

GTS NX

Different hazard conditions in slope stability

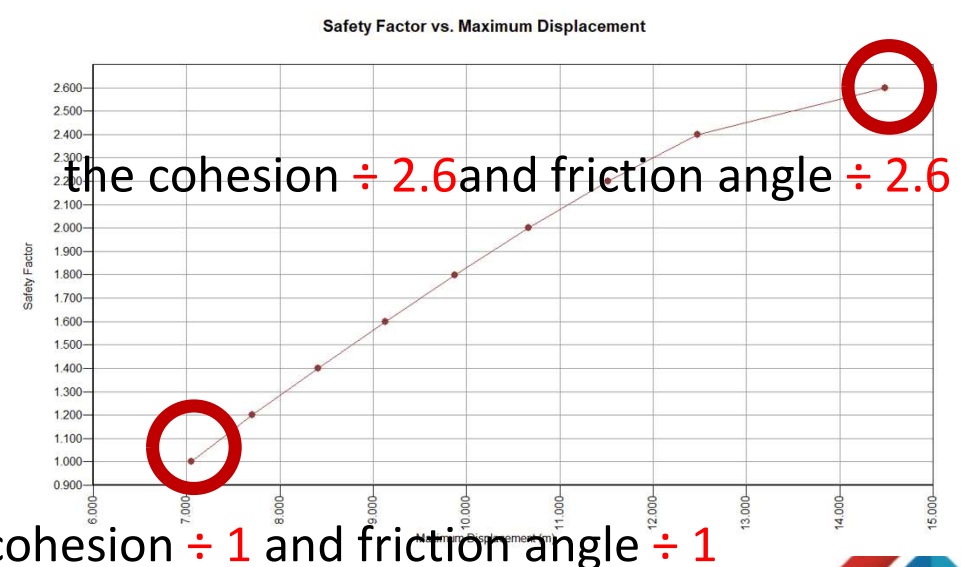
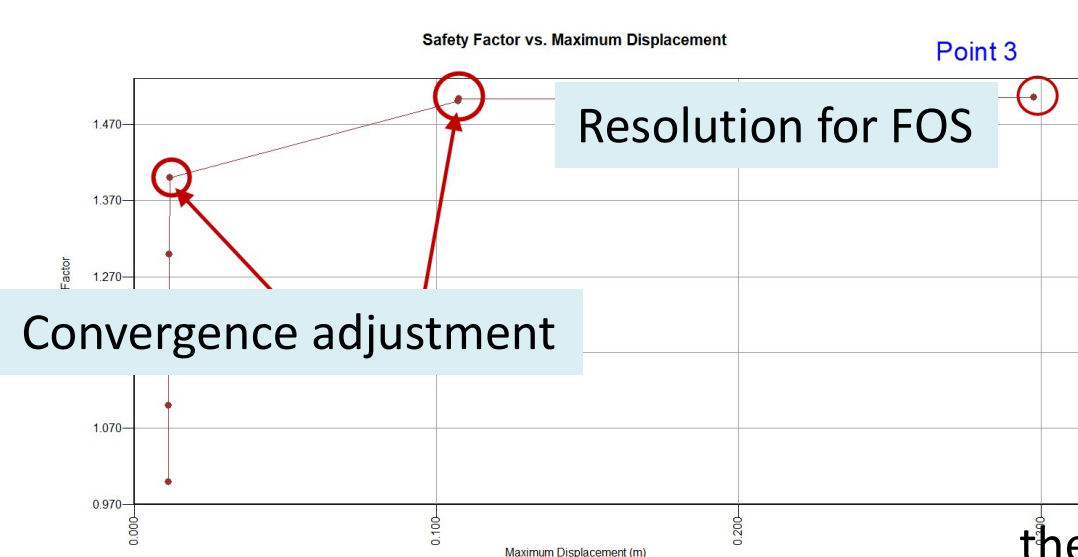
MIDAS Taiwan

Note: The parameters in the example use assumed conditions.

Strength Reduction Method (SRM)

In GTS NX, slope stability assessment uses the Strength Reduction Method (SRM), which determines the failure point by progressively reducing the soil's shear strength parameters. In this method, the soil's cohesion (c) and internal friction angle (ϕ) are systematically reduced using a reduction factor F ; this reduction factor value is the safety factor (FoS).

The slope stability calculation depends on the soil strength, which in turn depends on the soil's cohesion and internal friction angle, as well as instability factors such as soil weight, water pressure, and external loads. Users can adjust the convergence criteria (load/displacement/work) in the analysis definition according to their preferences.



Reference

Pseudo-static seismic

Pseudo-static seismic method is a simplified way to represent earthquake effects by replacing dynamic ground shaking with constant equivalent static forces

→ Applying inertial body forces proportional to gravity instead of time-varying acceleration

$$F_h = k_h W, \quad F_v = k_v W$$

Where:

- k_h = horizontal seismic coefficient
- k_v = vertical seismic coefficient

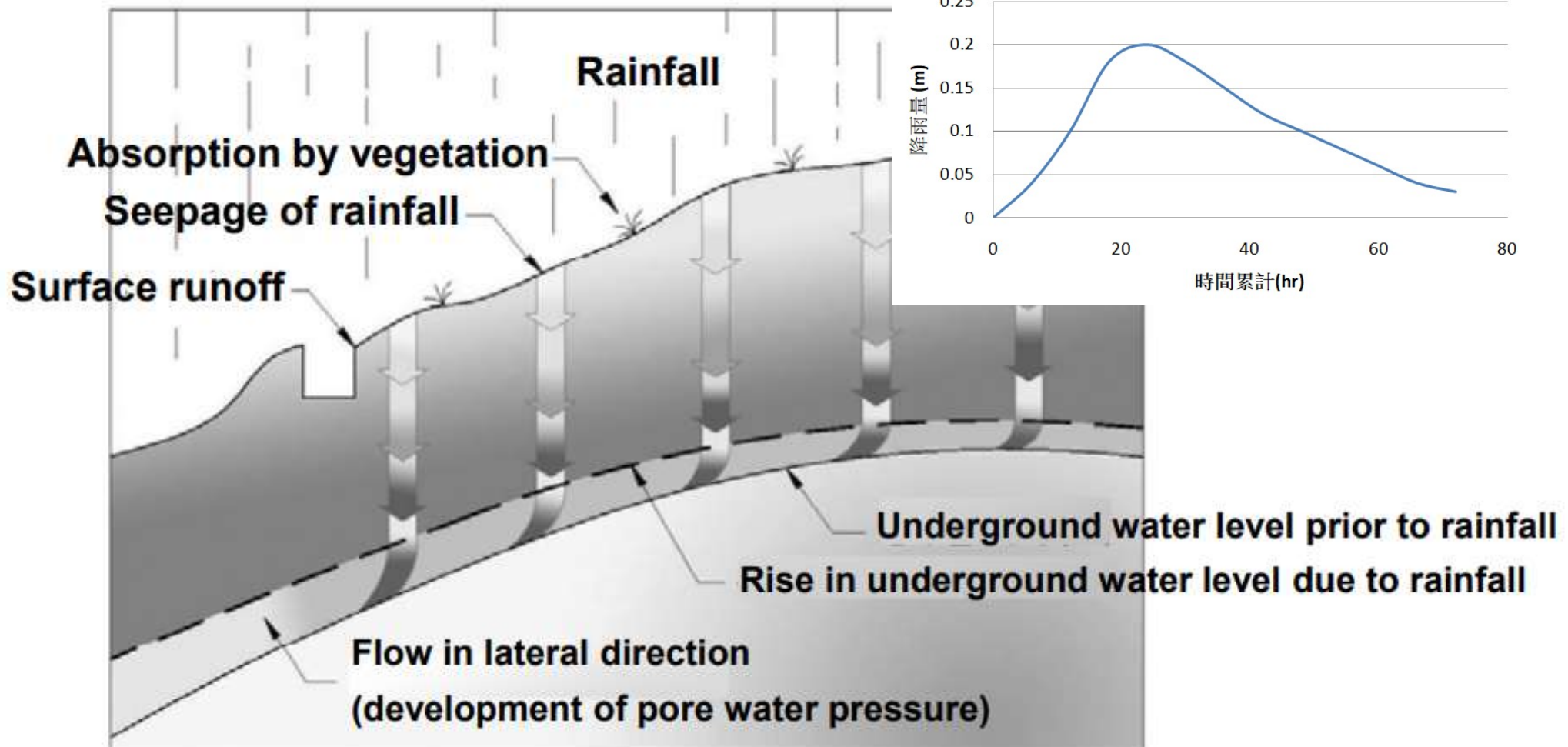
These forces are applied **uniformly to the entire soil mass.**

