OPTIMIZING DEEP EXCAVATION TECHNIQUES

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CONTENTS

DEEP EXCAVATION

- Soil or Rock Excavation generally greater than 15ft
- Requires careful selection of retaining structures, construction methods and other support systems
- Failure results in great loss of life, property and delays in the project

MIDAS

SOLUTIONS

Solutions to Deep Excavation Collapse:

- Use of Retaining Structures- Analysis & Design
- Proper simulation of Initial Stress conditions
- Proper simulation of Loadings

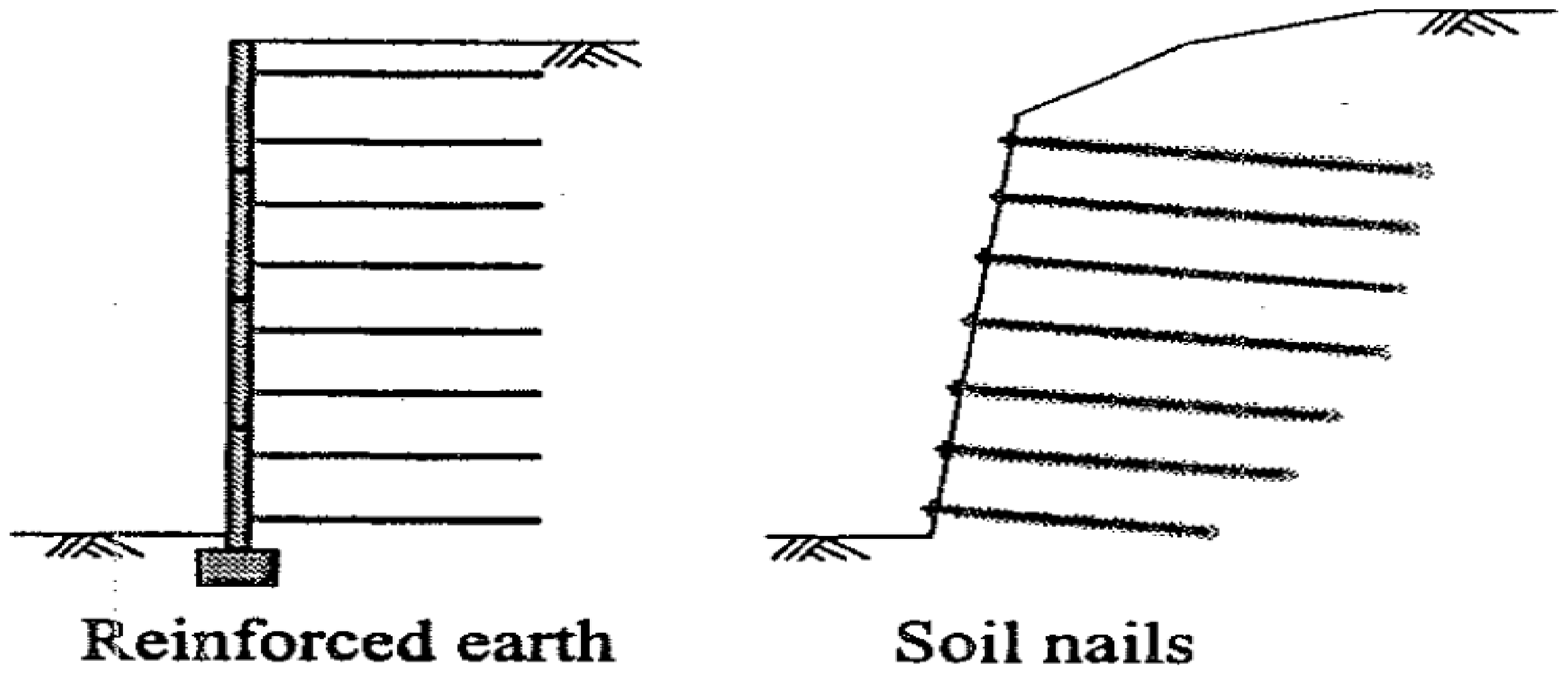
TYPES OF RETAINING STRUCTURES

Gravity Walls

Stability depends on the normal and shear stresses developed at the Wall Base

Anchored Earth Walls

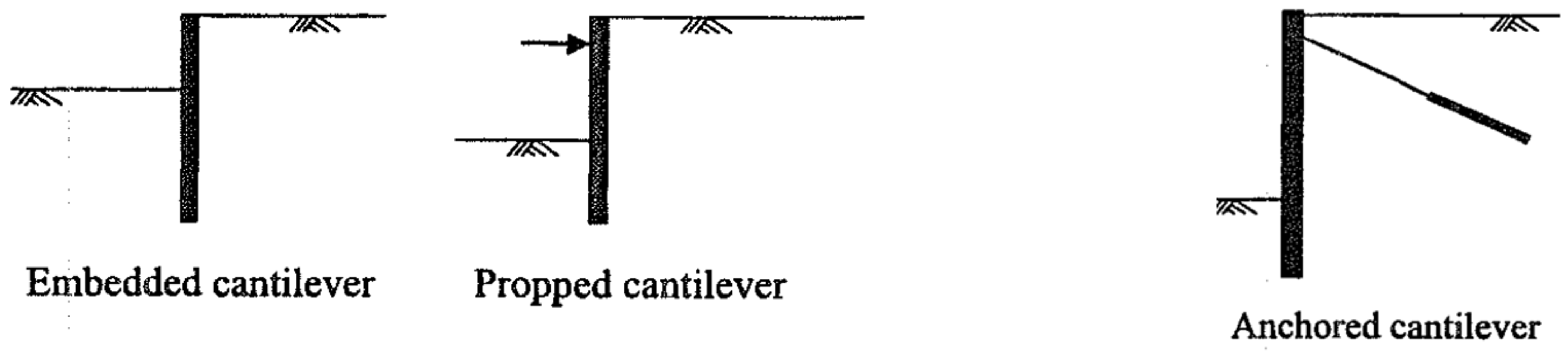
Internal Stability depends on the complex interaction between soil and reinforcing elements



TYPES OF RETAINING STRUCTURES

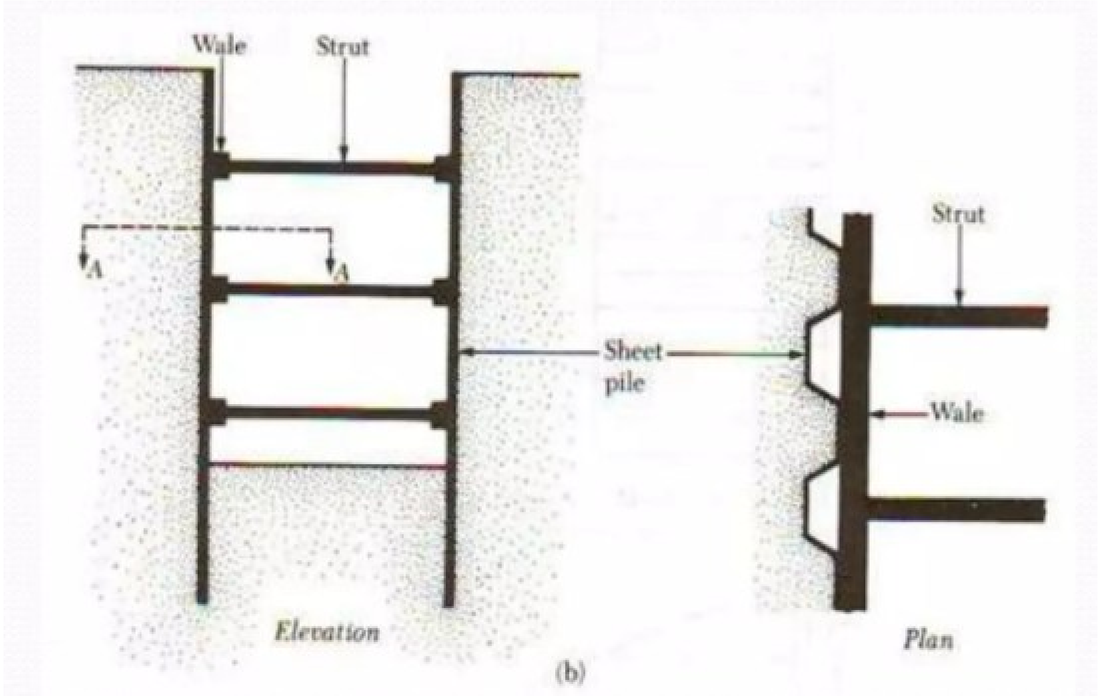
Embedded Walls

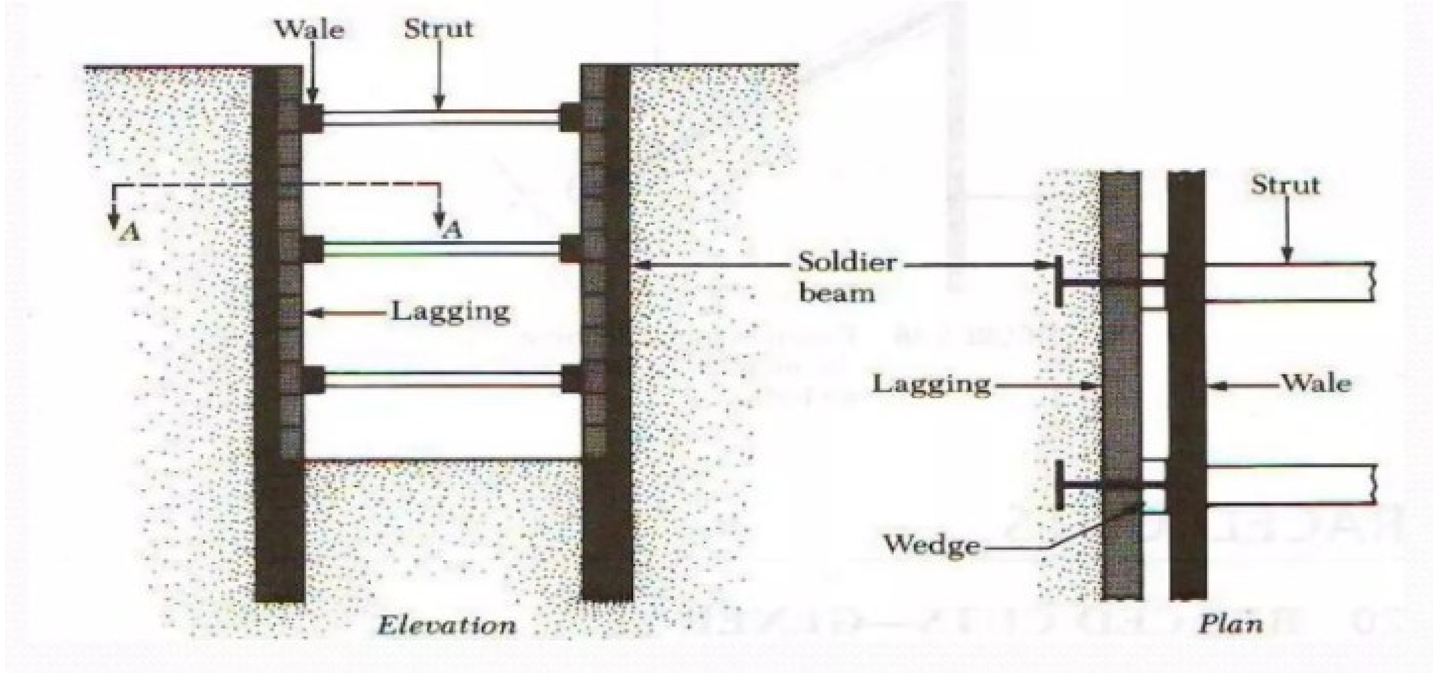
Stability of walls rely on the resistance of the ground below excavation level and on the resistance provided by any props or anchors



Braced Excavation

Stability of walls rely on the resistance of the ground below excavation level and on the resistance provided by struts and wallers
Braced Cuts can be: using sheet pile or using soldier beams





CONVENTIONAL DESIGN

- Lateral Earth Pressure calculation expected to act on the wall

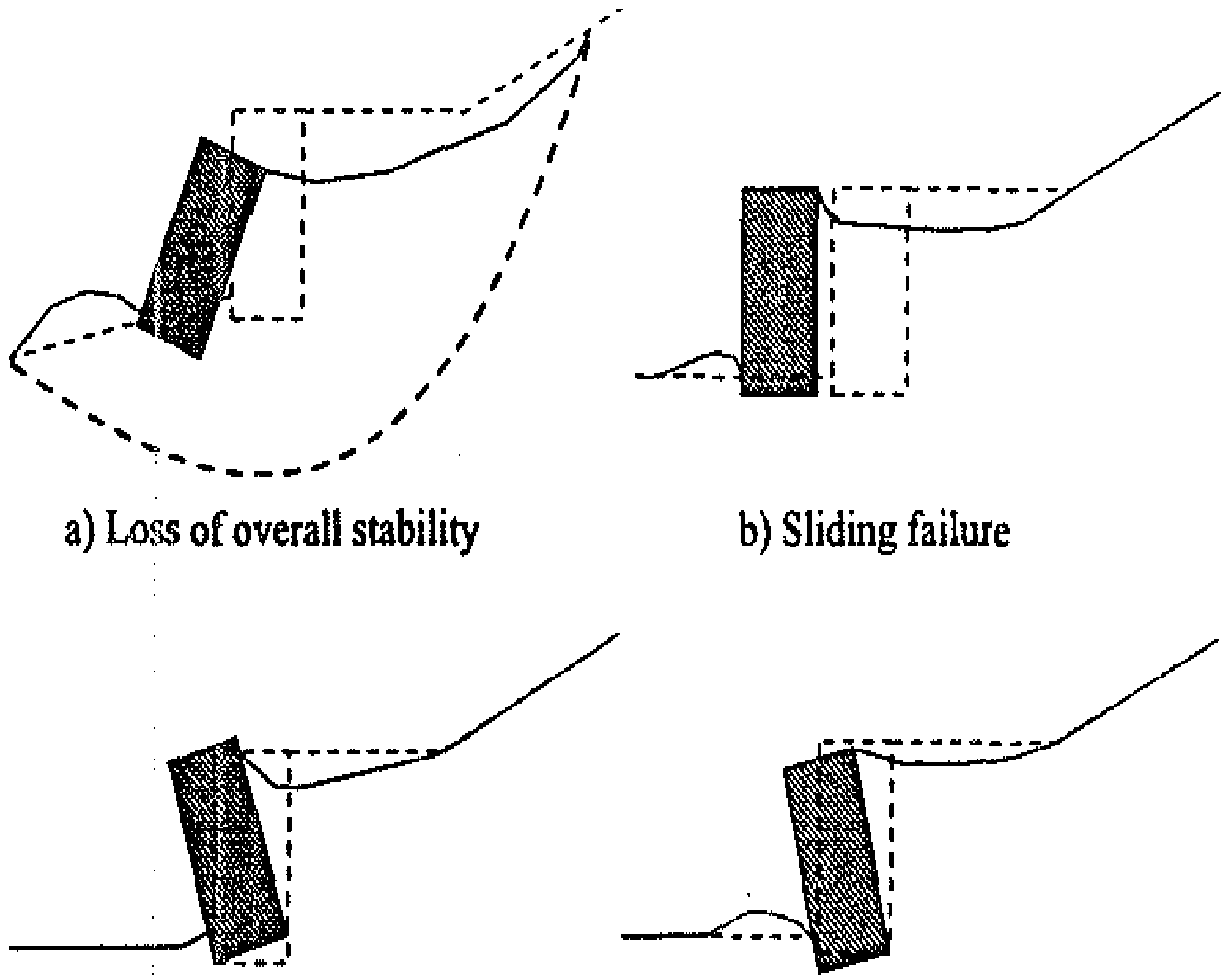
- External stability checks application to ensure overall shoring system stability

- Factor of Safety against Sliding & Overturning Calculation

- Bearing capacity Determination of the wall

- Checks against Failure (Overall Failure, Sliding Failure, etc)

- Checks for the structural stability of the shoring system



a) Loss of overall stability

b) Sliding failure

c) Overturning failure

d) Bearing capacity failure

NUMERICAL MODELLING CONSIDERATIONS

1) Modelling Type

- In reality, all geotechnical problems involving retaining structures require 3D modelling for accurate analysis.
- When simplifying problems to 2D, it is crucial to properly check and take care of the assumptions made.

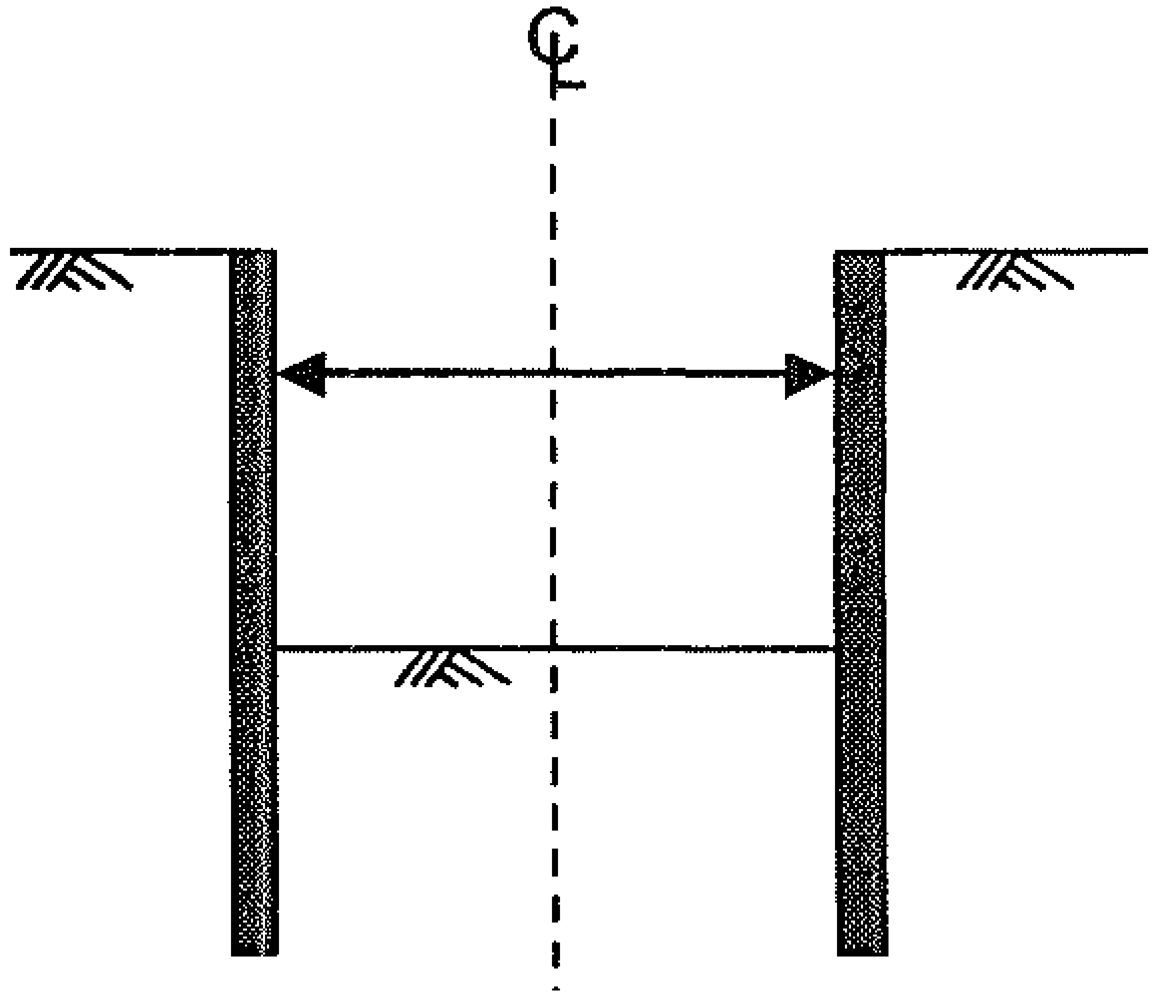
Advantages of Using GTS NX

- GTS NX offers a comprehensive solution as it allows for both 2D and 3D modelling within the same software.
- This flexibility ensures accurate and efficient analysis, catering to the complexity of geotechnical problems.

NUMERICAL MODELLING CONSIDERATIONS

2) Consideration of Assumptions

- For two dimensional and axi-symmetric analysis the assumption is frequently made that there is axis of symmetry about center line of an excavation and that only half section needs to be modelled from the axis of symmetry



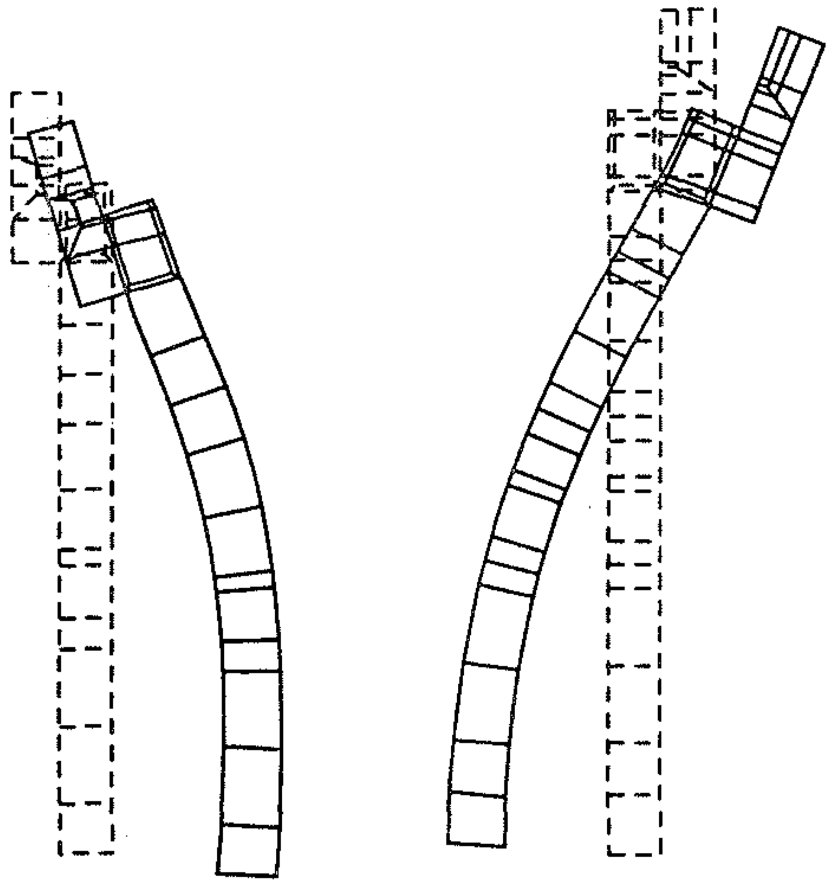


Figure 3.4: Displaced shape of walls of road tunnel

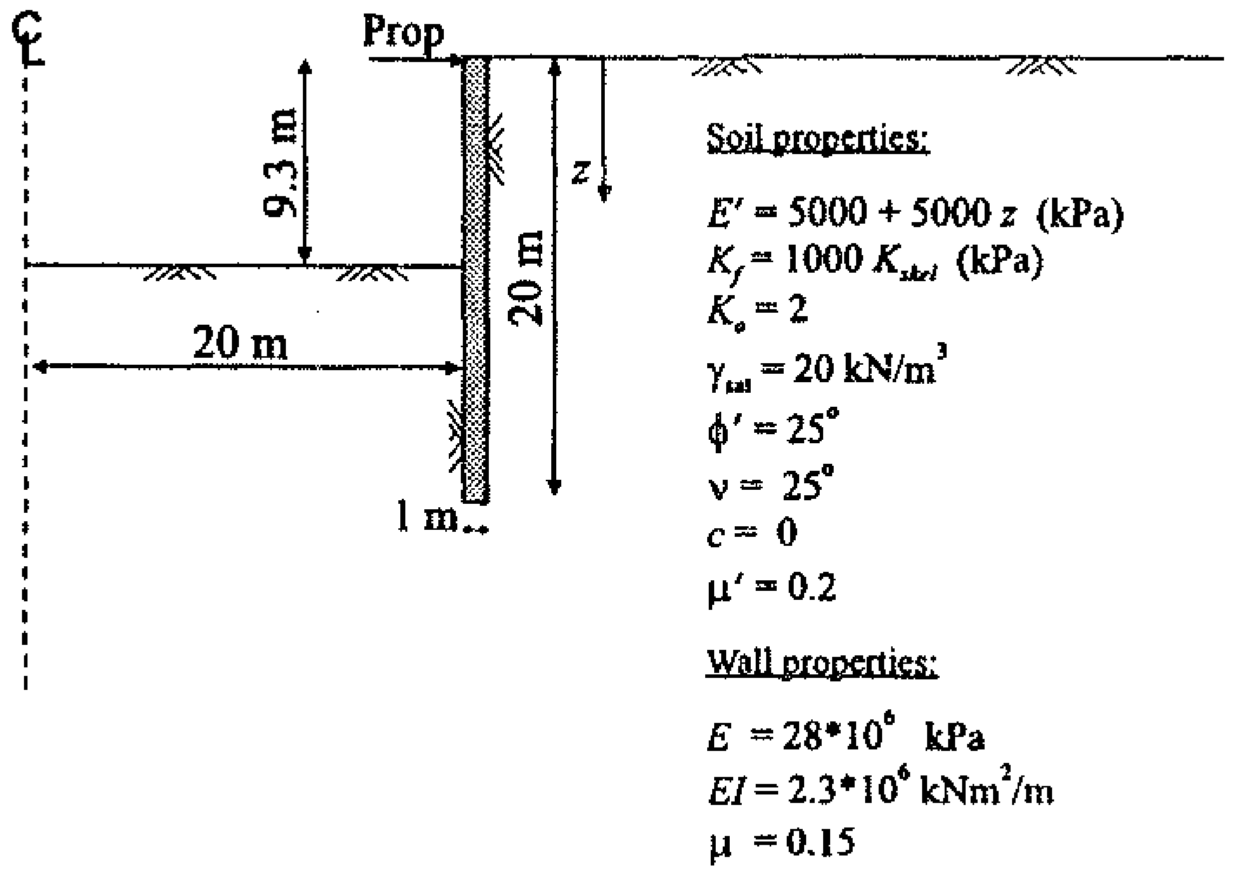
NUMERICAL MODELLING CONSIDERATIONS

3) Geometry of Finite Element Model

- Another decision arises that when performing numerical analysis what is the choice of the depth and lateral extent

a) Depth

- Soil stratigraphy often provides an obvious location
- Since soil stiffness and strength increases with depth analyses are not sensitive to location of bottom boundary until it is reasonably close to the bottom of wall



NUMERICAL MODELLING CONSIDERATIONS

3) Geometry of Finite Element Model

- Another decision arises that when performing numerical analysis what is the choice of the depth and lateral extent

b) Lateral Extent

- As the excavation is symmetric the position of Left Hand boundary of the mesh is fixed.
- Lateral extent on the right is more problematic and depends on constitutive model.

• Material model	• Behavior
Drucker-Prager	Elasto-Plastic with hardening and softening and ambient influences
Mohr Coulomb	
Modified Mohr Coulomb	Elasto-plastic with cap hardening
Hoek-brown	Elasto-plastic
Hyperbolic	Non-Linear Elastic
Strain-Softening	Strain Softening
Modified Cam clay	Elasto-plastic for clay

NUMERICAL MODELLING CONSIDERATIONS

Application of Mohr Coulomb and other Advanced Models:

1)For soil shear failure
   a) Use Mohr Coulomb model
   b) Use equivalent linear stiffness for compaction or unloading behavior

2) For nonlinear compaction and shear failure
   a) Use advanced models such as Hardening models(Modified Mohr Coulomb, etc)

Applications:

Mohr Coulomb: Stability Analysis, Soil Structure bonded failure, Excavation problems for basic behavior

Advanced Hardening models: settlement analysis, deep excavation for detailed behavior

NUMERICAL MODELLING CONSIDERATIONS

4) Initial Ground Conditions

- Whenever there is excavation, the loading of structure depends on stress changes associated with process it is important that these stresses are estimated accurately

5) Modified Ground Condition

- Consideration of nearby structures also becomes very much important and affects the stress variation, so it needs to be considered

6) Construction Method

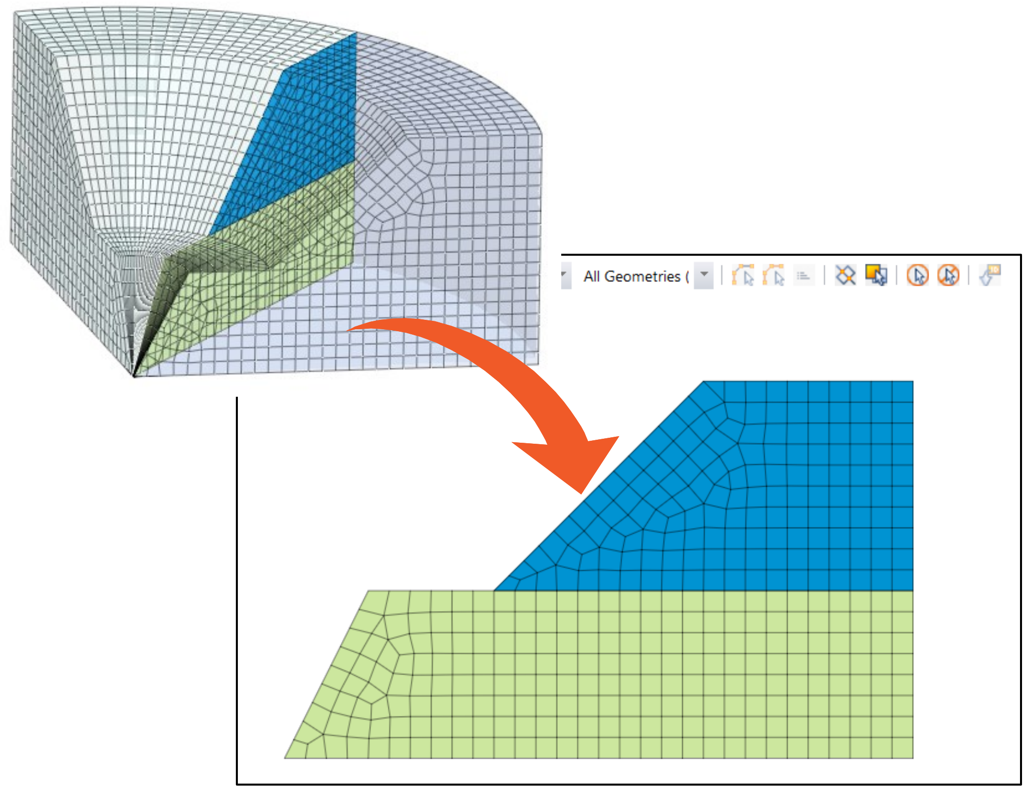
- One needs to simulate the construction method adopted using numerical analysis as it also affects the results

7) Water Table

- Consideration of nearby structures also becomes very much important and affects the stress variation, hence needs to be considered

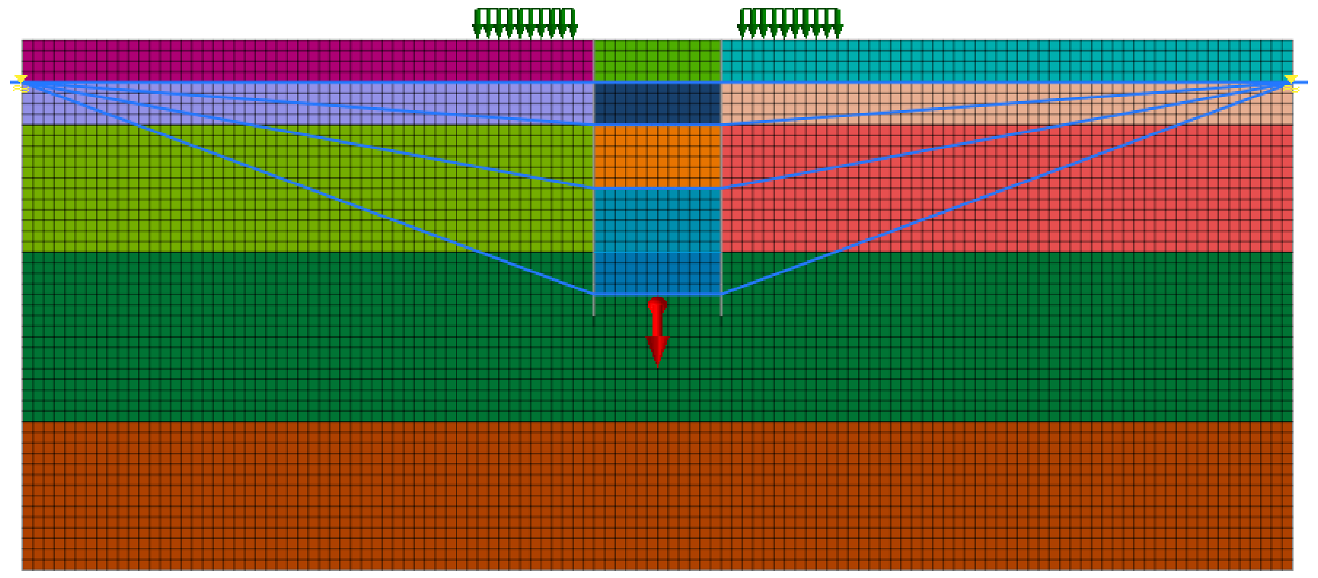
GTS NX INTRODUCTION

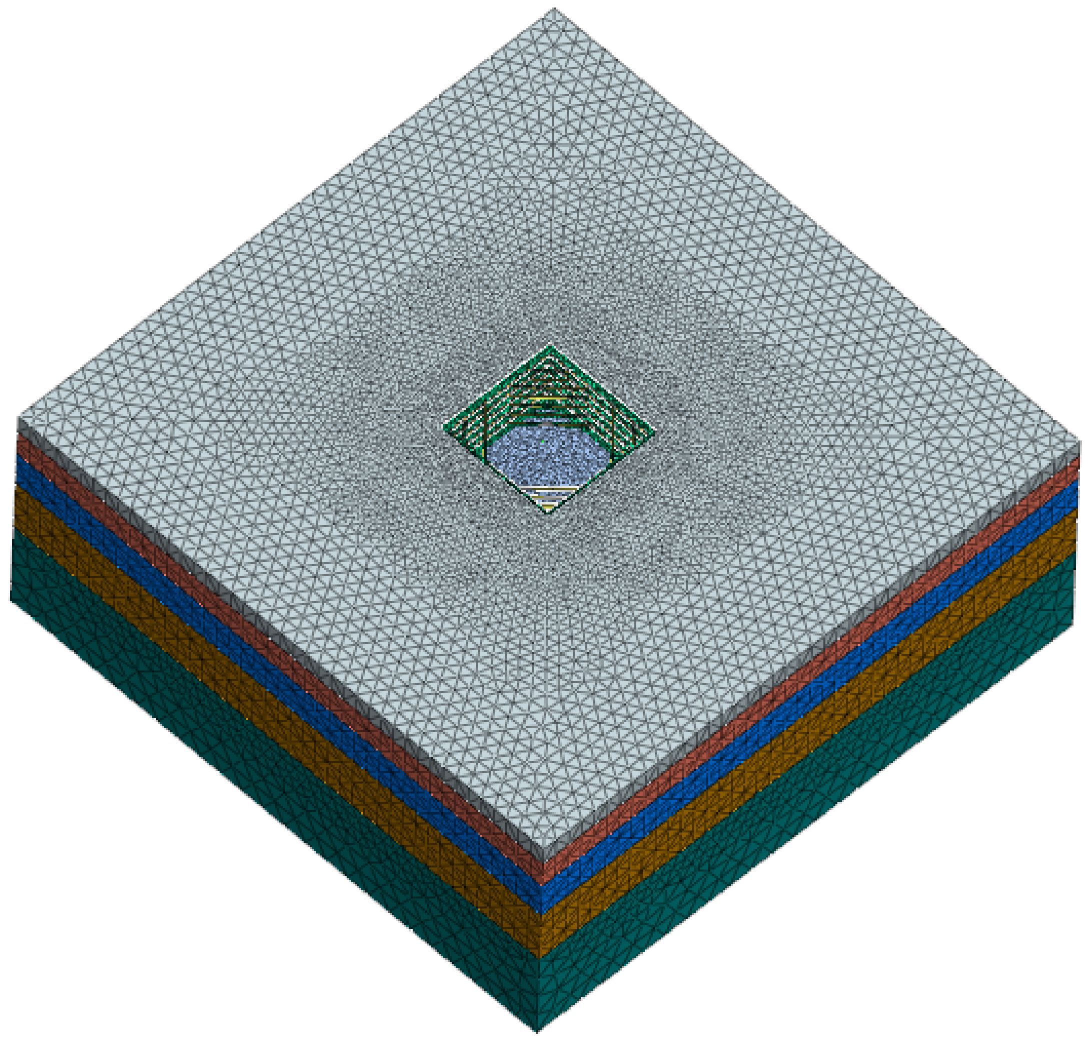
Finite Element Analysis Platform for Geotechnical Applications



