



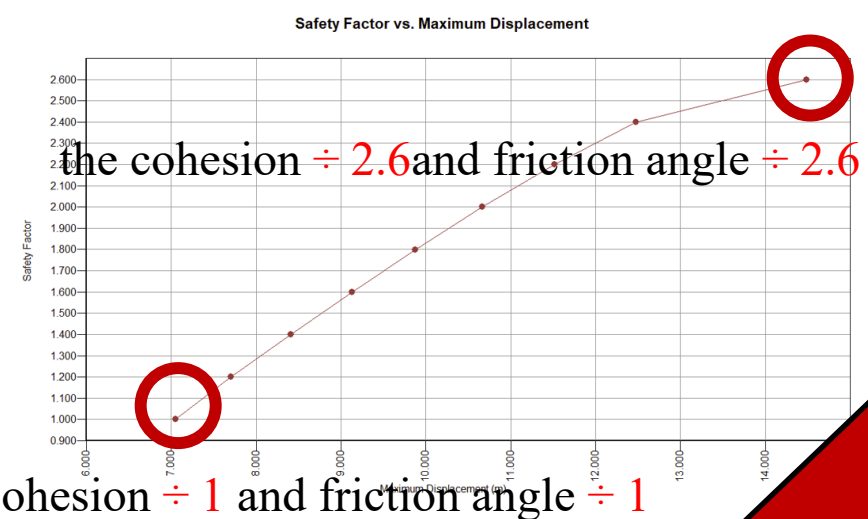
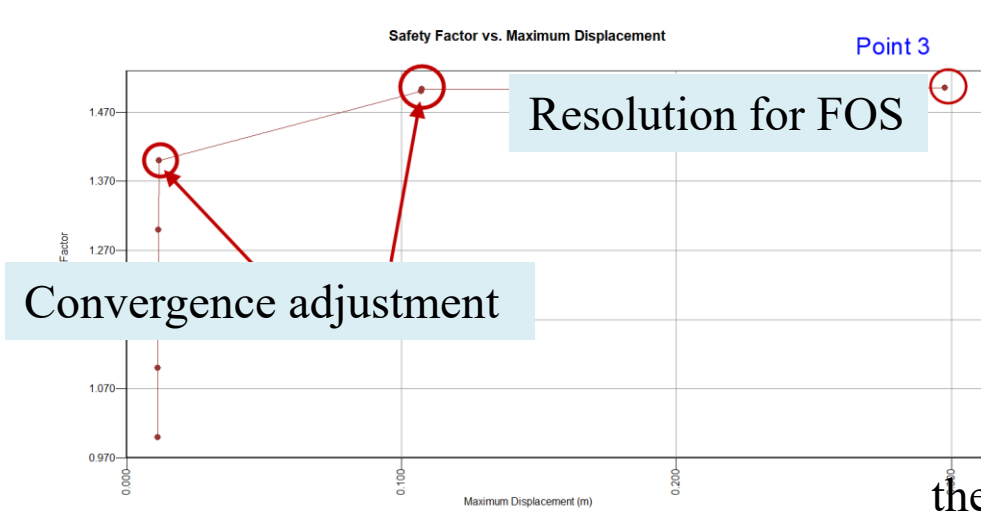
**MIDAS TAIWAN
GTS NX**

DIFFERENT HAZARD CONDITIONS IN SLOPE STABILITY

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

The intensity reduction method proposed by Griffith et al. (1999) and Matsui (1990)

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

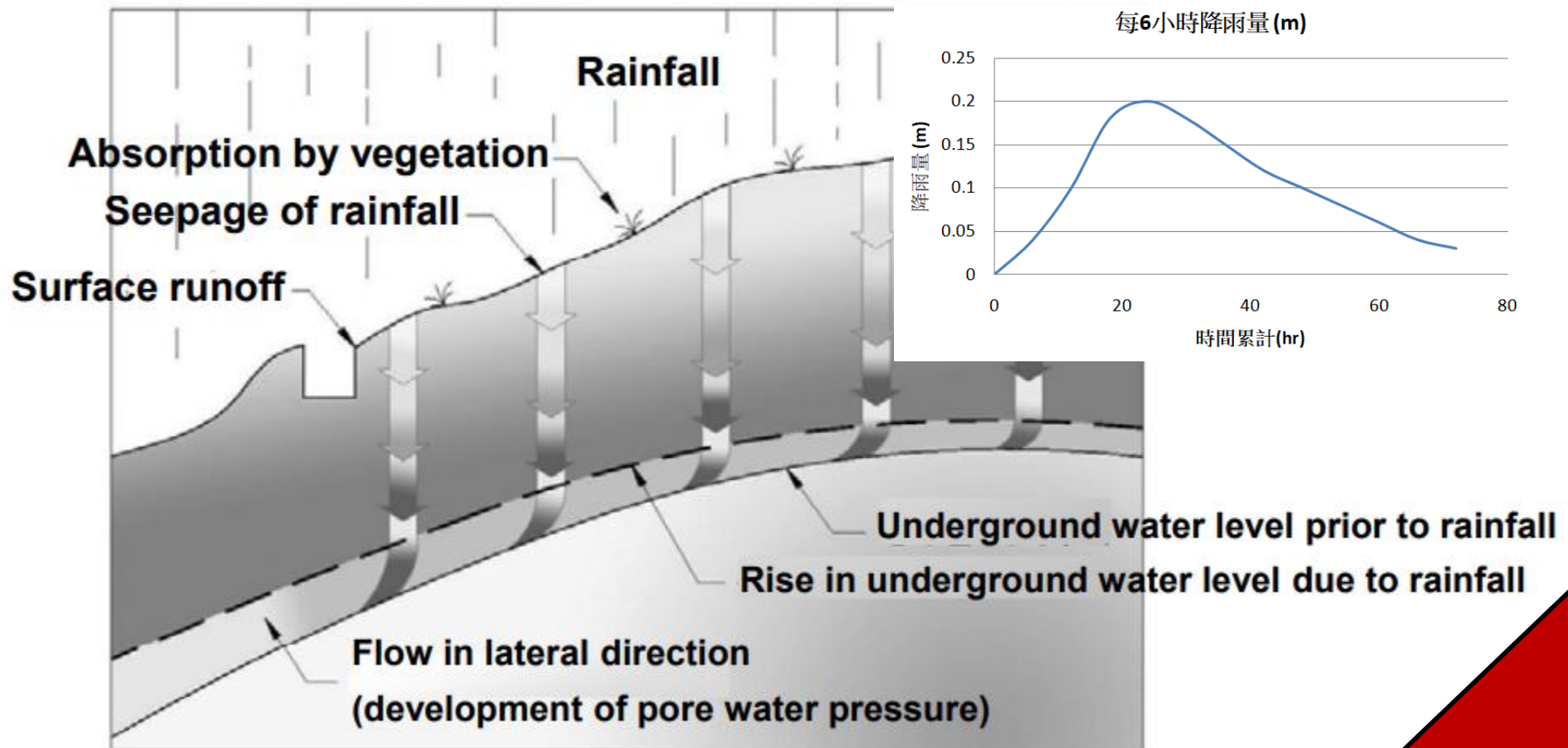
These forces are applied **uniformly to the entire soil mass**.

Reference

GTS NX/FEA NX/Soilworks Manual

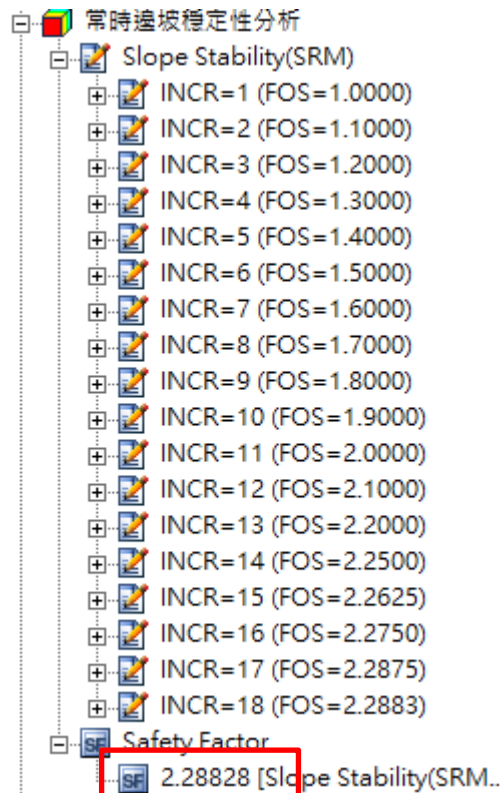
SEEPAGE THROUGH UNSATURATED SLOPE

SEEPAGE INDUCED BY RAINFALL



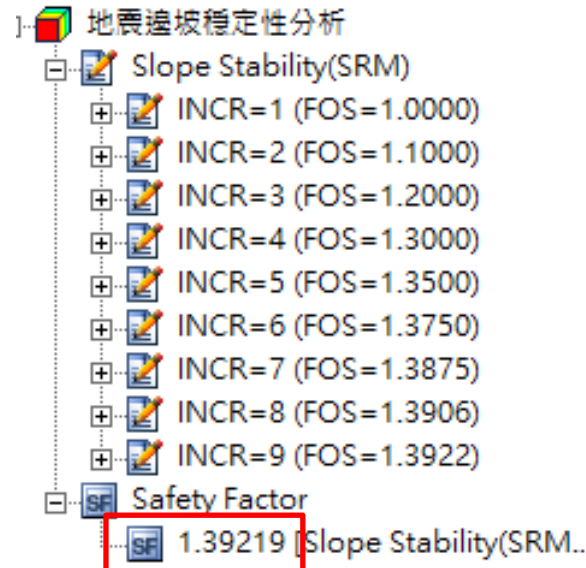
COMPARISON FOR DIFFERENT CASES

Normal case



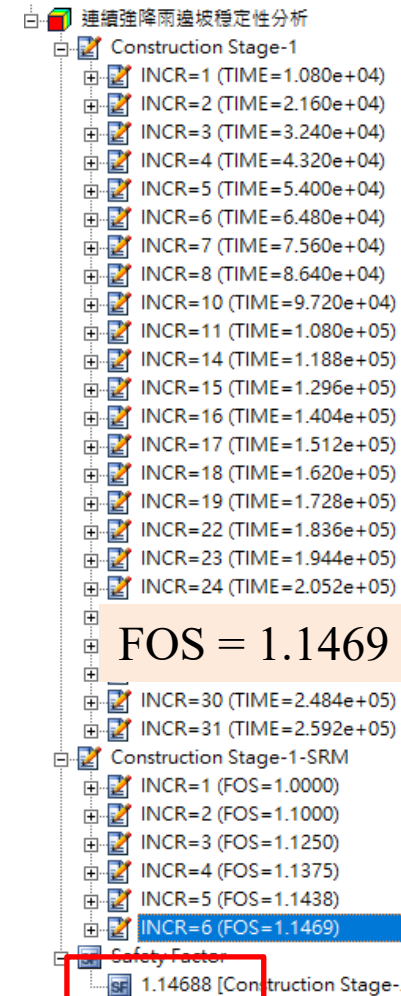
FOS = 2.2883

Pseudo-static seismic



FOS = 1.3922

Heavy rainfall case

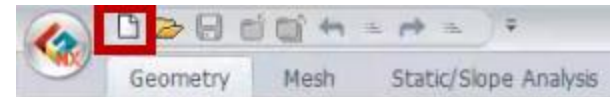
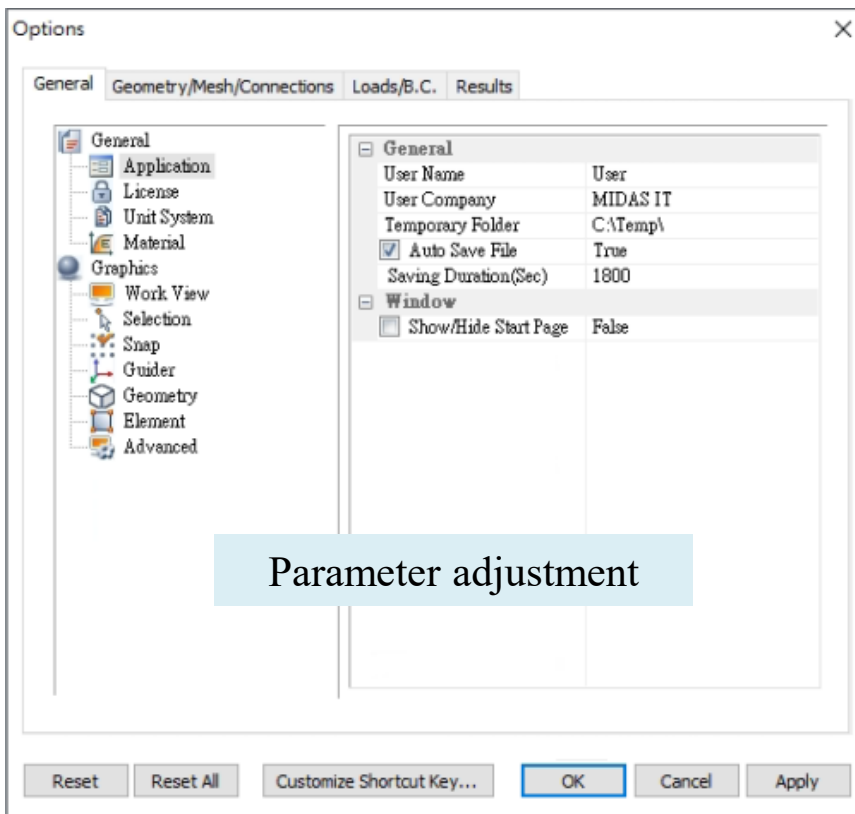




