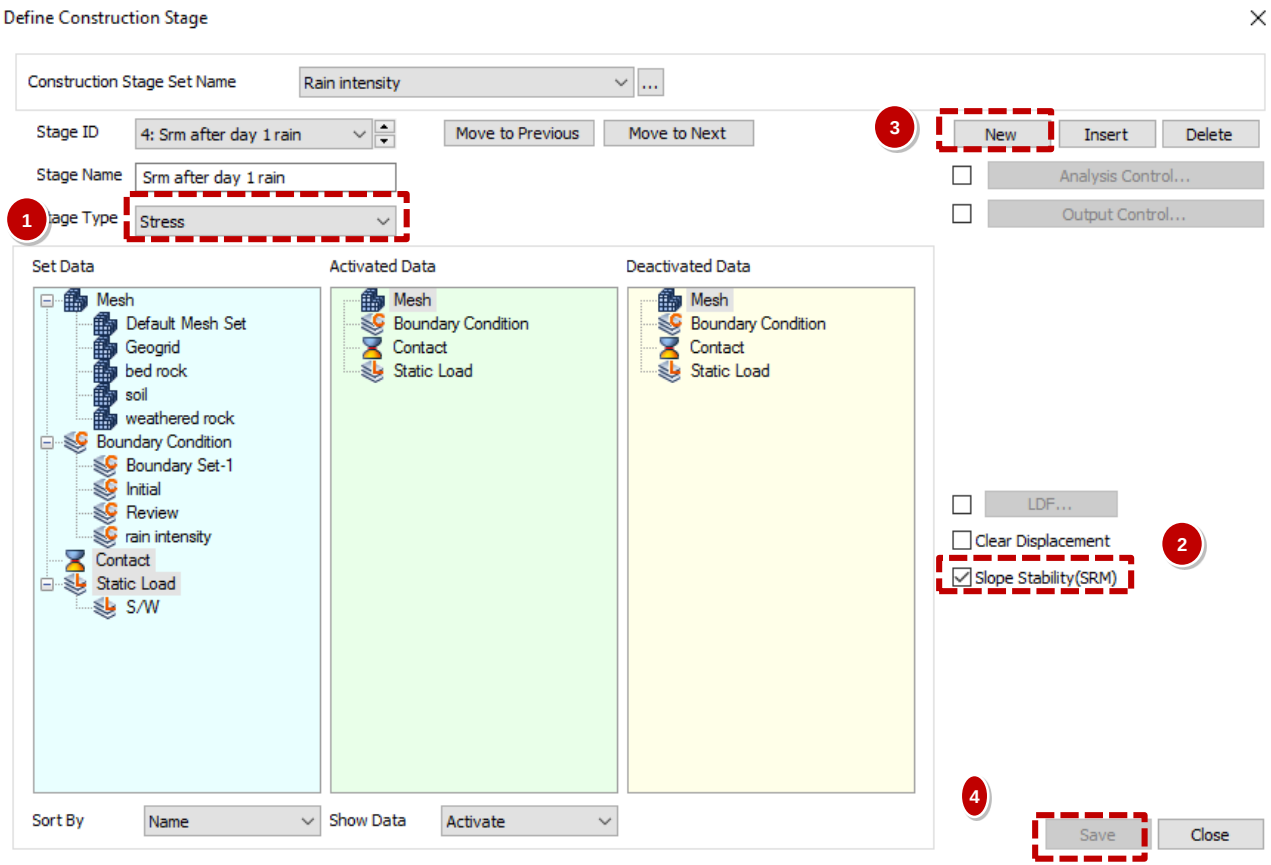


08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 4 Type : Stress
2. Check on Slope Stability SRM
3. Select Save
4. Select New

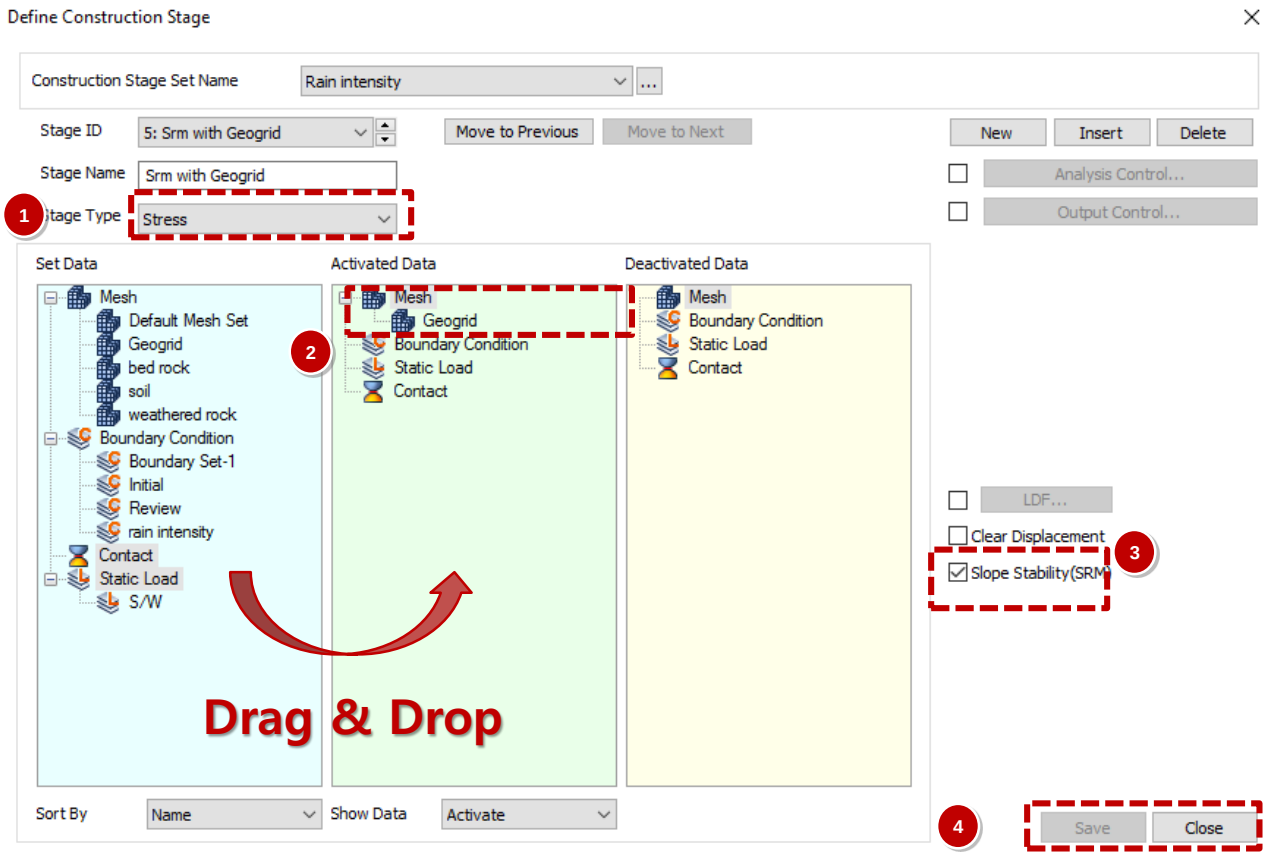


08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 5: Type : Stress
2. Activated Data : geogrid mesh set
3. Activate SRM
4. Select Save and Close

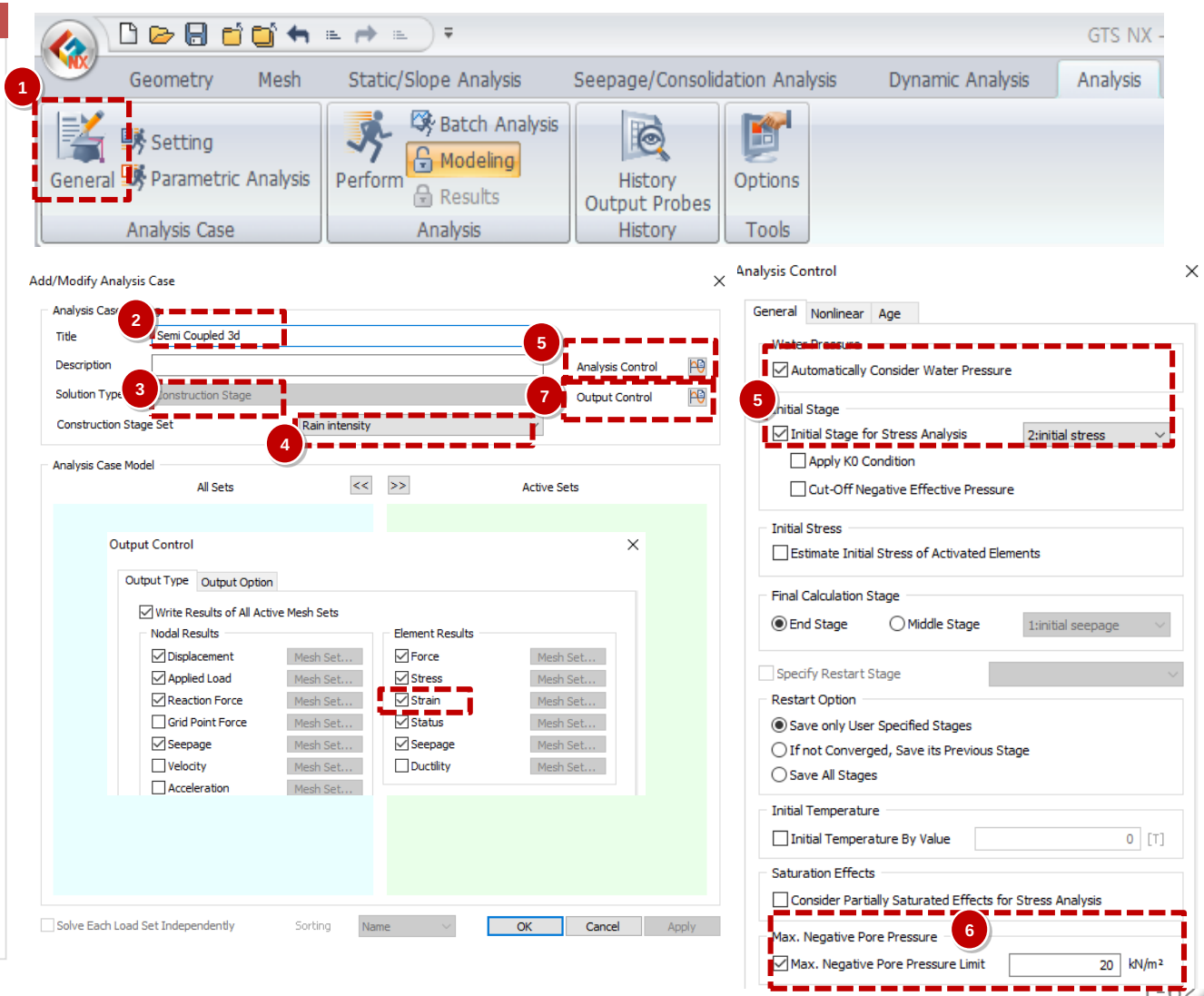


09 Analysis Case

GTS NX

Procedure

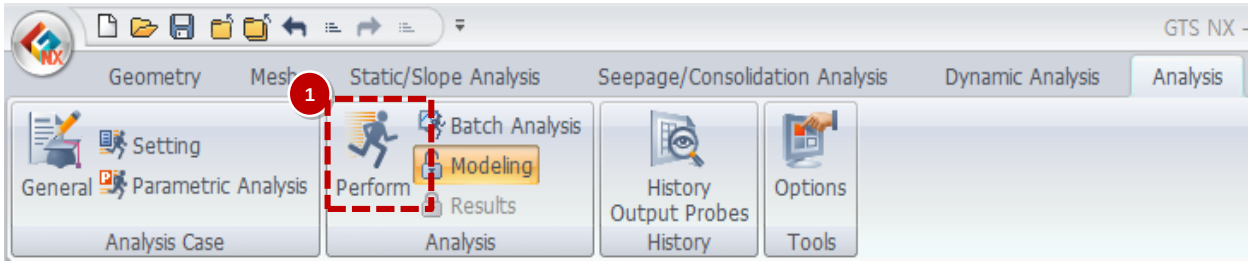
1. Analysis > Analysis Case > General
2. Title : Semi Coupled 3d
3. Solution Type : Construction Stage
4. Select Construction Stage Set Rain intensity
5. Analysis Control : Select Initial Stage for Stress Analysis (2. Initial Stress), Check: Auto Consider Water Pressure
6. Check Max Negative Pore Pressure: 20kN/n^2
7. Output Control: Check On: Strains

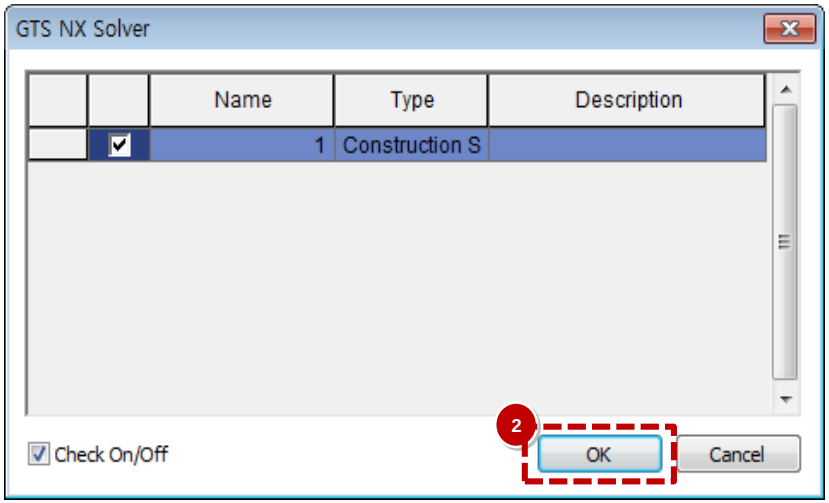


GTS NX

Procedure

1. Analysis > Analysis > Perform
2. Select OK





11 Post Processing (Pre mode vs Post mode)

GTS NX

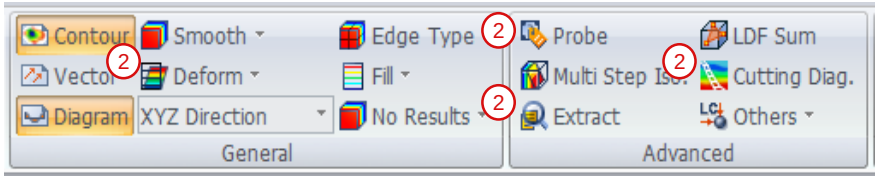
Procedure

① After analysis, model view will be converted to Post-Mode automatically, can back to Pre-Mode to change model information.