Axisymmetric

2D Modelling





3D Modelling

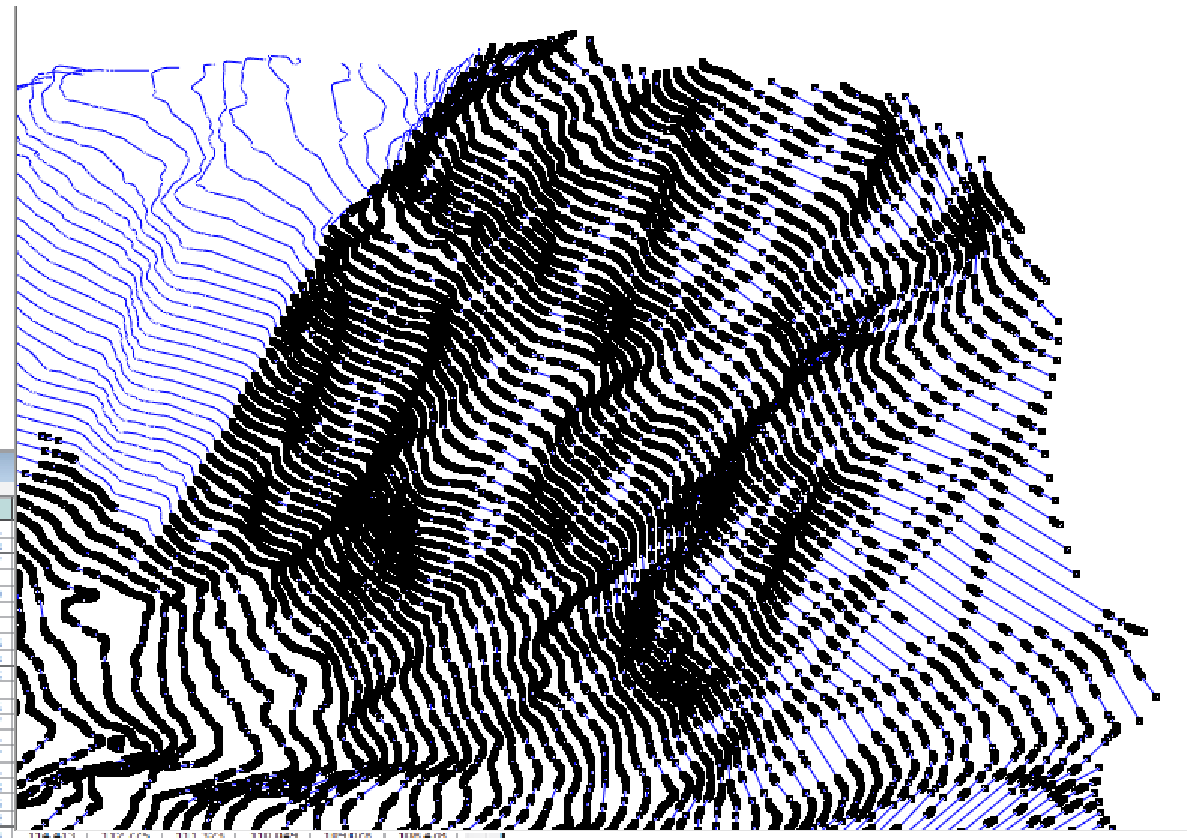
MIDAS

GTS MIDAS GTS NX

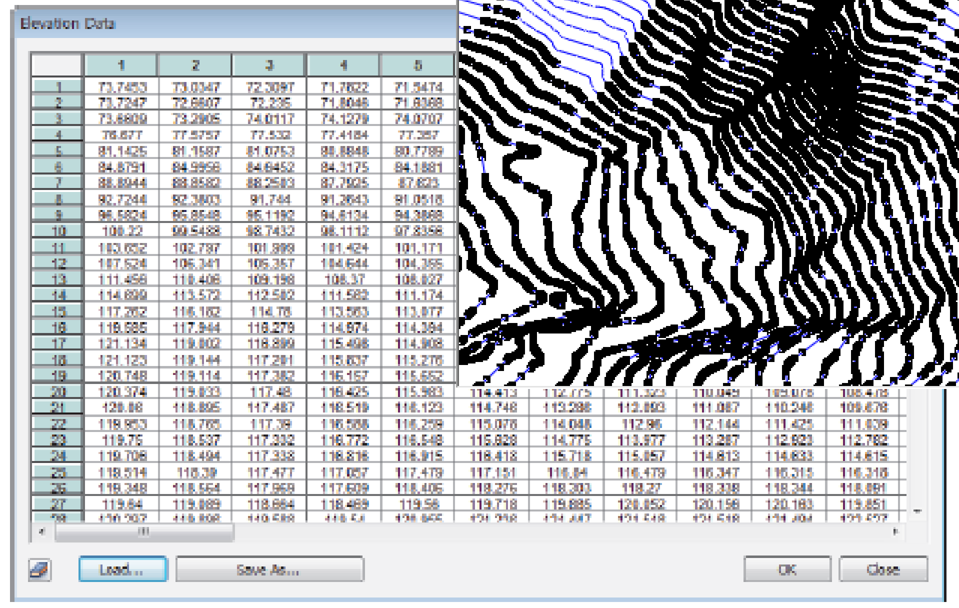
TOPOGRAPHY DEVELOPMENT

- Direct import of Survey Data Points and Elevation data from LIDAR Survey

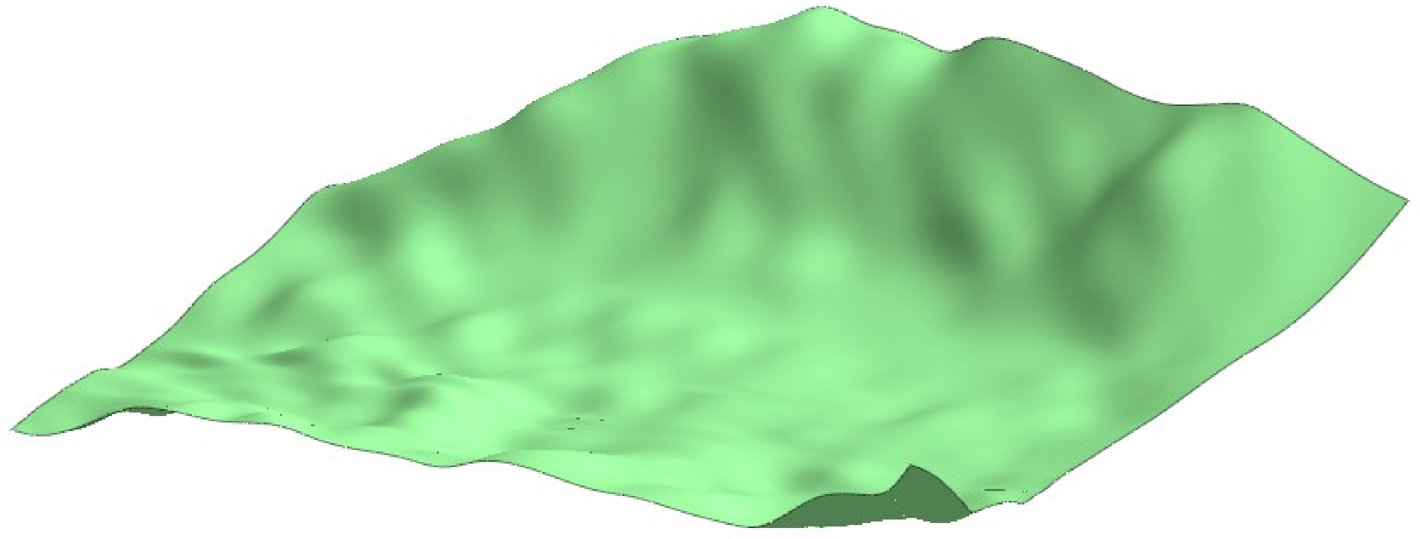
- Complex 3D topography modelling using imported data points (.csv/ .xlsx)



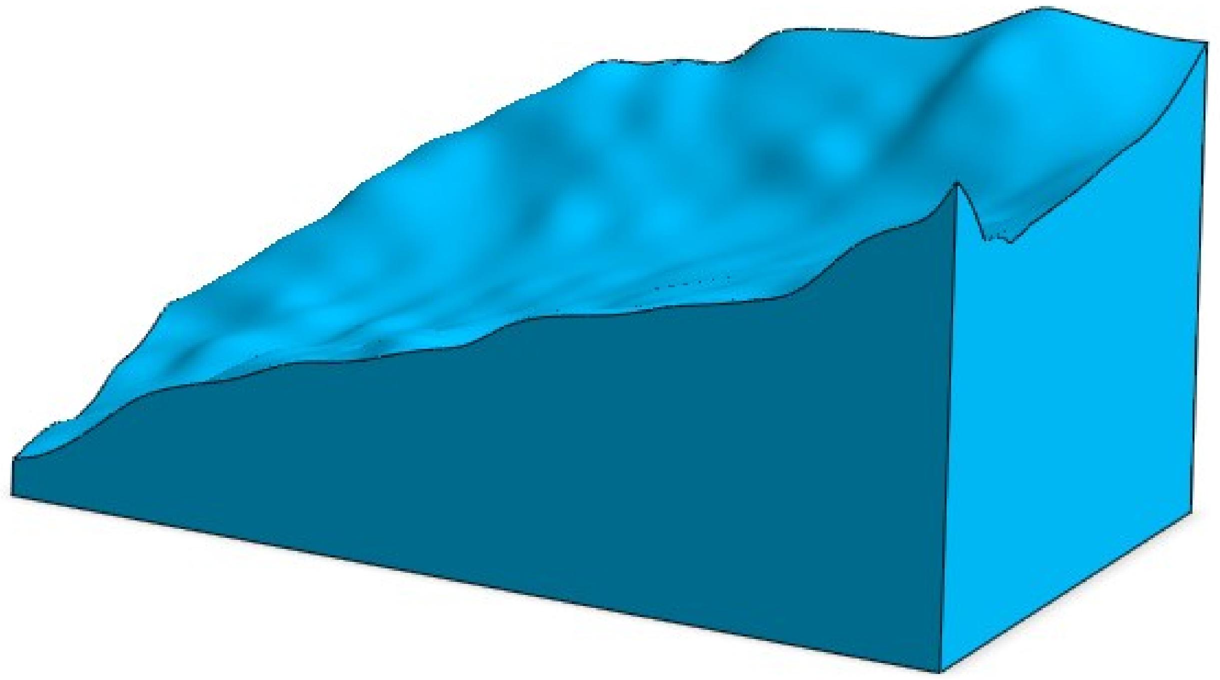
Data Points import



Elevation Data input

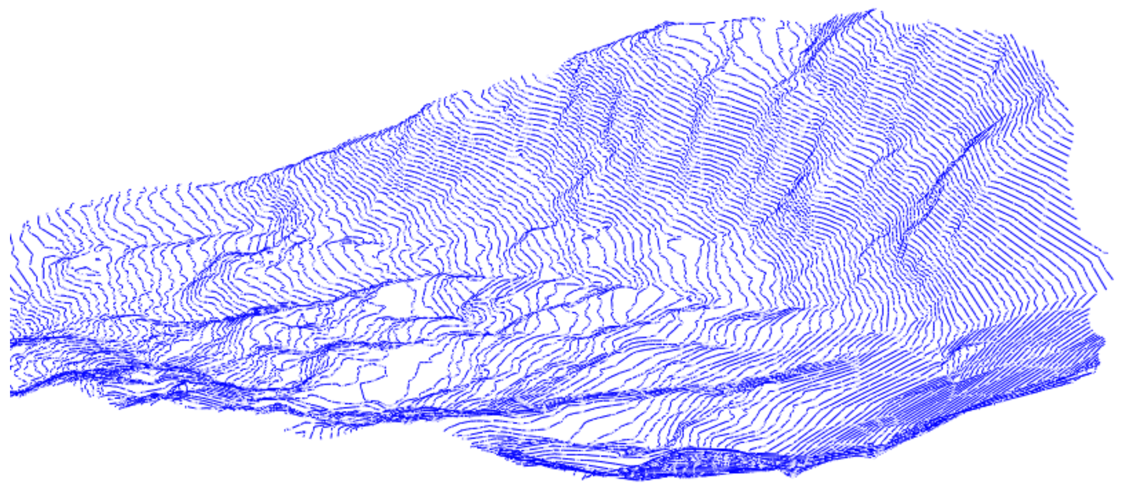


Surface Topography

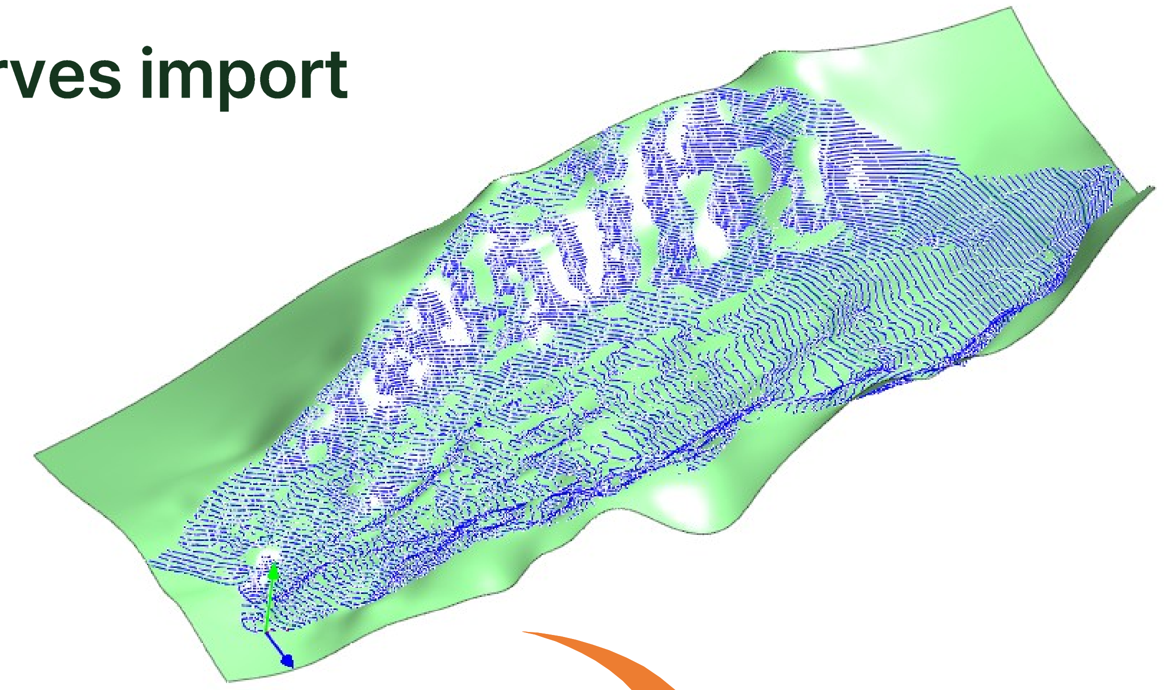


TOPOGRAPHY DEVELOPMENT

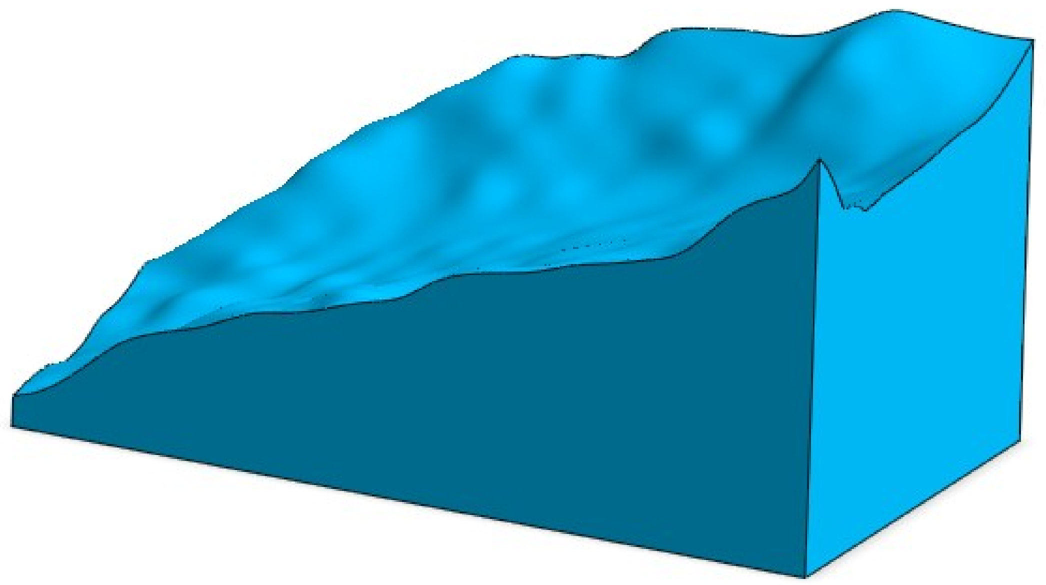
- Complex 3D topography modelling using imported contour curves
- Supports .dxf, .dwg and other CAD format drawings import

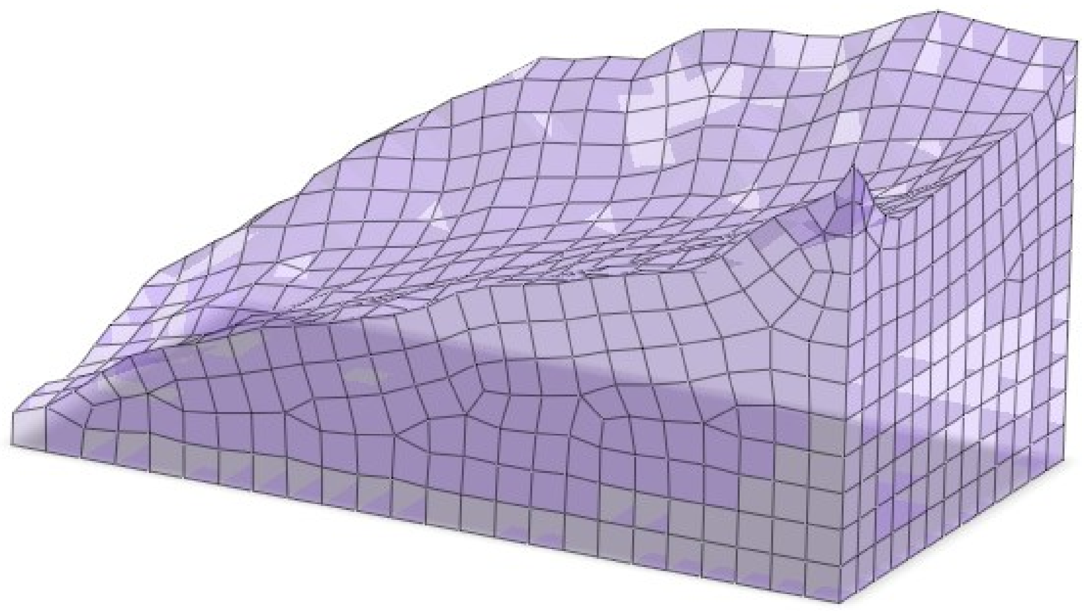


Contour curves import



Surface Topography





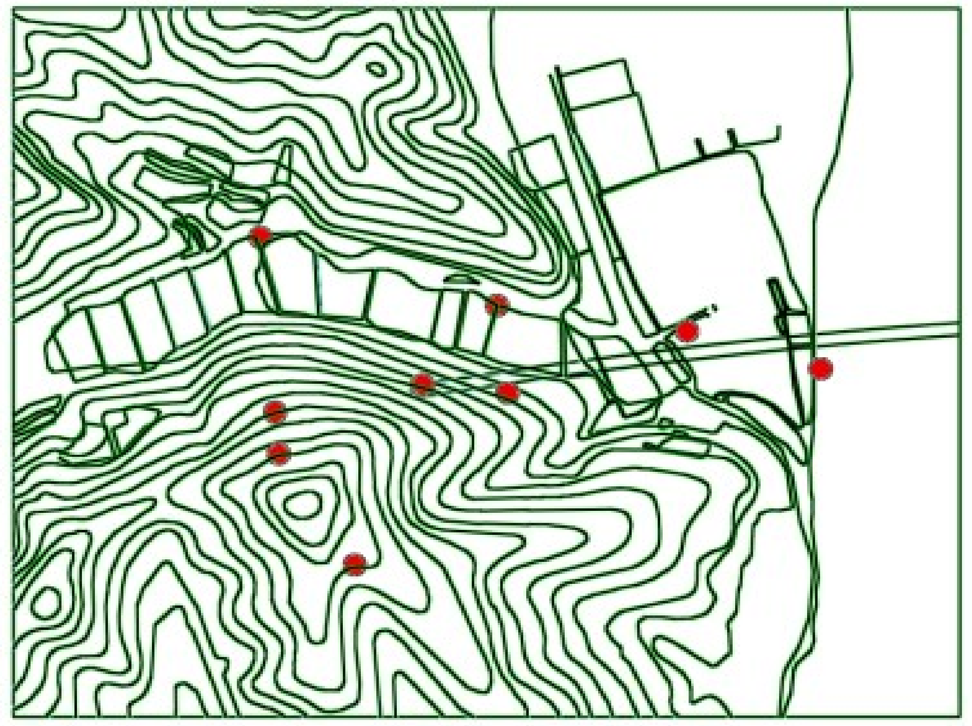
Geometry Modelling and Meshing

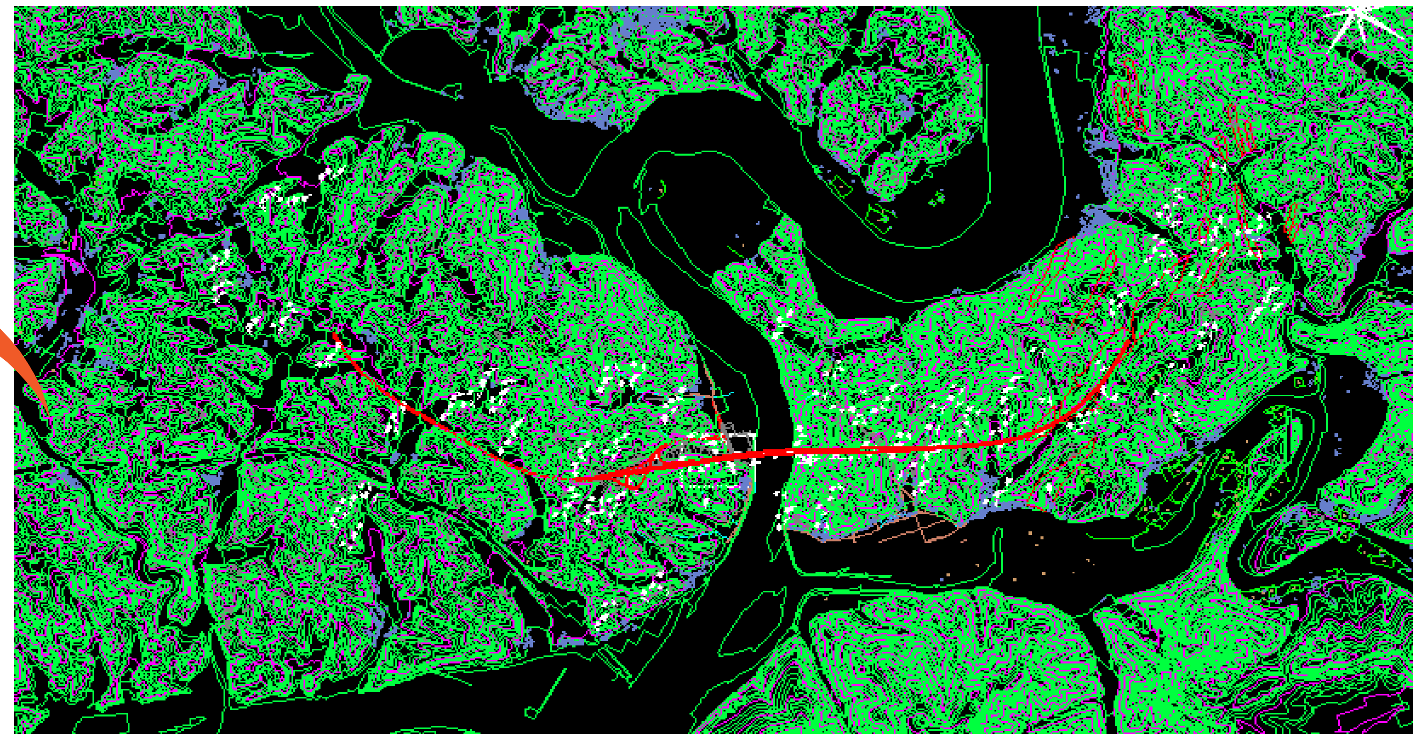
Parasolid (9 to 34) Files (*.x_t;*.xmt_txt;*.x_b;*.xmt_bin)
ACIS (R1 - 2022 1.0) Files (*.sat;*.sab;*.asat;*.asab)
STEP (AP203, AP214, AP242) Files (*.stp;*.step)
IGES (Up to 5.3) Files (*.igs;*.iges)
Pro-E (16 - Creo 8.0) Files (*.prt;*.prt.*;*.asm;*.asm.*)
CATIA V4 (CATIA 4.1.9 - 4.2.4) Files (*.model;*.exp;*.session)
CATIA V5 (V5 R8 - V5-6R2025) Files (*.CATPart;*.CATProduct)
SolidWorks (98 - 2022) Files (*.sldprt;*.sldasm)
Unigraphics (11 - NX2007) Files (*.prt)
Inventor Part (V6 - V2022) Files (*.ipt)
Inventor Assembly (V11 - V2022) Files (*.iam)

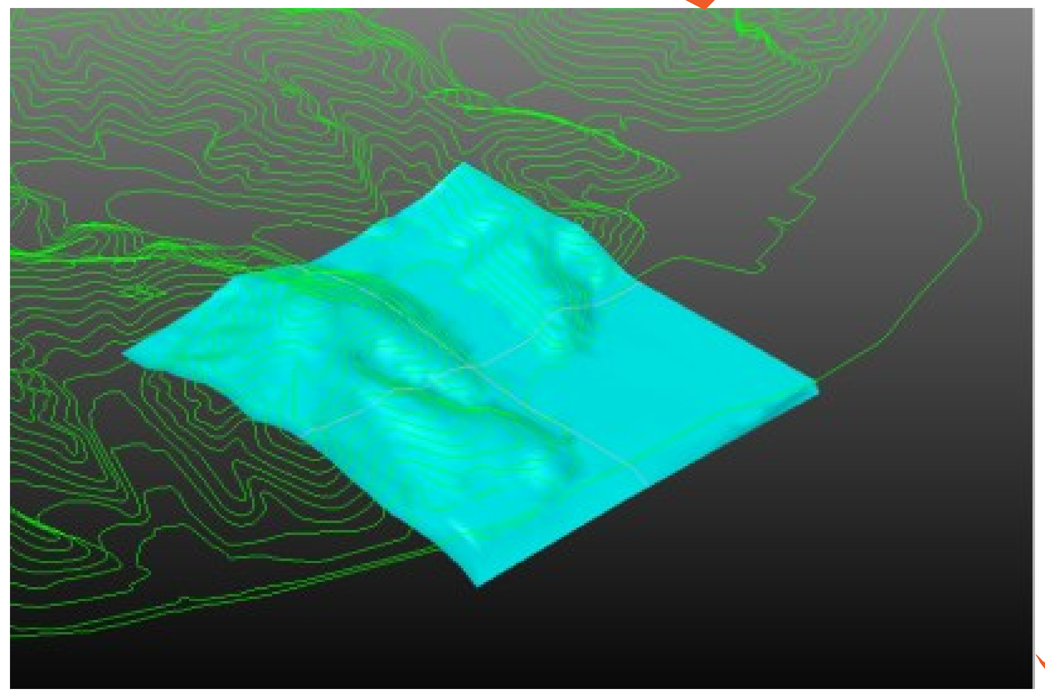
CAD Formats import

TOPOGRAPHY& STRATIFICATIO N DEVELOPMENT

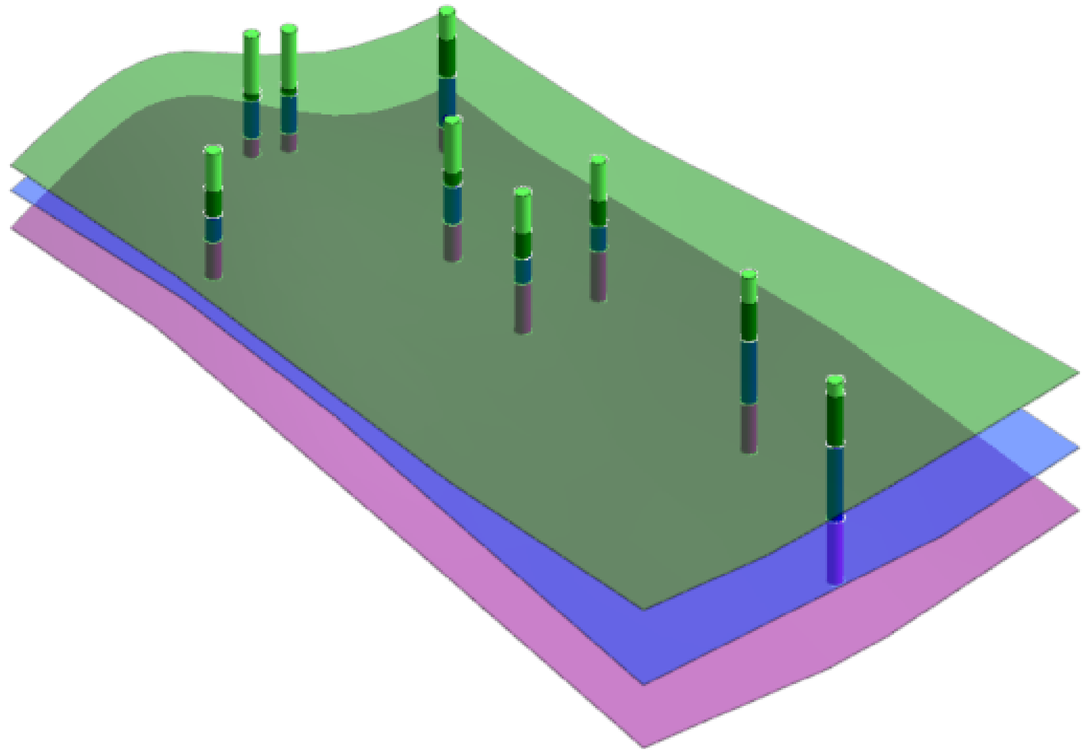
- Terrain Geometry Maker: Automatic generation of complex 3D surfaces using available contour data/Google Earth data
- Bedding Plane Wizard: Soil Stratification Modelling using available borehole data

