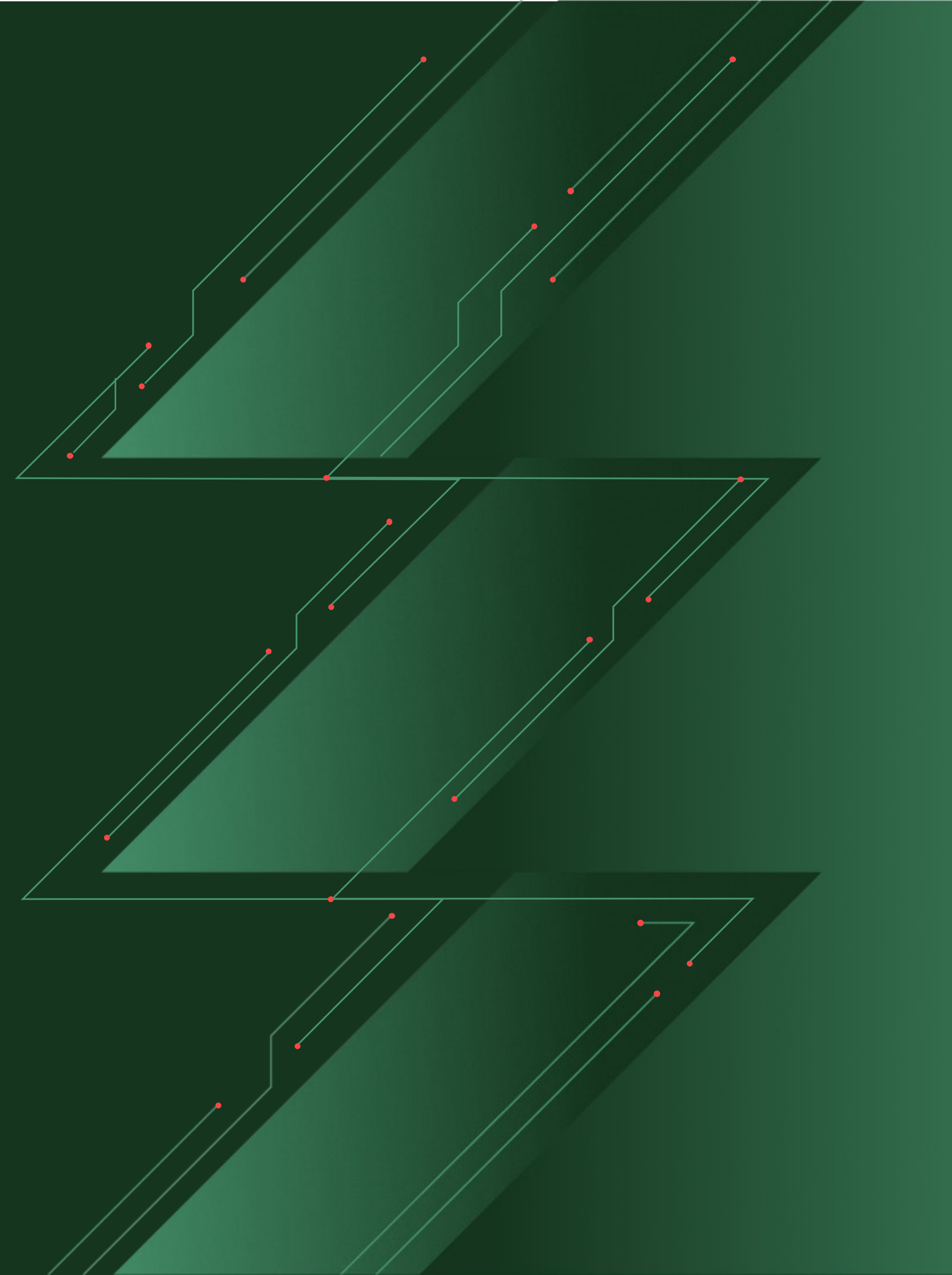


Global and Local Slope Stability: Strength Reduction Method for Factor of Safety Determination

Dr. Praveen Huded | Geotechnical Engineer, MIDAS IT



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01 Introduction

- Geometry, Meshing, and Analysis Features

02 Slope Stability Analysis

- Limit Equilibrium Method
- Strength Reduction Method

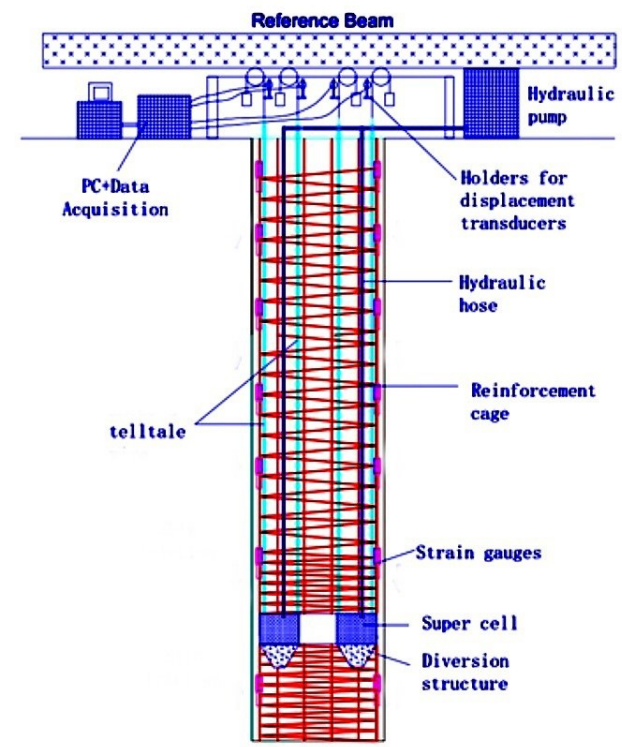
03 Problem Statement

- Slope Stability Analysis

04 Results

GTS NX

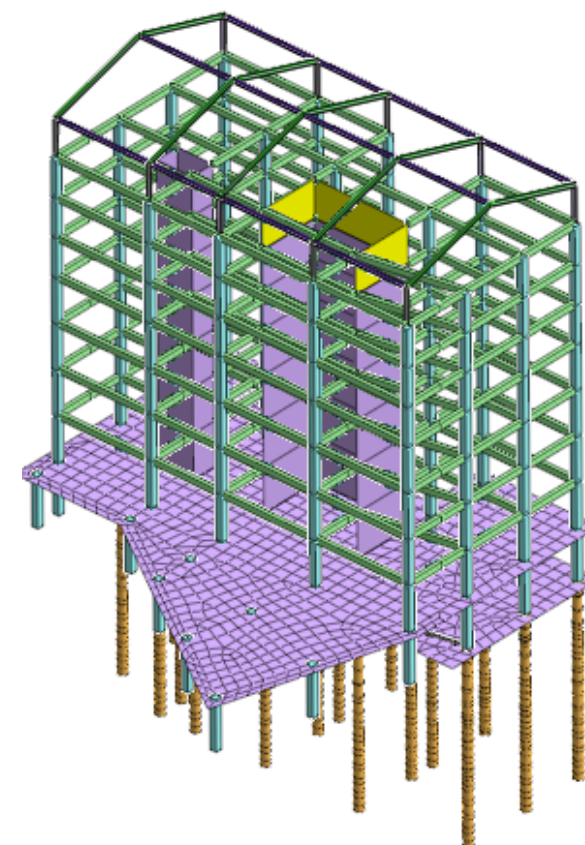
Finite element analysis
platform for geotechnical
applications



