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

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Integrated Solver Optimized for the next generation 64-bit platform

**Finite Element Solutions for Geotechnical Engineering** 









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Integrated Solver Optimized for the next generation 64-bit platform Finite Element Solutions for Geotechnical Engineering





## 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**.



### **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.

**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.







Time = 72 hrs











# 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





Part 1. Overview

Part 2. 2D Slope Stability SRM

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## Overview









## **OO** Slope Stability

#### 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				
Ко	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					

#### 02 Material for Soil and Structures GTS NX Porous Non-Linear Time Dependent General **Unsaturated Properties** 22 Unit Weight(Saturated) kN/m<sup>3</sup> Permeability Function Type: select 'User-defined' 0.5 Initial Void Ratio(eo) Unsaturated Property weathered rock and copy the data from the Excel sheet. .... Water Content Function: select 'User-defined' and copy the water content data from the Excel sheet. Add/Modify Unsaturated Function × 1 2 Weathered Soil Weathered Rock Soft Rock Function Name Scale Factor Permeability Graph Option Water Content Graph Option Pressure Pressure Pressure weathered rock 1 X-axis log scale Y-axis log scale X-axis log scale Y-axis log scale Load Load K Ratio K Ratio Load K Ratio 3 $(kN/m^2)$ $(kN/m^2)$ $(kN/m^2)$ Permeability Function Data 4 0 1.00E+00 0 1.00E+00 0 1.00E+00 5 1.00E+00 1.00E+00 1.00E+00 0.01 0.01 0.01 Function Type User Defined 0.9 6 0.0774 1.00E+00 0.0774 9.80E-01 0.0373 6.39E-01 0.8 7 Pressure 0.599 1.00E+00 0.599 9.73E-01 0.139 3.51E-01 K Ratio 0.7 (kN/m<sup>2</sup>) 8 4.64 9.61E-01 4.64 9.63E-01 0.518 1.84E-01 0.6 9 35.9 2.14E-03 35.9 8.00E-01 1.93 9.46E-02 1 0.0000 1.0000 0.5 10 278 5.15E-06 278 1.75E-02 72 4.29E-02 2 0.0100 1.0000 0.4 11 1.64E-02 26.8 3 0.0774 0.9800 0.3 12 100 3.74E-03 0.5990 0.9730 0.2 Δ 13 373 7.37E-04 0.1 5 4.6400 0.9630 Pressure Pressure Pressure ٥. 0.01 0.1 Negative Pore-Pressure 35,9000 0.8000 Water Water Water 0.001 0.0001 Load Load Load Content Content Content $(kN/m^2)$ $(kN/m^2)$ $(kN/m^2)$ 14 Water Content Function Data 15 3.80E-01 0.5 0.35 0 0 0 0.5 16 1.55 3.79E-01 16.6 0.491 0.45 0.349 Function Type User Defined 0.45 17 5.83 3.74E-01 27.6 0.483 10.4 0.344 0.4 Pressure Water 18 41.1 0.469 6.59 3.65E-01 42.6 0.331 0.35 Content (kN/m<sup>2</sup>) 19 7.05 3.48E-0 51.5 0.456 80 0.321 0.3 20 65 0.434 0.25 7.6 3.18E-01 127 0.311 1 0 0000 0 5000 21 8.45 2.85E-01 105 0.342 200 0.299 0.2 2 16.6000 0.4910 22 0.15 2.35E-01 134 0.285 10.5 3 27.6000 0 4830 0.1 23 150 0.264 13.8 1.98E-01 4 0.4690 41.1000 0.05 24 19.5 1.71E-01 179 0.24 5 51.5000 0.4560 ----------. . . . . . . 25 27.9 0.159 0.001 6 0.4340 0.0001 65.0000 Negative Pore-Pressure

OK

Cancel

Redraw Graph

26

27

28

48

169

0.14

0.122

## **03** Property for Soil and Structure

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







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



# 01 Open Project

start



1 - 14

### 02 Inspect Material for Soil & Structures

#### Procedure

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

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



N	laterial						×
	ID	3	Name	Weathering	) soil	Color	~
	Model Type Mohr-Coulomb					~	Structure
	General	Poro	us Non-Lin	ear Time De	ependent		
(	Elasti	c Modu	ılus(E)			36500	kN/m²
	Inc. of Elastic Modulus				0	kN/m³	
Ż.	Inc. of Elastic Modulus Ref. Height				0	m	
	Poisson's Ratio(Nu)					0.3	
	Unit Weight(Gamma)				18.5	kN/m³	
	Initial	Stress	Parameters				
	Ко	<b></b>	Anisotropy	HE		1	

