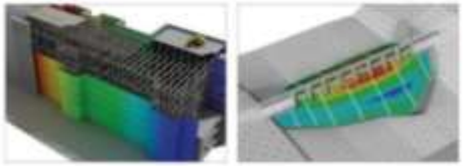
2D Liquefaction Analysis for Bridge Abutment

GTS NX
Geo-Technical analysis System New eXperience



Tutorial by Angel Francisco Martinez

Integrated Solver Optimized for the next generation 64-bit platform

Finite Element Solutions for Geotechnical Engineering

MIDAS

Introduction

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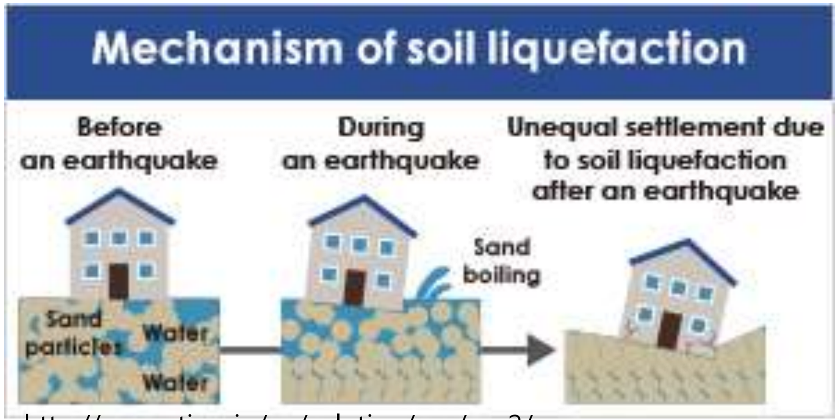
- Soil liquefaction is a phenomenon in which the strength and stiffness of a saturated soil/sand is reduced by earthquake shaking or other rapid loading.
- The pressures generated during large earthquake shaking can cause the liquefied sand and excess water to force its way to the ground surface.
- Soil particles can no longer support all the weight.
- Bridges and large buildings constructed on pile foundations may lose support from the adjacent soil and come to rest at a tilt after shaking.
- Sloping ground and ground next to rivers and lakes may slide on a liquefied soil layer ('lateral spreading').

2D Seismic Analysis Methods

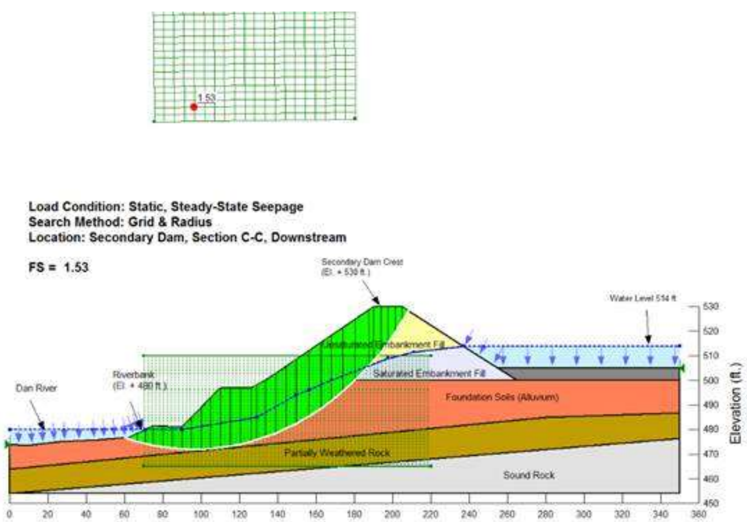
- **Pseudostatic Analysis**
  - **- Limit Equilibrium Method**
    - **+MIDAS Soilworks**
    - **+Slide**
- **Numerically Based Analysis**
  - **- Finite Element Method**
    - **+ MIDAS GTS NX**
    - **+ Quake/W**
    - **+ Plaxis**
  - **- Finite Difference Method**
    - **+ FLAC**

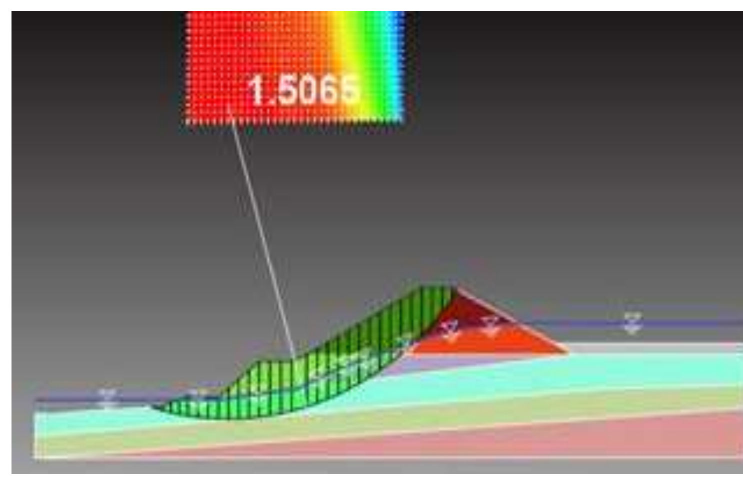


http://www.cti.co.jp/en/solution/cae/cae2/

Pseudostatic Analysis

- Representation of the complex, transient, dynamics of earthquake shaking by a single, constant, unidirectional load is crude.
- Method has been shown to be unreliable for soils with significant pore pressure buildup during cycling (i.e., not valid for liquefaction).
- Cannot predict deformation.
- Is only a relative index of slope stability
- Outdated and should only be used for **screening purposes**.
- More elaborate techniques are generally warranted and are rather easy to do with modern computing software.





Advanced Numerical Methods

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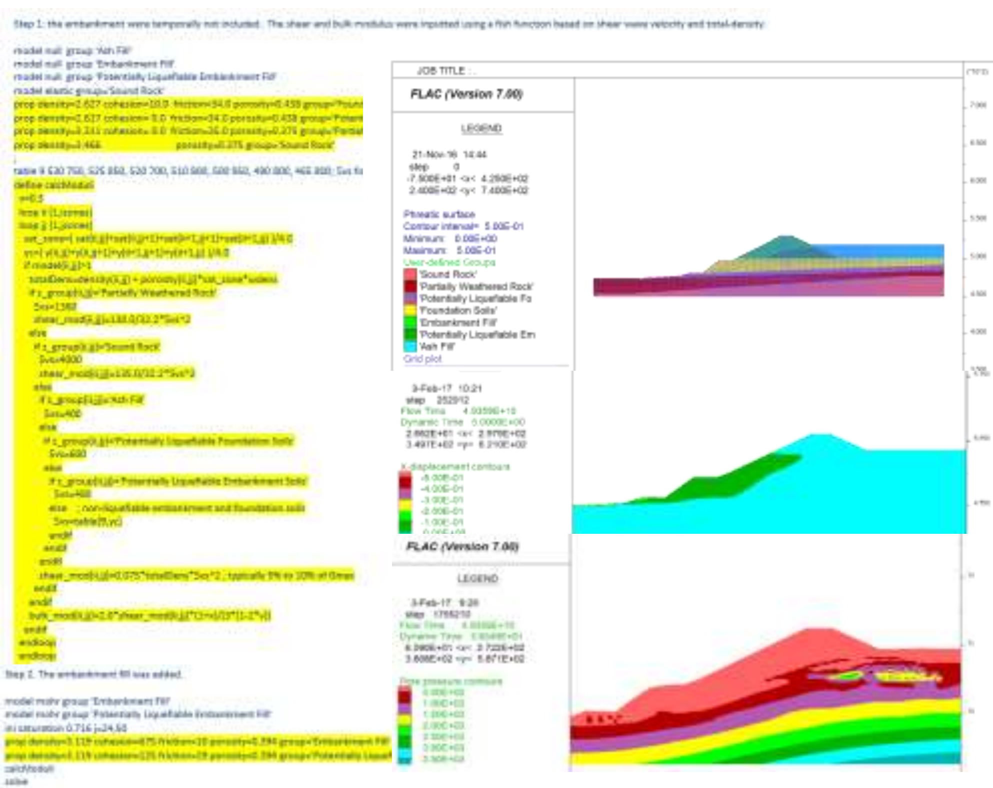
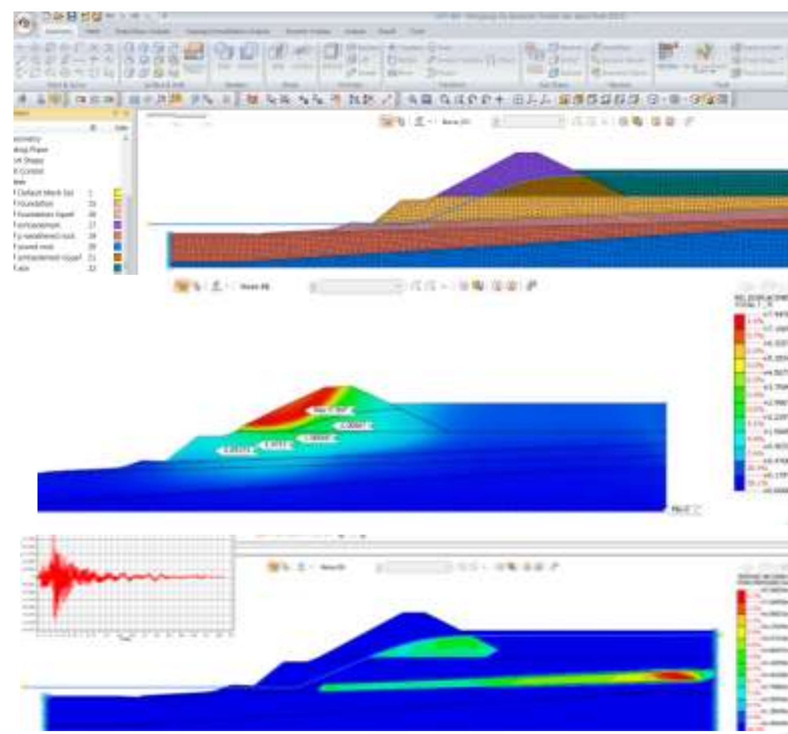
- Based on finite difference or finite element techniques
- Full dynamics modeled
- Deformation can be estimated using elasto-plastic or other constitutive models
- Required advanced training and Coding for FLAC models

FDM



FEM



2D Liquefaction Analysis of Bridge Abutment

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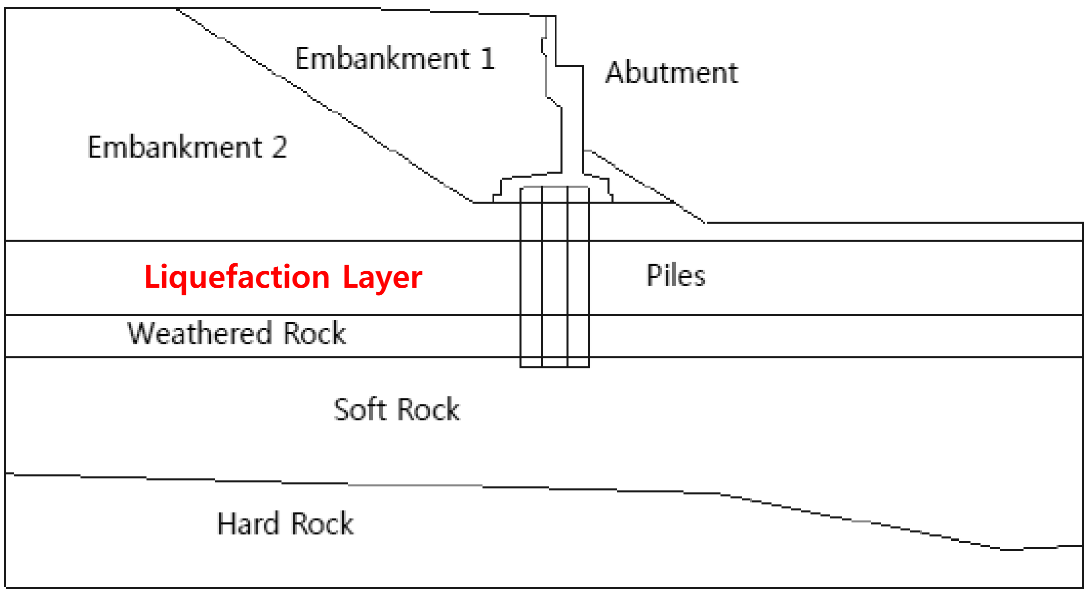
Objectives

1. Plane strain elements are used to model both the ground conditions and Abutment.
2. Pile elements are modeled as beam elements and embedded in Embankment, UBC Sand, and Soft Rock layers.
3. Model the load in surrounding ground generated by earthquake and evaluate dynamic behavior and vibration effect of ground and abutment.
4. Check the eigenvalue of ground through Eigenvalue analysis, Analyze ground dynamic behavior affected by earthquake.
5. Starting Files Required: GTS NX 2D liquefaction tutorial_start.gtb
6. Check Liquefied Layers