Reference

GTS NX/FEA NX/Soilworks Manual

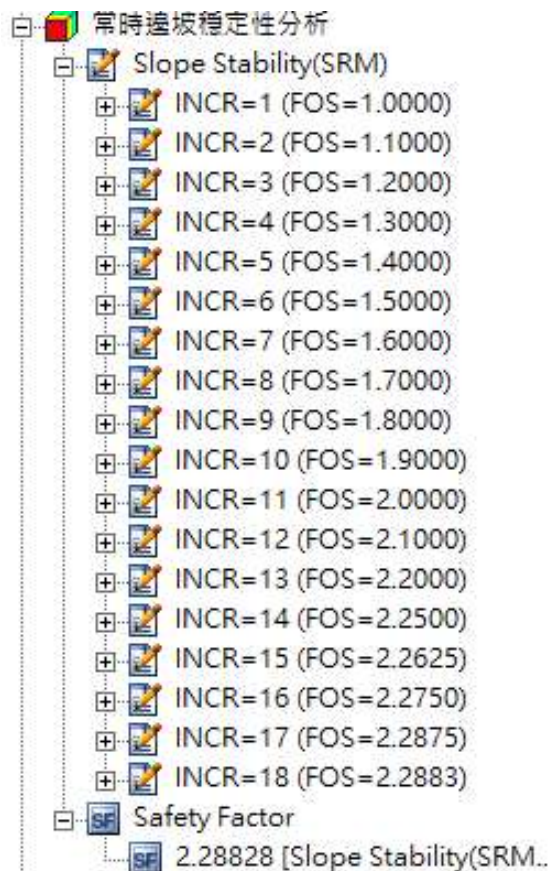
Seepage through Unsaturated Slope

Seepage induced by rainfall



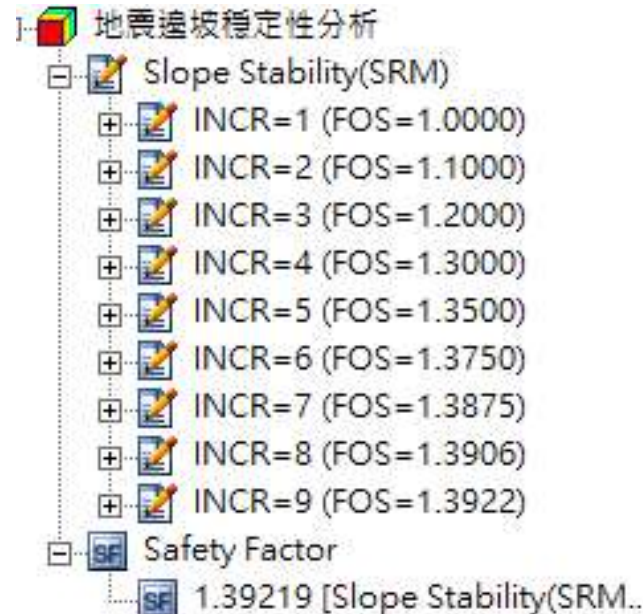
Comparison for different cases

Normal case



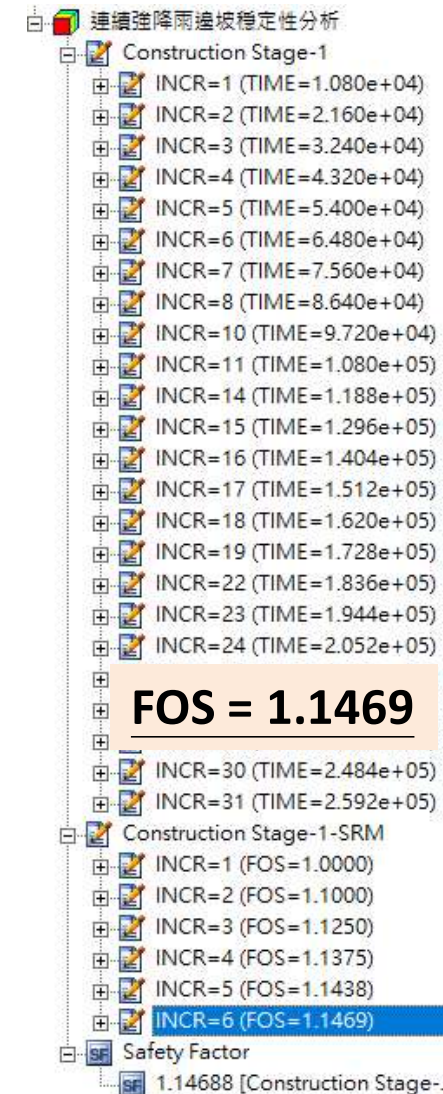
FOS = 2.2883

Pseudo-static seismic



FOS = 1.3922

Heavy rainfall case



FOS = 1.1469

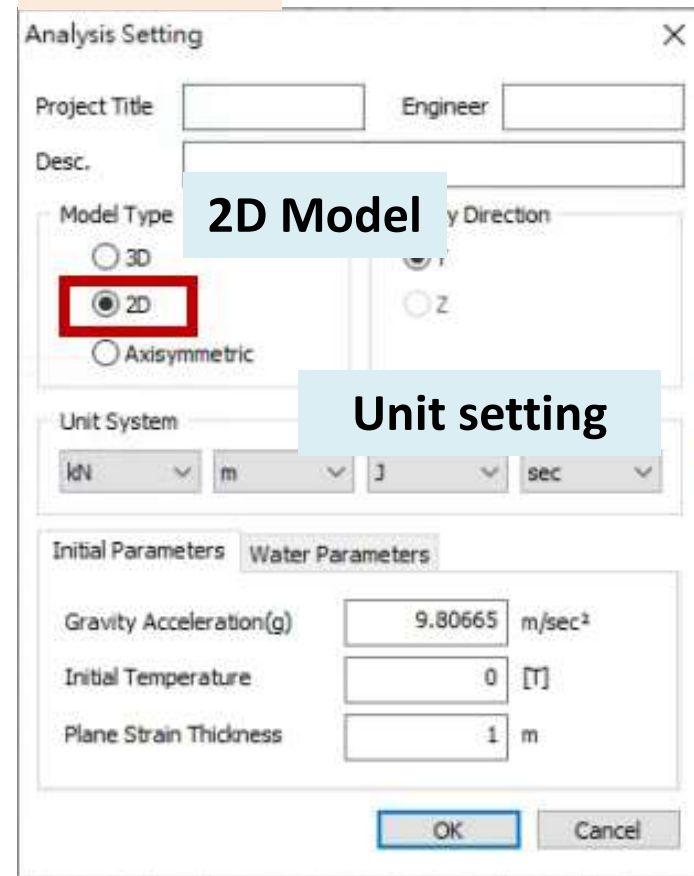
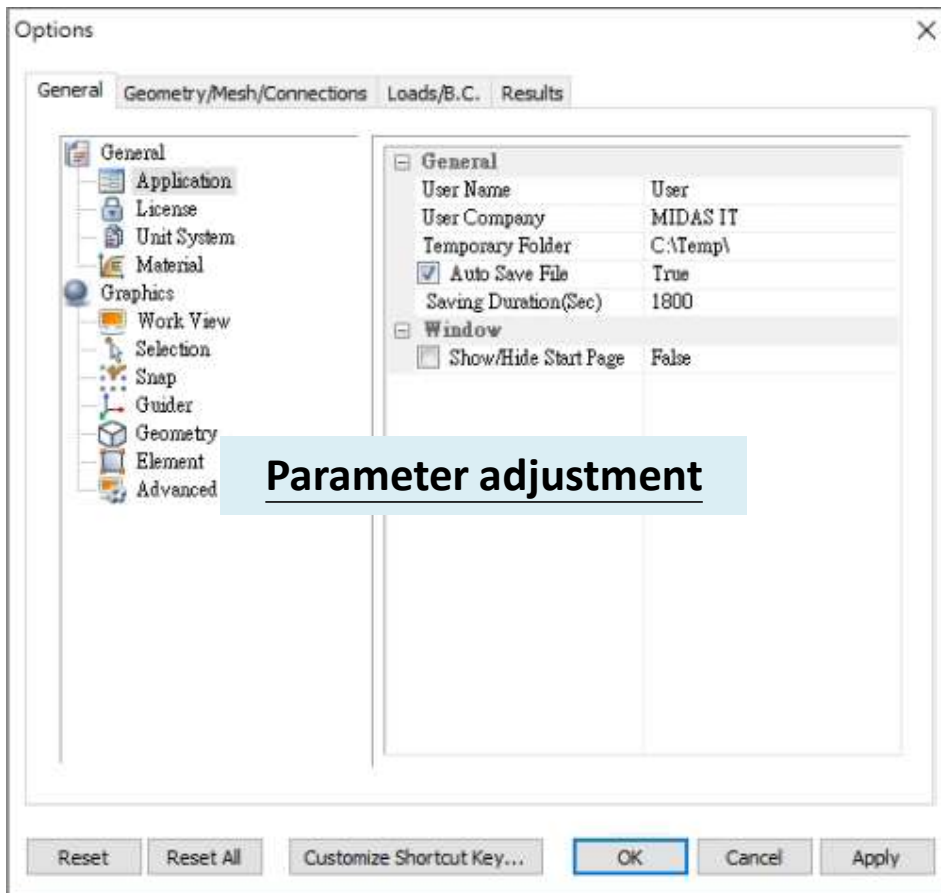


Part1. Normal condition

Import

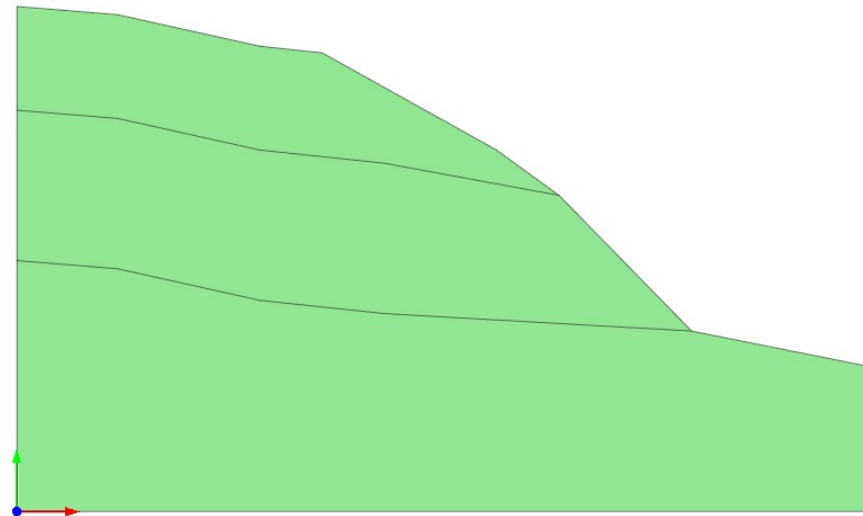
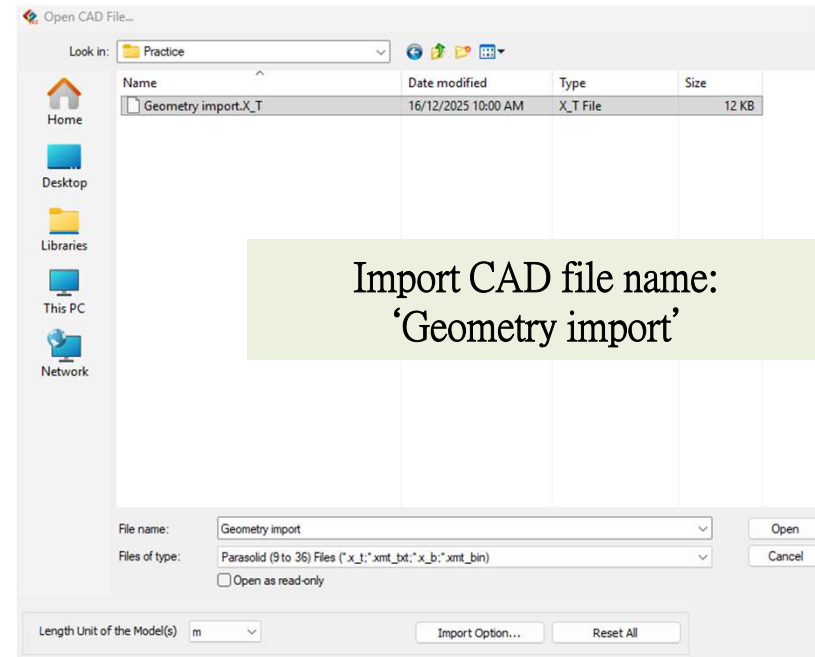


New file

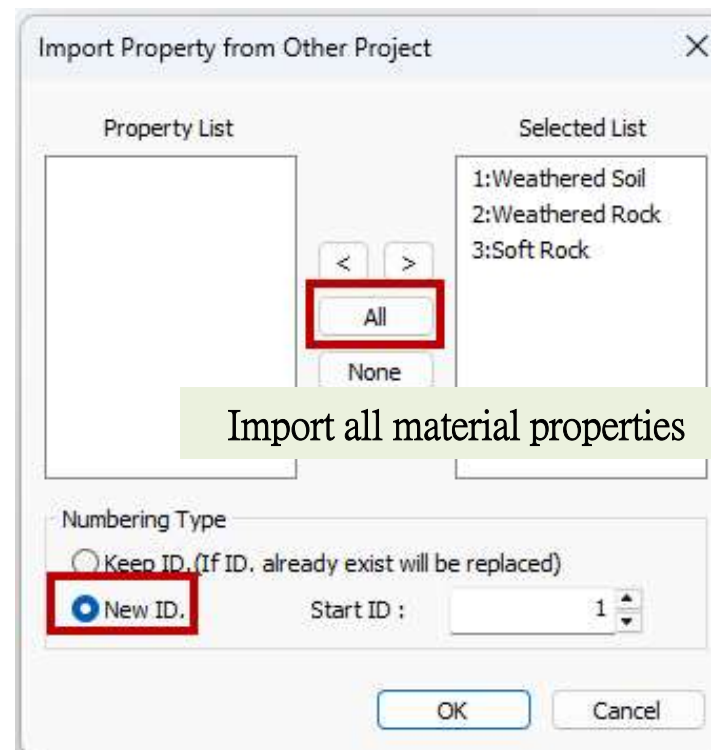
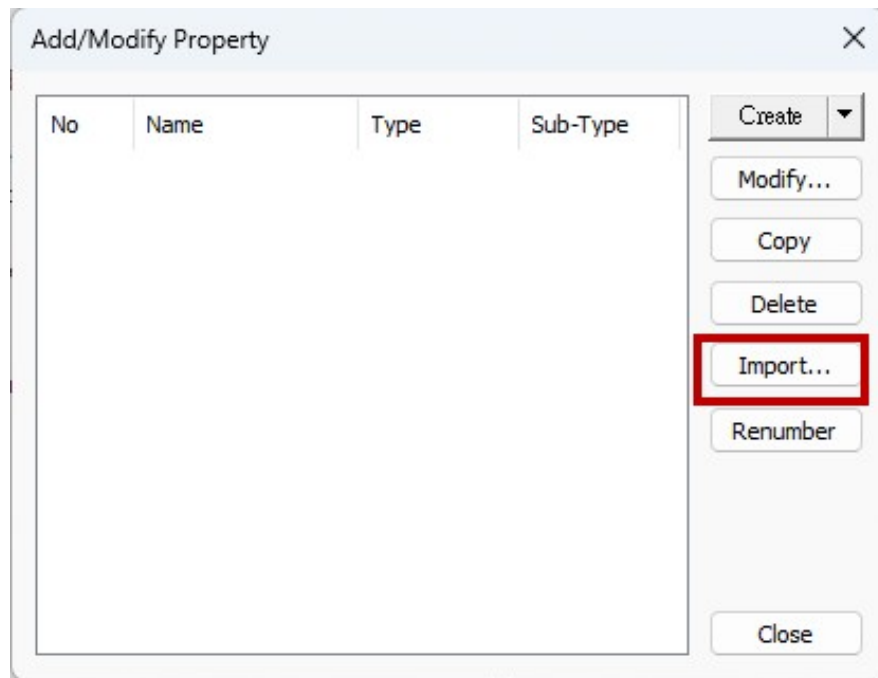
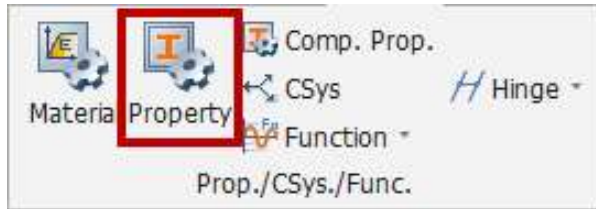