### 03 Inspect Property for Soil & Structures

#### Procedure

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

Mesh > Prop. > Property

2

Select nail property and click modify to inspect



dd/Mo	dify Property			×
No	Name	Туре	Sub-Type	Create 💌
1	weathered soil	2D	Plane Strain	Modify
2	weathered rock	2D	Plane Strain	
3	bed rock	2D	Plane Strain	Сору
4	Nail	1D	Truss	
				Delete



### 04 Generate Mesh (2D Element)

Area

6





#### Procedure

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



## **04** Generate Mesh (2D Element)

#### Procedure

Select Edge(s) > Select edges for "Bed Rock" as highlighted in the figure.

#### Input element Size : 3(3 m between two nodes)

**3** Select Property : Bed Rock

Input Mesh Set Name : Bed Rock

5 Click OK



#### 04 Generate Mesh (Extract 1D Element) GTS NX 属 Create 🔄 Modify Topo. 🕂 Extract 💵 Interface H Hinge Procedure 🙀 Delete 🔟 Parameters 🛄 Divide 📑 Pile/Pile Tip Infinite 🔀 Modify 🛄 Connection 🛛 🗱 Measure 📲 Free Field **1** Mesh > Element > Extract Element Select the TYPE: Edge(s) > 2 Select 10 edges for "nails" as Extract Element $\times$ highlighted in the figure. Geometry Mesh Type Edge **3** Select Property : Nail 2 L Selected 10 Object(s) L Orientation (Element Z-Axis) 4) Input Mesh Set Name : Nails ÷\$ Beta Angle: 90 [deg] 4: Nail 5 Click OK Mesh Set Register Based-on Object Shape Register Based-on Owner Shape Register Based-on Owner Mesh Set Nail $\sim$ ð ОК Cancel Apply

## 05 Define Boundary Condition (Seepage)

#### Procedure

- \* Nodal Seepage will be defined.
- Seepage Analysis > Boundary > Nodal Head
- 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
- <sup>5</sup> Boundary Set: Nodal Initial

Seepage/Consolidation Analysis	Dynamic Analysis	Analysis	Result	Tools
age Set	Set Define Set	📑 Char	nge Property	🕈 Nodal Head
nulate Stage 栏 Volume Data Export	Constraint	² Revi	ew 1	🔷 Nodal Flux
to Set	Constraint Equati	on <u>∓</u> ¥ Wat	er Level	🛩 Surface Flux
Construction Stage			E	Boundary



Nodal Head: Initial Water Level

### 05 Define Boundary Condition (Seepage)

#### Seepage/Consolidation Analysis Dynamic Analysis Analysis Result Tools Procedure 🕈 Nodal Head Set Define Set 🖶 Change Property e Set \* Review Boundary will be defined. late Stage 🔮 Volume Data Export 🎰 Constraint Review 1 Nodal Flux Constraint Equation T Water Level Surface Flux Set Construction Stage Boundary 1 Seepage Analysis > Boundary > Review 2) Select Target Edge(s) Seepage Boundary Х Nodal Head Review 3 Select top Surface edge Review-2 Name Edge Type 4 **Boundary Set: Review** Selected 15 Object(s) Boundary Set review Cancel Apply OK

### 05 Define Boundary Condition (Seepage)



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.

GTS NX

1-23

## 05 Define Boundary Condition (Ground)

#### Procedure

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



## 06 Load Condition (Self Weight)

#### Procedure

 Static / Slope Analysis > Load > Self Weight

#### 2 Load Set Name : S/W





### 07 Define Construction Stage (Create Stage Set)

#### Procedure

- \* 5 Construction stage will be defined for this project.
- Static / Slope Analysis > Construction Stage > Stage Set
- 2 Stage Type > Stress Seepage Slope
- 3 Select Add
- 4) Select Created Stage Set
  - Select Define CS...