Step 01 File > Open

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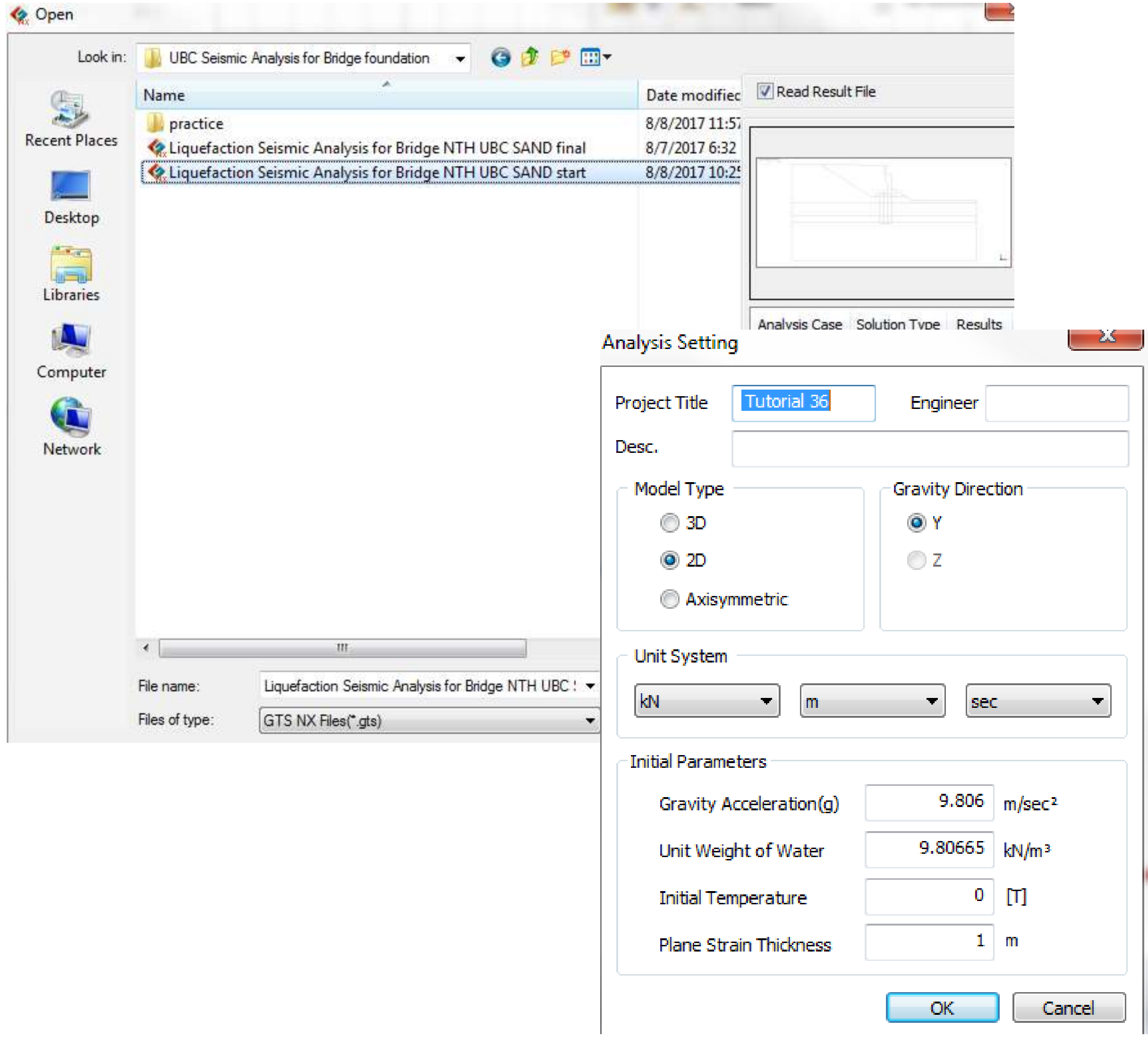
Procedure

1. Main Menu > File>Open...
2. Double click ‘GTS NX 2D liquefaction_start.gtb
3. Main Menu > Analysis > Setting > Unit System> kN>m>s
4. Click [OK].



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Materials

ID	Name	Type	Modulus of Elasticity(E) [kN/m2]	Poisson's Ratio(ν)	Unit Weight(Y) [kN/m3]	Unit Weight (Saturated) [kN/m3]	Cohesion (c) [kN/m2]	Friction Angle [Φ]	K0
1	Embankment	Mohr Coulomb	40,000	0.35	18	19	15	25	1
2	**Liquefaction Layer**	**UBC SAND**	**60,000**	**0.02**	**20**	**21**	**-**	**-**	**-**
3	Weathered Rock	Mohr Coulomb	100,000	0.3	20	21	35	33	1
4	Soft Rock	Mohr Coulomb	900,000	0.25	24	25	150	37	1
5	Abutment	Mohr Coulomb	21,000,000	0.18	25	-	-	-	-
6	Pile	Elastic	210,000,000	0.3	78	-	-	-	-

Step 02: Mesh> Material > UBC

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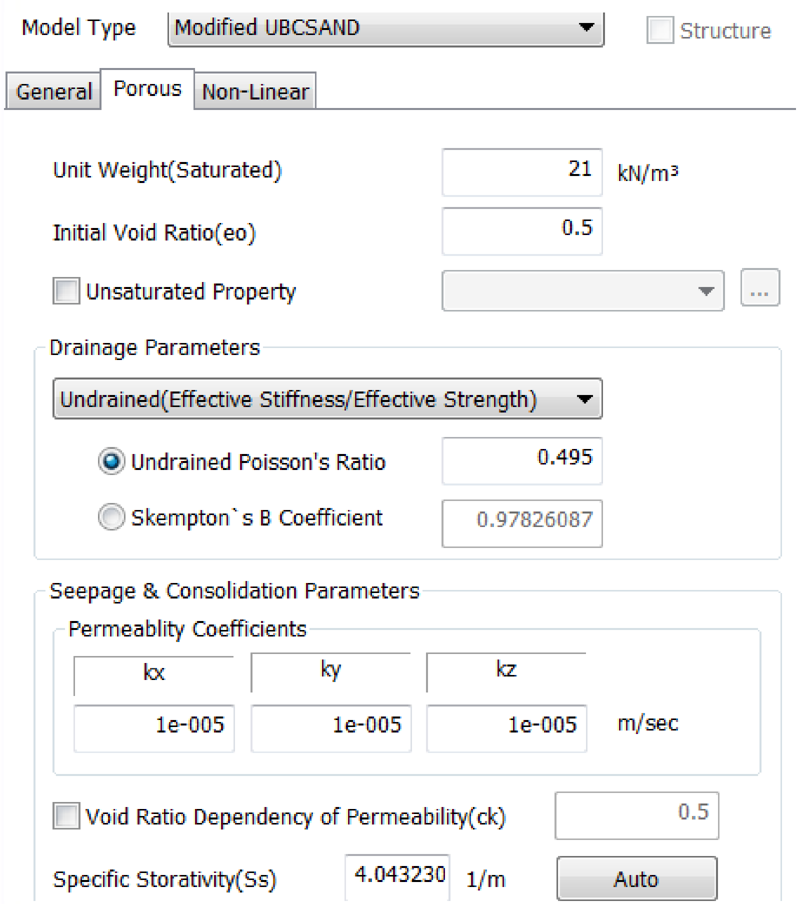
The Modified UBCSAND model is developed to simulate liquefaction phenomenon using **plastic theory based on explicit method for 2D effective stress state.** It is extended to enable **implicit nonlinear analysis for 3D stress state** based on the constitutive model[9, 10]

In elastic region, nonlinear elastic behavior can be simulated, elastic modulus changes according to the effective pressure applied. In **plastic region, the behavior is defined by three types of yield functions** : **shear (shear hardening), compression (cap hardening), and pressure cut-off.** In case of shear hardening, soil densification effect can be taken into account by cyclic loading.

* Note - **Implicit Method** : Explicit methods calculate the state of a system at a later time from the state of the system at the current time, while implicit methods find a solution by solving an equation involving both the current state of the system and the later one.

9 Beaty, M. and Byrne, PM., "An effective stress model for predicting liquefaction behaviour of sand," In Geotechnical earthquake engineering and soil dynamics III, Americal Society of Civil Engineers, Geotechnical Special Publication 75(1), 1998, pp. 766-777.
10 Puebla, H., Byrne, PM., and Phillips, R., "Analysis of CANLEX liquefaction embankments: protype and centrifuge models," Canadian Geotechnical Journal, 34, 1997, pp 641-657.

Step 02: Mesh> Material > UBC



Drainage parameters

The pore water pressure in stress analysis can be divided into normal state pore water pressure and abnormal state pore water pressure - **the excess pore water pressure generated between soil particles due to external loading under undrained conditions.** An excess pore water pressure of nearly 0 is called the drainage condition.

Undrained Material Type: Effective stiffness/effective strength

This is the most general case where the input stiffness parameters and strength parameters are the parameters of the ground skeleton. Like drained analysis, **GTS NX uses the input stiffness/strength parameters for undrained analysis.** The disadvantage is that the effective strength parameters in the undrained state are hard to obtain through experimentation.

Undrained Poisson's ratio and Skempton (B) coefficient are parameters used to calculate the bulk modulus of elasticity for water. **The undrained Poisson's ratio has a standard value of 0.495** with a compressibility of nearly '0 (zero)' and the Skempton coefficient expresses the saturation, with 1 meaning full saturation.

Step 02: Mesh> Material > UBC

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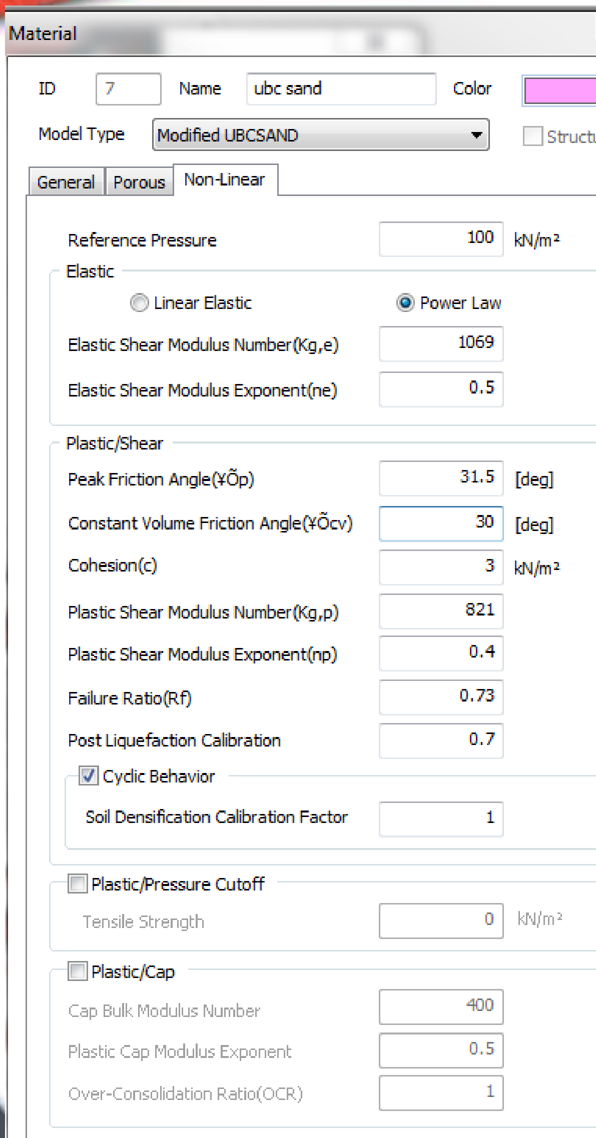

Parameter	Description	Reference
Pref	Reference Pressure	In-situ horizontal stress at mid-level of soil layer
Elastic (Power Law)		
K_G^e	Elastic shear modulus number	Dimensionless
ne	Elastic shear modulus exponent	Dimensionless
Plastic / Shear		
ϕ_p	Peak Friction Angle	Failure parameter as in MC model
ϕ_{cv}	Constant Volume Friction Angle	-
c	Cohesion	Failure parameter as in MC model
K_G^p	Plastic shear modulus number	Dimensionless
np	Plastic shear modulus exponent	Dimensionless
R_f	Failure ratio (qf / qa)	0.7~0.98 (< 1), decreases with increasing relative density
F_{post}	Post Liquefaction Calibration Factor	Residual shear modulus
F_{dens}	Soil Densification Calibration Factor	Cyclic Behavior
Advanced parameters		
Pcut	Plastic/Pressure Cutoff (Tensile Strength)	-
K_B^p	Cap Bulk Modulus Number	-
mp	Plastic Cap Modulus Exponent	-
OCR	Over Consolidation Ratio	Normal stress / Pre-overburden pressure