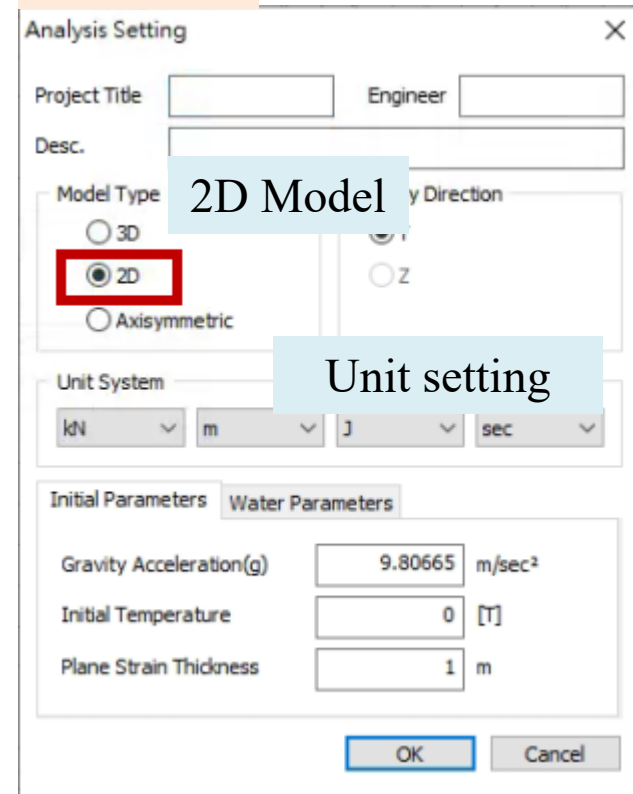
Part 1

NORMAL CONDITION

IMPORT

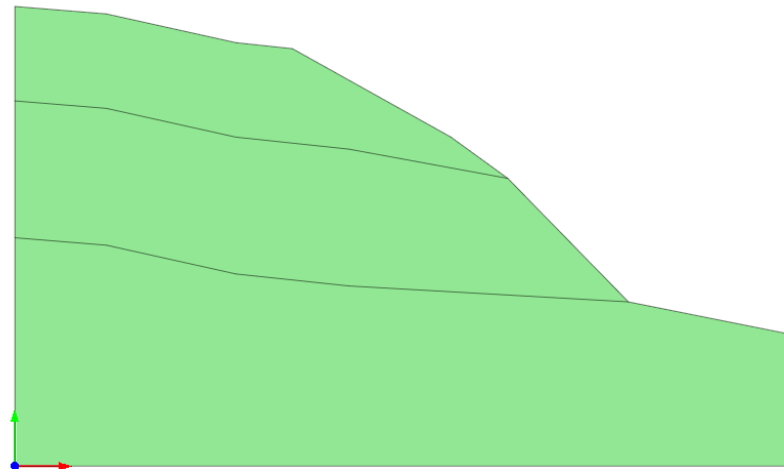
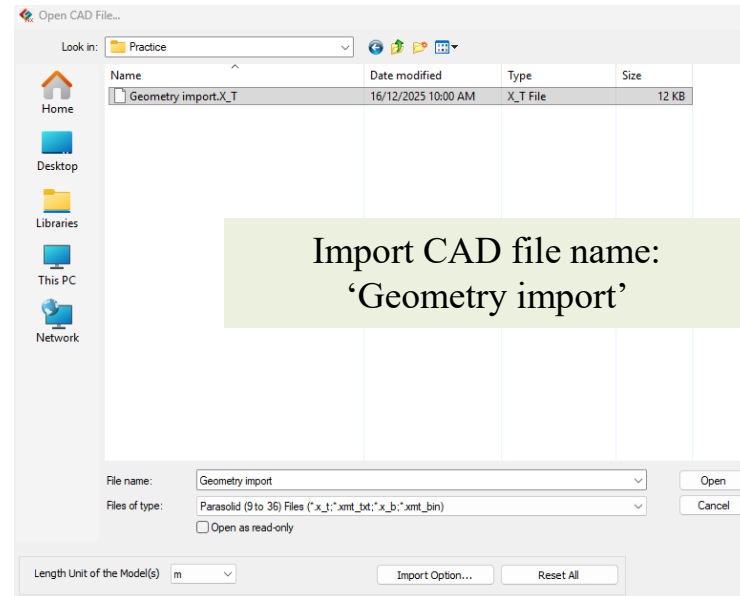
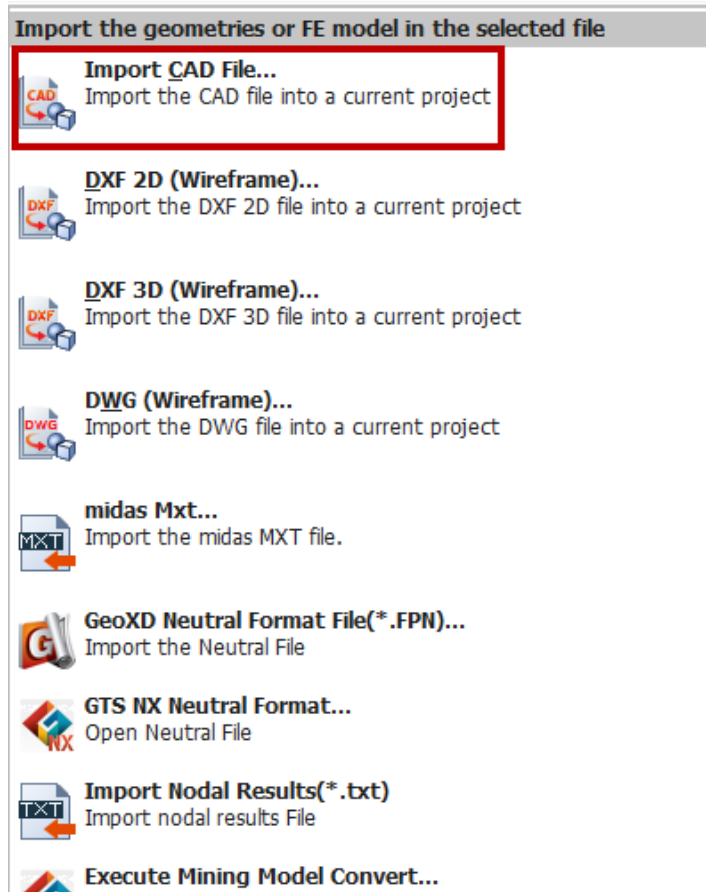


New file

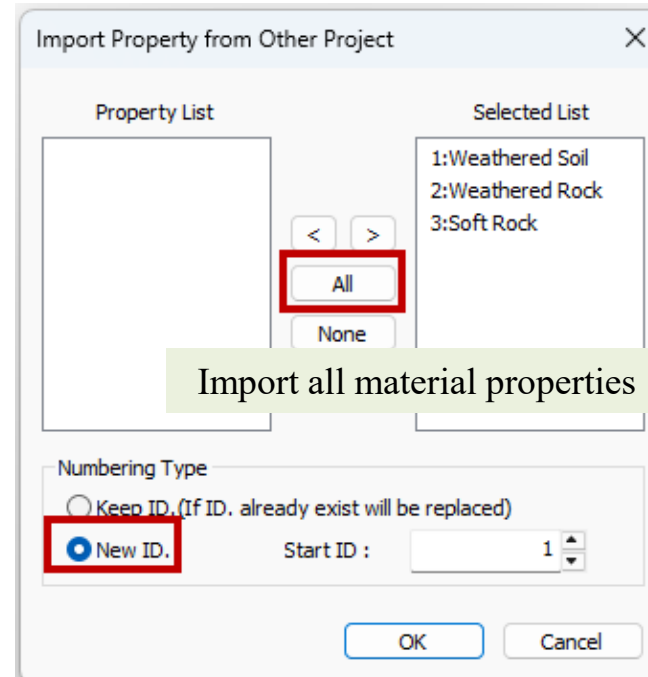
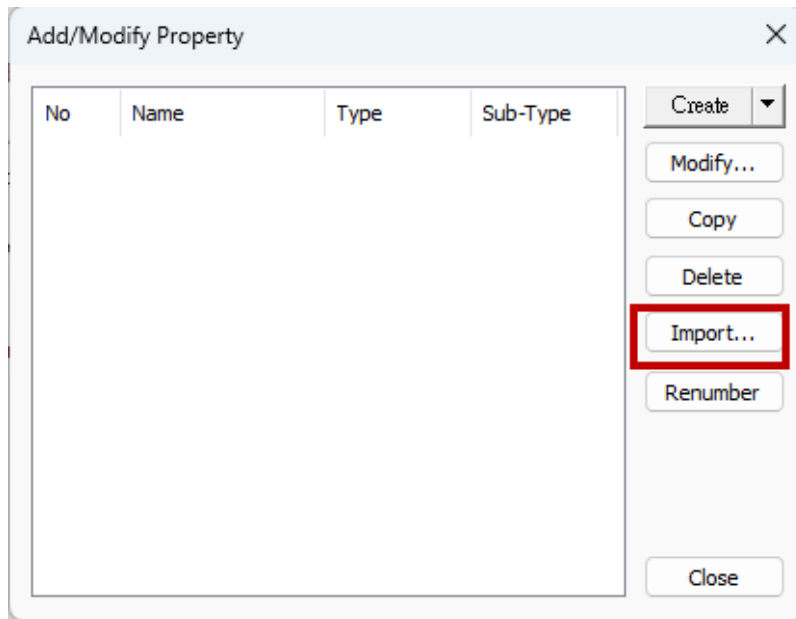
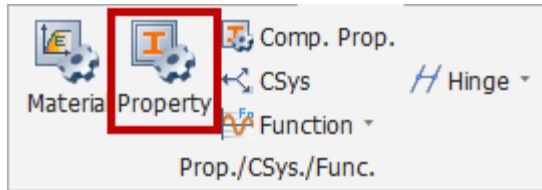