Unit setting as:
KN/m/J/sec

2D Model Import



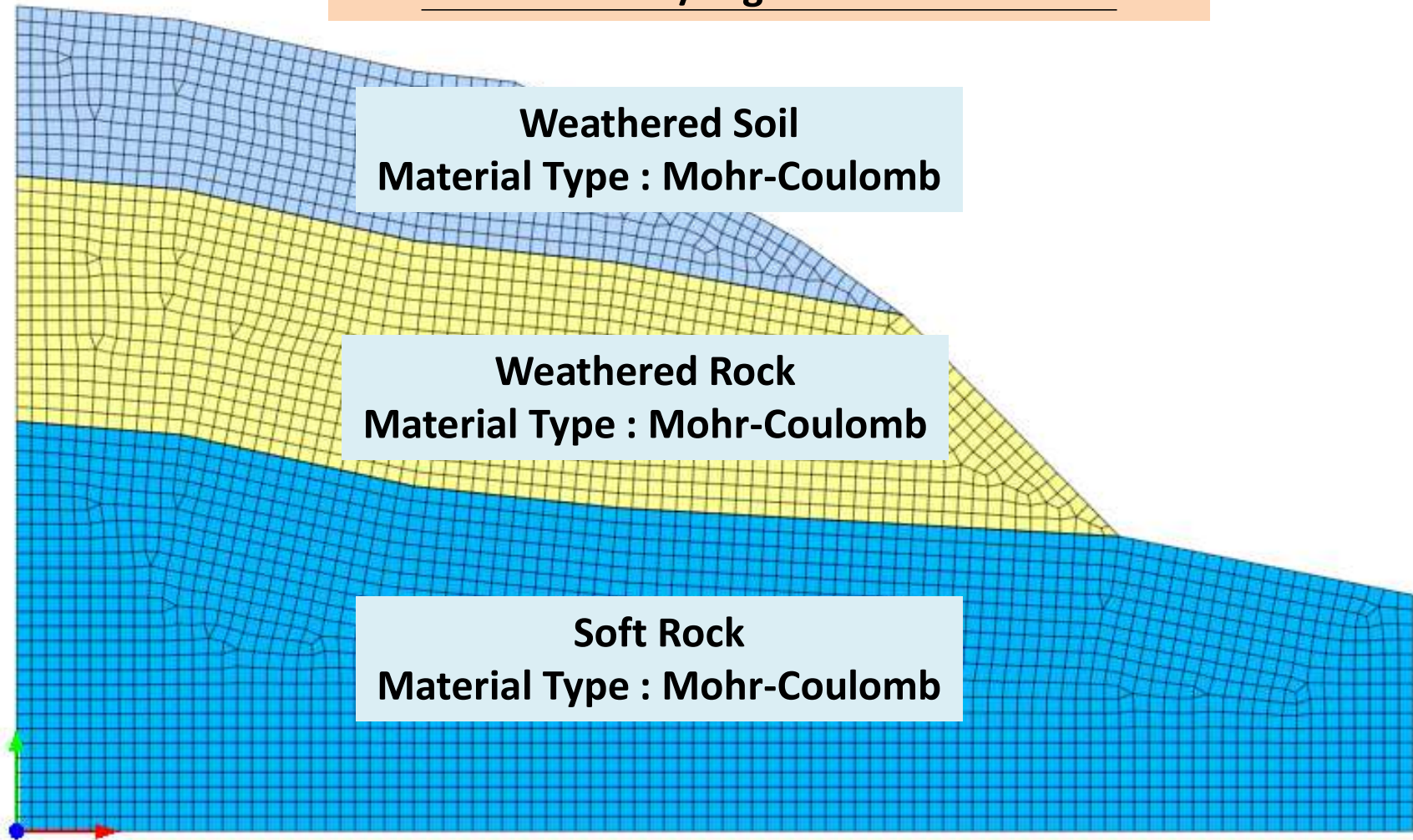
Material & Property



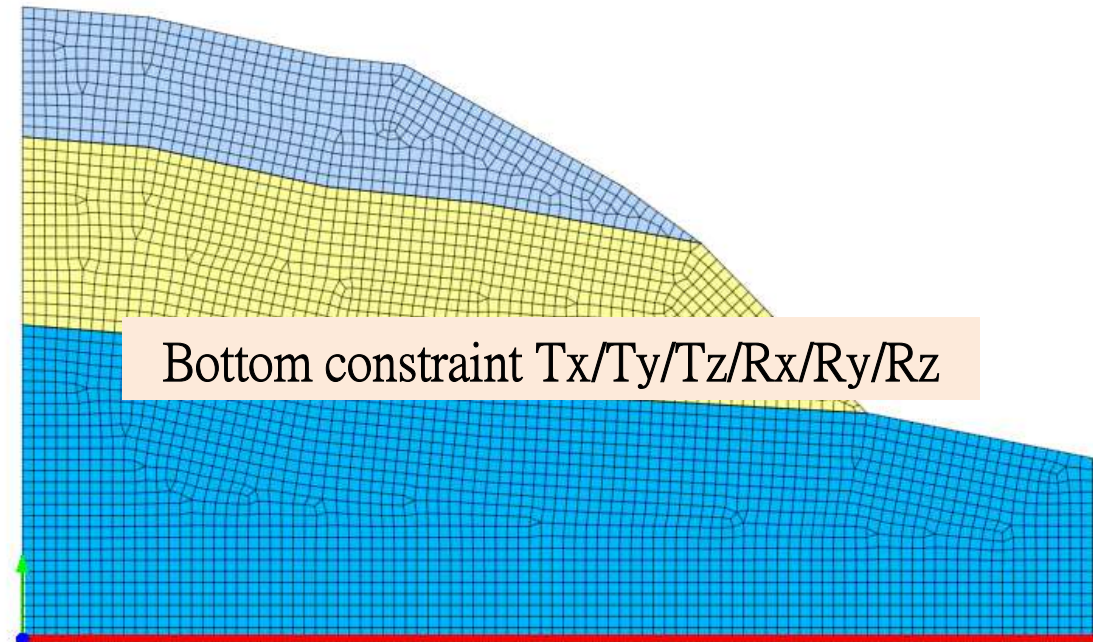
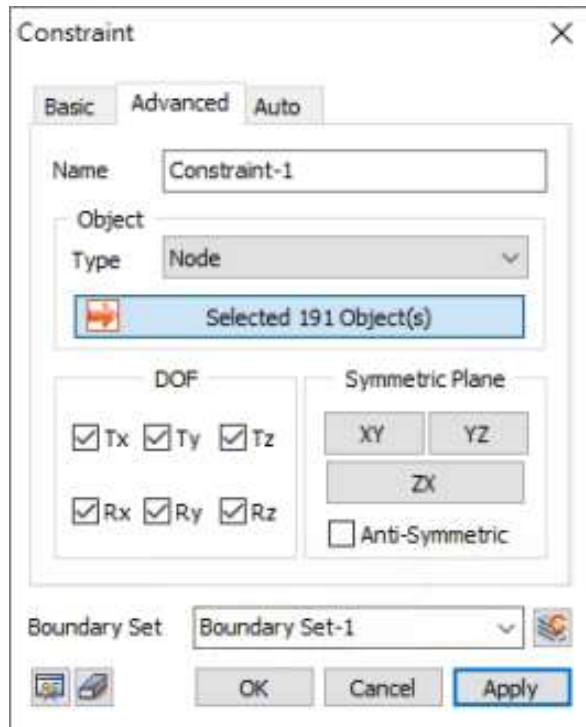
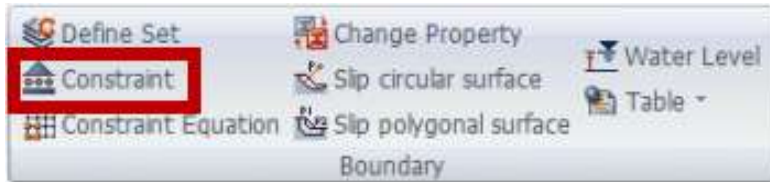
Import all material properties

2D Mesh Generation

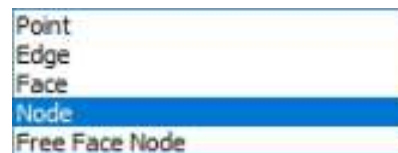
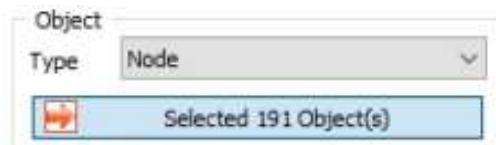
Mesh size: 0.5/ higher-order elements



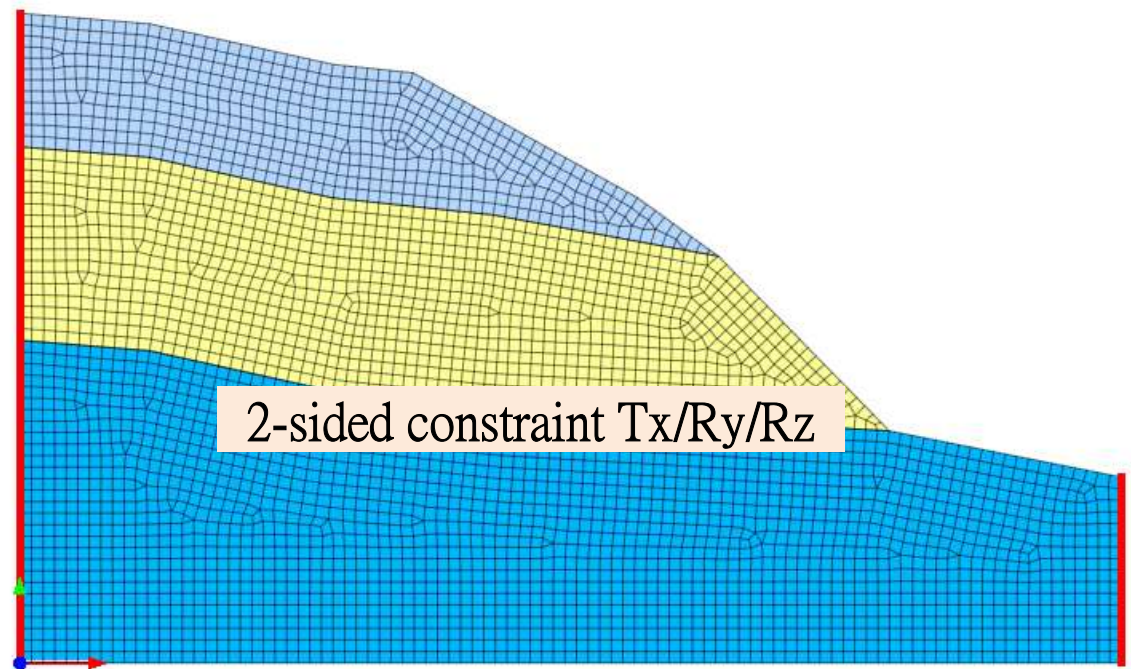
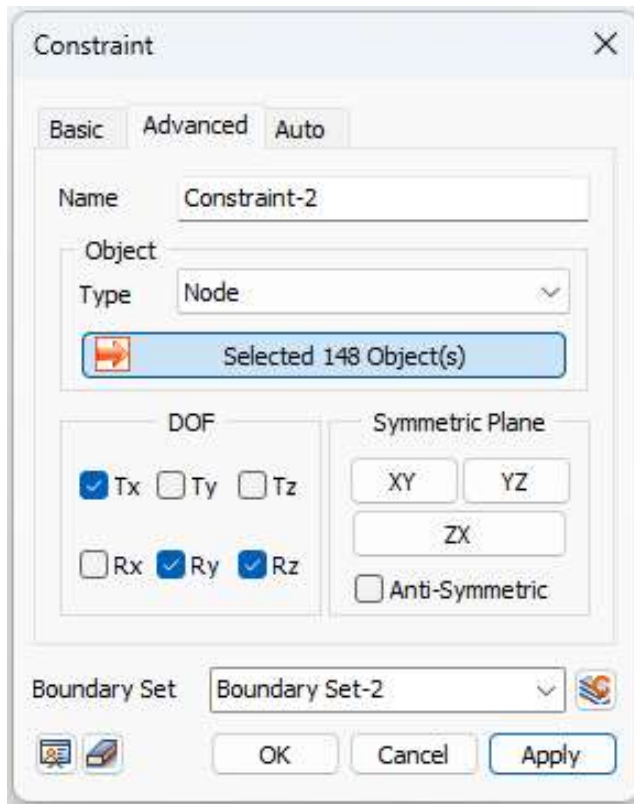
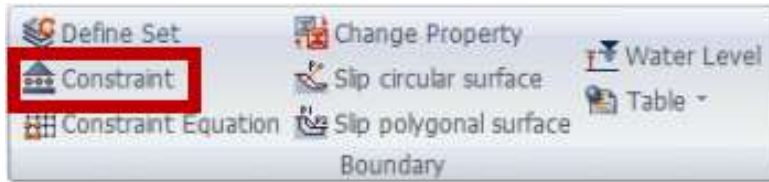
Bottom Boundary



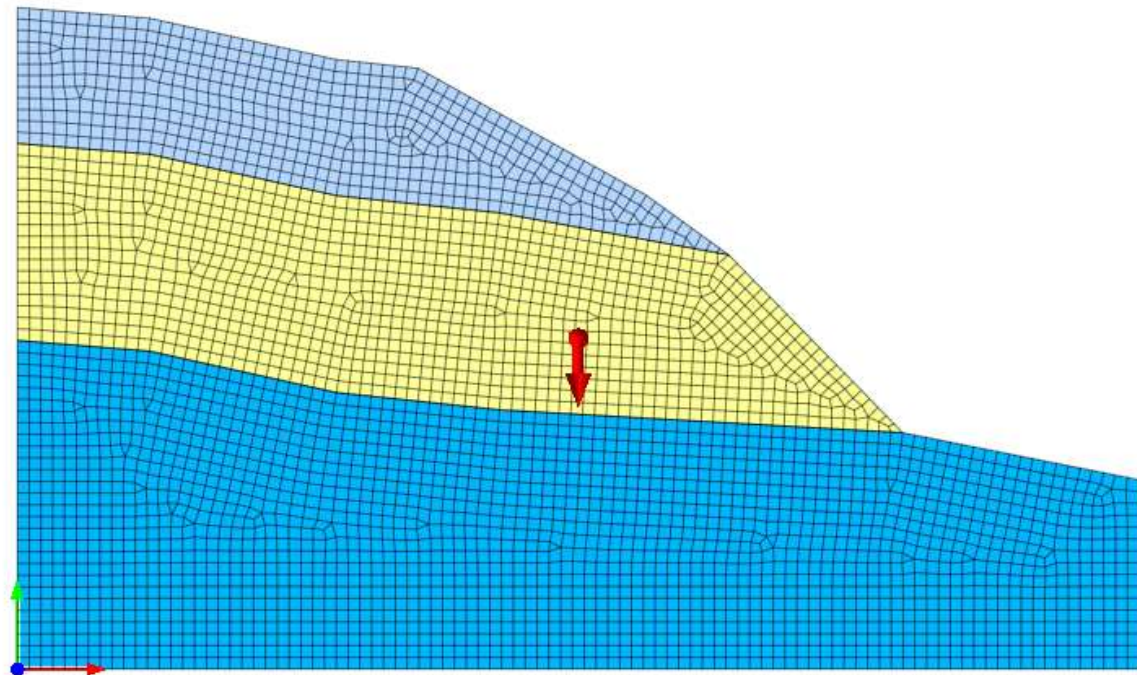
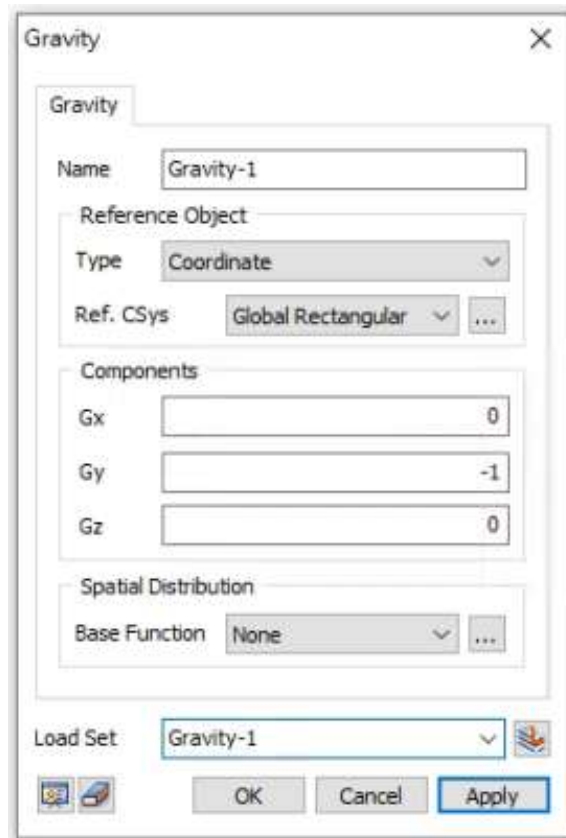
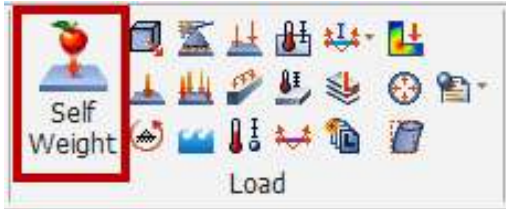
The geometric features or nodes can be applied to the boundary



2-Sided Boundary



Self-Weight

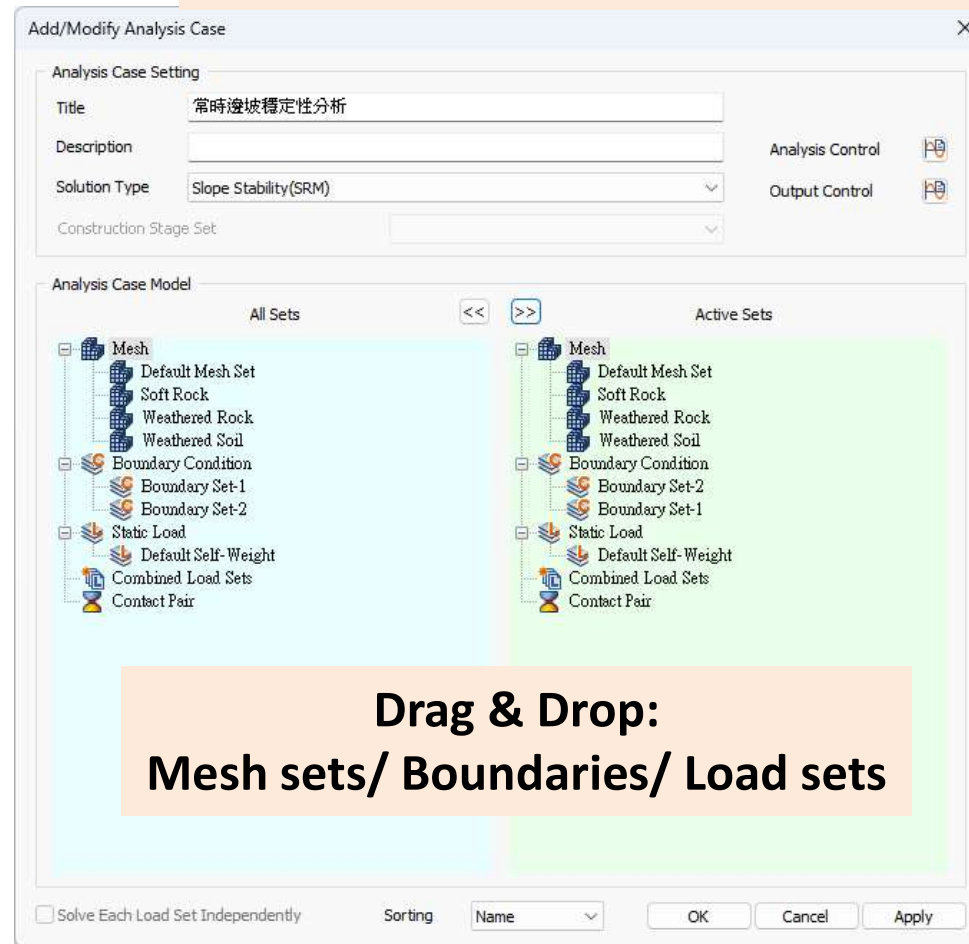


Analysis-1

(Slope stability (SRM) – Normal case)



Simulation type: Slope Stability(SRM)



Analysis-2

(Slope stability (SRM) – Normal case)

Convergence settings

General Slope Stability(SRM)

Geometry Nonlinearity

☐ Consider Geometric Nonlinear Effects

Nonlinear parameters

Maximum Number of Trials 50

Maximum Number of Iterations 50

Stiffness Update Scheme Full Newton-Raphson

Intermediate Output Request **Every Iteration**

Convergence Criteria / E

☐ Displacement(U)

☒ Load(P) 0.01

☐ Work(W) 0.0001

Safety Factor

Initial Safety Factor **1**

Increment of Safety Factor **0.1**

Resolution of Safety Factor **0.01**

☐ Safety Factor Function

Advanced Nonlinear Parameters...