Step 02: Mesh> Materials

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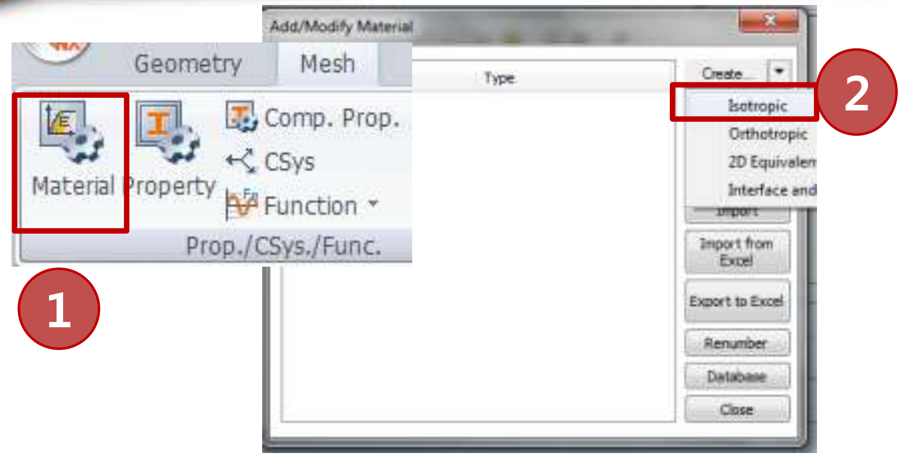
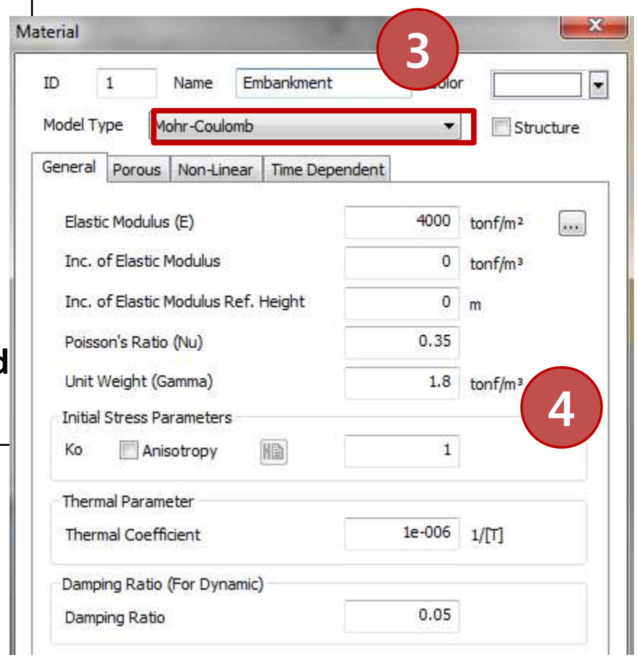
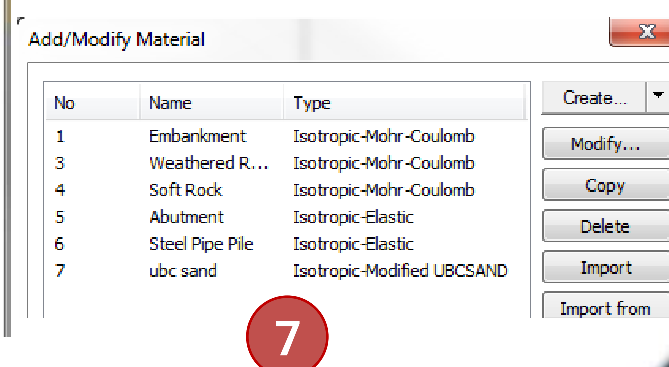
Procedure

1. Main Menu Model > materials
2. [Create]>Select Isotropic.
3. ID ‘1’, Name ‘Embankment’, Model Type [Mohr Coulomb].
4. Enter the material properties as shown.
5. Click [OK].
6. Click [Apply].
7. Similarly create the materials for all the soil layers – Weathered Rock, Liquefaction, Soft Rock, and Abutment.







Properties

ID	Name	Type	Subtype
1	Embankment	2D	Plane Strain
2	**Liquefaction Layer**	2D	Plane Strain
3	Weathered Rock	2D	Plane Strain
4	Soft Rock	2D	Plane Strain
5	Abutment	2D	Plane Strain
6	Pile	1D	Beam

Step 03: Mesh> Property

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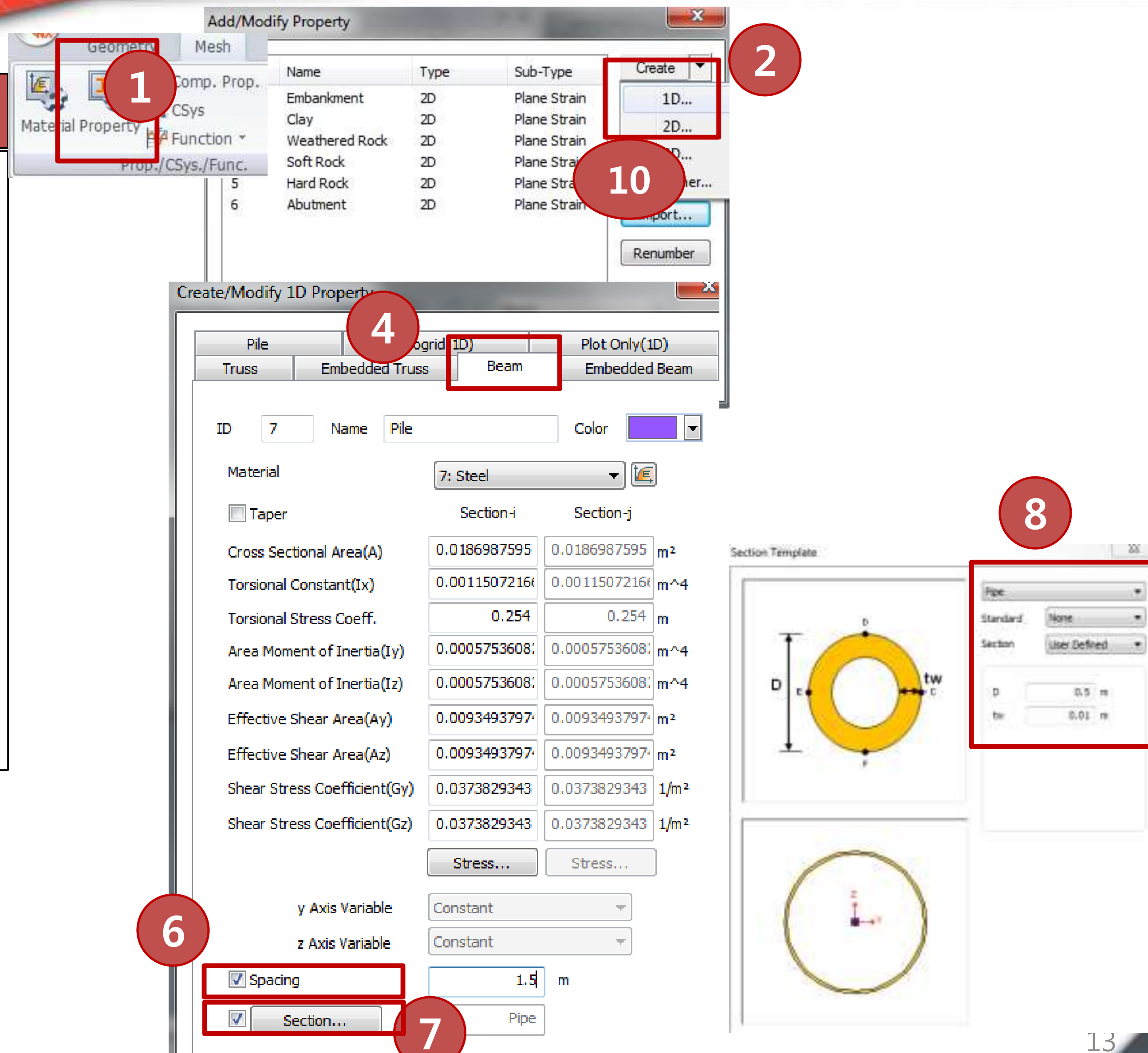
Procedure

1. Main Menu Model > Property
2. Click on [Add] > Select [1D].
3. ID ‘7’, Name ‘Pile’.
4. Element Type > [Beam].
5. Material > Steel’
6. Spacing 1.5m
7. Click-on ‘Sectional Library’
8. Select [Pipe], D > Enter ‘0.5’m, tw > enter ‘0.01’m.
9. Click [OK], Click [OK].
10. Repeat for 2D Plane Strain soil layers



Step 04 Mesh > 2D Mesh

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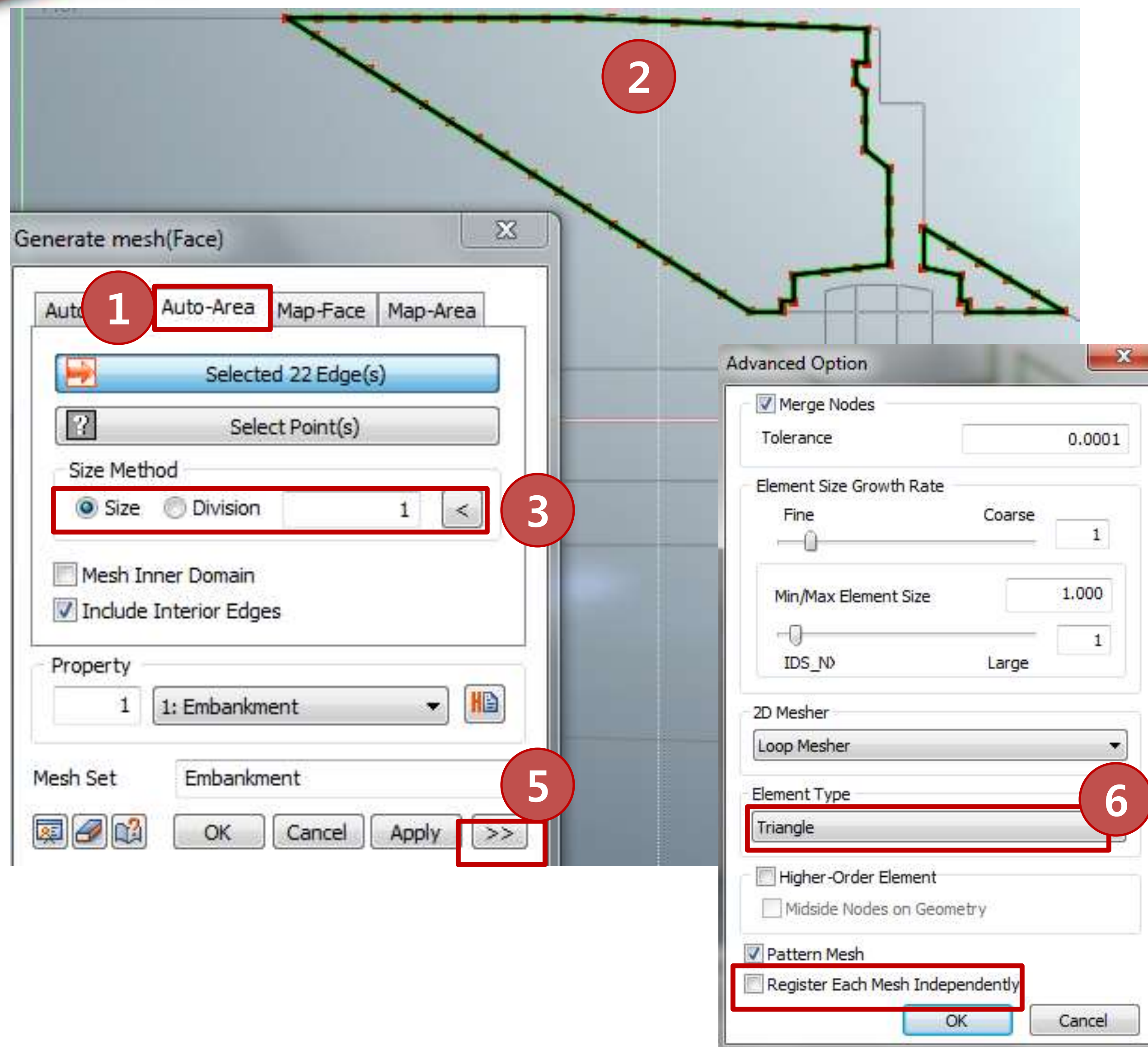
Procedure

1. Main Menu > Mesh > Generate> 2D> Auto Area
2. Select Object Edges > Select the edges as shown.
3. Mesh Size > Element Size '1',
4. Property > Select 'Embankment' Name > 'Embankment'.
5. Click [Advanced Option].
6. Type [Triangle], Check-off [Register Each Area Independently].Click [OK].
7. Click [Apply].
8. Similarly create the mesh sets for Liquefaction, Weathered Rock, Soft Rock, & Abutment.