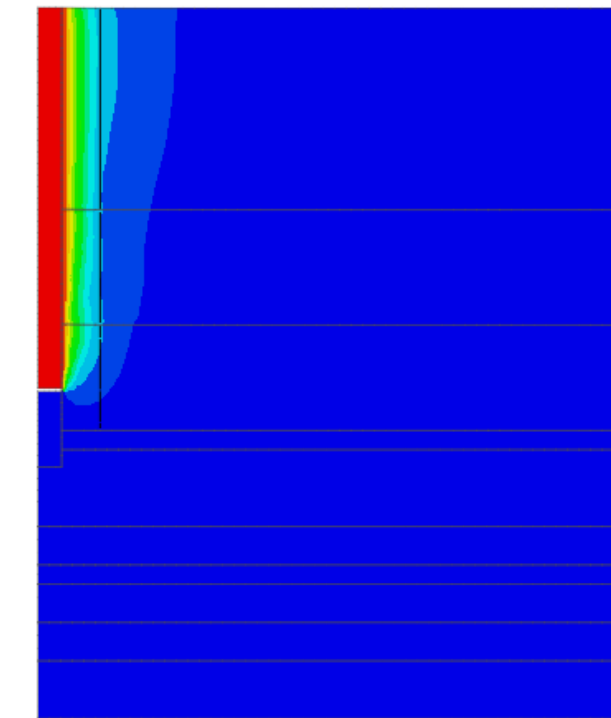
O-Cell Test



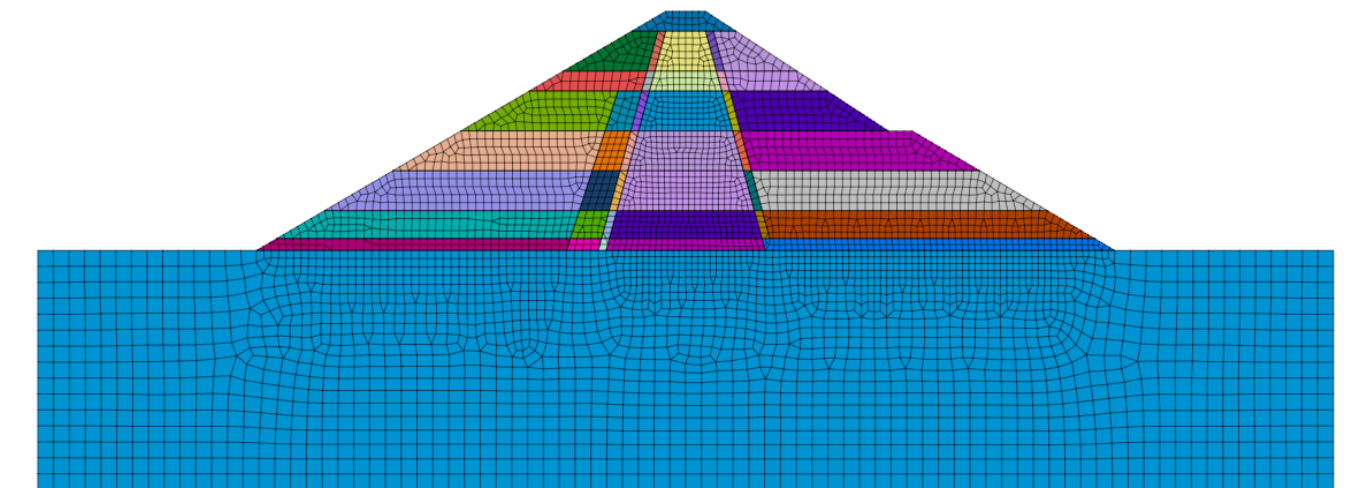
Earthen Dam/Embankment



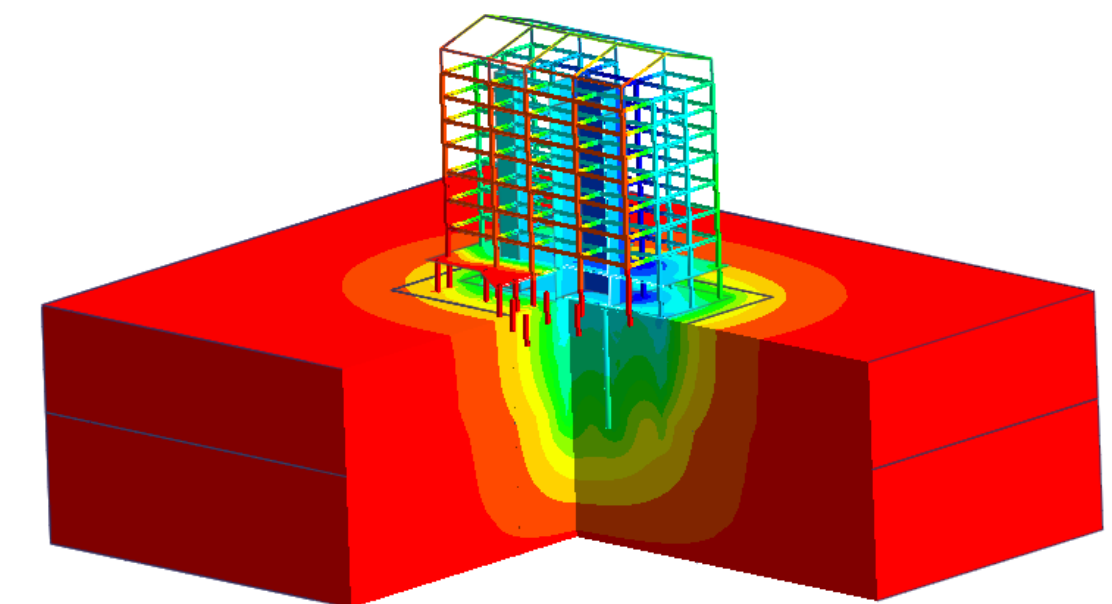
Pile Raft Foundation



Axisymmetric

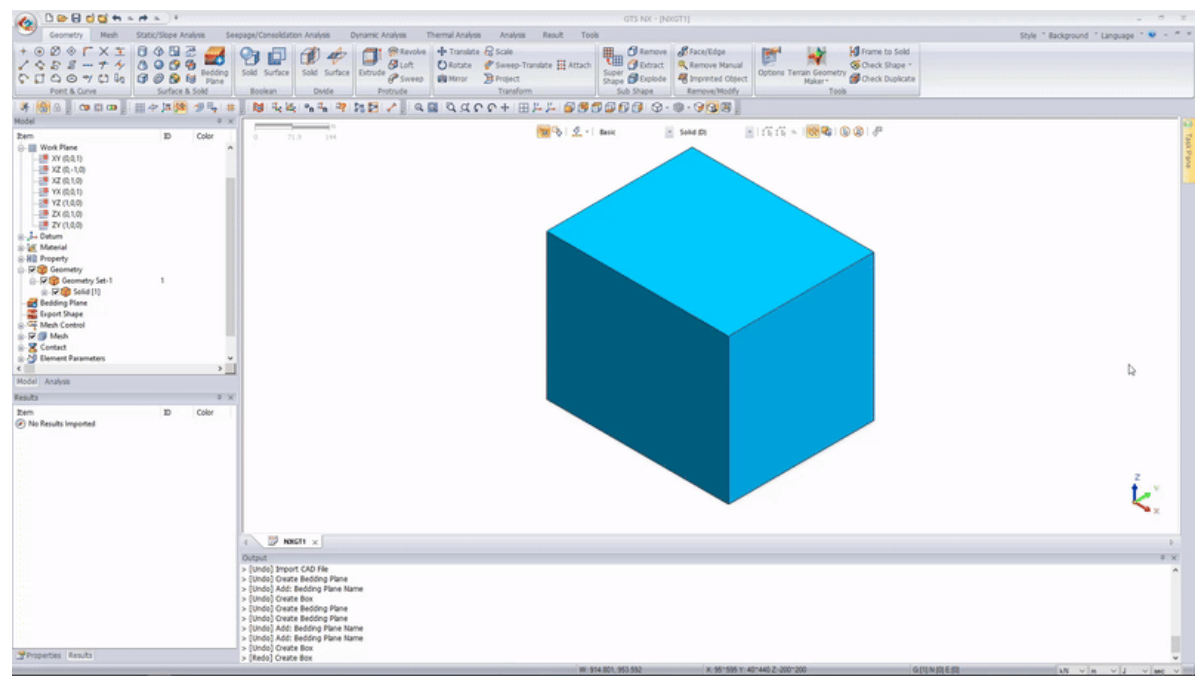


Plane Strain Model

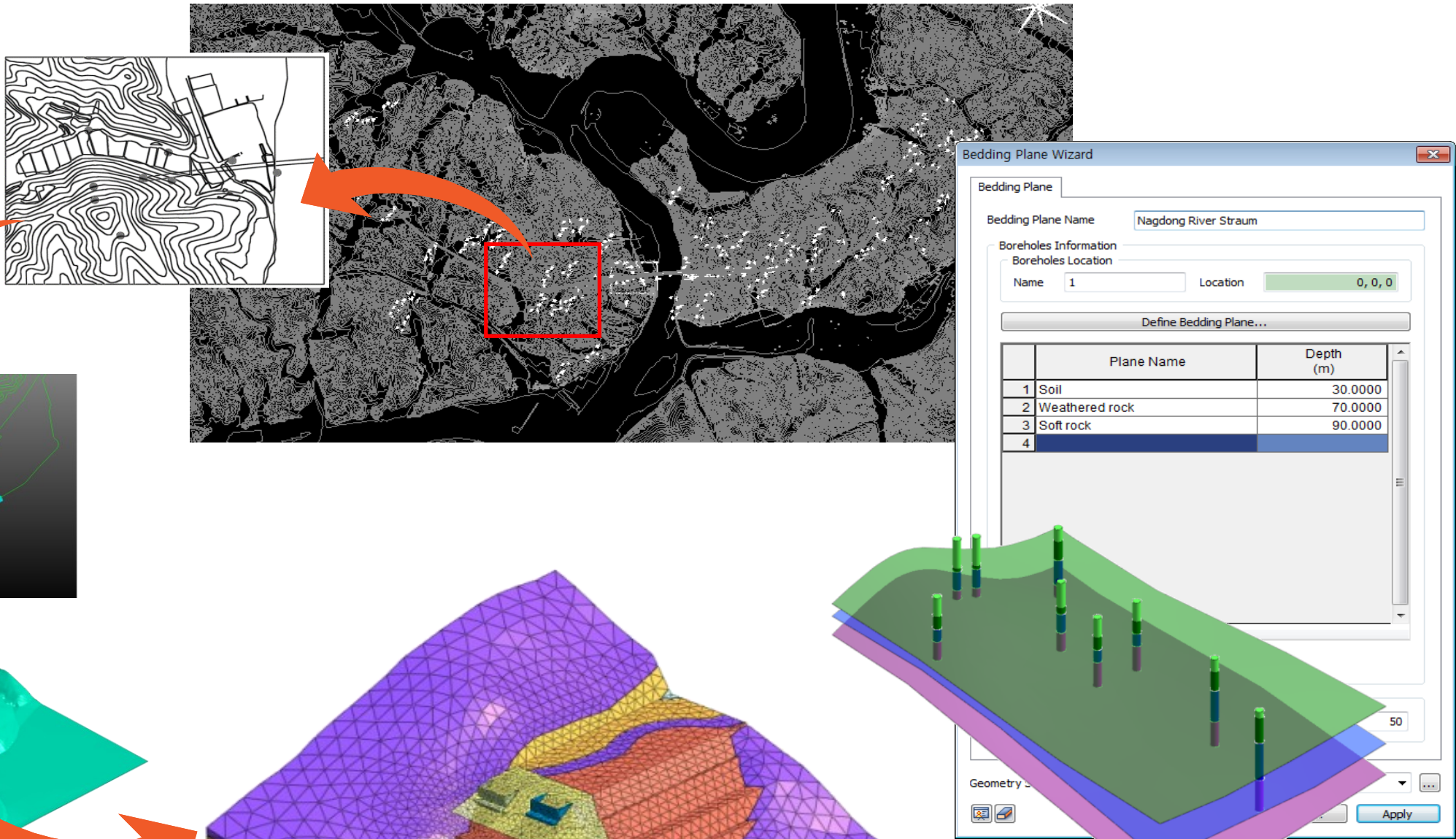


3D Model

Topography and Soil Stratum development



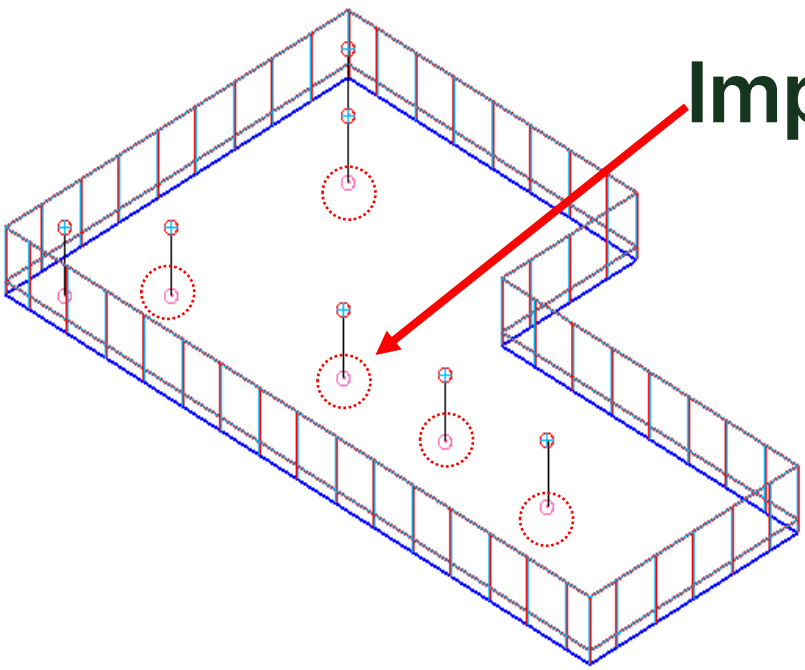
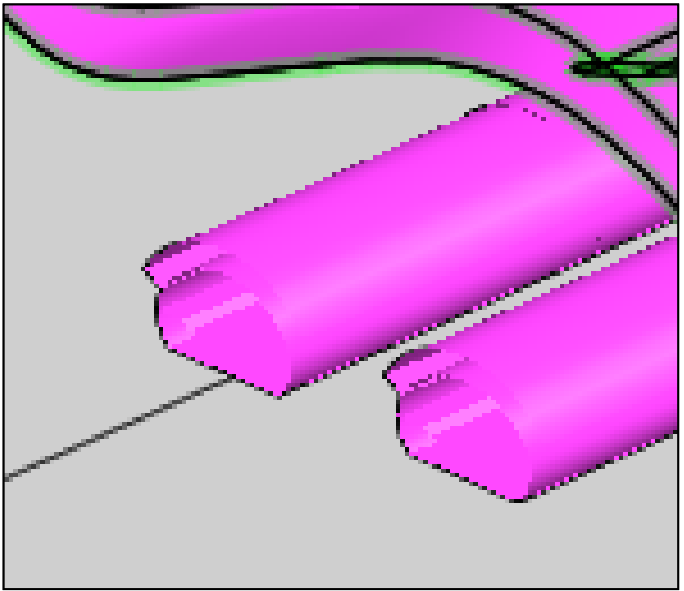
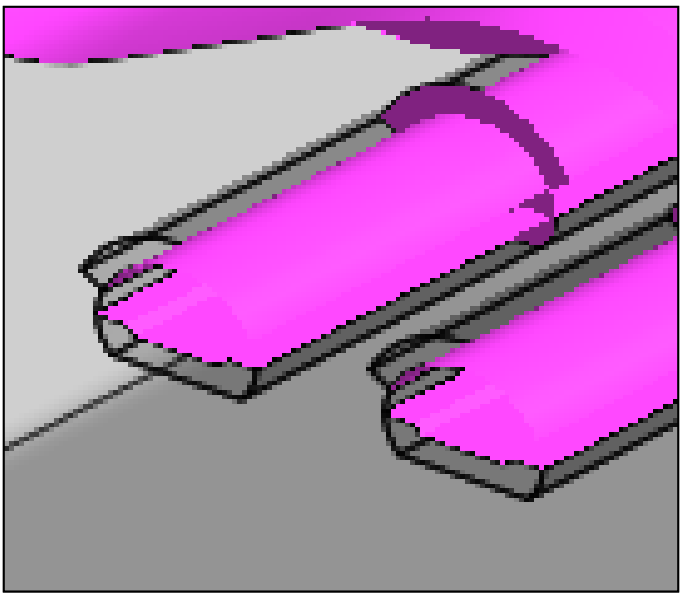
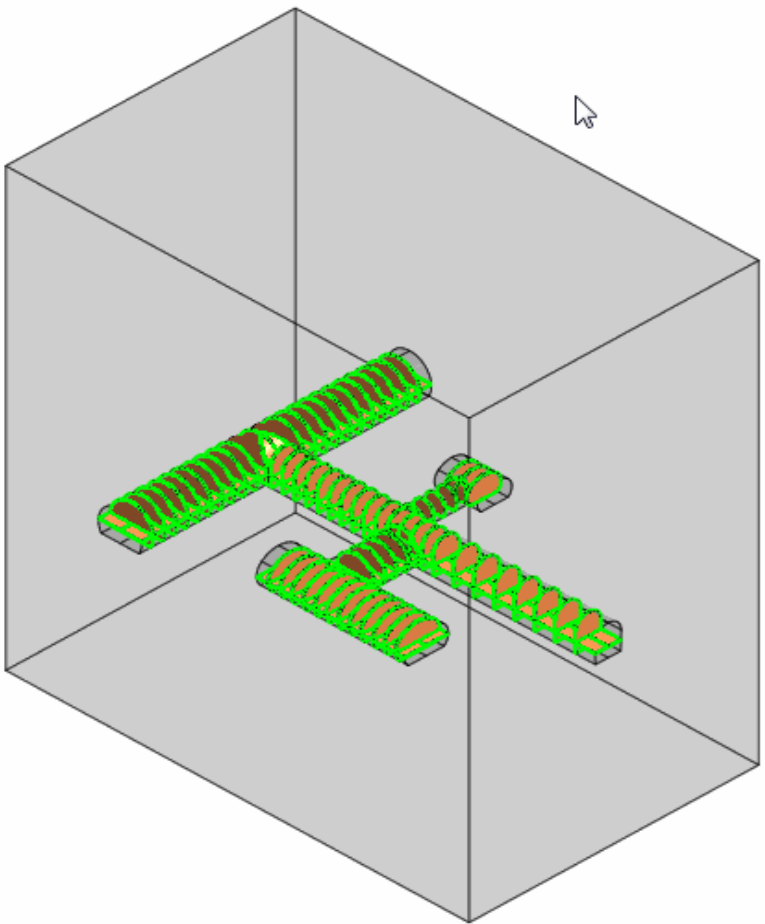
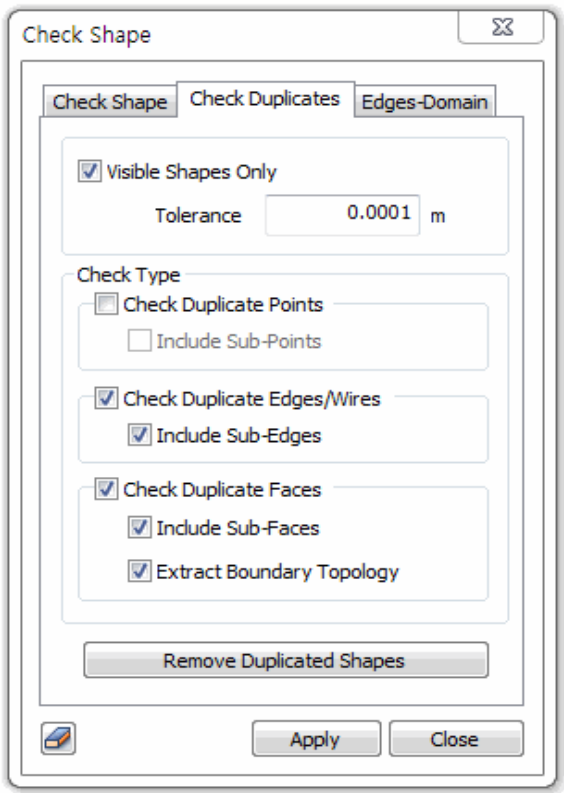
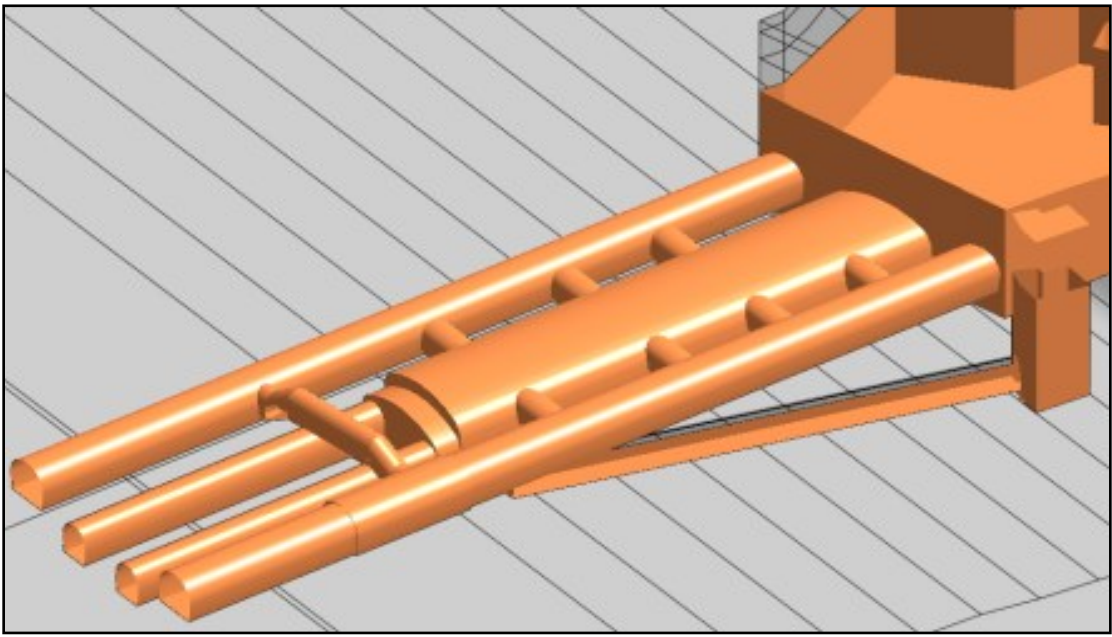
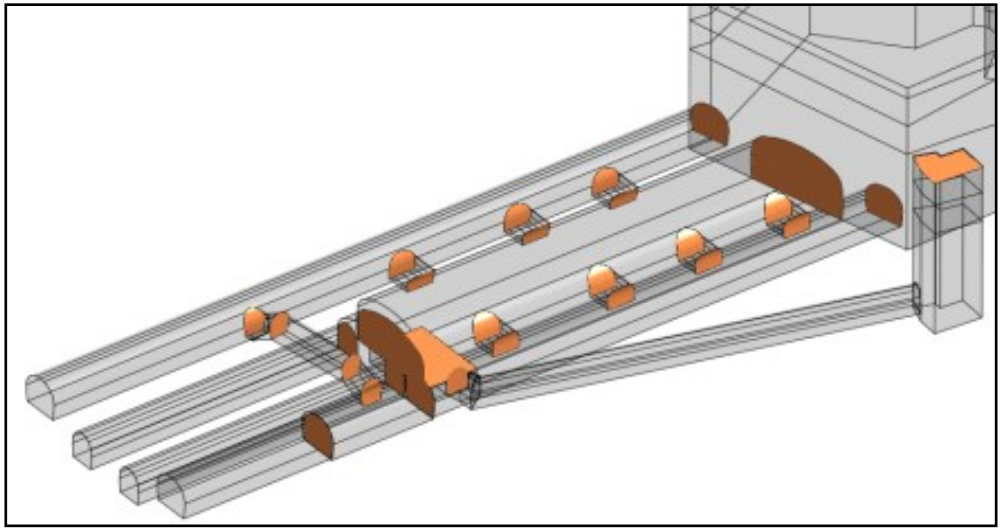
Bedding Plane Wizard



Terrain Geometry Maker-
Create ground surface
using topography data

Bedding Plane
Wizard-Generates
soil strata using
borehole data

Automated modeling function



Imprint Points

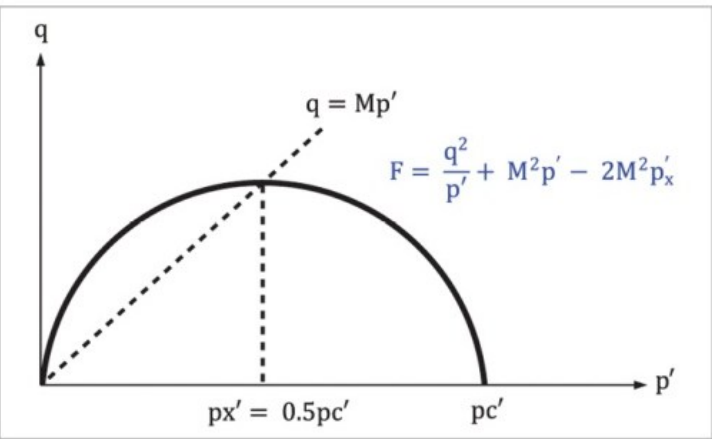
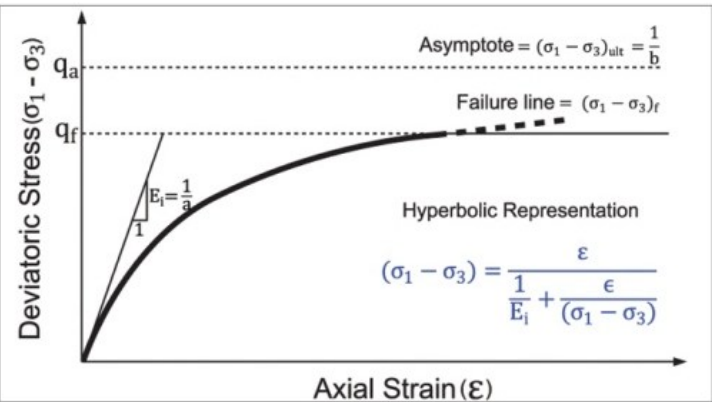
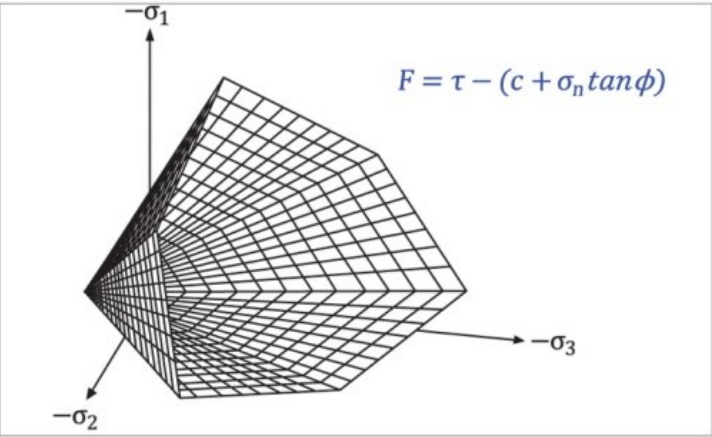
Material Models

Elastic Materials

- Linear Elastic Isotropic
- Linear Elastic
- Transversely Isotropic
- Interface Elastic
- Nonlinear Elastic (1D)
- Jardine
- D-Min
- Hyperbolic (Duncan-Chang)

Plastic Materials

- von Mises
- Tresca
- Mohr-Coulomb
- Drucker-Prager
- Strain-Softening
- Modified Cam Clay
- Jointed Rock
- Modified Mohr Coulomb
- Hoek Brown
- Inverse Rankine
- Coulomb Friction (Interface)
- Janssen