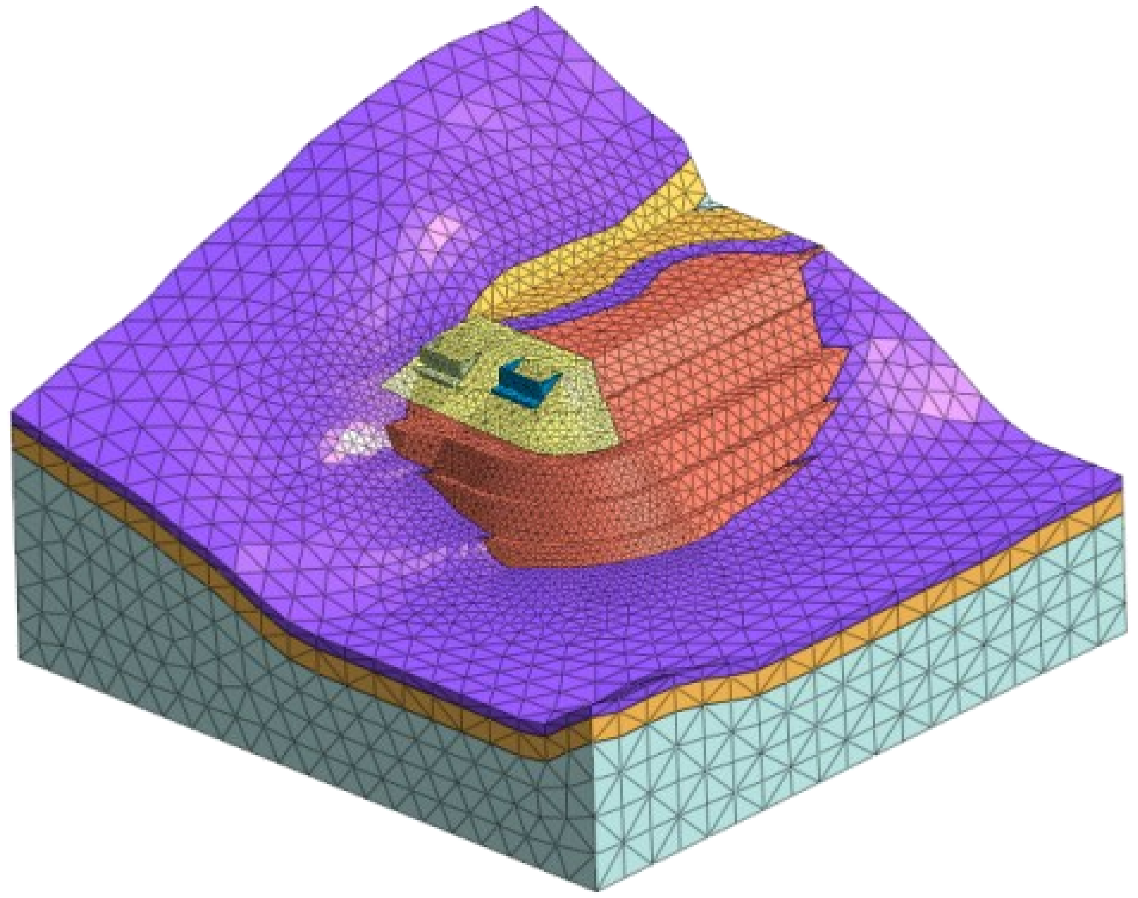






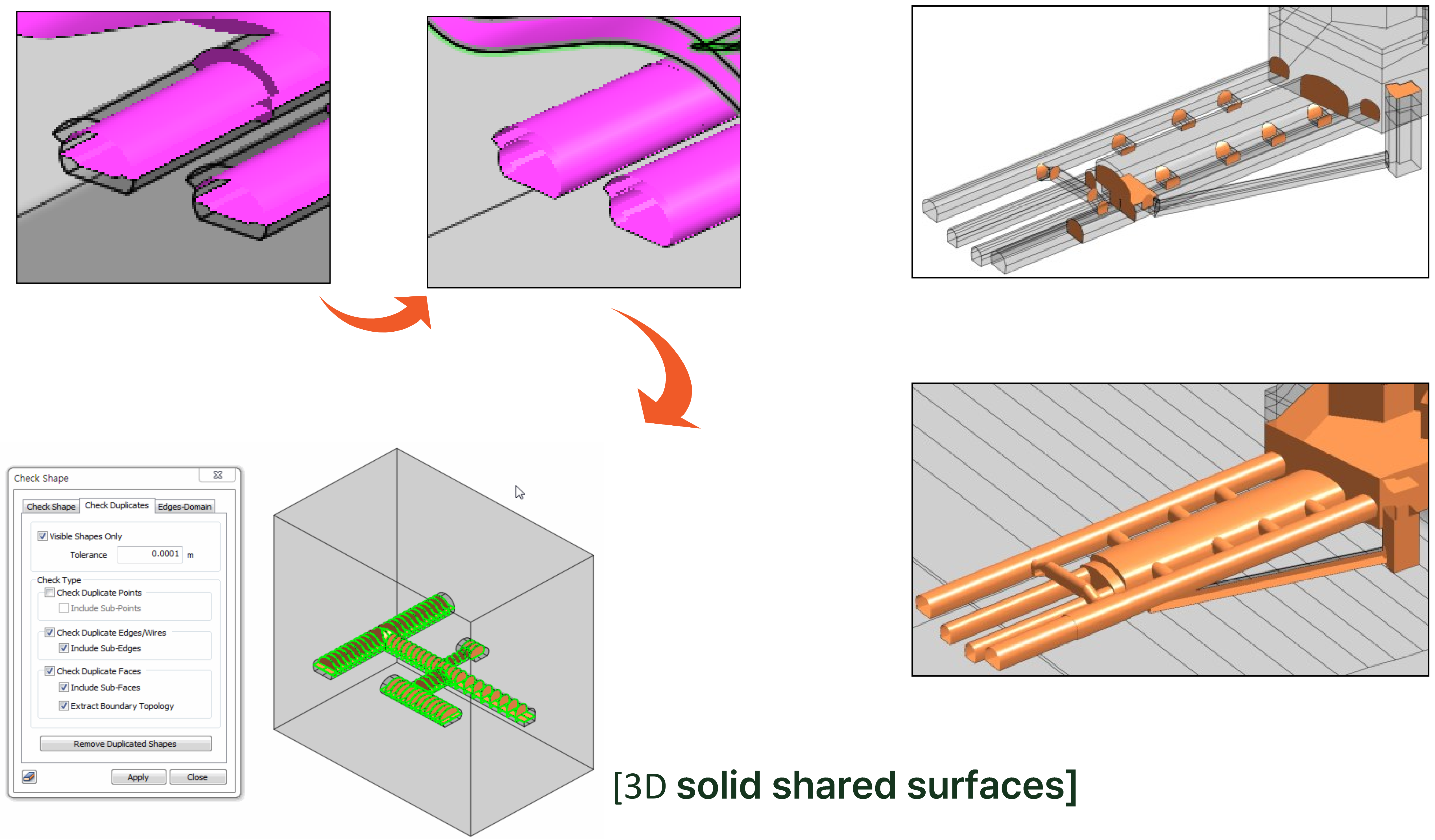
[Automatically generate 3D geological stratum through actual field data]



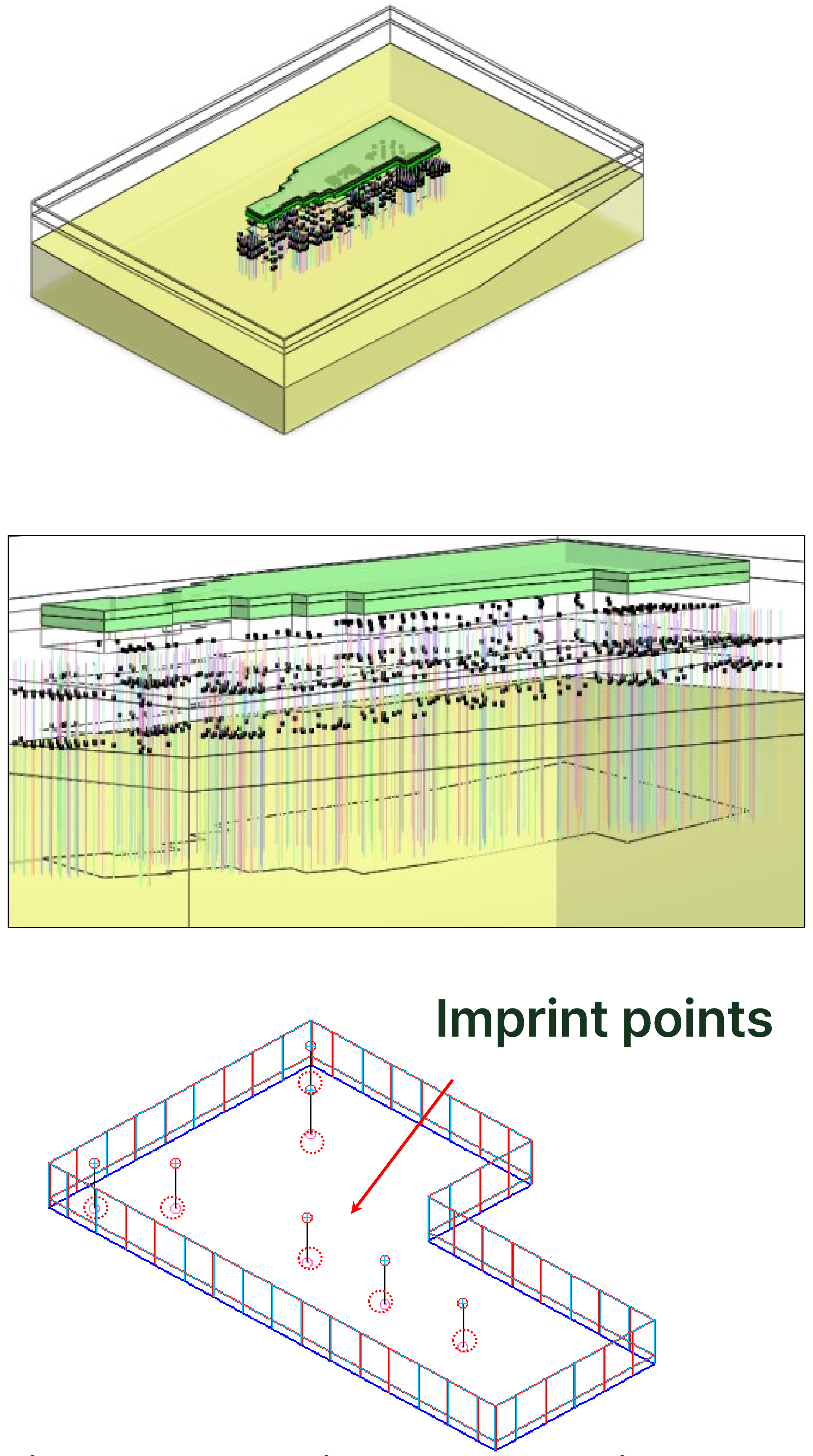


AUTOMATED FEATURES

Automatic Generation Function For 3D Solid Shared Surfaces And Imprints



[3D **solid shared surfaces]**



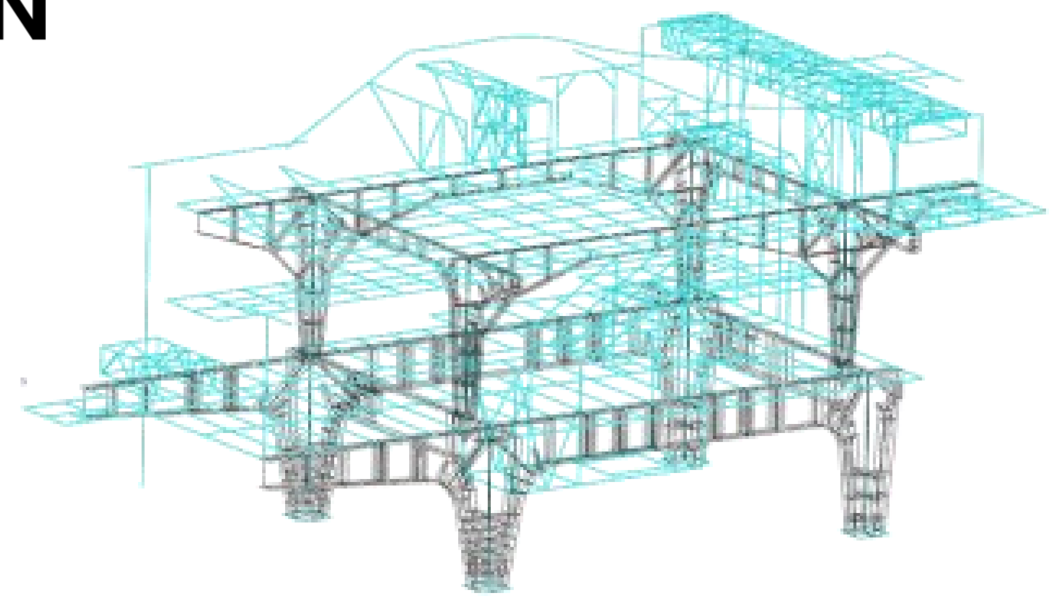
[Solids to Line Connection Automation by points]

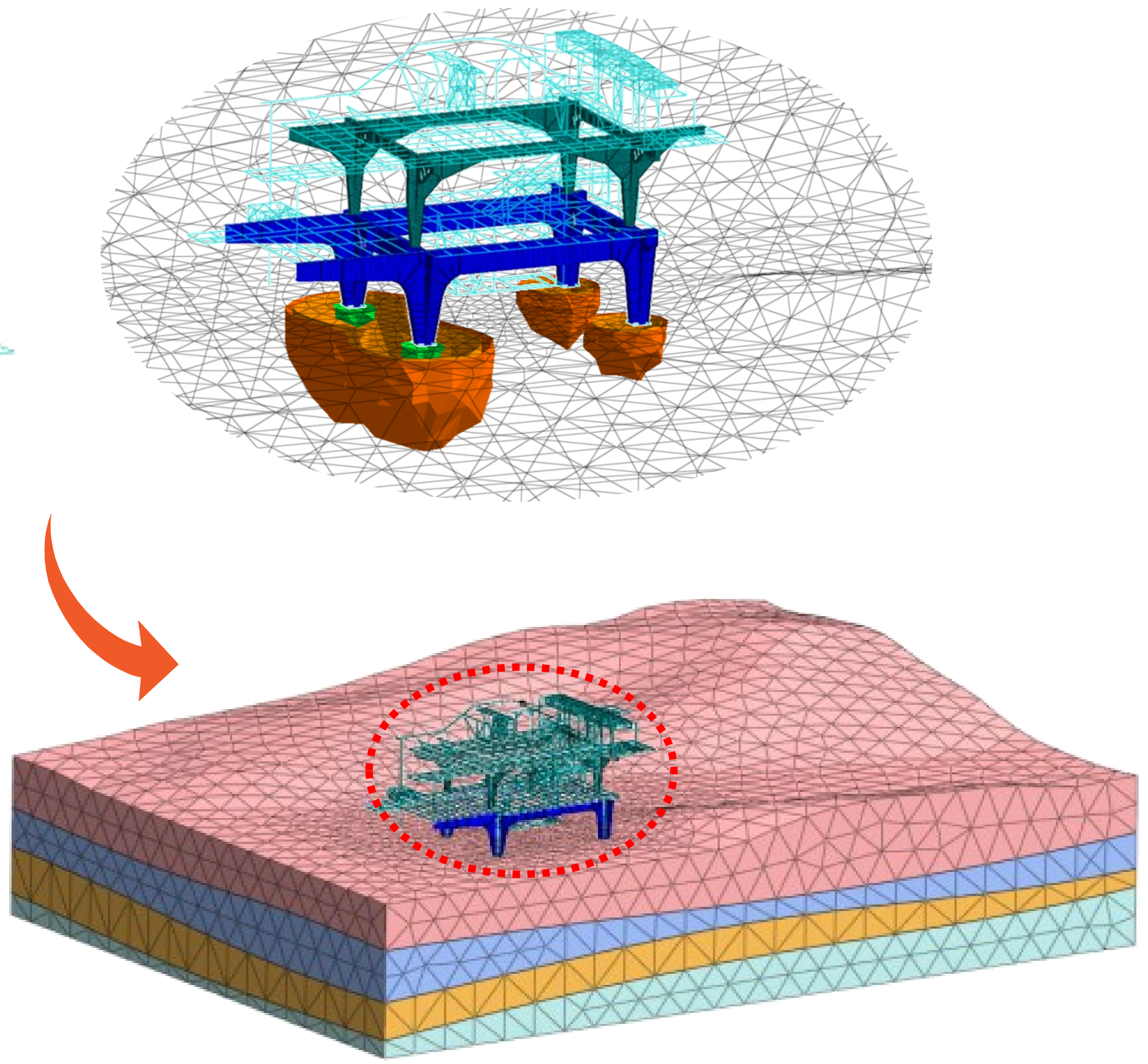
INTEROPERABILITY

- Model information compatibility with MIDAS software, which provides a full-modeling interface.
- Superstructure Data, Nodal Results can be exported/ imported within Midas Family Programs

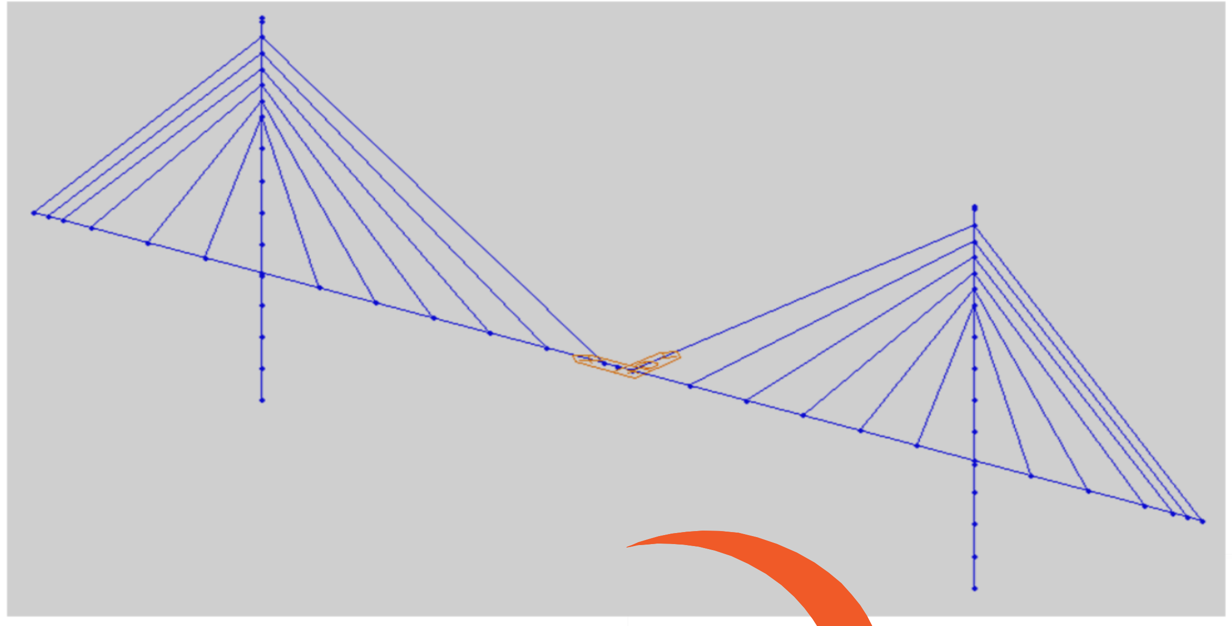
MIDAS GEN

Architectural structure foundation / Ground coupled analysis

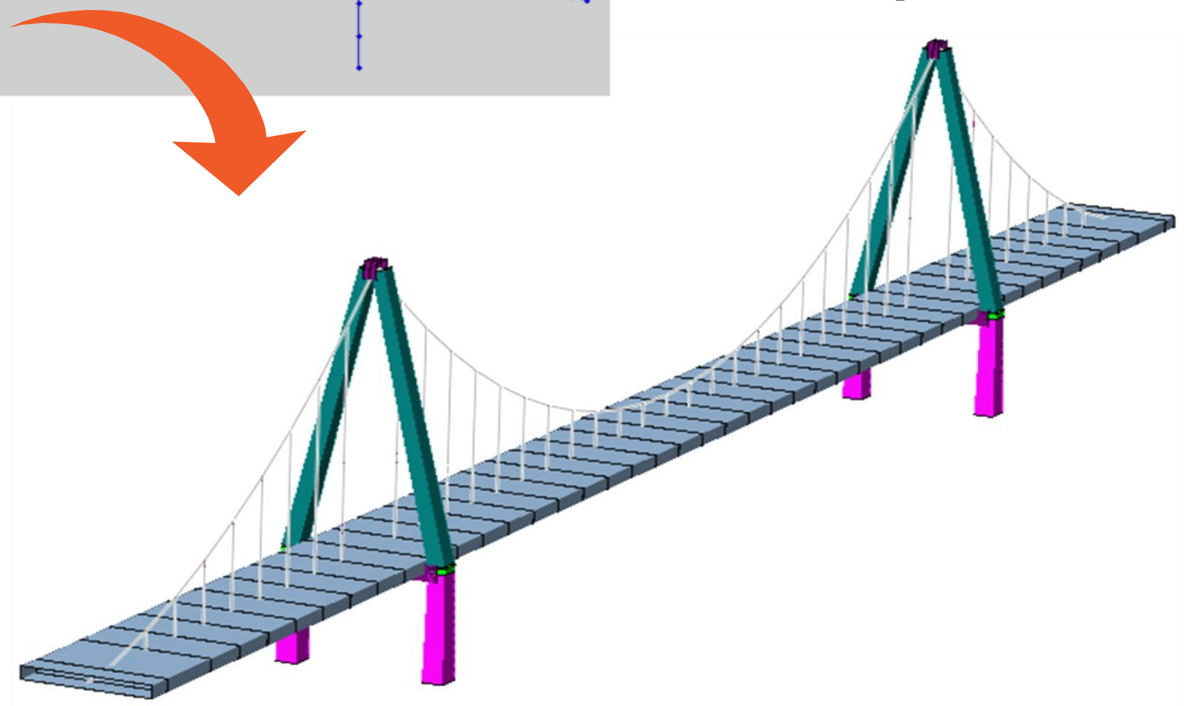




MIDAS CIVIL

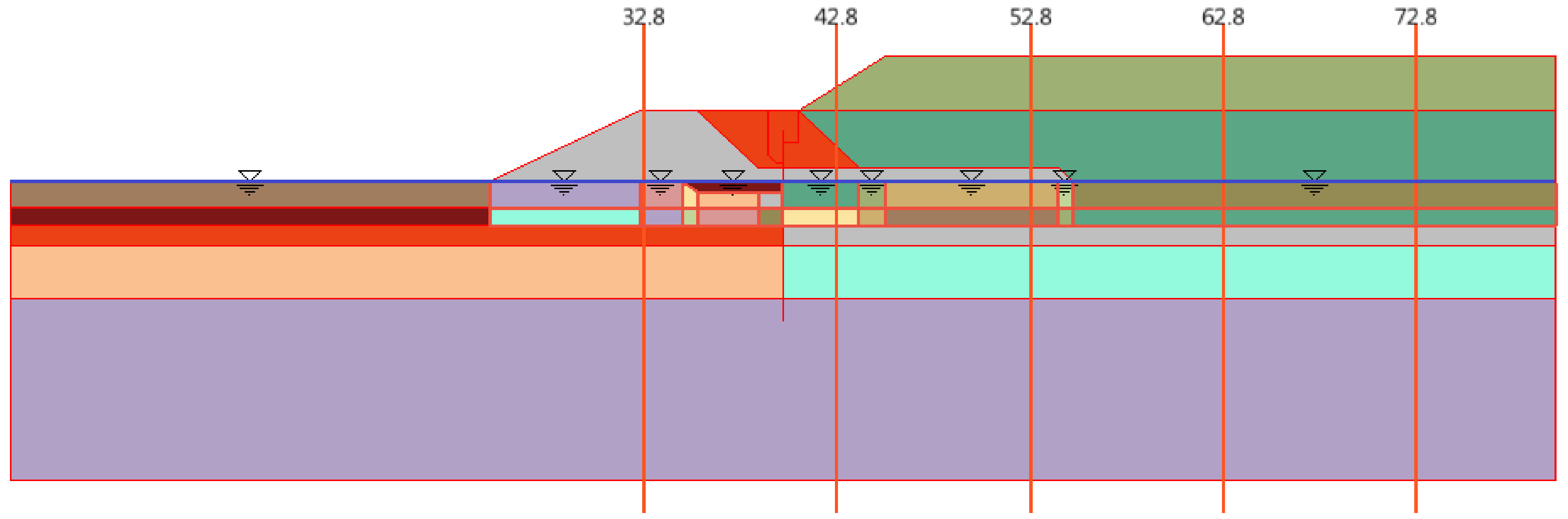


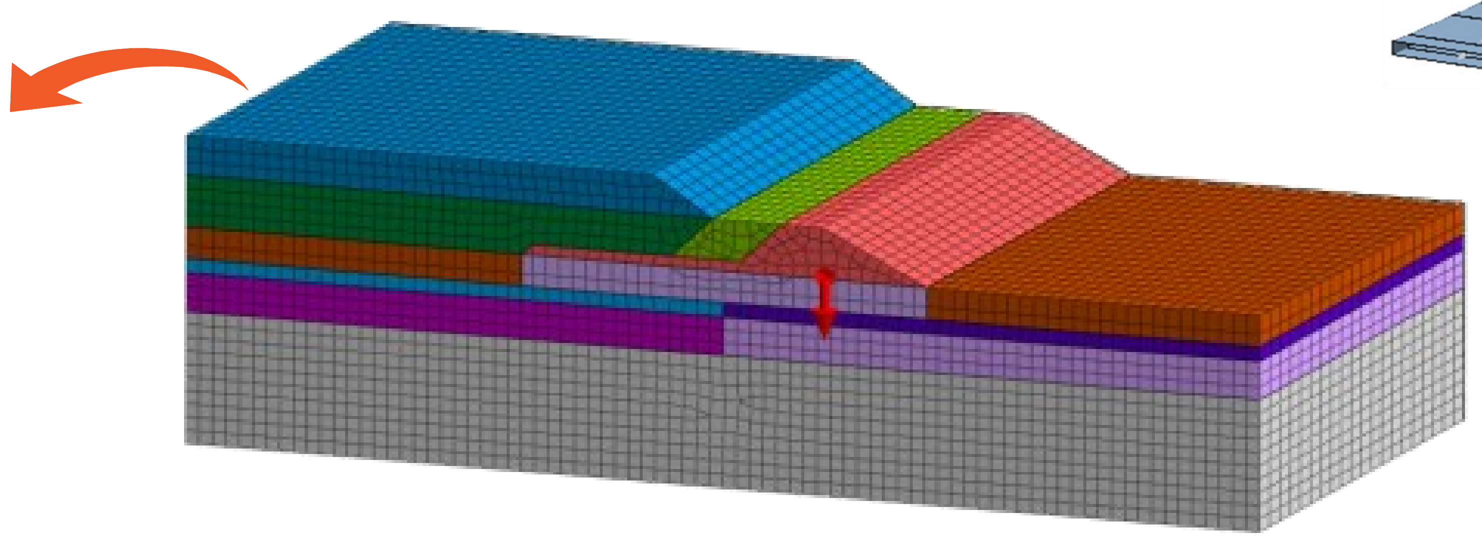
Bridge structure foundation / Ground coupled analysis



MIDAS SOILWORKS

2D FE ↔ 3D Analysis connectivity

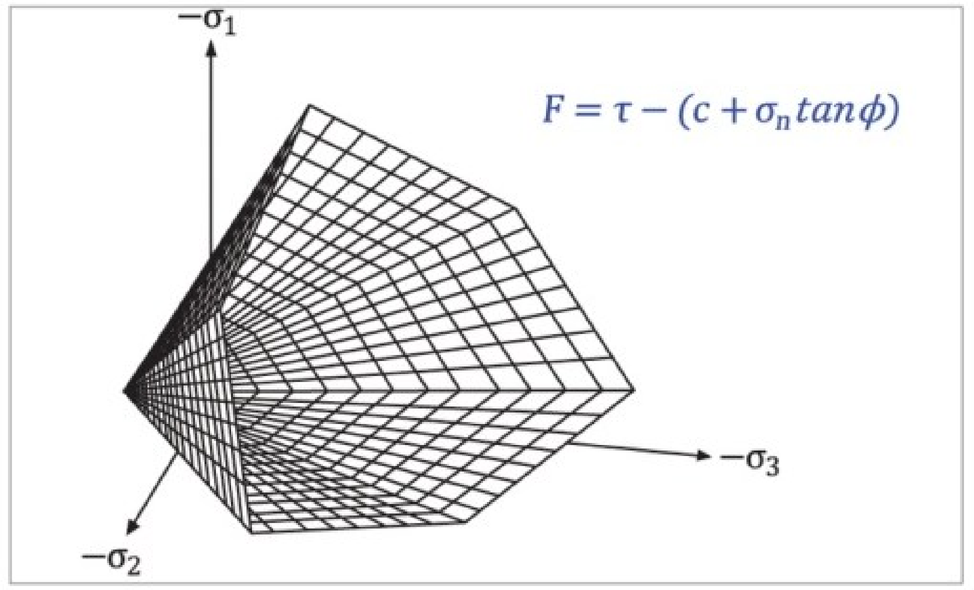


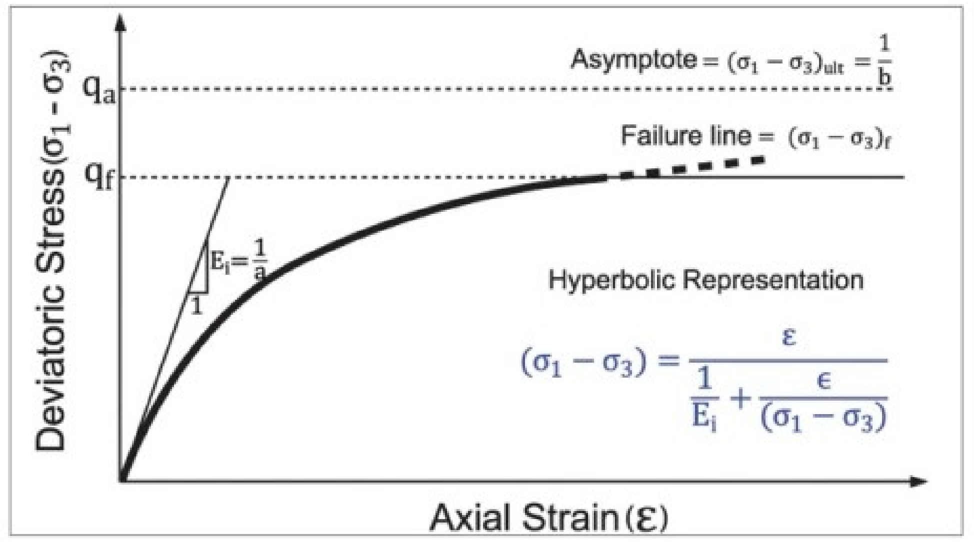


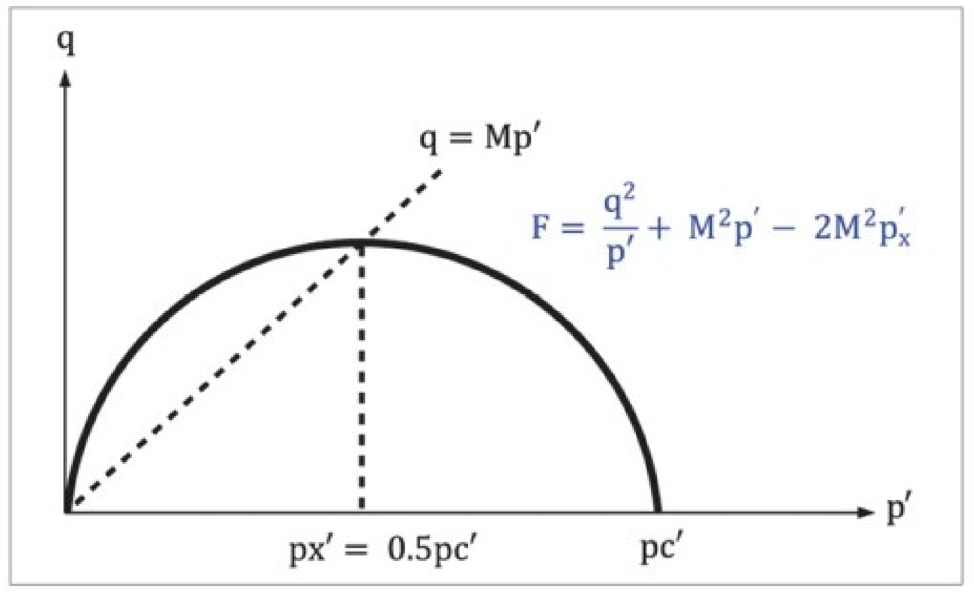
SOIL/ ROCK CONSTITUTIVE MATERIAL MODELS

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

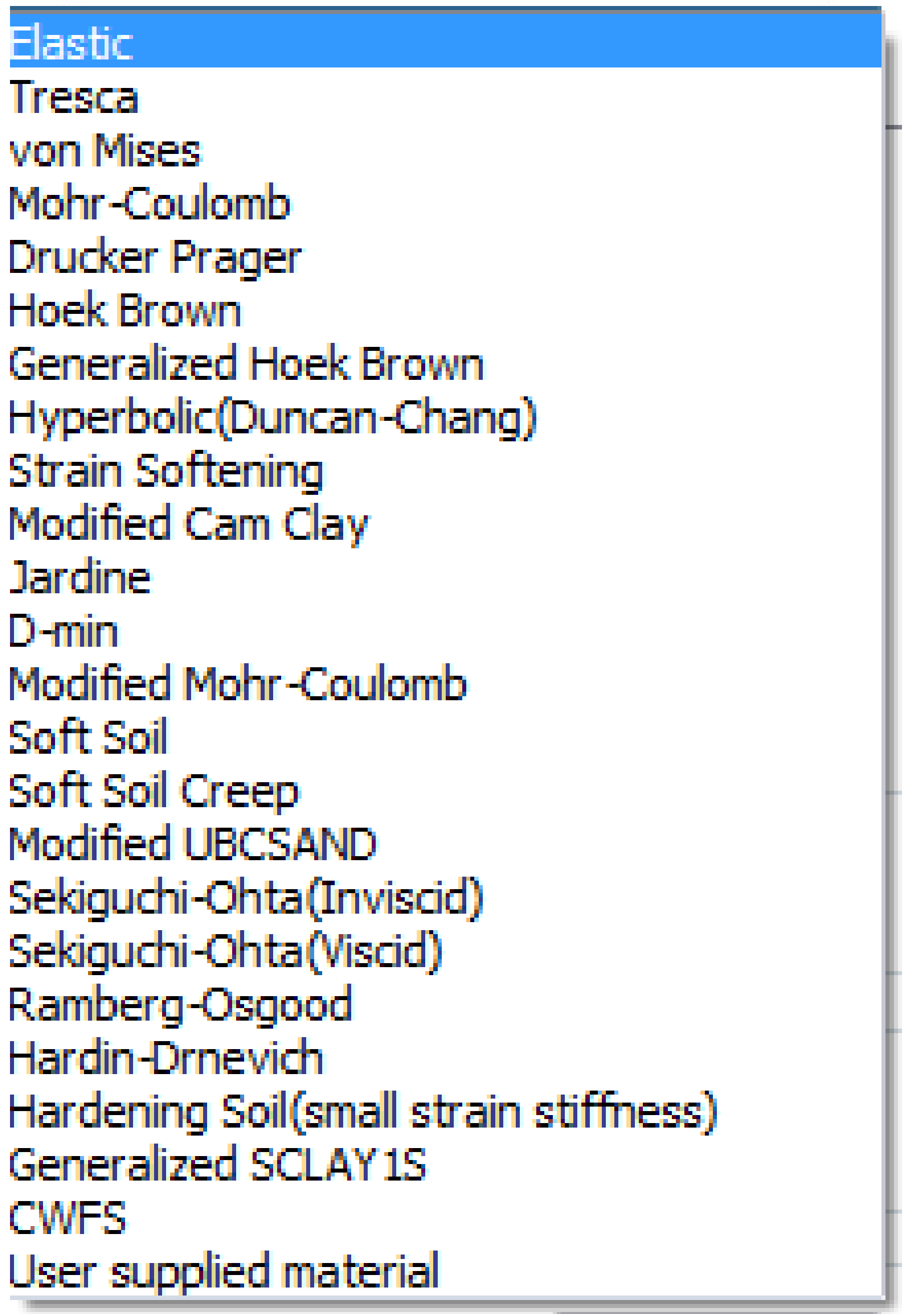
- Effective Stiffness / Effective Strength
- Effective Stiffness / Undrained Strength
- Undrained Stiffness / Undrained Strength

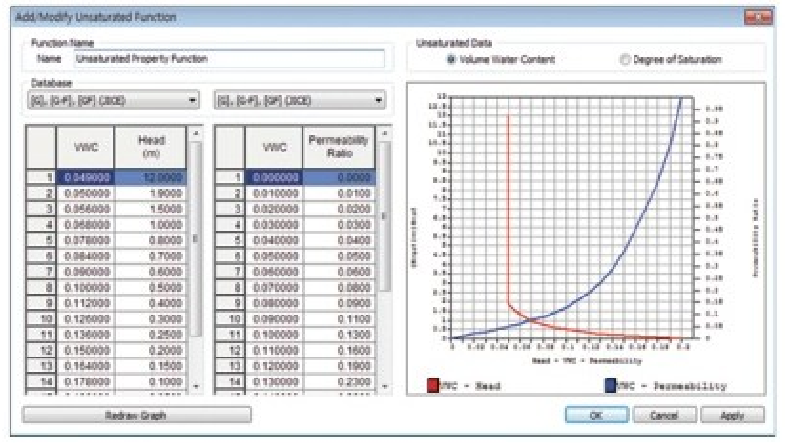
Functions

- 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)