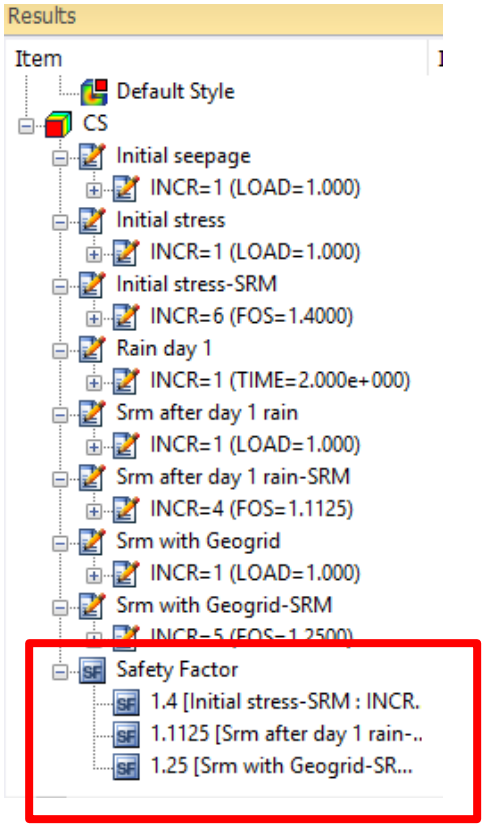
② All results will be represented by graphic based output, table, diagram and graph.

③ Results are given by stages and types of elements.

The results are set in order of the stages.
The bottom of the results tab lists the FOS for all the stages in order.



3



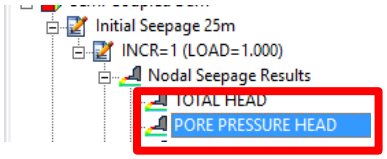
11 Post Processing (Post mode)

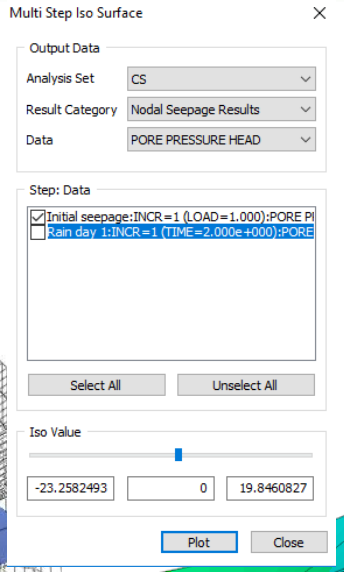
GTS NX

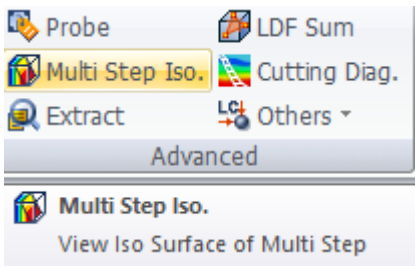
Procedure

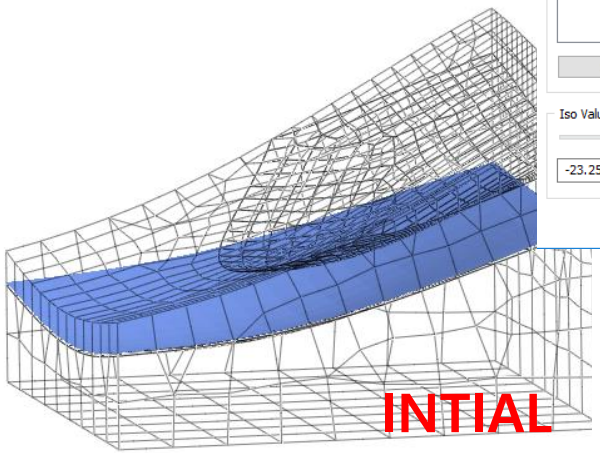
1. Expand the results for **Rain** and double click **Nodal Seepage > Pore Pressure Head** to verify the Pore Stress dues to change in Water Level.

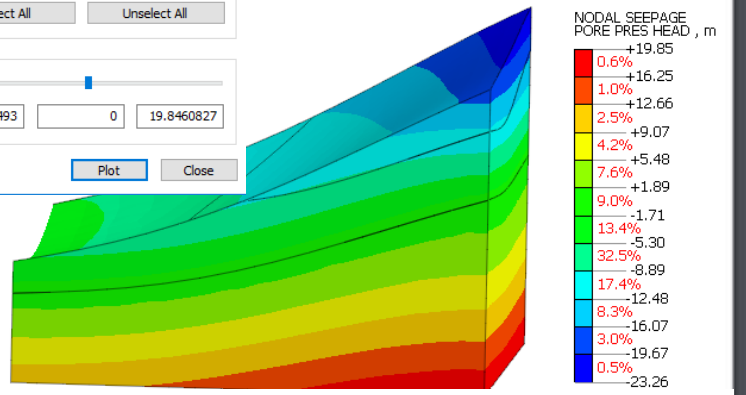
2. You can activate the water level lines by using the Multi Step Iso surface function and setting pore pressure to 0 for each stage. Click PLOT

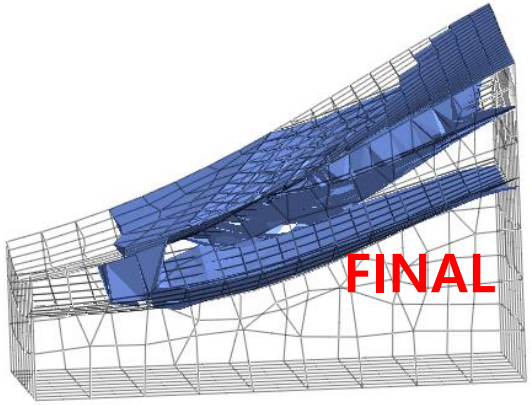


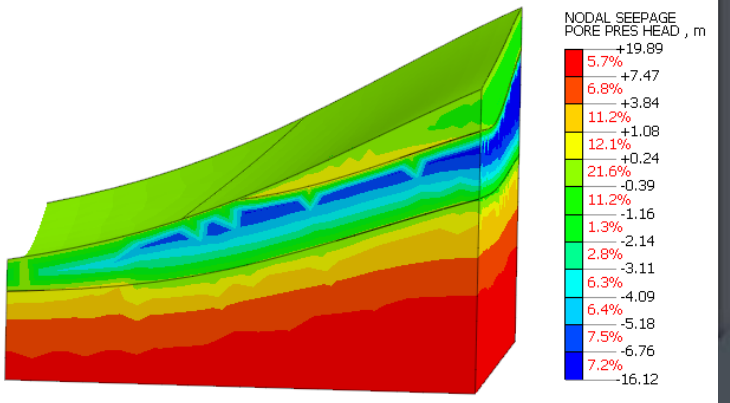












11 Post Processing (Post mode)

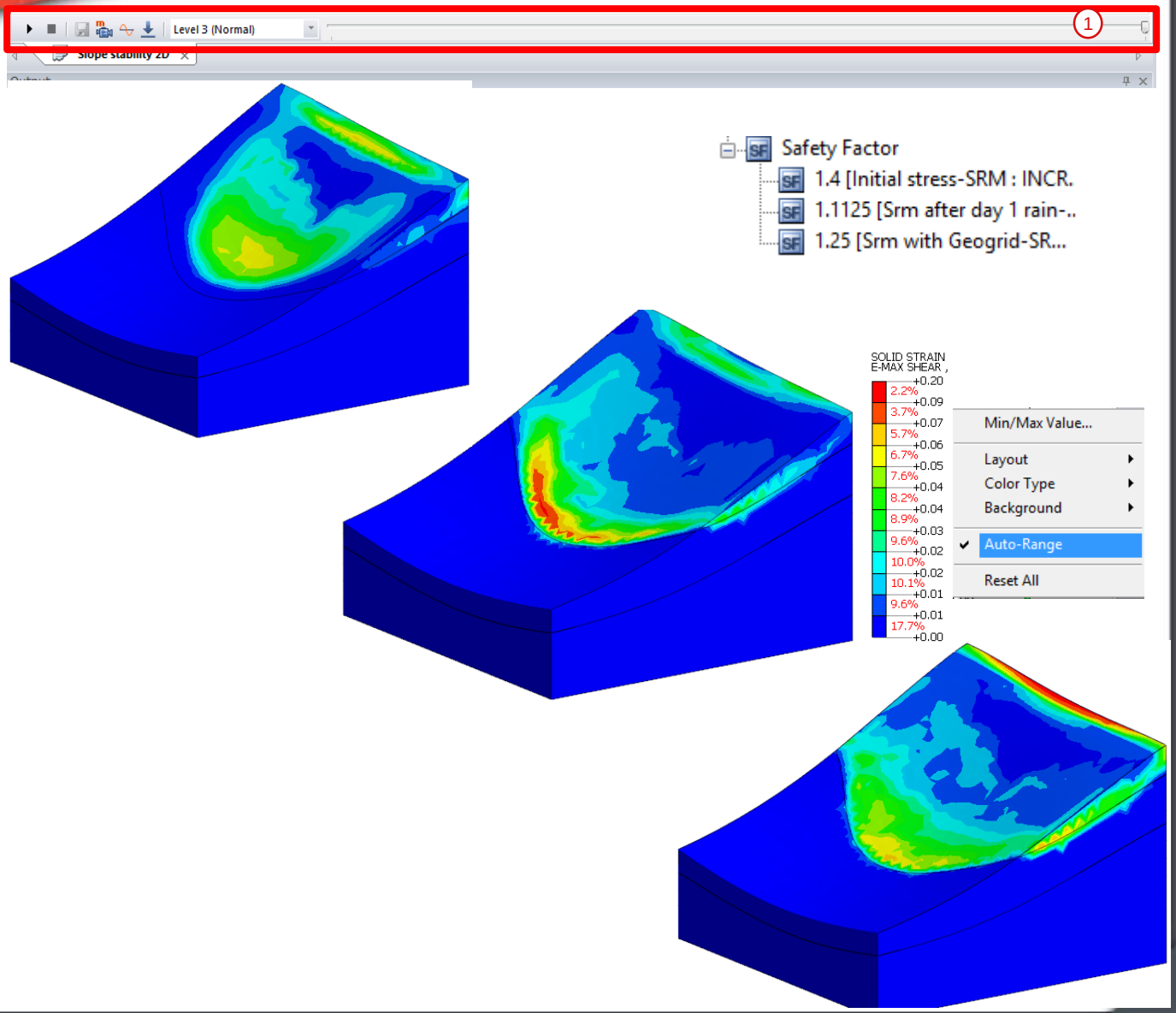
GTS NX

Procedure

1. Inspect the changes in the model by navigating the stages using the bar on the bottom of the model / above the output window. Press Right or Left key on keyboard to go forward and backward in the stages respectably.

2. Inspect the slope stability results for the last stage by selecting the Plane Strain Strains.
The images shows max shear strains for the 1st 3 stages of the analysis.

3. Right click the legend and select AUTO RANGE to see results more clearly.
You can create a video animation of the stages by selecting **Multi Stage Animation > Select All Stages > Play > Save**



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Part 4. 2D Dam Stability SAM

Overview

GTS NX

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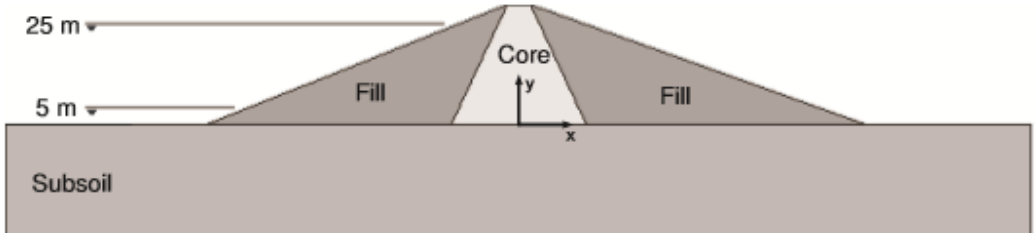
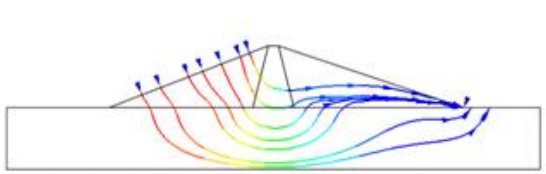
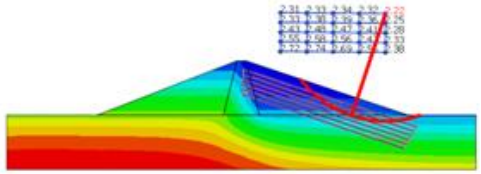
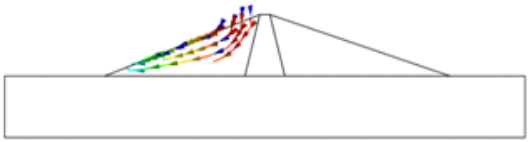
STEP 03	Mesh generation
STEP 04	Boundary Conditions
STEP 05	Load Conditions
STEP 06	Define Construction Sequence
STEP 07	Analysis Case
STEP 08	Perform analysis and check result

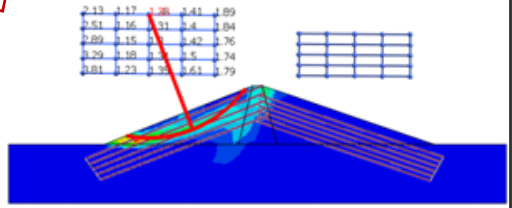
Dam stability during drawdown (SAM 2D)