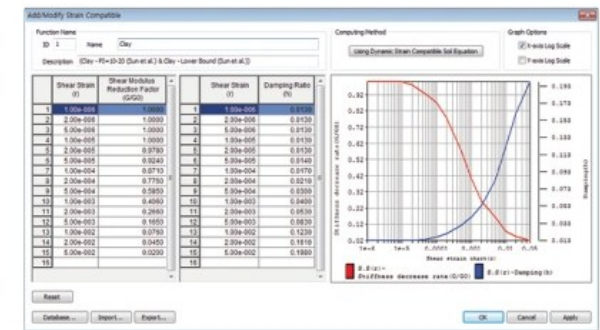


Undrained Materials

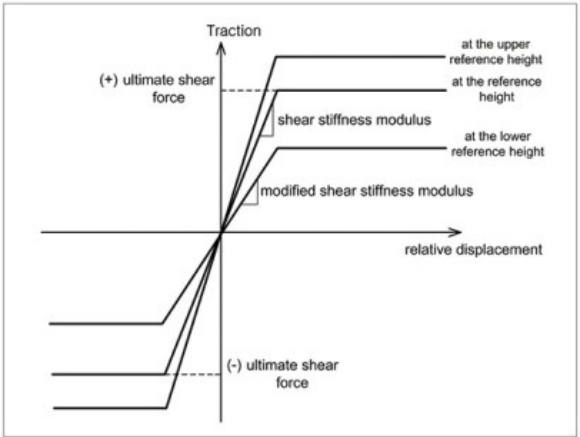
- Effective Stiffness / Effective Strength
- Effective Stiffness / Undrained Strength
- Undrained Stiffness / Undrained Strength

Functions

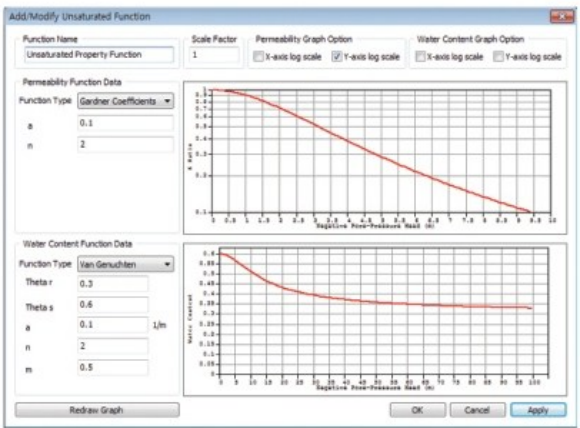
- General non-spatial functions (pile / pile tip bearing nonlinear function)
- Nonlinear elastic functions (truss / point spring / elastic link)
- Unsaturated property functions (Gardner, Frontal, Van Genuchten)
- Strain compatibility functions (2D equivalent linear)



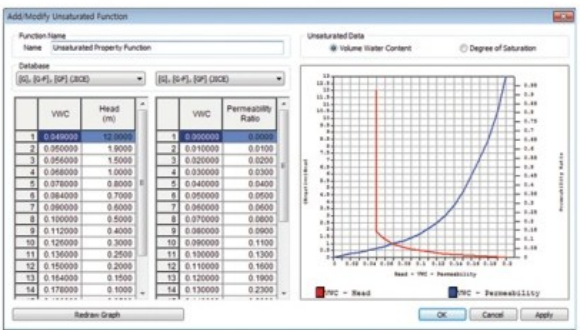
Strain compatibility ▲



Pile bearing ▲



Unsaturated property (Individual) ▲



Unsaturated property (Relation) ▲

- Elastic
- Elastic
- Tresca
- von Mises
- Mohr-Coulomb
- Drucker Prager
- Hoek Brown
- Generalized Hoek Brown
- Hyperbolic(Duncan-Chang E-v)
- Hyperbolic(Duncan-Chang E-B)
- Strain Softening
- Modified Cam Clay
- Jardine
- D-min
- Modified Mohr-Coulomb
- Soft Soil
- Soft Soil Creep
- Modified UBCSAND
- Sekiguchi-Ohta(Inviscid)
- Sekiguchi-Ohta(Viscid)
- Ramberg-Osgood
- Bowl Model with RO
- Hardin-Drnevich
- Hardening Soil(small strain stiffness)
- Generalized SCLAY1S
- CWFS
- Rankine
- Concrete Smeared Crack
- Concrete Damaged Plasticity
- PM4Sand
- GHE-S

Section Property Database

H-Section

Standard

BS-EN

Section

300 ASB 249

UB 838x292x176

UB 762x267x197

UB 762x267x173

UB 762x267x147

UB 762x267x134

UB 686x254x170

UB 686x254x152

UB 686x254x140

UB 686x254x125

UB 610x305x238

UB 610x305x179

UB 610x305x149

UB 610x229x140

UB 610x229x125

H

B1

tw

tf1

B2

tf2

r1

r2

Section Template

Sheet-Pile

Standard

KS(04)

Sub-Shapes

U Type

Section

U:SP-II

U:SP-III

U:SP-IIIa

U:SP-IV

U:SP-VM

U:SP-VA

U:SP-IIW

H

B

tw

Offset

Center-Center

OK

Cancel

Create/Modify 1D Property

Pile

Geogrid(1D)

Plot Only(1D)

Pipe

Truss

Embedded Truss

Beam

Embedded Beam

ID

13

Name

1D Property

Color

Material

5: Conc'

☐ Hinge Property

☐ Taper

	Section-i	Section-j
Cross Sectional Area(A)	0.0318	0.0318 m ²
Torsional Constant(Ix)	2e-005	2e-005 m ⁴
Torsional Stress Coeff.	0.103432966	0.103432966 m
Area Moment of Inertia(Iy)	1.29e-007	1.29e-007 m ⁴
Area Moment of Inertia(Iz)	6.4e-008	6.4e-008 m ⁴
Effective Shear Area(Ay)	0.0150159088	0.0150159088 m ²
Effective Shear Area(Az)	0.0120783266	0.0120783266 m ²
Shear Stress Coefficient(Gy)	86.6083279	86.6083279 1/m ²
Shear Stress Coefficient(Gz)	90.7337143	90.7337143 1/m ²

Stress...

Stress...

y Axis Variable

Constant

z Axis Variable

Constant

☐ Spacing

1 m

☒ Section...