#### Procedure

- 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





1

2

3

4

Select Save

Select New





1-30



## 09 Analysis Case

#### Procedure 🗅 🗁 🔚 🖆 🎬 🦛 🖦 🔶 🕫 GTS NX Static/Slope Analysis Seepage/Consolidation Analysis Geometry Mesh Dynamic Analysis Analysis 1) Analysis > Analysis Case > General Batch Analysis 100 0 Settina Modelina ÷. Rear Parametric Analysis Perform History Options Results 2 Title : Semi Coupled Output Probes Analysis Case Analysis History Tools **3** Solution Type : Construction × Analysis Control Х Add/Modify Analysis Case Stage Analysis Case General Nonlinear Age 2 Title emi coupled Description Analysis Control Automatically Consider Water Pressure 4 Select Construction Stage Set Solution Type Output Control hitial Stage Semi coupled Construction Stage Initial Stage for Stress Analysis 2:initial stress Analysis Case Model Apply K0 Condition << >> All Sets Active Sets Analysis Control : Select Initial Cut-Off Negative Effective Pressure Stage for Stress Analysis (2. Initial Stress Output Control Х Estimate Initial Stress of Activated Elements Initial Stress), Output Type Output Option Final Calculation Stage **Check: Auto Consider Water** Write Results of All Active Mesh Sets O Middle Stage End Stage 1:initial seepage Nodal Results Pressure Element Results Force ✓ Displacement Mesh Set... Specify Restart Stage Applied Load ✓ Stress Reaction Force Strain Restart Option 6 Check Max Negative Pore Grid Point Force ✓ Status Save only User Specified Stages Pressure: 20kN/n^2 Seepage Seepage Mesh Set... O If not Converged, Save its Previous Stage Velocity Mesh Set Ductility Mesh Set... O Save All Stages Acceleration Mesh Set... Initial Temperature 7) Output Control: Initial Temperature By Value 0 [T] **Check On: Strains** Saturation Effects Consider Partially Saturated Effects for Stress Analysis Solve Each Load Set Independently OK Cancel Apply 6 Max. Negative Pore Pressure Max. Negative Pore Pressure Limit 20 kN/m<sup>2</sup>

## **10** Perform Analysis and Check Results



1 Analysis > Analysis > Perform

2 Select OK





### **1** Post Processing (Pre mode vs Post mode)

#### Procedure

- After analysis, model view will be converted to Post-Mode automatically, can back to Pre-Mode to change model information.
- <sup>(2)</sup>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.



### **11** Post Processing (Post mode)



### **11** Post Processing (Post mode)

#### ▶ ■ Level 3 (Normal) Procedure Inspect the changes in the model by navigating the stages using Safety Factor the bar on the bottom of the 1.70469 [Dry srm-SRM : INC.. SF model / above the output 1.07539 [rain srm 1-SRM : IN. 2.00469 [srm with nails-SRM. window. Press Right or Left key on keyboard to go forward and backward in the stages PLANE STRAIN STRAIN E-MAX SHEAR , None +0.252 +0.17 +0.14 (3) Inspect the slope stability results +0.12 +0.10 for the last stage by selecting the Min/Max Value... +0.09 Plane Strain Strains. Layout +0.07 Color Type +0.06 The images shows max shear Background +0.04strains for the 1st 3 stages of the +0.03 Auto-Range +0.02 +0.01 Reset All 4N % +0.00 Right click the legend and select AUTO RANGE to see results more

You can create a video animation of the stages by selecting Multi Stage Animation > Select All Stages > Play > Save

(1)

(2)

3

respectably.

analysis.

clearly.

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### Part 1. Overview

- Part 2. 2D Slope Stability SRM
- Part 3. 3D Slope Stability SRM
- Part 4. 2D Dam Stability SAM



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### Overview







Name	Weathered Soil	Weathered Rock	Bed Rock	Geogrid	
Material	Isotropic	Isotropic	Isotropic	Orthotropic	
	•	•	•	Geogrid	
Model Type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Elastic Modulus 1	
				550000 kN/m^2	
Elastic Modulus (E) (kN/m^2)	40,000	150,000	1,850,000	Elastic Modulus 2	
Poisson's Ratio(v)	0.3	0.25	0.28	475000 kN/m^2	
Unit Weight(r) (kN/m^3)	18	21	24		
Ко	1	1	1	Shear Modulus	
		375000 kN/m^2			
Unit Weight(Saturated) (kN/m^3)	19	22	25	Weight	
Permeability Coe. (m/day)	0.504	0.00254	3.86e-005	7 kN/m^3	
Non-Linear					
Friction Angle	21	25	38		
Cohesion (kN/m^2)	9	40	100		