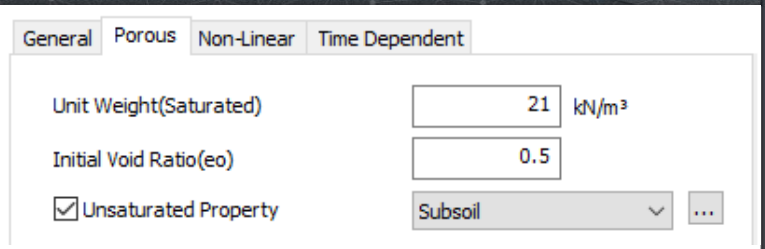


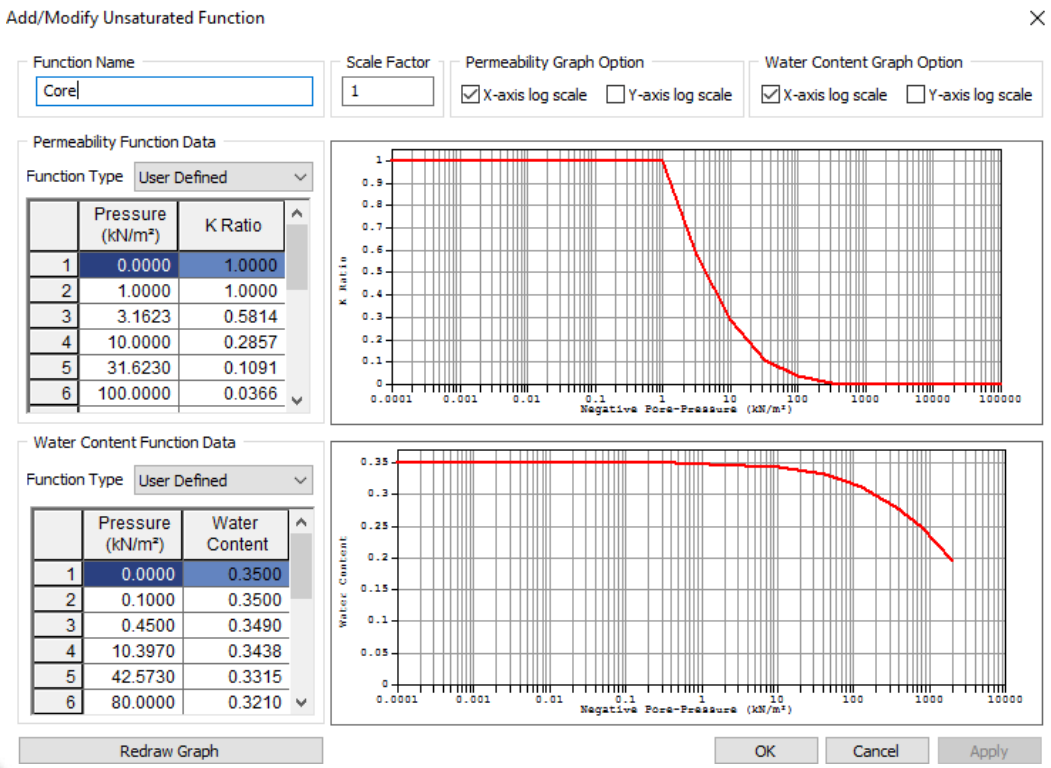
Name	Core	Fill	Subsoil
Material	Isotropic	Isotropic	Isotropic
Model Type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
General			
Elastic Modulus (E) (kN/m2)	4,500	21,000	50,000
Poisson's Ratio(v)	0.35	0.33	0.3
Inc. Of Elastic Modulus (kN/m3)	300		
Inc. Of Elastic Modulus Ref. Height (m)	30		
Unit Weight(r) (kN/m3)	16	16	17
Porous			
Unit Weight(Saturated) (kN/m3)	18	20	21
Permeability Coe. (m/day)	0.0001	1	0.01
Unsaturated Property	Core	Fill	Subsoil
Non-Linear			
Friction Angle	19	20	45
Cohesion (kN/m2)	11	9	100

Unsaturated Properties

Permeability Function Type: select 'User-defined and copy the data from the Excel sheet.

Water Content Function: select 'User-defined' and copy the water content data from the Excel sheet.



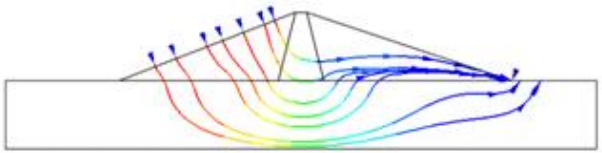


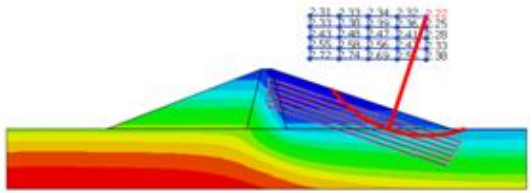
Core		Fill		Subsoil	
Pressure (kN/m^2)	K Ratio	Pressure (kN/m^2)	K Ratio	Pressure (kN/m^2)	K Ratio
0	1	0	1	0	1
1	1	0.54556	1	3.5938	1.01318
3.1623	0.5813576	1.2743	0.9938483	21.544	0.09093
10	0.2856904	2.9764	0.9926483	129.15	0.000155
31.623	0.109149	6.9519	0.9926483	774.26	9.24E-07
100	0.0365977	16.238	0.9920828	1111.1	7.79E-08
316.23	0.0075094	37.927	0.5529655	4641.6	3.91E-09
714.29	0.0021089	88.587	0.0567683	27826	4.19E-11
1000	0.0011344	206.91	0.0015964	105930	2.02E-12
3162.3	9.935E-05	483.29	8.274E-05		
10000	6.623E-06	526.32	6.641E-05		
31623	3.829E-07	1128.8	1.627E-05		
69541	5.455E-08	2636.7	3.174E-06		
100000	2.173E-08	6158.5	5.161E-07		

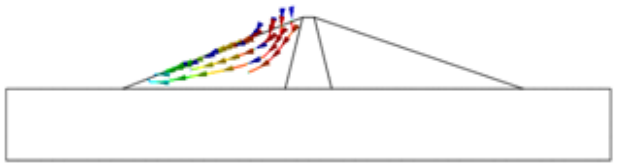
* WC Ratio

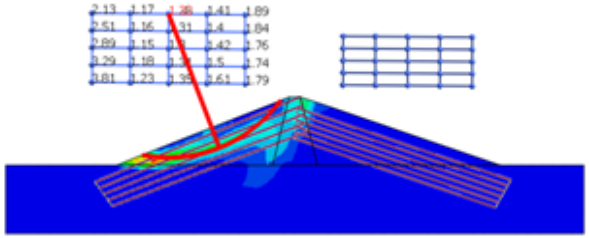
Core		Fill		Subsoil	
Pressure (kN/m^2)	WC Ratio	Pressure (kN/m^2)	WC Ratio	Pressure (kN/m^2)	WC Ratio
0	0.35	0	0.41	0	0.39
0.1	0.35	6.0154	0.40781	3.3139	0.38782
0.45	0.349	19.558	0.3957	6.867	0.38099
10.397	0.34377	27.392	0.38077	14.3	0.3377
42.573	0.33148	39.999	0.33772	18.6	0.2806
80	0.321	49.565	0.29515	22.4	0.2234
127.01	0.31103	60	0.25309	26.2	0.1663
200	0.299	80	0.22151	33.622	0.12028
368.06	0.281	100	0.21309	62.974	0.075189
800	0.248	199.89	0.16303	100	0.061047
2048.2	0.19499	1117.4	0.11765	352.29	0.035115

Name	Core	Fill	Subsoil
Property	2D	2D	2D
Model Type	Plain Strain	Plain Strain	Plain Strain
Material	Core	Fill	Subsoil

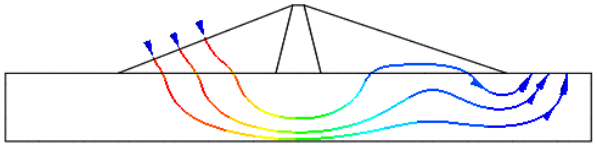


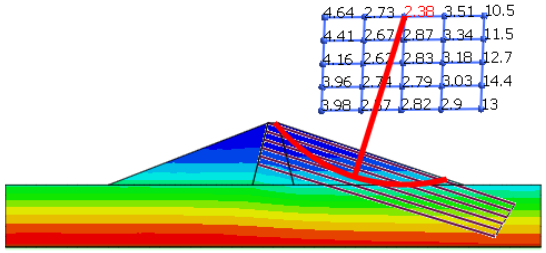






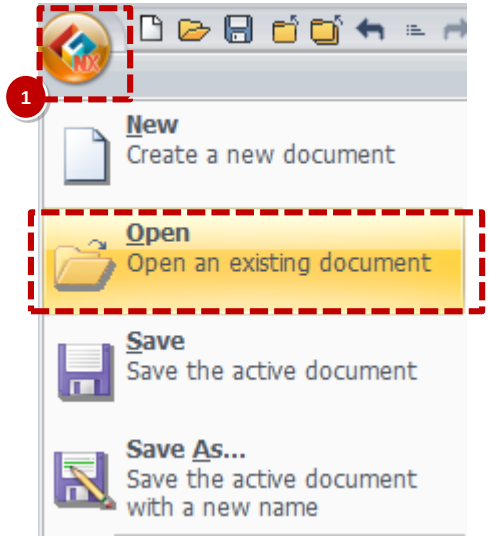
1. Initial Full Dam
2. Rapid Drawdown
3. Low Filled Dam

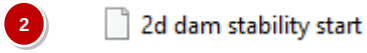


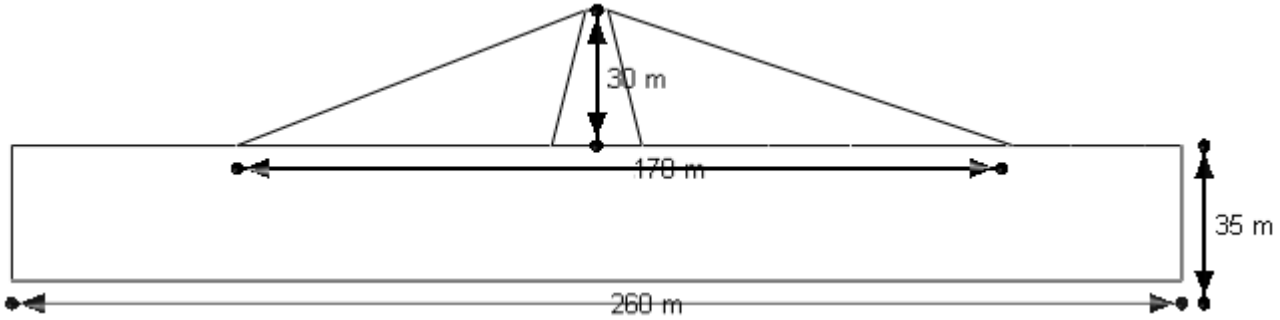


Procedure

1. Main Menu > Open
2. Select 2D Dam stability start





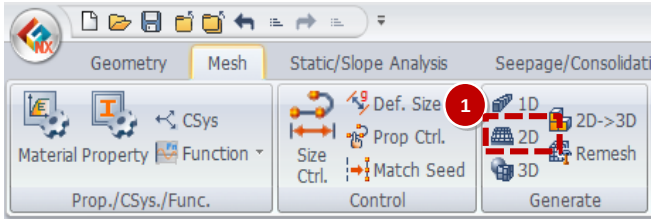


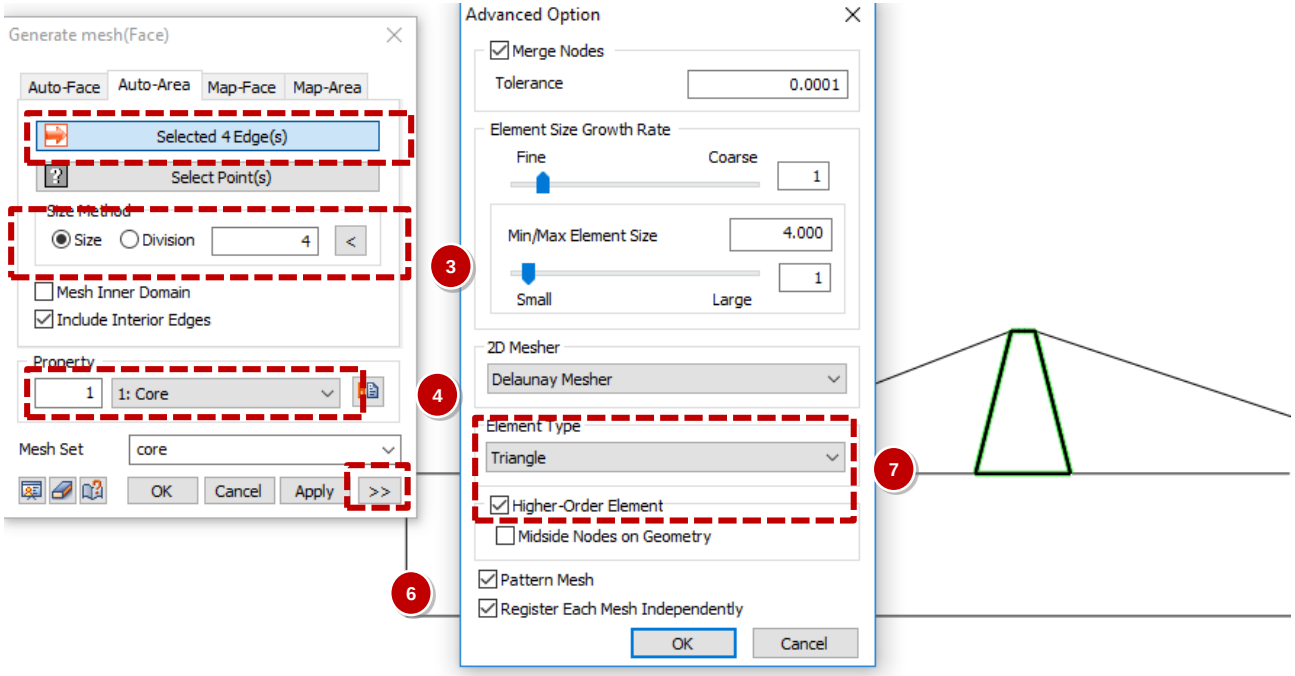
02 Generate Mesh (2D Element)

GTS NX

Procedure

1. Mesh > Generate > 2D > Auto - Area
2. Select Edge(s) > Select 4 edges for “core” as highlighted in the figure.
3. Input element Size : 4
   (4 m between two nodes)
4. Select Property : core
5. Input Mesh Set Name : core
6. Click on the >> icon to open the Advanced Option Window
7. Element Type: Triangle
   Activate Higher Order Elements
8. Click OK , then Click Apply (by clicking apply, window keeps HOE option on)



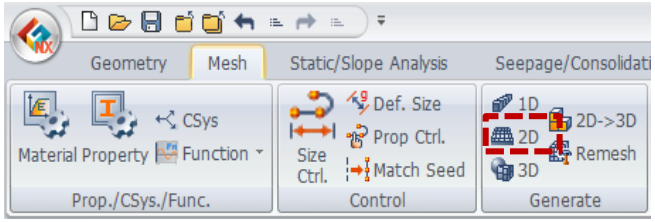


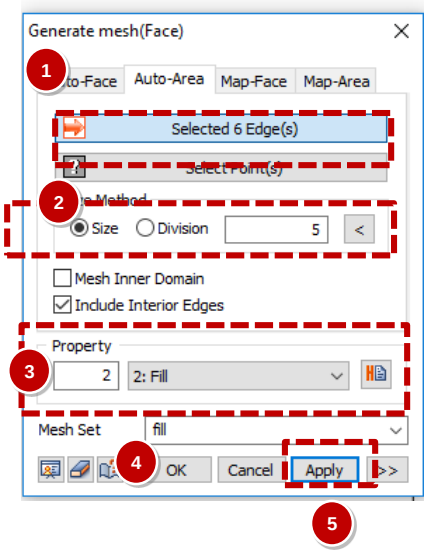
02 Generate Mesh (2D Element)