Step 05 Mesh > Element>Extract

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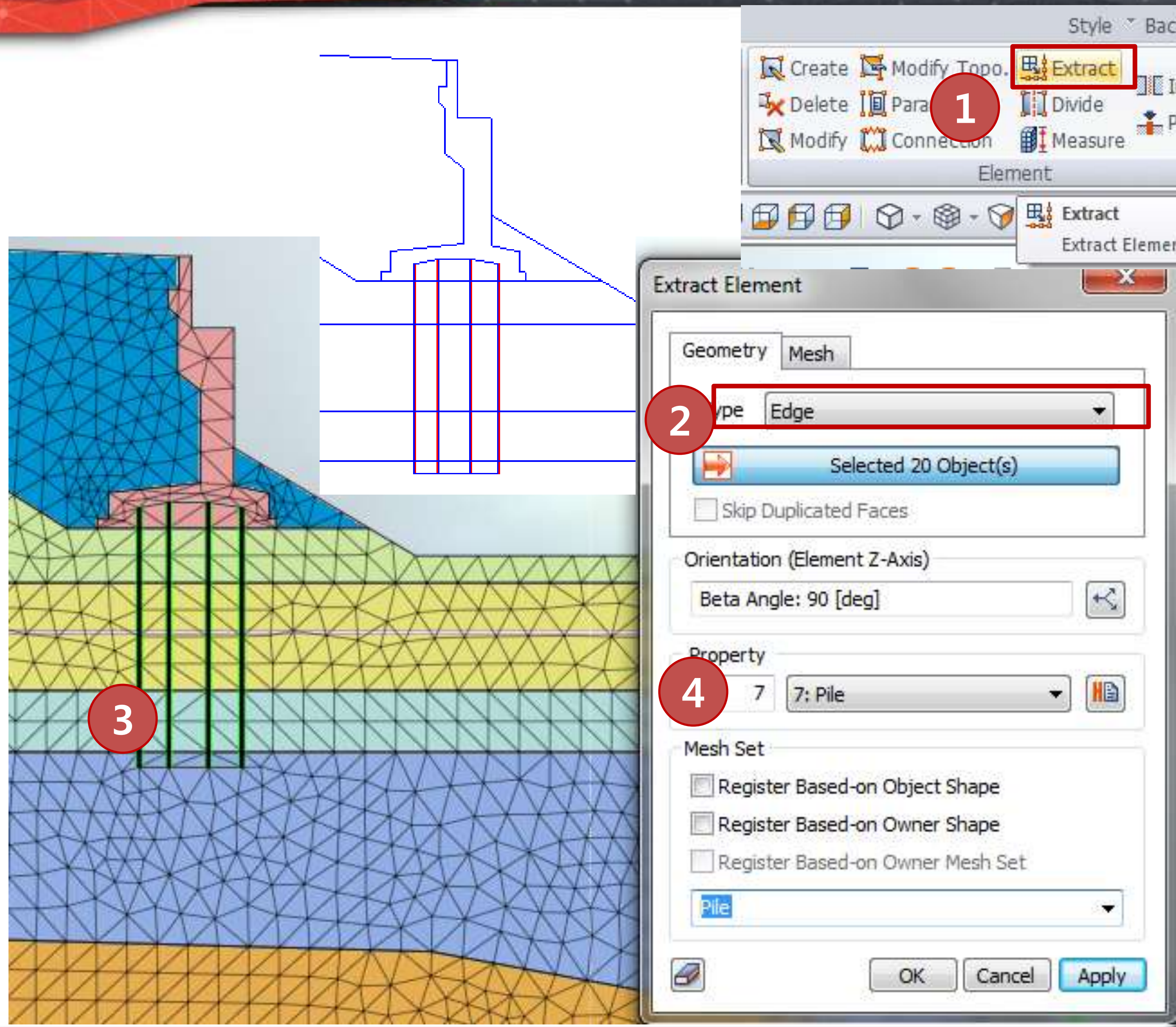
Procedure

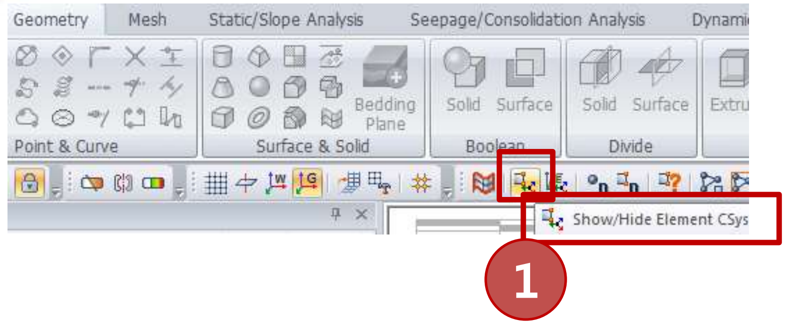
1. Main Menu > Mesh > Element >Extract Element
2. From Geometry > Select [Edge].
3. Select the 20 edges of the Pile as shown.
4. Property ID > ' 7 : Pile '.
5. Mesh Set > Enter name 'Piles'.
6. Click [OK]

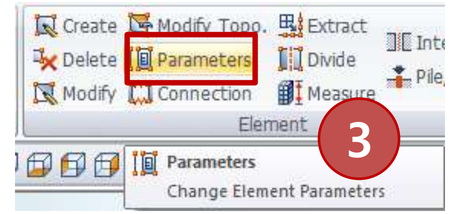


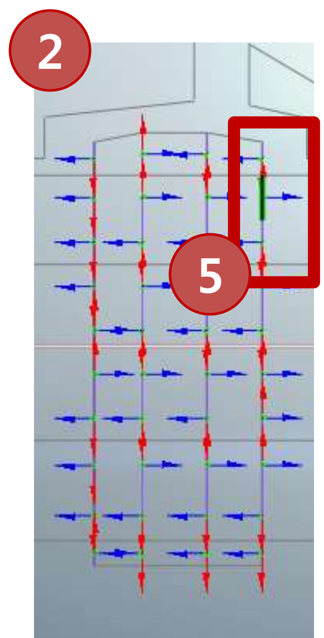
Step 06 Mesh >Element > Parameter

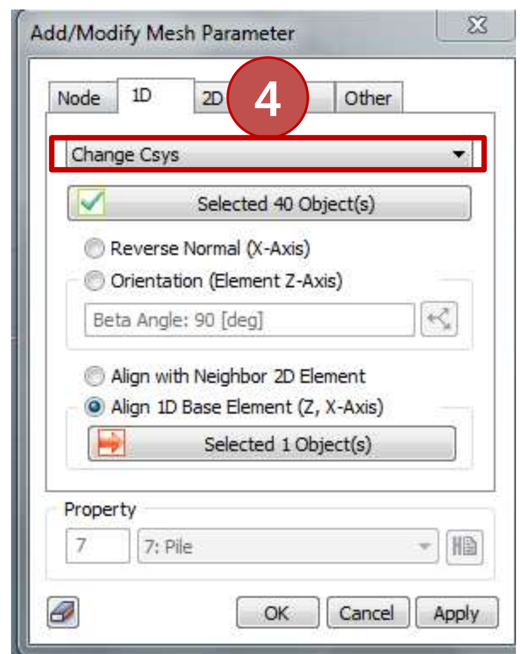
Procedure

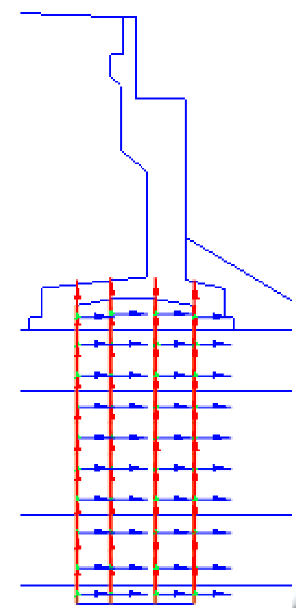
1. Main Menu Display > Element Csys.
2. As can be seen the Element Csys are not aligned in the same direction. This will result in wrong display of results.
3. Main Menu > Mesh > Element > Change Element Parameter.
4. In Selection filter select [1D]>> Change Cys.
5. "Base Element" select any element whose Z axis is parallel to Global X-axis
6. Select the "Pile" mesh set from the works tree.
7. Click [OK].







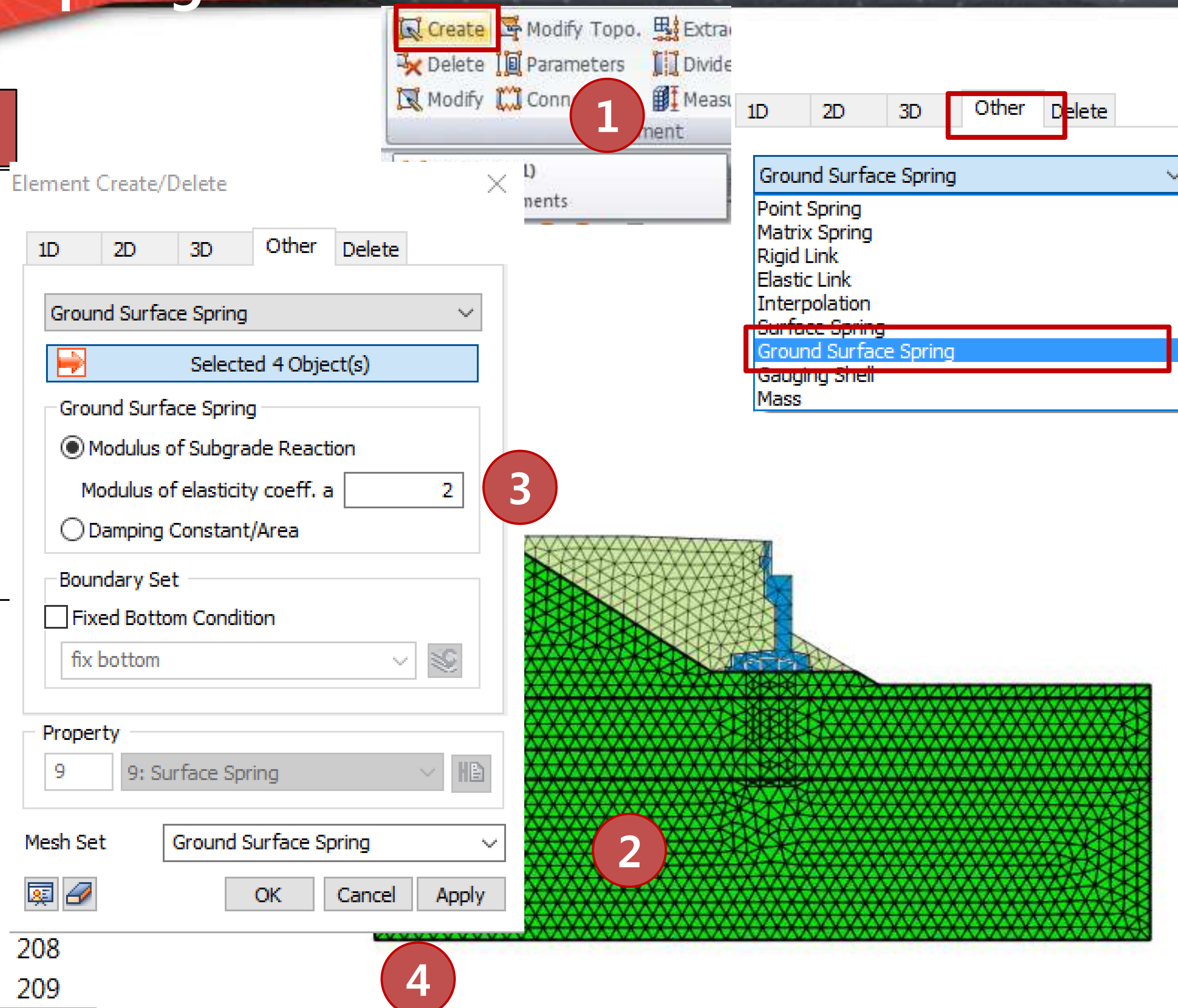


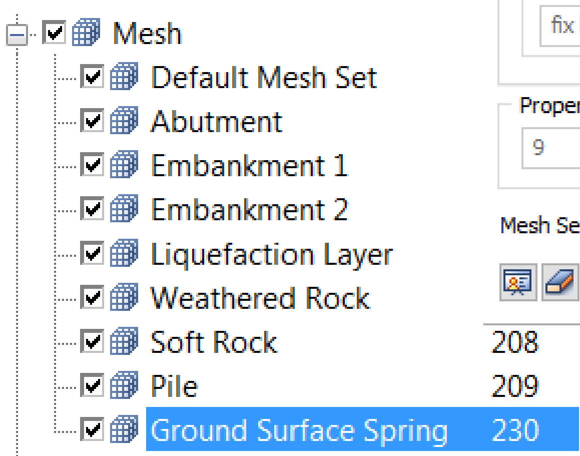


Step 07 Mesh >Element > Create Ground Surface Spring

Procedure

1. Main Menu >Mesh > Element > Other> Ground Surface Spring
2. Select the 4 bottom ground layers as shown
3. Type the value of "2" for modulus of elasticity coefficient
4. Click [Apply].





Modulus of Subgrade Reaction

The ‘Create Ground Surface Spring’ feature can generate automatically for dynamic analysis.