Unit setting: KN/m/J/sec

2D MODEL IMPORT

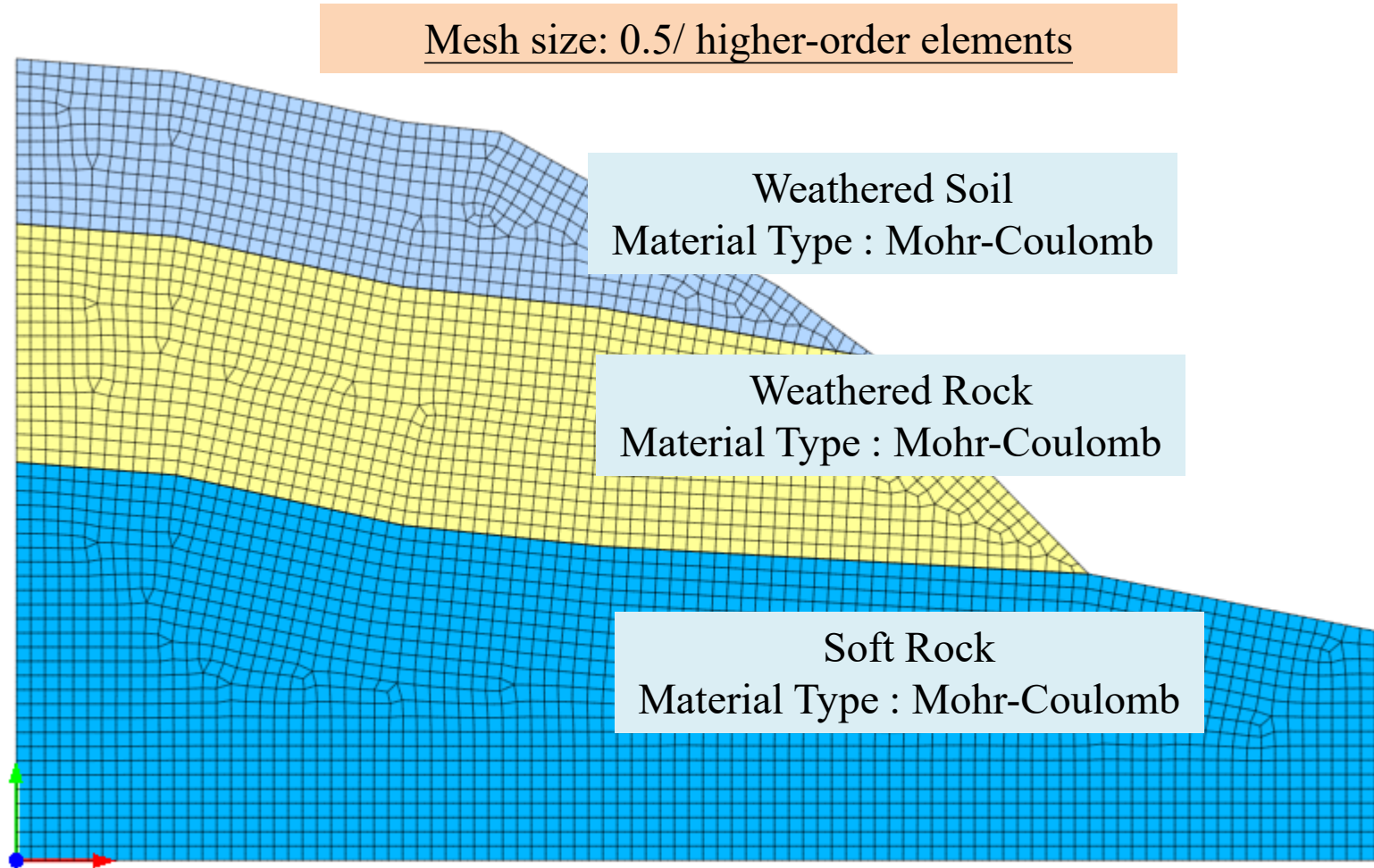


MATERIAL & PROPERTY



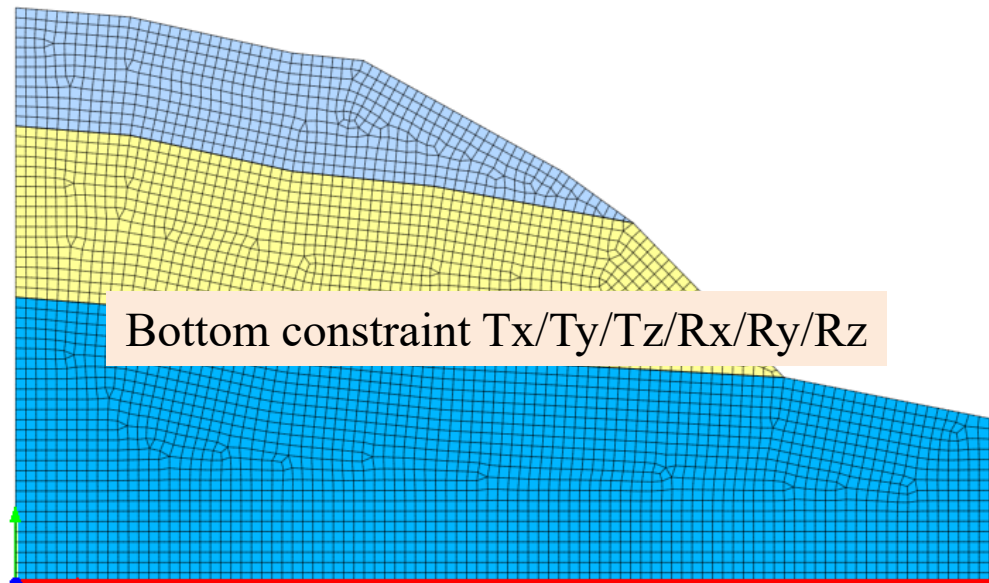
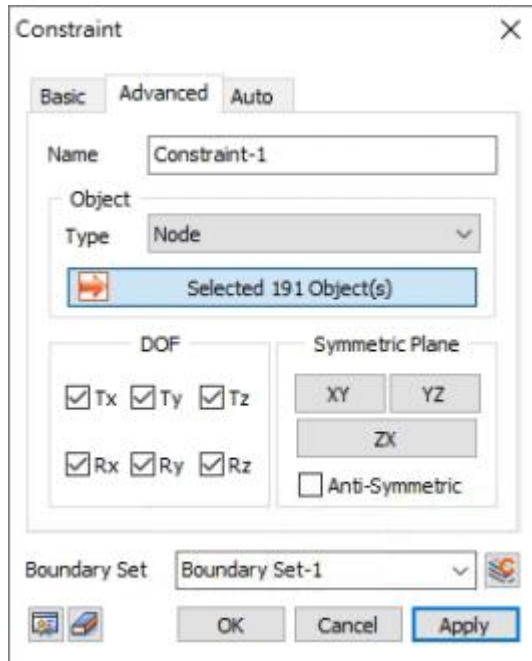
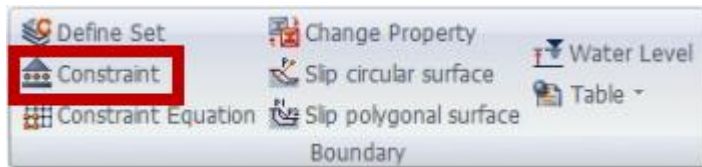
Import all material properties

2D MESH GENERATION

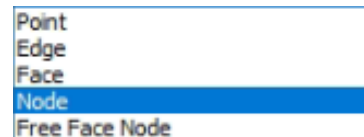
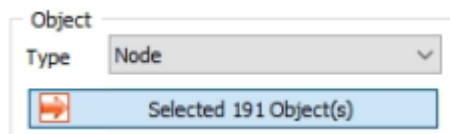


Note: Using higher-order elements and smaller grid sizes for slope analysis

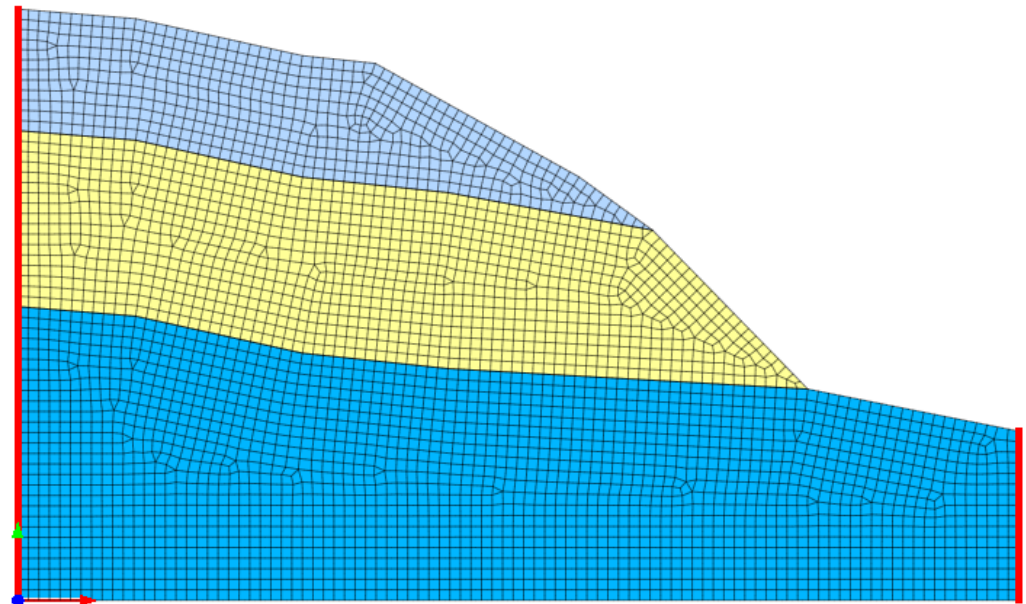
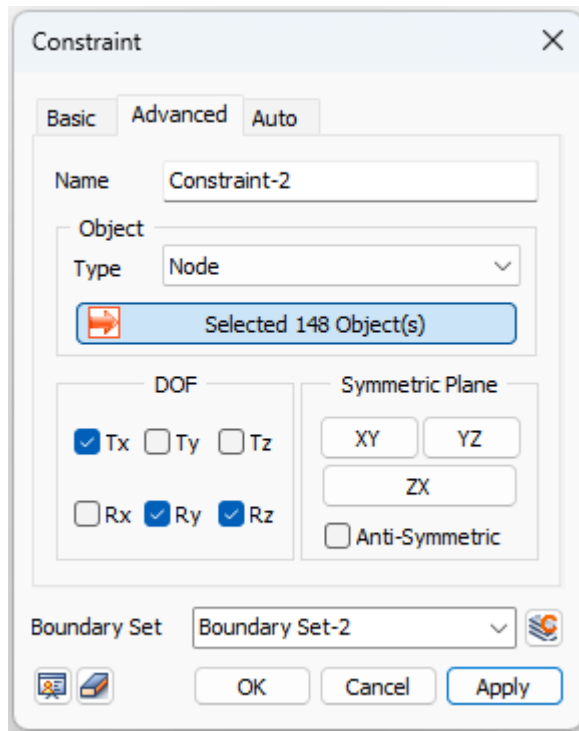
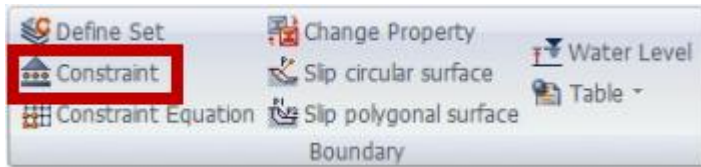
BOTTOM BOUNDARY



The geometric features or nodes can be applied to the boundary



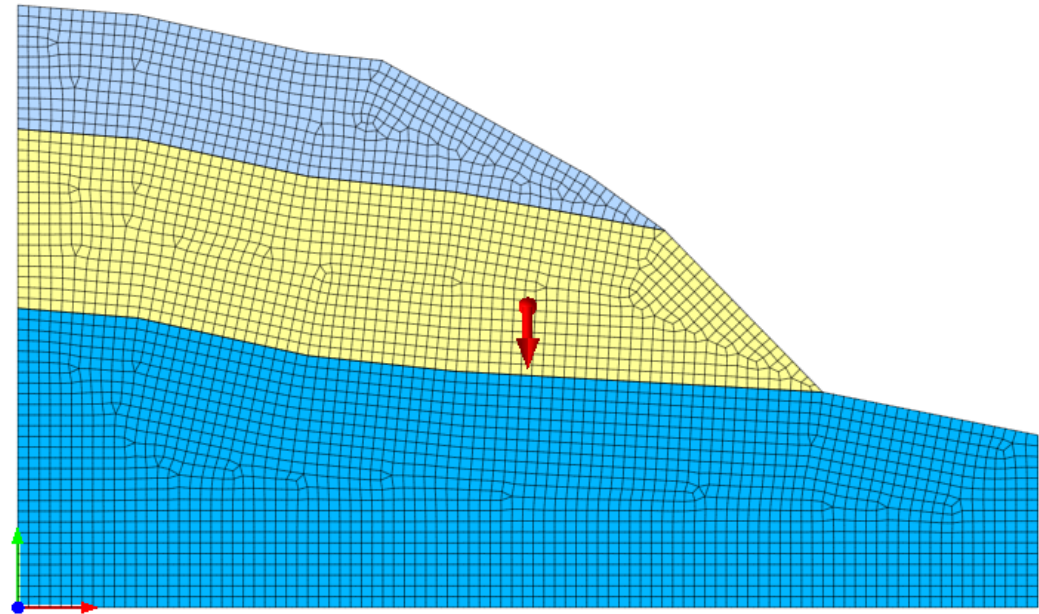
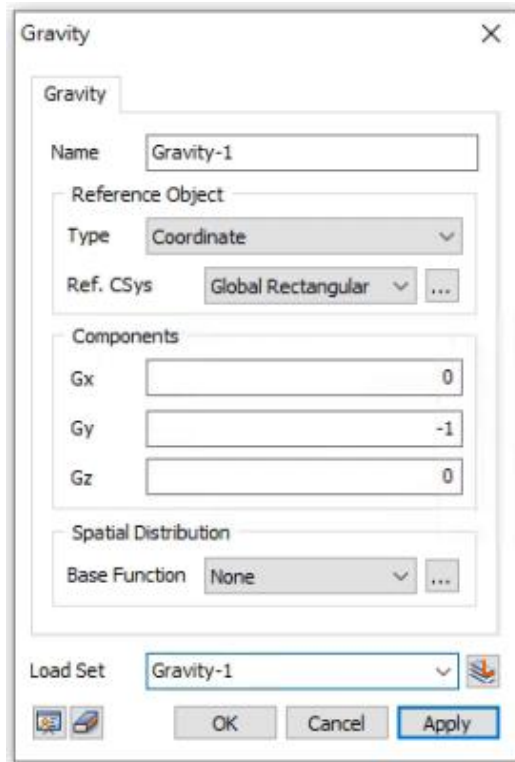
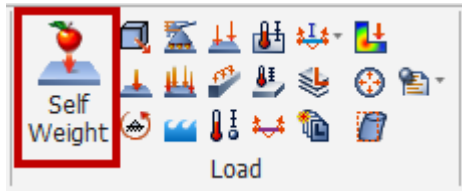
2-SIDED BOUNDARY