H-Section

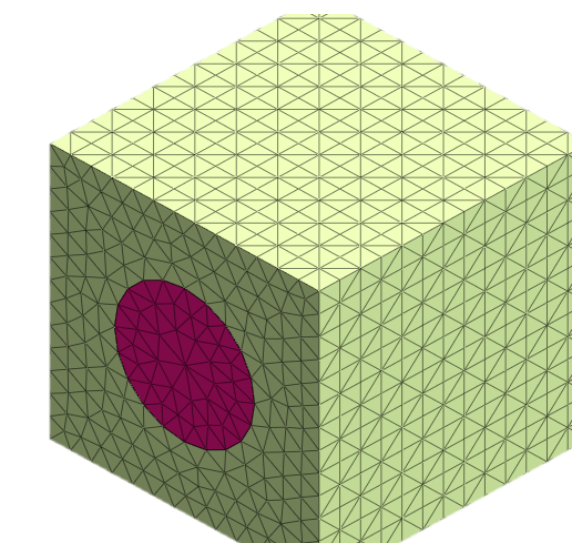
OK

Cancel

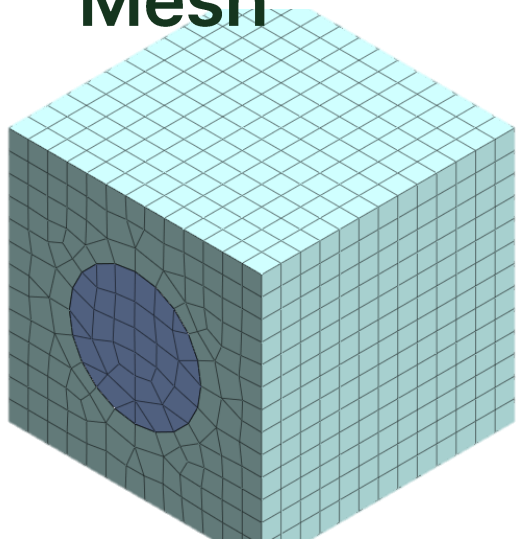
Apply

Automatically Calculate section parameters

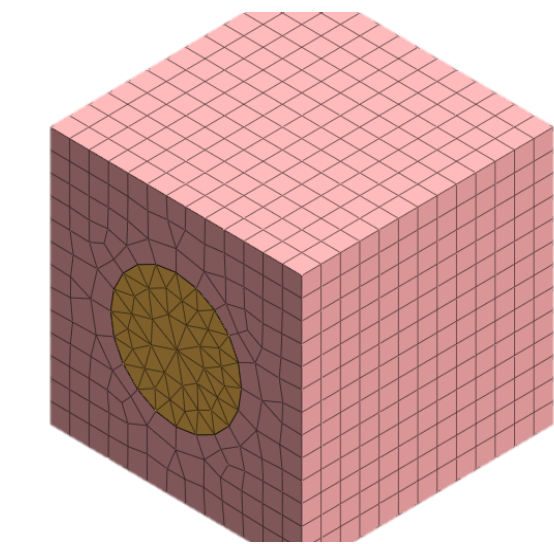
Mesh Generation



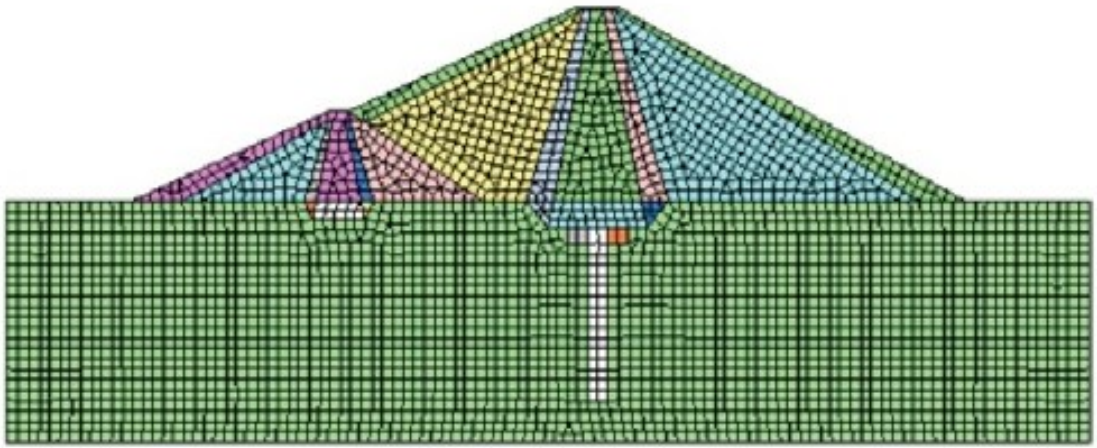
Tetrahedral Mesh



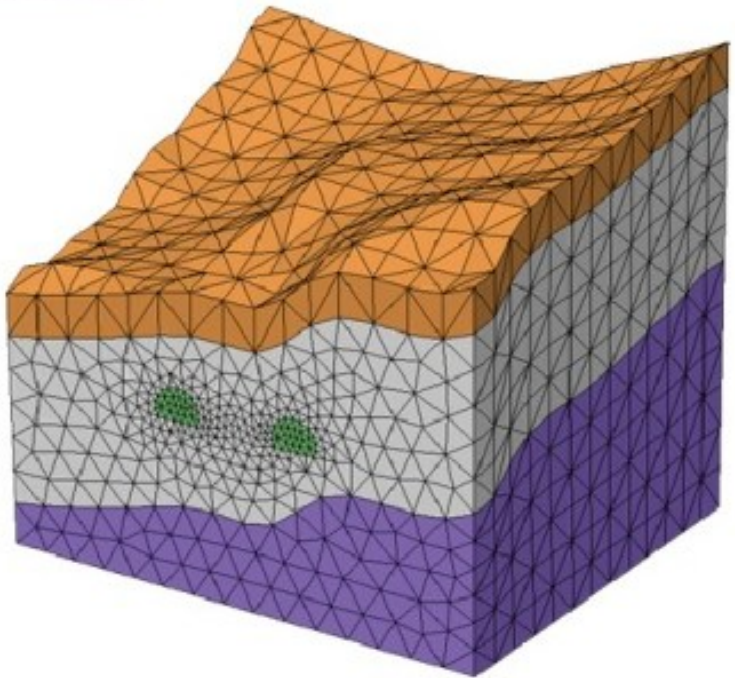
Hexahedral Mesh



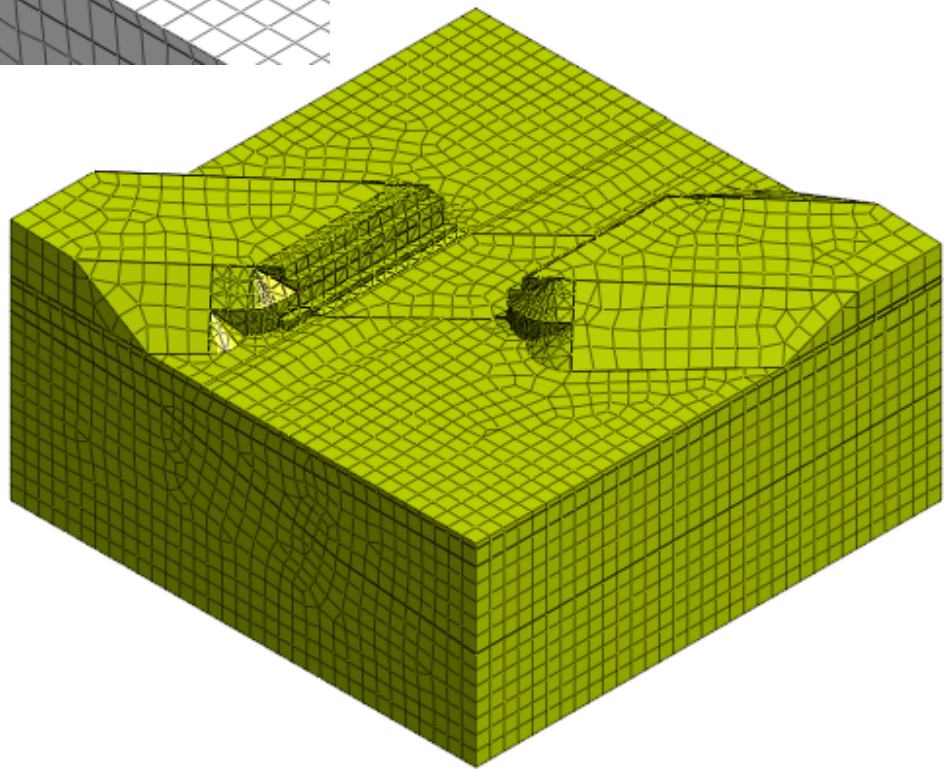
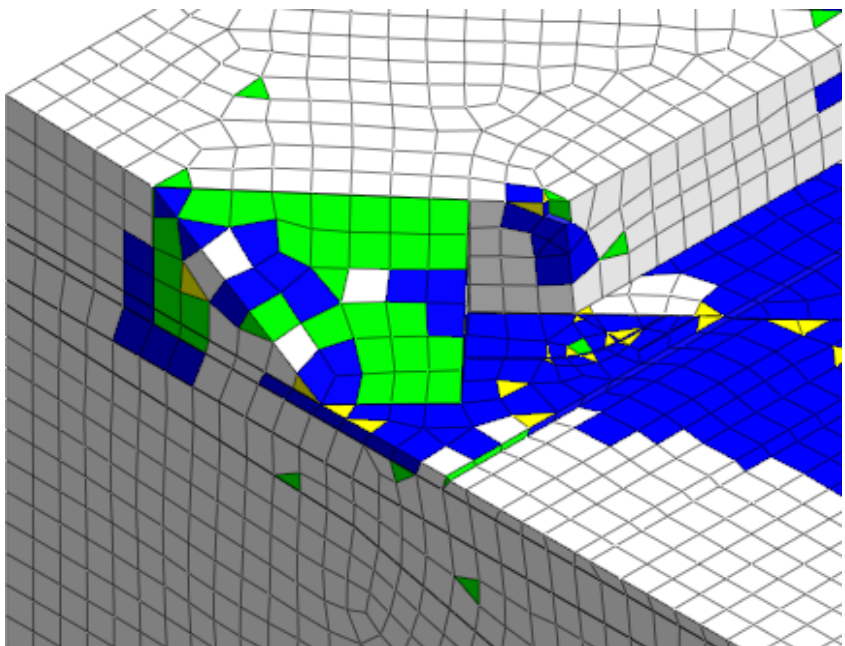
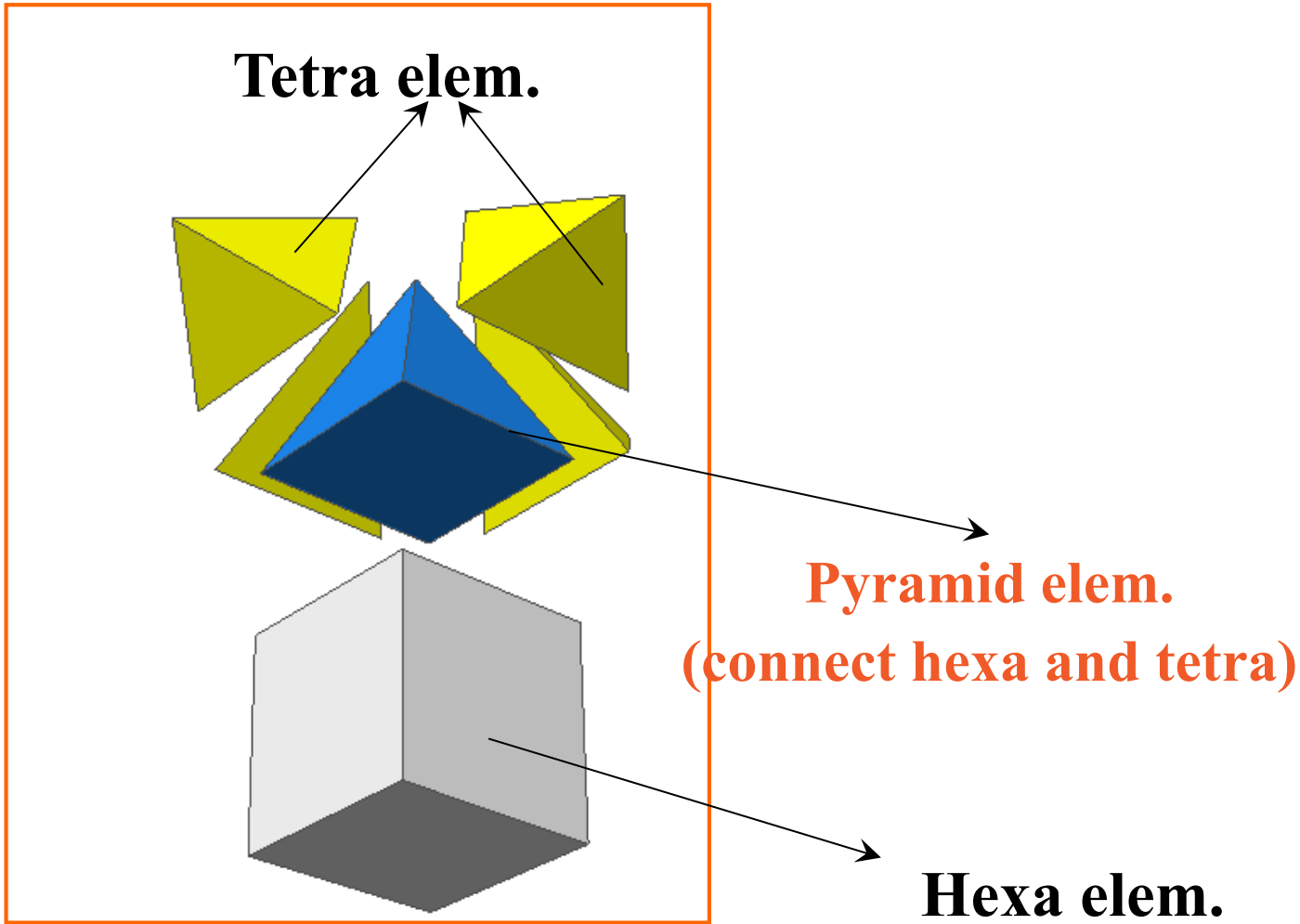
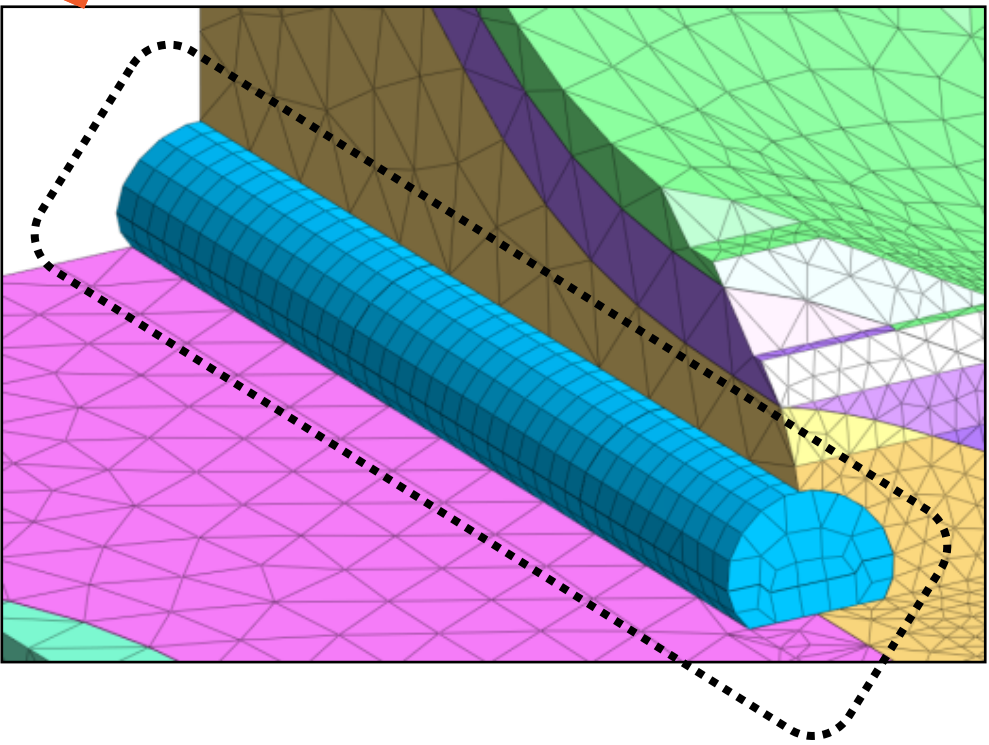
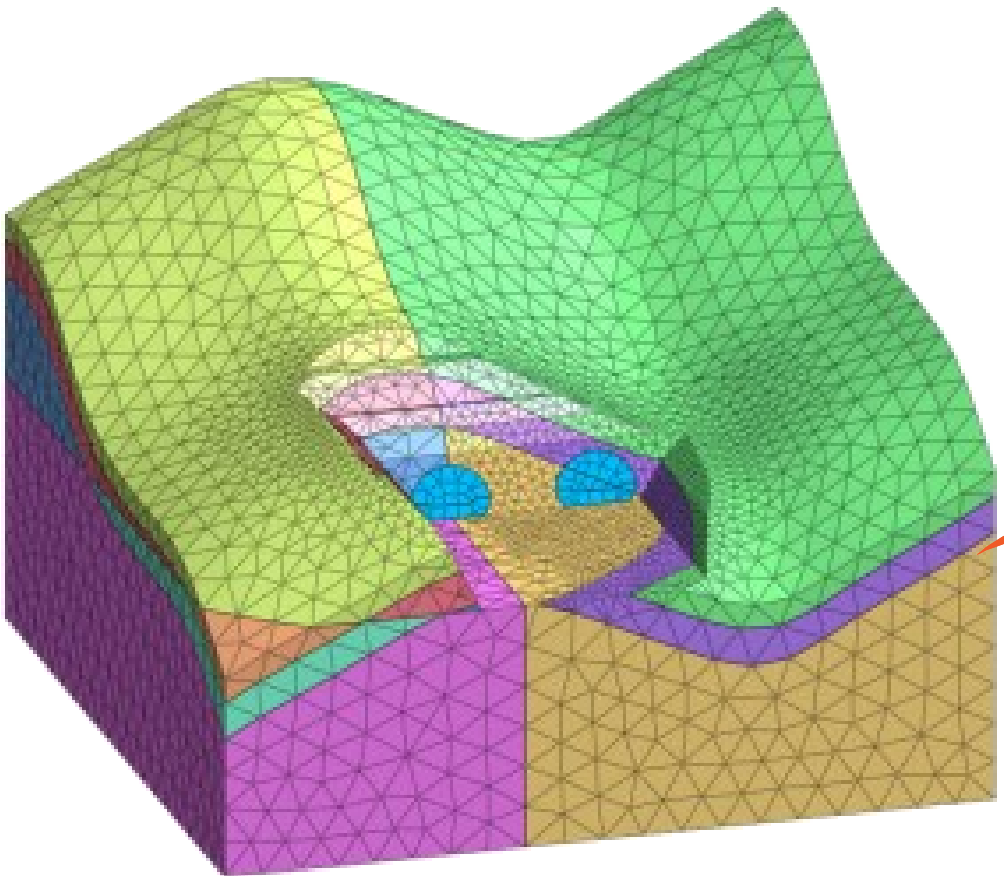
Hybrid Mesh
(Tetra+ Hexa)



2D Auto Mesh



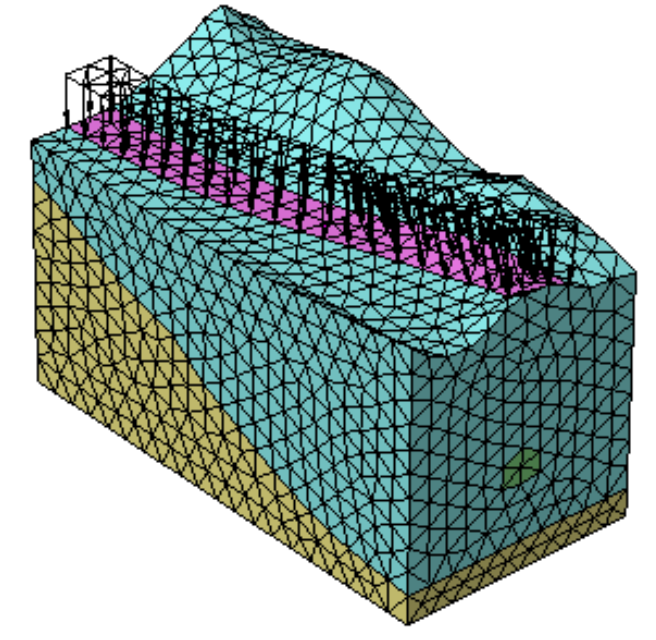
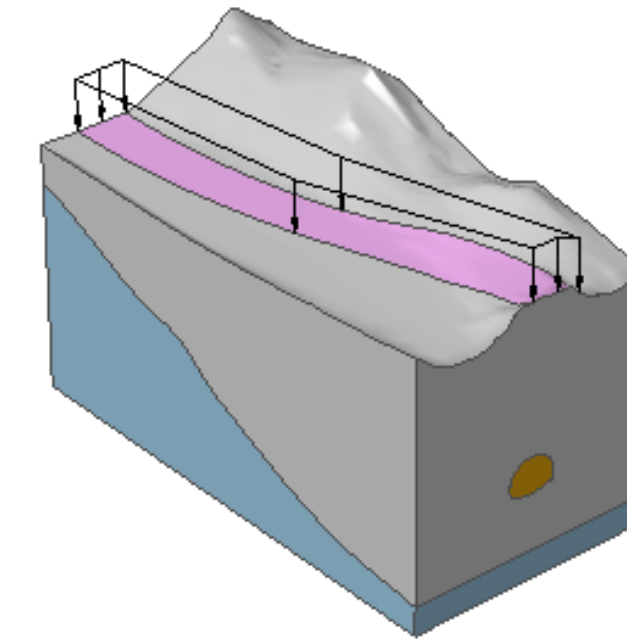
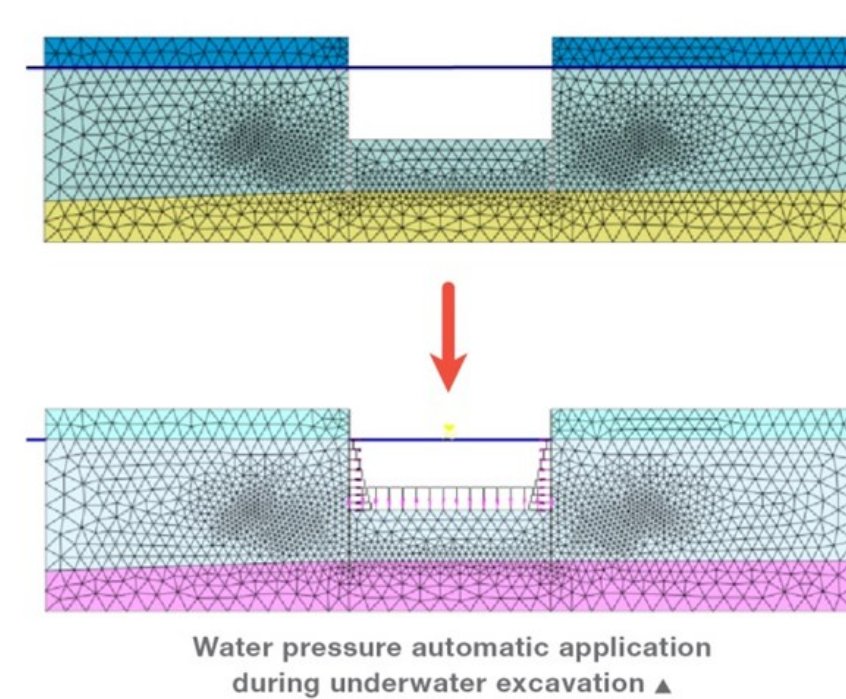
3D Auto Mesh



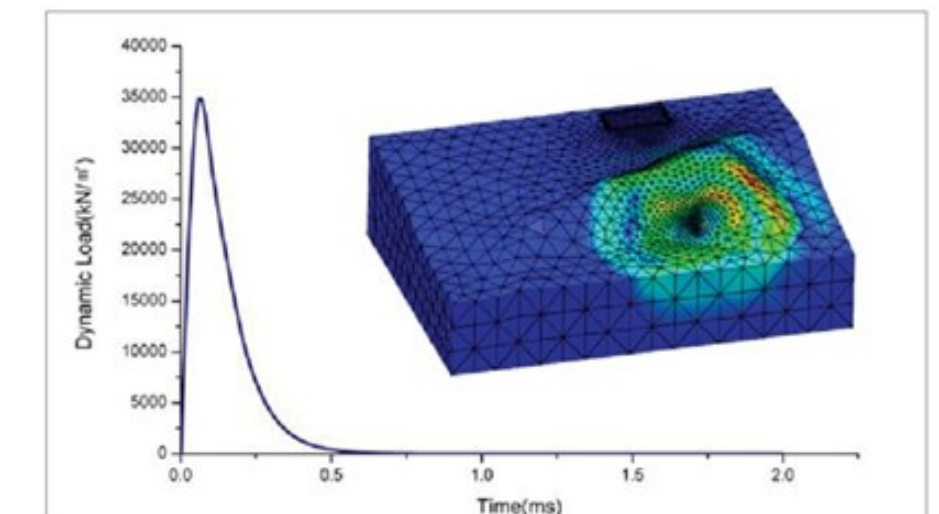
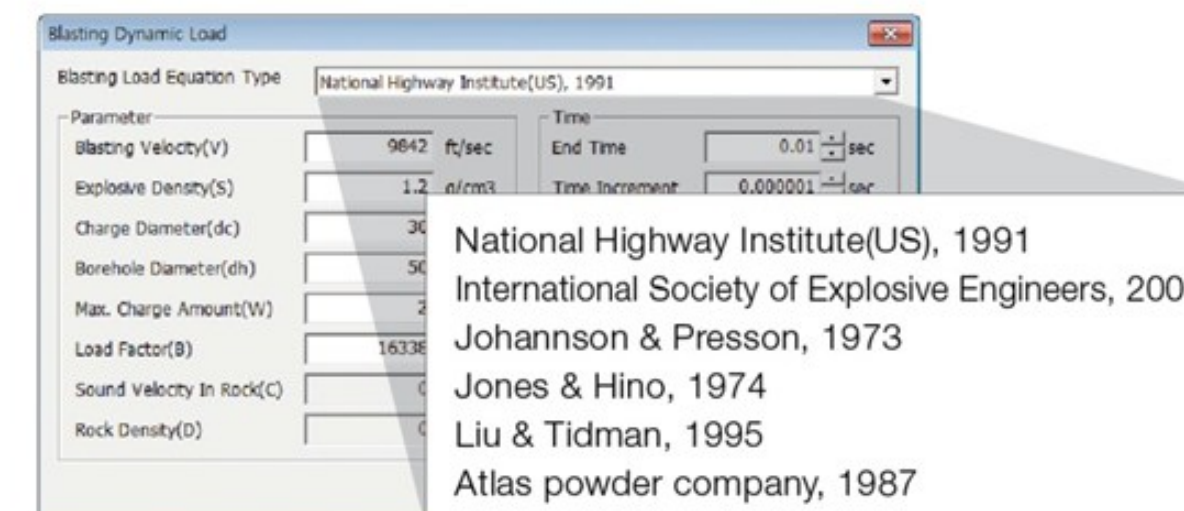
Load Assignment

Static Loads

- Self weight
- Force
- Moment
- Displacement
- Pressure
- Water pressure
- Line beam load
- Element beam load
- Temperature
- Prestress
- Initial equilibrium force
- Combined load

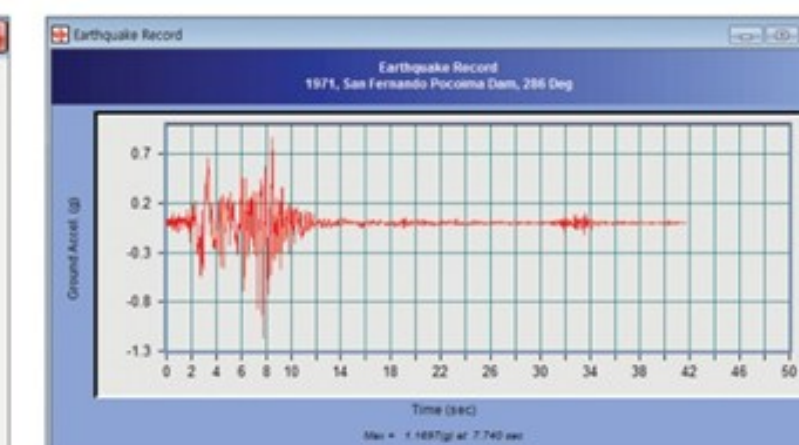
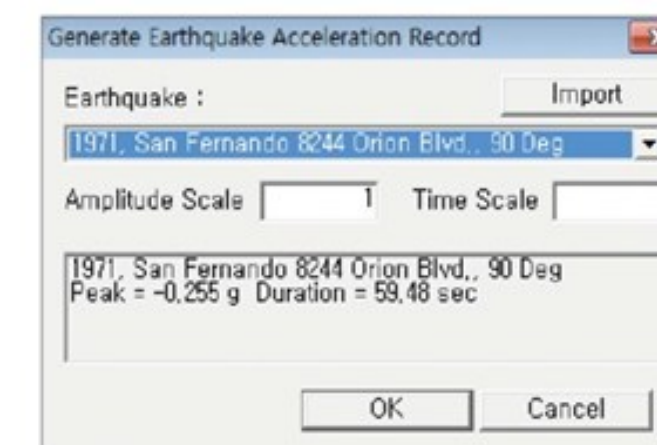