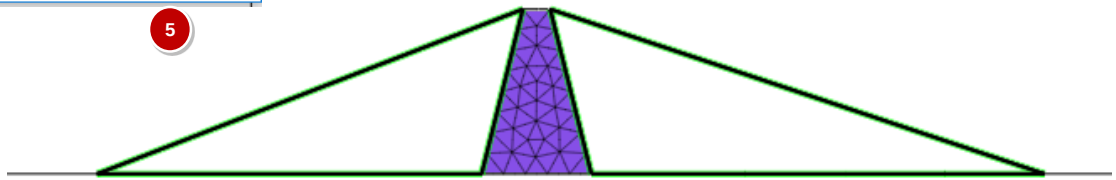
GTS NX

Procedure

1. Select Edge(s) > Select edges for "Fill" as highlighted in the figure.
2. Input element Size : 5
   (5 m between two nodes)
3. Select Property : Fill
4. Input Mesh Set Name : Fill
5. Click Apply (by clicking apply, window keeps Higher Order Elements option on)





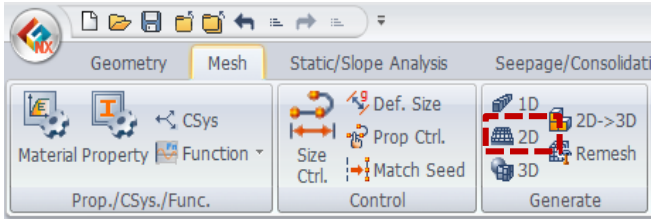


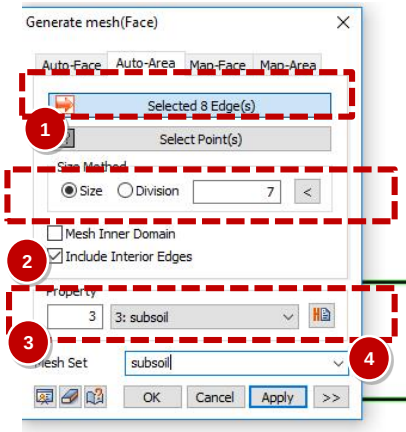
04 Generate Mesh (2D Element)

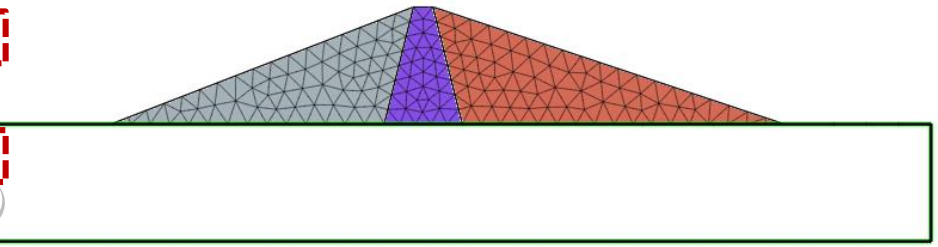
GTS NX

Procedure

1. Select Edge(s) > Select edges for "subsoil" as highlighted in the figure.
2. Input element Size : 7
   (7 m between two nodes)
3. Select Property : subsoil
4. Input Mesh Set Name : subsoil
5. Click OK







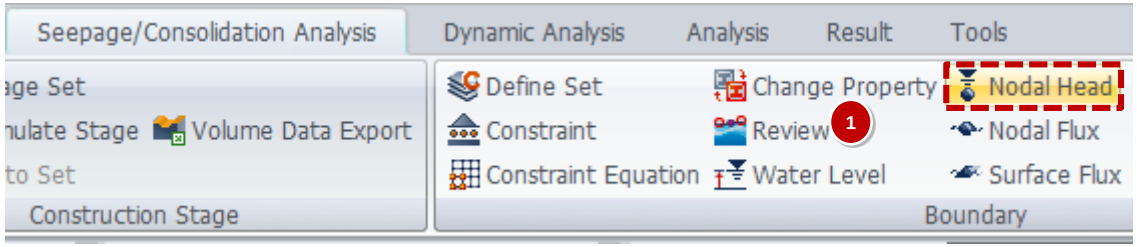
03 Define Boundary Condition (Seepage)

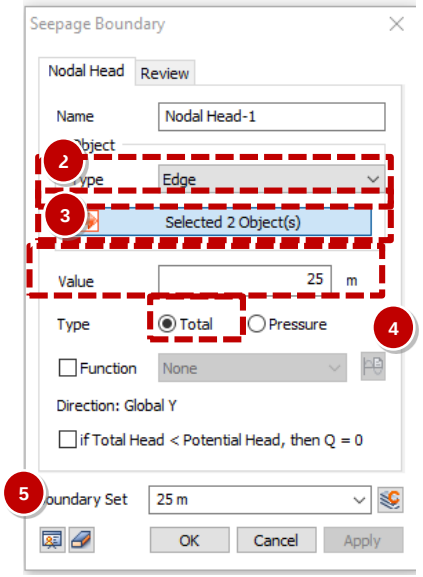
GTS NX

Procedure

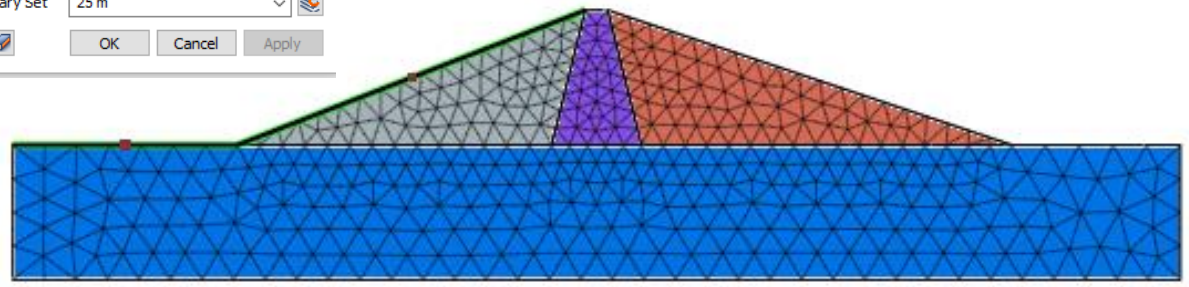
* Nodal Seepage will be defined.

1. Seepage Analysis > Boundary > Nodal Head
2. Select Target Edge(s) > Select edges to define water level as highlighted in the figure.
3. Value = 25 m
4. Type: Total
5. Boundary Set: 25m





Nodal Head: Initial Water Level



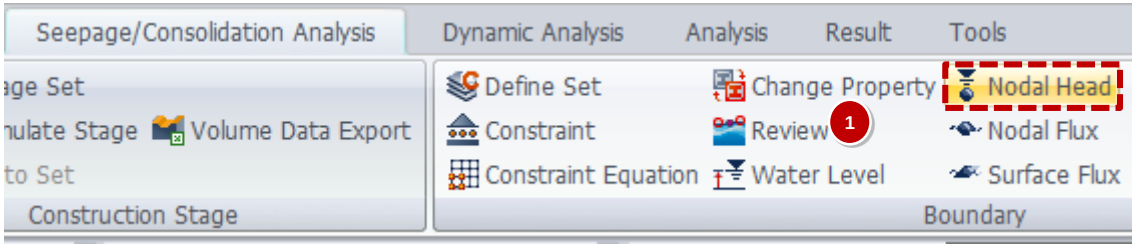
03 Define Boundary Condition (Seepage)

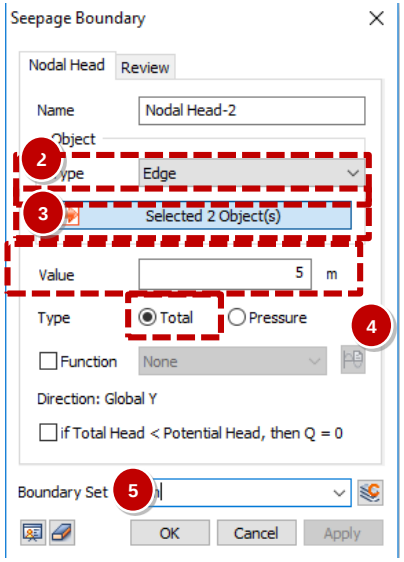
GTS NX

Procedure

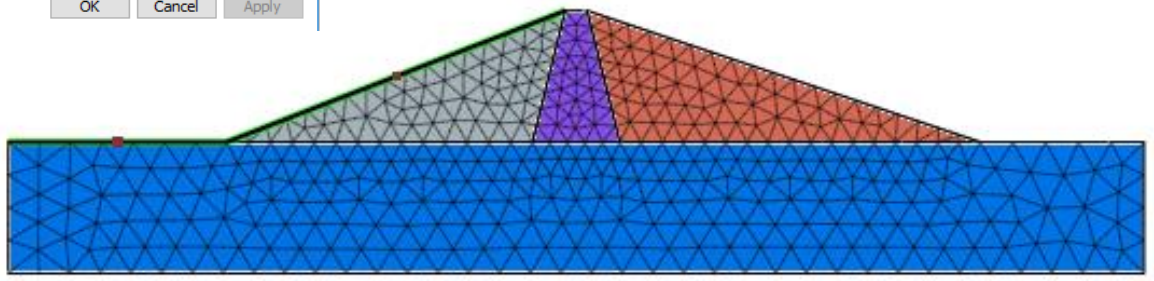
* Nodal Seepage will be defined.

1. Seepage Analysis > Boundary > Nodal Head
2. Select Target Edge(s) > Select edges to define water level as highlighted in the figure.
3. Value = 5 m
4. Type: Total
5. Boundary Set: 5m





Nodal Head: Final Water Level



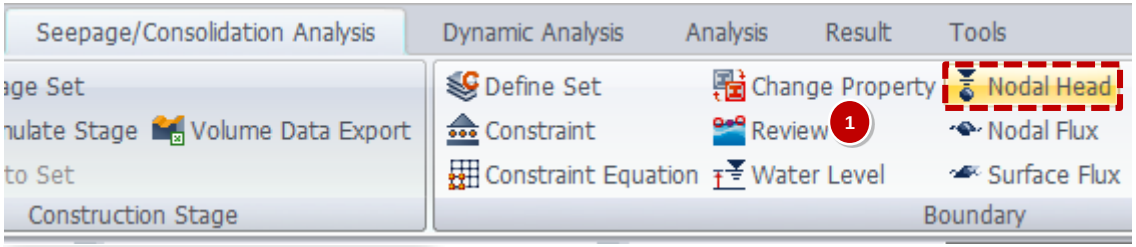
03 Define Boundary Condition (Seepage)

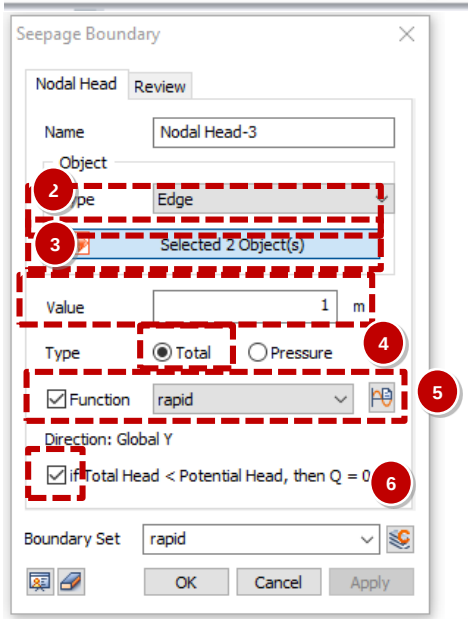
GTS NX

Procedure

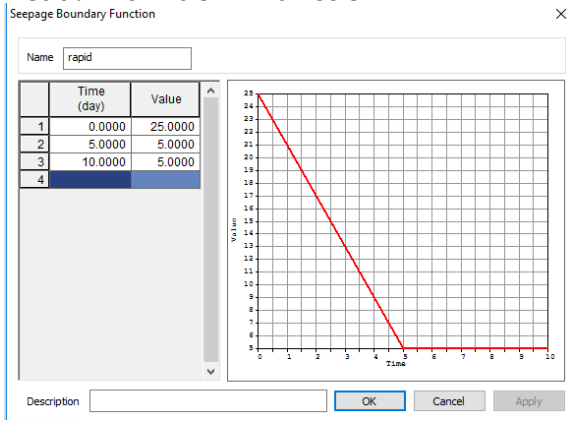
* Nodal Seepage will be defined.

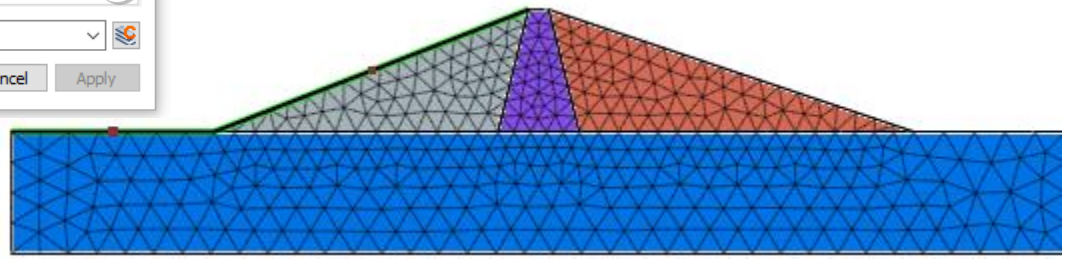
1. Seepage Analysis > Boundary > Nodal Head
2. Select Target Edge(s) > Select edges to define water level as highlighted in the figure.
3. Value = 1 m
4. Type: Total
5. Function: Rapid
   Create a function for drawn down as shown in table
6. Turn on if Total Head < Pressure Head, then Q = 0





Nodal Head: Draw down function





As the water level changes with time (rapid drawdown), suction can occur and the seepage flow can be reversed. If the water level falls suddenly in dams, the descending water level speed is generally faster than the seepage speed within the body. To simulate these real conditions, the head boundary conditions need to change automatically according to the water level.

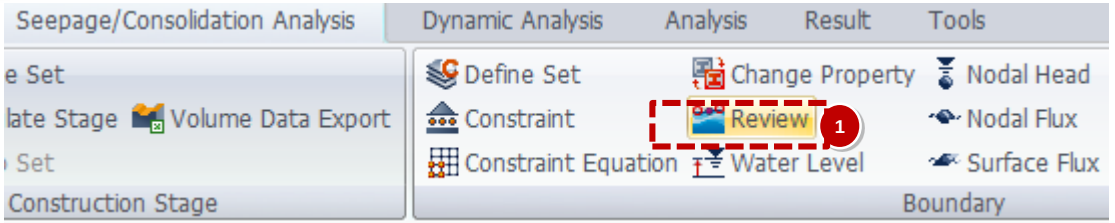
03 Define Boundary Condition (Seepage)

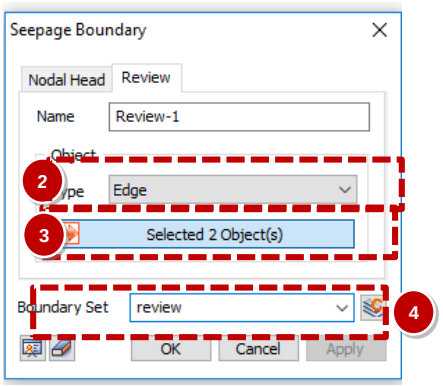
GTS NX

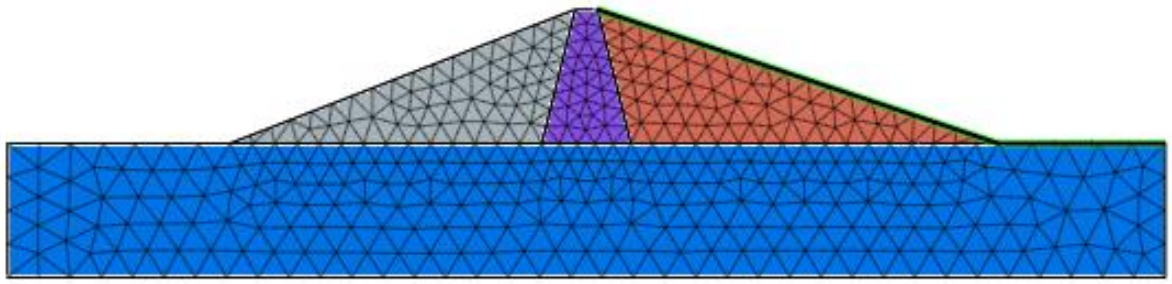
Procedure

* **Review** **Boundary** will be defined.