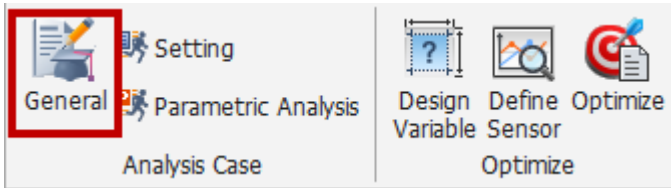
2-sided constraint $T_x/R_y/R_z$

It is recommended to set boundary sets for different location

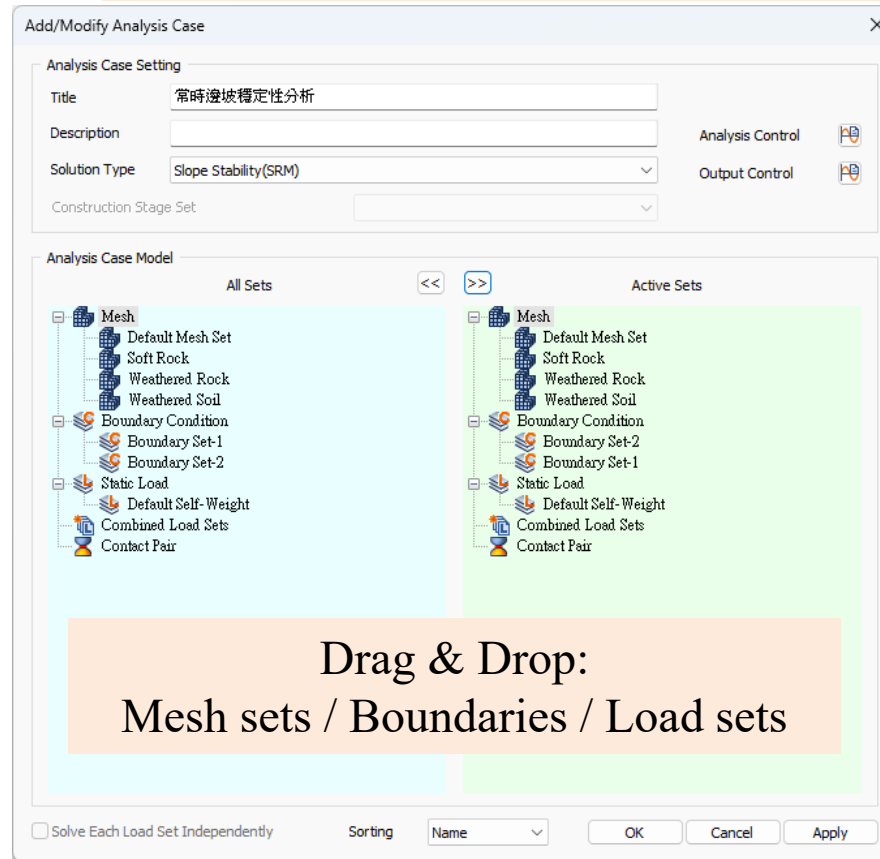
SELF-WEIGHT



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 / Error

☐ 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

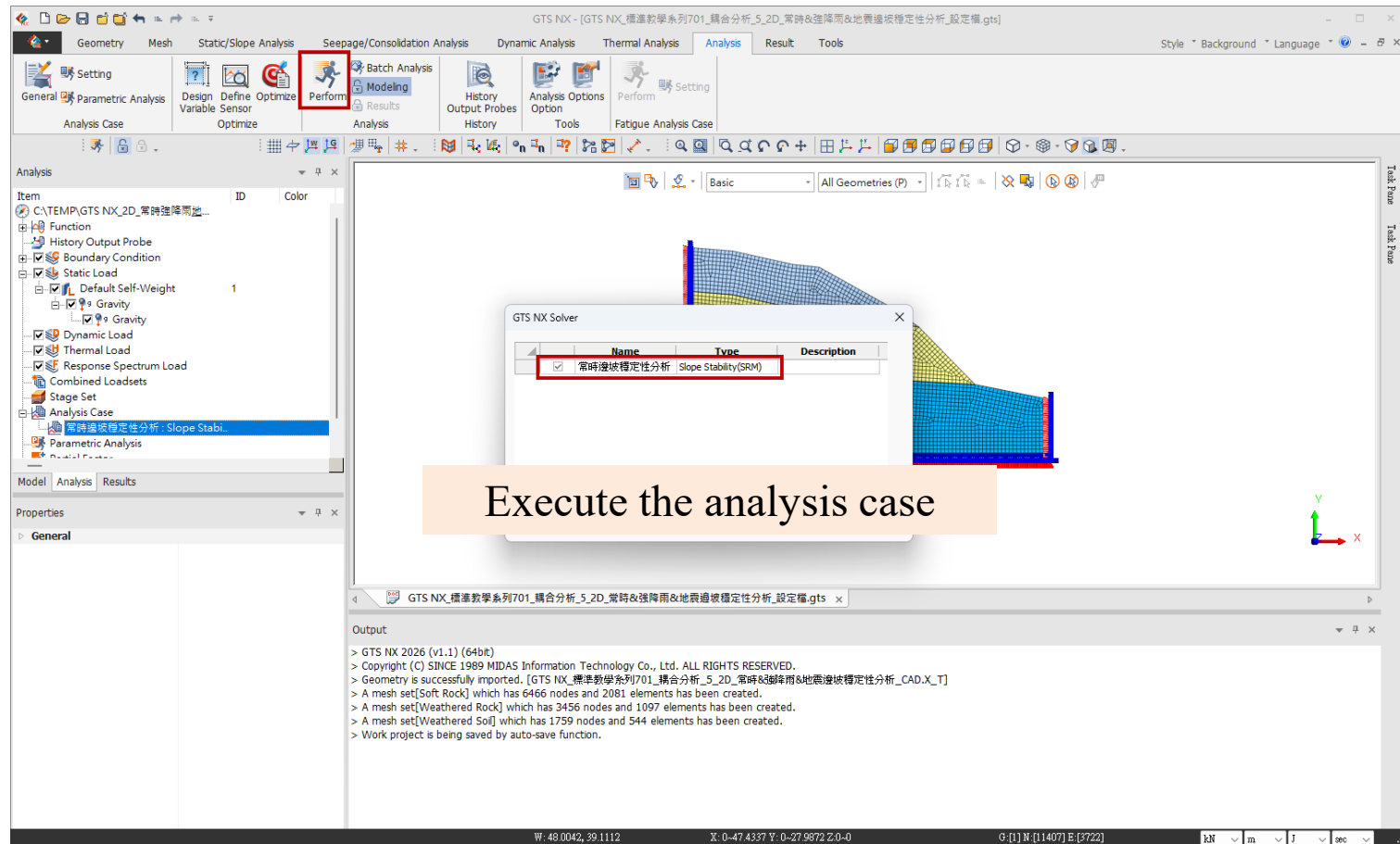
Number of Beam Output Segments 4

OK Cancel

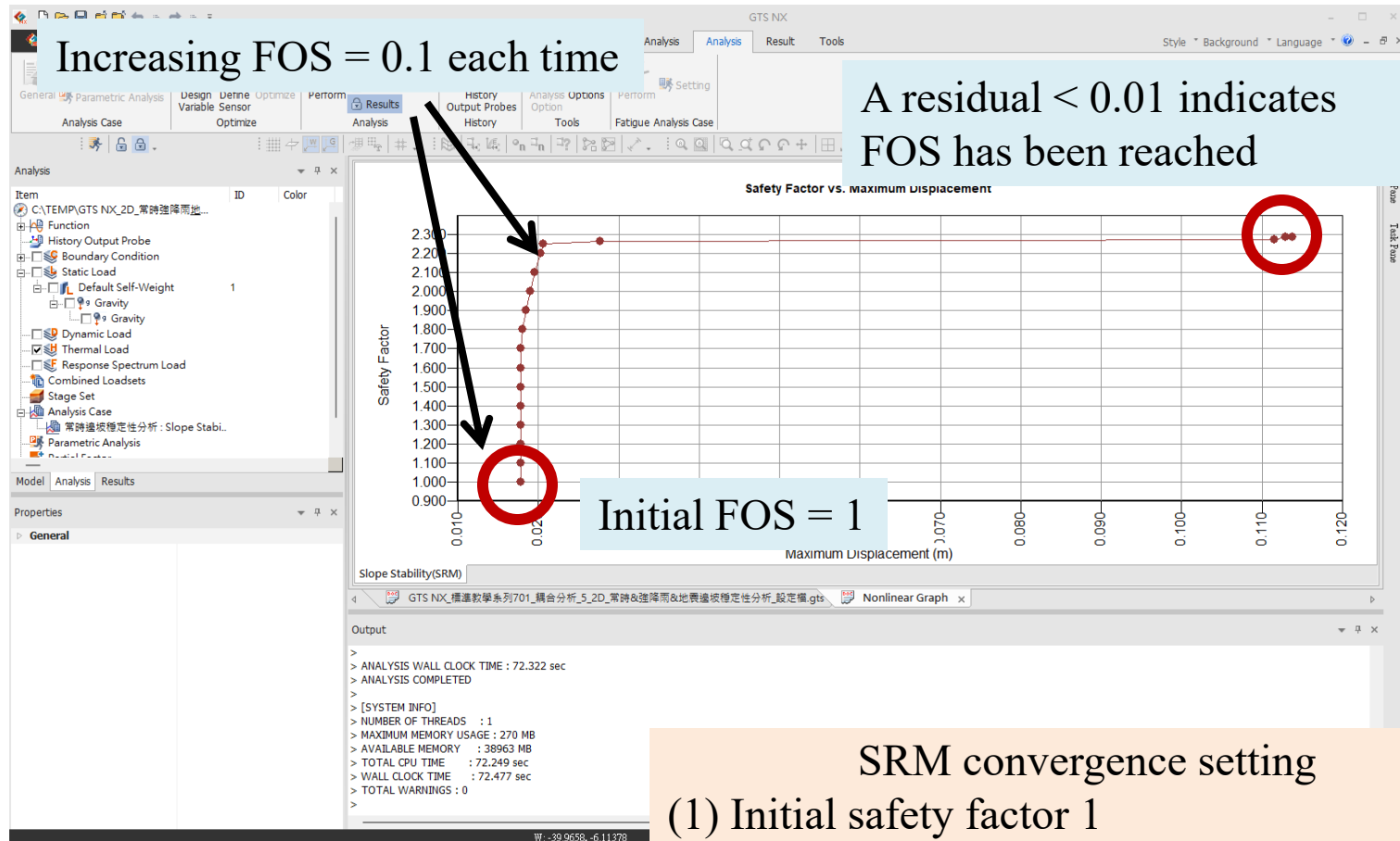
SRM convergence adjustment

- (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

Results

Self-weight analysis, FOS = 2.2883

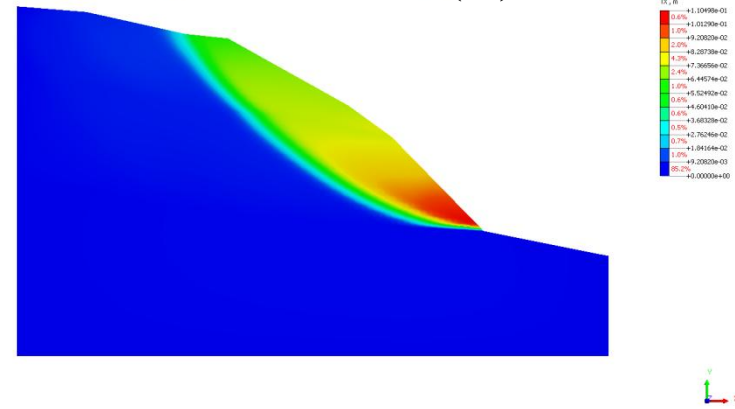
- INCR=6 (FOS=1.5000)
- INCR=7 (FOS=1.6000)
- INCR=8 (FOS=1.7000)
- INCR=9 (FOS=1.8000)
- INCR=10 (FOS=1.9000)
- INCR=11 (FOS=2.0000)
- INCR=12 (FOS=2.1000)
- INCR=13 (FOS=2.2000)
- INCR=14 (FOS=2.2500)
- INCR=15 (FOS=2.2625)
- INCR=16 (FOS=2.2750)
- INCR=17 (FOS=2.2875)
- INCR=18 (FOS=2.2883)
 - Displacements
 - Grid Forces
 - Plane Strain Forces
 - Plane Strain Stresses
 - Plane Strain Strains