Orthotropic

- Transversely Isotropic
- Jointed Rock Mass
- 2D Orthotropic
- Geogrid

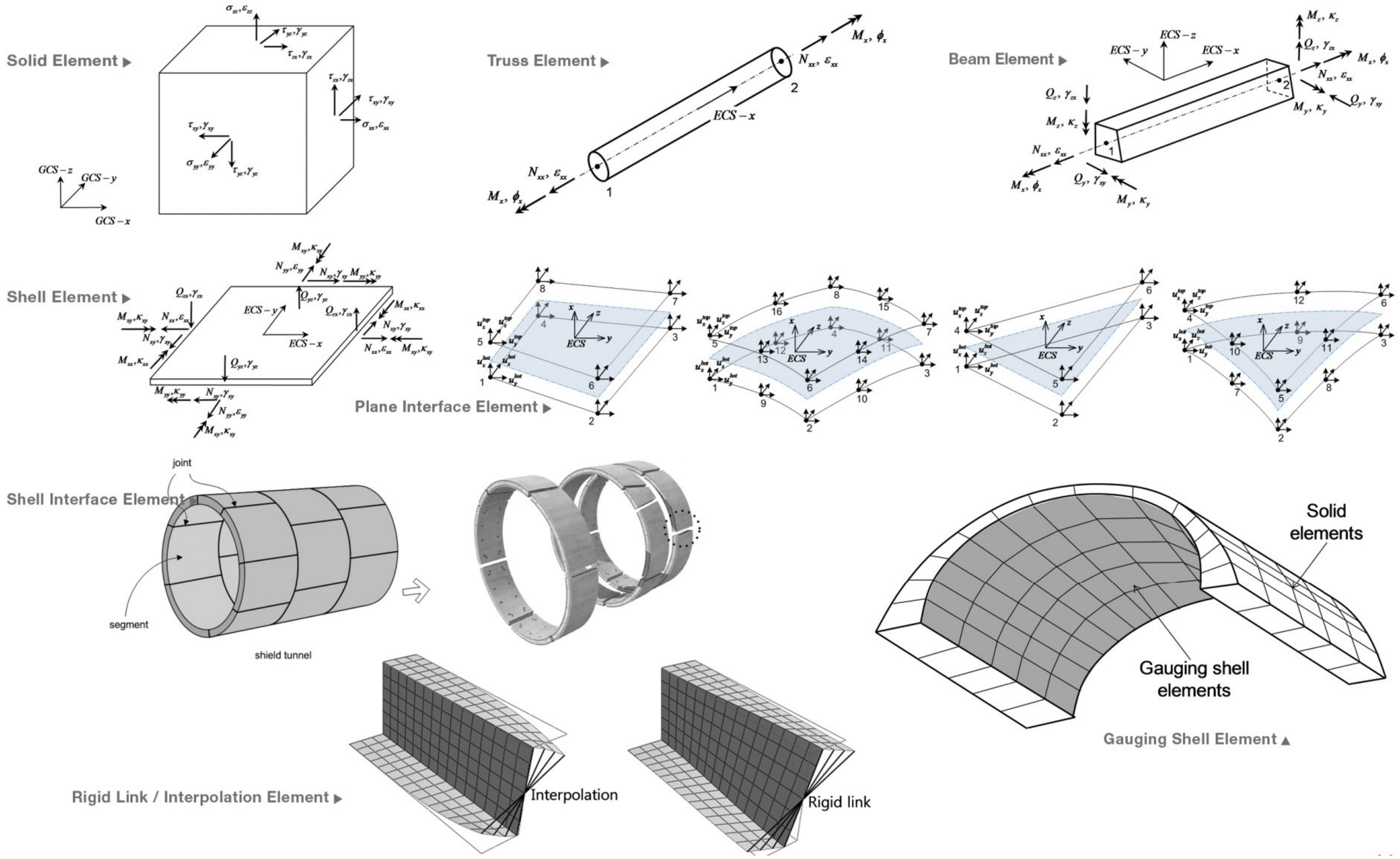


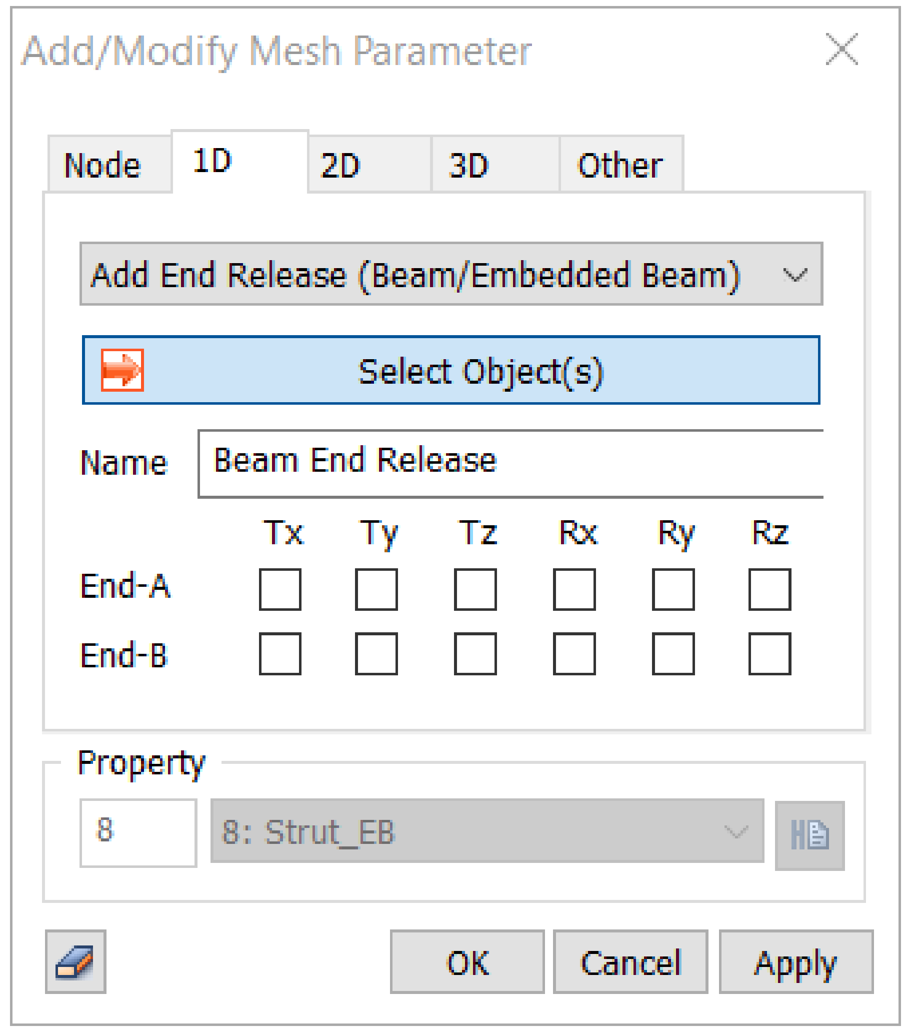


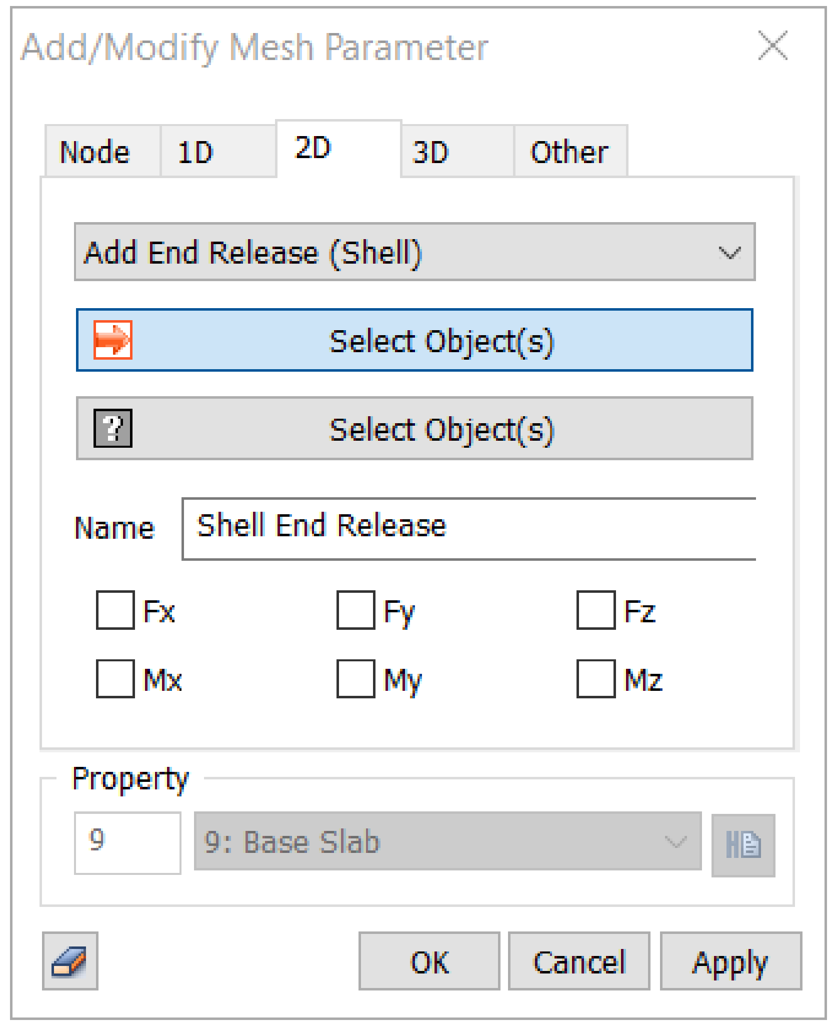
Unsaturated property (Relation) ▲

ELEMENT LIBRARY

1D: Truss, Embedded Truss, Beam, Embedded Beam, Geogrid (1D), Pile, Pipe, etc
2D: Plane Strain, Plane Stress, Shell, Gauging Shell, Geogrid (2D), Sloshing Fluid, etc
3D: Solid, Sloshing fluid
Other Advanced Element Types: Point Spring, Matrix Spring, Elastic Link, Rigid Link, Interface, Shell Interface, Infinite, Fluid Boundary, Free Field, Seepage



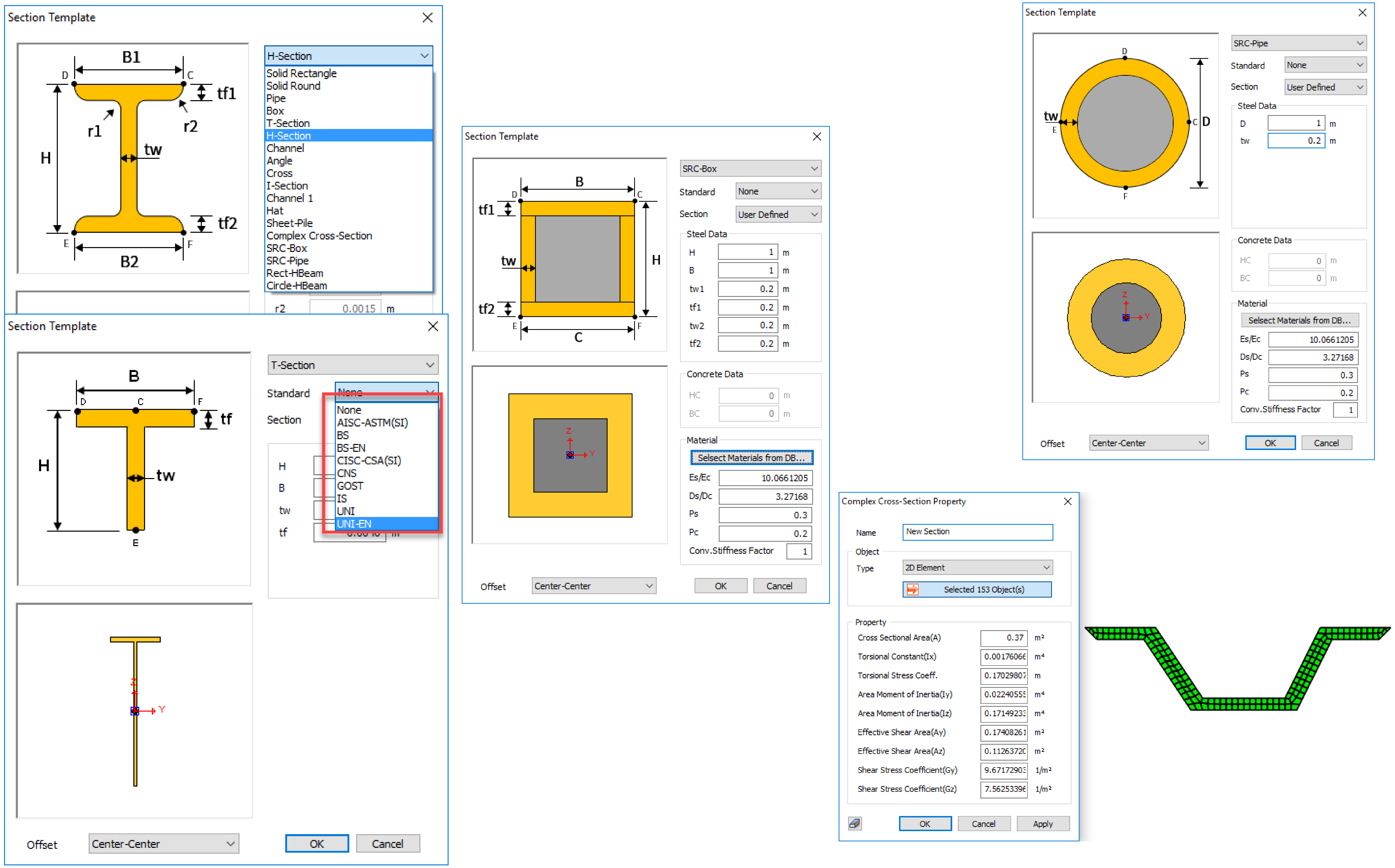




Define Hinge/Joint/Shear Lock Between 1D & 2D structural elements

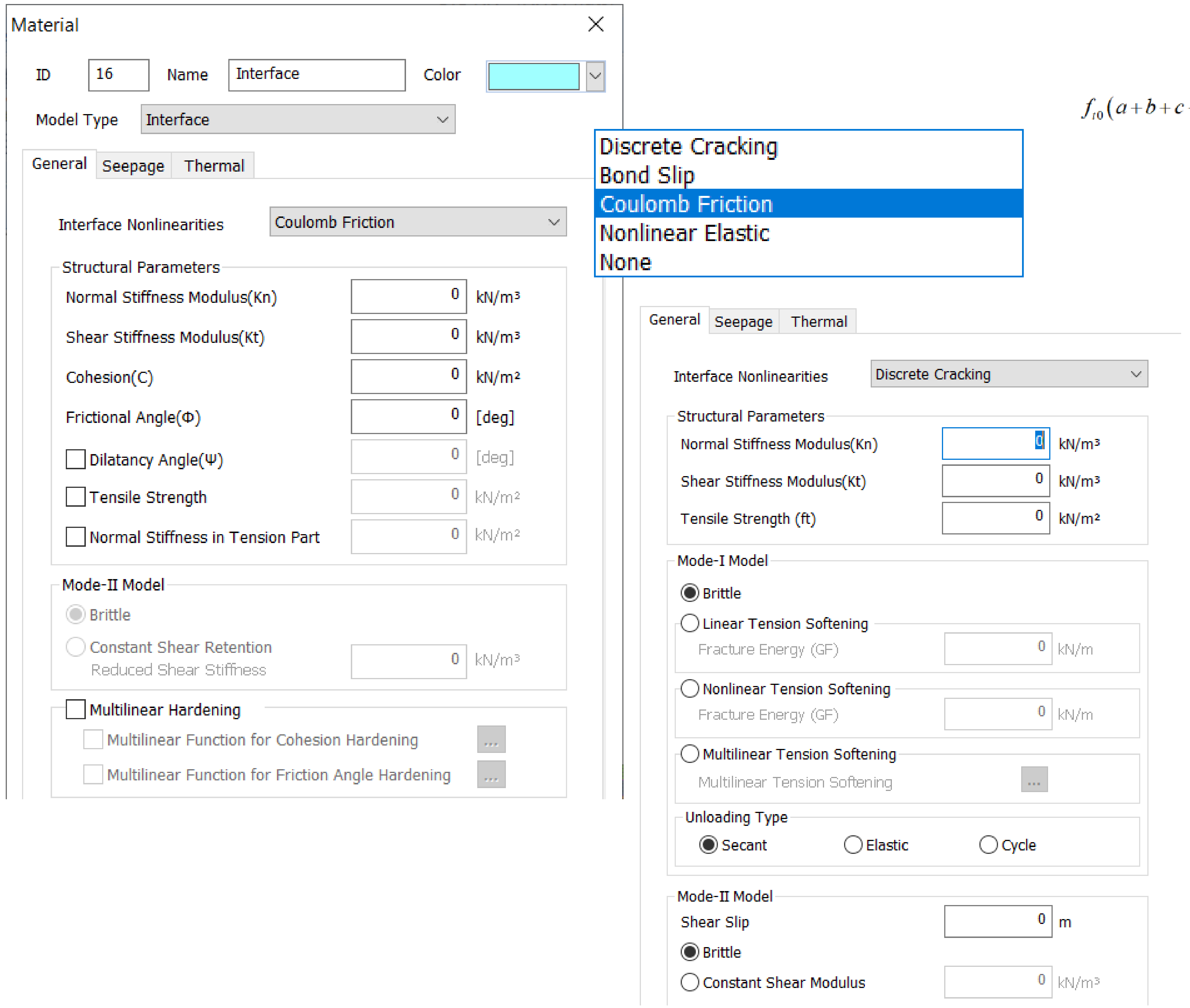
ELEMENT LIBRARY

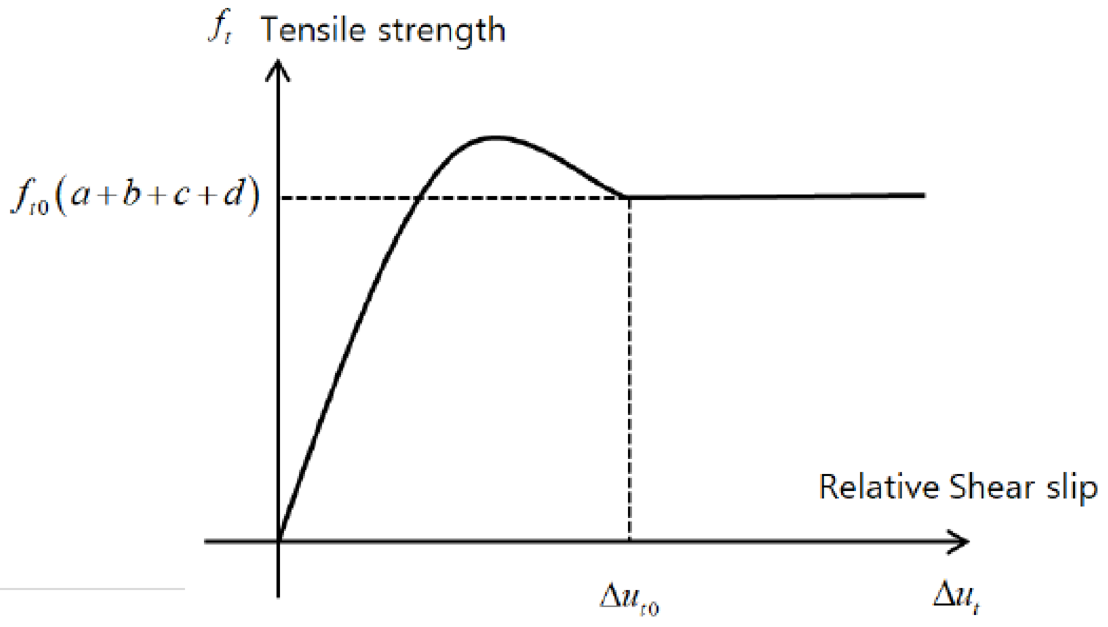
Section Property Database

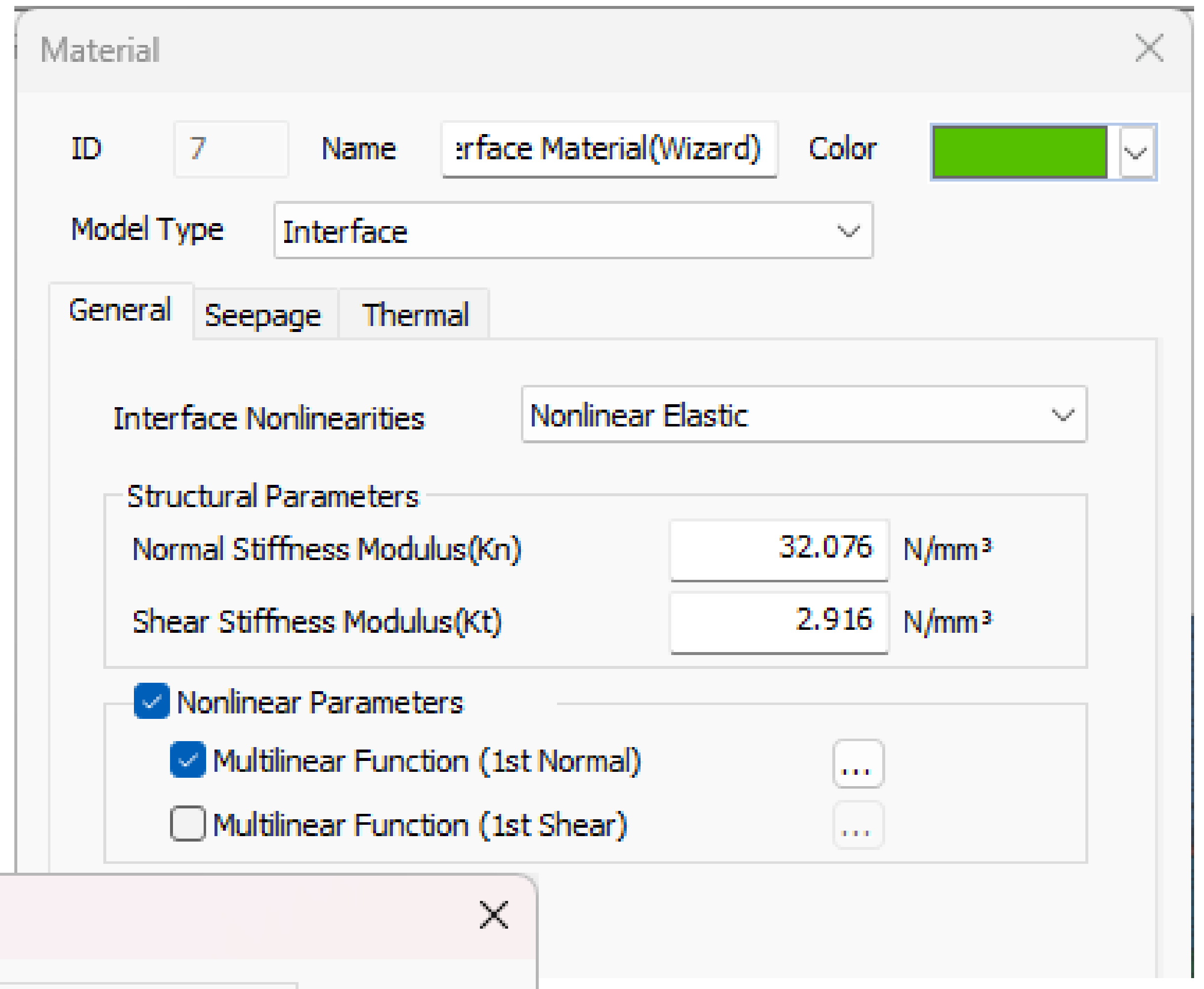


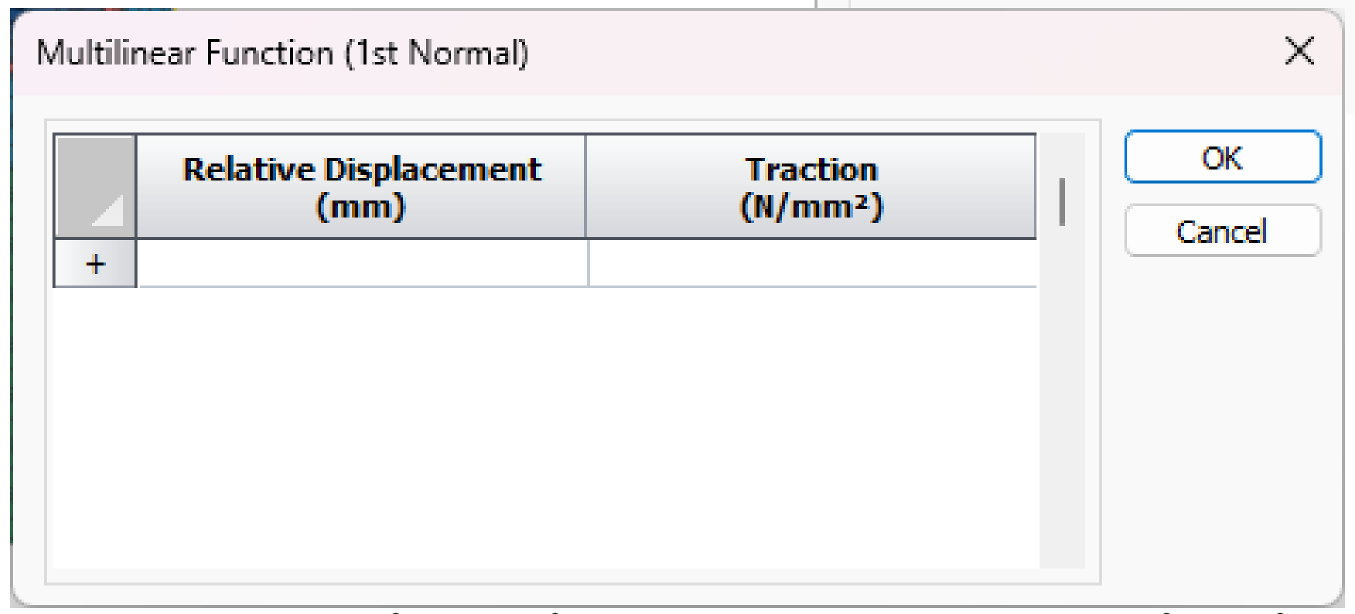
INTERFACE ELEMENTS

- Interface element definition to simulate relative behaviour between ground and structural elements
- Interface Nonlinearities: Discrete Cracking, Bond Slip, Coulomb Friction, Nonlinear Elastic, Elastic







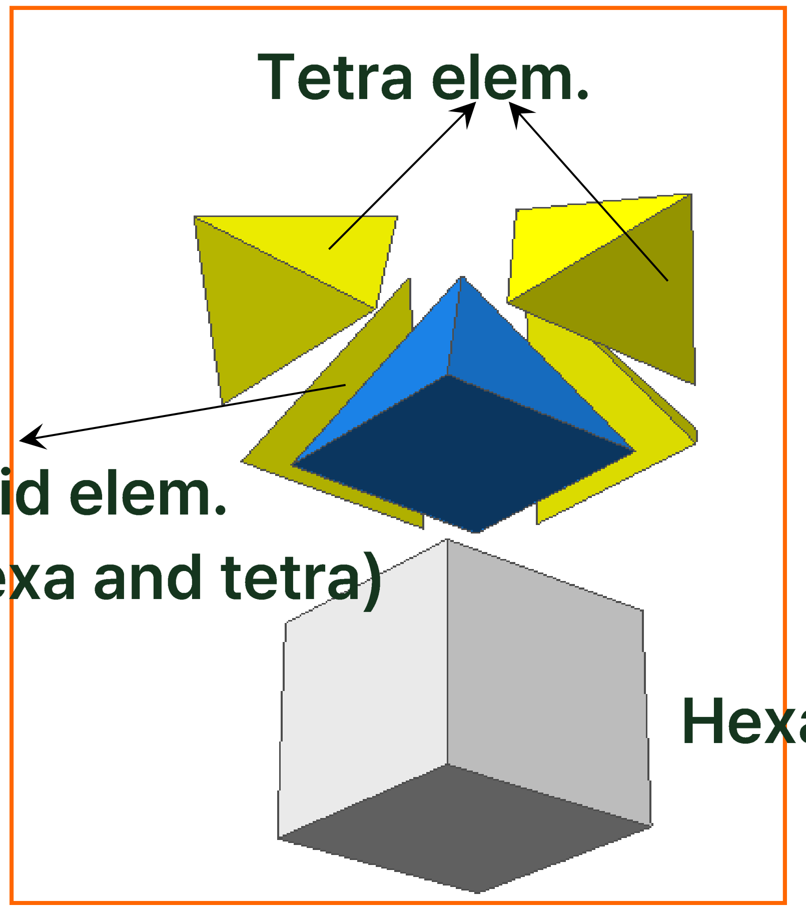


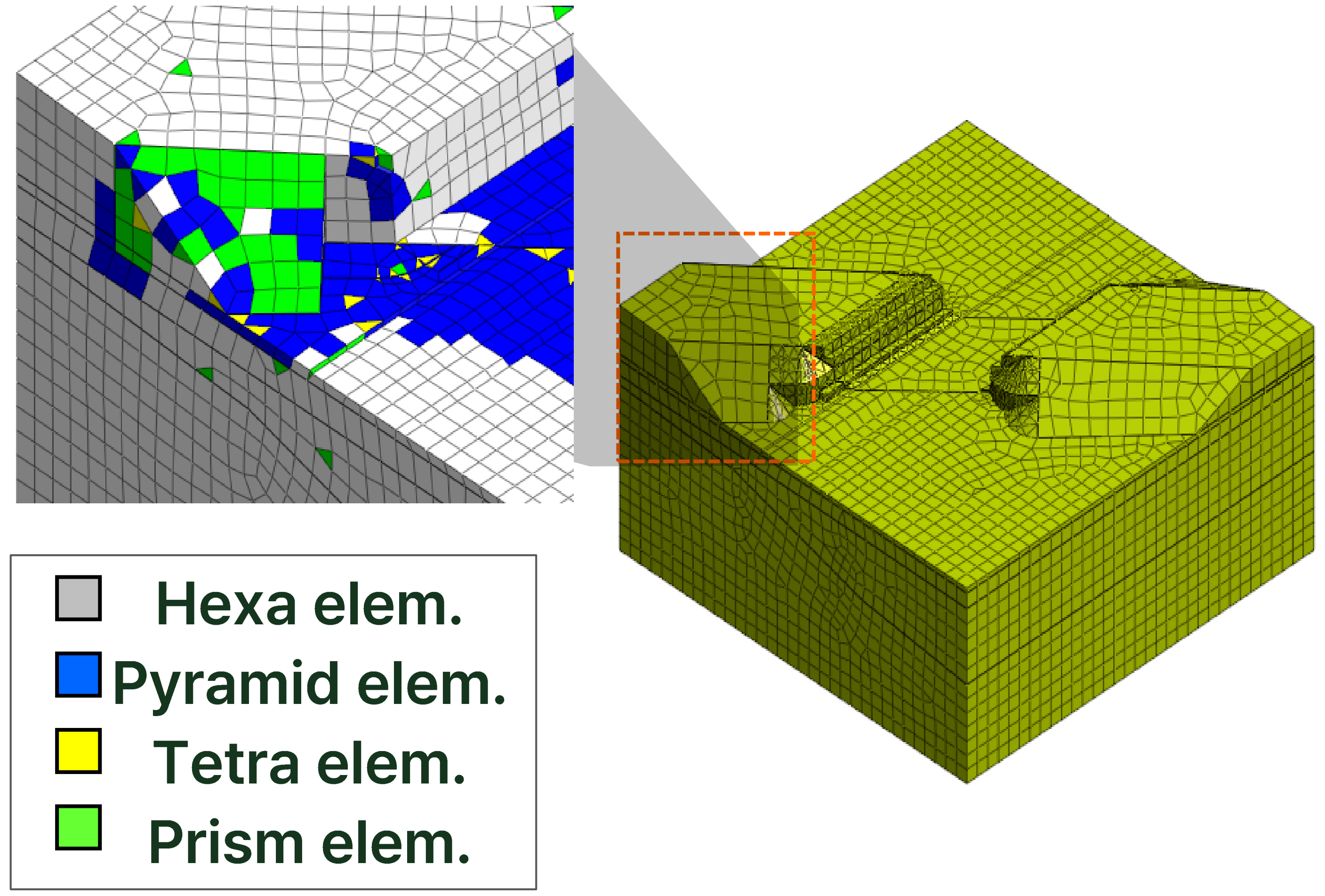
Relative Displacement- Traction input for interface stiffness

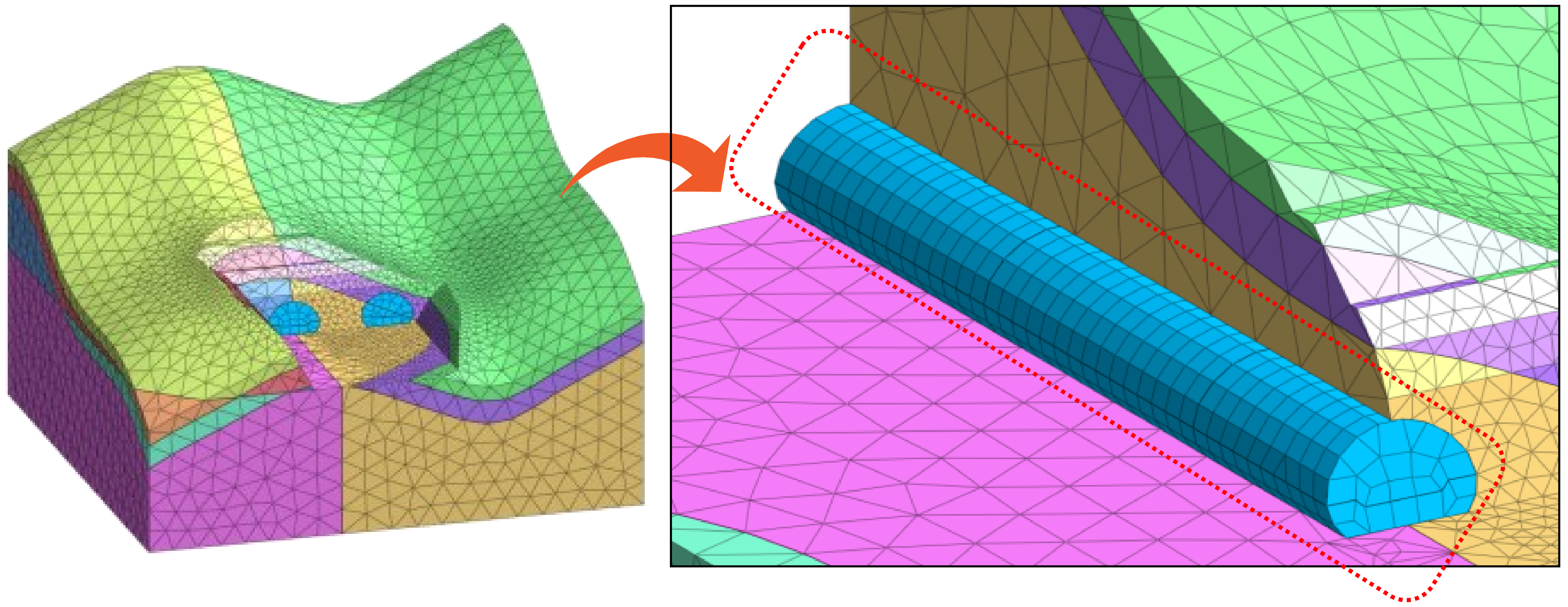
MESHER

- Supports Linear & Higher Order Elements
- Hybrid Mesher: Increasing Analysis Accuracy
- Mesh Size Control: Controlling Mesh Gradation
- Mesh Extrude: Easily create 3D meshes out of 2D elements
- Mesh Quality and Feature check tools
- Complete control over mesh size and element type
- Triangular, Quadrilateral, Tri + Quad, Tetrahedral, Hybrid, etc element types