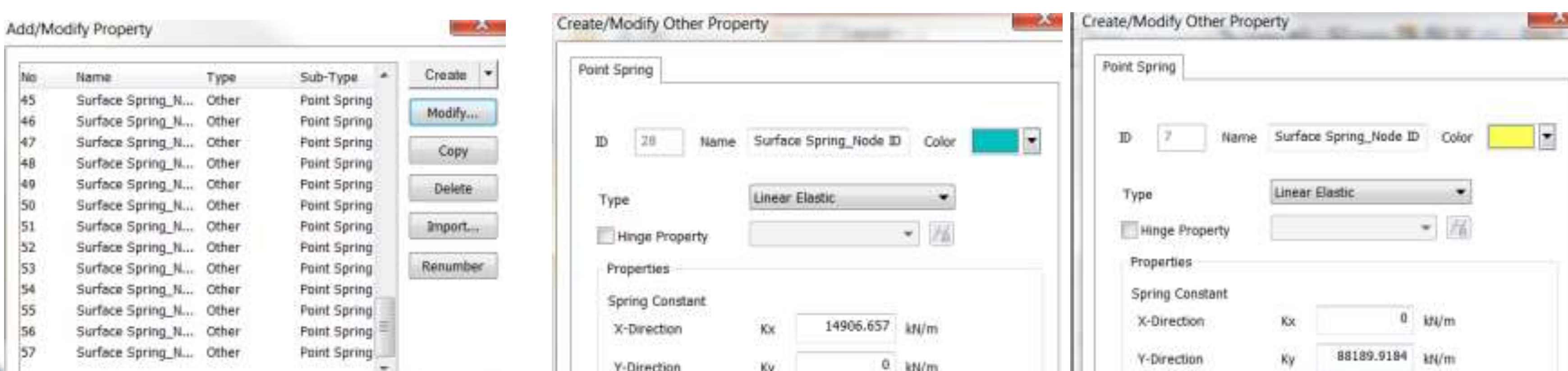
The modulus of subgrade reaction is calculated by equations in the ‘Create Ground Surface Spring’ feature.

Modulus of Vertical Subgrade Reaction : $k_v = k_{v0} \cdot (\frac{B_v}{30})^{-3/4}$ $(\mathrm{kgf/cm^3})$

Modulus of Horizontal Subgrade Reaction : $k_h = k_{h0} \cdot (\frac{B_h}{30})^{-3/4}$ $(\mathrm{kgf/cm^3})$

Where, $k_{vo} = \frac{1}{30} \cdot \alpha \cdot E_0 = k_{h0}$, $B_v = \sqrt{A_v}$, $B_h = \sqrt{A_h}$

α : Estimated factor for Modulus of subgrade reaction (use between 2.0~4.0)



Step 08 Analysis > General

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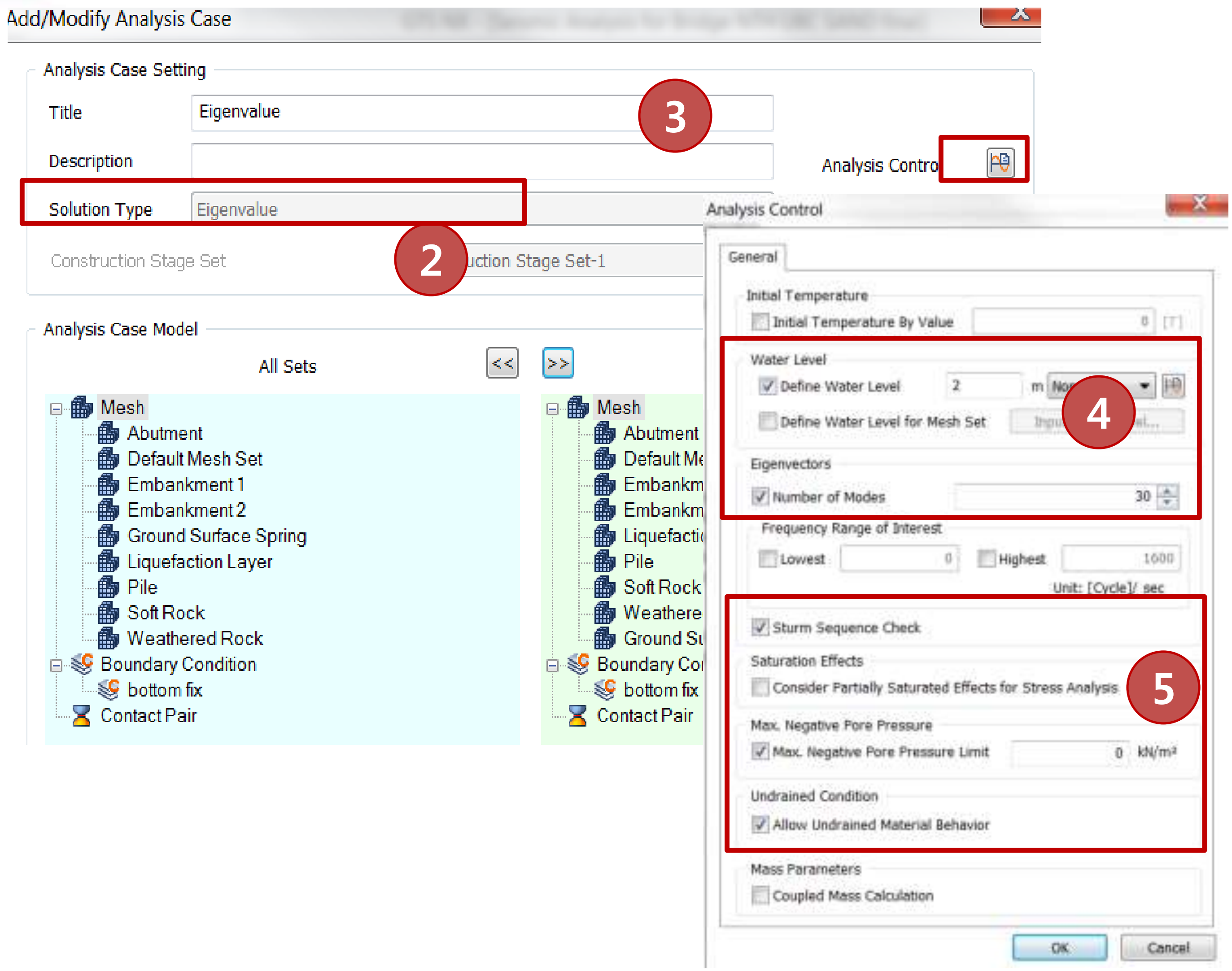
Procedure

1. Main Menu > Analysis > General
2. Name 'Eigen Value', Analysis Type > Select [Eigenvalue].
3. Click-on Analysis Control [ ].
4. Water Level 2m Number of Frequencies '30'.
5. Check ON: Sturm Sequence Check, Max Negative Pore Pressure (0), and Allow Undrained Behavior

Click [OK], Click [OK].



Step 9 Analysis > Perform

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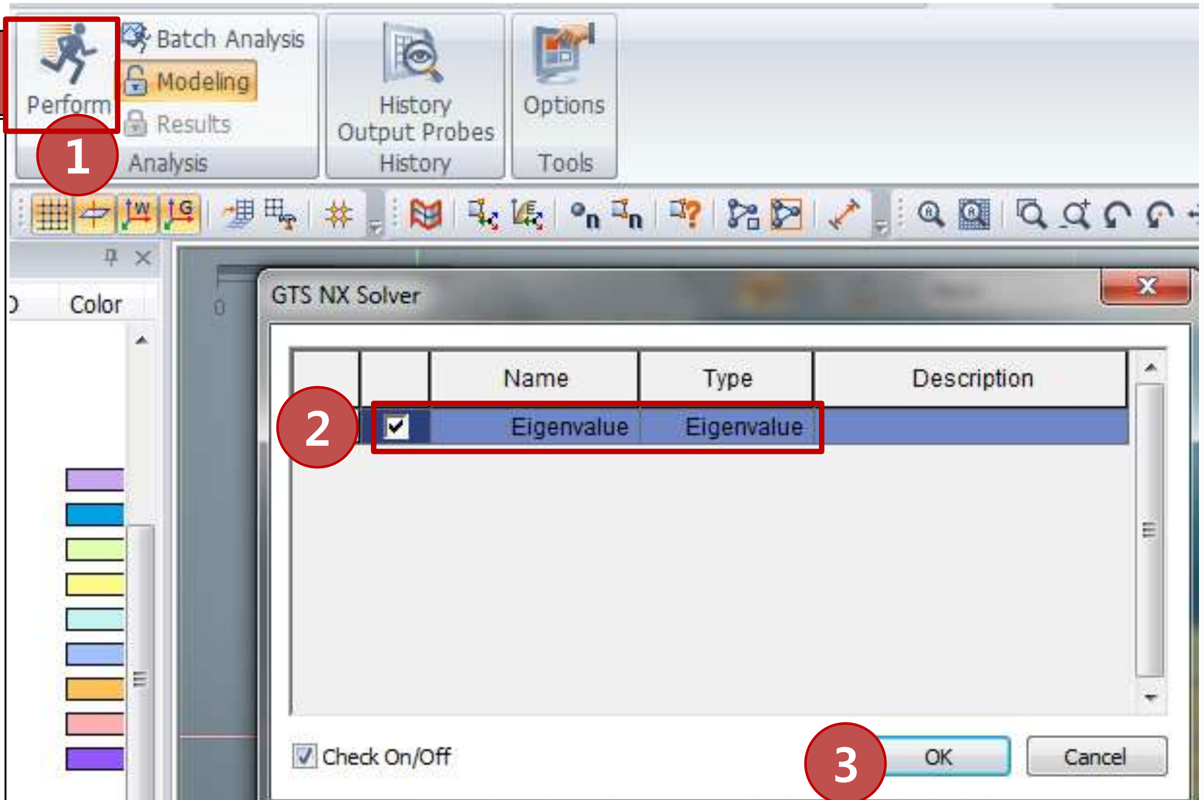
Procedure

1. Main Menu > Analysis > Perform…
2. Check –on ‘EigenValue’.
3. Click [OK].
4. All the messages during the analysis will be shown in the Output Window. Especially, one needs to be very cautious about warning messages, because these messages indicate that the analysis results may not be correct. The model is automatically saved before the analysis. The result is saved as binary file(*.TA*) in the same folder as the model. The detail analysis information is also saved in a text file(*.OUT).



- [SYSTEM INFO]
- NUMBER OF THREADS : 4
- MAXIMUM MEMORY USAGE : 206 MB
- AVAILABLE MEMORY : 6262 MB
- TOTAL CPU TIME : 2.683 sec
- WALL CLOCK TIME : 1.498 sec
- TOTAL WARNINGS : 0

Step 10 Results > Vibration Mode

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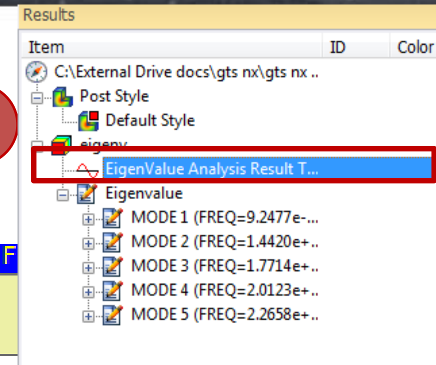
Procedure

1. Main Menu > Result > Vibration Mode Shape...
2. Check the periods of 1st and 6th modes where mass participation is the largest.
3. Keep the record of periods of 0.407 sec and 0.188 sec.