Model Analysis Results

SRM for safety factor calculation

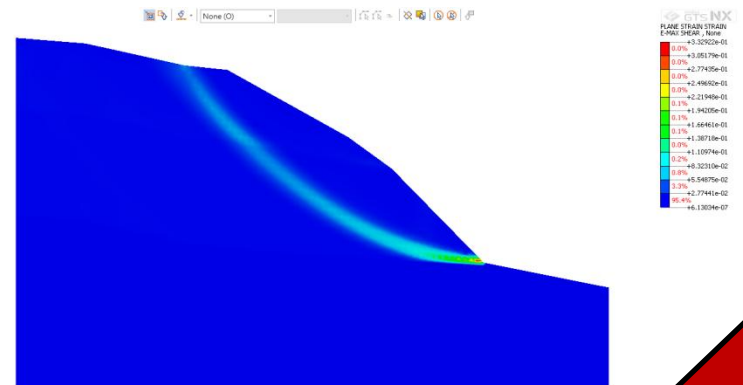
Failure surface indicated by horizontal displacement & maximum shear strain

Tx Translation(m)



[DATA] 常時運転穩定性分析, Slope Stability(SRM), INCR=18 (FOS=2.2883), [UNIT] MN, m

Maximum Shear Strain



[DATA] 常時運転穩定性分析, Slope Stability(SRM), INCR=18 (FOS=2.2883), [UNIT] MN, m

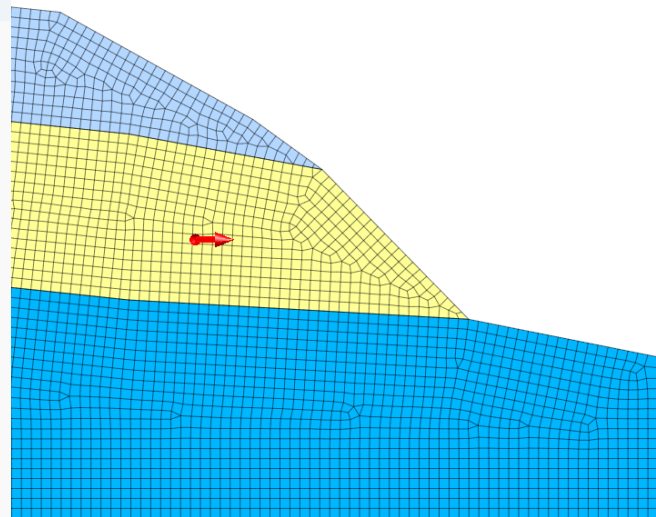
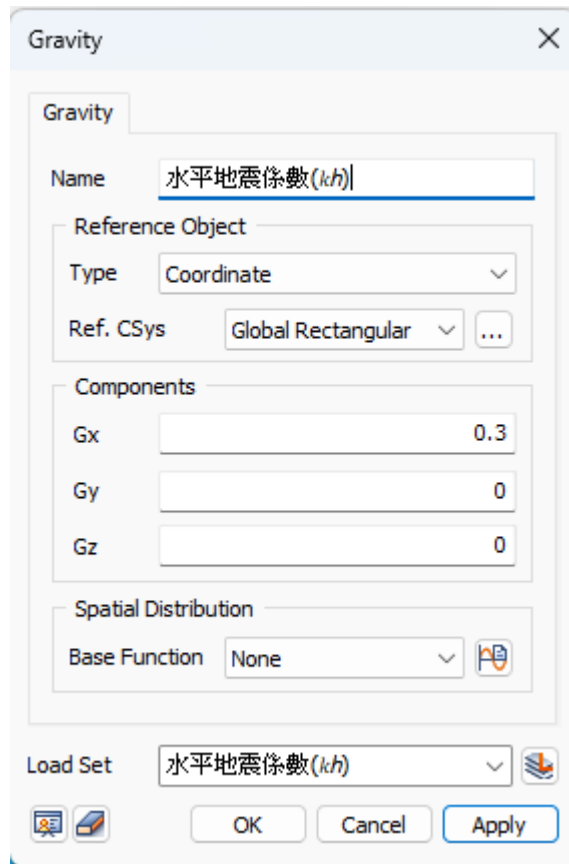
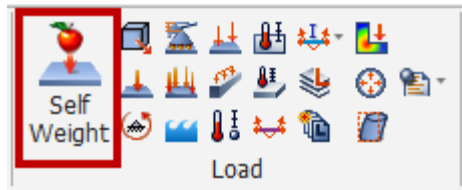


Part 2

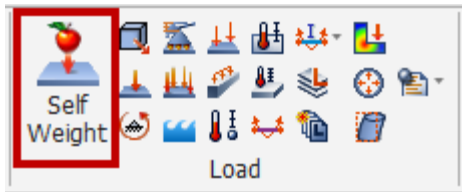
PSEUDO-STATIC SEISMIC

CASE

HORIZONTAL SEISMIC COEFFICIENT (K_H)



VERTICAL SEISMIC COEFFICIENT (K_v)



Gravity

Gravity

Name Gravity-3

Reference Object

Type Coordinate

Ref. CSys Global Rectangular

Components

Gx 0

Gy -0.15

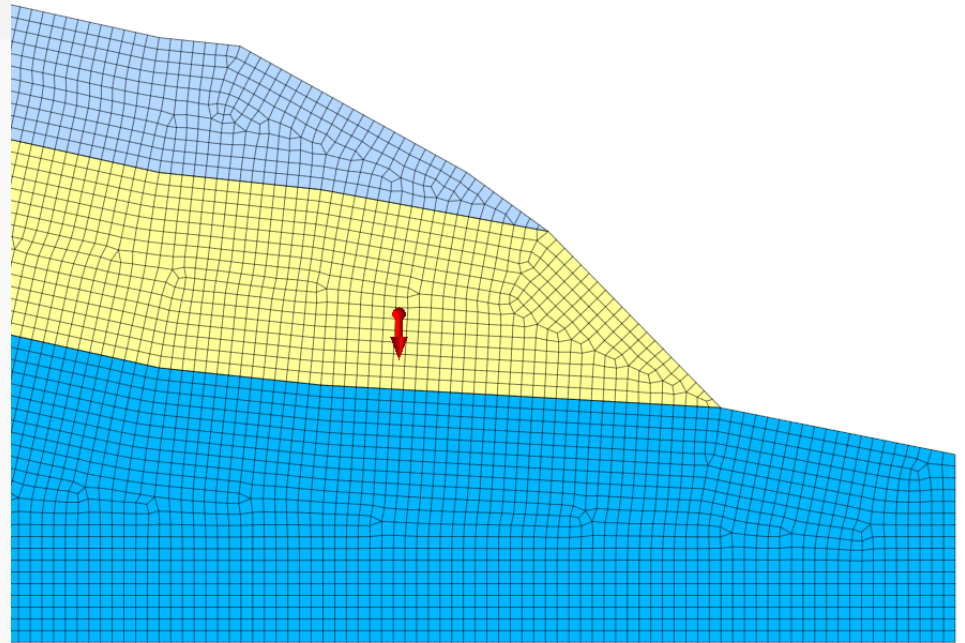
Gz 0

Spatial Distribution

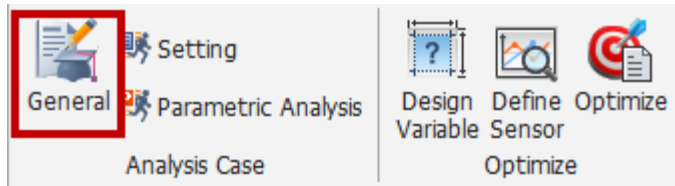
Base Function None

Load Set 垂直地震係數(k_v)

OK Cancel Apply



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 / Error

☐ 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 Control

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

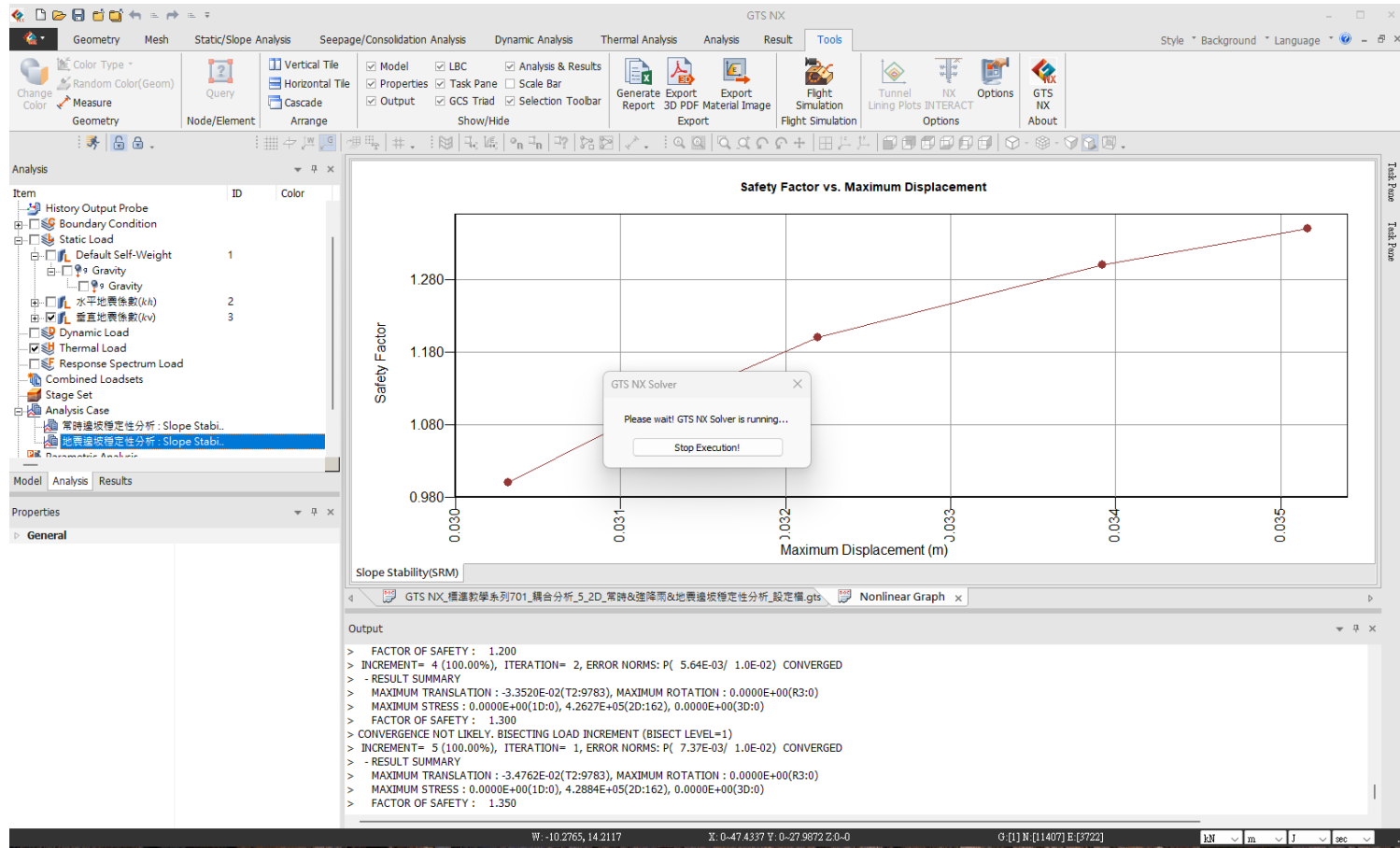
☒ Composite Shell Mid-Plane Results

Number of Beam Output Segments: 4

SRM convergence adjustment

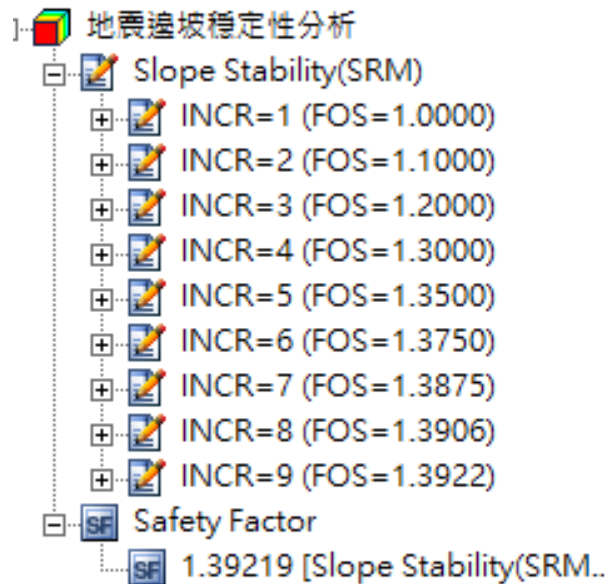
- (1) Initial safety factor 1
- (2) FOS increment by 0.1 each time
- (3) Residual < 0.01, minimum FOS reached