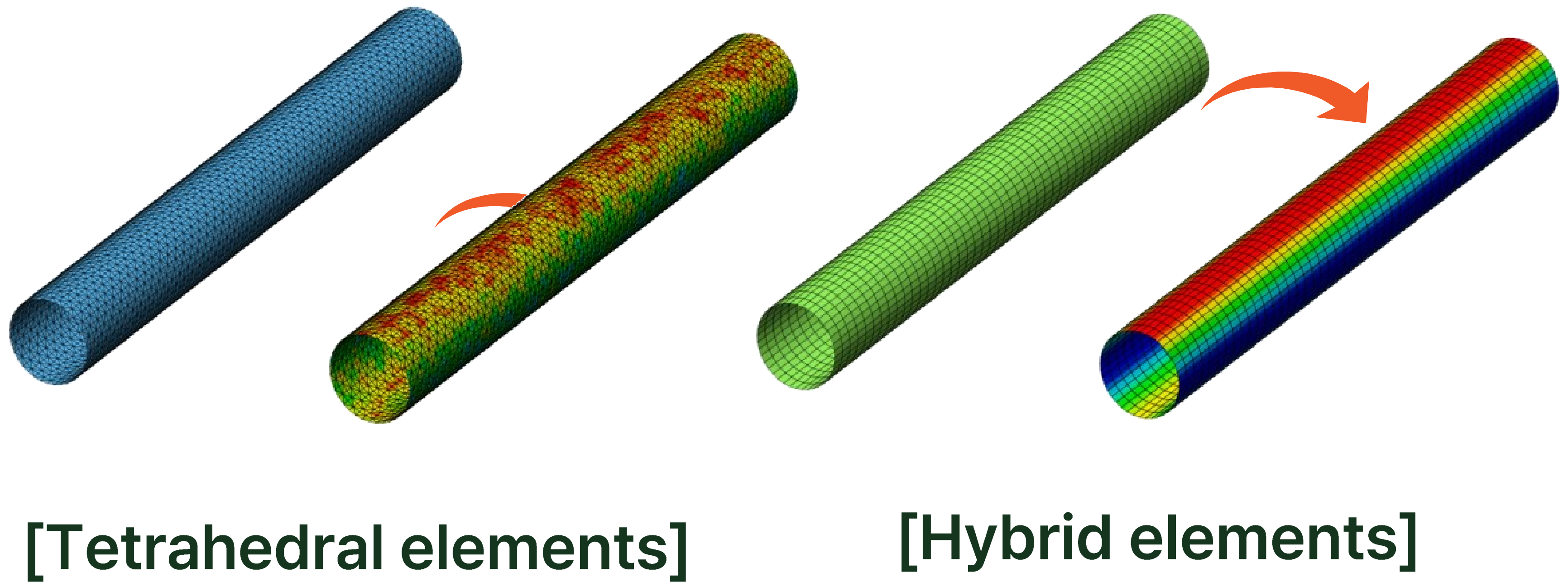
Element configuration of hybrid mesh







[can be checked through consistent structure results without any changes in element coordinate system]

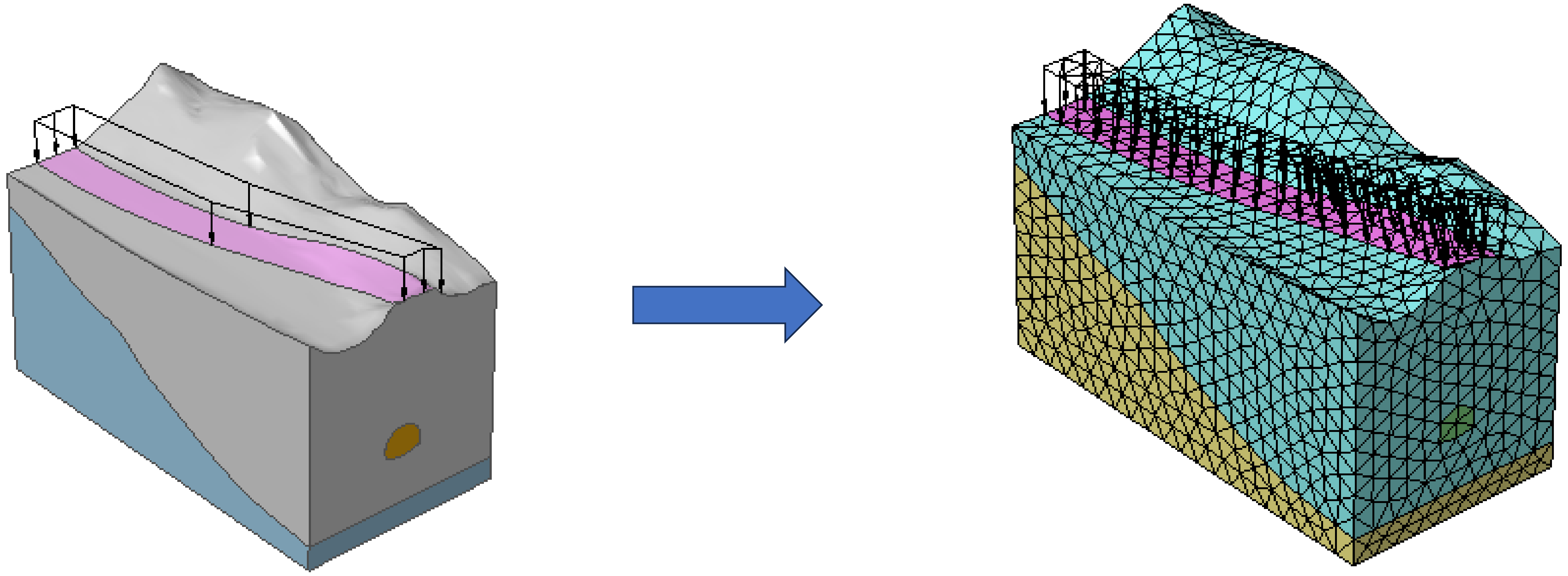


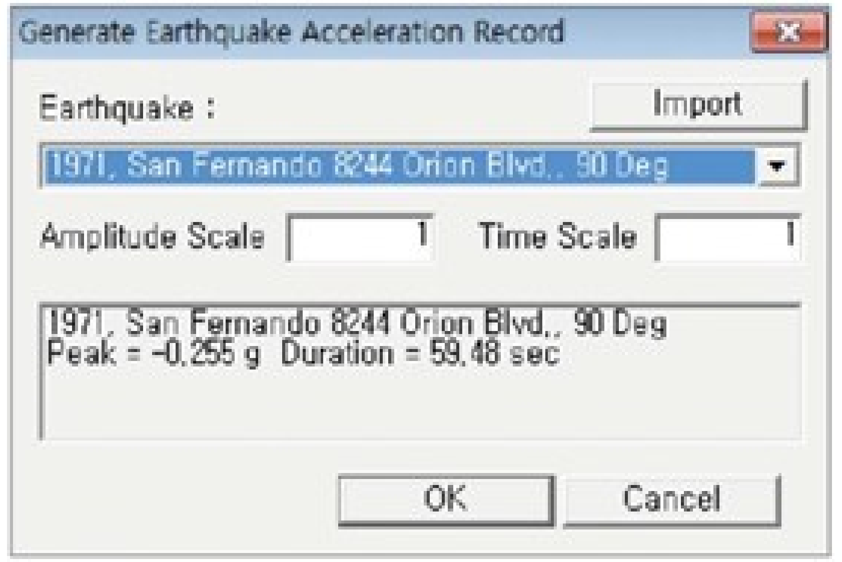
LOAD APPLICATION

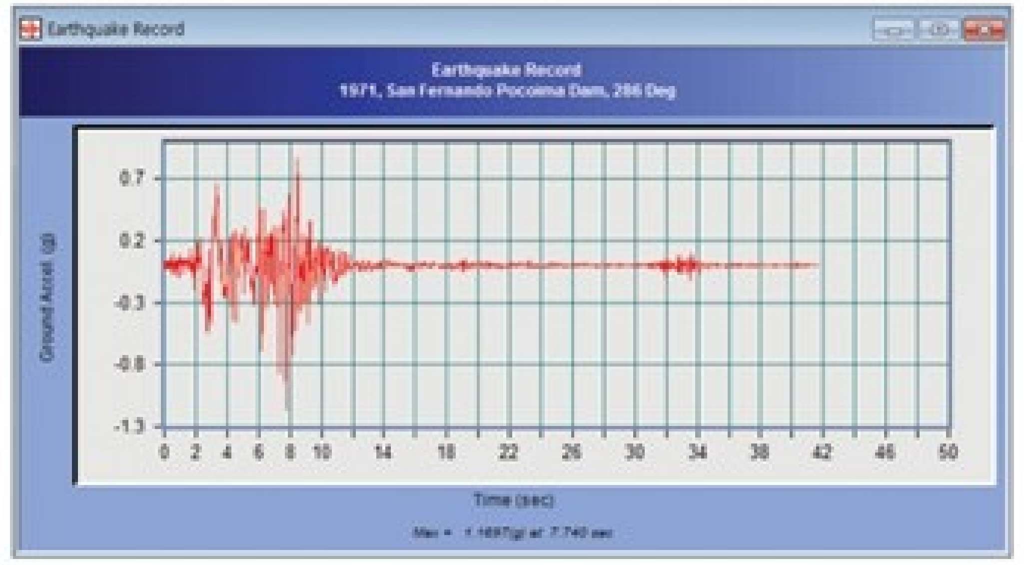
Loads can be applied to mesh elements and geometry as well

Static Loads
Self weight
Force
Moment
Displacement
Pressure
Water pressure
Line beam load
Element beam load
Temperature
Prestress
Initial equilibrium force
Combined load
Beam/ Shield Contraction

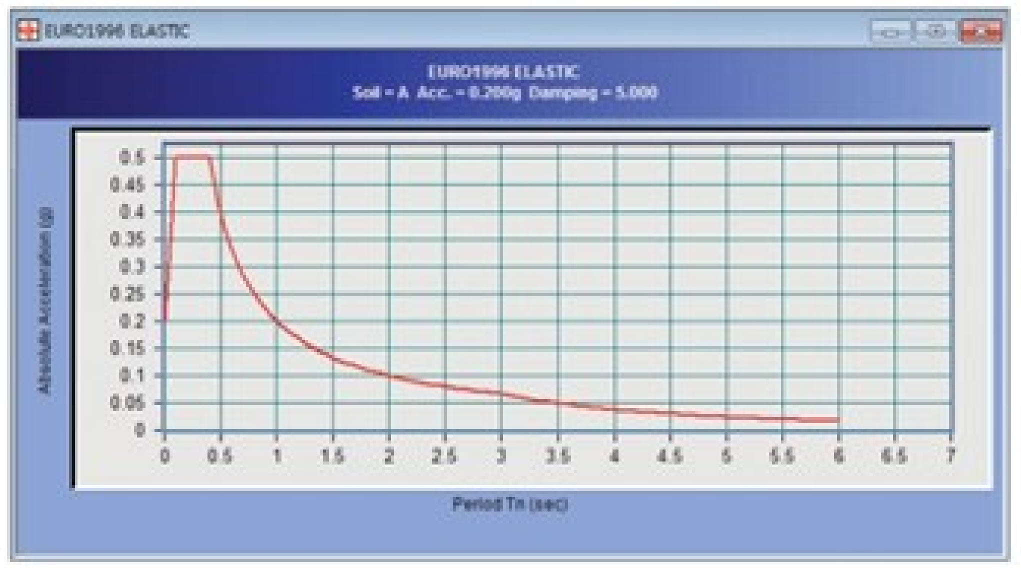
Dynamic Loads
Response spectrum
Ground acceleration
Time varying static
Dynamic nodal
Dynamic surface
Load to Mass
Train Dynamic Load Table







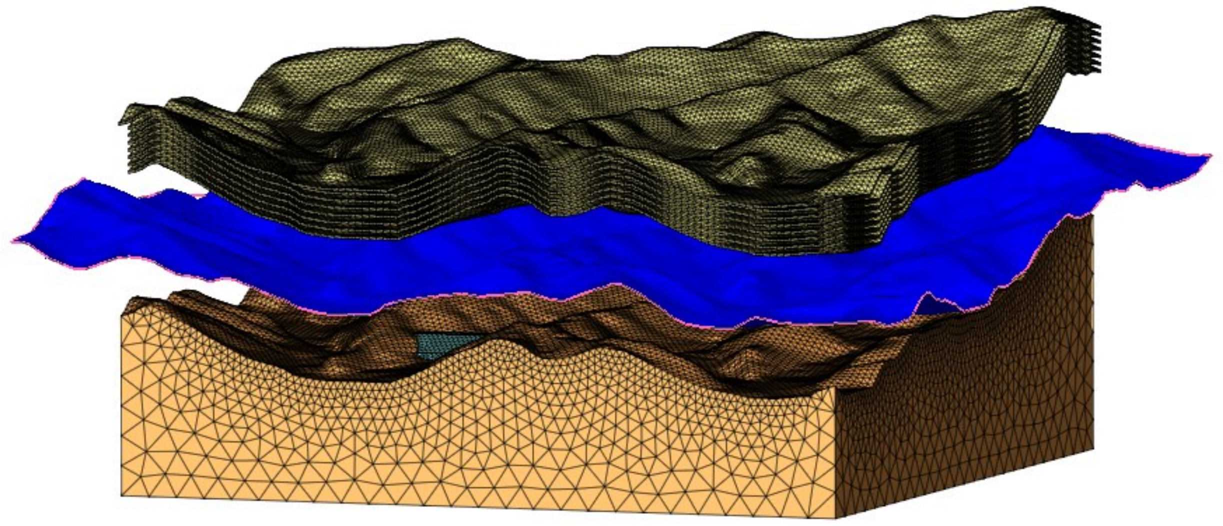
Earthquake record



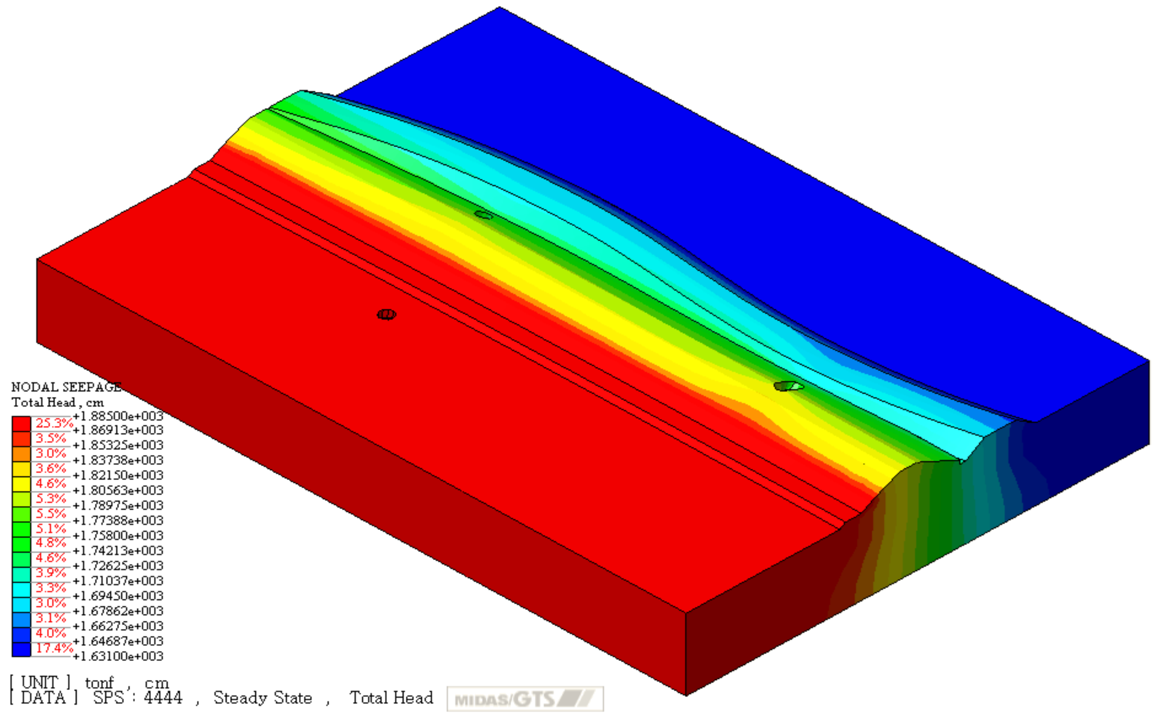
Design response spectra

WATER LEVEL REFLECTION

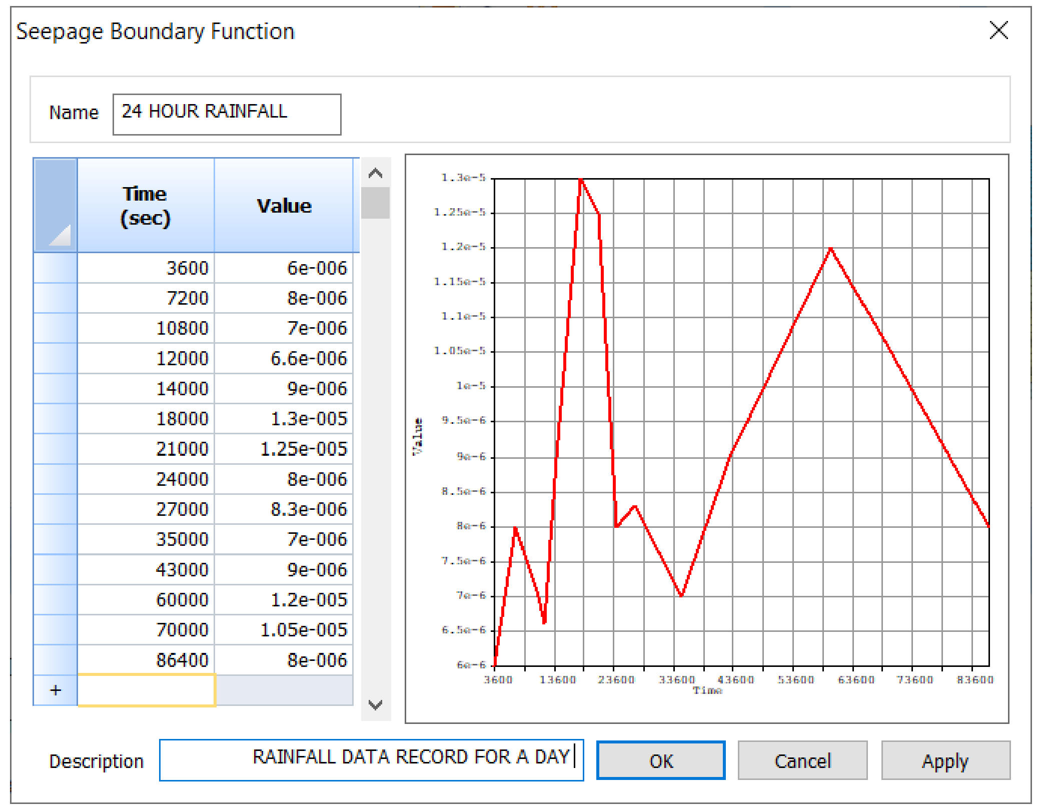
- Water Level definition in model geometry
- Water Level Function input with respect to x, y, z coordinates
- Automatic calculation of seepage force according to water head



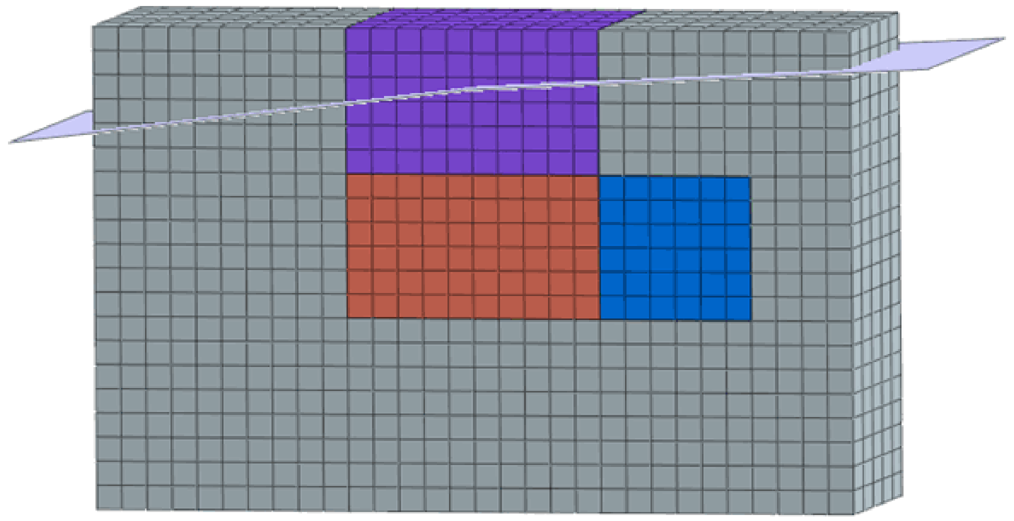
[Automatic generation of 3D water level surfaces]



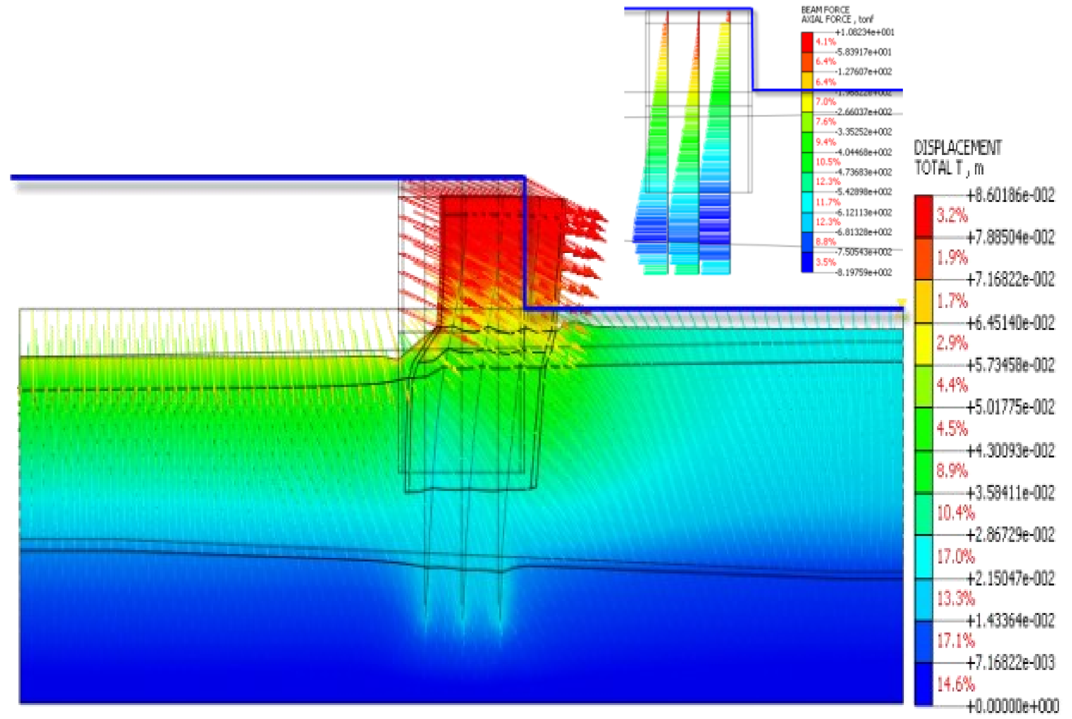
[3D seepage analysis considering partial saturation]



[Transient Functions (e.g., Rainfall Distribution)]



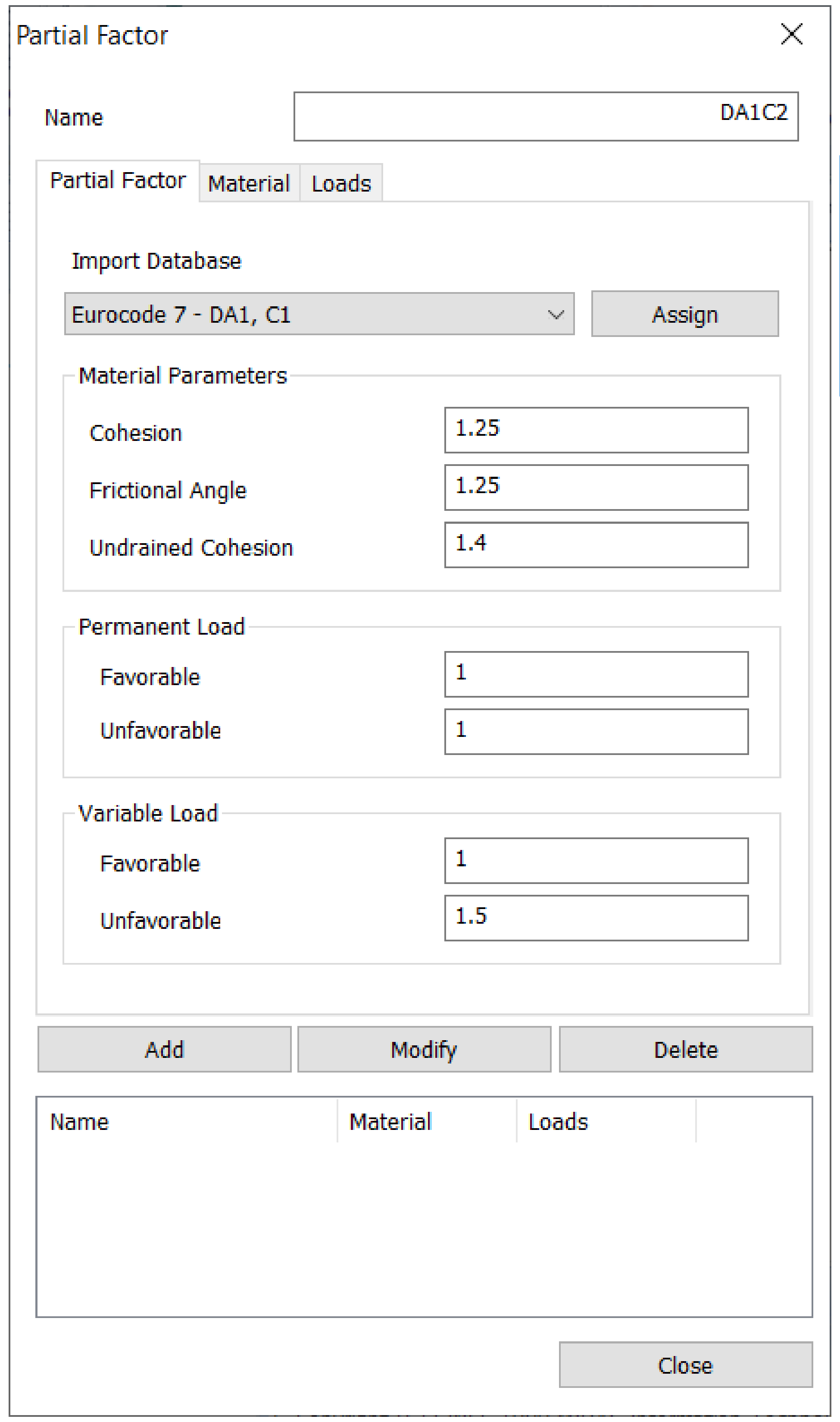
[Automatic calculation of seepage force]

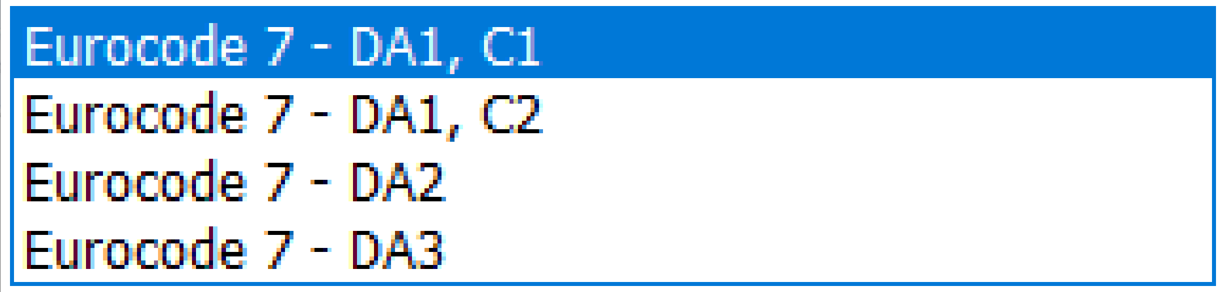


[Seepage force + Automatic water pressure]

PARTIAL FACTORS DEFINITION

- DA1, C1: Partial factor will apply to load only.
- DA1, C2: Partial factor will apply to load and soil material.
- DA2: DA2 is similar with DA1, C1. But the factors for pile and footing are different.
- DA3: DA3 is similar with DA1, C2. But the factor for load (Unfavorable under Variable) is different.

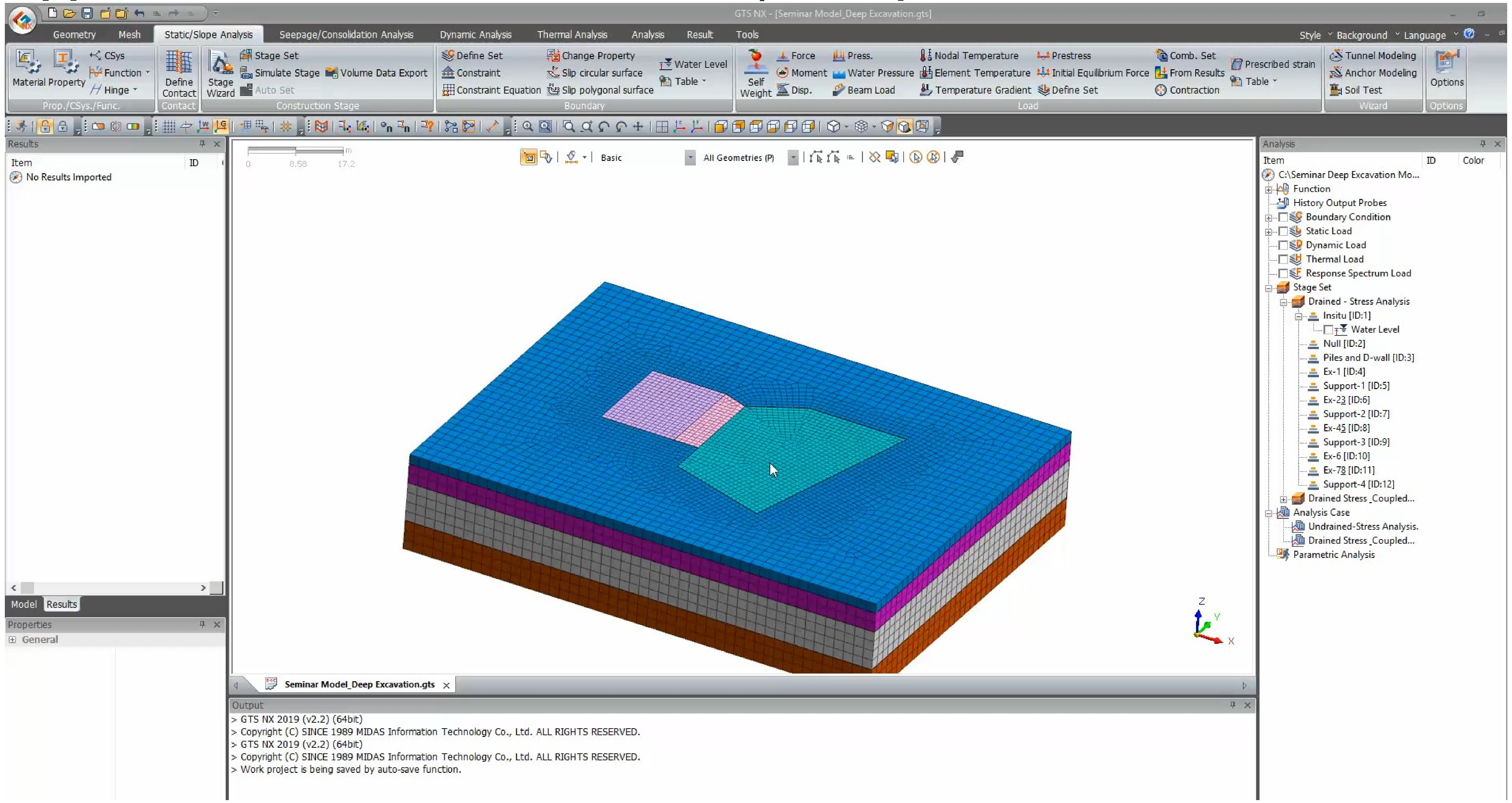




Values of Partial Factor	Permanent		Variable		Soil		
	Fav.	Unfav.	Fav.	Unfav.	Effective Cohesion (c)	tan Φ'	Undrained Strength (su)
Eurocode 7 - DA1, C1	1.000	1.350	1.000	1.500	1.000	1.000	1.000
Eurocode 7 - DA1, C2	1.000	1.000	1.000	1.300	1.250	1.250	1.400
Eurocode 7 - DA2	1.000	1.350	1.000	1.500	1.000	1.000	1.000
Eurocode 7 - DA3	1.000	1.350	1.000	1.500	1.250	1.250	1.400

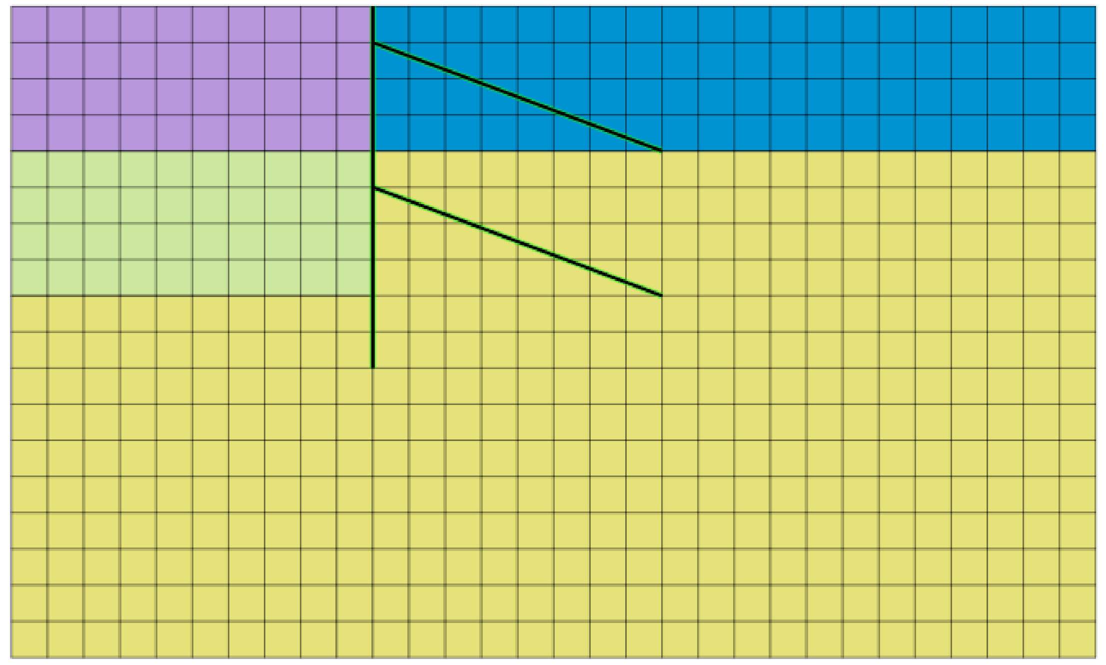
VOLUME DATA EXPORT

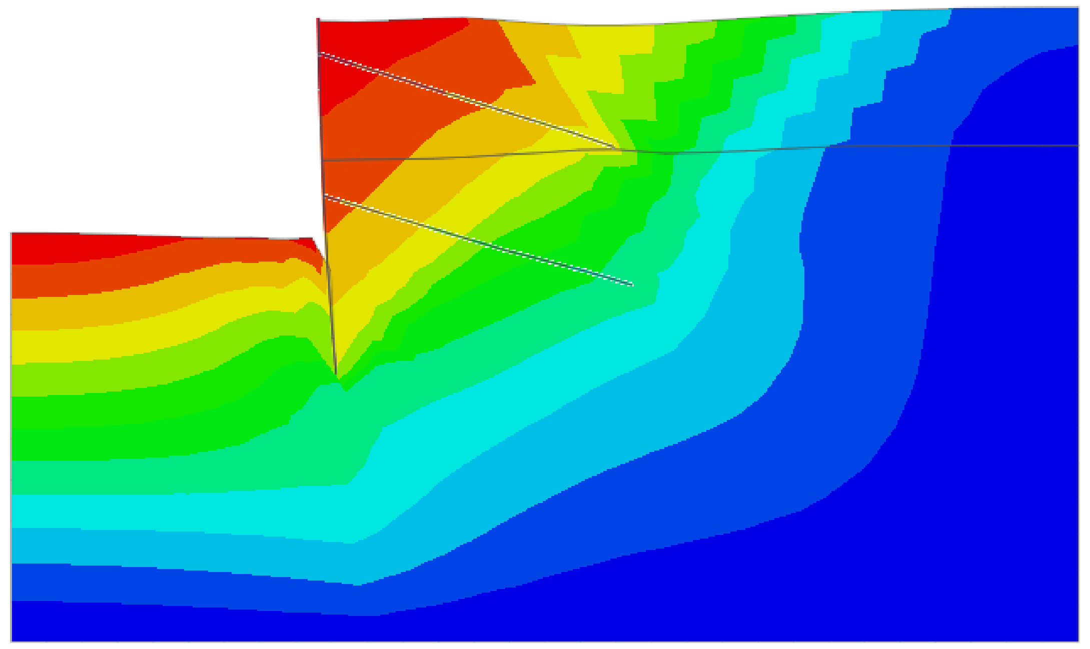
- The volume data of 1D/2D/3D elements defined to the construction stage is exported to Excel File.
- This shows the length/area/volume of activated/deactivated set for stages.
- This doesn't apply for the other element types (point spring, matrix spring, free field, interface, shell interface, pile tip, elastic link, rigid link, user supplied behavior for shell interface, mass).