1

2

PERCENTAGE MODAL EFF

MODE NUMBER	T1	T2	T3	R1		
1	27.89%	0.44%	0.00%	0.00%	[illegible]	[illegible]
2	0.07%	6.68%	0.00%	0.00%	0.00%	16.61%
3	0.01%	12.27%	0.00%	0.00%	0.00%	4.55%
4	1.14%	0.69%	0.00%	0.00%	0.00%	0.02%
5	0.82%	3.77%	0.00%	0.00%	0.00%	0.23%
6	14.68%	0.87%	0.00%	0.00%	0.00%	1.01%
7	0.01%	0.98%	0.00%	0.00%	0.00%	0.00%

REAL EIGENV

MODE NUMBER	EIGENVALUE	RADIANS	CYCLES	PERIOD
1	2.376695e+002	1.541653e+001	2.453618e+000	4.075614e-001
2	4.462398e+002	2.112439e+001	3.[illegible]2051e+000	2.974375e-001
3	4.780094e+002	2.186343e+001	[illegible]73e+000	2.873833e-001
4	7.722640e+002	2.778964e+001	[illegible]858e+000	2.260981e-001
5	8.290507e+002	2.879324e+001	4.582587e+000	2.182174e-001
6	1.111551e+003	3.333993e+001	5.306214e+000	1.884583e-001

3

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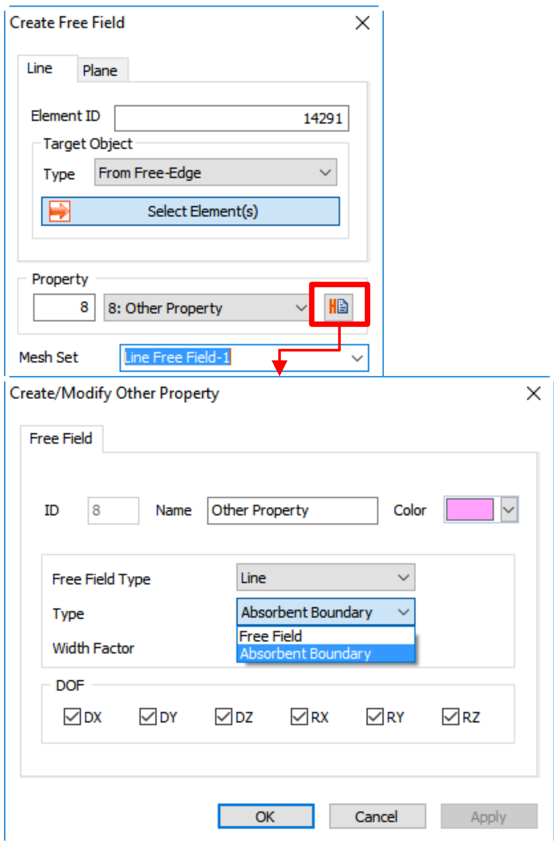
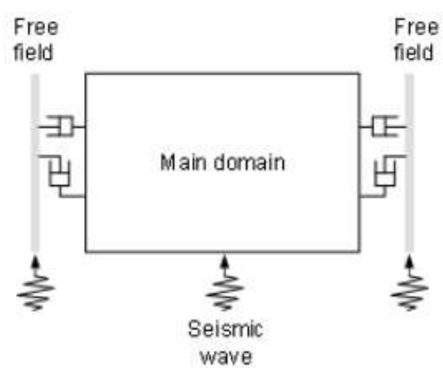
Free Field (Infinite boundary, Absorbent boundary)

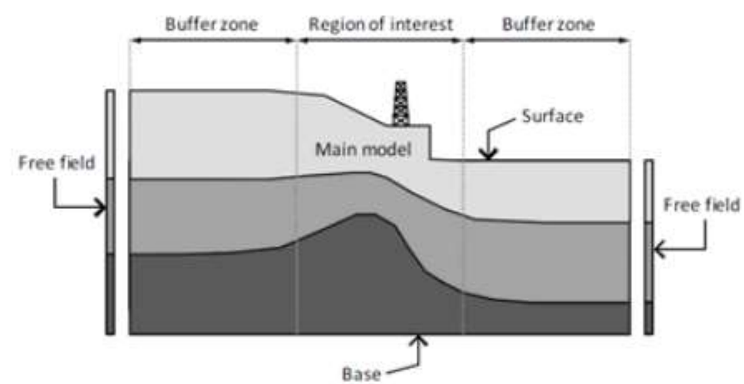


For the seismic analysis, users need to model infinite ground to eliminate the boundary effect caused by reflection wave. Since it is not possible to model infinite ground, users can apply Free Field Element at the boundary.

Absorbent Boundary : Enable to eliminate reflection wave at the ground boundary
Width Factor (Penalty Parameter) : In order to minimize the size effect of the model, users have to input more than 10^4, This value will be multiplied by model width (In case of 2D, this is plain strain thickness (unit width).



[Schematic Overview of Free Field Element]



[Free field effect (O), Absorb reflection (O)]

Step 11 Mesh > Element > Free Field

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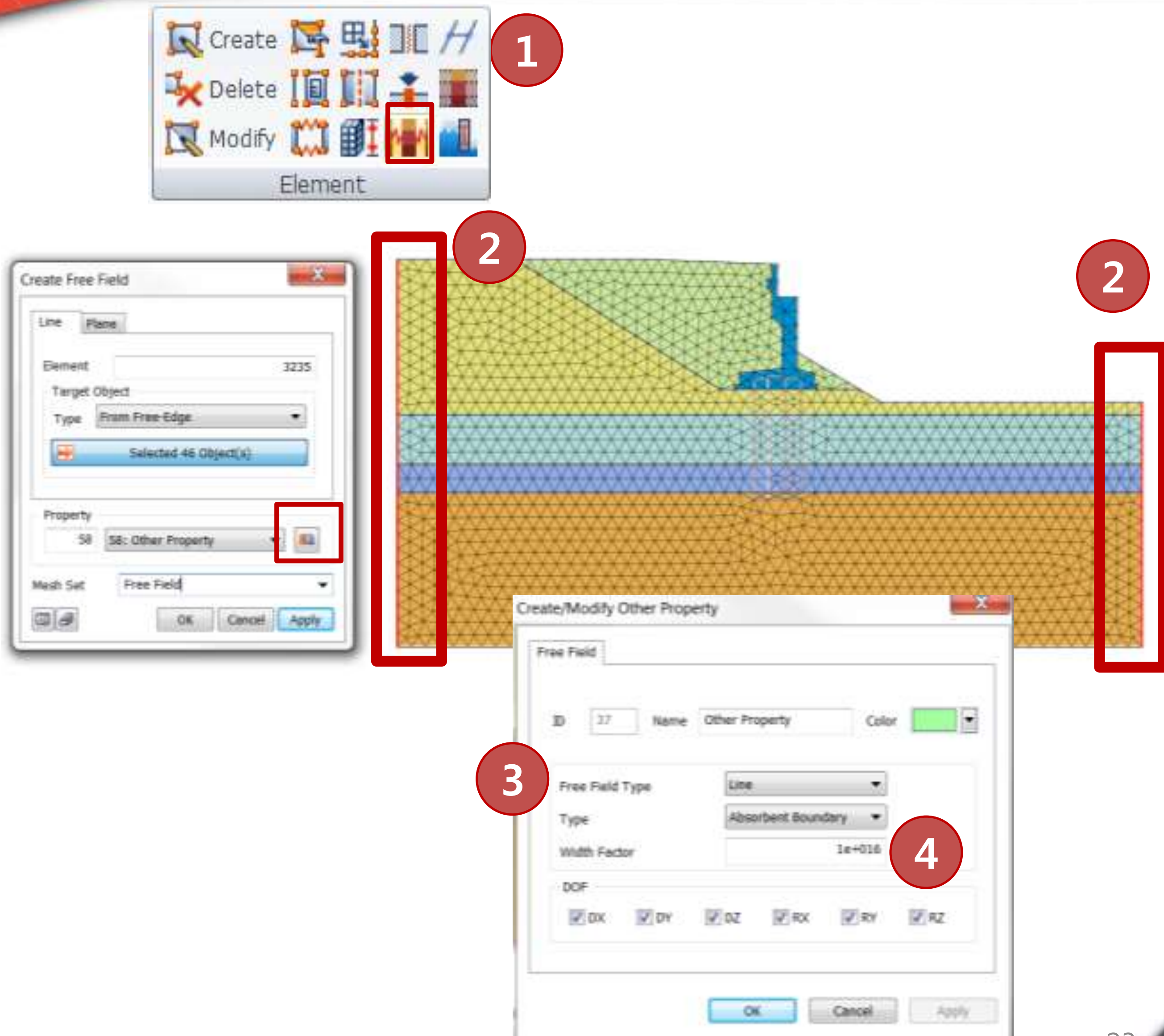
Procedure

1. Main Menu >Mesh > Element > Free Field >
2. Select the 2 side boundary nodes
3. Select Property as Absorbent
4. Width Factor 1+e16
5. Click [Apply].



Step 11 Boundary for Free Field

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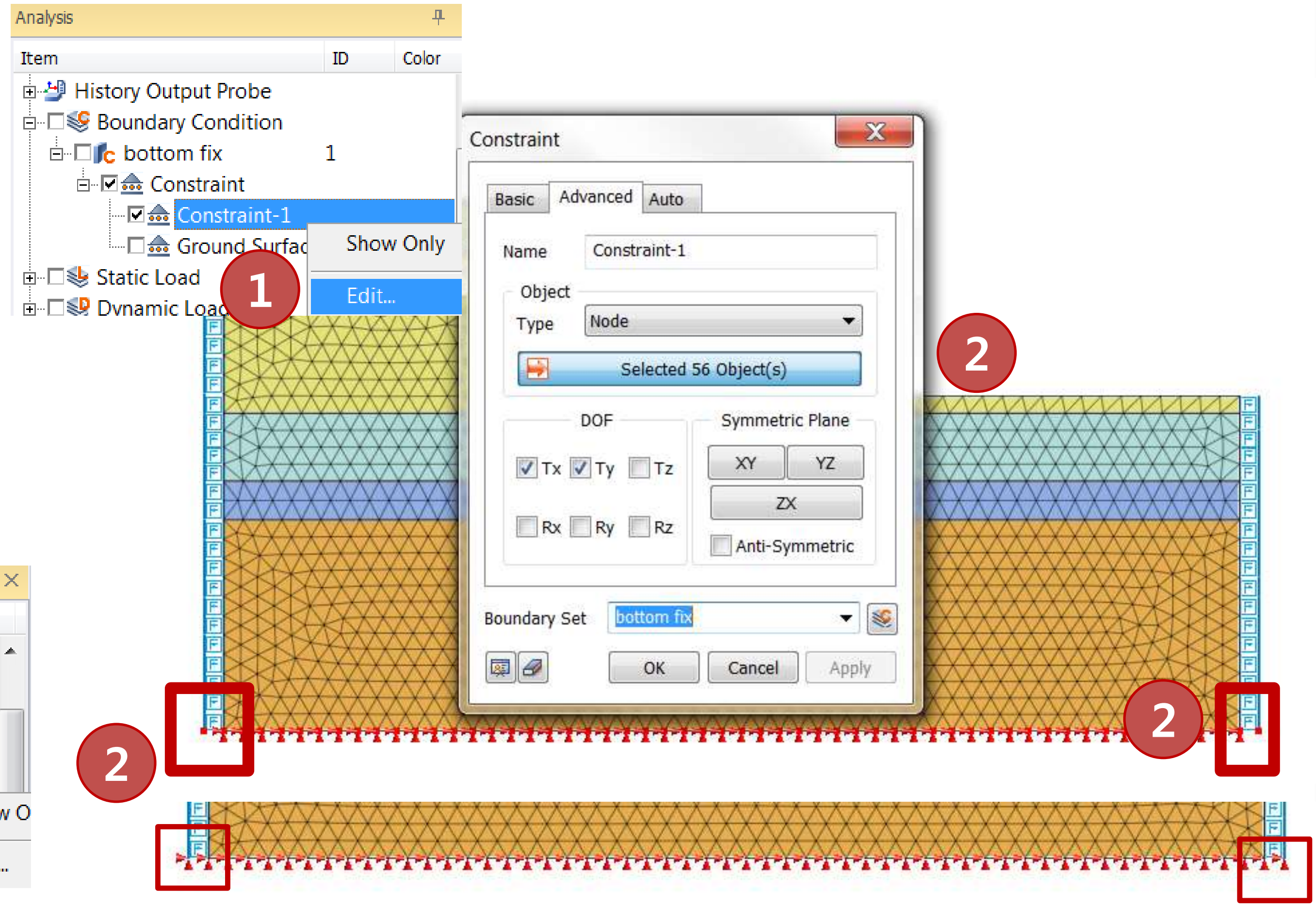
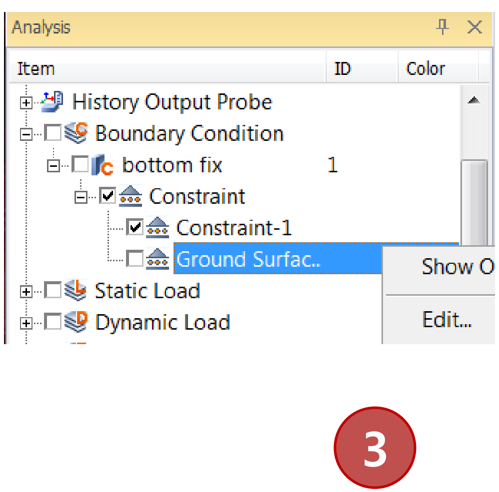
Procedure

1. Tree Menu > Analysis > Boundary Conditions >Bottom Fix > Constraint > Edit
2. Select the 2 Free Field Elements
3. Delete the Ground Surface Spring