1. Seepage Analysis > Boundary > Review
2. Select Target Edge(s)
3. Select edges as shown
4. Boundary Set: Review





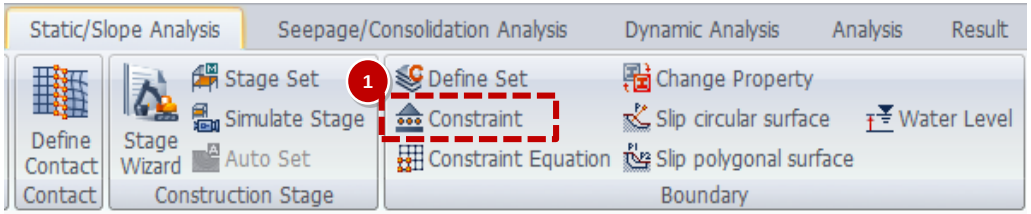


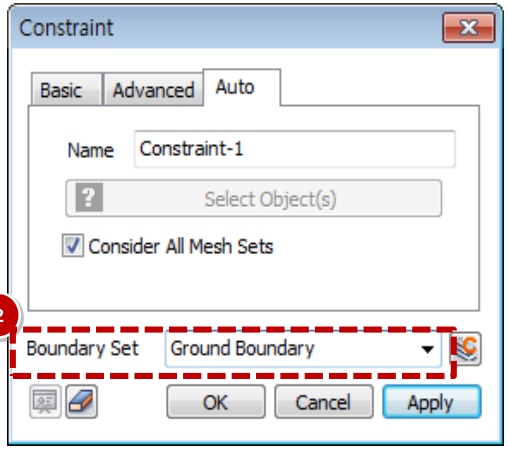
04 Define Boundary Condition (Ground)

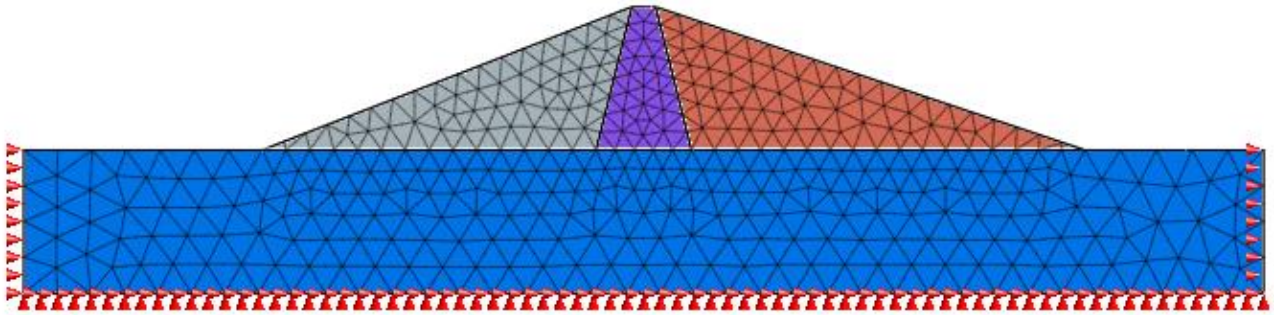
GTS NX

Procedure

1. Static / Slope Analysis > Boundary > Constraint > Auto
2. Boundary Set Name : Ground Boundary





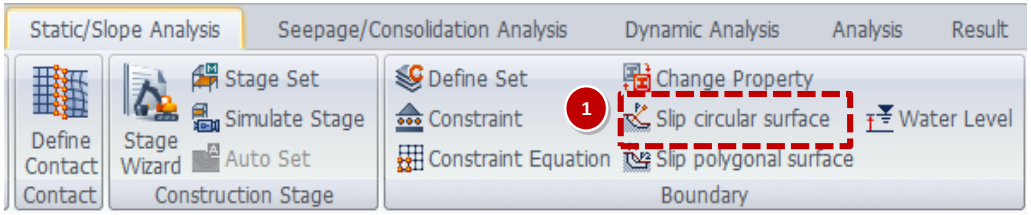


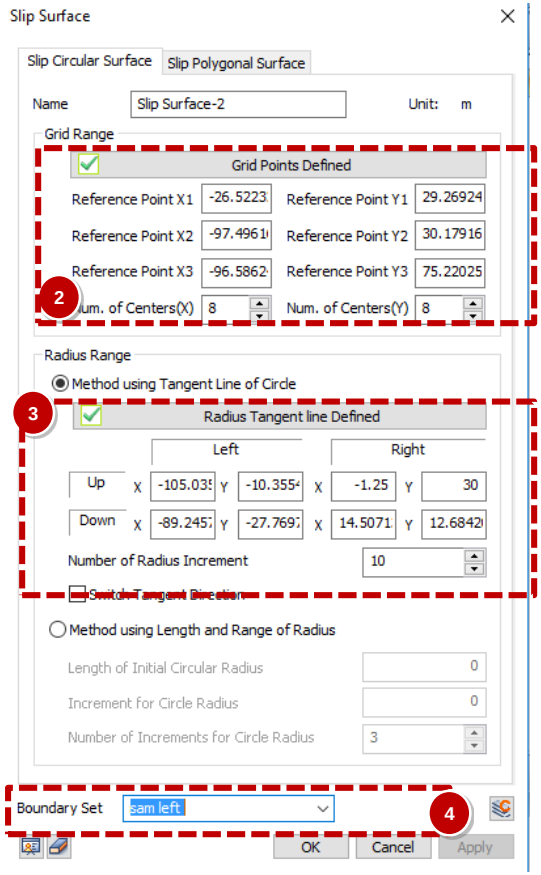
05 Define Boundary Condition (SAM)

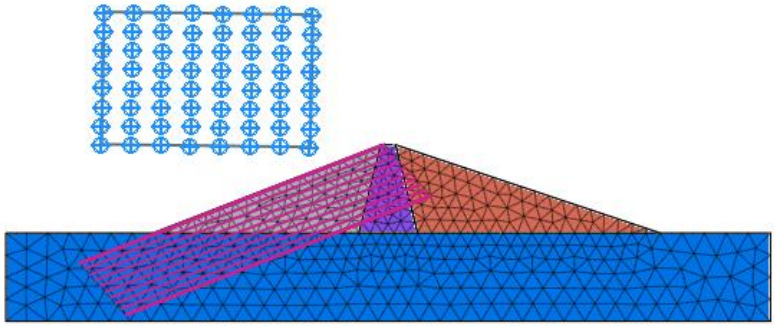
GTS NX

Procedure

1. Static / Slope Analysis > Boundary > Slip circular surface
2. Create 8 X 8 grid on left side of dam similar to LEM as shown.
3. Create radius tangent rectangle on left side of dam as shown with 10 radius increments
4. Boundary Set Name : sam left





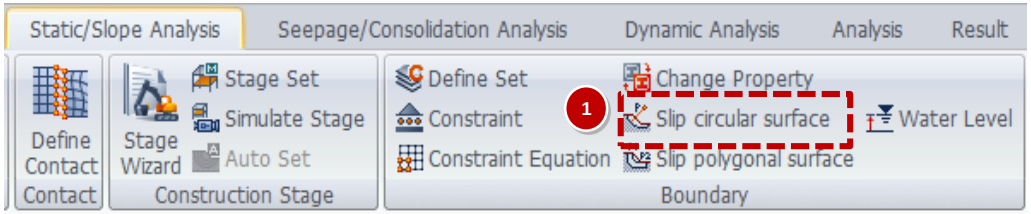


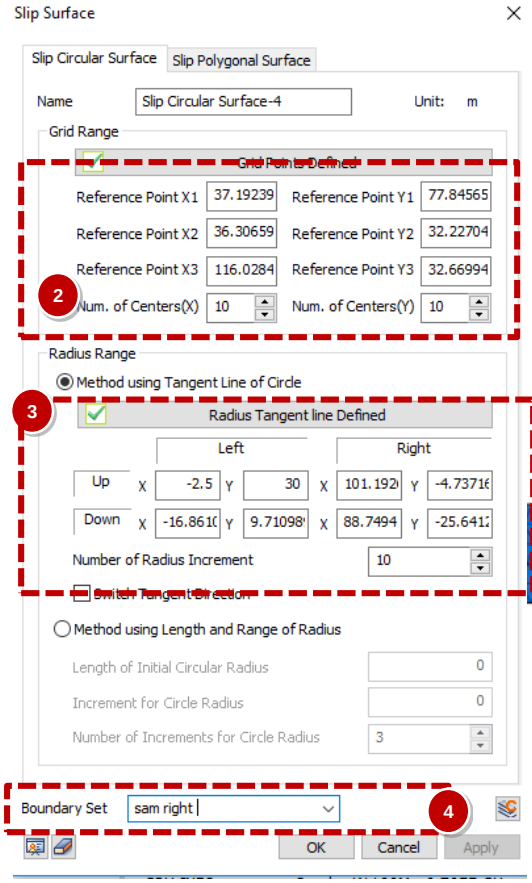
05 Define Boundary Condition (SAM)

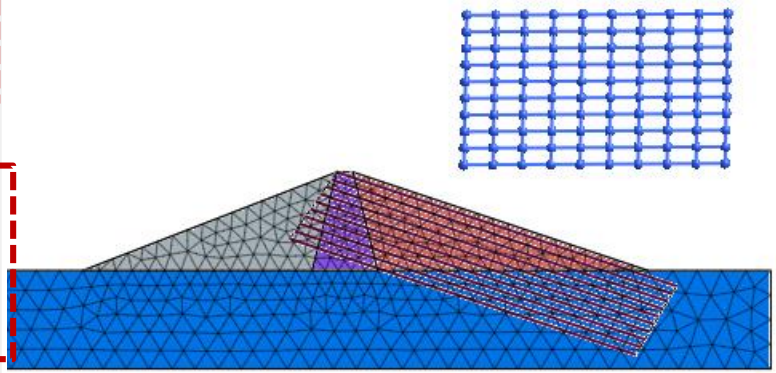
GTS NX

Procedure

1. Static / Slope Analysis > Boundary > Slip circular surface
2. Create 10 X 10 grid on left side of dam similar to LEM as shown.
3. Create radius tangent rectangle on left side of dam as shown with 10 radius increments
4. Boundary Set Name : sam right





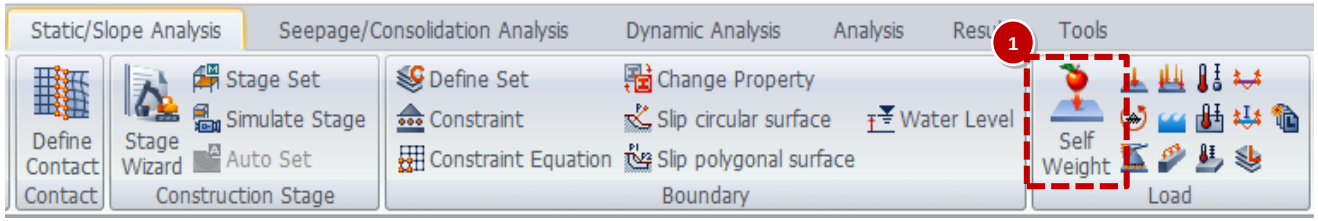


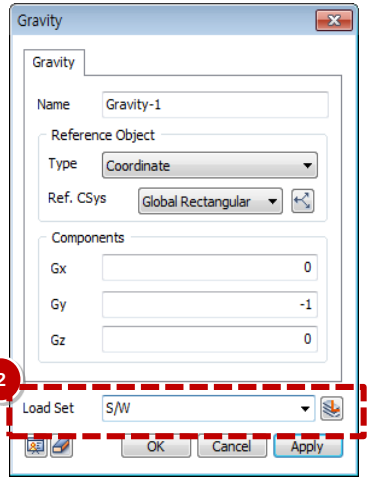
06 Load Condition (Self Weight)

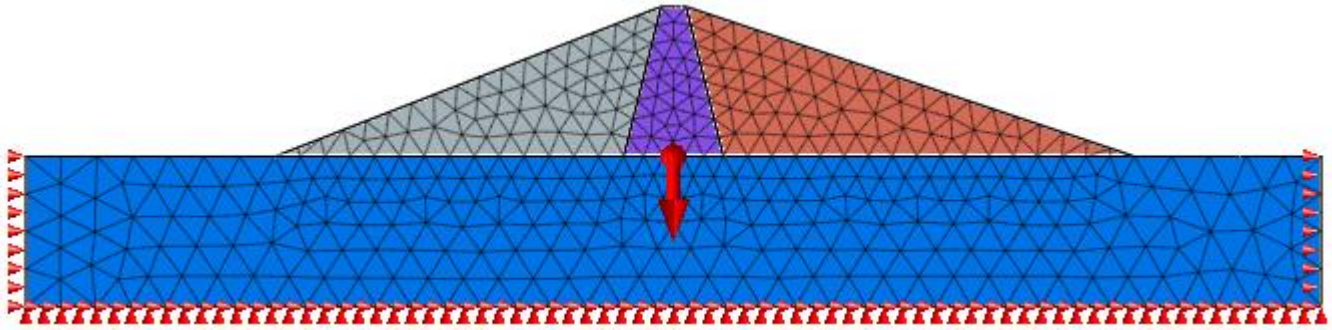
GTS NX

Procedure

1. Static / Slope Analysis > Load > Self Weight
2. Load Set Name : S/W







07 Define Construction Stage (Create Stage Set)

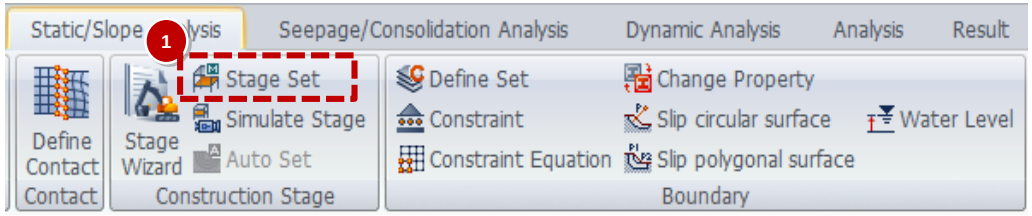
GTS NX

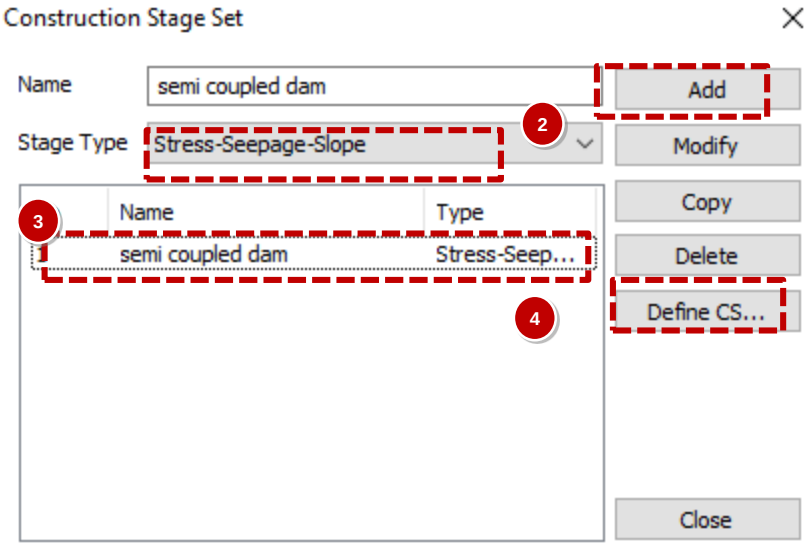
Procedure

* 6 Construction stage will be defined for this project.