CALCULATION



RESULTS | PSEUDO-STATIC SEISMIC CASE

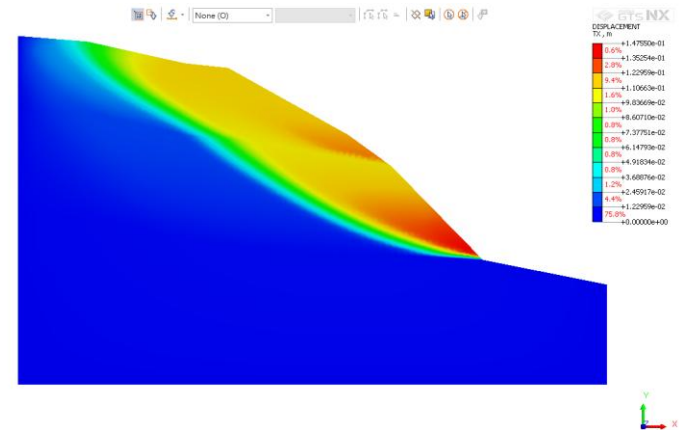
Pseudo-static seismic by k_h & k_v ,
FOS = 1.3922



SRM for safety factor calculation

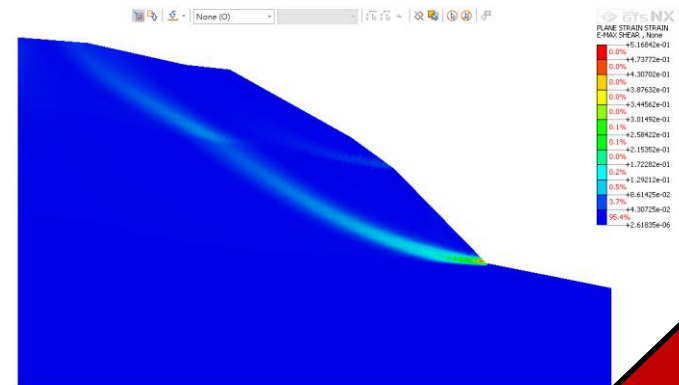
Failure surface indicated by horizontal displacement and maximum shear strain

Tx Translation(m)



[DATA] 地震遠坡穩定性分析, Slope Stability(SRM), INCR=9 (FOS=1.3922), [UNIT] MN, m

Maximum Shear Strain



[DATA] 地震遠坡穩定性分析, Slope Stability(SRM), INCR=9 (FOS=1.3922), [UNIT] MN, m



Part 3

HEAVY RAINFALL CASE

POROUS MATERIAL 1 | WEATHERED SOIL

Weathered Soil

Material

ID: 1 Name: weathered Soil Color:

Model Type: Mohr-Coulomb ☐ Structure

General Porous Non-Linear Thermal Time Dependent

Unit Weight(Saturated): 19.5 kN/m³

Initial Void Ratio(eo): 0.5

☒ Unsaturated Property Loam ...

Drainage Parameters

Drained

☒ Undrained Poisson's Ratio 0.495

☐ Skempton's B Coefficient 0.97383435

Seepage & Consolidation Parameters

Permeability Coefficients

kx	ky	kz	
0.001	0.001	0.001	m/sec

☐ Void Ratio Dependency of Permeability(ck) 0.5

Specific Storativity(Ss) 0.001 1/m Auto

Add/Modify Unsaturated Function

Name	Type	
		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 ³ /m ³)	Or(m ³ /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	6.94444e-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"/>

Loam Data

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

	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

Material 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	
0.0001	0.0001	0.0001	m/sec

☐ 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(Hygi...	Individual

Database

Material database in GTS NX

Unsaturated Function Database

Database: Van Genuchten data(1980)

No	Soil	Ks (m/sec)	Os(m ³ /m ³)	Or(m ³ /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)	3.50694e-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(Guelph_drying)	3.65741e-06	0.52	0.218	1.15	2.03	<input type="checkbox"/>
5	Loam(Guelph_wetting)	0	0.434	0.218	2	2.76	<input type="checkbox"/>
6	Clay(Beit Netofa)	9.49074e-09	0.446	0	0.152	1.17	<input type="checkbox"/>

Van Genuchten date (1980)
Sandstone (Hygiene)

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

OK Cancel

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

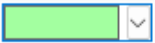
Note 1: The relevant parameters use assumed conditions.

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

POROUS MATERIAL 2 | 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

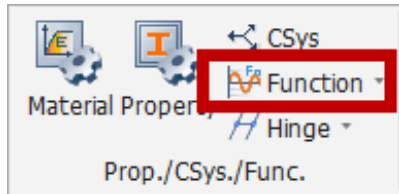
	Coefficient of permeability(K) (m/sec)	Specific Storativity(Ss) (1/m)
Soft Rock	$10^{-6} \sim 10^{-4}$	$10^{-6} \sim 10^{-3}$

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

kN m J hr



Unit (kn/m/J/hr)

Seepage Boundary

Seepage Boundary

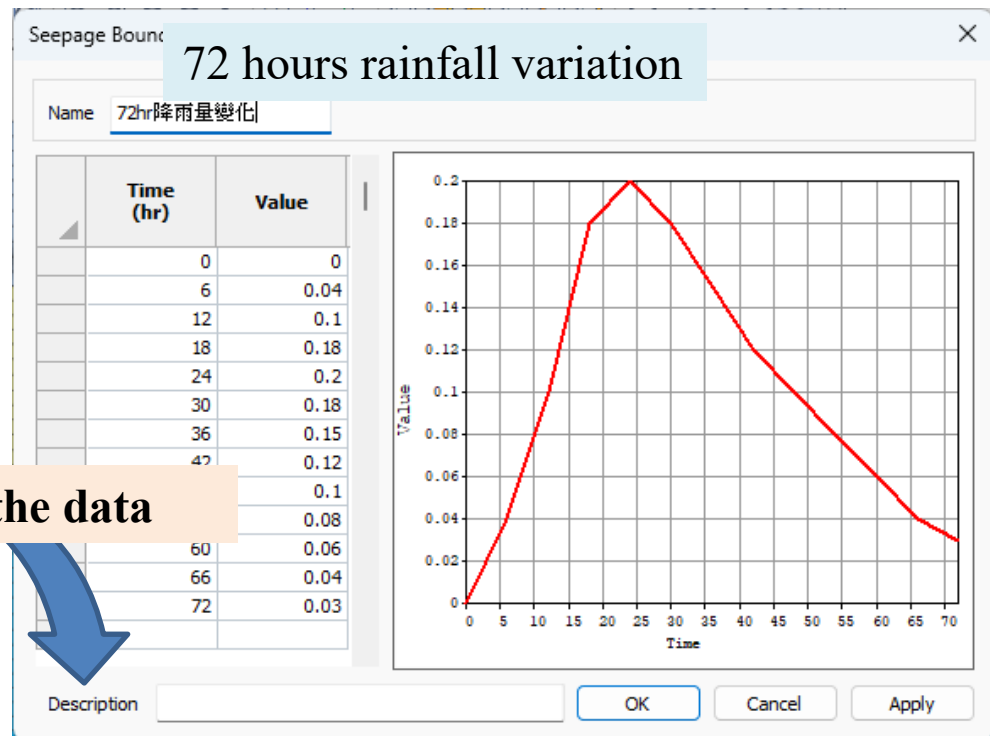
Nonlinear Elastic-Truss
Nonlinear Elastic-Point Spring/Elastic Link
Unsaturated Property
Strain Compatible

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



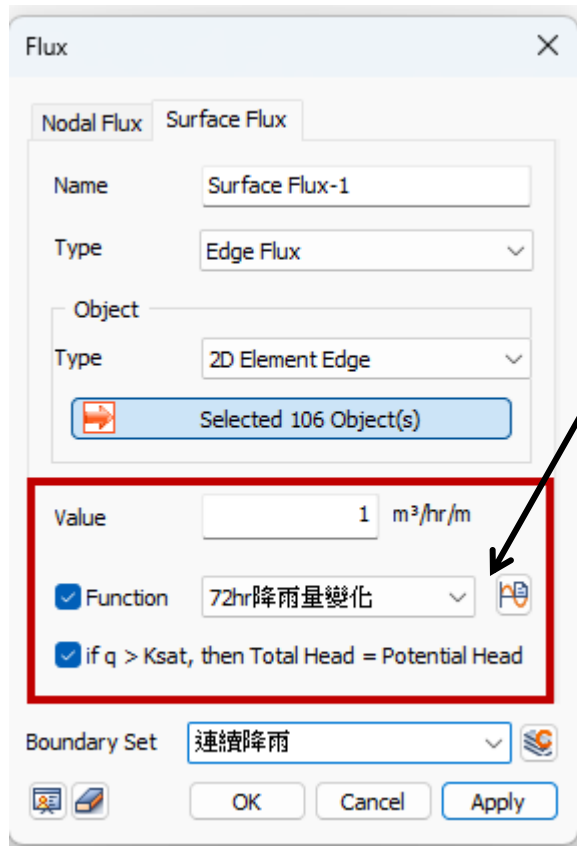
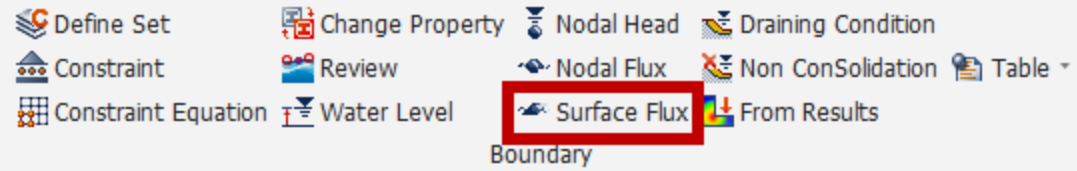
註:GTS NX不支援Y軸單位切換。

SURFACE FLUX

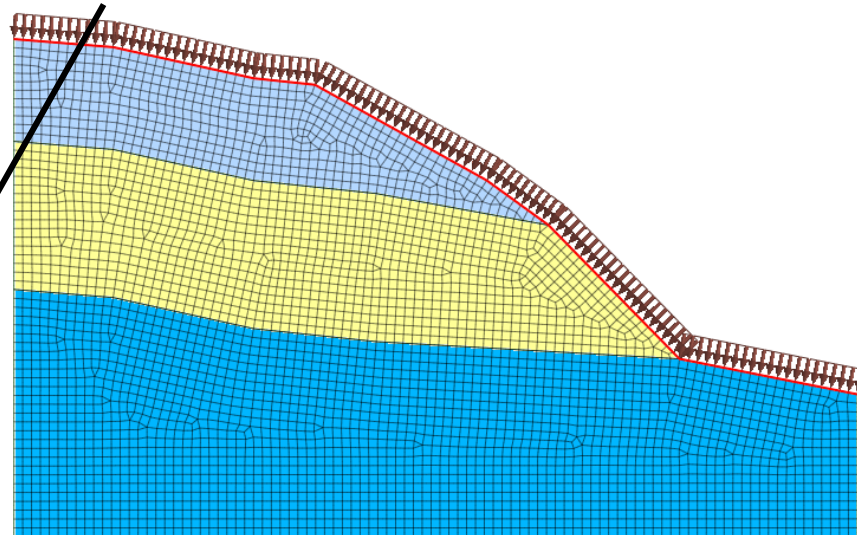
Unit (kN/m/J/hr)

kN m J hr

Seepage/Consolidation Analysis



$$\text{Flux} = \text{Value} \times \text{Function}$$

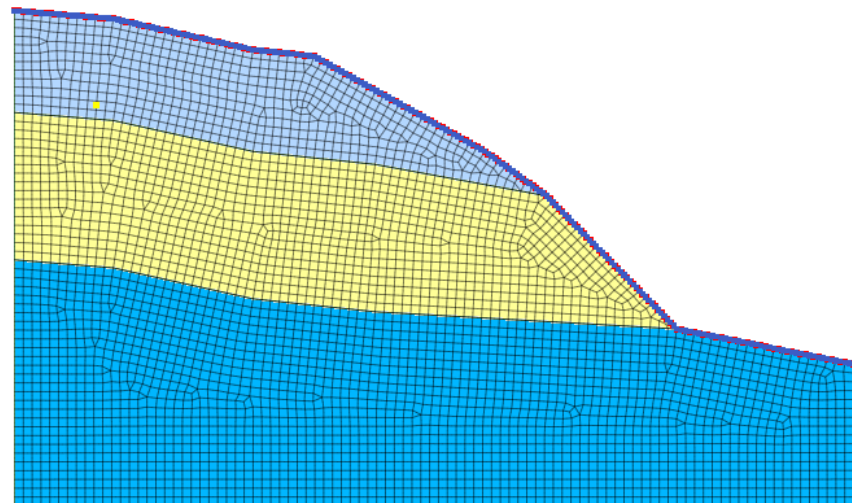
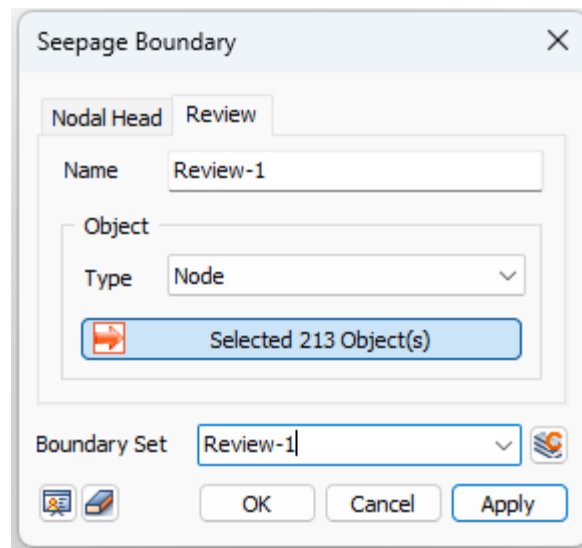