OK Cancel

Output setup

Output=>Strain

Shear strain indicates the failure arc

Output Type Output Option

☒ Write Results of All Active Mesh Sets

Nodal Results

☒ Displacement Mesh Set...

☒ Applied Load Mesh Set...

☒ Reaction Force Mesh Set...

☐ Grid Point Force Mesh Set...

☐ Contact Mesh Set...

Element Results

☒ Force Mesh Set...

☒ Stress Mesh Set...

☒ Strain Mesh Set...

☒ **Status** Mesh Set...

☐ Damaged Index Mesh Set...

☐ Ductility Mesh Set...

Output Option

☒ Binary ☐ Binary and Text

Element Output Location

☒ Element Corner Results

☐ Shell Mid-Plane Results

☒ Composite Shell Mid-Plane Results

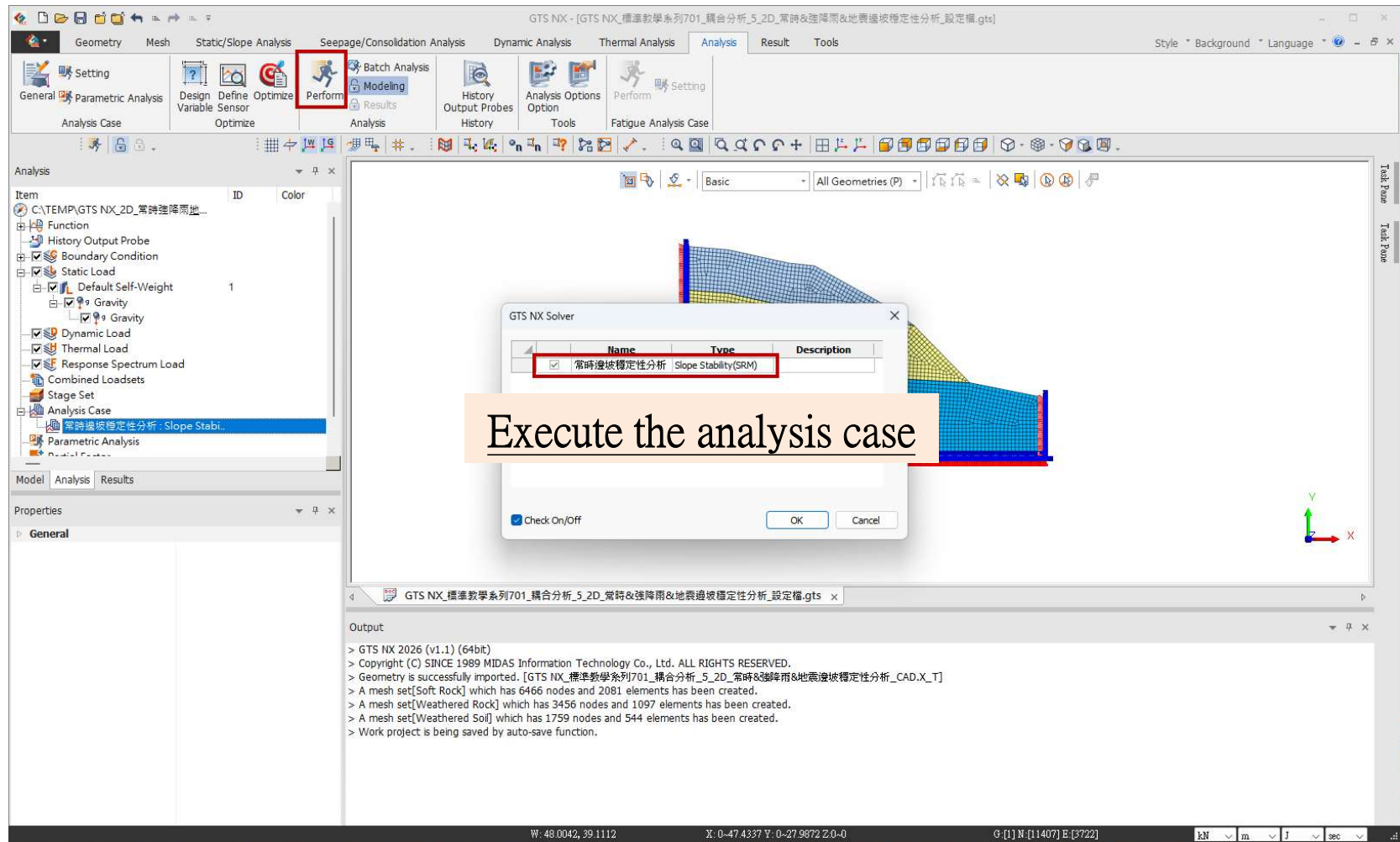
Number of Beam Output Segments 4

OK Cancel

SRM convergence adjustment

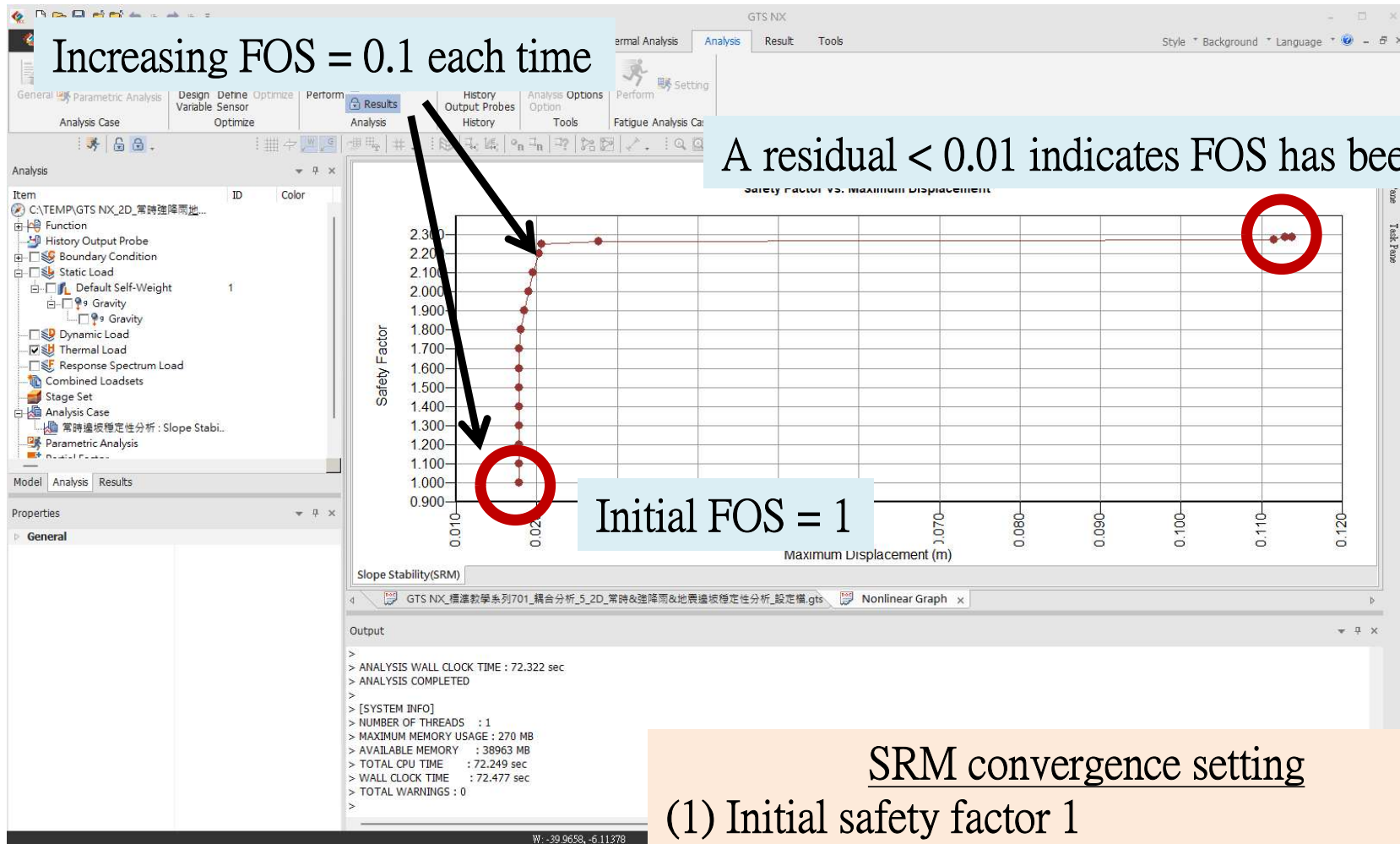
- (1) Initial safety factor 1
- (2) FOS increment by 0.1 each time
- (3) Residual < 0.01, minimum FOS reached

Calculation



Safety factor indication

(Convergence criteria)



SRM convergence setting

- (1) Initial safety factor 1
- (2) FOS increment by 0.1 each time
- (3) Residual < 0.01, minimum FOS reached

Results

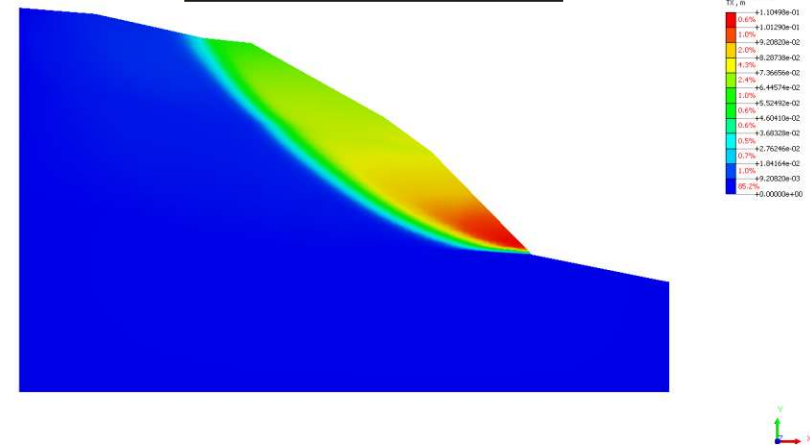
(Normal case)

Failure surface indicated by horizontal displacement
& maximum shear strain

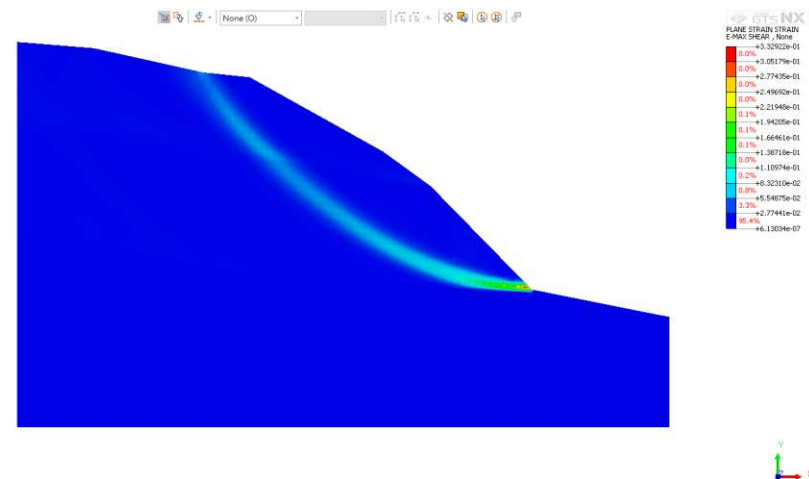


SRM for safety factor calculation

Tx Translation(m)



Maximum Shear Strain

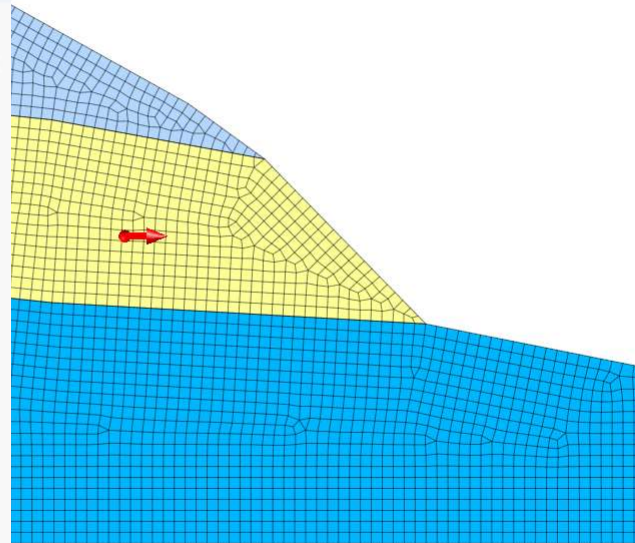
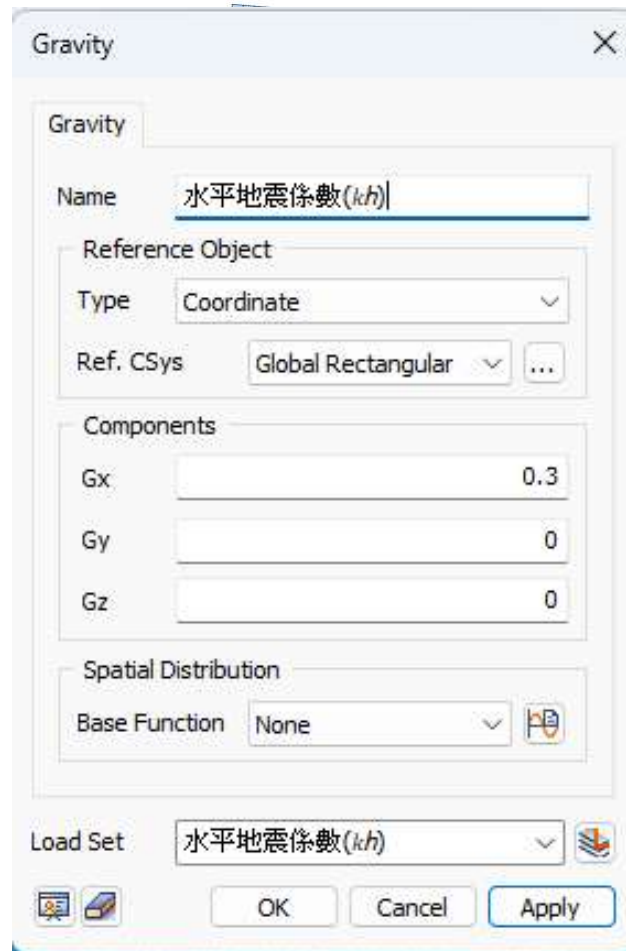
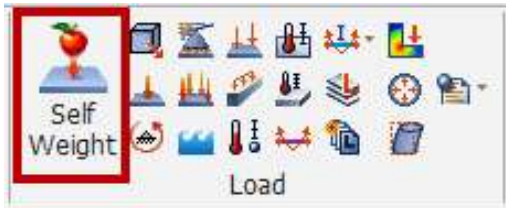