Automatic transfer to FE

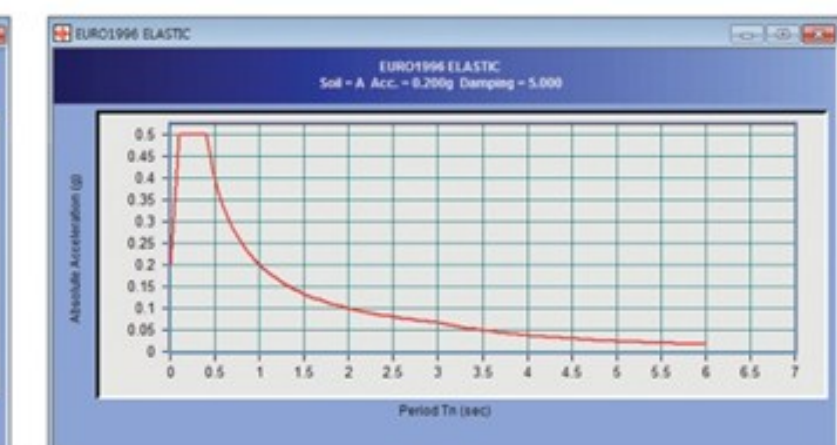


Dynamic Loads

- Response spectrum
- Ground acceleration
- Time varying static
- Dynamic nodal
- Dynamic surface
- Load to Mass
- Train Dynamic Load Table

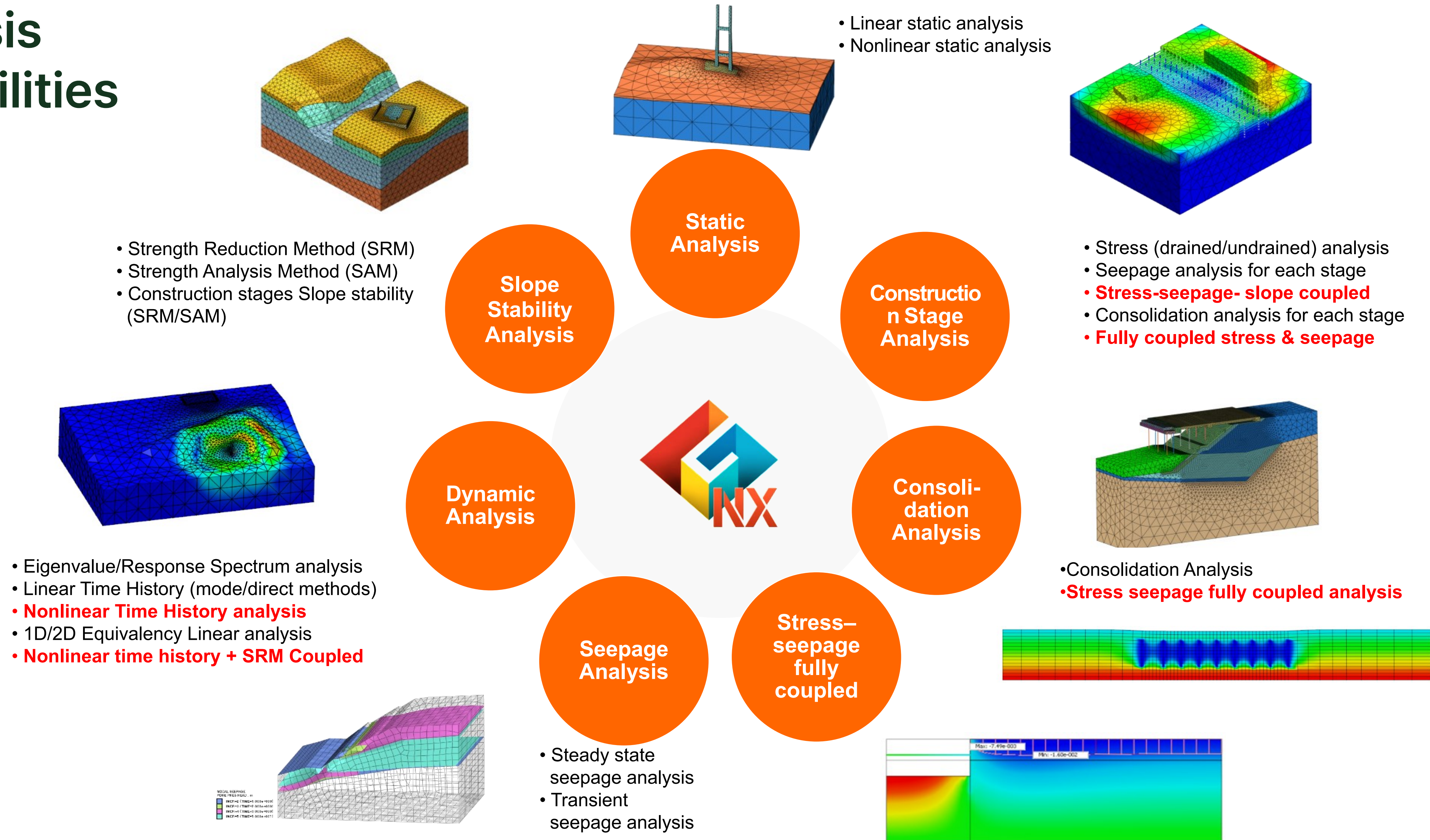


Earthquake record

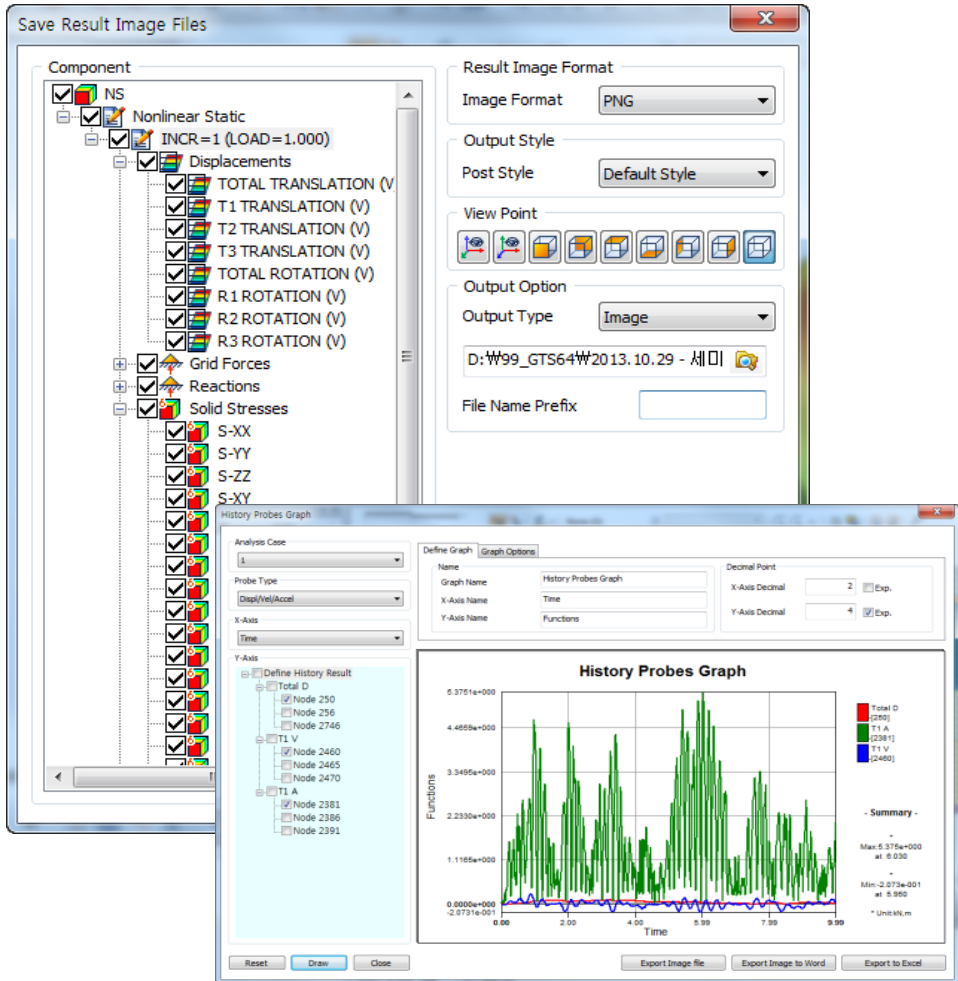
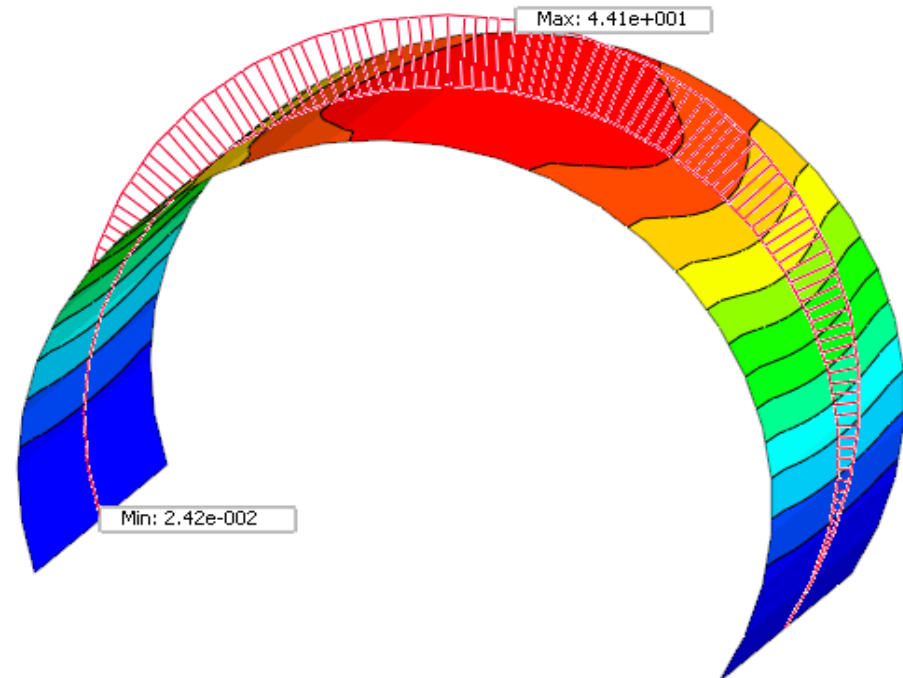
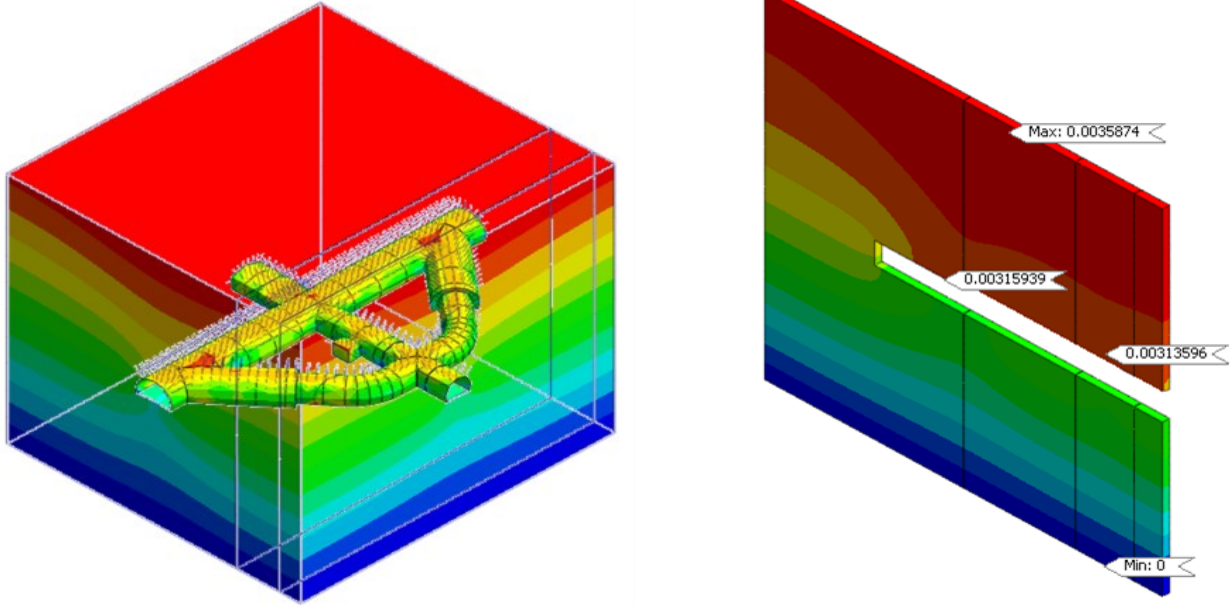
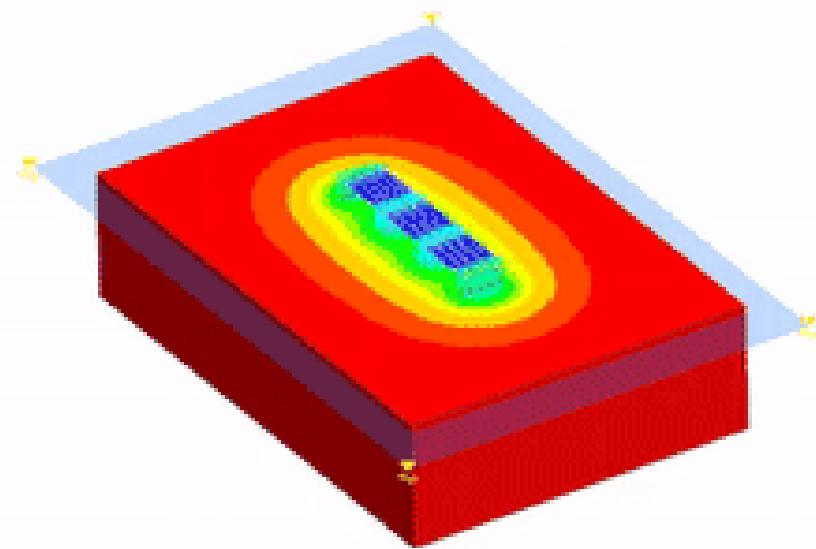
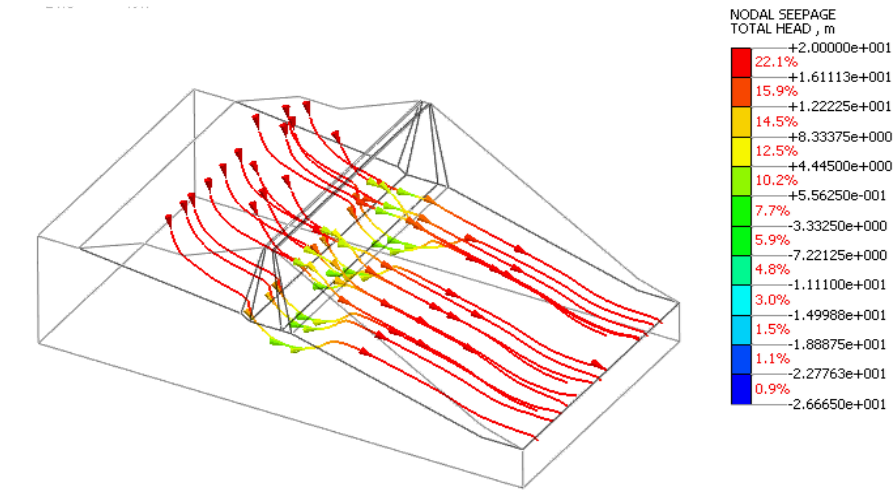