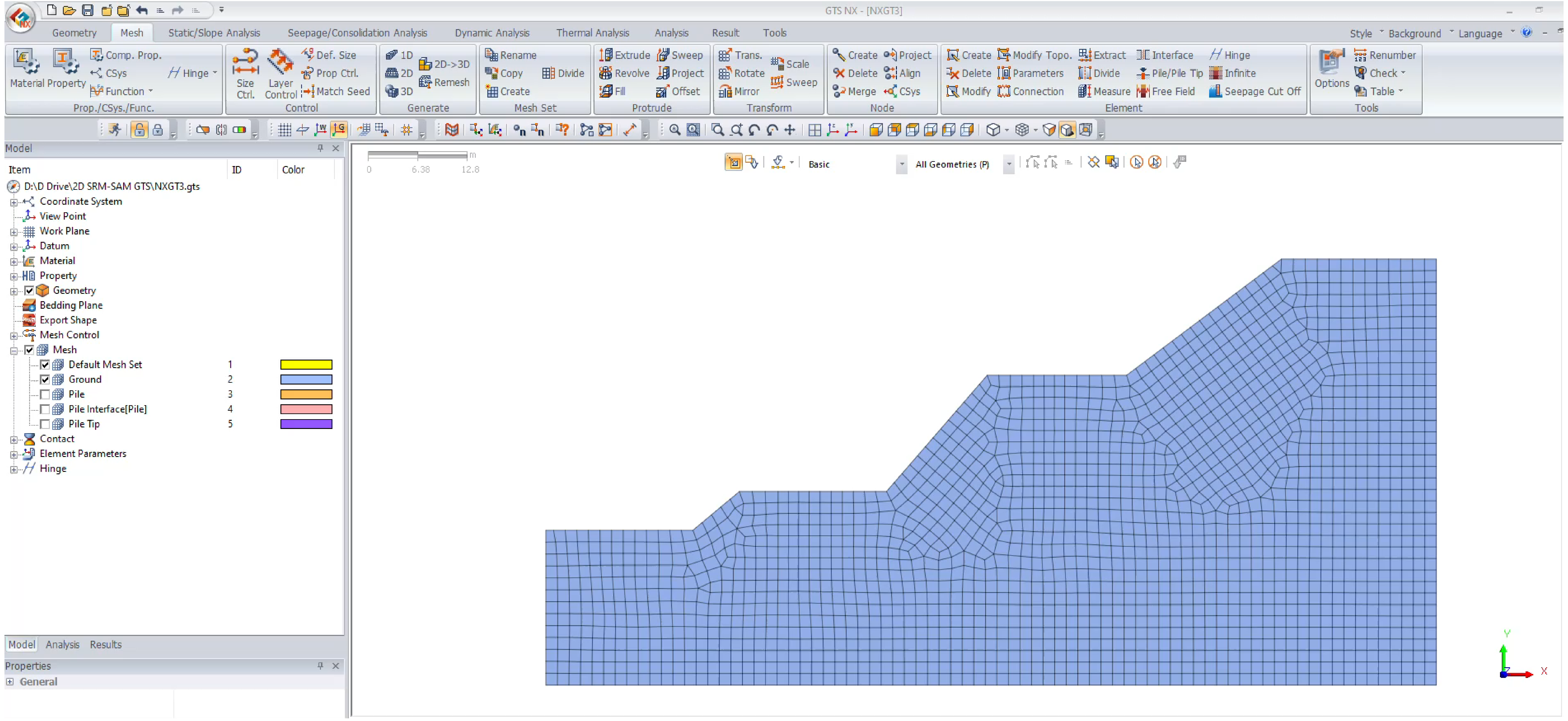


ANCHOR WIZARD

- Anchor Wizard: Auto- generation of anchors or rock bolts mesh along with prestress loads based on inputs
- Ground Anchors Modelling
- Earth Reinforcements for Slope Stability

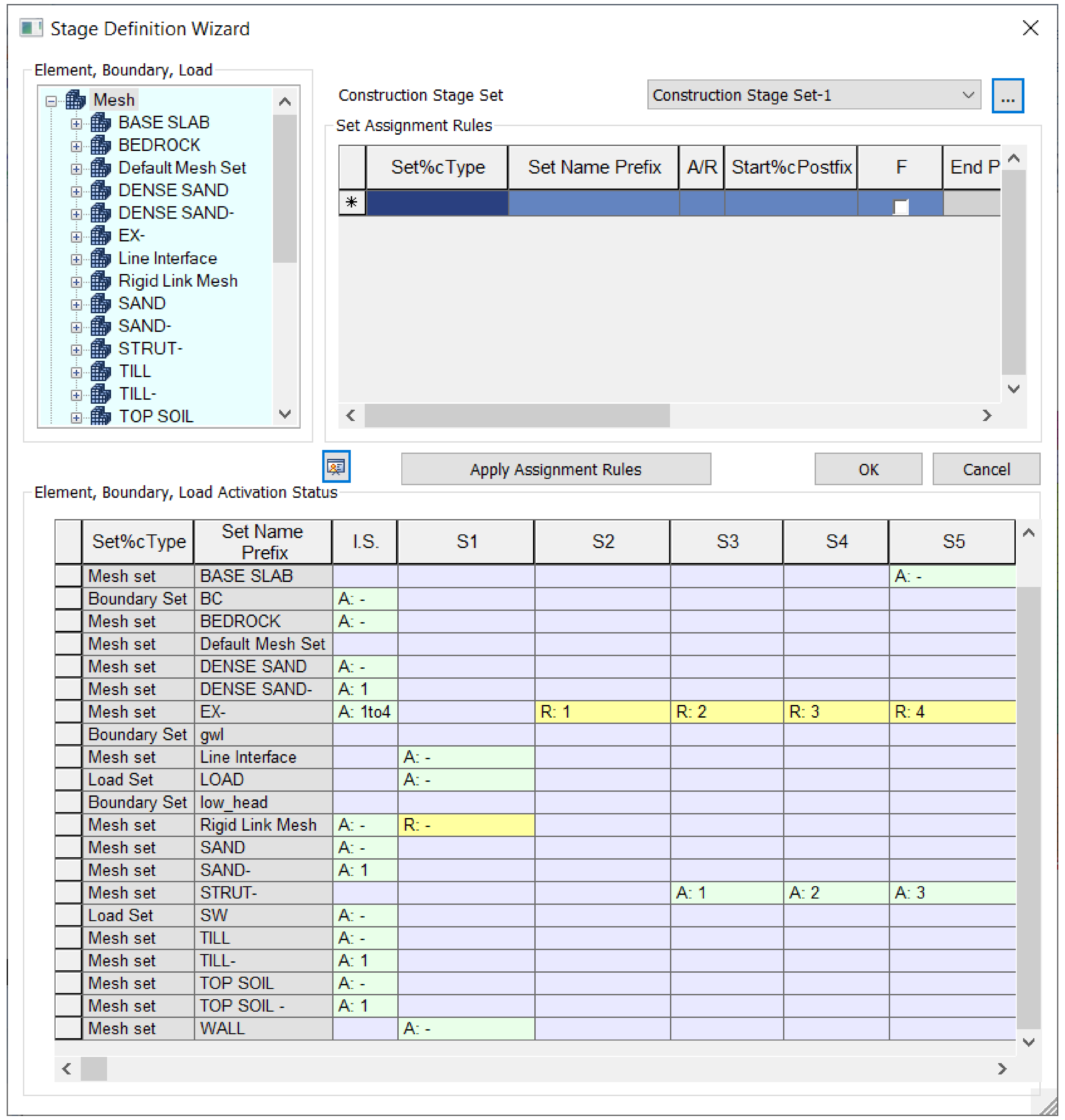


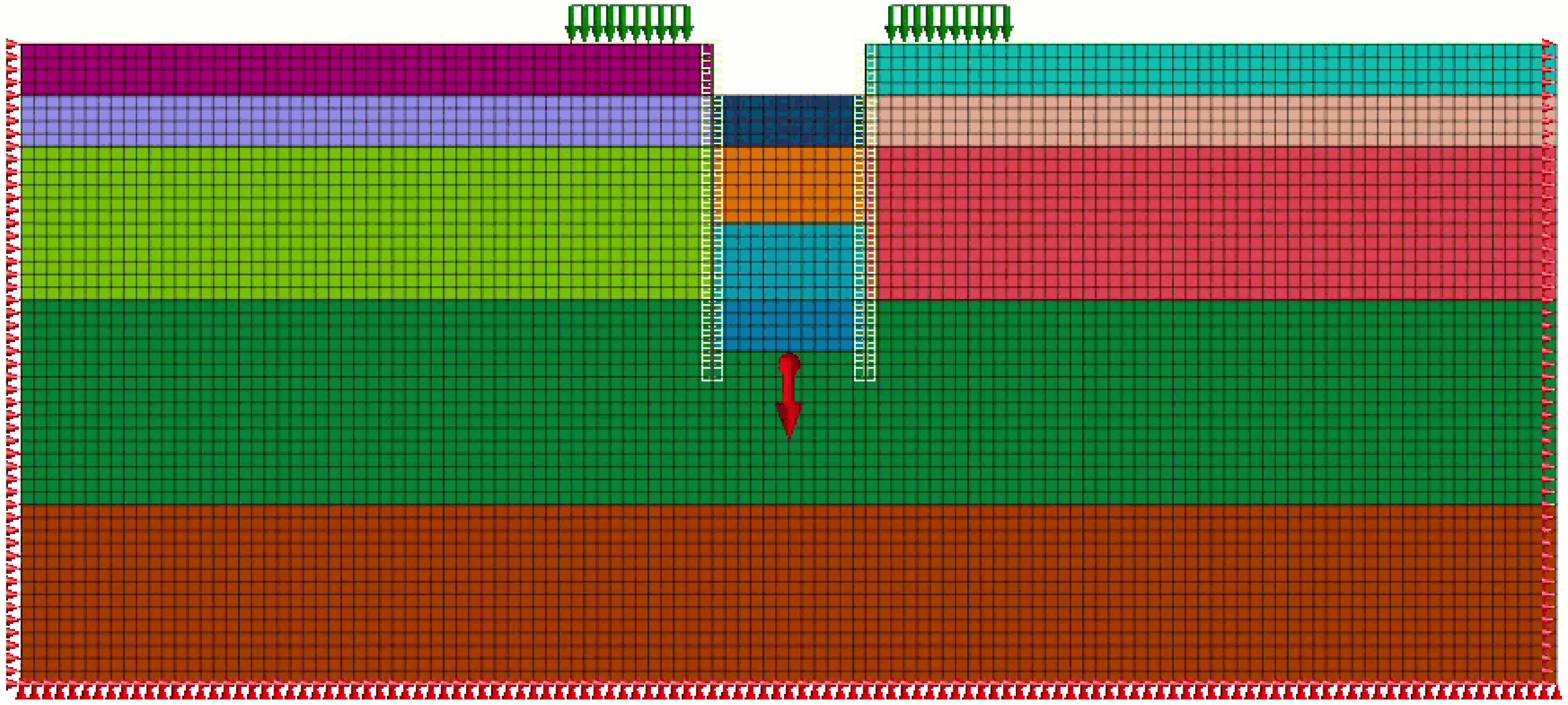




STAGE DEFINITION WIZARD

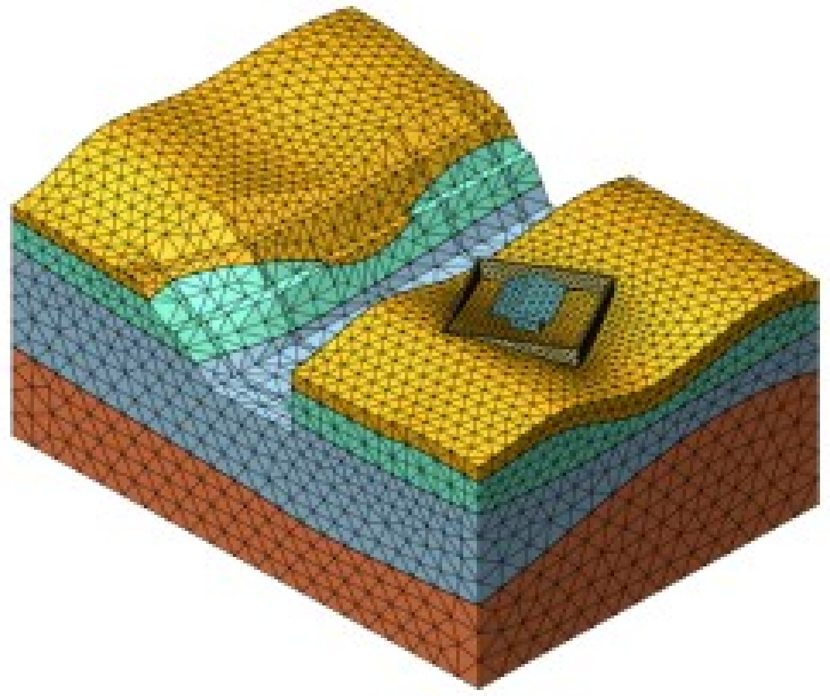
- Stage Wizard automatically creates Construction Stages based on inputs
- Restart Analysis: Analysis can be restarted from a specific stage



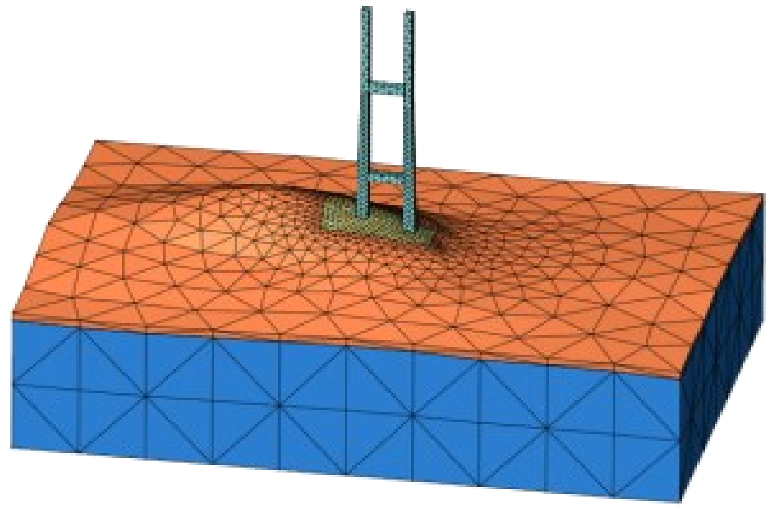


ANALYSIS CAPABILITIES

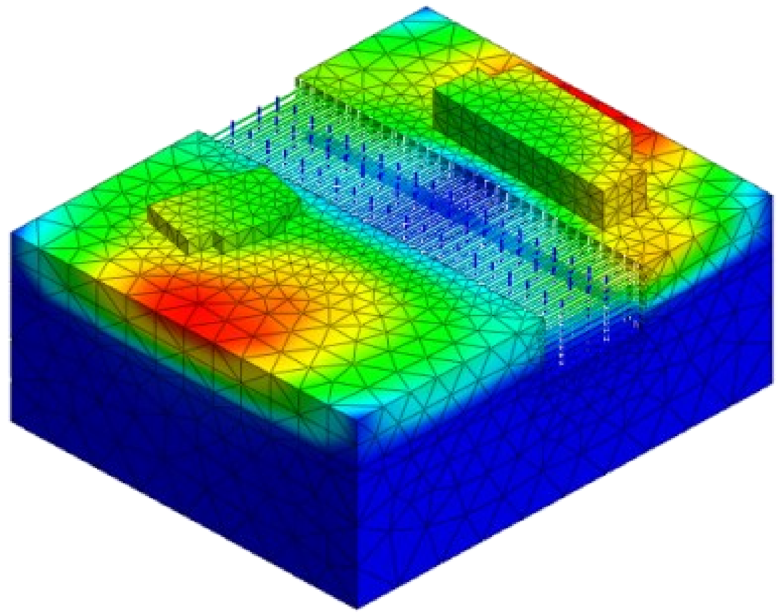
MIDAS GTS NX



- Strength Reduction Method (SRM)
- Stress Analysis Method (SAM)
- Construction stages Slope stability (SRM/SAM)



- Linear static analysis
- Nonlinear static analysis



- Stress (drained/undrained) analysis
- Seepage analysis for each stage
- Stress-seepage- slope coupled
- Consolidation analysis for each stage
- Fully coupled stress & seepage
- Thermal stress Analysis

Static Analysis

Slope Stability Analysis

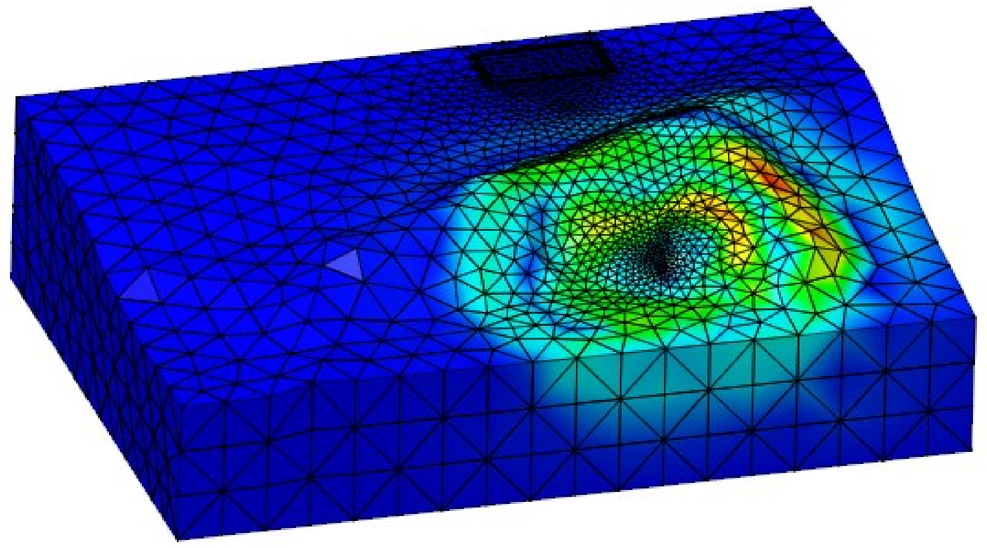
Construction Stage Analysis

Dynamic Analysis

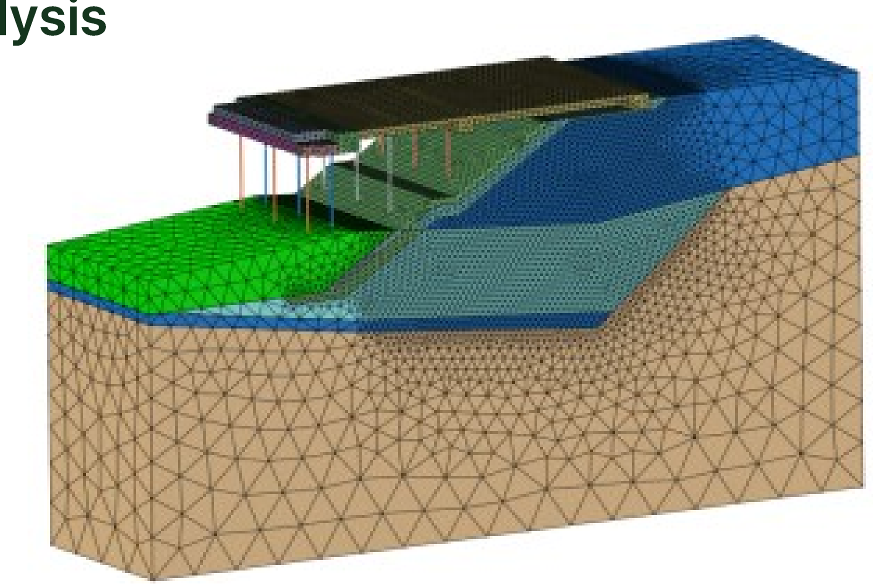
Consolidation Analysis

Seepage Analysis

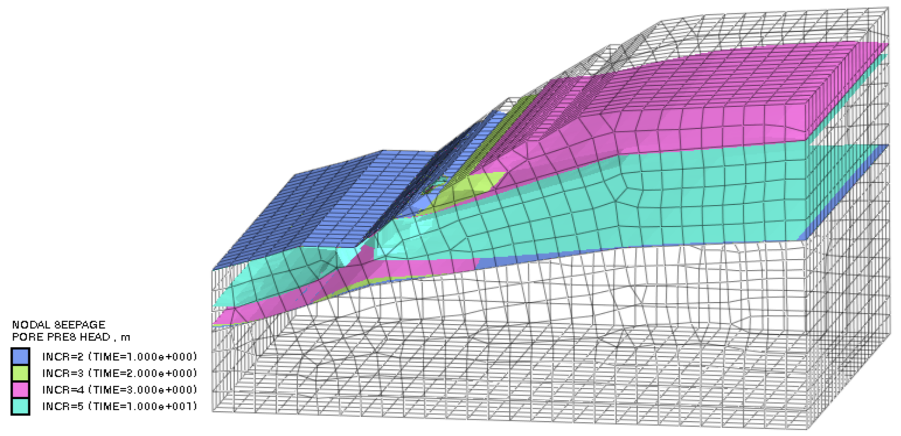
Stress–seepage fully coupled



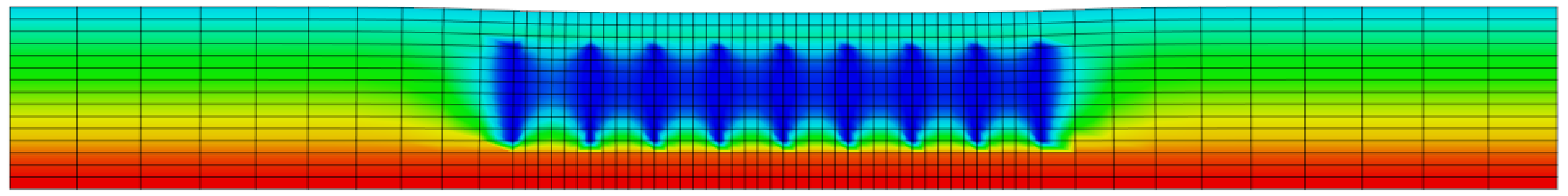
- Eigenvalue/Response Spectrum analysis
- Linear Time History (mode/direct methods)
- Nonlinear Time History analysis
- 1D/2D Equivalency Linear analysis
- Nonlinear time history + SRM Coupled

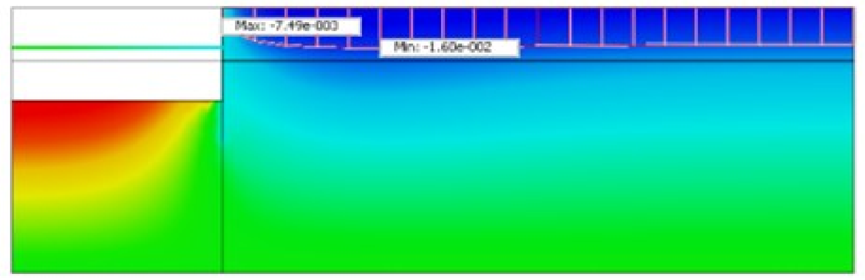


- Consolidation Analysis (coupled with SRM)
- Stress–seepage fully coupled analysis



- Steady state
- seepage analysis
- Transient
- seepage analysis

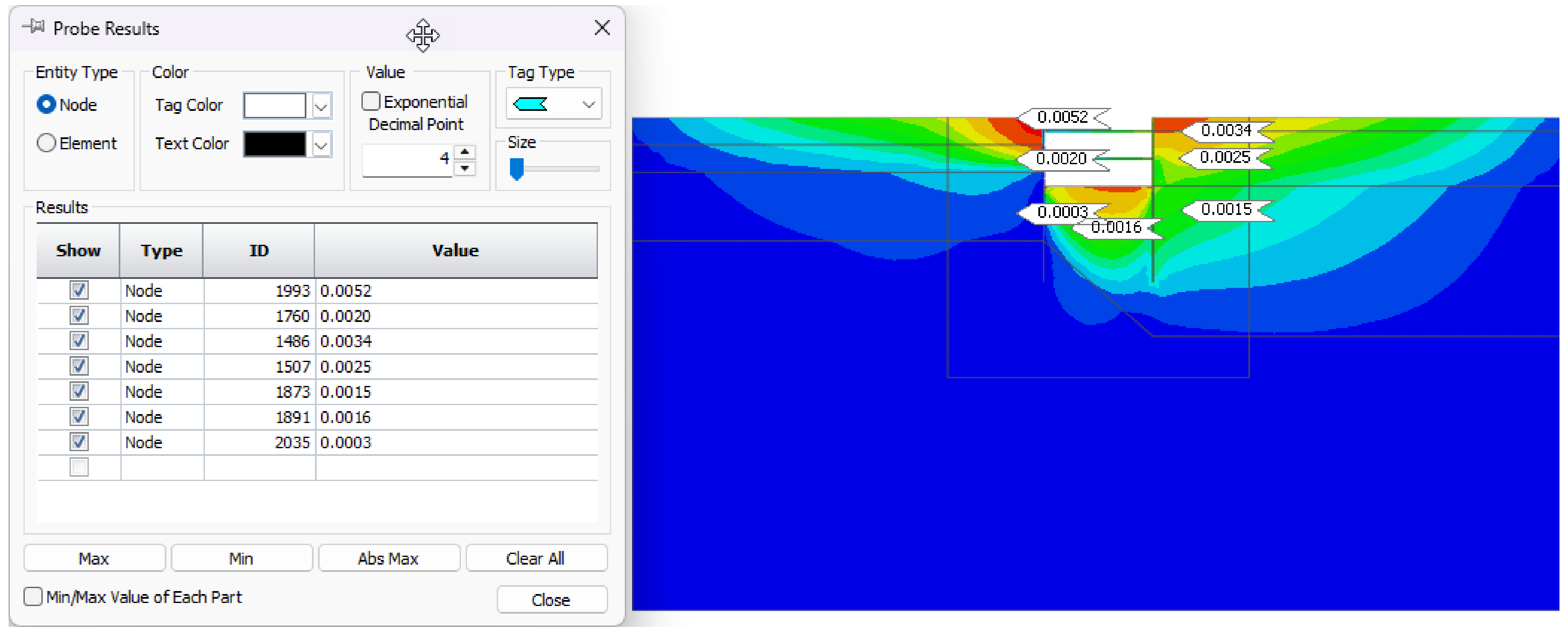


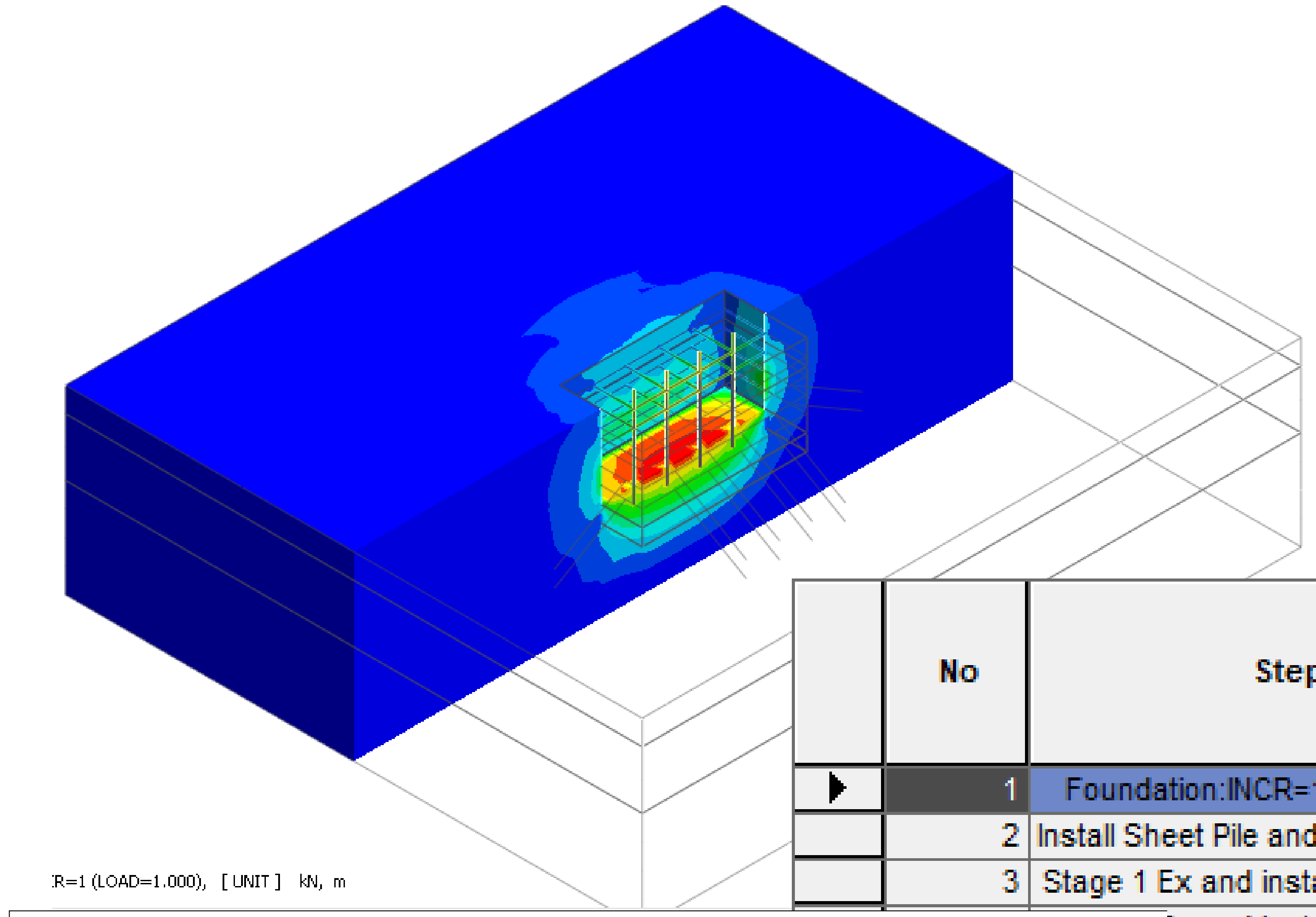


MIDAS

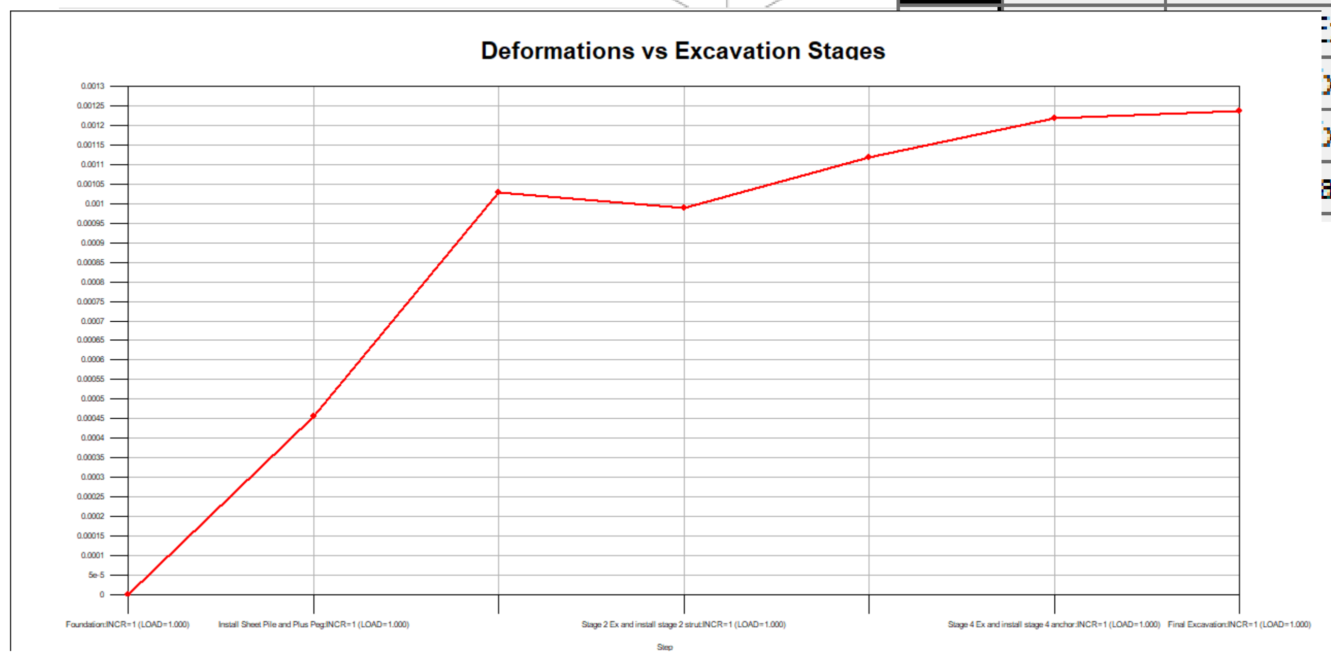
POST PROCESSING

Data output at all nodes/ elements by default
Probe: Check results at required nodes/ elements