1. Static / Slope Analysis > Construction Stage > Stage Set
2. Stage Type > Stress – Seepage Slope

   Select Add
3. Select Created Stage Set
4. Select Define CS...



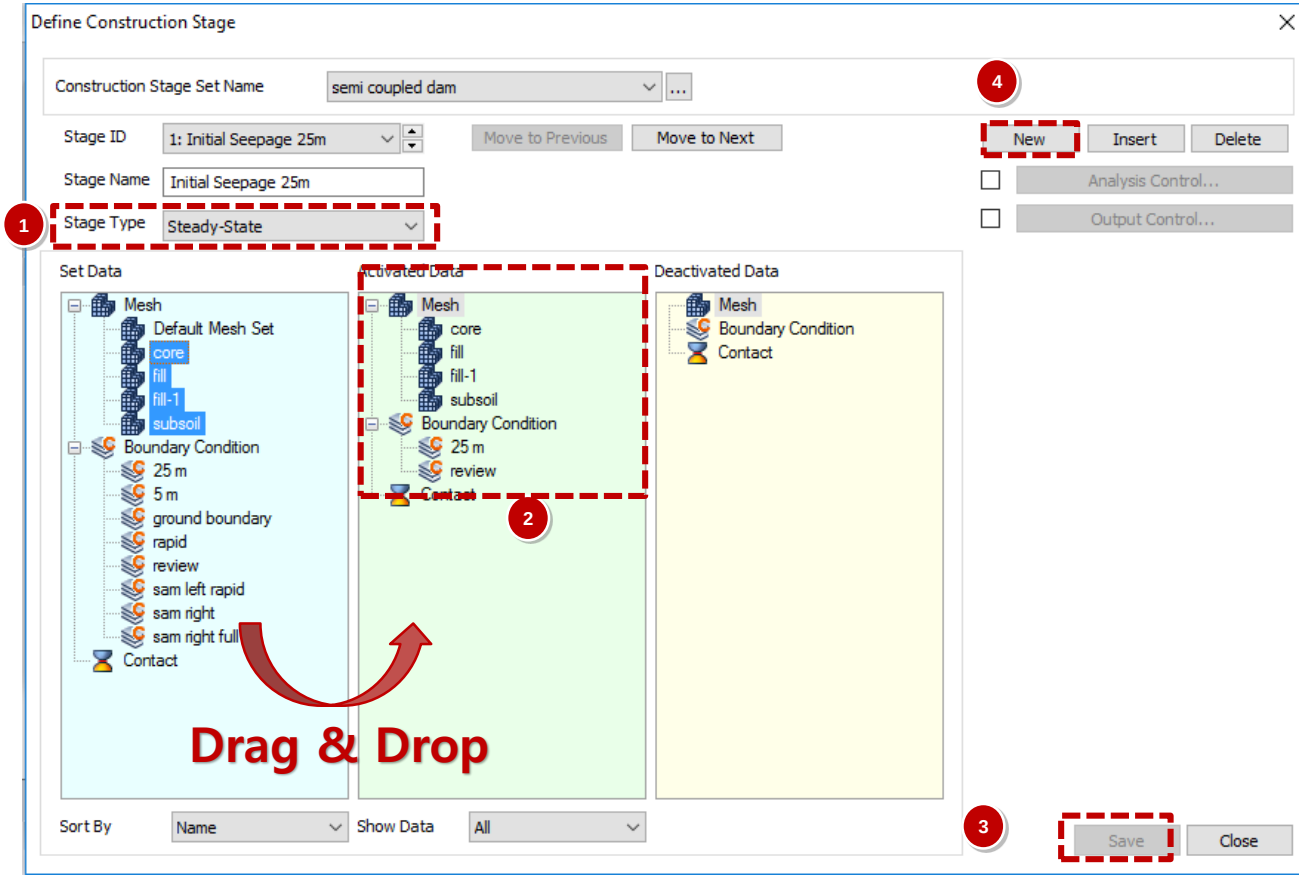


08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 1 Type : Seepage Steady State
2. Activated Data : All Mesh Sets for initial state of ground (2D elements), and Nodal Initial 25m and review seepage boundary
3. Select Save
4. Select New

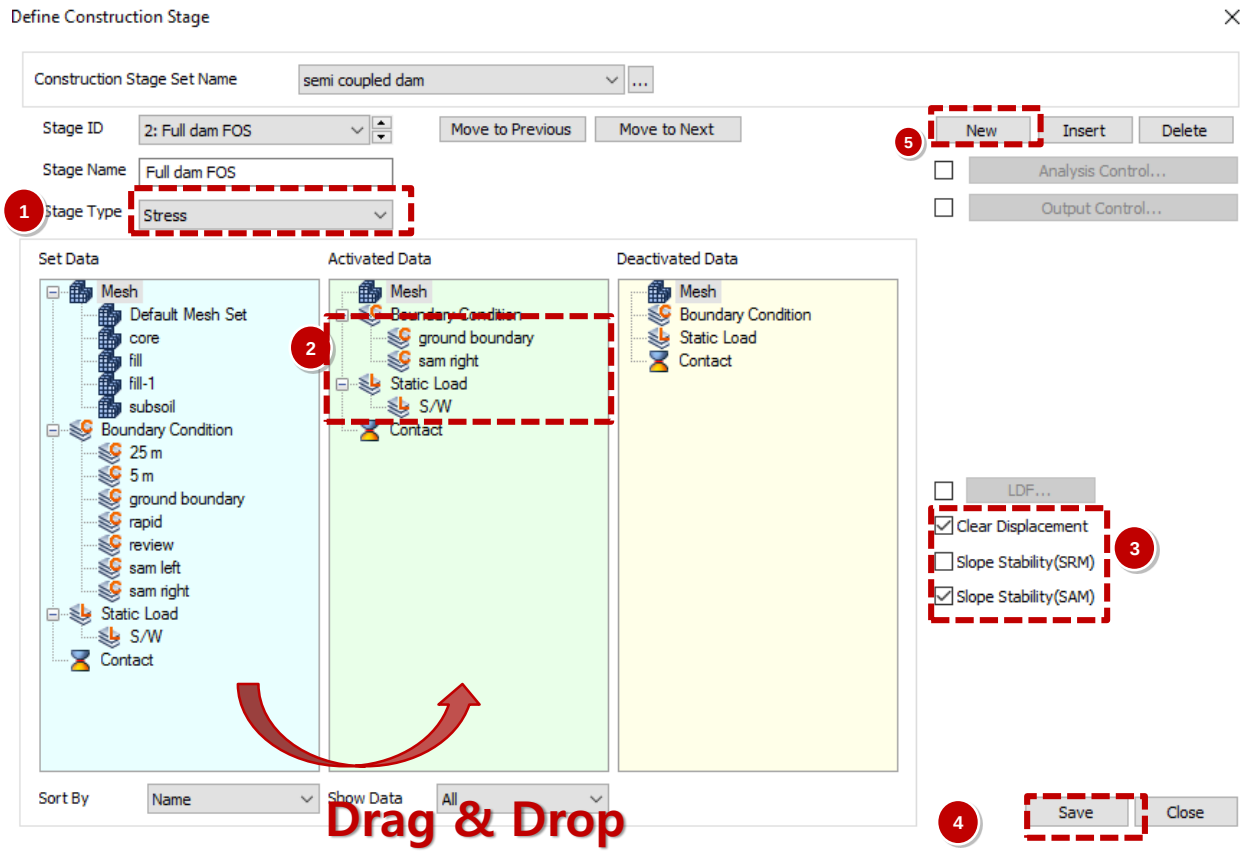


08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 2 Type : Stress
2. Activated Data : Ground Boundary, SAM right and Self Weight
3. Check on Clear Displacement and Slope Stability SAM
4. Select Save
5. Select New

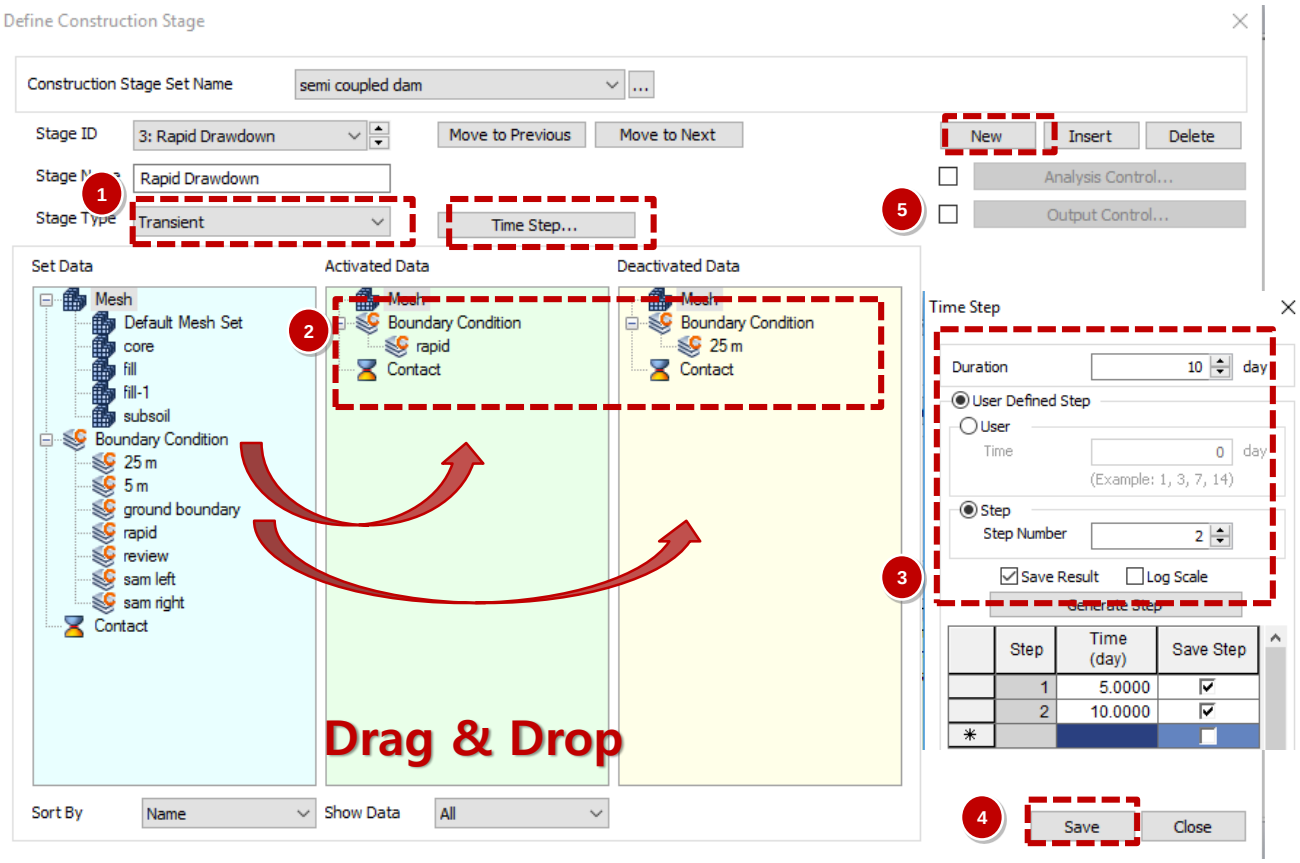


08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 3 Type : Seepage
   Transient (rapid draw down)
2. Activated Data : Boundary Sets
   rapid
   Deactivate Data: Boundary Set
   25m
3. Click Time Step
   10 days 2 Steps
   Save Result / Generate Step
4. Select Save
5. Select New