Design response spectra

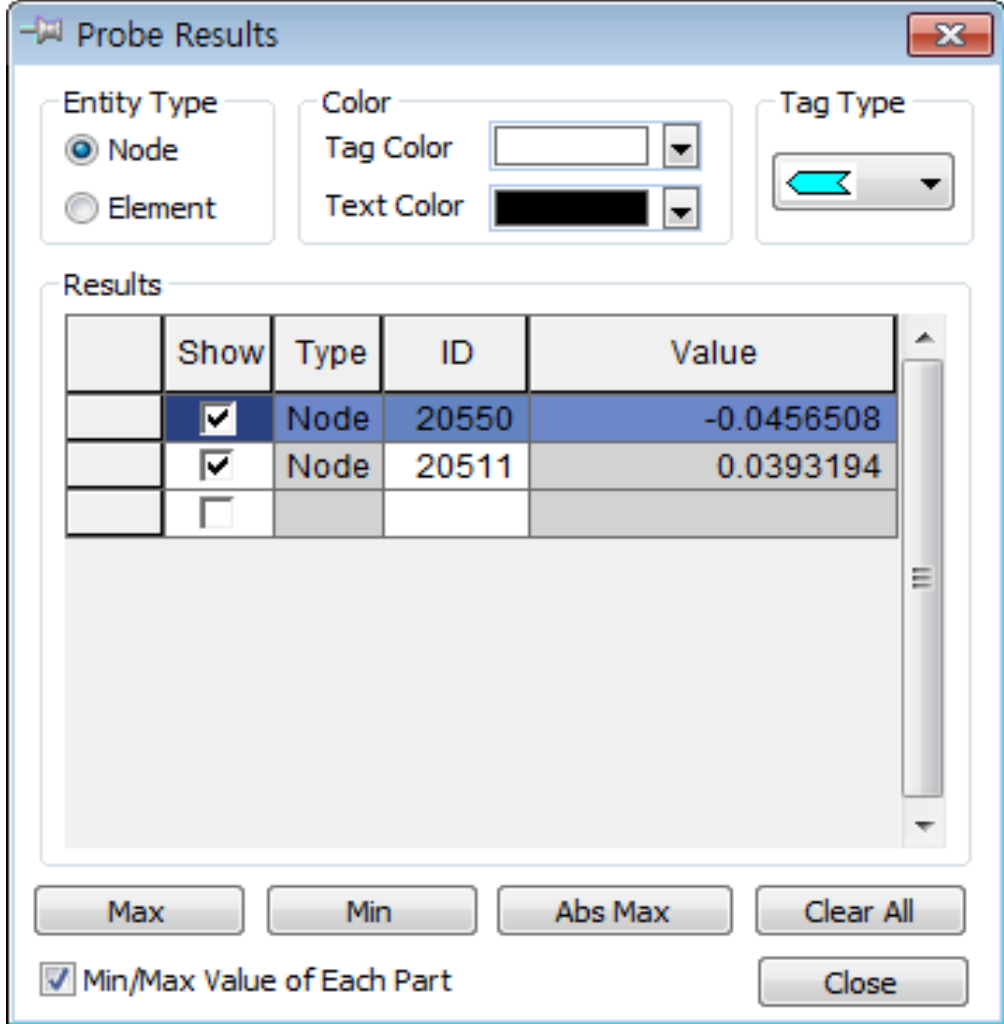
Analysis Capabilities



Result Extraction



Printing result images/graphs



Probe Result

No	Step	Step Value	Node: 6960 TZ TRANSLATION (V) (m)
1	Initial:INCR=1 (LOAD=1.000)	1.000000e+000	0.000000e+000
2	Bottom foundation:INCR=1 (LOAD=	1.000000e+000	0.000000e+000
3	Top construction:INCR=1 (LOAD=1.	1.000000e+000	0.000000e+000
4	Loading:INCR=1 (LOAD=0.033)	3.333330e-002	-1.812772e-004
5	Loading:INCR=2 (LOAD=0.067)	6.666670e-002	-3.625544e-004
6	Loading:INCR=3 (LOAD=0.100)	1.000000e-001	-5.438315e-004
7	Loading:INCR=4 (LOAD=0.133)	1.333330e-001	-7.251087e-004
8	Loading:INCR=5 (LOAD=0.167)	1.666670e-001	-9.063859e-004
9	Loading:INCR=6 (LOAD=0.200)	2.000000e-001	-1.087663e-003
10	Loading:INCR=7 (LOAD=0.233)	2.333330e-001	-1.268940e-003
11	Loading:INCR=8 (LOAD=0.267)	2.666670e-001	-1.450217e-003
12	Loading:INCR=9 (LOAD=0.300)	3.000000e-001	-1.631495e-003
13	Loading:INCR=10 (LOAD=0.333)	3.333330e-001	-1.812772e-003
14	Loading:INCR=11 (LOAD=0.367)	3.666670e-001	-1.994049e-003
15	Loading:INCR=12 (LOAD=0.400)	4.000000e-001	-2.175325e-003

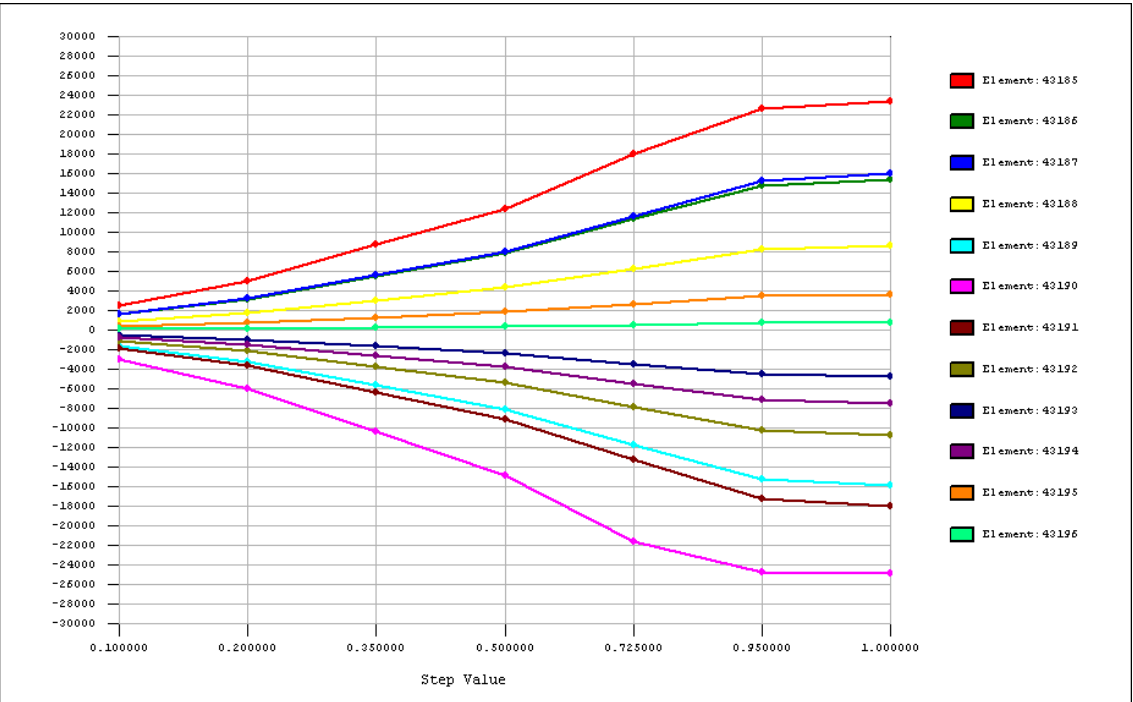
Sorting Dialog...

Style Dialog...

Show Graph...

Node	TOTAL TRANSLATION (...)	TX TRANSLATION (...)	TY TRANSLATION (...)	TZ TRANSLATION (...)
100	2.291e-005	-1.420e-006	0.000e+000	-2.287e-005
104	3.552e-005	1.456e-005	0.000e+000	-3.239e-005
108	3.130e-005	9.075e-006	0.000e+000	-2.995e-005
109	2.677e-005	3.633e-006	0.000e+000	-2.652e-005
120	4.873e-005	3.112e-006	0.000e+000	-4.863e-005
121	4.855e-005	5.408e-006	0.000e+000	-4.825e-005
122	4.828e-005	8.470e-006	0.000e+000	-4.753e-005
123	4.783e-005	1.240e-005	0.000e+000	-4.619e-005
124	4.728e-005	1.644e-005	0.000e+000	-4.433e-005
125	4.366e-005	1.761e-005	0.000e+000	-3.995e-005
126	4.065e-005	1.826e-005	0.000e+000	-3.632e-005
151	2.698e-005	1.935e-005	0.000e+000	-1.880e-005
152	2.858e-005	2.002e-005	0.000e+000	-2.040e-005
153	3.097e-005	1.802e-005	0.000e+000	-2.519e-005
154	4.496e-005	3.167e-006	0.000e+000	-4.485e-005
155	4.349e-005	3.034e-006	0.000e+000	-4.339e-005
156	4.114e-005	2.779e-006	0.000e+000	-4.104e-005
157	4.079e-005	4.733e-006	0.000e+000	-4.051e-005
158	4.016e-005	7.325e-006	0.000e+000	-3.949e-005

Excel compatible table



Slope Stability Analysis



Natural Slope

The slopes are formed by natural cause.
Slopes in Hilly areas.

The slopes are constructed for roads,
railway lines, canals, earth dams etc.

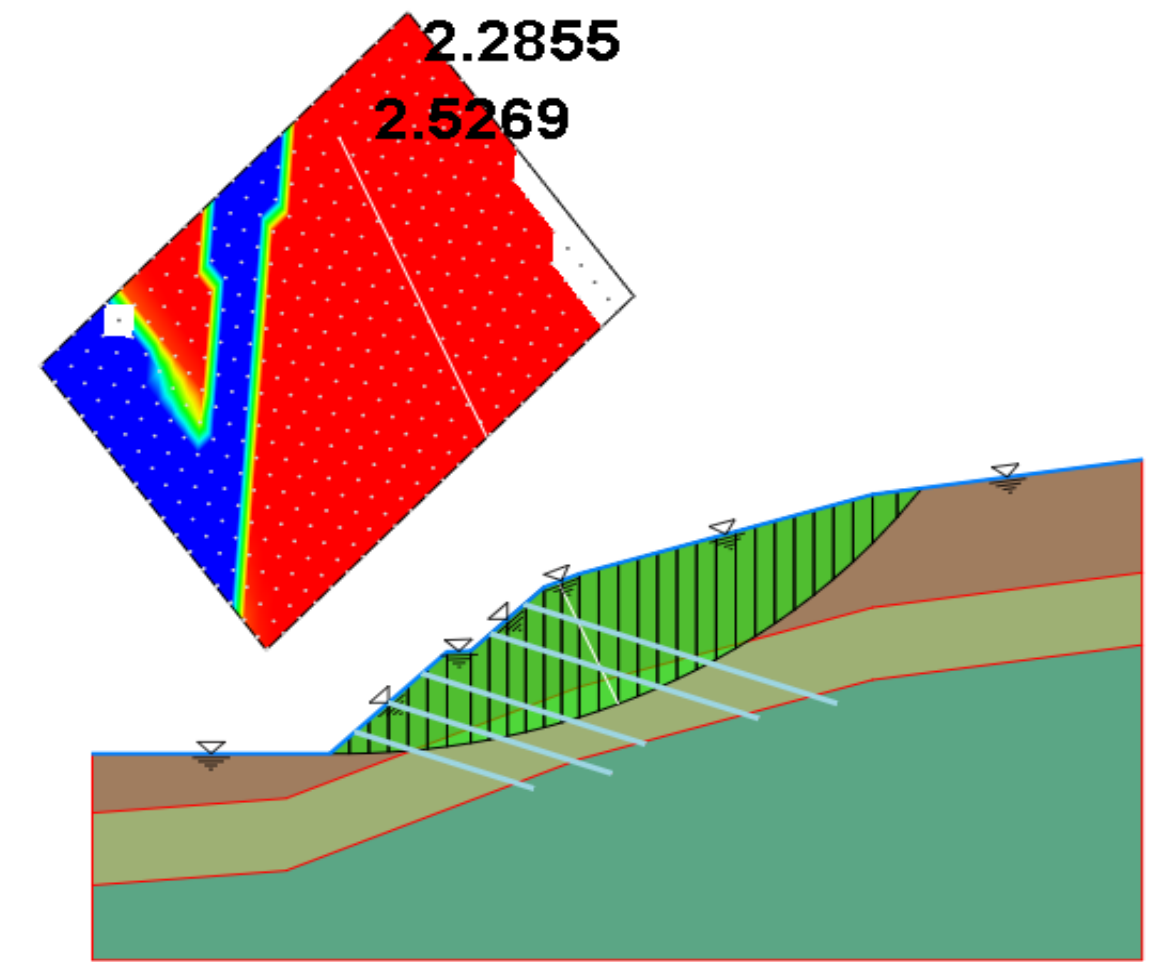


Embankment

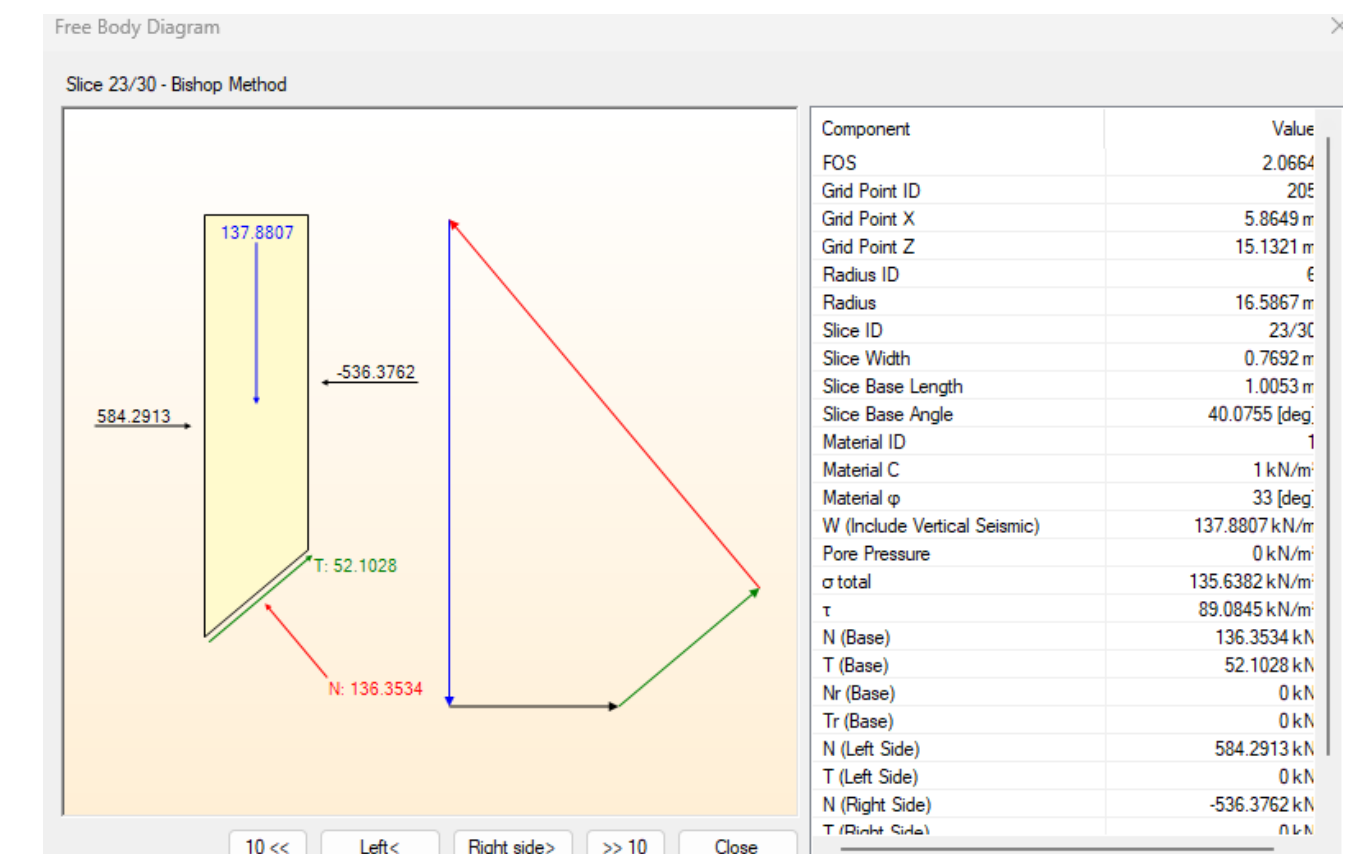
Limit Equilibrium Method (LEM)

Limit Equilibrium Method

- The method discretizes the potential sliding mass into vertical slices and solved for static equilibrium to assess the Factor of Safety.
- The formulation is based on principles of limiting equilibrium.