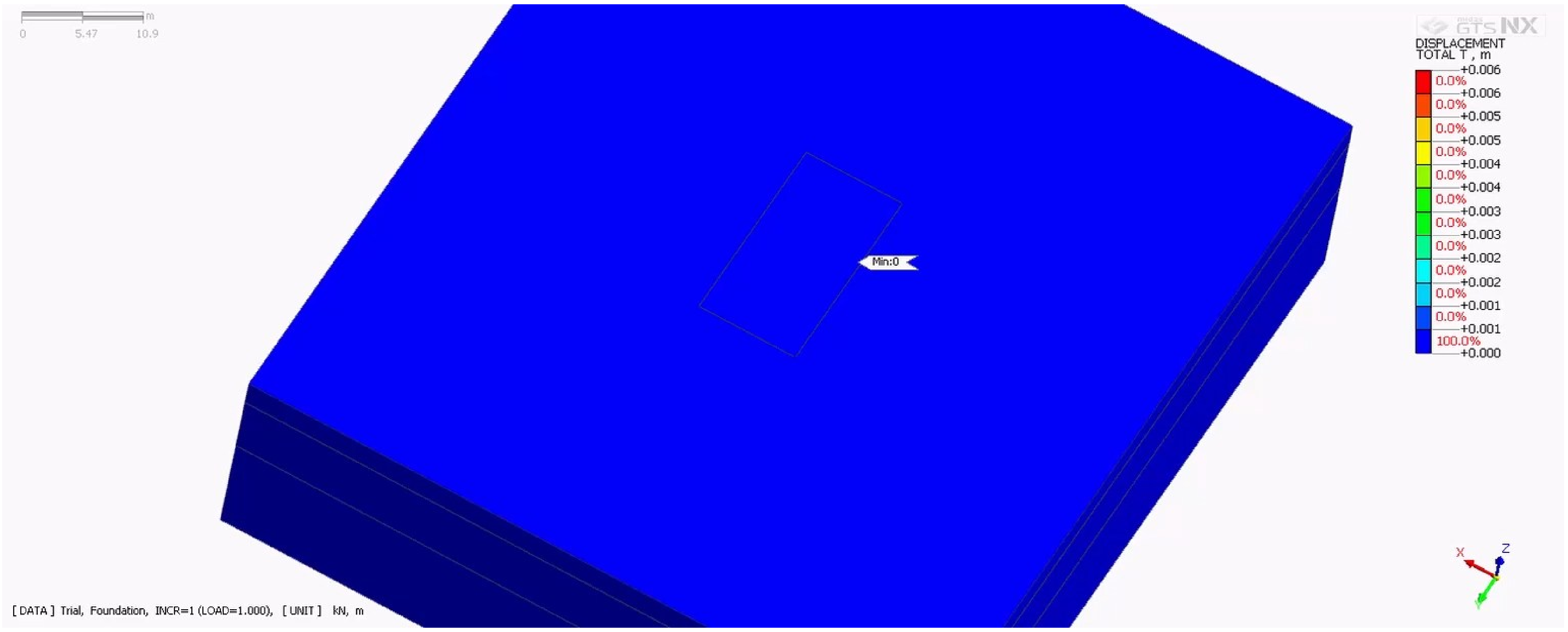




	No	Step	Step Value	Node: 2895 TOTAL TRANSLATION (V) (m)
▶	1	Foundation:INCR=1 (LOAD=1.000)	1.000000e+00	0.000000e+00
	2	Install Sheet Pile and Plus Peg:INCR=	1.000000e+00	4.559448e-04
	3	Stage 1 Ex and install stage 1 strut:I	1.000000e+00	1.027546e-03
		Ex and install stage 2 strut:I	1.000000e+00	9.880139e-04
		x and install stage 3 ancho	1.000000e+00	1.118965e-03
		x and install stage 4 ancho	1.000000e+00	1.218652e-03
		avation:INCR=1 (LOAD=1.0	1.000000e+00	1.237819e-03

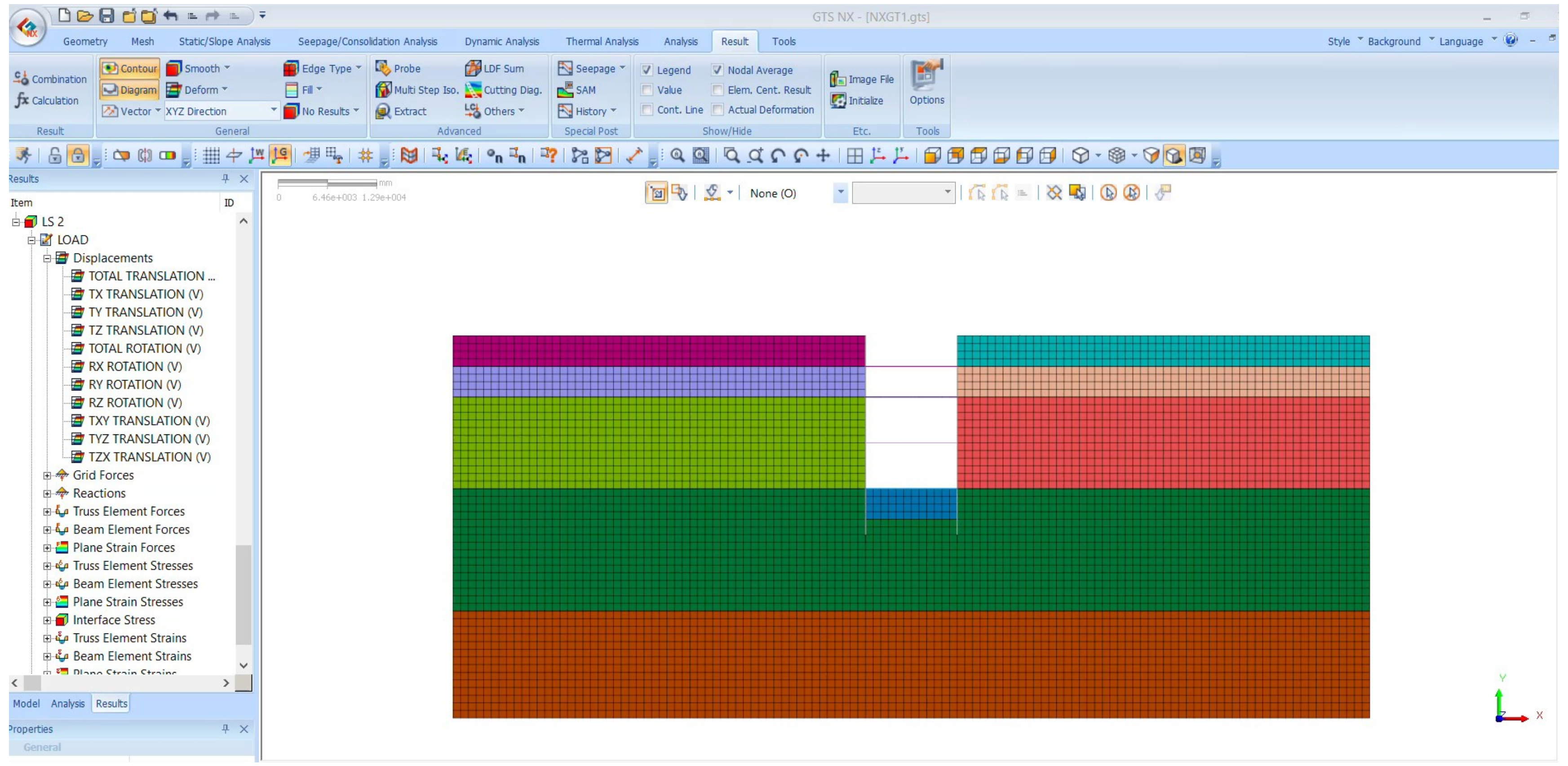


Results extracted as Tables/ Graphs
Extracted tables/ Graphs can be directly exported to Excel

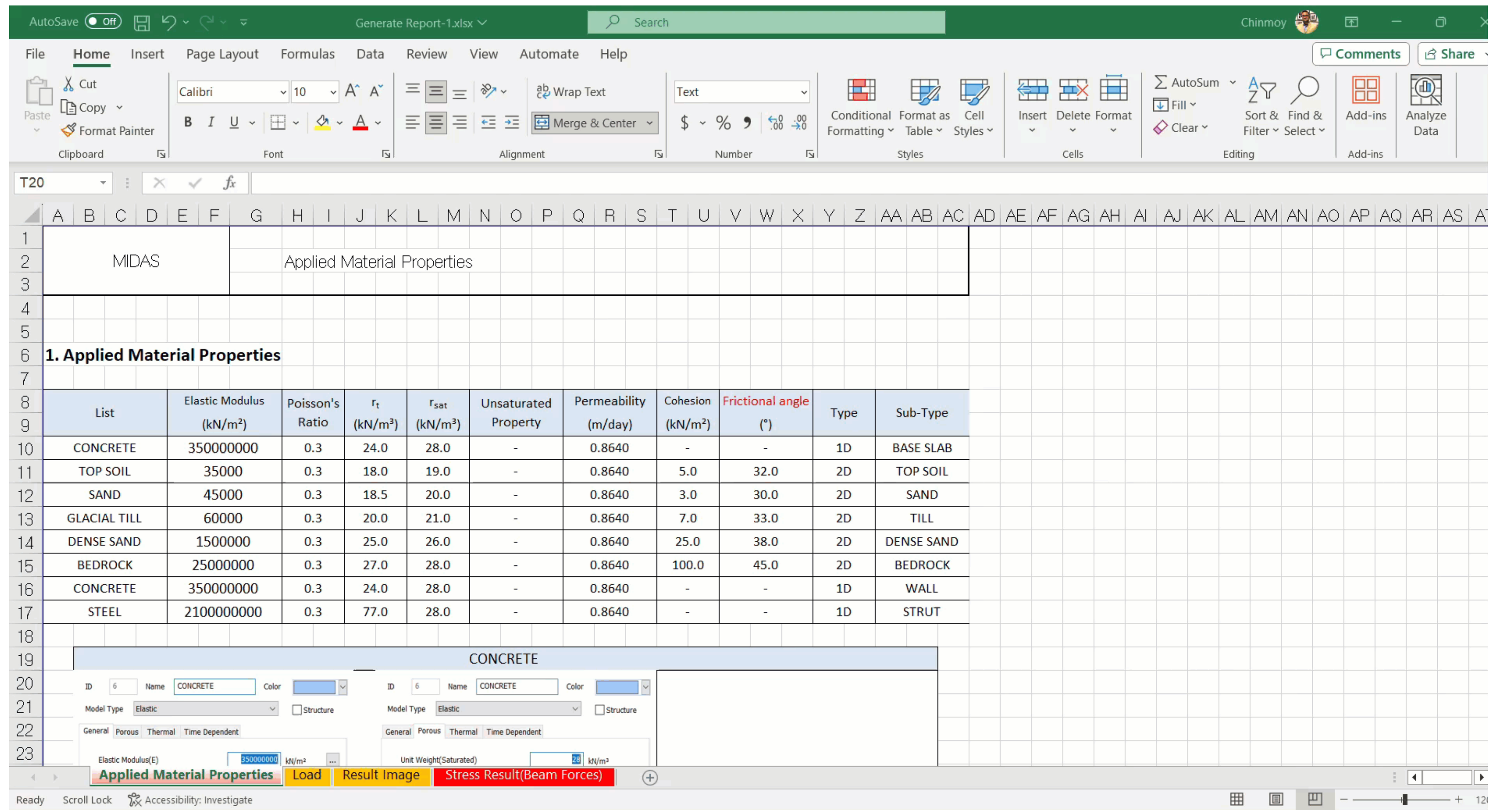


Result Extraction as Image, Animation, Excel, pdf and Word formats

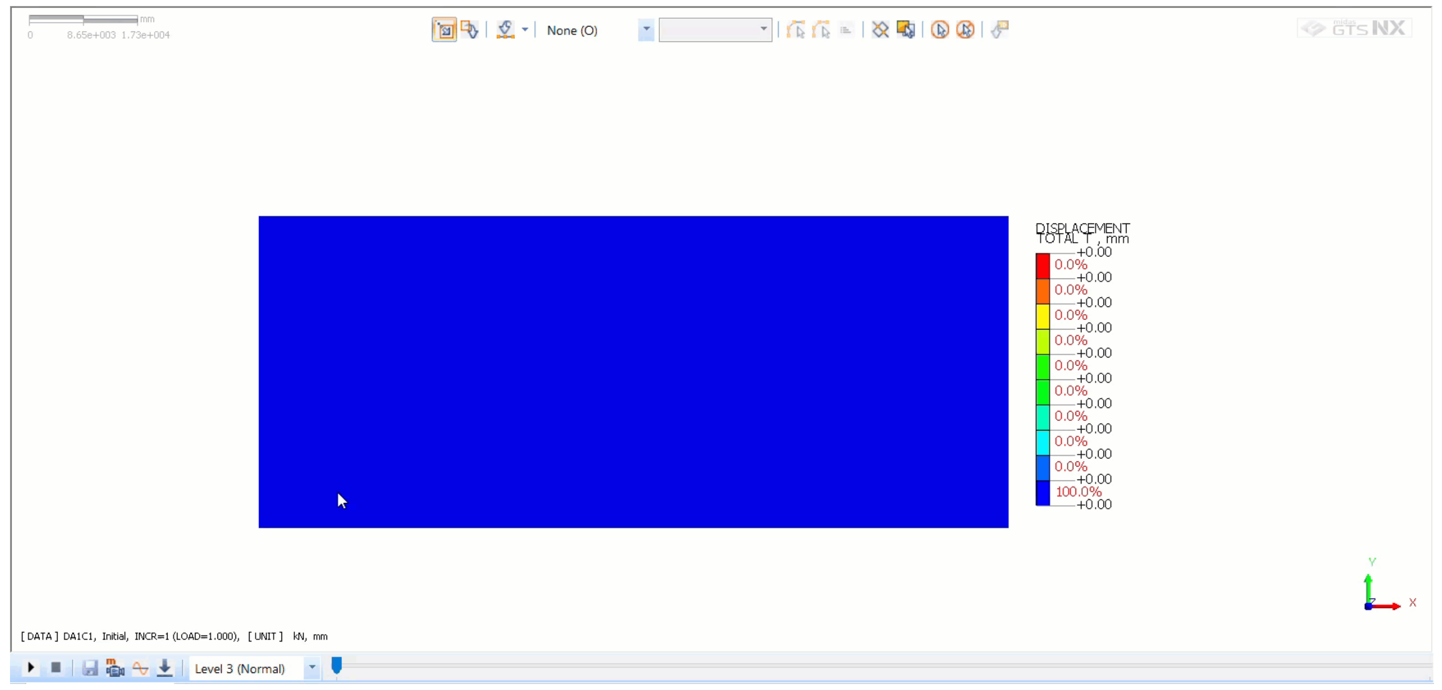
POST PROCESSING



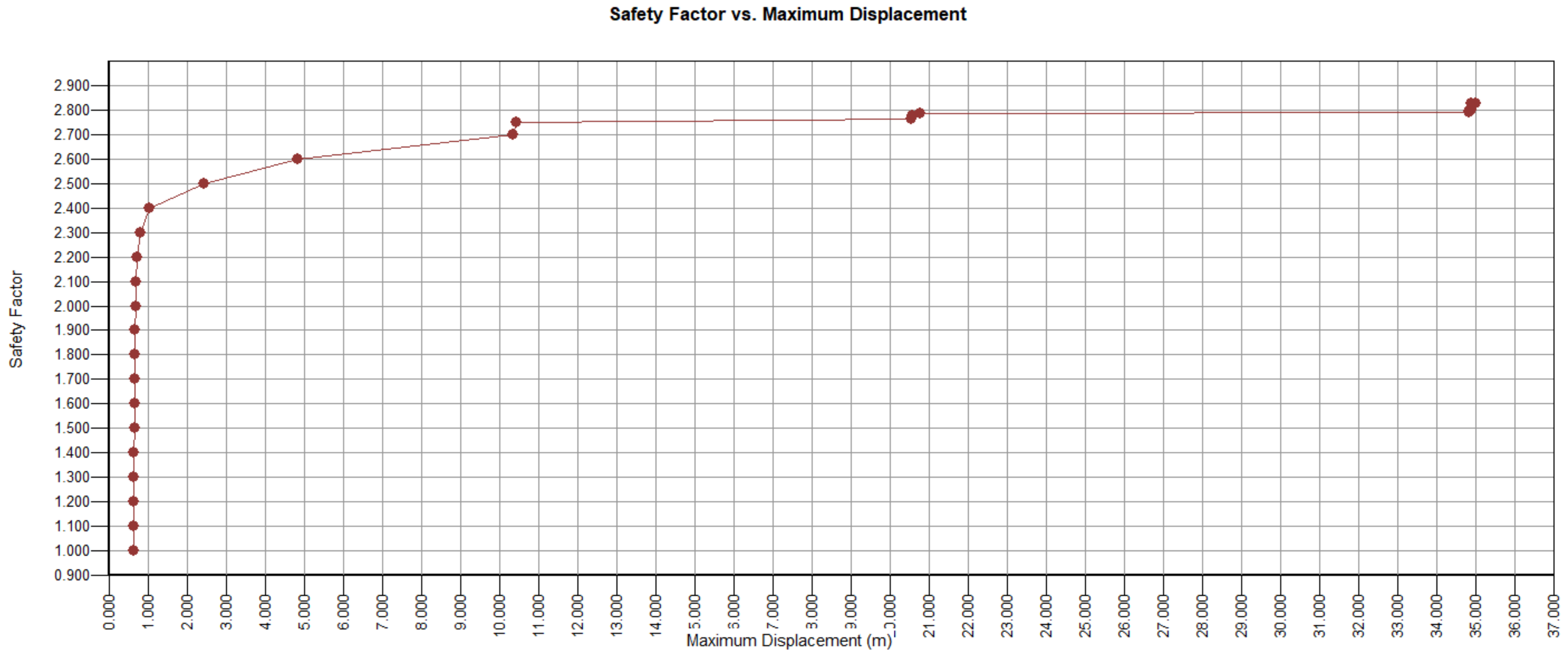
[Combination/Envelope Results]



[Comprehensive Excel Results Output]

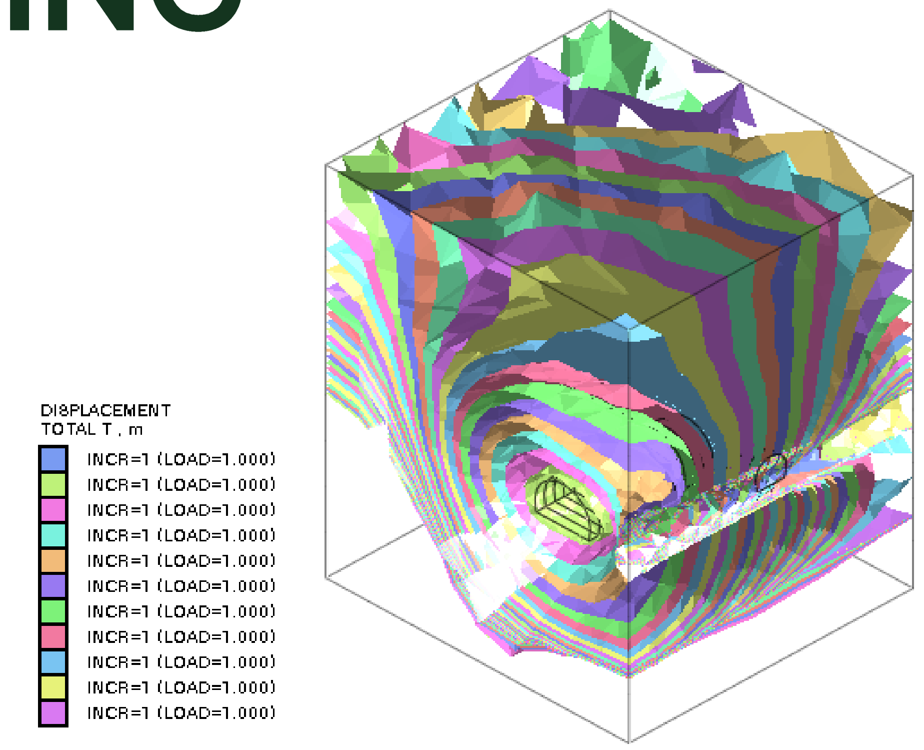


[Stage Bar for Results Visualization]

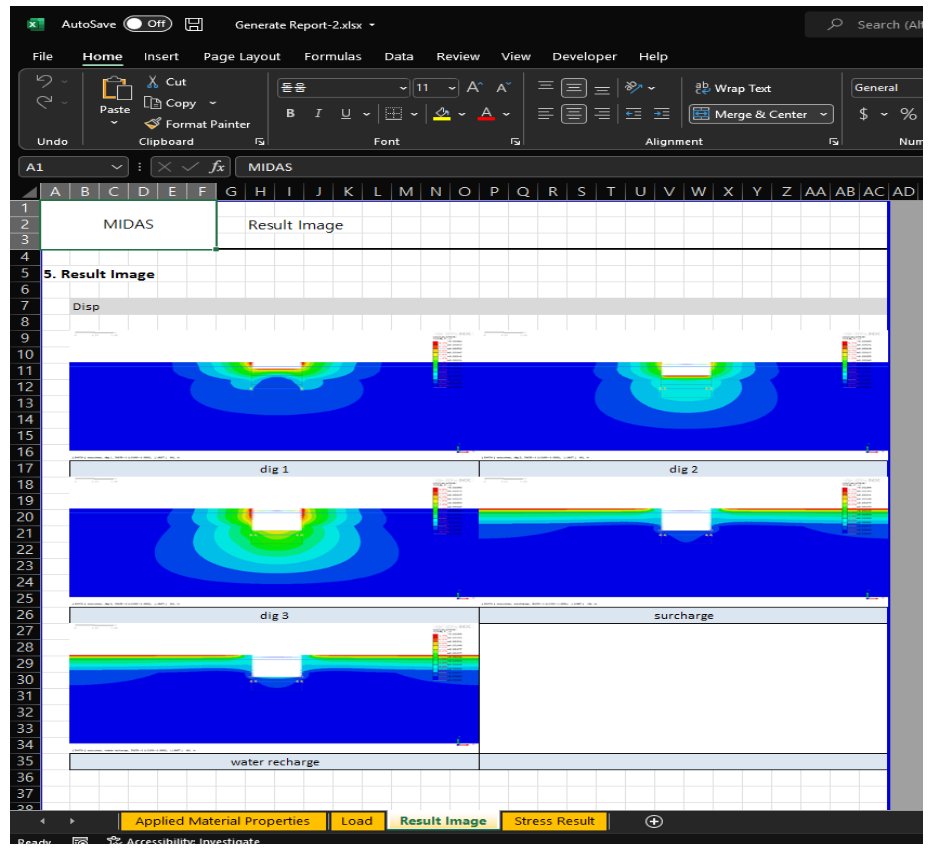


[Safety Factor vs Maximum Displacement Chart]

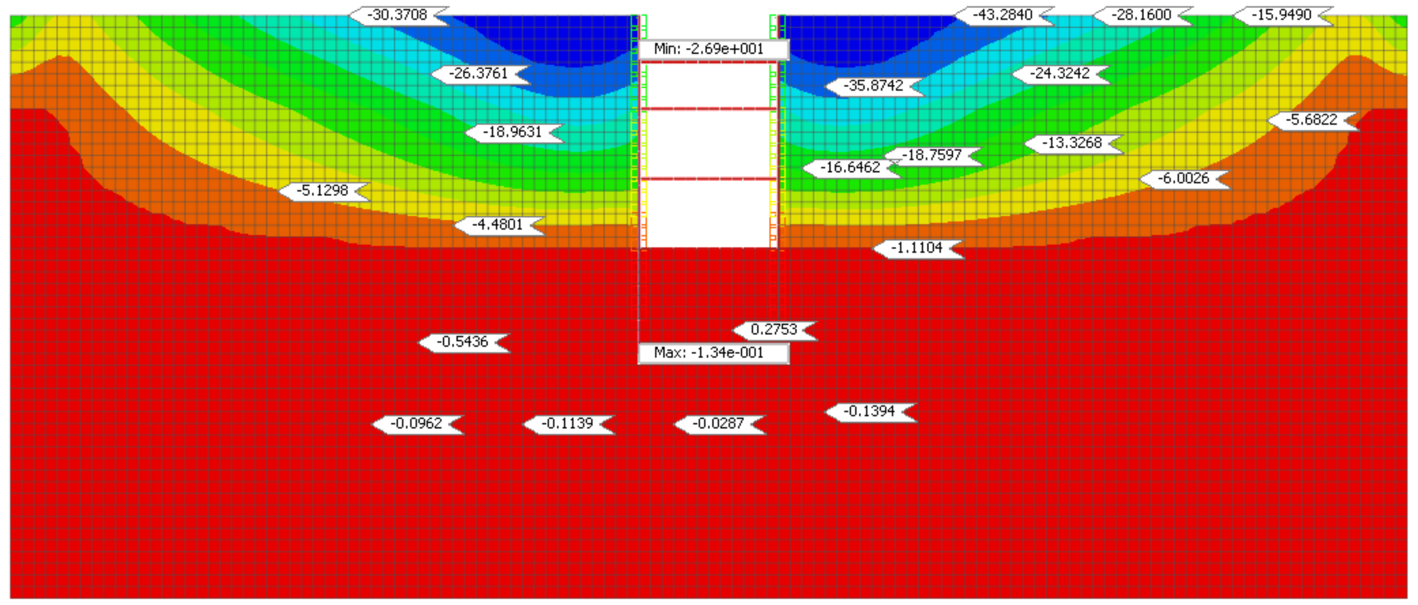
POST PROCESSING



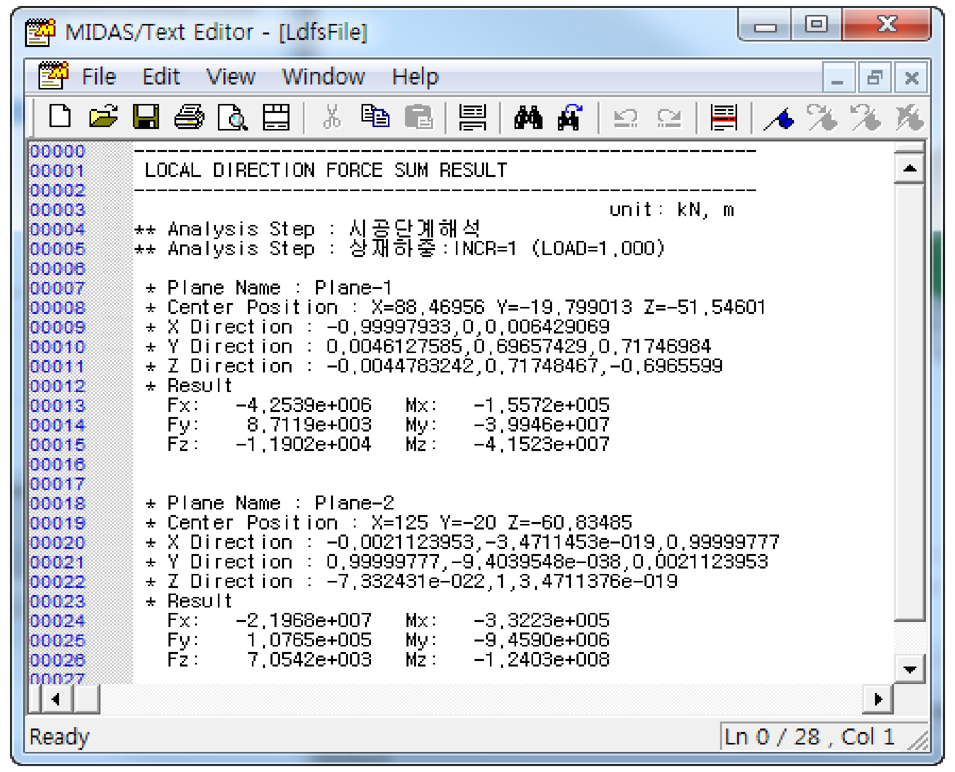
[Print multi-step lines/surfaces]



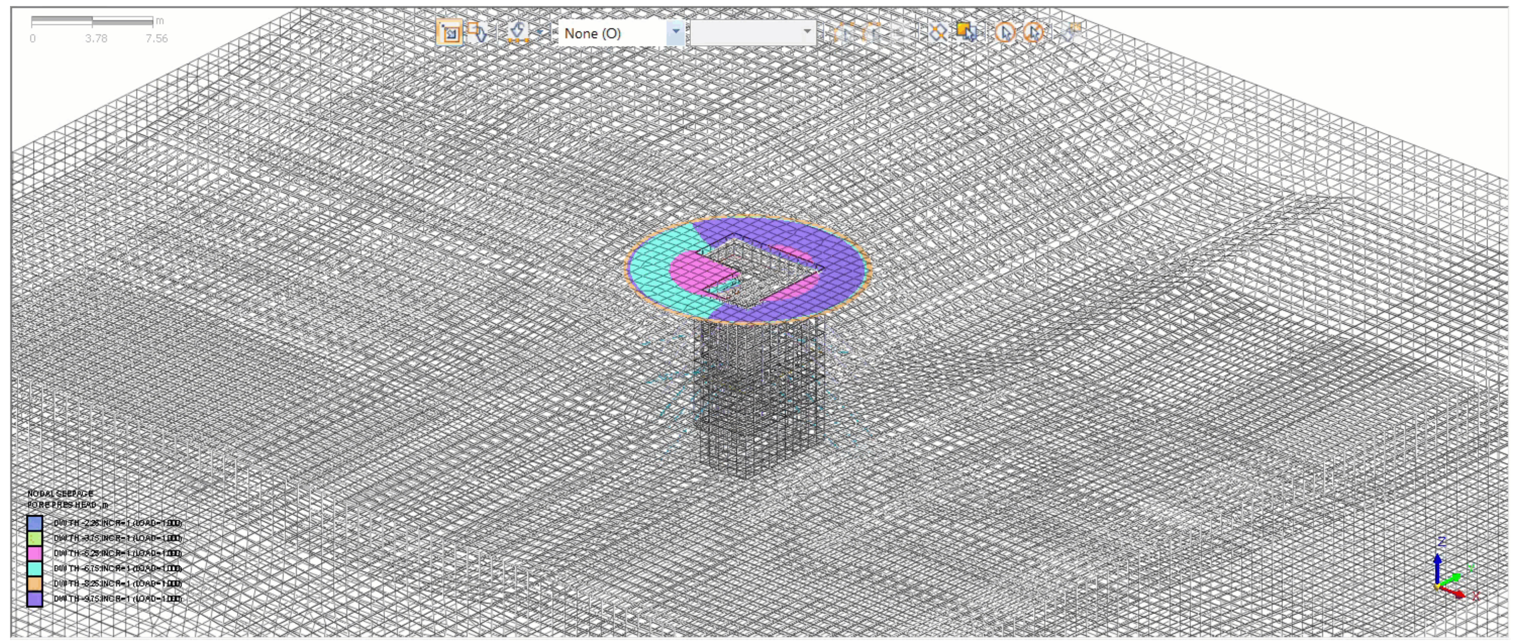
[Excel Export (Images/Charts/Tables)]



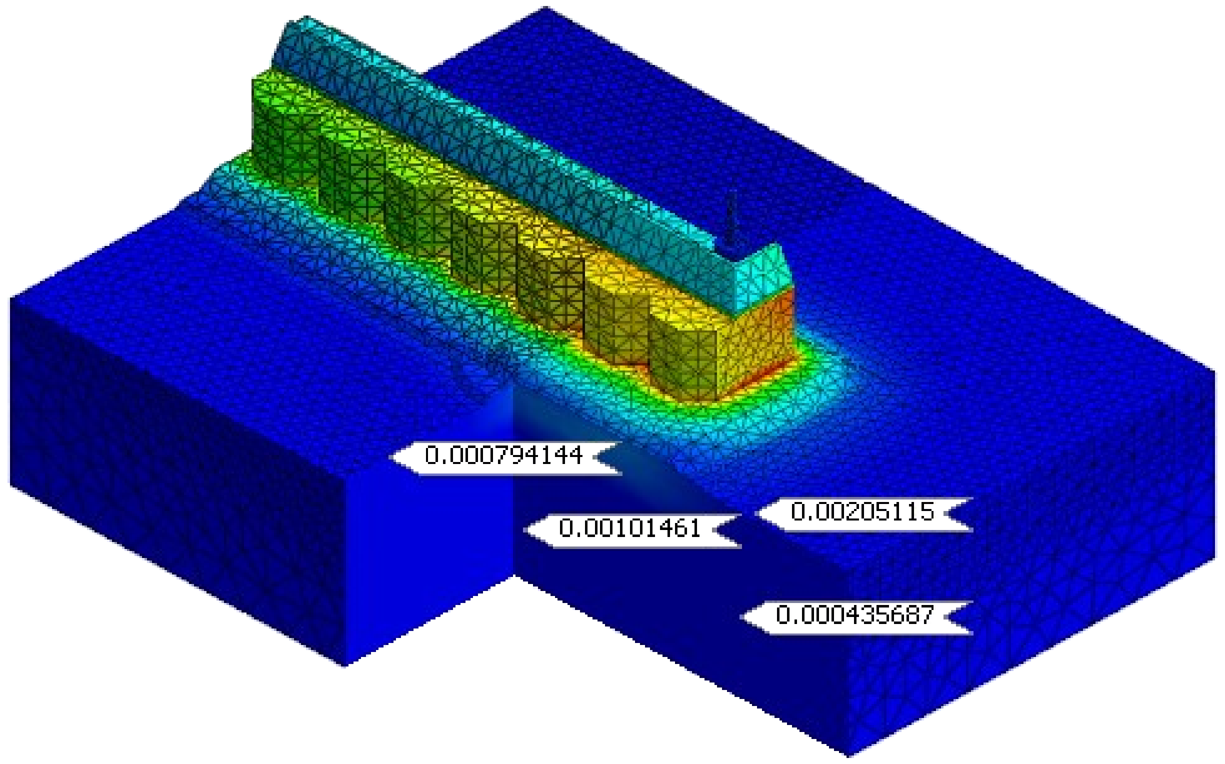
[Connect multi-step animation results]



[Print force sum of specified section (solid/shell)]



[Multi Step Phreatic Surfaces (GWL Drawdown)]

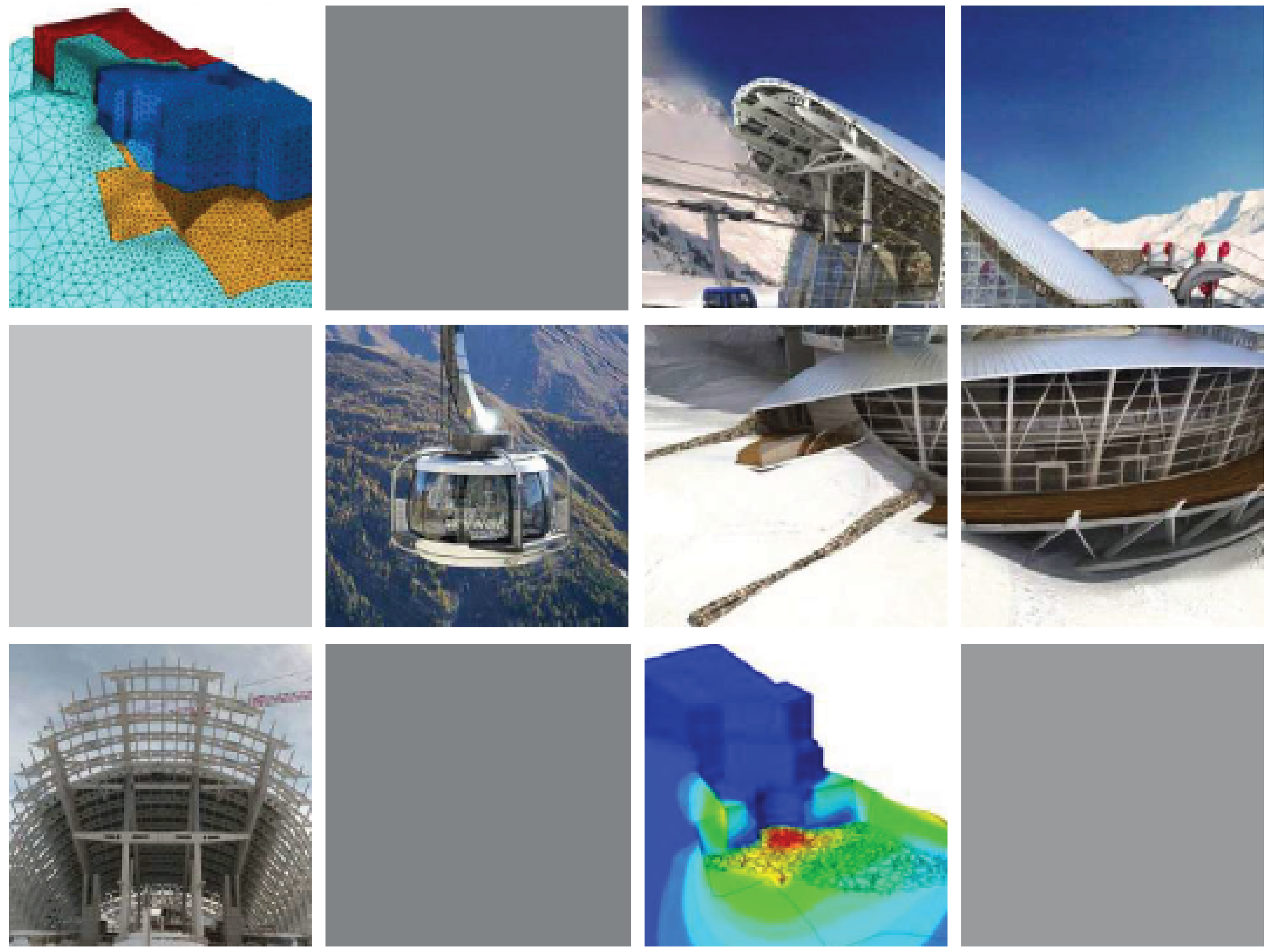


[Print clipping results]

PROJECT ACCOMPLISHMENTS

Skyway Monte Bianco
- Funlvla del Monte Blanco
Courmayeur, Italy

Owner	Funivie Monte Bianco AG
General Contractor	Cogeis
Engineering Consultant	Holzner & Bertagnolli Engineering
Architecture	Studio Progetti
Design	Dimensione Ingenierie
Construction Period	2010 - 2015
Project Type	Aerial Lift
Main features in modelling	- Rock excavation stability on top of the mountain - Tensile variations of the existing tie rods cableway
Description on this project	The cable car in Aosta Valley, at the entrance to the Mont Blanc tunnel, leads from Courmayeur to 1,200m above sea level. The new cable car valley station is being built near an existing station, as well as a restaurant which must remain operational. A 3D FEM analysis was required to analyze the interaction of the new construction and current adjacent structures.