Setting:

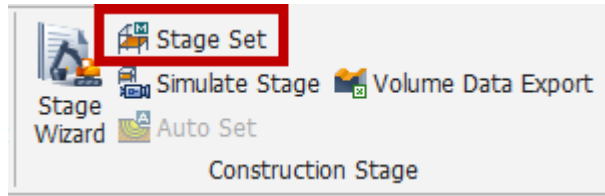
if surface flux $>$ coefficient of permeability
total head = potential head

REVIEW / SEEPAGE

Seepage/Consolidation Analysis



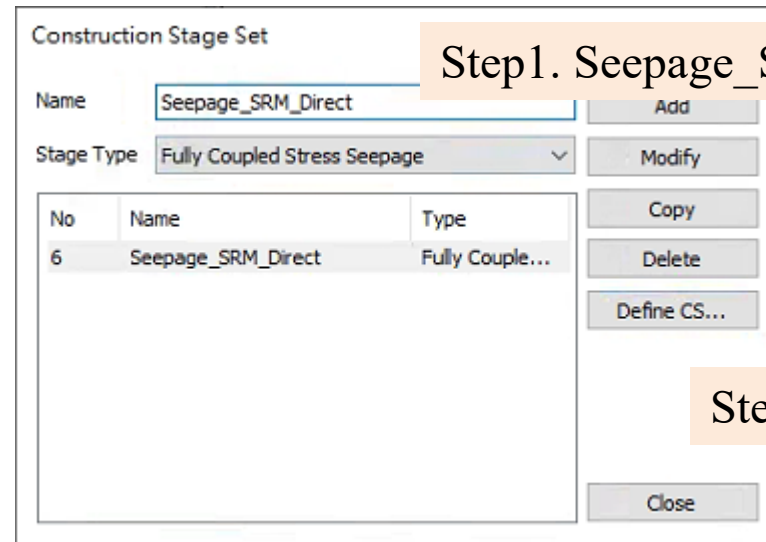
CONSTRUCTION STAGE 1 | PSEUDO-STATIC SEISMIC CASE



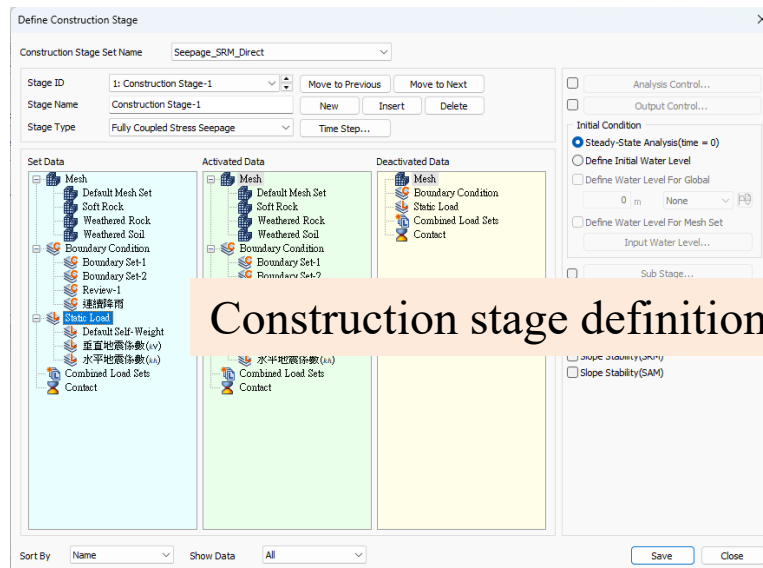
Construction phase types in GTS NX

Fully Coupled Stress Seepage

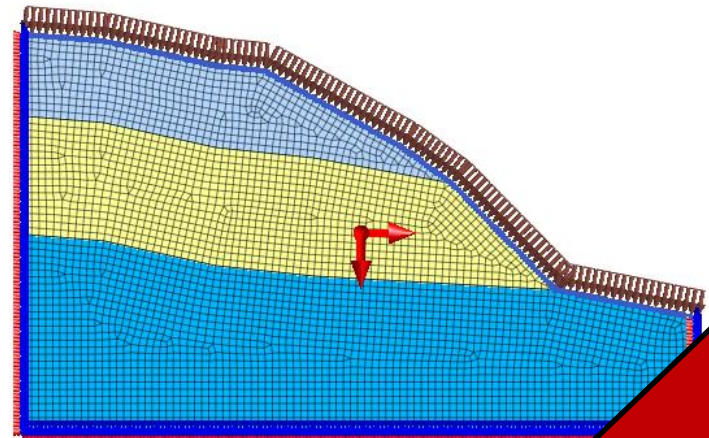
Fully Coupled Stress Seepage
Stress-Nonlinear Time History
Heat Transfer
Seepage-Thermal Stress
Heat of Hydration(Thermal Stress)
Fully Coupled Stress Seepage Heat
Stress-Seepage-Slope-Nonlinear Time History



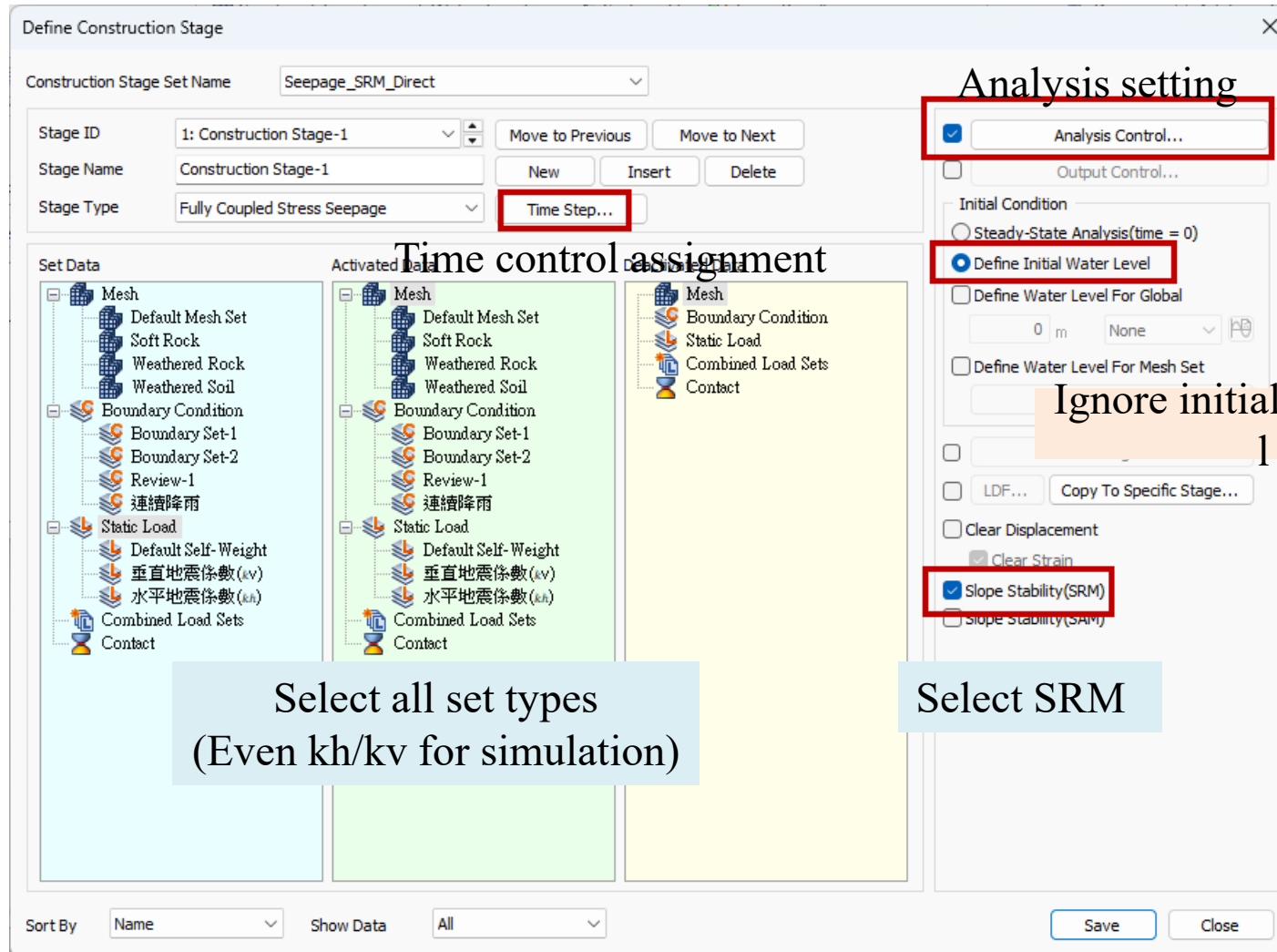
Step2.Define CS



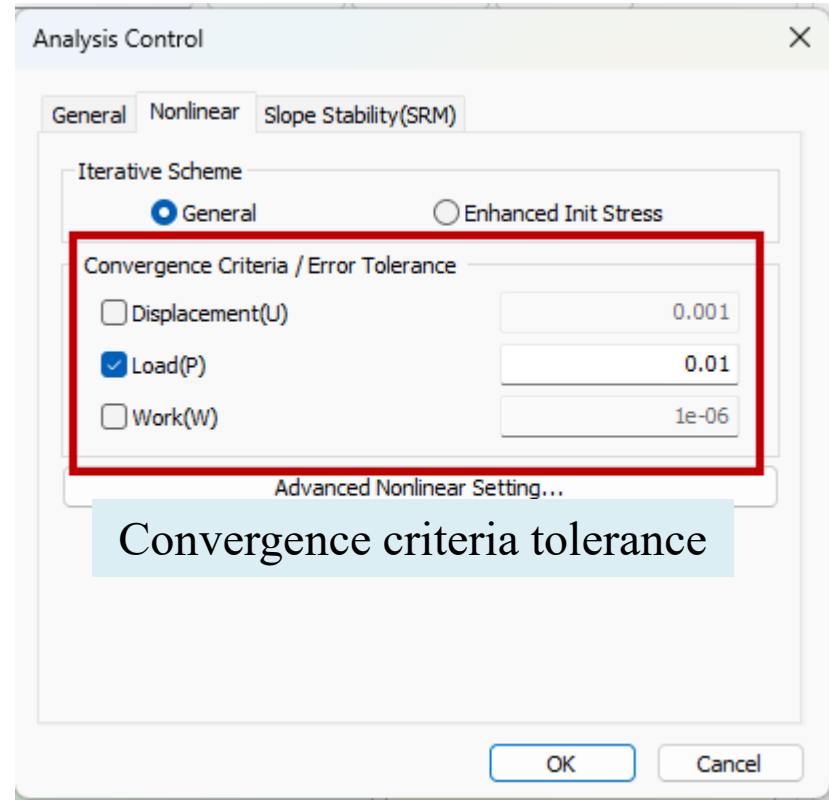
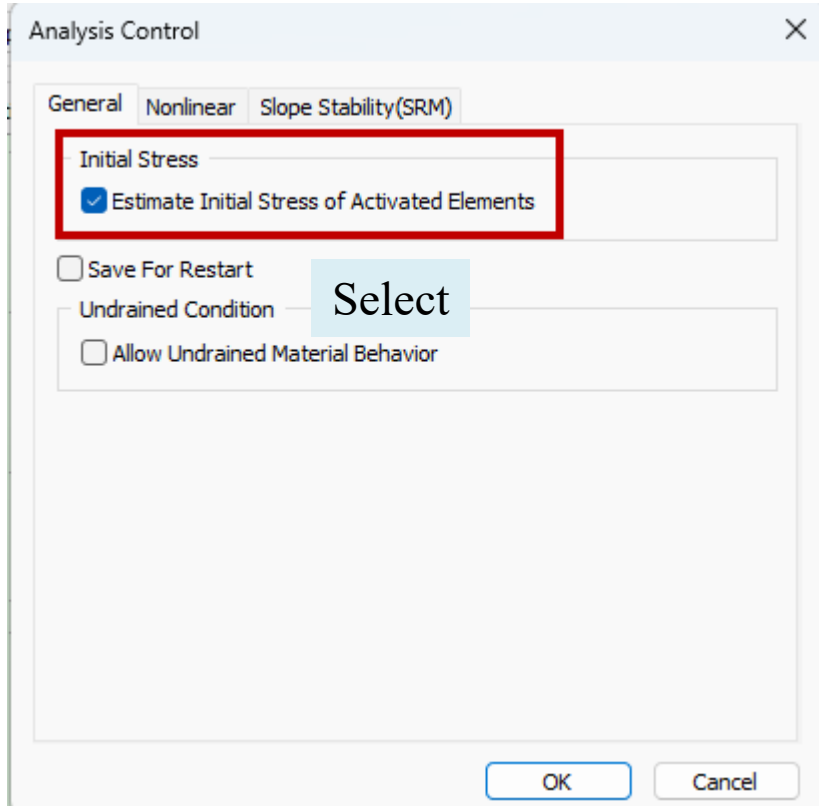
Activate all mesh sets/boundary sets