## 03 Property for Soil and Structure

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

# 01 Open Project

#### Overview

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



### 02 Inspect Material / Property for Soil & Structures

1

2

3

#### 🗅 🗁 🗟 🔂 🗂 🖛 🛎 🏓 🛎 Procedure \* You can inspect and modify Geometry Mesh Static/Slope Material / Property from start files Comp. Prop. H Hinge -← CSys 1 Material Propert Function \* rop./CSys./Func. Mesh > Prop. > Material or 8 8 🗘 🕼 💷 🚛 🕂 🛱 Property 3 Material $\times$ Select geogrid material and ID 4 Name geogrid 2d Color click modify to inspect Add/Modify Material $\times$ Model Type $\sim$ Structure Geoarid Create... No Name Type Select geogrid property and 1 Isotropic-Mohr-Coulomb weathered rock Parameter1 Parameter2 Modify.... click modify to inspect 2 Bed rock Isotropic-Mohr-Coulomb Copy 3 Isotropic-Mohr-Coulomb Weathering soil Elastic Modulus(E1) 550000 kN/m<sup>2</sup> 2 lete Orthotropic-Geogrid Elastic Modulus(E2) 475000 kN/m<sup>2</sup> Shear Modulus(G12) 375000 kN/m<sup>2</sup> Create/Modify 2D Property × Geogrid(2D) Add/Modify Property Х $\sim$ Color ID 4 Name geogrid Create • No Name Sub-Type Type soil 3D Solid 1

Modify...

Material

Thickness

Solid

Solid

Geogrid(2D

2

3

weathered rock

bed rock

3D

3D

E

m

 $\sim$ 

0.01

4: geogrid 2d

### 03 Geometry works (Create or Import from Excel)

X-Axis

10

Y-Axis



#### Procedure

- Geometry > Surface Solid > Bedding Plane
- 2 Select Import > Excel file "Bore Hole data 3D Slope Stability"

3 X and Y = 10

4 Click OK

## 03 Geometry works



## 03 Geometry works

Solid

Click OK

on keyboard



GTS NX

4

### 04 Generate Mesh (3D Element)



GTS N

Advanced Option

X

### solid 2) Select object > Select solid for

Procedure

- "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
- Click on the >> icon to open 7 the Advanced Option Window
- <sup>8</sup> Activate Higher Order Elements

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

### **04** Generate Mesh (3D Element)

#### Procedure

- Mesh > Generate > 3D > Auto solid
- Select object > Select solid for "weathered rock" as highlighted in the figure.
- Input element Size : 5 (5m between two nodes)
- 4 Select Hybrid mesh
- **5** Select Property : weathered rock
- Input Mesh Set Name : weathered rock
  - Activate Higher Order Elements should still be on.
- Click Apply





### 04 Generate Mesh (3D Element)

solid

figure.

Click OK







GTS NX

#### 1 - 49

### 04 Extract Mesh (2D Element)

GTS NX

### Procedure

- **1** Mesh > Element > Extract
- 2 Type: Geometry > Face
- 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)

#### 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

GTS NX

Pressu

Cancel



5 Ş

 $\sim$ 

Apply

Х

### 05 Define Boundary Condition (Seepage)



### 05 Define Boundary Condition (Seepage)



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)

#### Procedure

- Static / Slope Analysis > Boundary > Constraint > Auto
- Boundary Set Name : Ground Boundary



## 06 Load Condition (Self Weight)

#### Procedure

 Static / Slope Analysis > Load > Self Weight

#### 2 Load Set Name : S/W





### **07** Define Construction Stage (Create Stage Set)

#### Procedure

- \* 5 Construction stage will be defined for this project.
- Static / Slope Analysis > Construction Stage > Stage Set
- 2 Stage Type > Stress Seepage Slope
- 3 Select Add
- 4 Select Created Stage Set
  - Select Define CS...