FOS of a Slip Circle



Force/Moment Equilibrium

The factor of safety is defined as the factor by which the soil strength must be reduced so that the potential sliding mass is a point of limiting equilibrium

Methods

Method	Moment Equilibrium	Horizontal Force Equilibrium	Interslice normal Force (E)	Interslice shear Force (X)	Inclination of X/E resultant
Fellenius	Yes	No	No	No	No force
Bishop's	Yes	No	Yes	No	Horizontal
Janbu	No	Yes	Yes	No	Horizontal
Spencer	Yes	Yes	Yes	Yes	Constant
Morgenstern- Price	Yes	Yes	Yes	Yes	Variable

LEM methods differ in the way the static equations are considered for equilibrium

Finite Element Analysis

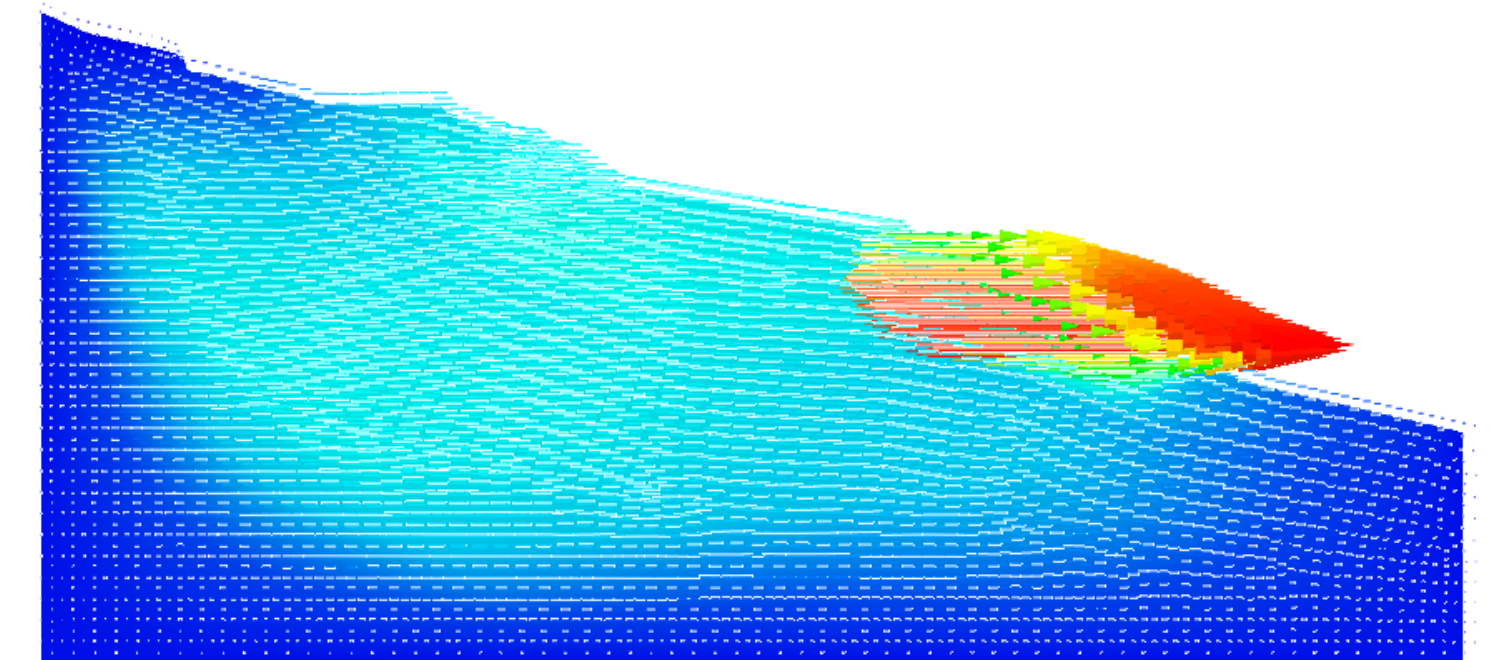
Strength Reduction Method

Strength Reduction Method (SRM)

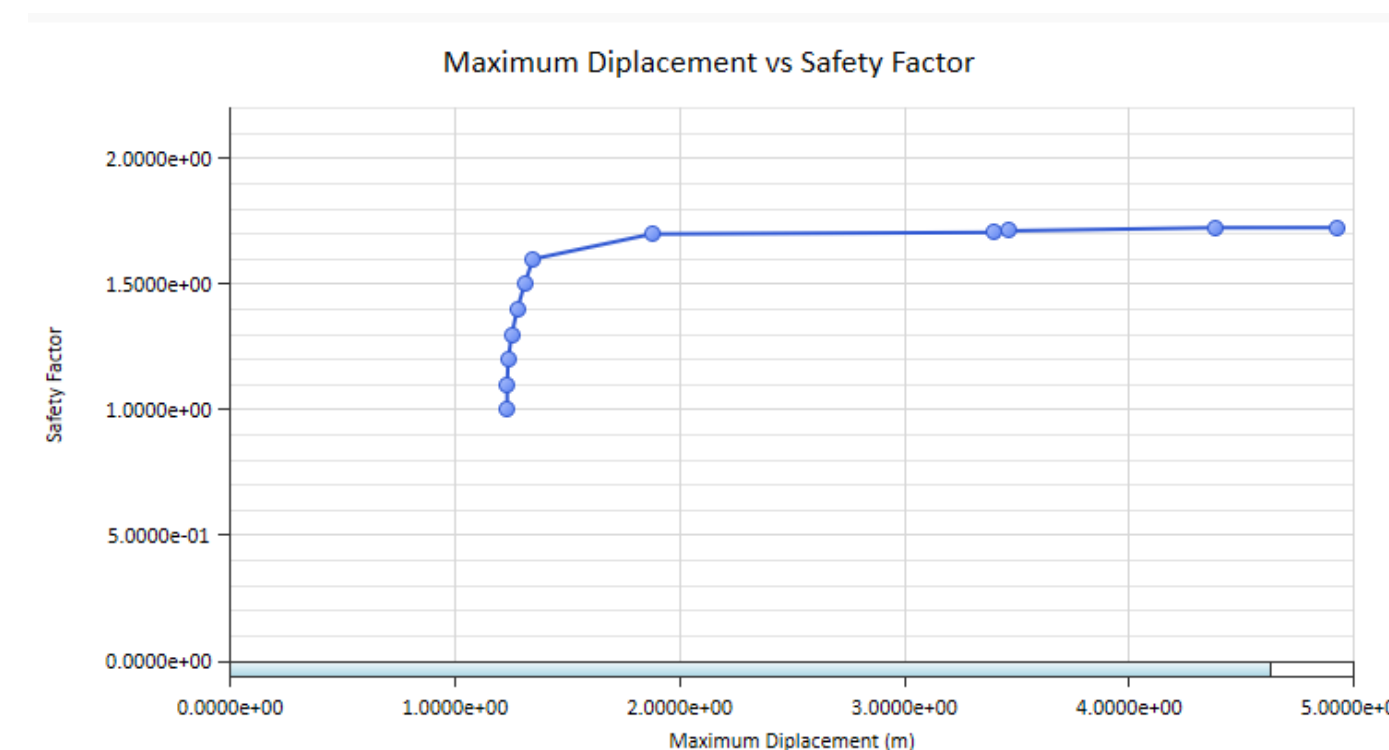
- The soil strength parameters such as cohesion and internal friction angle are gradually reduced until the numerical divergence occur.

Advantages

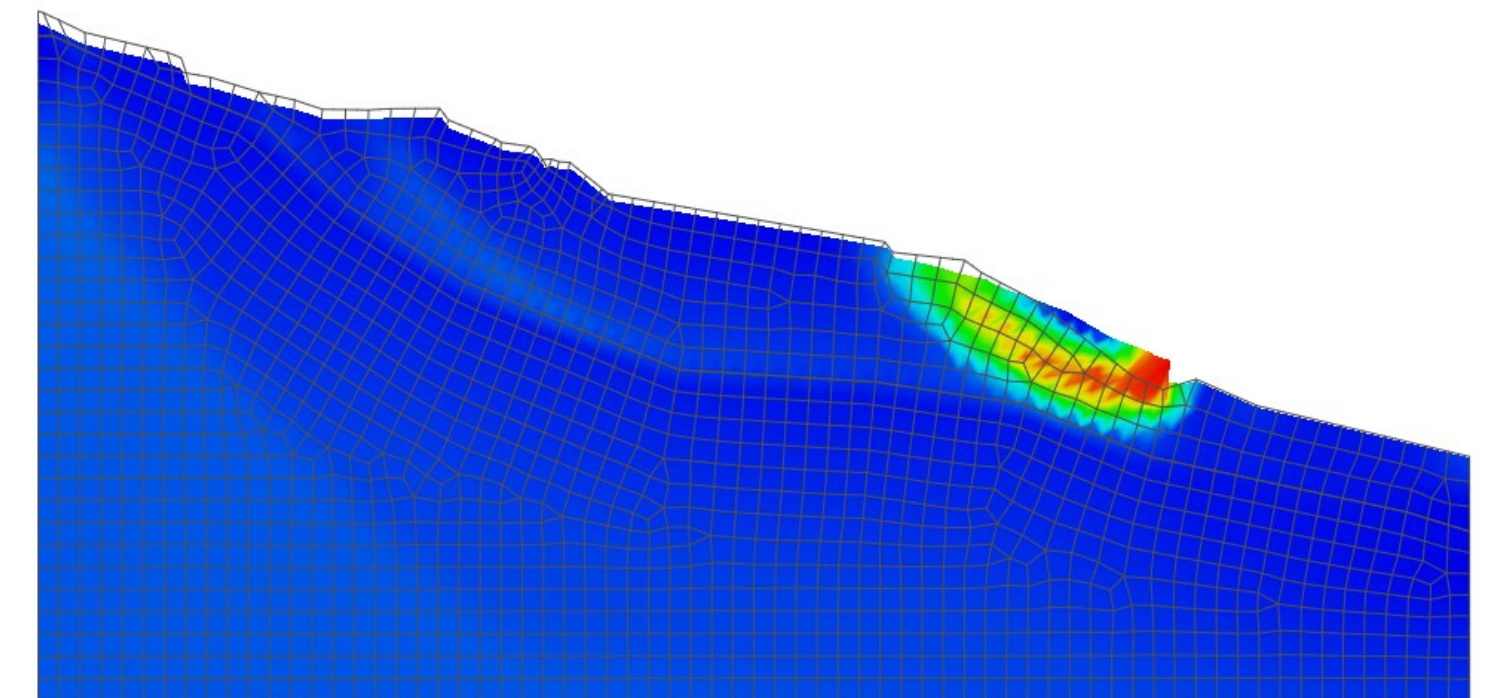
- Failure surfaces and its shape is not assumed.
- Possible to monitor the progressive failure.