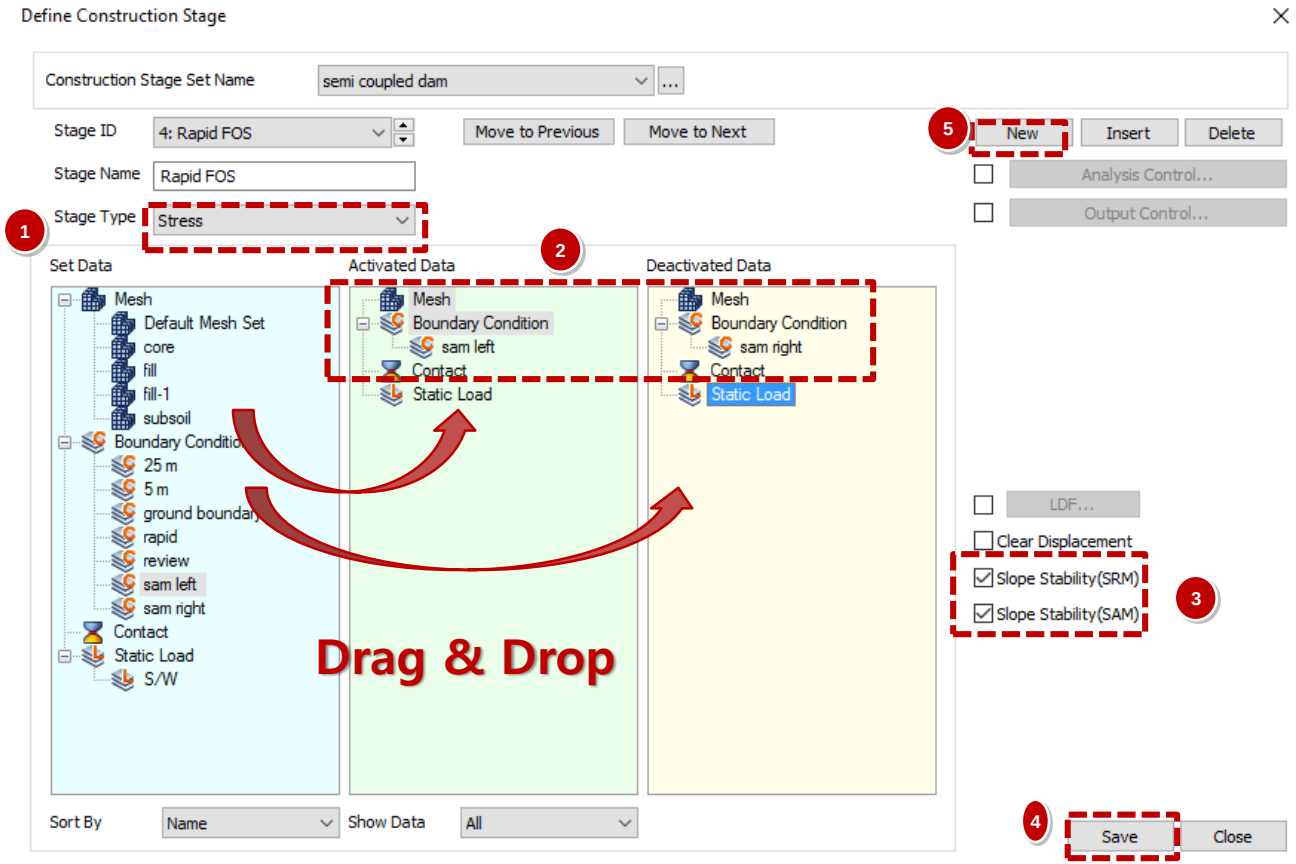


08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 4 Type : Stress
2. Activated Data : Boundary Sets sam left
   Deactivate Data: Boundary Set sam right
3. Check on Slope Stability SAM and SRM
4. Select Save
5. Select New

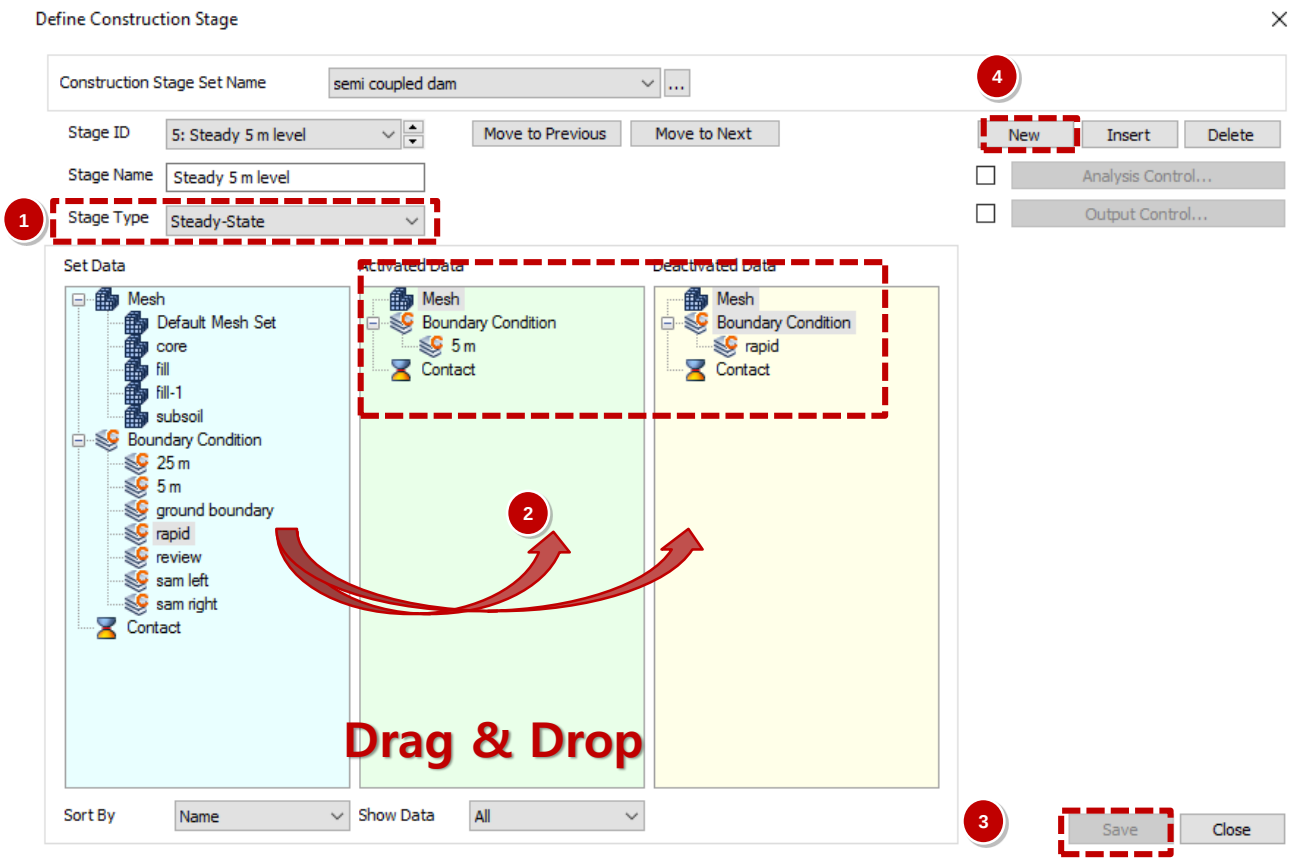


08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 5 Type : Seepage Steady State
2. Activated Data : Seepage boundary 5m
   Deactivate Data: Seepage boundary rapid
3. Select Save
4. Select New

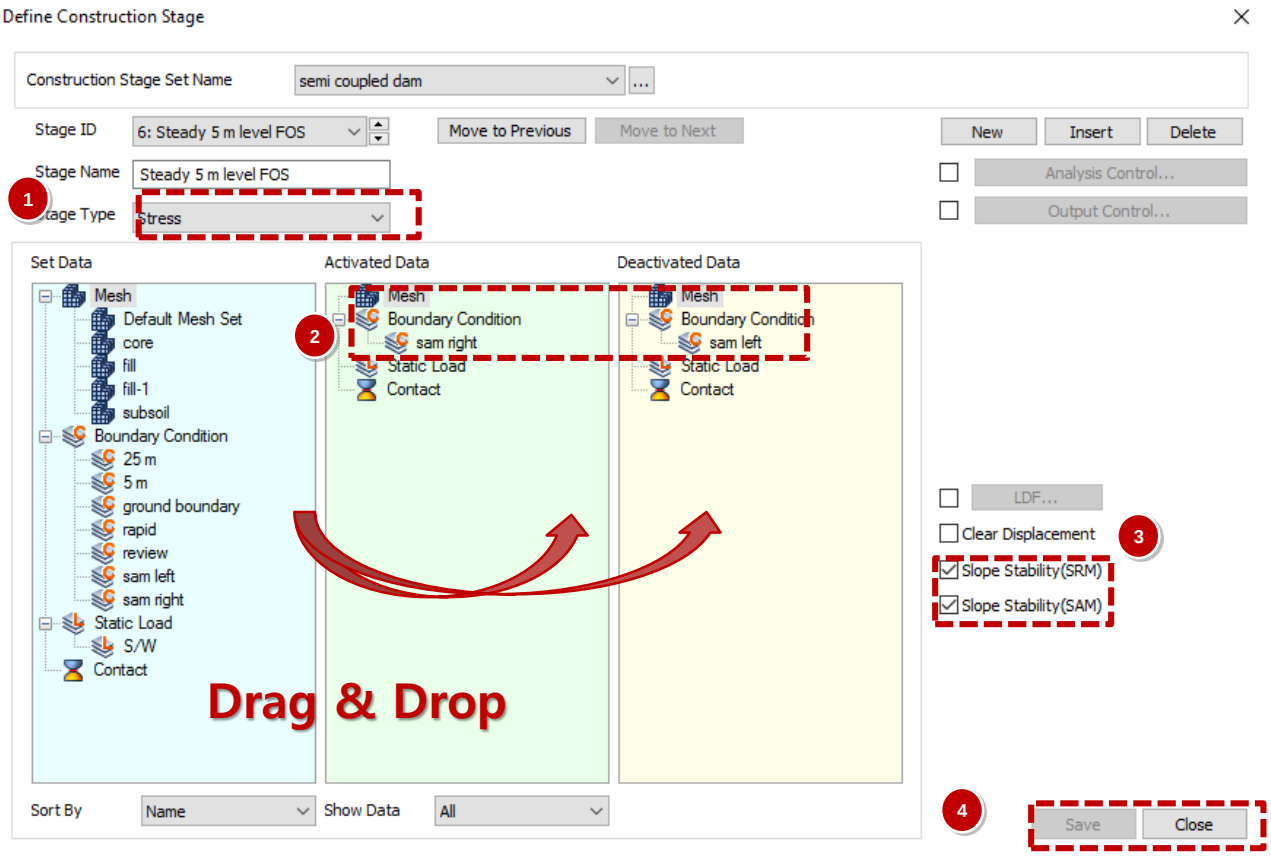


08 Define Construction Stage (Drag & Drop)

GTS NX

Procedure

1. Stage 6: Type : Stress
2. Activated Data : sam right
   Deactivate Data: sam left
3. Activate slope stability SAM and SRM
4. Select Save and Close

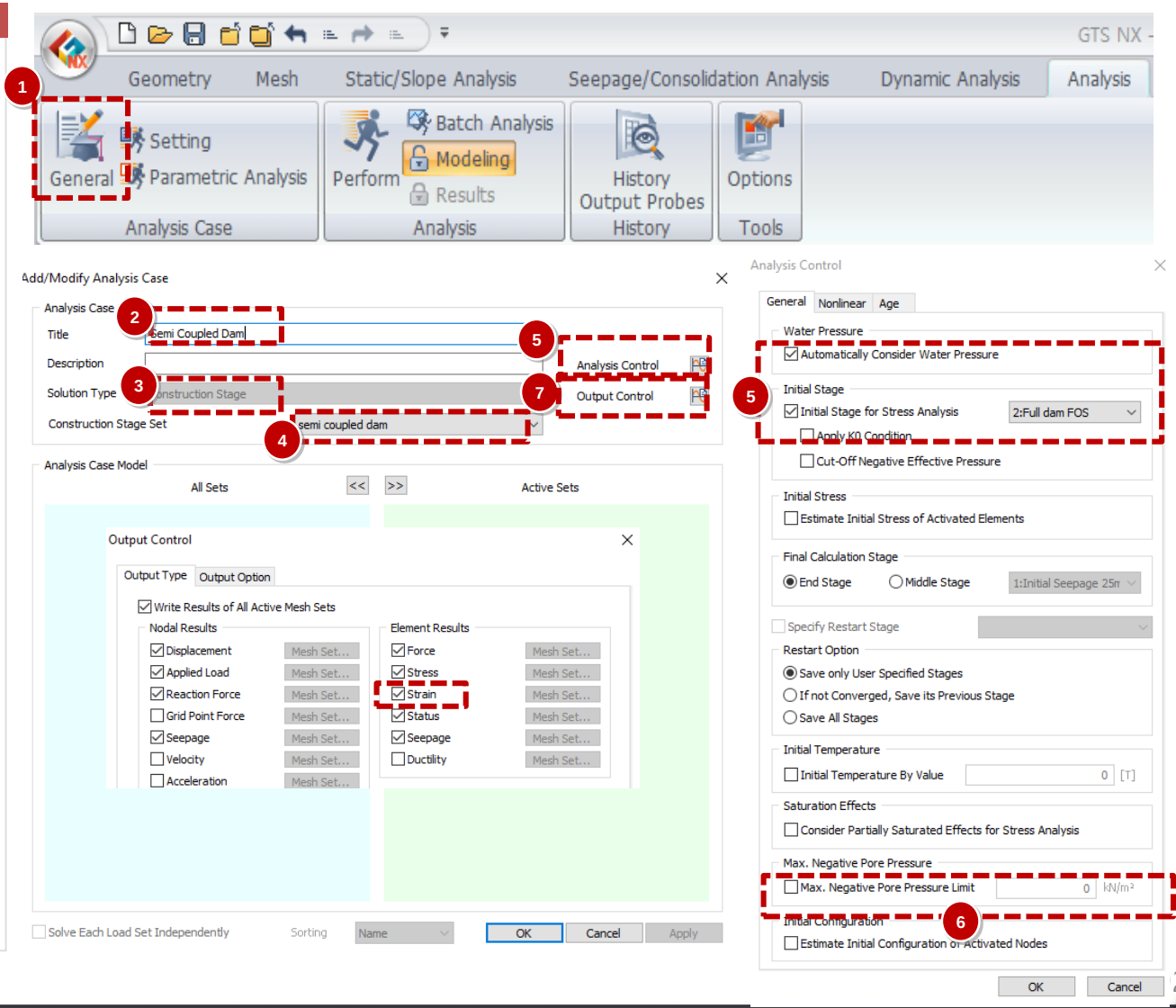


09 Analysis Case

GTS NX

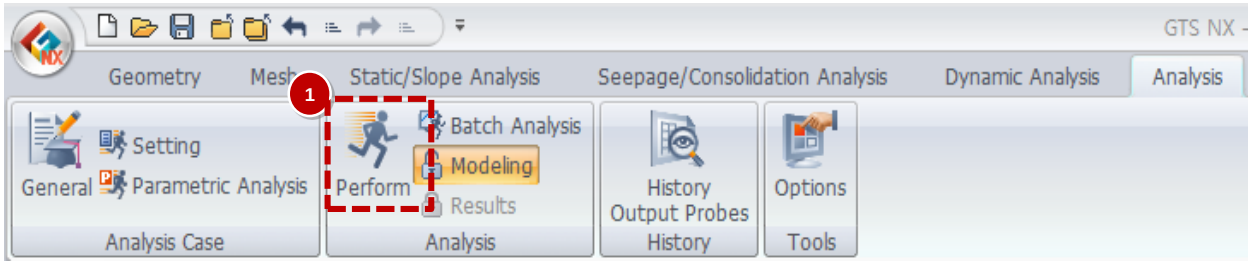
Procedure

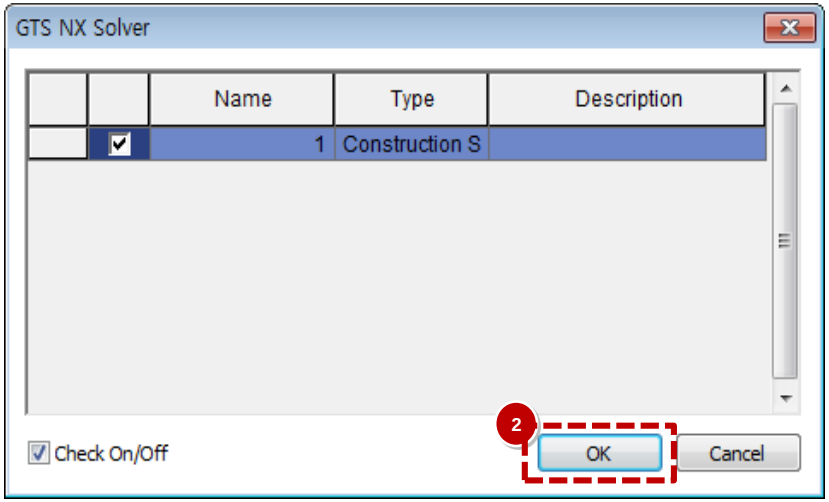
1. Analysis > Analysis Case > General
2. Title : Semi Coupled Dam
3. Solution Type : Construction Stage
4. Select Construction Stage Set Semi coupled dam
5. Analysis Control : Select Initial Stage for Stress Analysis (2. Full Dam FOS), Check: Auto Consider Water Pressure
6. Check off Max Negative Pore
7. Output Control: Check On: Strains