[DATA] 重力連動安定性分析, Slope Stability(SRM), INCR=18 (FOS=2.2883), [UNIT] MN, m

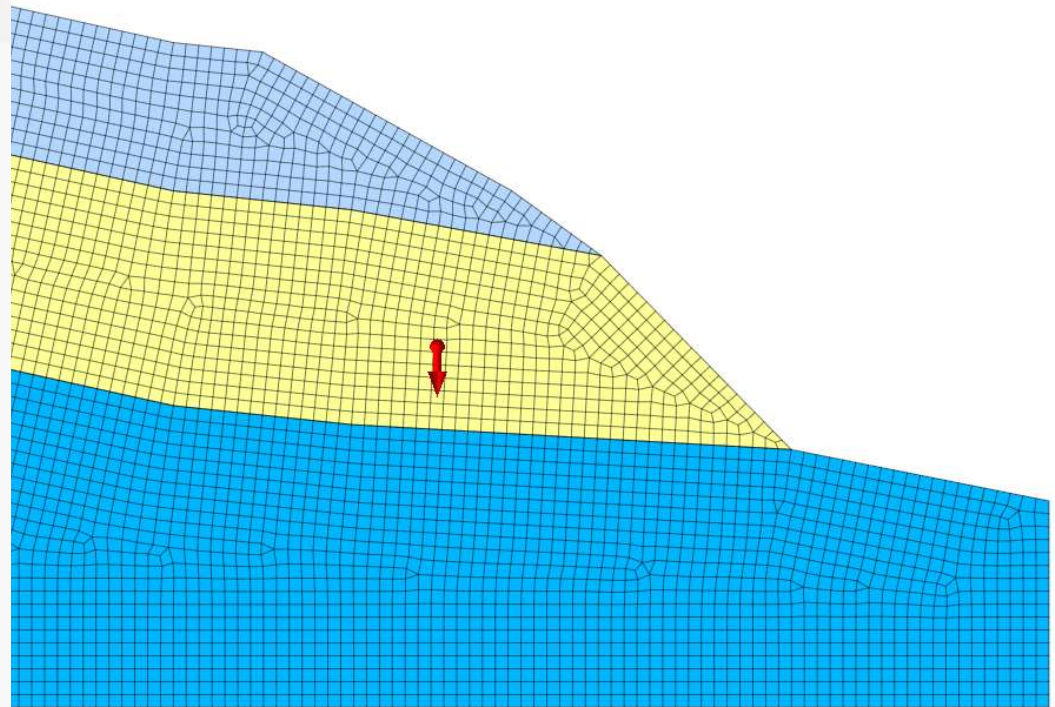
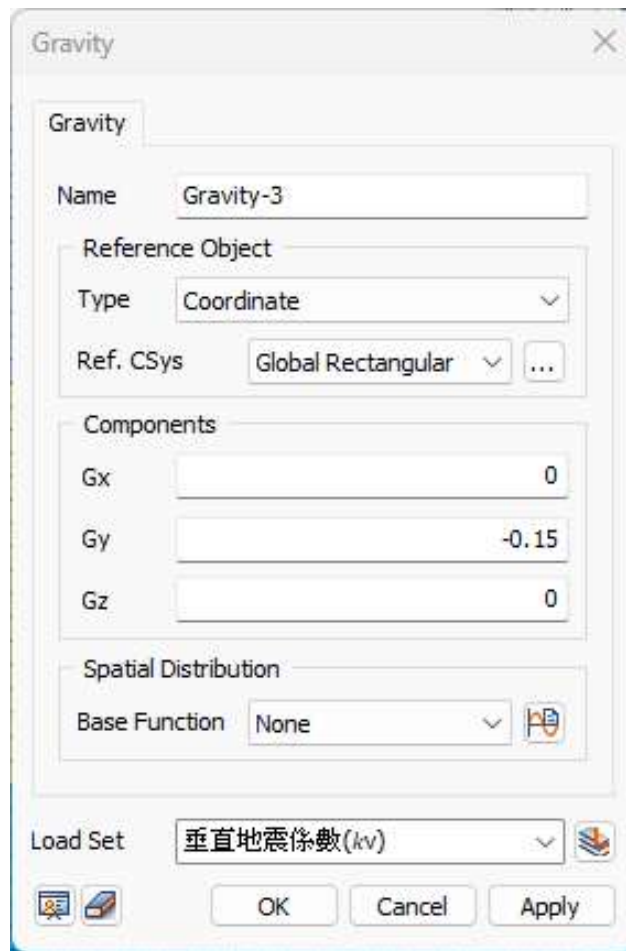
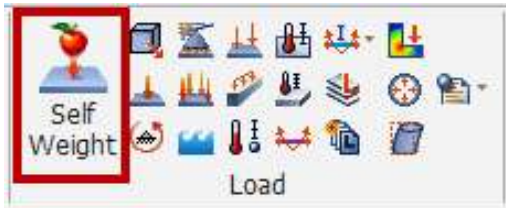


Part2. Pseudo-static seismic case

Horizontal seismic coefficient (k_h)

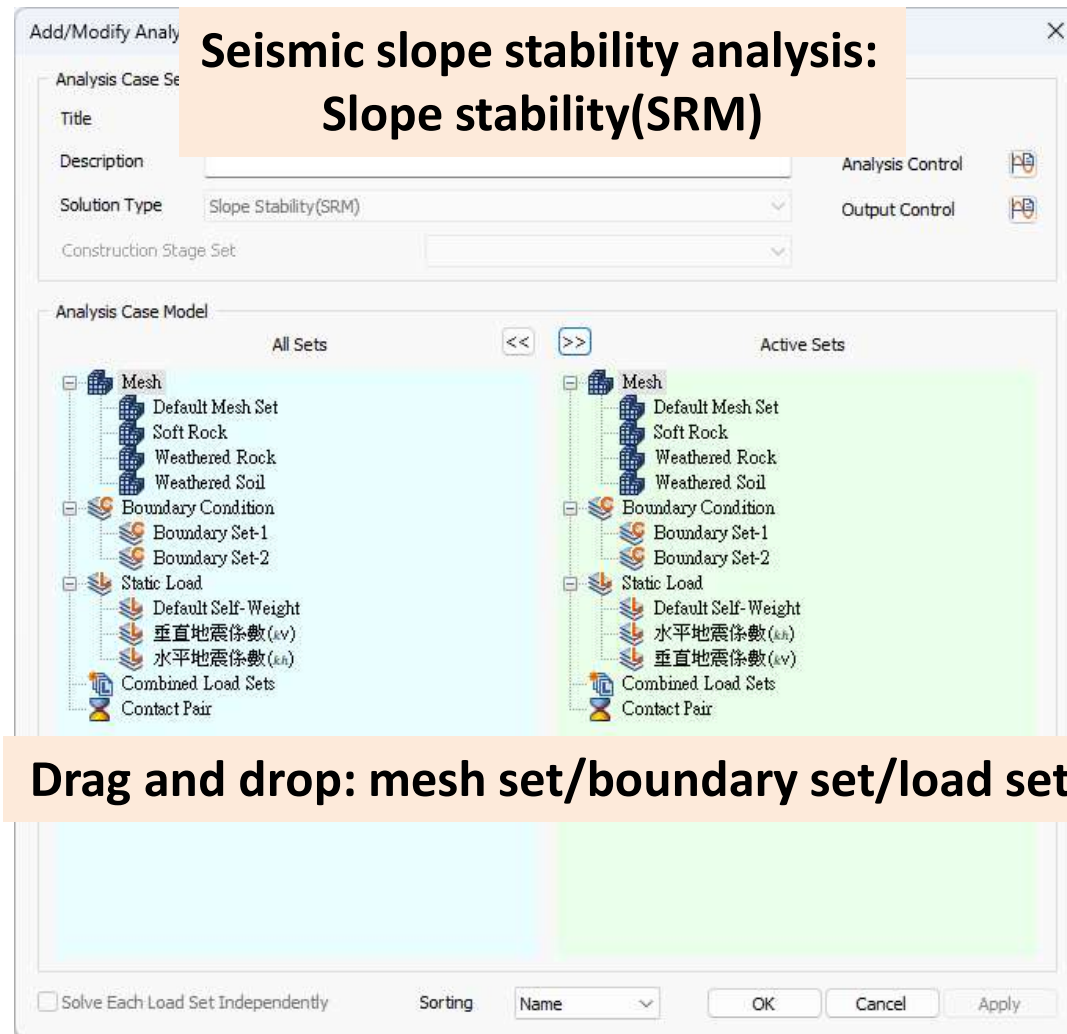


Vertical seismic coefficient (k_v)



Analysis-1

(Pseudo-static seismic case)



Analysis-2

(Pseudo-static seismic case)

Convergence settings

General Slope Stability(SRM)

Geometry Nonlinearity

☐ Consider Geometric Nonlinear Effects

Nonlinear parameters

Maximum Number of Trials 50

Maximum Number of Iterations 50

Stiffness Update Scheme Full Newton-Raphson

Intermediate Output Request **Every Iteration**

Convergence Criteria / E

☐ Displacement(U)

☒ Load(P) 0.01

☐ Work(W) 0.0001

Safety Factor

Initial Safety Factor **1**

Increment of Safety Factor **0.1**

Resolution of Safety Factor **0.01**

☐ Safety Factor Function

Advanced Nonlinear Parameters...

OK Cancel

Output setup

Output=>Strain

Shear strain indicates the failure arc

Output Type Output Option

☒ Write Results of All Active Mesh Sets

Nodal Results

☒ Displacement Mesh Set...

☒ Applied Load Mesh Set...

☒ Reaction Force Mesh Set...

☐ Grid Point Force Mesh Set...

☐ Contact Mesh Set...

Element Results

☒ Force Mesh Set...

☒ Stress Mesh Set...

☒ Strain Mesh Set...

☒ **Status** Mesh Set...

☐ Damaged Index Mesh Set...

☐ Ductility Mesh Set...

Output Option

☒ Binary ☐ Binary and Text

Element Output Location

☒ Element Corner Results

☐ Shell Mid-Plane Results

☒ Composite Shell Mid-Plane Results

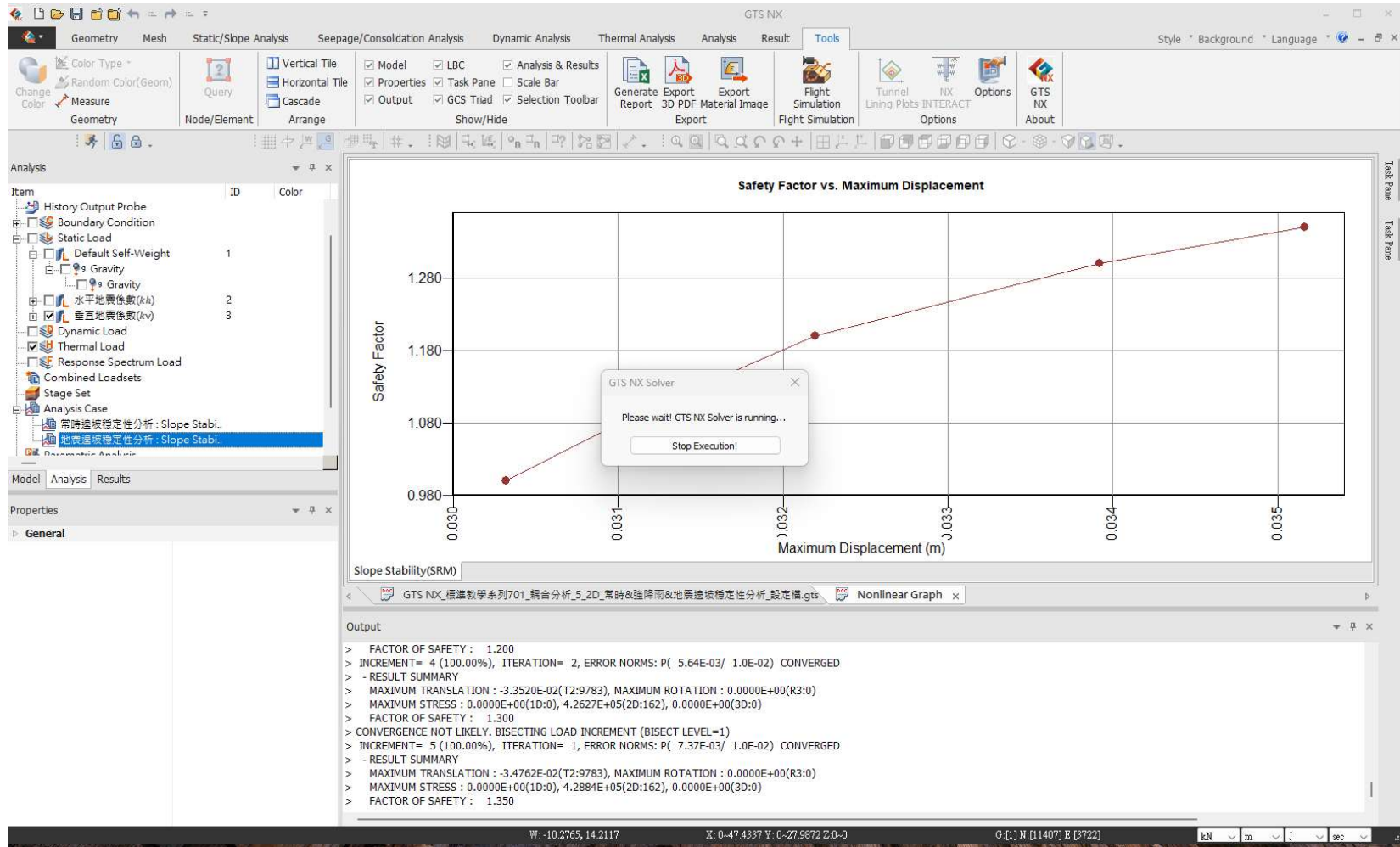
Number of Beam Output Segments 4

OK Cancel

SRM convergence adjustment

- (1) Initial safety factor 1
- (2) FOS increment by 0.1 each time
- (3) Residual < 0.01, minimum FOS reached

Calculation



Results

(Pseudo-static seismic case)

Failure surface indicated by horizontal displacement
& maximum shear strain

Pseudo-static seismic by k_h & k_v , FOS = 1.3922

地震遠坡穩定性分析

Slope Stability(SRM)