Potential Direction of Soil Displacement

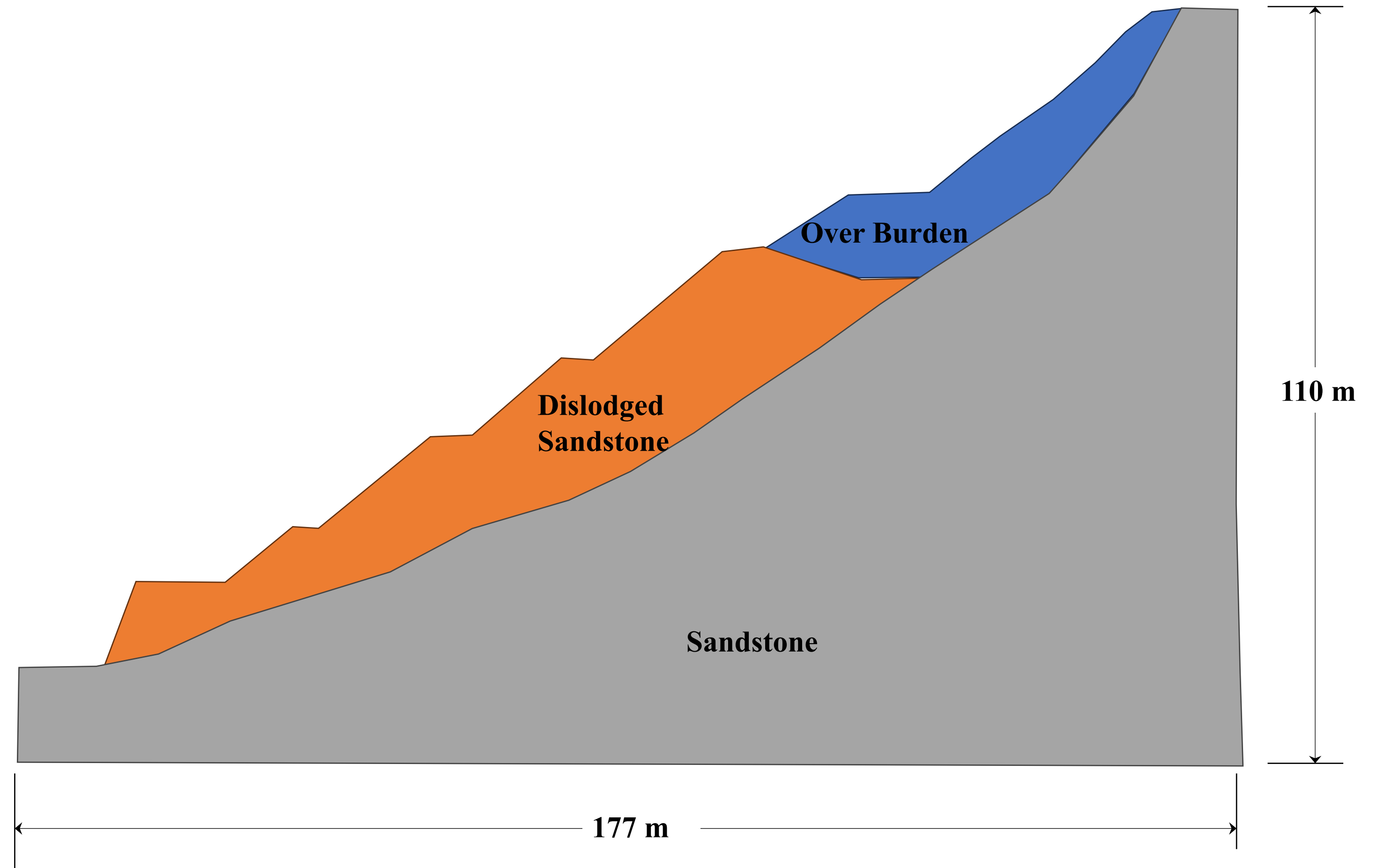


Factor of Safety Plot



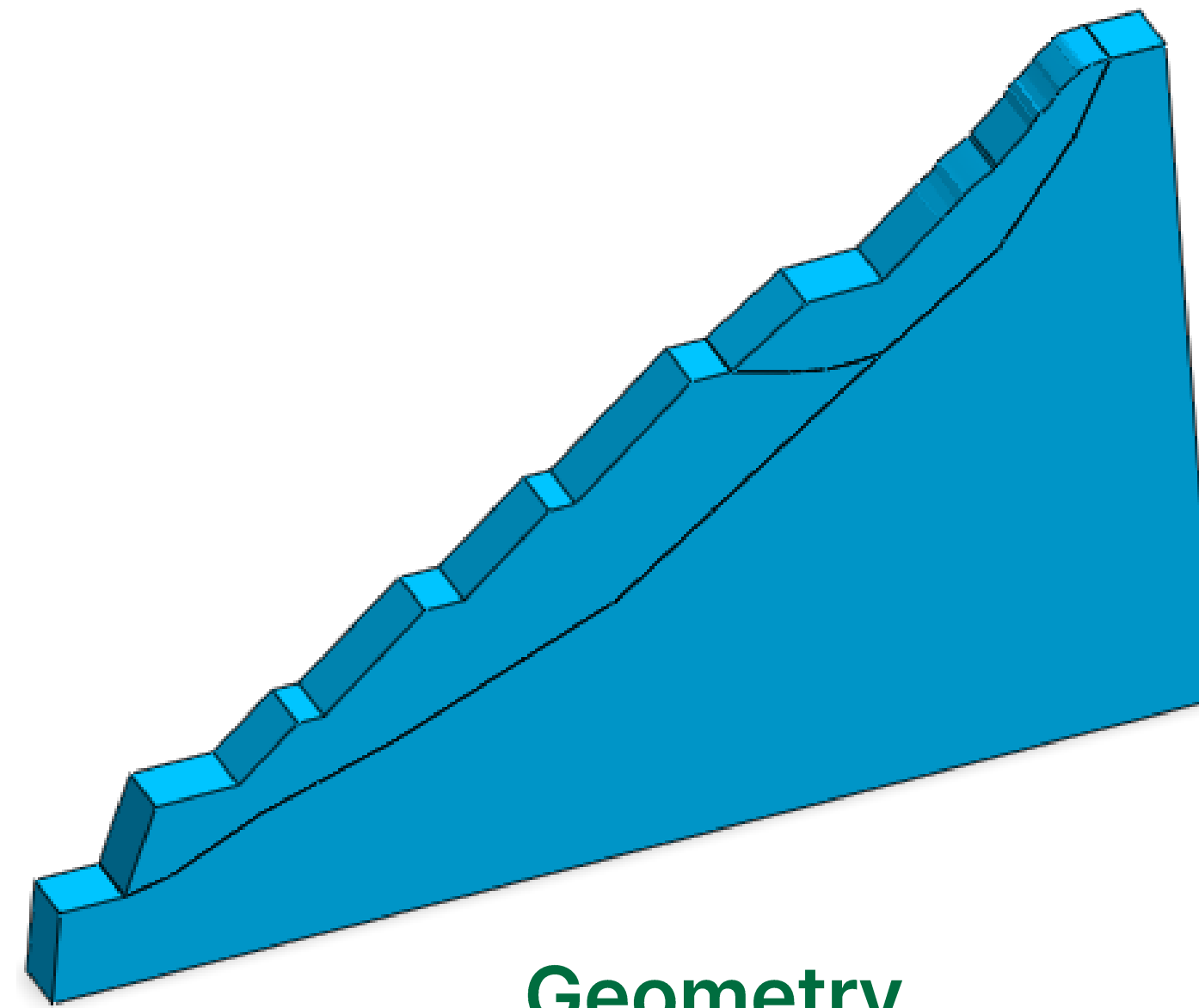
Potential Slip Surface

Problem Statement

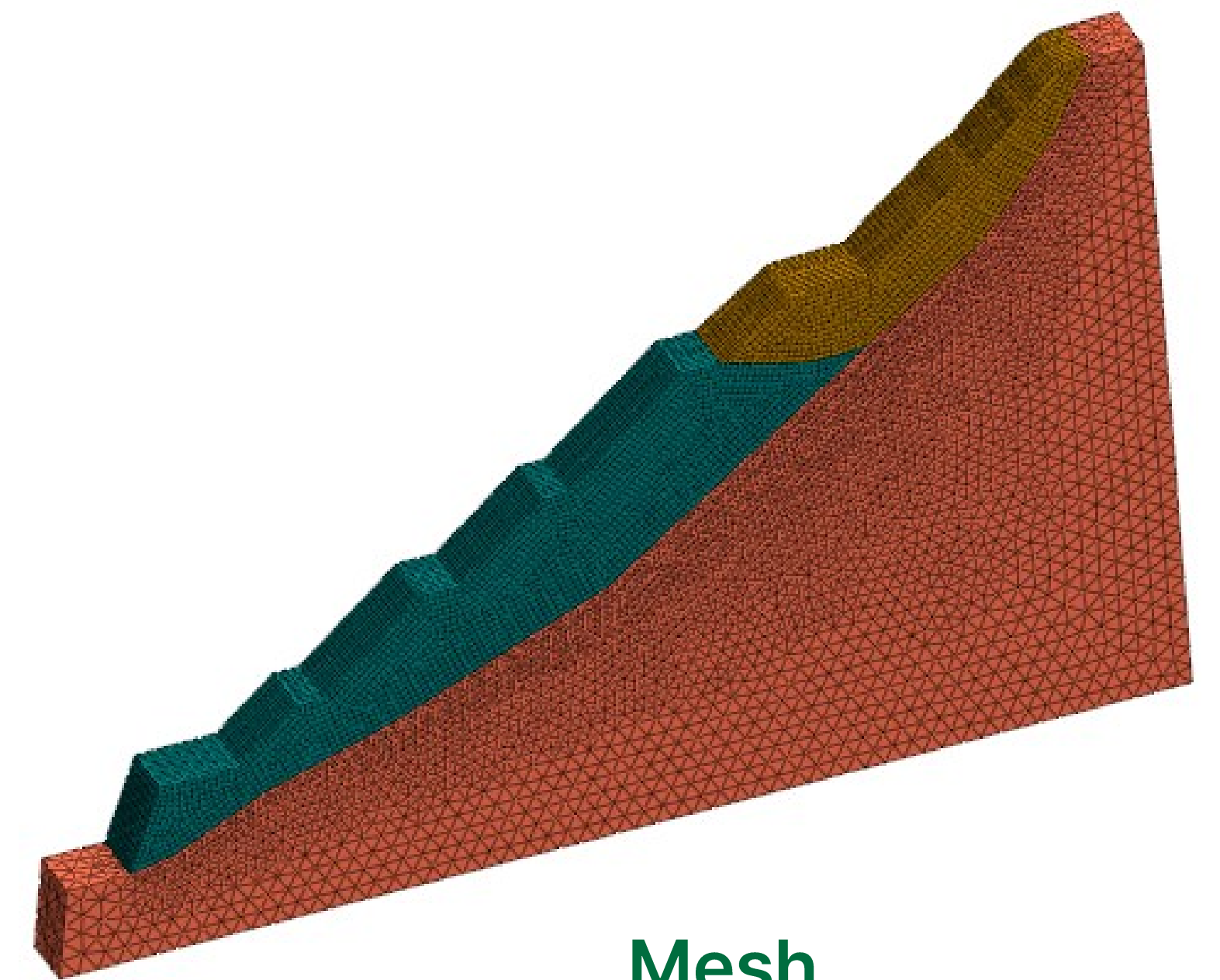


**Analyze the Slope for Global and Local Slope Stability using
Strength Reduction Method**

Global Slope Stability

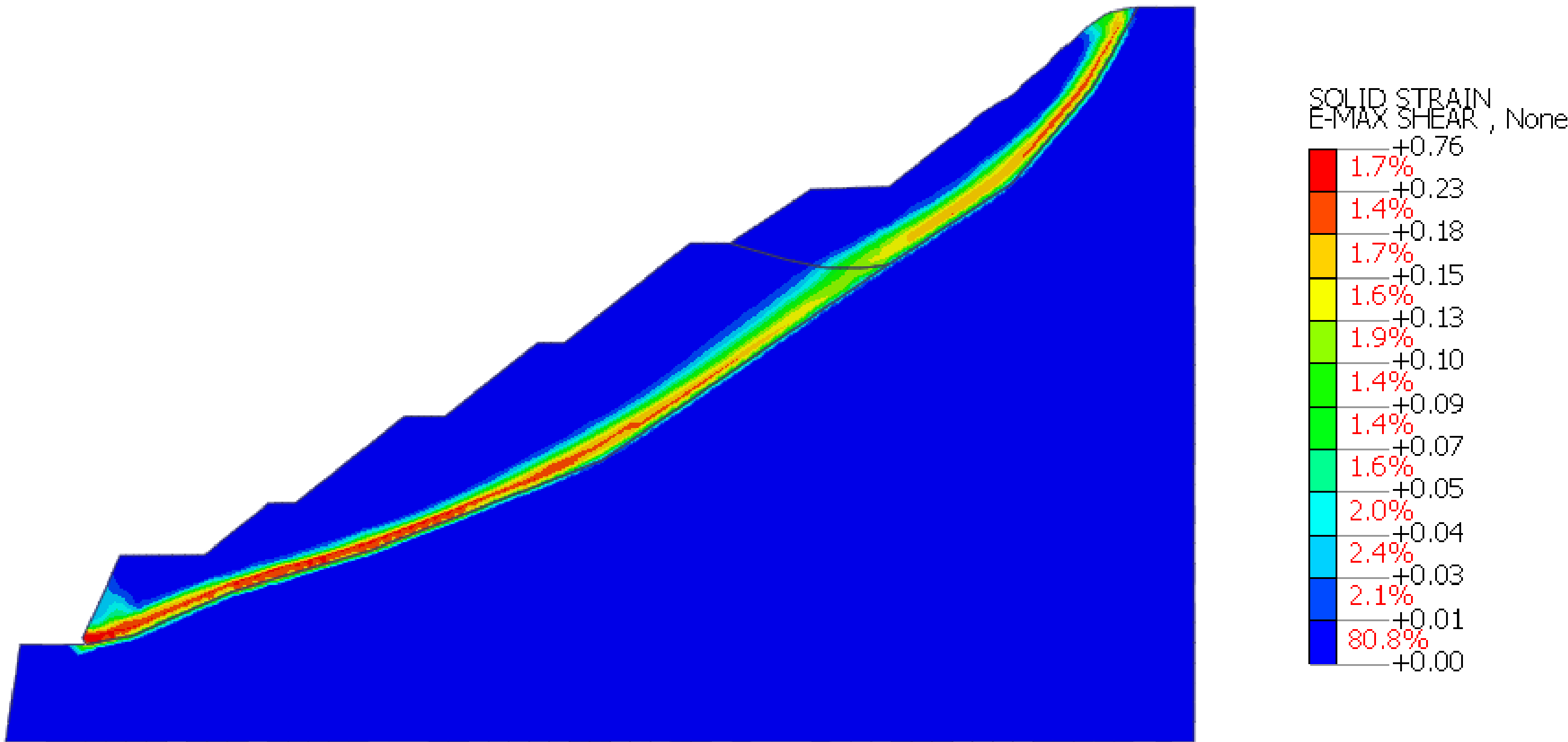


Geometry

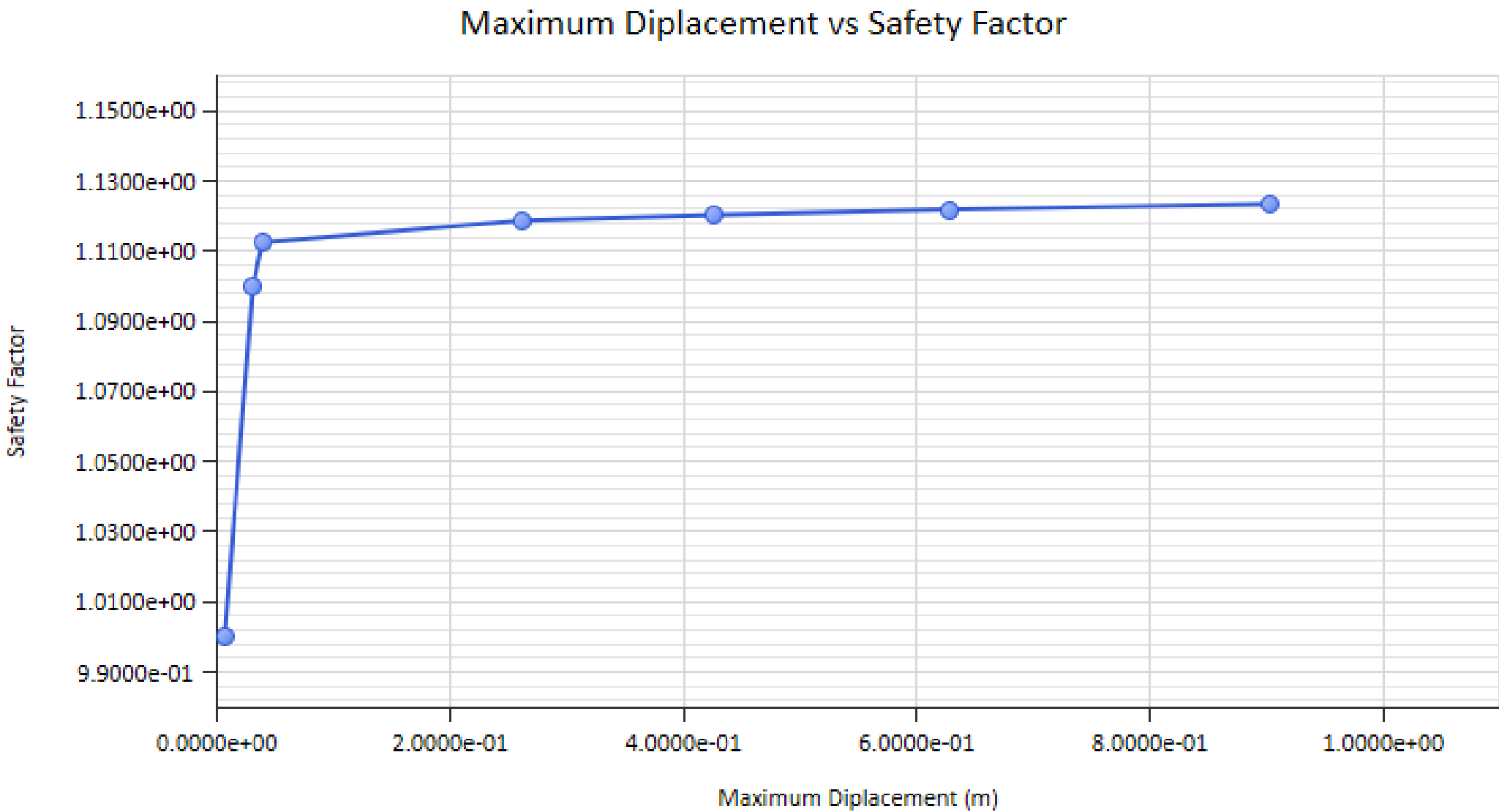


Mesh

Global Slope Stability

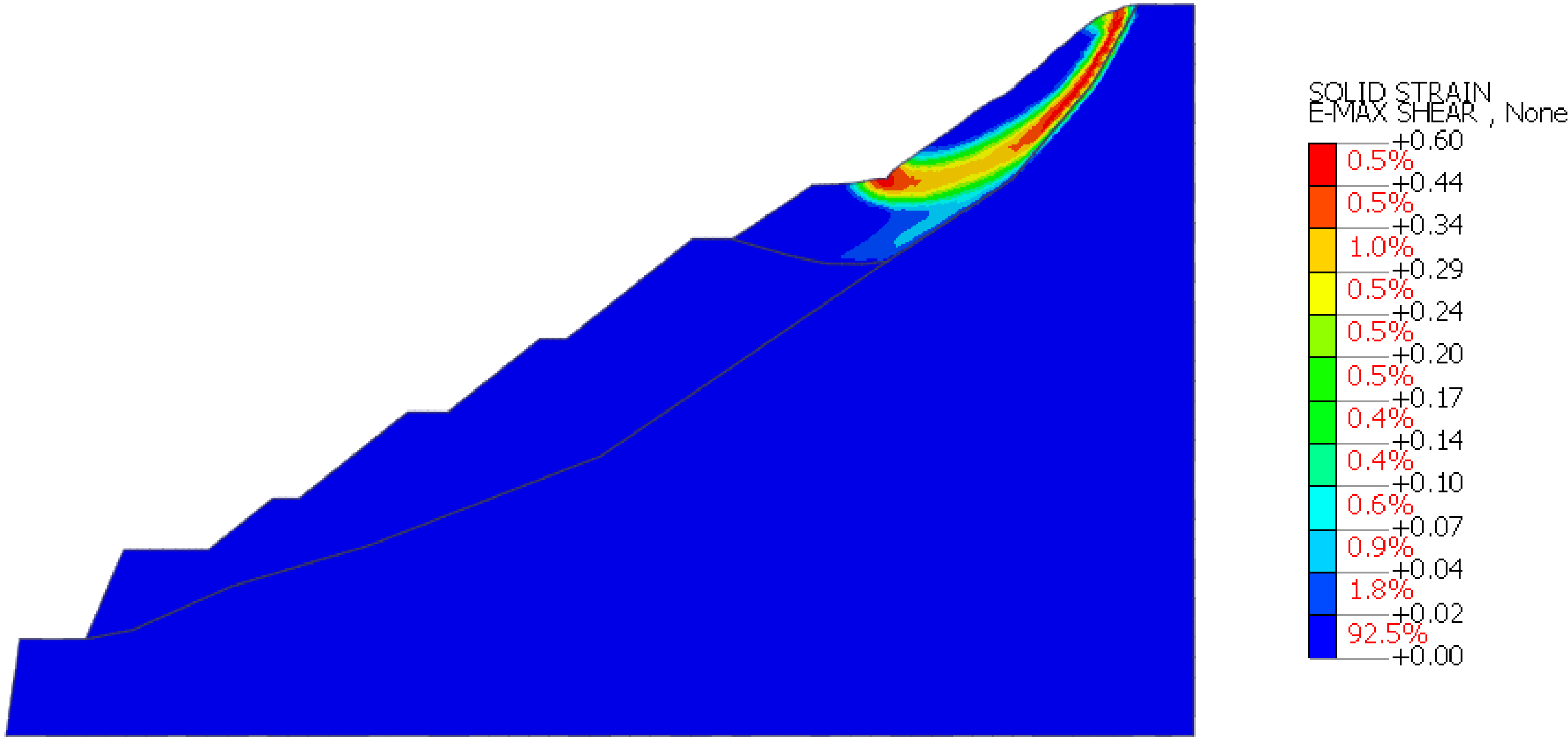


Potential Slip Plane



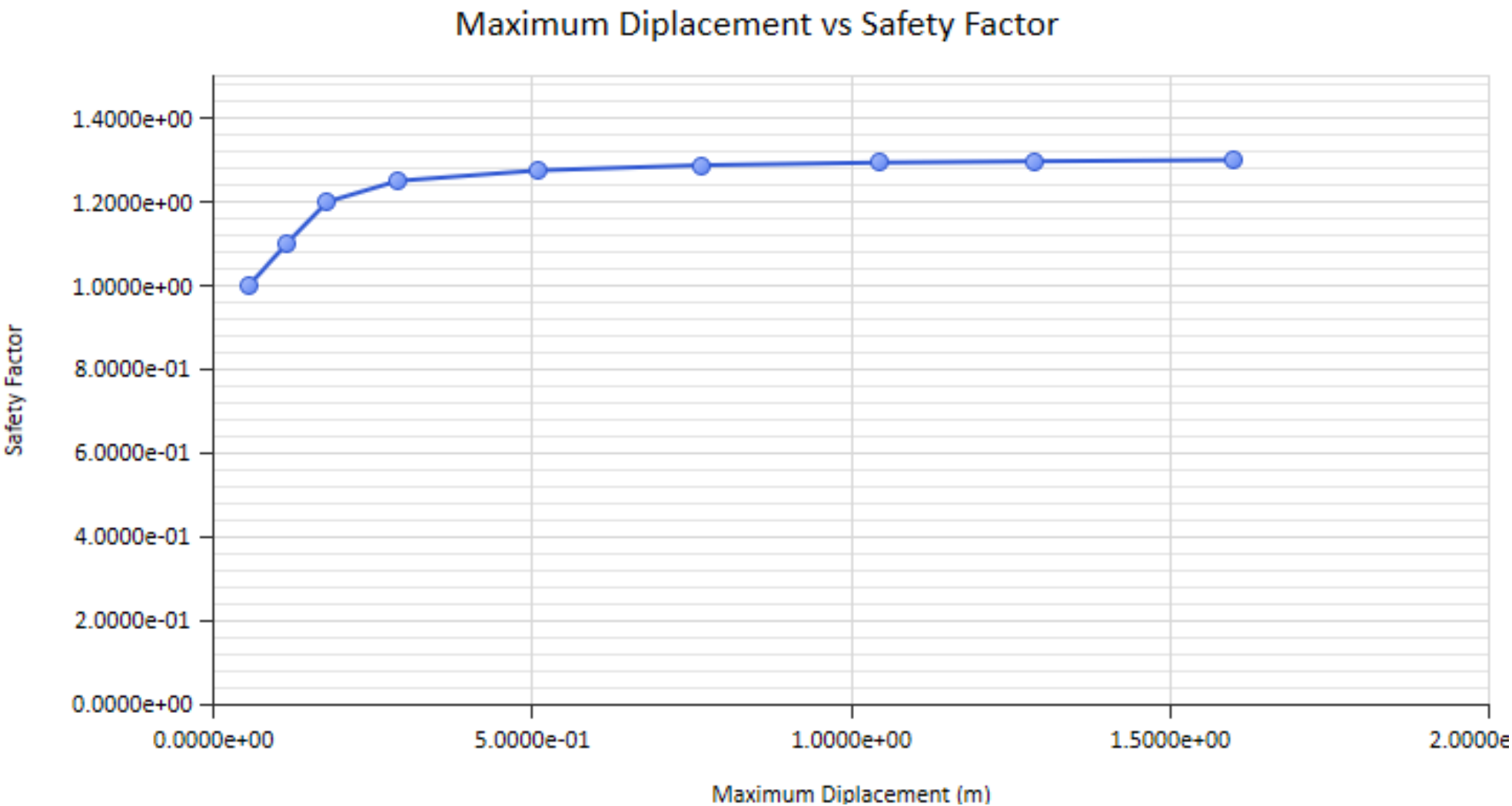
FOS-1.12

Local Slope Stability of Overburden Layer



Potential Slip Plane

FOS-1.30



Thank You