CONSTRUCTION STAGE 2 | FULLY COUPLED STRESS SEEPAGE



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

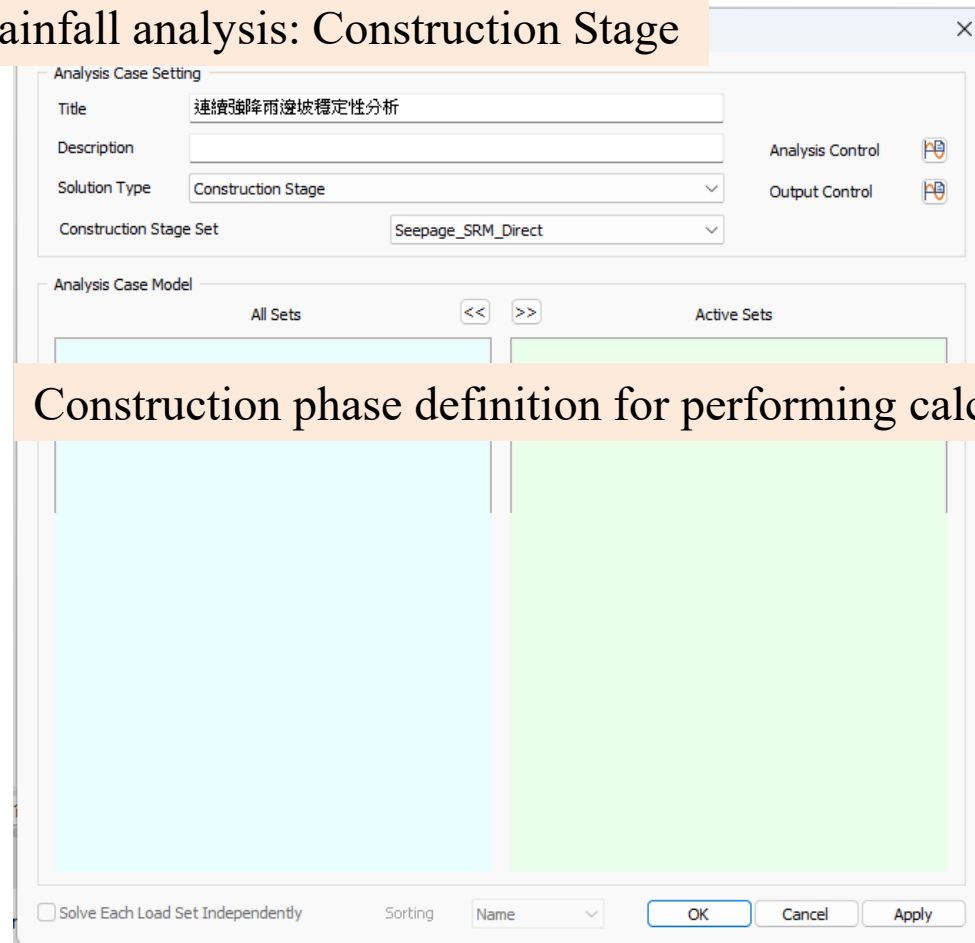
ANALYSIS | HEAVY RAINFALL CASE



72hr of heavy rainfall analysis: Construction Stage

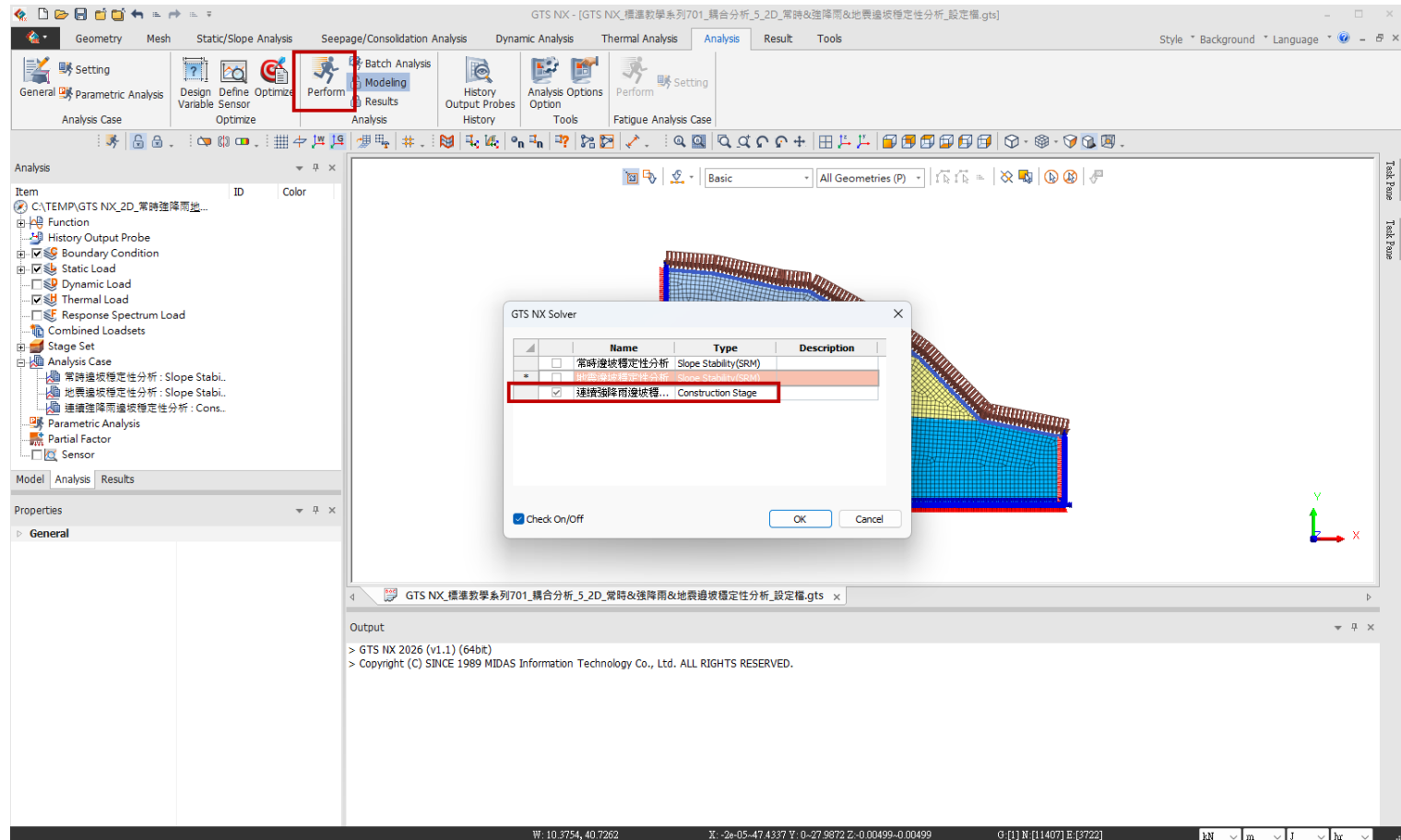
Construction Stage

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

連續強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=1.296e+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)

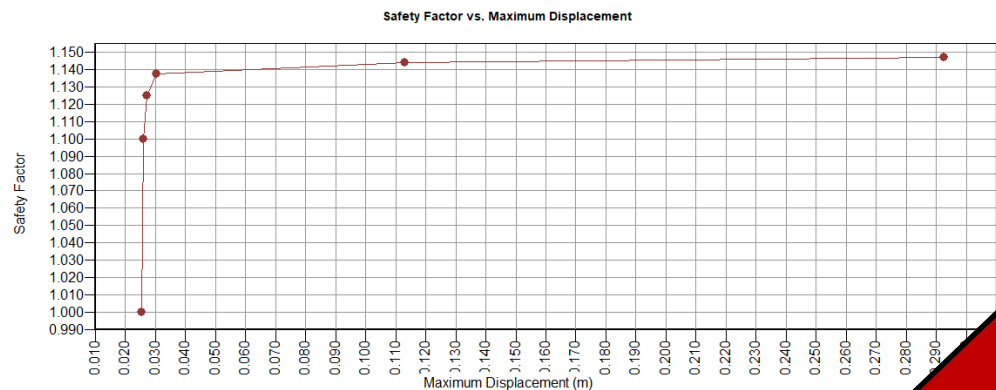
SRM is calculated from the last step

- INCR=29 (TIME=2.376e+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

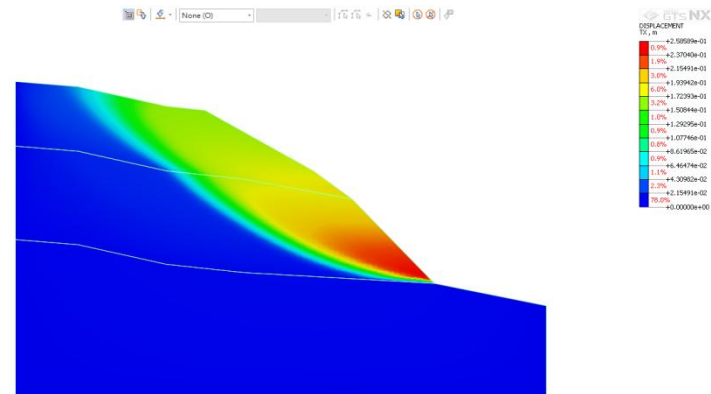
Failure surface indicated by horizontal displacement
& maximum shear strain

Heavy rainfall simulation, FOS = 1.1469

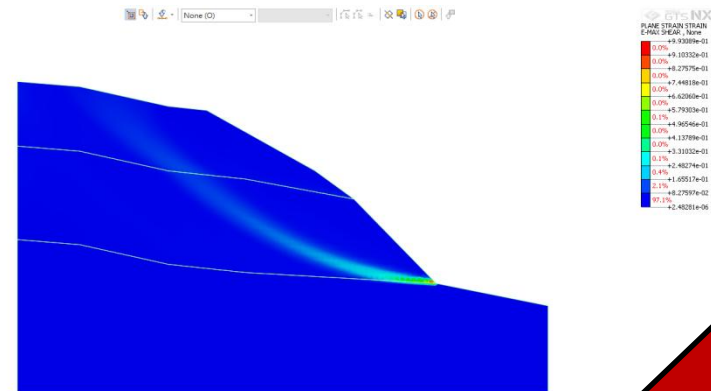
- Construction Stage-1-SRM
 - INCR=1 (FOS=1.0000)
 - INCR=2 (FOS=1.1000)
 - INCR=3 (FOS=1.1250)
 - INCR=4 (FOS=1.1375)
 - INCR=5 (FOS=1.1438)
 - INCR=6 (FOS=1.1469)
- Safety Factor
 - 1.14688 [Construction Stage-1-SRM]

SRM for safety factor calculation

Tx Translation(m)



Maximum Shear Strain



[DATA] 連續降雨前堤壩穩定性分析, Construction Stage-1-SRM, INCR=6 (FOS=1.1469), [UNIT] MN, m

[DATA] 連續降雨前堤壩穩定性分析, Construction Stage-1-SRM, INCR=6 (FOS=1.1469), [UNIT] MN, m