INCR=1 (FOS=1.0000)

INCR=2 (FOS=1.1000)

INCR=3 (FOS=1.2000)

INCR=4 (FOS=1.3000)

INCR=5 (FOS=1.3500)

INCR=6 (FOS=1.3750)

INCR=7 (FOS=1.3875)

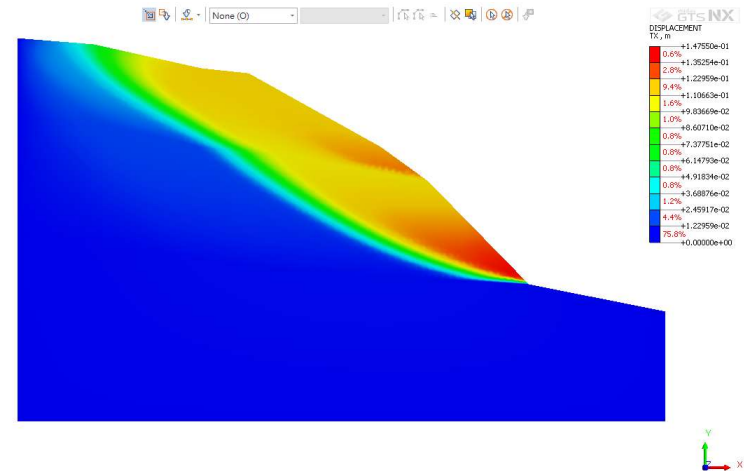
INCR=8 (FOS=1.3906)

INCR=9 (FOS=1.3922)

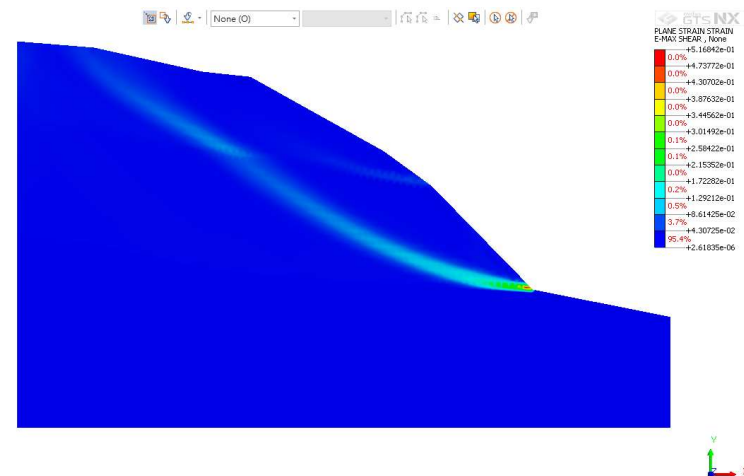
Safety Factor

1.39219 [Slope Stability(SRM..

Tx Translation(m)



Maximum Shear Strain



SRM for safety factor calculation



Part3. Heavy rainfall case

Porous Material-1

(weathered Soil)

Weathered Soil

Model Type: Mohr-Coulomb

Unit Weight(Saturated): 19.5 kN/m³

Initial Void Ratio(eo): 0.5

☒ Unsaturated Property

Drainage Parameters: Drained

Undrained Poisson's Ratio: 0.495

Skempton's B Coefficient: 0.97383435

Seepage & Consolidation Parameters

Permeability Coefficients: kx, ky, kz (0.001 m/sec)

Void Ratio Dependency of Permeability(ck): 0.5

Specific Storativity(Ss): 0.001 1/m

Add/Modify Unsaturated Function

Name: Type:

Buttons: Add, Modify, Delete, Database, Close

Material database in GTS NX

Unsaturated Function Database

Database: Van Genuchten data(Carsel and Parrish, 1988)

No	Soil	Ks (m/sec)	Os(m ² /m ³)	Or(m ² /m ³)	a (1/m)	n	Select
1	Sand	8.25e-05	0.43	0.045	14.5	2.68	<input type="checkbox"/>
2	Loamy Sand	4.05324e-05	0.41	0.057	12.4	2.28	<input type="checkbox"/>
3	Sandy Loam	1.72801e-05	0.41	0.065	7.5	1.89	<input type="checkbox"/>
4	Loam	2.88889e-06	0.43	0.078	3.6	1.56	<input checked="" type="checkbox"/>
5	Silt	6.34444e-07	0.46	0.034	1.6	1.37	<input type="checkbox"/>
6	Silt Loam	1.25e-06	0.45	0.067	2	1.41	<input type="checkbox"/>
7	Sandy Clay Loam	3.63889e-06	0.39	0.1	5.9	1.48	<input type="checkbox"/>
8	Clay Loam	7.22222e-07	0.41	0.095	1.9	1.31	<input type="checkbox"/>
9	Silt Clay Loam	1.94444e-07	0.43	0.089	1	1.23	<input type="checkbox"/>
10	Sandy Clay	3.33333e-07	0.38	0.1	2.7	1.23	<input type="checkbox"/>
11	Silty Clay	5.55556e-08	0.36	0.07	0.5	1.09	<input type="checkbox"/>
12	Clay	5.55556e-07	0.38	0.068	0.8	1.09	<input type="checkbox"/>

Reference - Developing Joint Probability Distributions of Soil Water Retention Characteristics ROBERT F. CARSEL and RUDOLPH S. PARRISH, 1988

Van Genuchten data (Carsel and Parrish,1988)
Loam

	Coefficient of permeability(K) (m/sec)	Specific Storativity(Ss) (1/m)
Weathered Soil	10 ⁻⁵ ~10 ⁻³	10 ⁻⁶ ~10 ⁻³

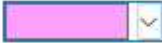
Note 1: The relevant parameters use assumed conditions.

Note 2: Unsaturated parameters are not defined in the seepage calculation process; the soil is treated as saturated.

Porous Material-2

(Weathered Rock)

Weathered Rock

ID 2 Name weathered Rock Color 

Model Type Mohr-Coulomb ☐ Structure

General Porous Non-Linear Thermal Time Dependent

Unit Weight(Saturated) 22 kN/m³

Initial Void Ratio(eo) 0.5

☒ Unsaturated Property Sandstone(Hygiene) ...

Drainage Parameters

Drained

☒ Undrained Poisson's Ratio 0.495

☐ Skempton's B Coefficient 0.97826087

Seepage & Consolidation Parameters

Permeability Coefficients

kx ky kz m/sec

0.0001 0.0001 0.0001

☐ Void Ratio Dependency of Permeability(ck) 0.5

Specific Storativity(Ss) 0.001 1/m Auto

Add/Modify Unsaturated Function

Name	Type
Silt	Individual
Sandstone(Hygiene)	Individual

Add Modify Delete Database Close

Material database in GTS NX

Unsaturated Function Database

Database Van Genuchten data(1980)

No	Soil	Ks (m/sec)	Os(m ² /m ³)	Or(m ² /m ³)	a (1/m)	n	Select
1	Sandstone(Hygiene)	1.25e-05	0.25	0.153	0.79	10.4	<input checked="" type="checkbox"/>
2	Silt Loam(Touchet)	3.52594e-05	0.469	0.19	0.5	7.09	<input type="checkbox"/>
3	Silt Loam	5.74074e-07	0.396	0.131	0.423	2.06	<input type="checkbox"/>
4	Loam(Quelph_drying)	3.65741e-06	0.52	0.218	1.15	2.03	<input type="checkbox"/>
5	Loam(Quelph_wetting)	0	0.434	0.218	2	2.76	<input type="checkbox"/>
6	Clay(Bett Netofa)	9.49074e-09	0.446	0	0.152	1.17	<input type="checkbox"/>

Reference - A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils M. TH. VAN GENUCHTEN, 1980

OK Cancel

Van Genuchten data (1980)
Sandstone (Hygiene)

	Coefficient of permeability(K) (m/sec)	Specific Storativity(Ss) (1/m)
Weathered Rock	10 ⁻⁶ ~10 ⁻⁴	10 ⁻⁶ ~10 ⁻³

Note 1: The relevant parameters use assumed conditions.

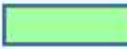
Note 2: Unsaturated parameters are not defined in the seepage calculation process; the soil is treated as saturated.

Porous Material-3

(Soft Rock)

Soft Rock

Material

ID: 3 Name: Soft Rock Color: 

Model Type: Mohr-Coulomb ☐ Structure

General Porous Non-Linear Thermal Time Dependent

Unit Weight(Saturated): 25 kN/m³

Initial Void Ratio(eo): 0.5

☐ Unsaturated Property Loam

Drainage Parameters

Drained

☒ Undrained Poisson's Ratio 0.495

☐ Skempton's B Coefficient 0.980541198

Seepage & Consolidation Parameters

Permeability Coefficients

kx	ky	kz	
0.0001	0.0001	0.0001	m/sec

☐ Void Ratio Dependency of Permeability(ck) 0.5

Specific Storativity(Ss) 0.001 1/m Auto

Flow of rainfall case does not calculate as saturated

	Coefficient of permeability(K) (m/sec)	Specific Storativity(Ss) (1/m)
Soft Rock	$10^{-6} \sim 10^{-4}$	$10^{-6} \sim 10^{-3}$

Note 1: The relevant parameters use assumed conditions.

Note 2: Unsaturated parameters are not defined in the seepage calculation process; the soil is treated as saturated.

In-situ Recorded Rainfall

(Hourly rainfall)

Unit (kn/m/J/hr)

kN m J hr



Seepage Boundary

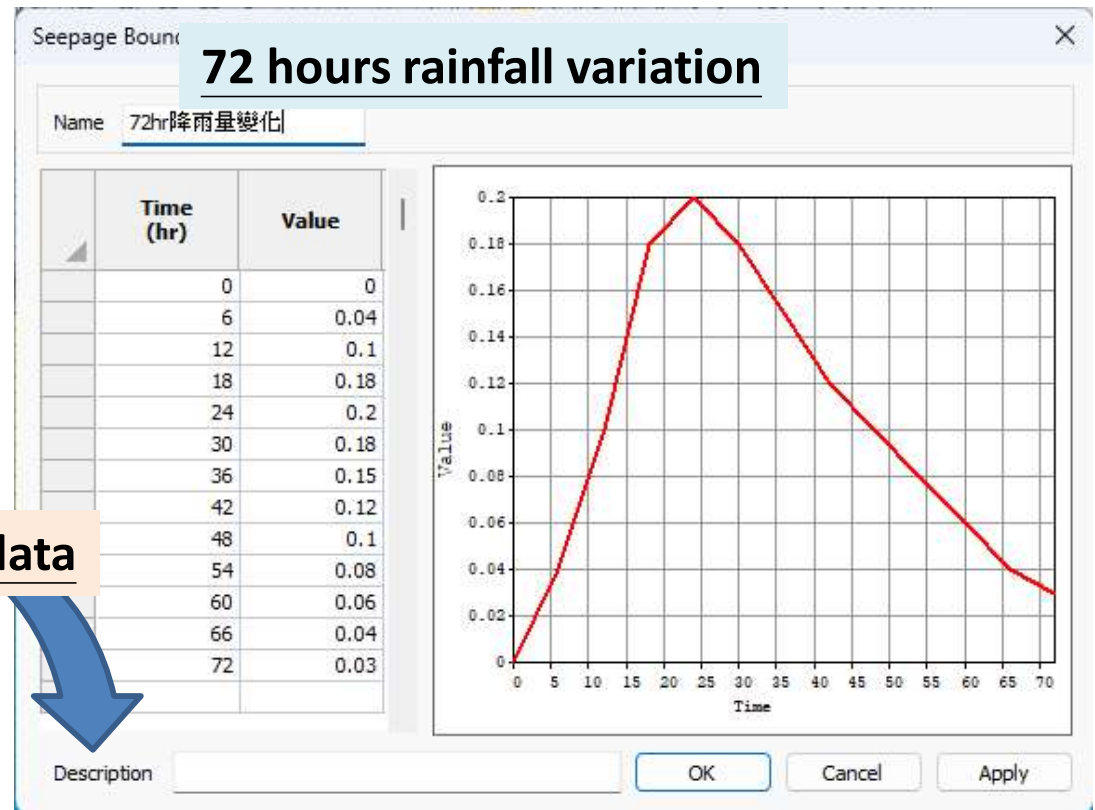


Excel data



時間累計(hr)	每6小時降雨量 (m)
0	
6	
12	0.1
18	0.18
24	0.2
30	0.18
36	0.15
42	0.12
48	0.1
54	0.08
60	0.06
66	0.04
72	0.03

Copy & paste the data



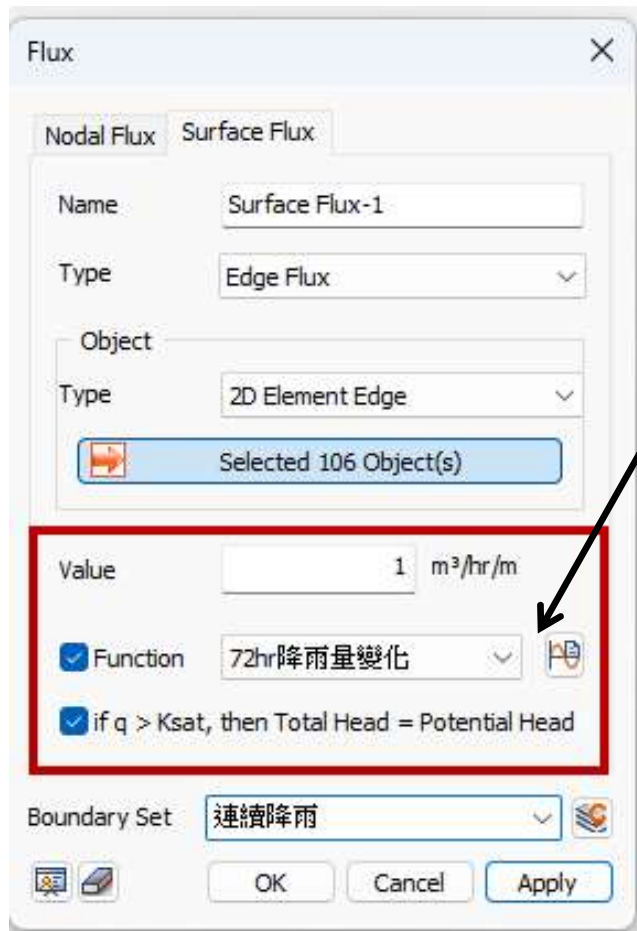
註:GTS NX不支援Y軸單位切換。

Surface Flux

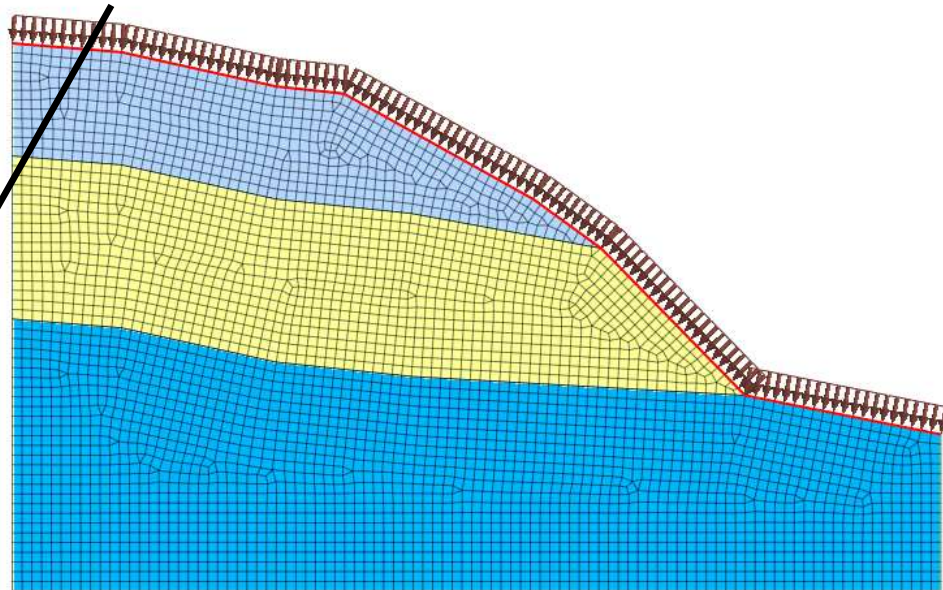
Unit (kN/m/J/hr)