Procedure

1. Analysis > Analysis > Perform
2. Select OK





11 Post Processing (Pre mode vs Post mode)

GTS NX

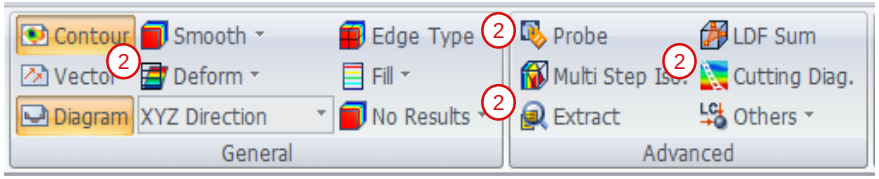
Procedure

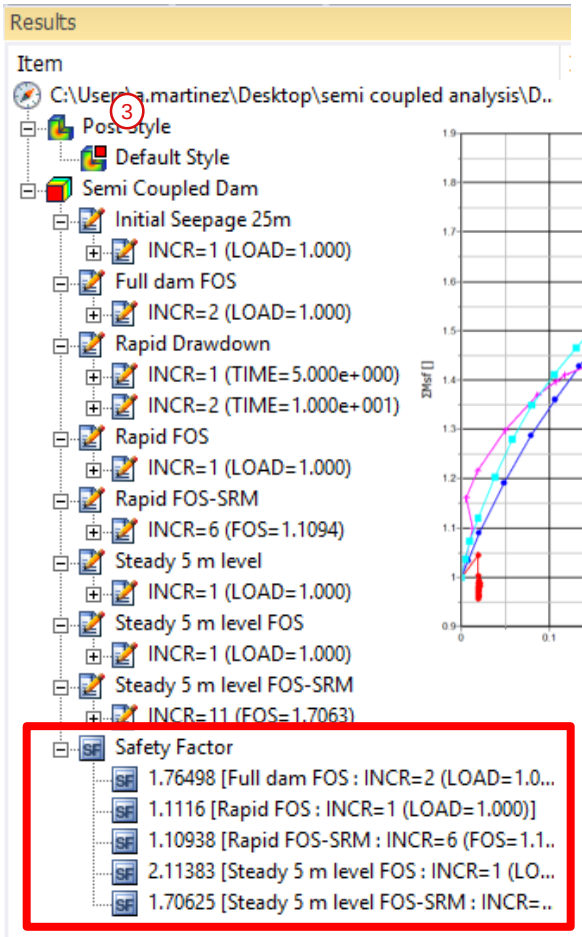
1. After analysis, model view will be converted to Post-Mode automatically, can back to Pre-Mode to change model information.

2. All results will be represented by graphic based output, table, diagram and graph.

3. Results are given by stages and types of elements.

The results are set in order of the stages.
The bottom of the results tab lists the FOS for all the stages in order.
Results similar to plaxis dam drawdown tutorial for corresponding water levels





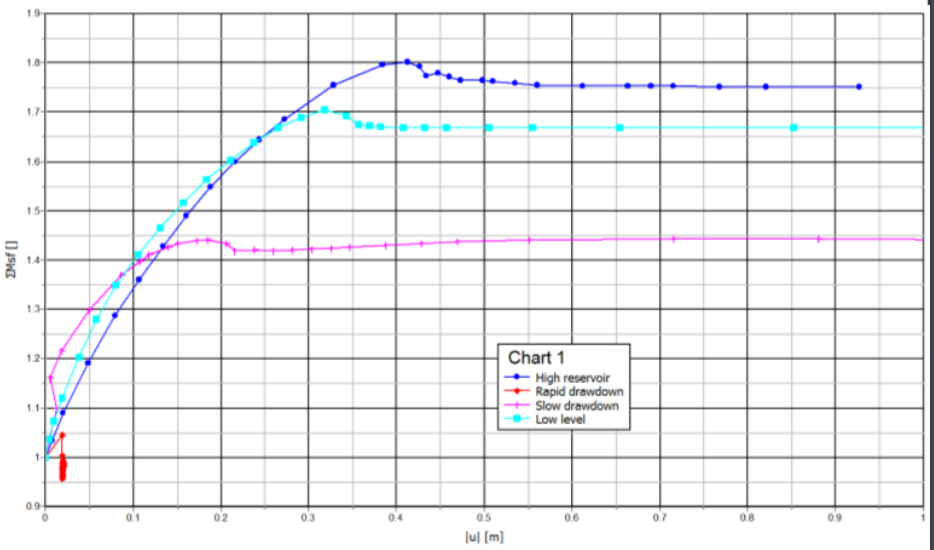
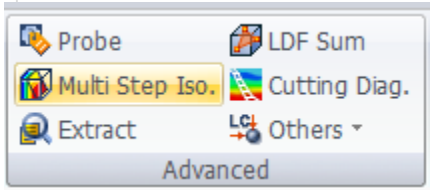


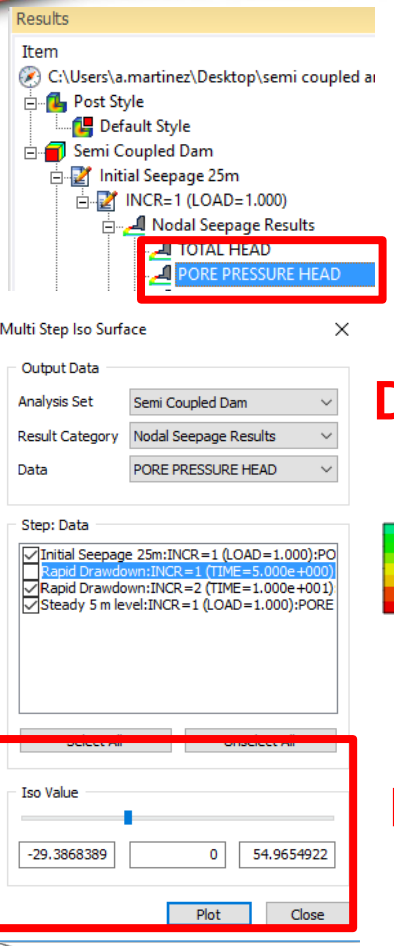
Figure 7.18 Safety factors for different situations

Procedure

1. Expand the seepage results and double click **Nodal Seepage > Pore Pressure Head** to verify the Pore Stress dues to change in Water Level.

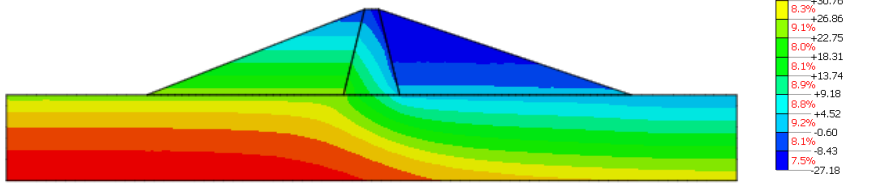
2. You can activate the water level lines by using the Multi Step Iso surface function and setting pore pressure head to 0 for each stage. Click PLOT



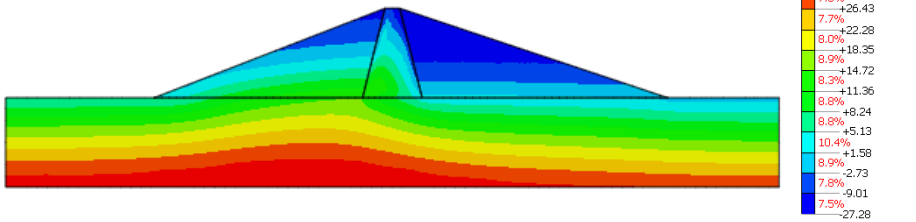


2

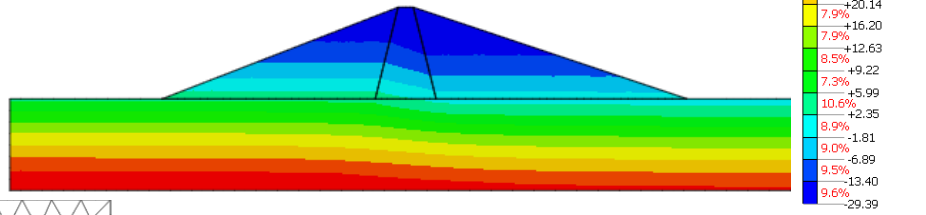
Full level

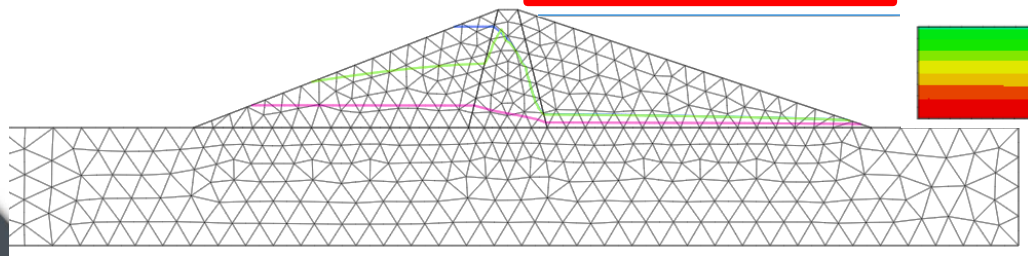


Draw down



Low level





11 Post Processing (Post mode)

GTS NX

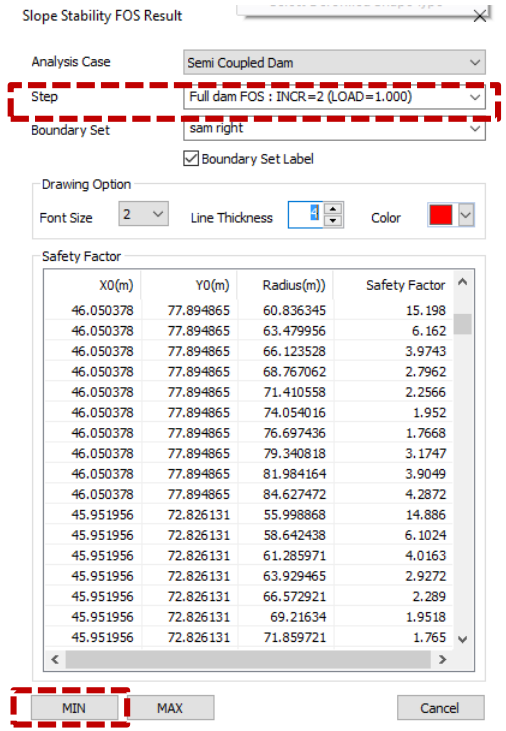
Procedure

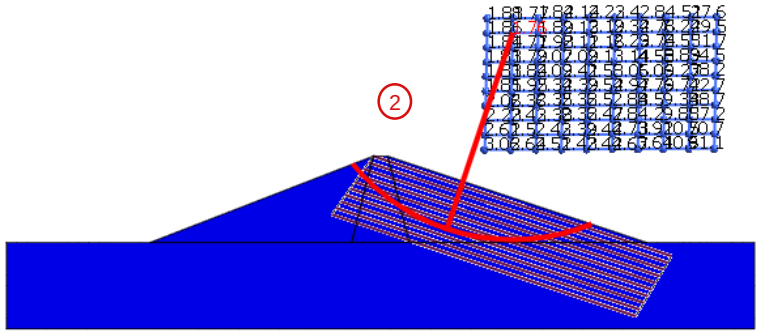
1. Inspect the slope stability results for the last stage by selecting the Plane Strain Strains.
   Click on Results > Special Post > SAM.

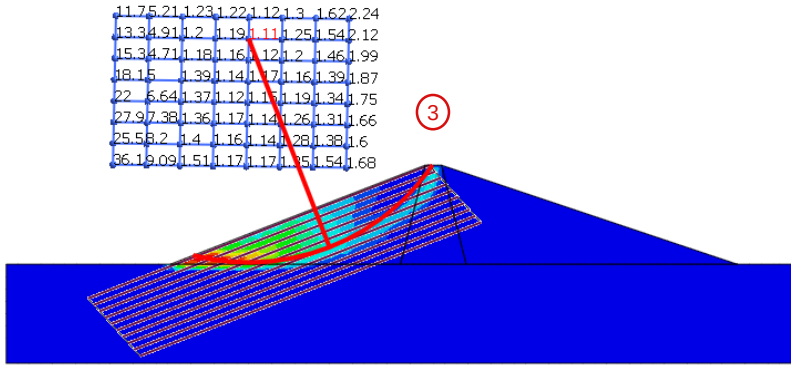
2. Select Stage Full Dam and click MIN

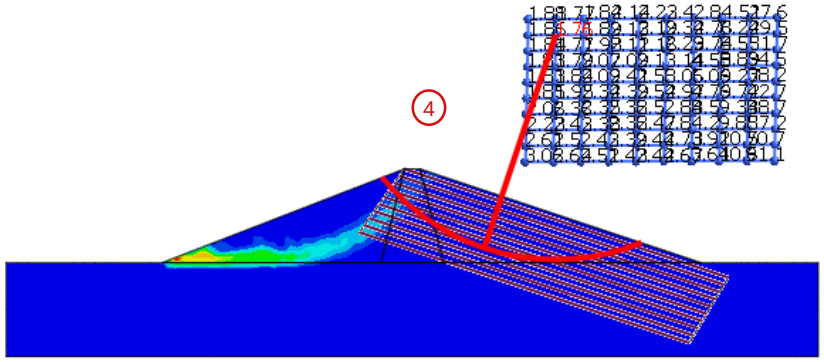
3. Select Stage Rapid FOS and click MIN

4. Select Stage for Steady 5m FOS and click MIN









Thank you