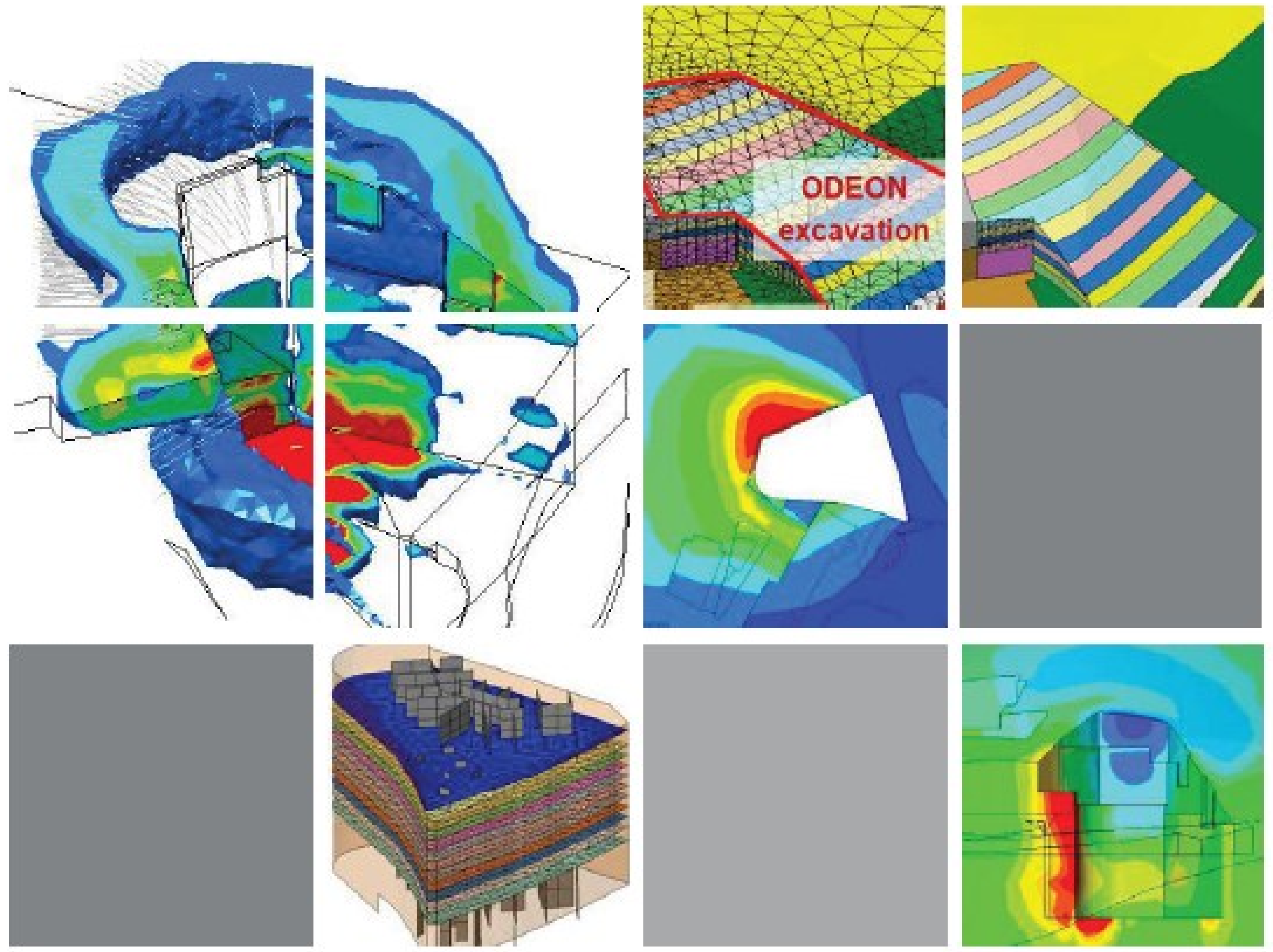
PROJECT ACCOMPLISHMENTS

Odeon Tower

Mona

TRACTEBEL
ENGIE

Owner	Group Marzocco
General Contractor	Vinci Construction France
Engineering Consultant	Coyne et Bellier
Architecture	Alexandre Giraldi
Construction Period	2010 - 2015
Project Type	Office Building
Size of the Structure	170m Height (49-Story)
Main features in modelling	- Assessment of ground movements especially at adjacent building foundations - Deep excavation in a sloping site and retaining system (especially arching effects on the uphill side)
Description on this project	The Odeon Tower is a double - skyscraper in the Principality of Monaco. It was the first high-rise in the city to be built since the 1980s. But high-rise constructions had been abandoned due to aesthetic concerns and criticism of over-development. 3D model of excavation and construction sequence was necessary to ensure adjacent school buildings will not be affected.



MIDAS

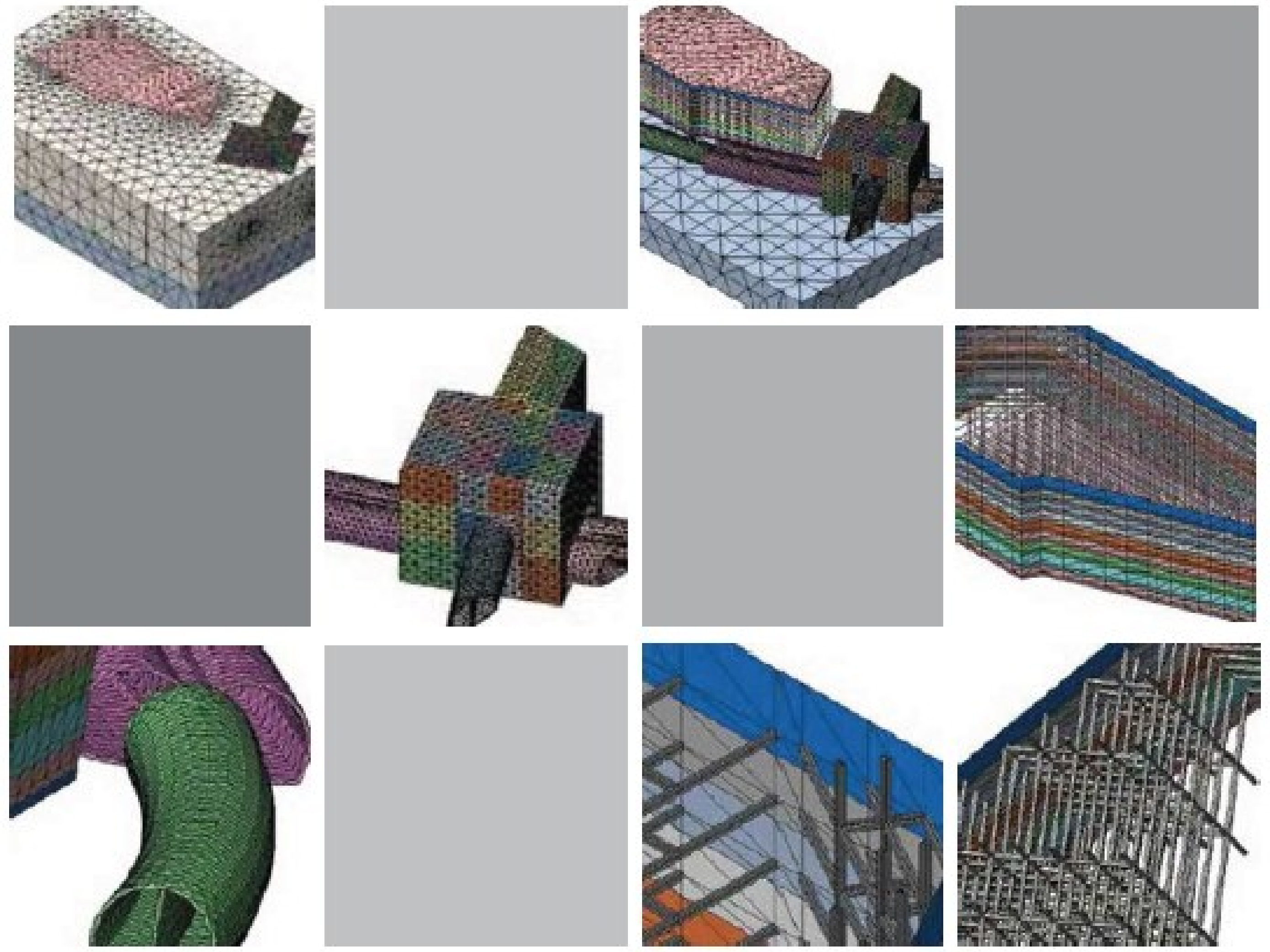
PROJECT ACCOMPLISHMENTS

Subway Impact Assessment

- Minam Complex Construction

Busan, Korea

JIN YOUNG CONSULTANTS CO., LTD



Design for Construction

Investigation of existing subway structure subjected to excavation for new building construction.

Overview

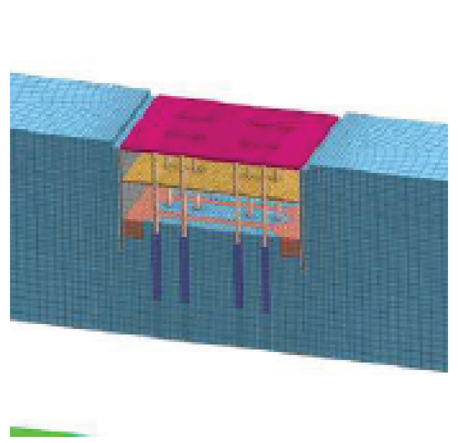
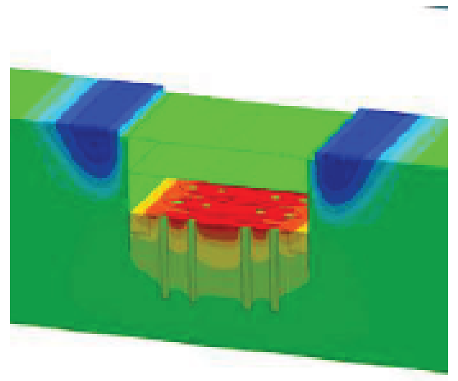
Safety investigation for 2-Arch tunnels and 1-Arch type tunnel where a large-scale excavation for a new building foundation takes place with temporary shoring within close proximity.

MIDAS

PROJECT ACCOMPLISHMENTS

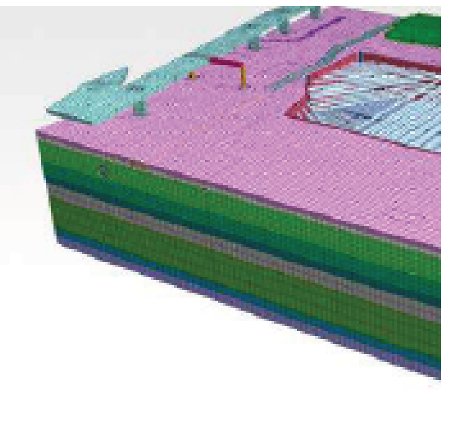
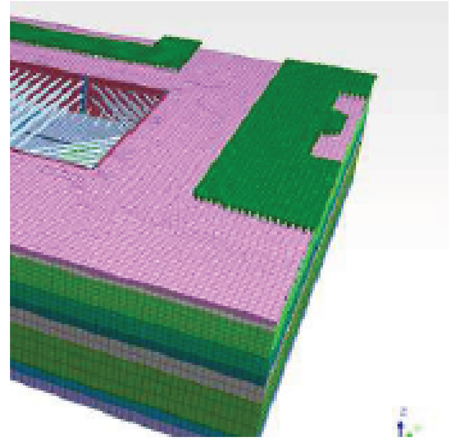
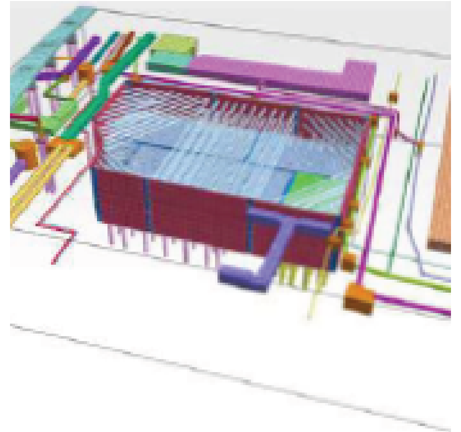
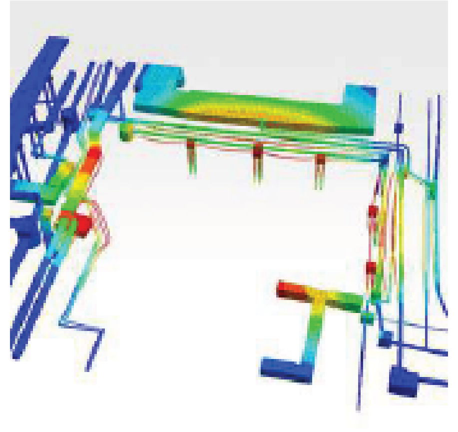
Deep Excavation
Pile Foundation

A construction stage analysis was used to design the complex foundation, which is a combination of piled raft and retaining walls with a thickness of 1m and depth of 36m. There is a three-story underground structure of rectangular shape with dimensions in the plan of 170.5m x 58m. Vertical bearing structures are steel columns, which are supported by piles with a diameter of 2m and a depth of 51m.

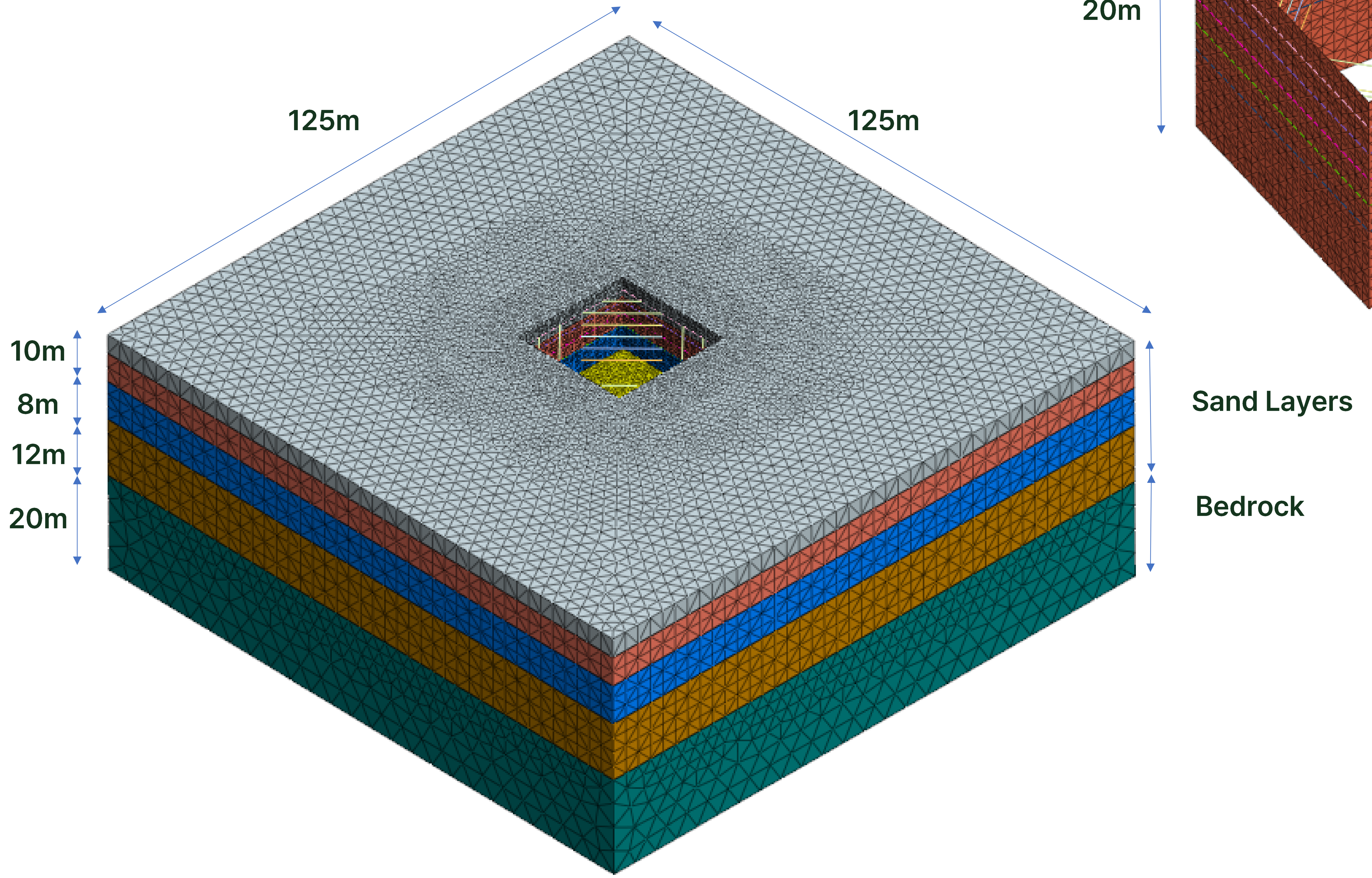

Deep Excavation
Effect of Adjacent Structure

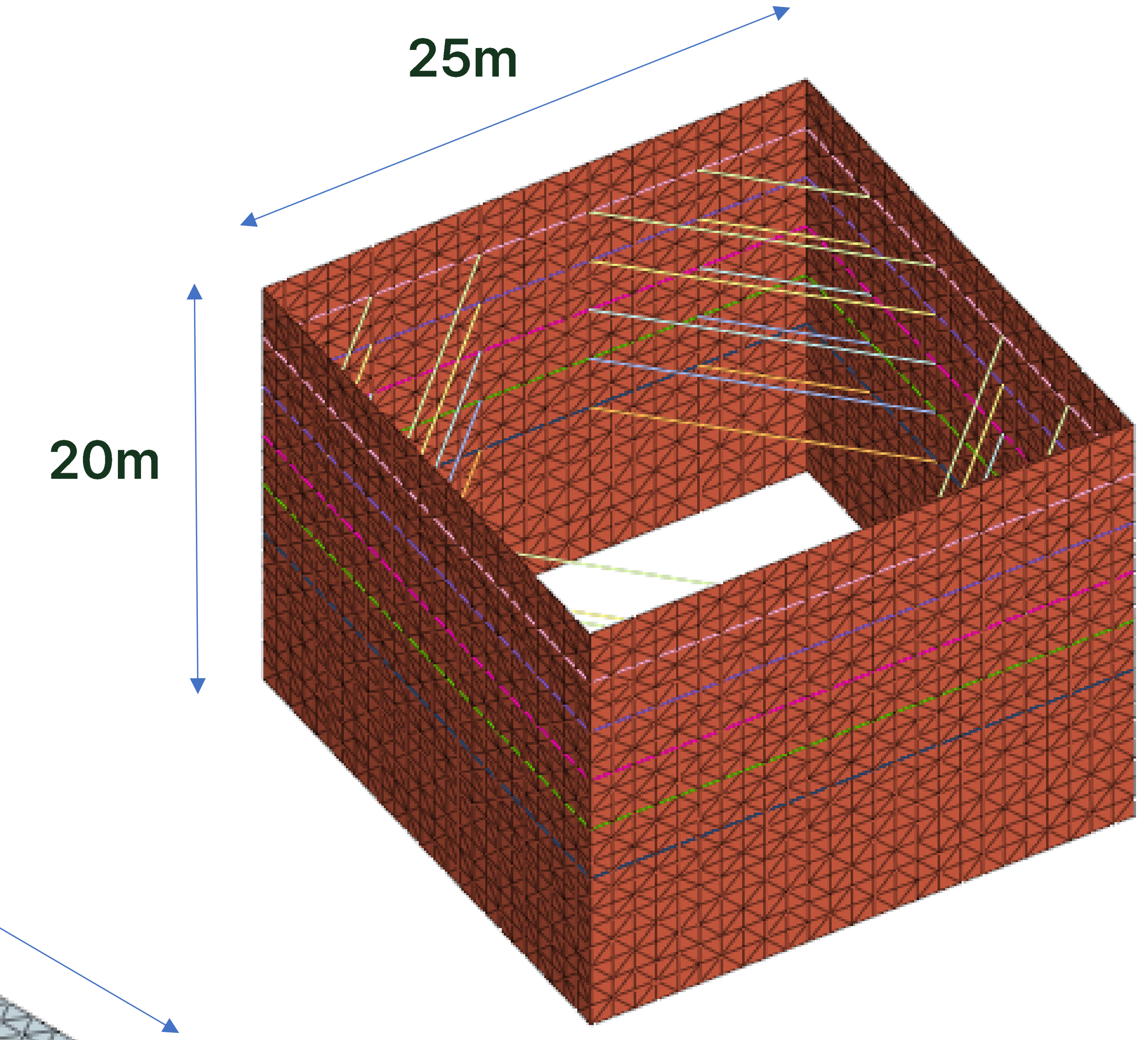
A 3D FEM analysis was used to calculate the impact on surrounding buildings and a network of pipelines during the excavation and construction of multi-functional complex with deep pile foundation.

PROBLEM STATEMENT

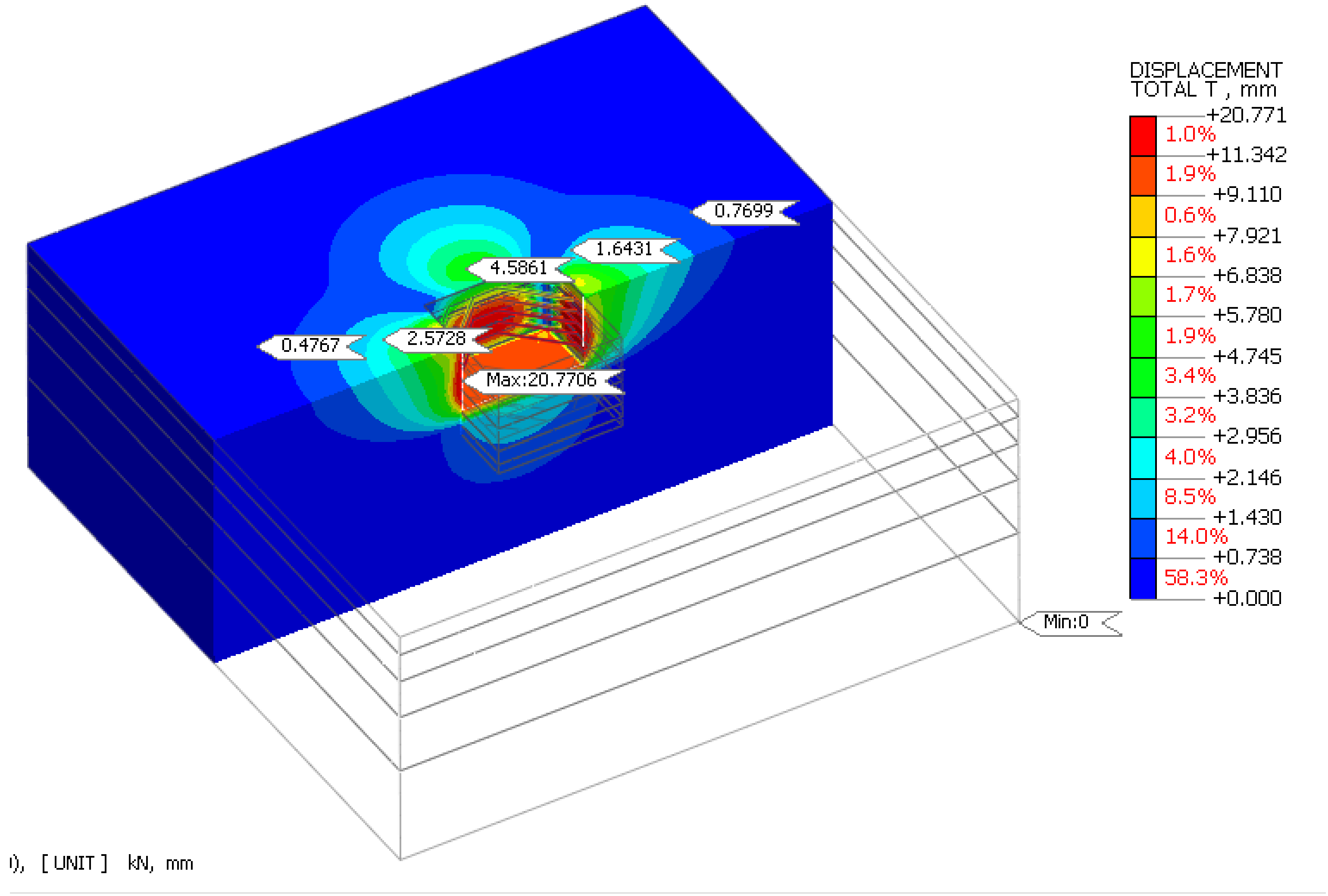
3D Excavation
Non-Linear Static Construction Stage Analysis
Sheet Pile Thickness 0.15m
Struts 0.15mx0.15m
Walers 0.1mx0.1m

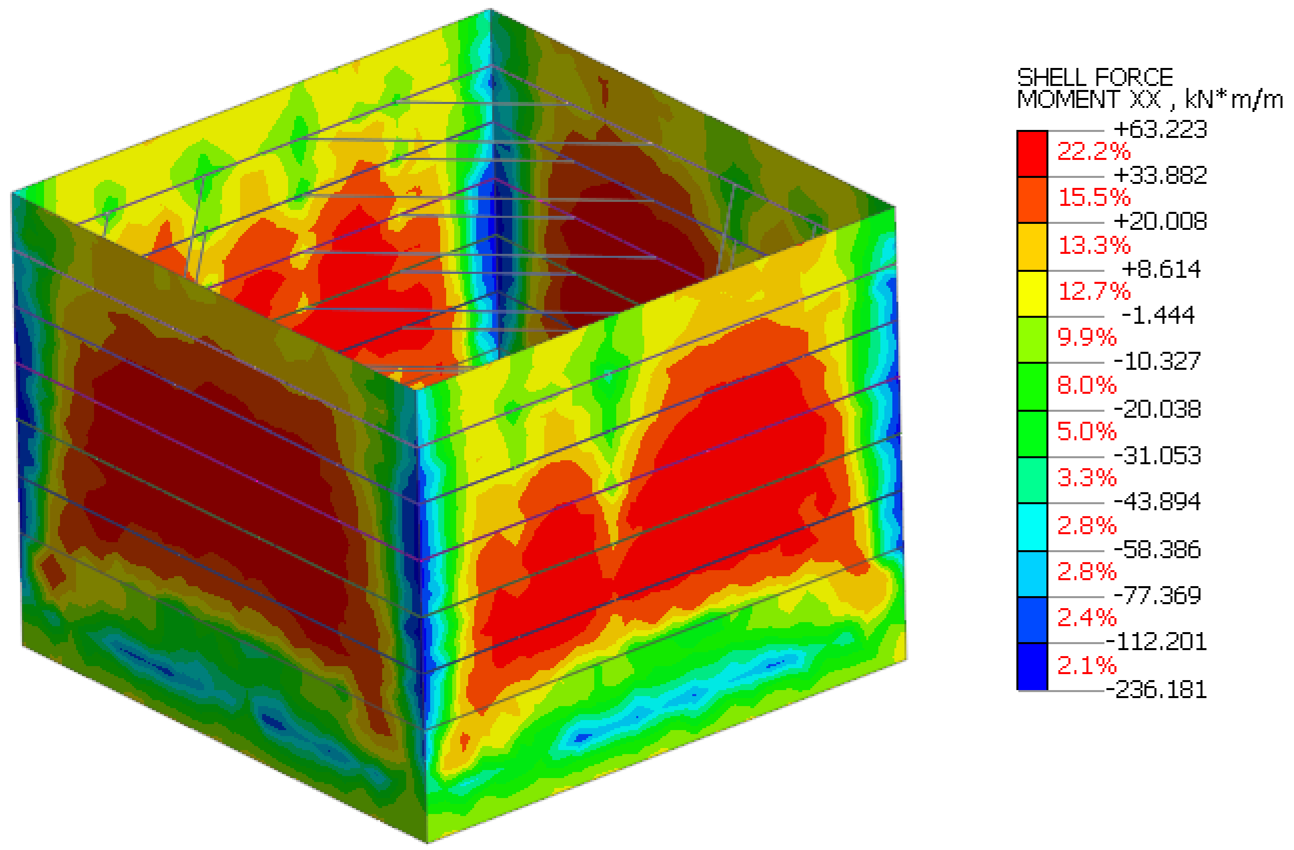


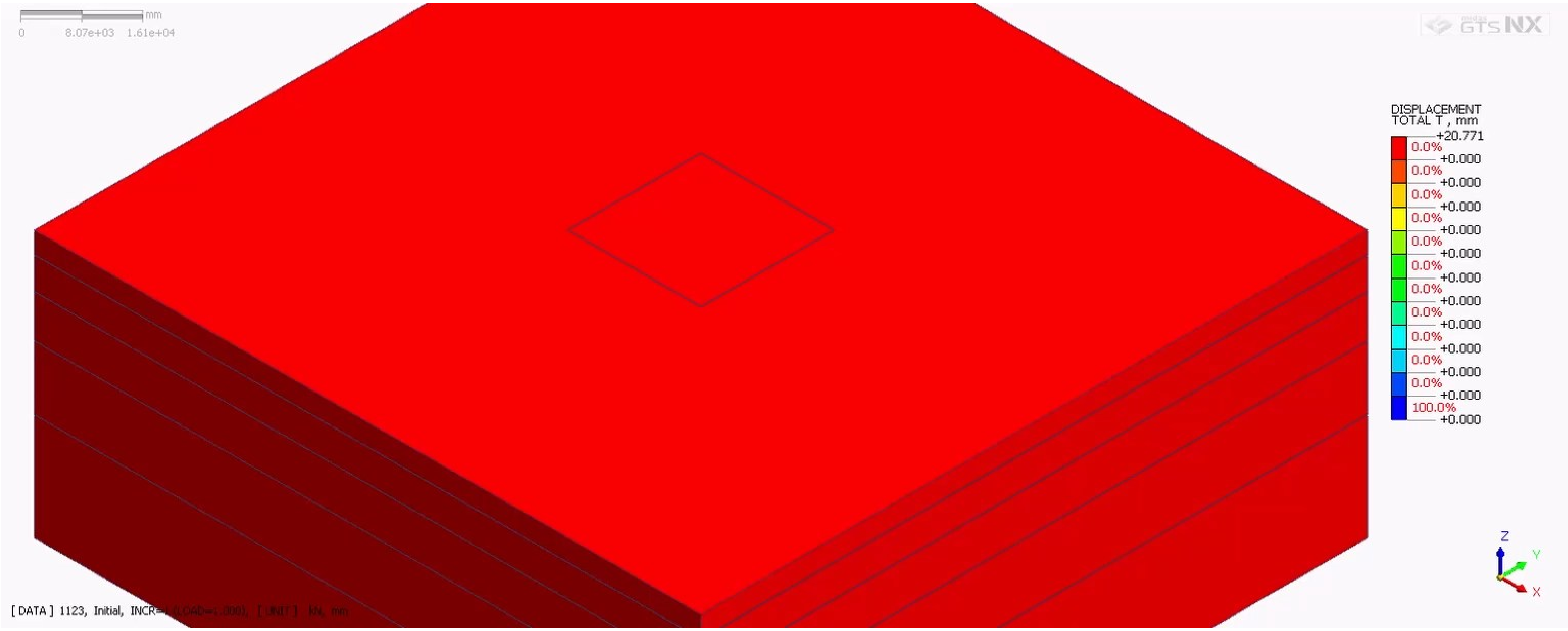


MIDAS

ANALYSIS RESULTS







THANK YOU