kN m J hr

Seepage/Consolidation Analysis



Flux = Value × Function

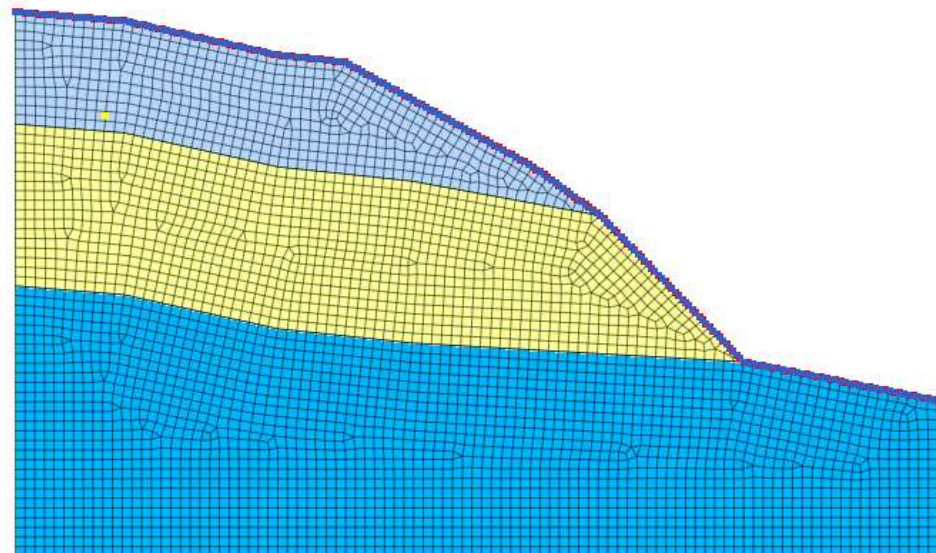
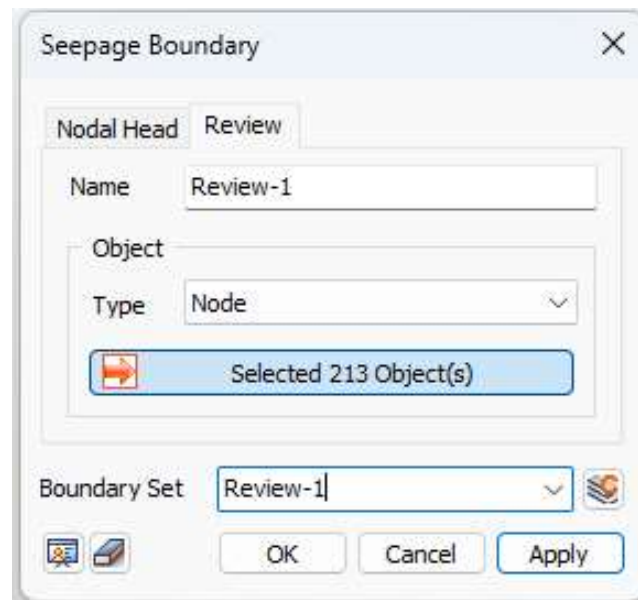


Setting:

if surface flux > coefficient of permeability
total head = potential head

Review/ Seepage

Seepage/Consolidation Analysis



Construction Stage-1

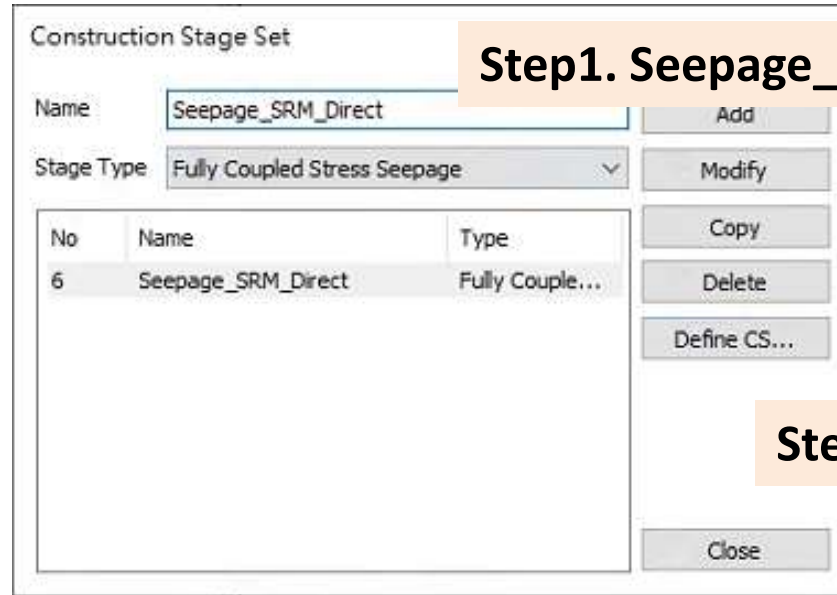
(Pseudo-static seismic case)



Construction phase types in GTS NX

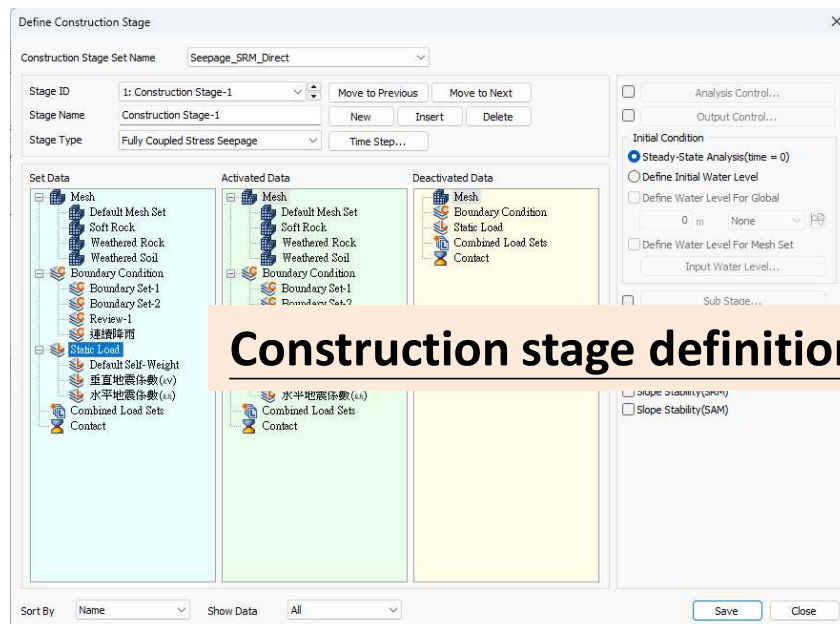
Fully Coupled Stress Seepage

Fully Coupled Stress Seepage
Stress-Nonlinear Time History
Heat Transfer
Seepage-Thermal Stress
Heat of Hydration(Thermal Stress)
Fully Coupled Stress Seepage Heat
Stress-Seepage-Slope-Nonlinear Time History



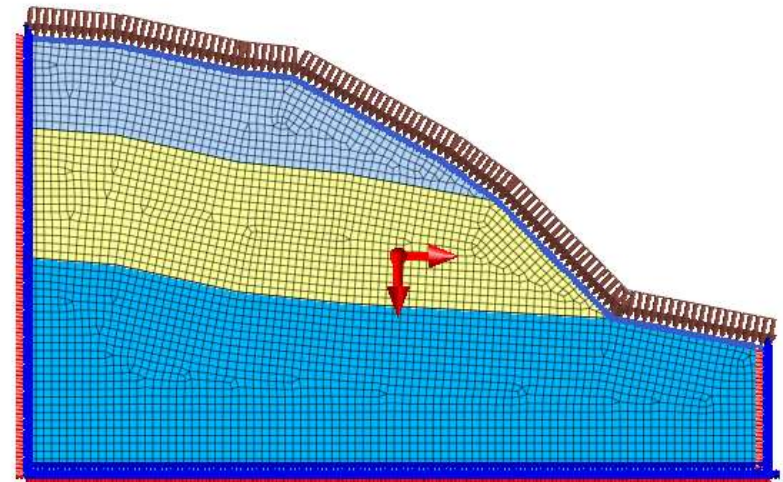
Step1. Seepage_SRM_Direct

Step2. Define CS



Construction stage definition

Activate all mesh sets/boundary sets



Construction Stage-2

(Fully Coupled Stress Seepage)

Define Construction Stage

Construction Stage Set Name: Seepage_SRM_Direct

Stage ID: 1: Construction Stage-1

Stage Name: Construction Stage-1

Stage Type: Fully Coupled Stress Seepage

Time Step...

Set Data

Activated Data

Analysis setting

Analysis Control...

Output Control...

Initial Condition

Steady-State Analysis(time = 0)

Define Initial Water Level

Define Water Level For Global

Define Water Level For Mesh Set

LDF...

Copy To Specific Stage...

Clear Displacement

Clear Strain

Slope Stability(SRM)

Slope Stability(SAM)

Select all set types
(Even kh/kv for simulation)

Select SRM

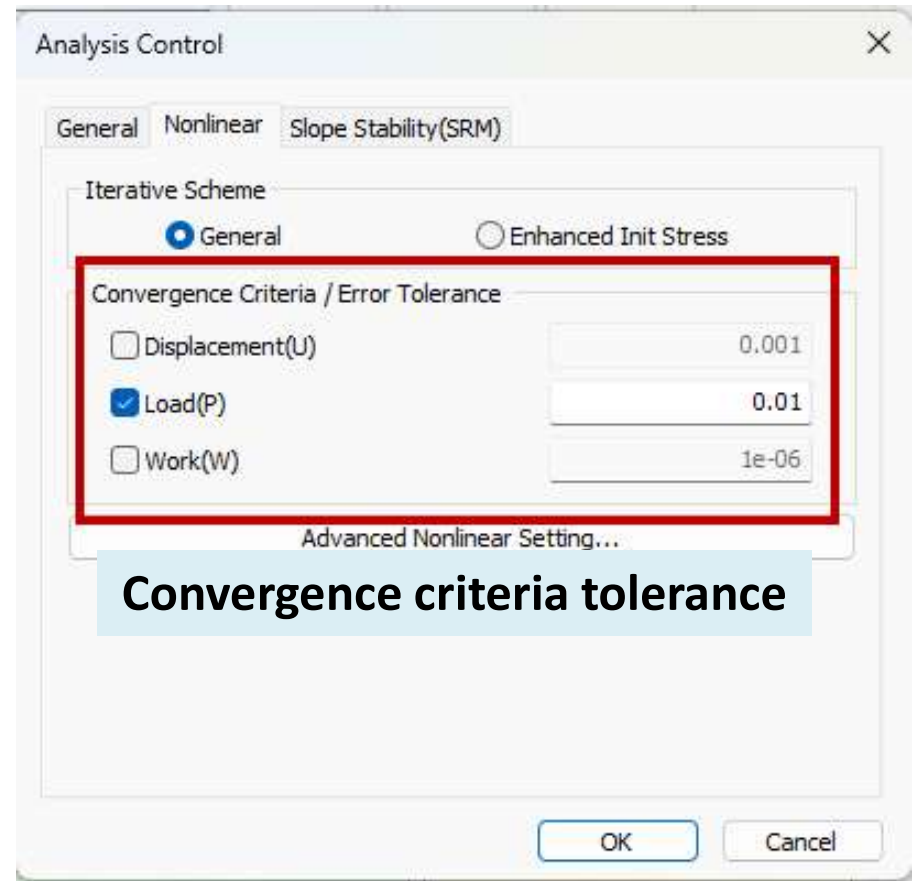
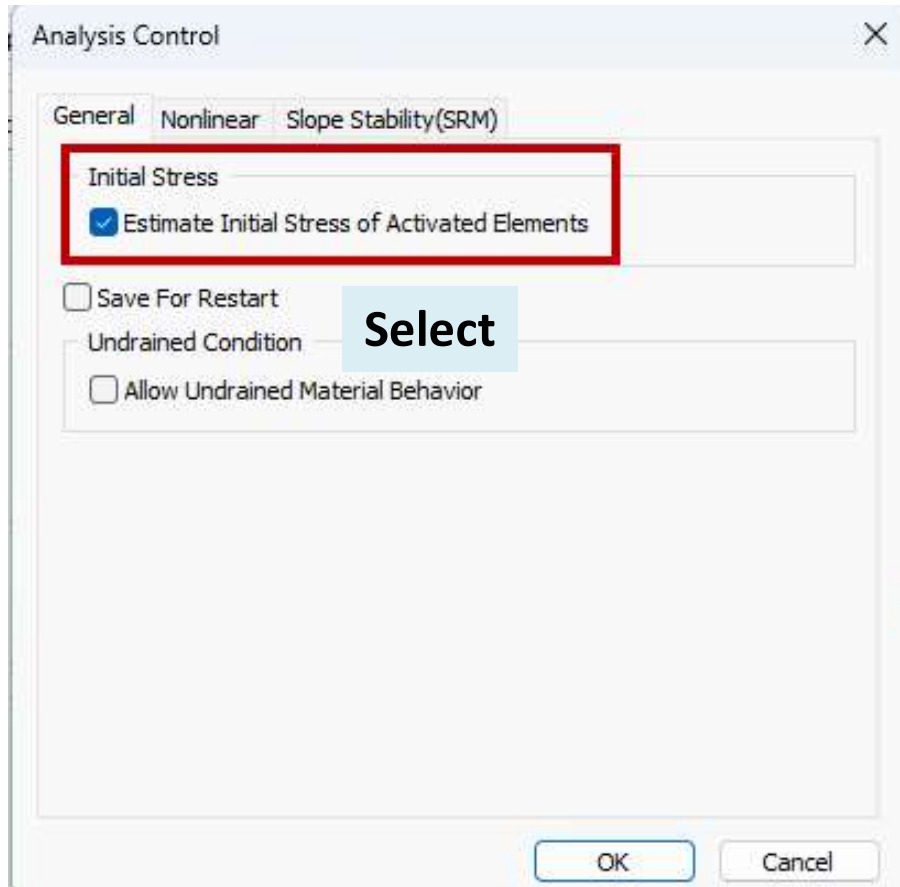
Ignore initial water level

Save

Close

Construction Stage-3

(Analysis & Control)



Construction Stage-4

(Analysis Control/ Time Control)

Analysis Control

General Nonlinear Slope Stability(SRM)

Nonlinear parameters

Maximum Number of Trials 50

Maximum Number of Iterations 50

Stiffness Update Scheme Full Newton-Raphson

Intermediate Output Request Every Iteration

Convergence Criteria / Error Tolerance

☐ Displacement(U) 0.01

☒ Load(P) 0.01

☐ Work(W) 0.0001

Safety Factor

Initial Safety Factor 1

Increment of Safety Factor 0.1

Resolution of Safety Factor 0.01

☐ Safety Factor Function

Advanced Nonlinear Parameters...