Step 12 Dynamic Analysis > Ground Acceleration

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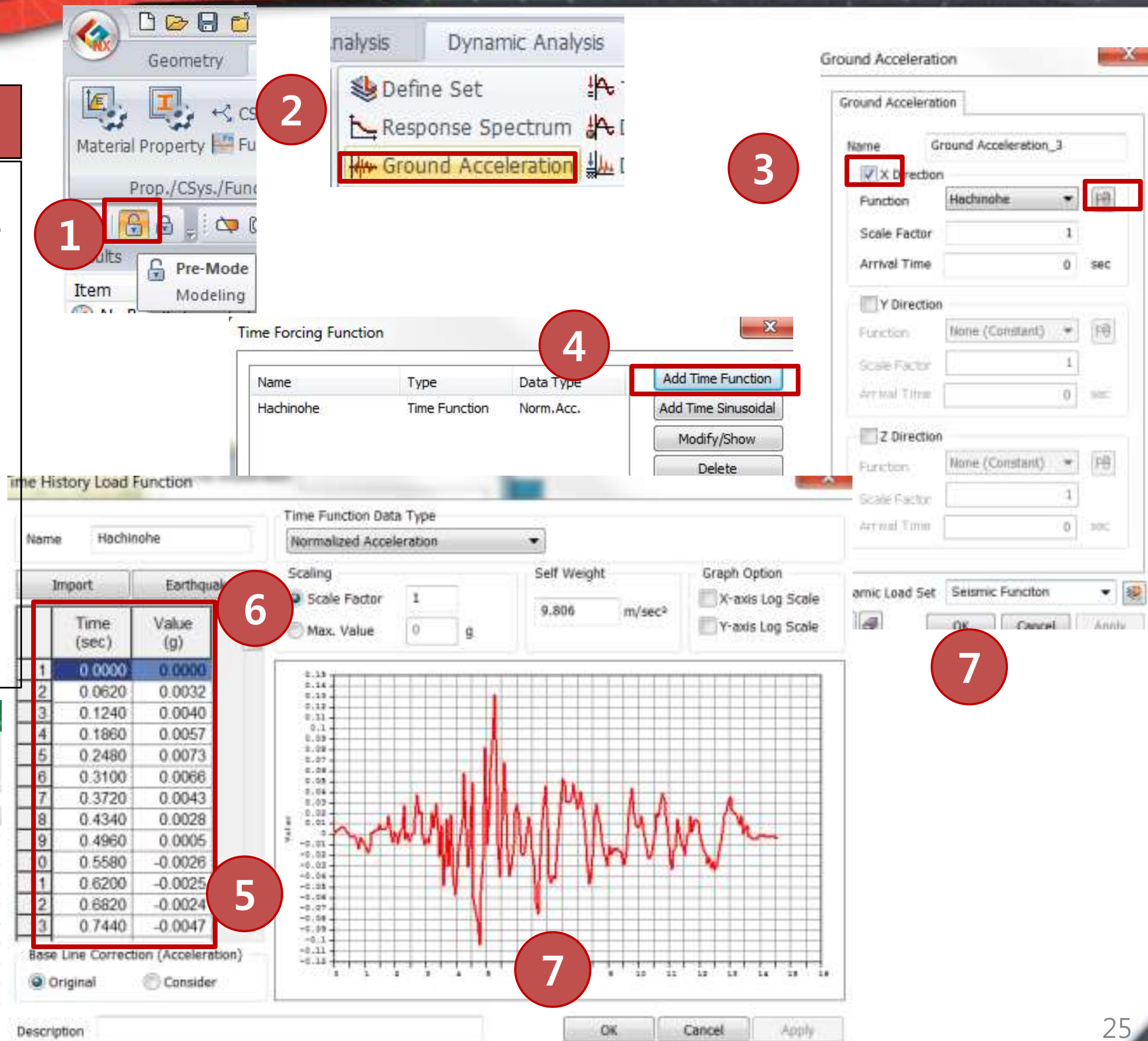
Procedure

1. Return to the Pre Mode
2. Main Menu > Dynamic Analysis> Load > Ground Acceleration
3. Activate X direction and click icon
4. Add Time Functions Copy Paste function from Excel
5. Type Hachinohe in Name
6. Click OK OK.



Step 13 Construction Stage

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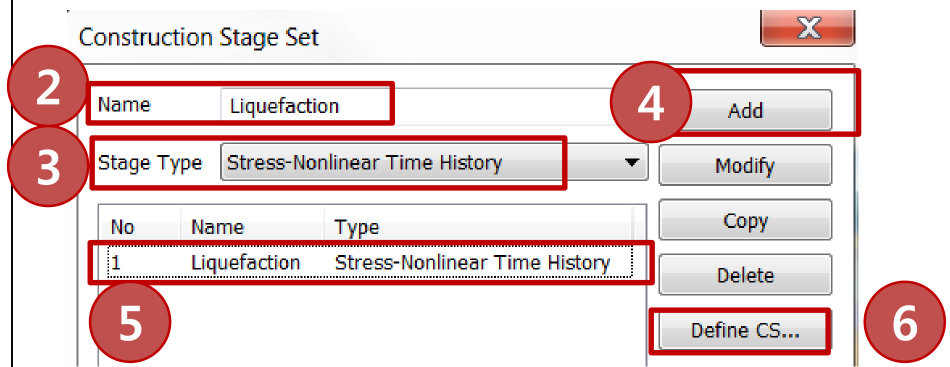
Procedure

1. **Main Menu > Static / Slope Analysis > Construction Stage > Stage Set**
2. **Name: Liquefaction**
3. **Stage Type > Stress – Nonlinear Time History**
4. **Click > Add**
5. **Select ''Liquefaction Set'' from Table**
6. **Click > Define CS**



Step 13 Construction Stage

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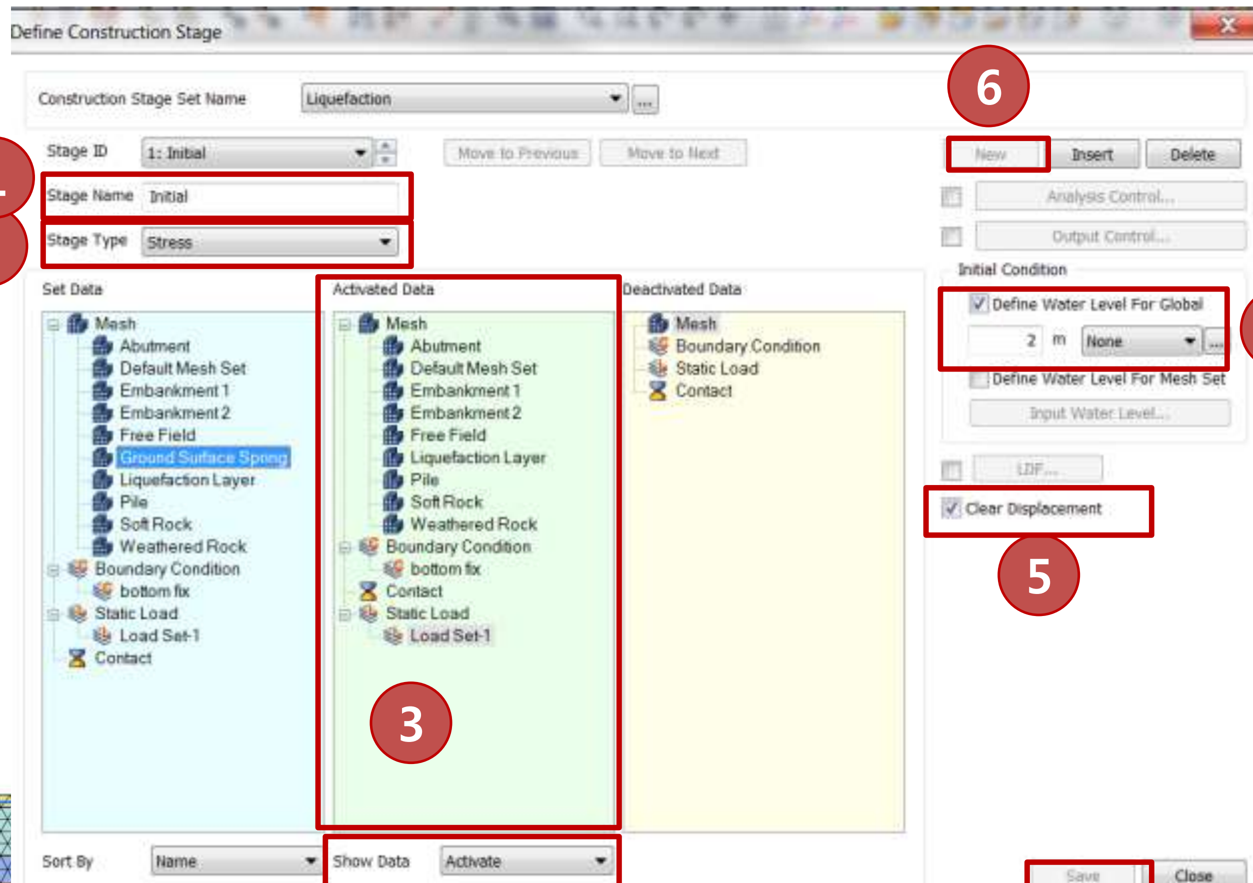
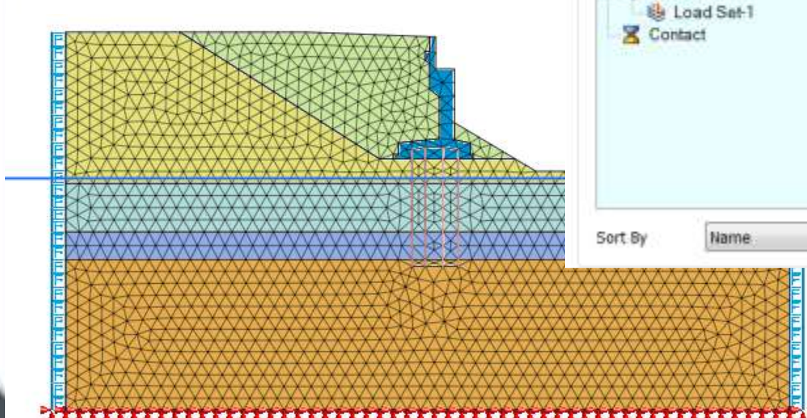
Procedure

1. Stage name: Initial
2. Stage Type: Stress
3. Drag and Drop all data sets except Ground Surface Springs from Set Data to Activated Data
4. Set Water Level to 2m
5. Clear Displacement
6. Save > New





Step 13 Construction Stage

GTS NX

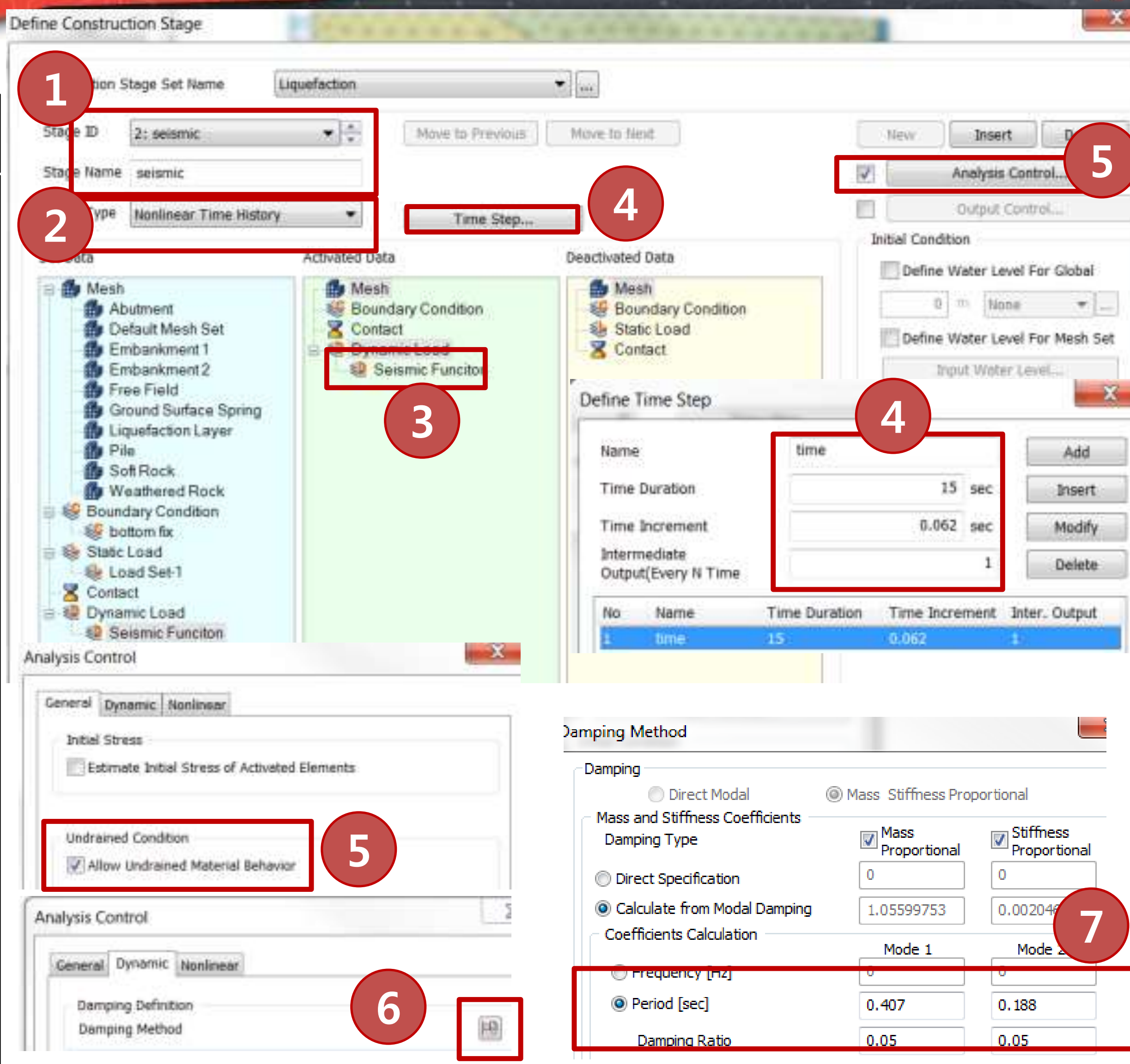
Procedure

1. Stage name: Time History
2. Stage Type: Time History
3. Drag and Drop Dynamic Load "Artificial" to Activated Data
4. Time Step > Define Time Step > Time Duration: 15s > Time Increment > 0.062 >Add
5. Analysis Control > General > Activate Undrained Behavior
6. Analysis Control > General > Dynamic > Damping Method
7. Select Calculate from Modal Damping, and Select Period [sec]

Enter the periods for 0.407s and 0.188s from previous eigenvalue analysis.