#### Procedure

- 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



3

4

5



#### Procedure

- Stage 3 Type : Seepage Transient (rain)
- 2 Activated Data : Boundary Sets Rain and Review
  - Deactivate Data: Boundary Set nodal review
- Click Time Step
  2 days 1 Steps
  Save Result / Generate Step
- Select Save
- Select New



### 1-59







## 09 Analysis Case



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



### **10** Perform Analysis and Check Results



1 Analysis > Analysis > Perform

2 Select OK





### **1** Post Processing (Pre mode vs Post mode)

#### Procedure

- After analysis, model view will be converted to Post-Mode automatically, can back to Pre-Mode to change model information.
- <sup>(2)</sup>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 (1)	Post-Mode
Item	Results

(3)





### Post Processing (Post mode)



### **11** Post Processing (Post mode)

(1)

(2)

(3)





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### Overview



### **02** Material for Soil and Structures



## 02 Material for Soil and Structures

### **Unsaturated Properties**

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

Unit Weight(Saturated)		21	kN/m³		
Initial Void Ratio(eo)		0.5			
Unsaturated Property	Subsoil			$\sim$	

General Porous Non-Linear Time Dependent

GTS N

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





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
# 01 Open Project



# 02 Generate Mesh (2D Element)

#### Procedure

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



	Advanced Option X	
Generate mesh(Face) X	Merge Nodes	
Auto-Face Auto-Area Map-Face Map-Area	Tolerance 0.0001	
Selected 4 Edge(s)	Element Size Growth Rate	
Select Point(s)	Fine Coarse	
Size O Division 4	Min/Max Element Size 4.000	
☐ Mesh Inner Domain ☑ Indude Interior Edges	Small Large	_
Property	2D Mesher	
1 1: Core 🗸 🗈 4	Delaunay Mesher 🗸 🗸	
	Element Type	
Mesh Set 🗸 🗸 🗸	Triangle V	
🐺 🖉 🛱 OK Cancel Apply >>	Higher-Order Element	
	Pattern Mesh	
	Register Each Mesh Independently	
	OK Cancel	

# 02 Generate Mesh (2D Element)

#### Procedure

Select Edge(s) > Select edges
 for "Fill" as highlighted in the figure.

## Input element Size : 5 (5 m between two nodes)

3) Select Property : Fill

Input Mesh Set Name : Fill

Click Apply (by clicking apply, window keeps Higher Order Elements option on)





# Generate Mesh (2D Element)





#### Procedure

- \* Nodal Seepage will be defined.
- Seepage Analysis > Boundary > Nodal Head
- 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





 Seepage Analysis > Boundary > Nodal Head

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



GTS N

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

#### Procedure

\* Review Boundary will be defined.

 Seepage Analysis > Boundary > Review

2 Select Target Edge(s)

#### **3** Select edges as shown

**O**Boundary Set: Review

Seepage/Consolidation Analysis	Dynamic Analysis	Analysis	Result	Tools
e Set	Set Define Set	📳 Chan	ge Property	🚡 Nodal Head
late Stage 栏 Volume Data Export	💼 Constraint	Revie	W (1)	🔷 Nodal Flux
Set	🖽 Constraint Equa	tion <u><del>7 =</del> Wate</u>	er Level	🛥 Surface Flux
Construction Stage			B	oundary



## 04 Define Boundary Condition (Ground)

Boundary

#### Procedure Static/Slope Analysis Seepage/Consolidation Analysis Dynamic Analysis Analysis Result 🛱 Stage Set ) 🥸 Define Set Change Property 1) Static / Slope Analysis > Simulate Stage 🛛 🎰 Constraint Slip circular surface \_\_\_\_∓¥ Water Level Boundary > Constraint > Auto Define Stage Wizard Auto Set 🖽 Constraint Equation 👑 Slip polygonal surface Contact Boundary Contact Construction Stage 2) Boundary Set Name : Ground X Constraint Advanced Auto Basic Constraint-1 Name Select Object(s) Consider All Mesh Sets Boundary Set Ground Boundary OK Cancel Apply

## 05 Define Boundary Condition (SAM)

#### Procedure

- Static / Slope Analysis > Boundary > Slip circular surface
- 2 Create 8 X 8 grid on left side of dam similar to LEM as shown.
- 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)