Time Step

Time Step

Duration 72 hr

☒ User Defined Step

☐ User

Time 0 hr
(Example: 1, 3, 7, 14)

☒ Step

Step Number 24

☒ Save Result ☐ Log Scale

Generate Step

	Step	Time (hr)	Save Step
▶	1	3.0000	<input checked="" type="checkbox"/>
	2	6.0000	<input checked="" type="checkbox"/>
	3	9.0000	<input checked="" type="checkbox"/>
	4	12.0000	<input checked="" type="checkbox"/>
	7	21.0000	<input checked="" type="checkbox"/>
	8	24.0000	<input checked="" type="checkbox"/>

☐ Auto Time Step

Initial Time Step

☒ Auto 0 hr

Max. Pore Pressure Changes per Step 0.101971621 tonf/m²

Ratio of Max Time Step to Initial 5

Save Step Last Increment

OK Close

72 hours with 24 steps of calculation

SRM convergence adjustment

- (1) Initial safety factor 1
- (2) FOS increment by 0.1 each time
- (3) Residual < 0.01, minimum FOS reached

Analysis

(Heavy Rainfall Case)

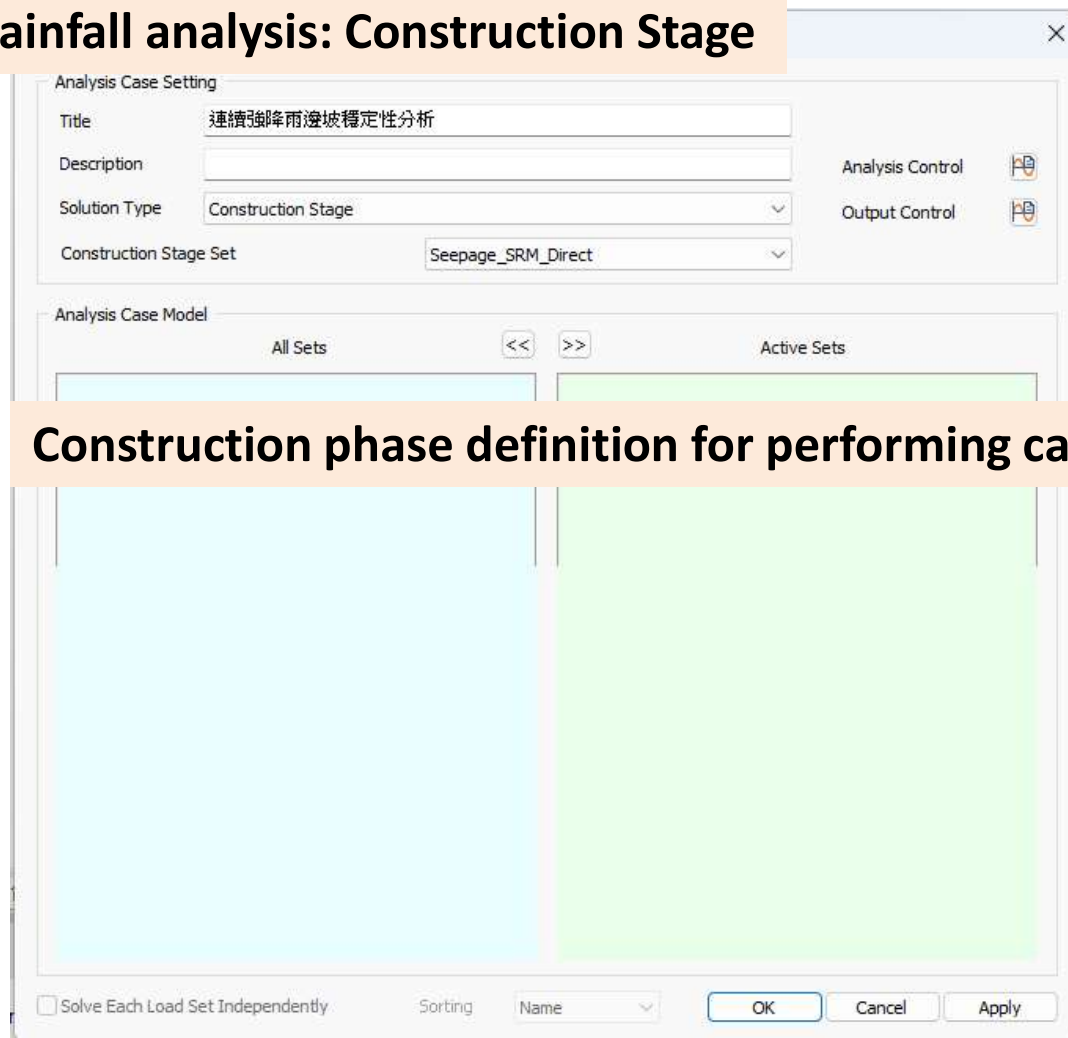


72hr of heavy rainfall analysis: Construction Stage

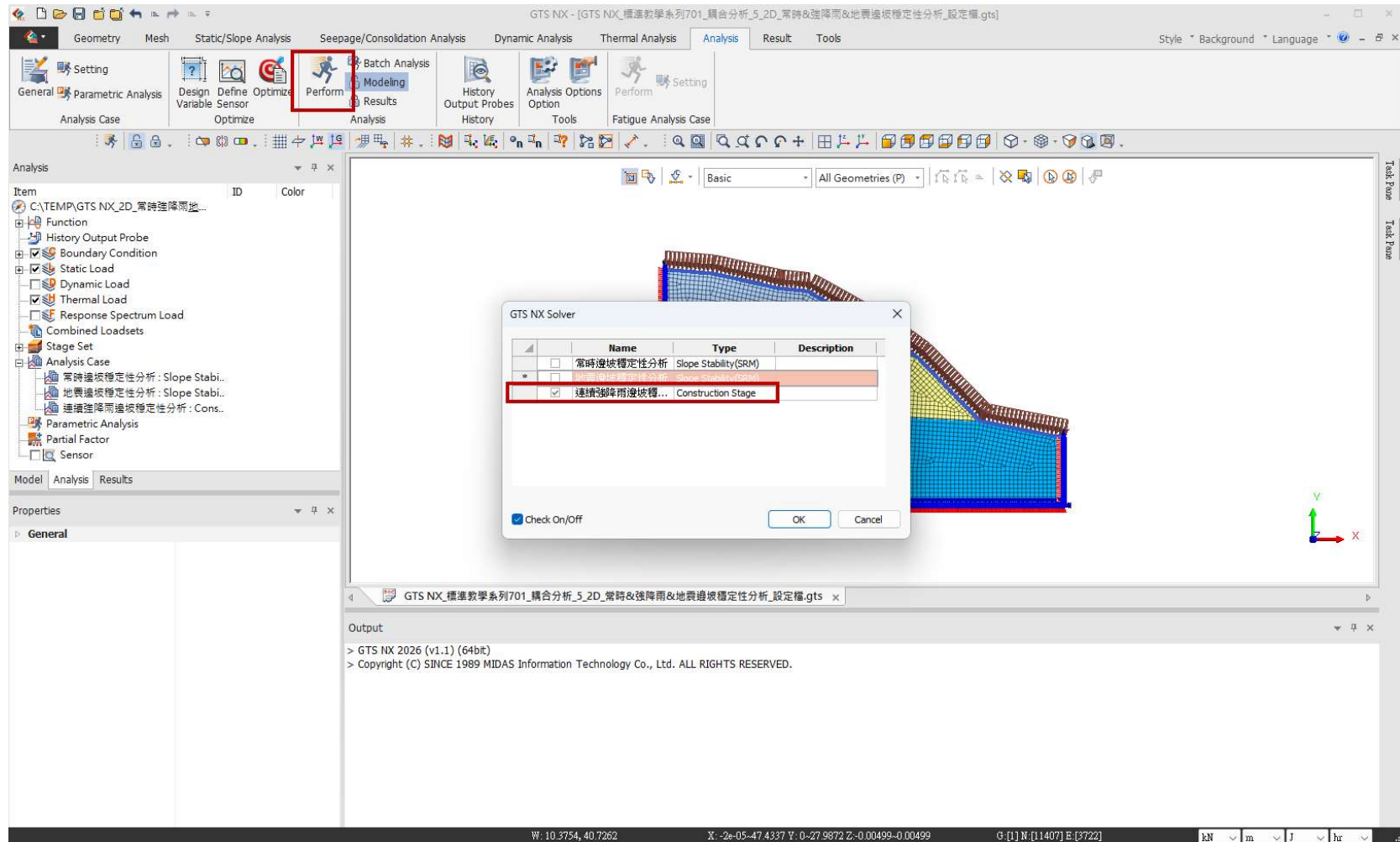
Construction Stage

Linear Static
Nonlinear Static
Construction Stage
Eigenvalue
Response Spectrum
Linear Time History (Modal)
Linear Time History (Direct)
Nonlinear Time History
Nonlinear Time History + SRM
2D Equivalent Linear
Consolidation
Fully Coupled Stress Seepage
Seepage (Steady-state)
Seepage (Transient)
Slope Stability (SRM)
Slope Stability (SAM)

Construction phase definition for performing calculations



Calculation



Direct Method Analysis Results

連續降雨邊坡穩定性分析

Construction Stage-1

- INCR=1 (TIME=1.080e+04)
- INCR=2 (TIME=2.160e+04)
- INCR=3 (TIME=3.240e+04)
- INCR=4 (TIME=4.320e+04)
- INCR=5 (TIME=5.400e+04)
- INCR=6 (TIME=6.480e+04)
- INCR=7 (TIME=7.560e+04)
- INCR=8 (TIME=8.640e+04)
- INCR=10 (TIME=9.720e+04)

Each time step of calculation

INCR=11 (TIME=3.300e+01)

- Displacements
- Grid Forces
- Nodal Seepage Results
- Reactions
- Solid Stresses
- Solid Strains
- 3D Elem Seepage Results

Seepage-stress coupling analysis

- INCR=15 (TIME=1.290e+05)
- INCR=16 (TIME=1.404e+05)
- INCR=17 (TIME=1.512e+05)
- INCR=18 (TIME=1.620e+05)
- INCR=19 (TIME=1.728e+05)
- INCR=22 (TIME=1.836e+05)
- INCR=23 (TIME=1.944e+05)
- INCR=24 (TIME=2.052e+05)
- INCR=26 (TIME=2.160e+05)

SRM is calculated from the last step

- INCR=29 (TIME=2.370e+05)
- INCR=30 (TIME=2.484e+05)
- INCR=31 (TIME=2.592e+05)

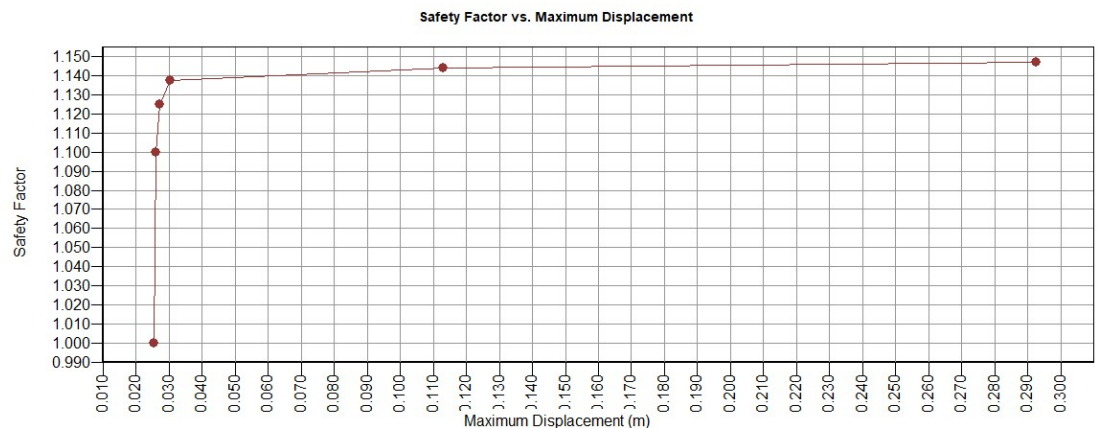
Construction Stage-1-SRM

- INCR=1 (FOS=1.0000)
- INCR=2 (FOS=1.1000)
- INCR=3 (FOS=1.1250)
- INCR=4 (FOS=1.1375)
- INCR=5 (FOS=1.1438)
- INCR=6 (FOS=1.1469)

Safety Factor

1.14688 [Construction

SRM analysis results



Analysis Results

(Heavy Rainfall Case)

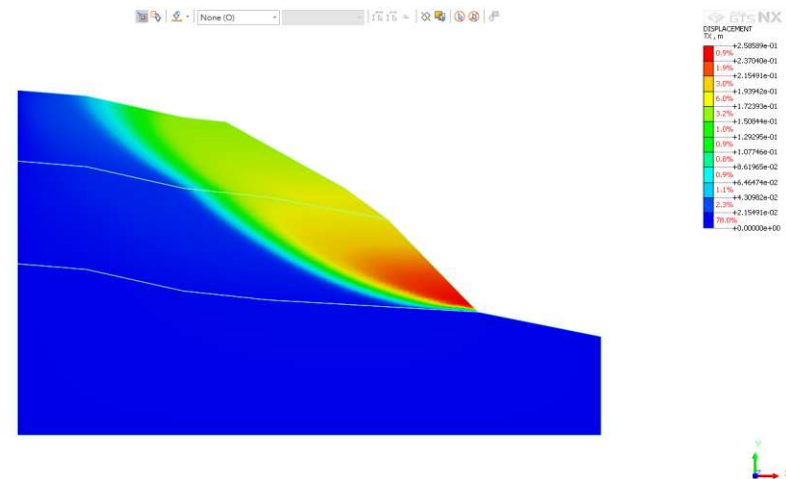
Failure surface indicated by horizontal displacement
& maximum shear strain

Heavy rainfall simulation, FOS = 1.1469

- Construction Stage-1-SRM
 - INCR=1 (FOS=1.0000)
 - INCR=2 (FOS=1.1000)
 - INCR=3 (FOS=1.1250)
 - INCR=4 (FOS=1.1375)
 - INCR=5 (FOS=1.1438)
 - INCR=6 (FOS=1.1469)
- Safety Factor
 - 1.14688 [Construction Stage-1-SRM]

SRM for safety factor calculation

Tx Translation(m)



Maximum Shear Strain