#### 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

Static/Slope Analy	/sis Seepage/	Consolidation Analys	is Dynamic Analysis	Analysis	Result	
Define Contact	Stage Set Simulate Stage Auto Set	Set Define Set	Change Property	ce <u>∓</u> ¥ Wat face	ter Level	
Contact Cons	struction Stage		Boundary			
Slip Circular Surface Slip Circular Slip Cir	lip Polygonal Surface	Unit: m				
Reference Point Reference Point Reference Point Num. of Centers Radius Range	X1      37.19239      Reference        X2      36.30659      Reference        X3      116.0284      Reference        X0      10      Num. of C	Point Y1 77.84565 Point Y2 32.22704 Point Y3 32.66994 enters(Y) 10				
Method using Ta	ngent Line of Circle Radius Tangent line Def	ined				******
Up X Down X -16	-2.5 Y 30 X 10	1.192) Y -4.7371£				
Number of Radius	s Increment	10				
O Method using Ler	ngth and Range of Radius					
Length of Initial C	Iircular Radius	0				
Increment for Cir Number of Incren	cle Radius nents for Circle Radius	3				
Boundary Set sam rig	nt   ~	4				
u 🖅	OK	Cancel Apply				0.2

# 06 Load Condition (Self Weight)

#### Procedure

 Static / Slope Analysis > Load > Self Weight

#### 2 Load Set Name : S/W





## 07 Define Construction Stage (Create Stage Set)

#### Procedure

- \* 6 Construction stage will be defined for this project.
- Static / Slope Analysis > Construction Stage > Stage Set
- Stage Type > Stress Seepage Slope
  - Select Add
- **3** Select Created Stage Set
- **4** Select Define CS...



Close

#### Procedure

- 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

Х Define Construction Stage ~ ... Construction Stage Set Name semi coupled dam ~ Stage ID 1: Initial Seepage 25m Move to Previous Move to Next New Insert Delete Stage Name | Initial Seepage 25m Analysis Control. Stage Type Steady-State Set Data Deactivated Data 🖃 💼 Mesh Mesh fh Mesh Soundary Condition Default Mesh Set core fill-1 subsoil Soundary Condition 🥩 25 m Boundary Condition 🥵 25 m 😔 review Ş 5 m ş ground boundary 2 s rapid s review sc. sam left rapid sam right sam right full Contact Drag & Drop Show Data All  $\sim$ Sort By Name 3 Close

Weight

**Select Save** 

Select New

3

4

5



### Procedure

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



#### Procedure

- 1 Stage 4 Type : Stress
- 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



#### Procedure

- Stage 5 Type : Seepage Steady State
- Activated Data : Seepage boundary 5m Deactivate Data: Seepage boundary rapid

3) Select Save

4 Select New

Define Construction Stage  $\times$ ~ ... Construction Stage Set Name semi coupled dam ~ + Stage ID 5: Steady 5 m level Move to Previous Move to Next Insert Delete Stage Name Steady 5 m level Analysis Control.. Stage Type Steady-State Set Data activated pata 🖃 🏙 Mesh 🏥 Mesh Mesh Default Mesh Set Se Boundary Condition Boundary Condition <u> </u>5 m 鬡 rapid core fill 🔀 Contact 🔀 Contact fill-1 subsoil Boundary Condition 퉻 25 m 遂 5 m 🥸 ground boundary 😻 rapid review sam left sam right Z Contact Drag & Drop Sort By Show Data All  $\sim$ Name Close

3

(4)

and SRM



# 09 Analysis Case

#### Procedure

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



Cancel

OK

## **10** Perform Analysis and Check Results

### Procedure

1 Analysis > Analysis > Perform

2 Select OK





## **1** Post Processing (Pre mode vs Post mode)

#### Procedure

- After analysis, model view will be converted to Post-Mode automatically, can back to Pre-Mode to change model information.
- <sup>(2)</sup>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



## Post Processing (Post mode)



## **11** Post Processing (Post mode)





GTS N





(2)Select Stage Full Dam and click MIN

(1)

(4)

SAM.

- 3 Select Stage Rapid FOS and click MIN
  - Select Stage for Steady 5m FOS and click MIN

# Thank you