Enter 0.05 in Damping Ratio for both Mode 1 and 2

Click [OK] > [Save] > [OK]

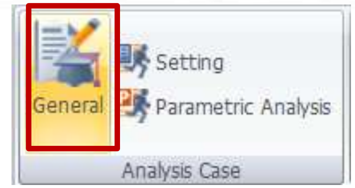


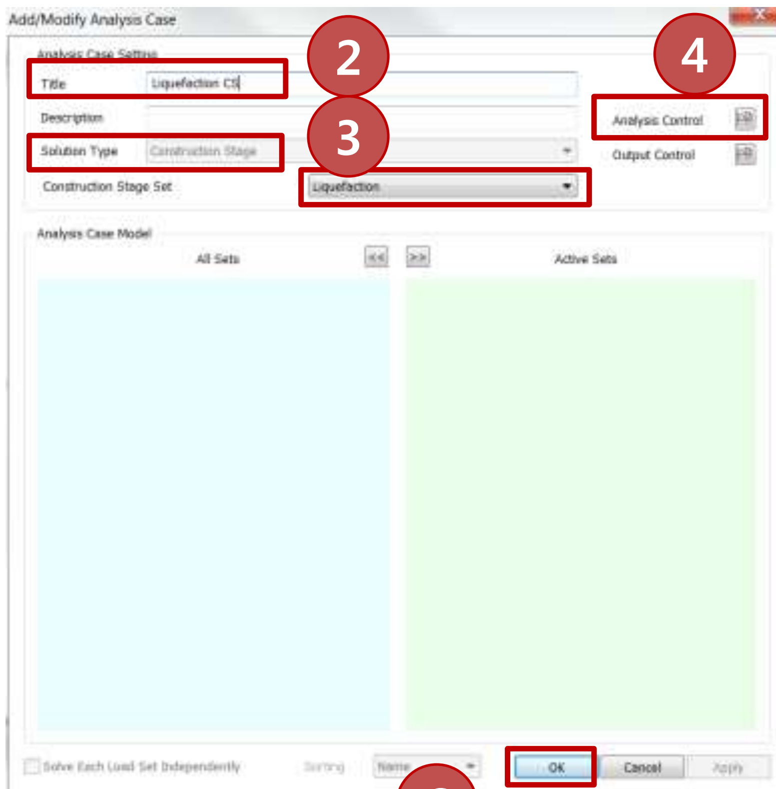
Step 14 Analysis Stage

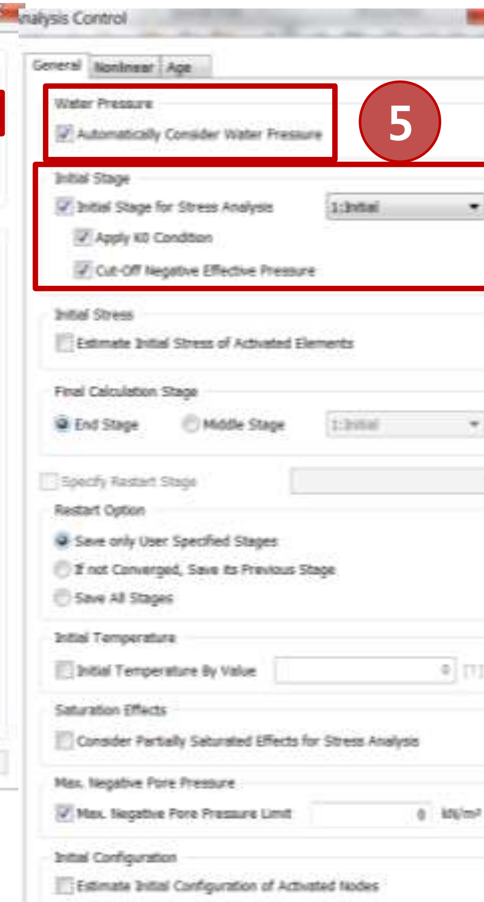
GTS NX

Procedure

1. Analysis > Case > General
2. Title: Liquefaction CS
3. Solution Type: Construction Stage > Liquefaction
4. Analysis Control >
5. General > Set as shown
6. Ok > Ok







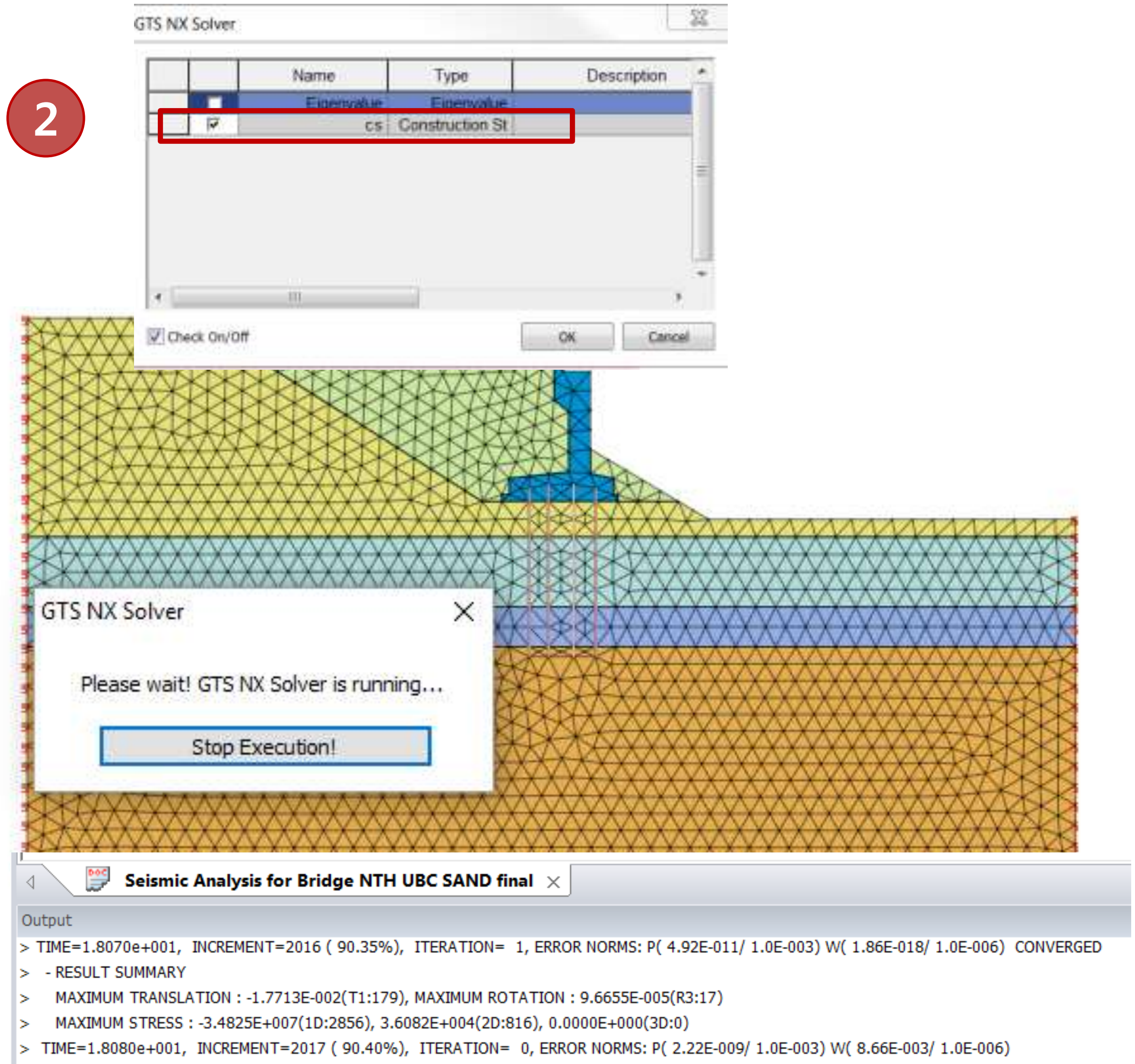
Step 15 Analysis > Perform

GTS NX

Procedure

1. **Main Menu > Analysis > Perform…**
2. **Check –on 'CS' only.**
3. **Click [OK].**

All the messages during the analysis will be shown in the Output Window. Especially, one needs to be very cautious about warning messages, because these messages indicate that the analysis results may not be correct. The model is automatically saved before the analysis. The result is saved as binary file(*.TA*) in the same folder as the model. The detail analysis information is also saved in a text file(*.OUT).

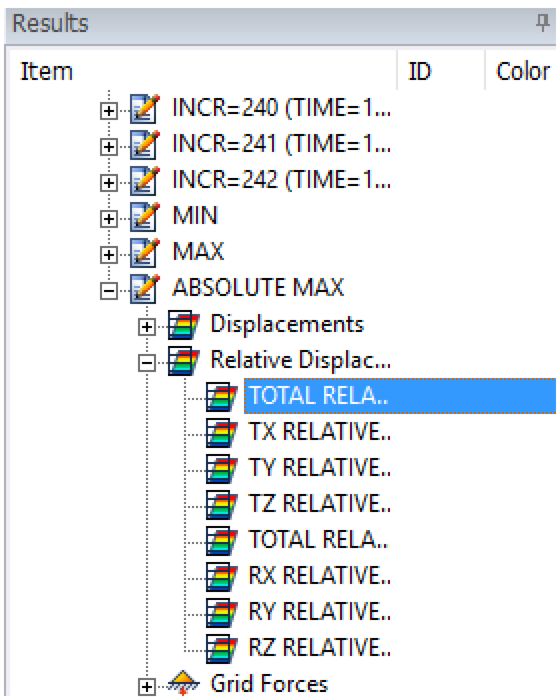


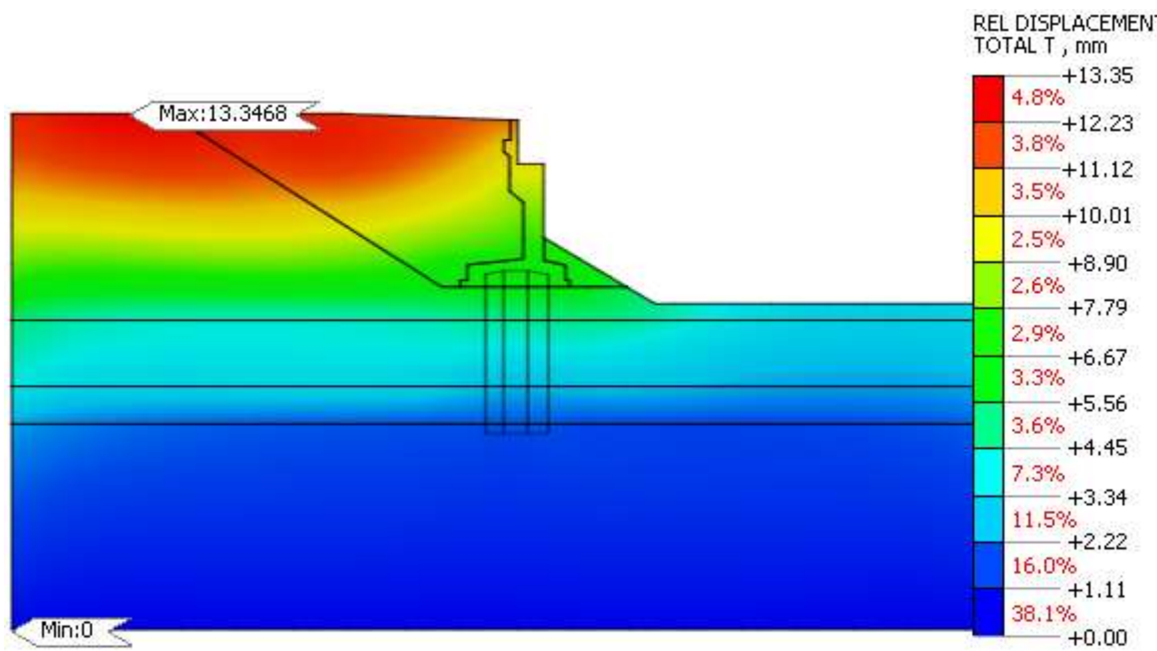
Step 16 Results > Displacements

GTS NX

Procedure

1. **Post Works Tree > Time History> Absolute Max > Relative Displacement > Total**



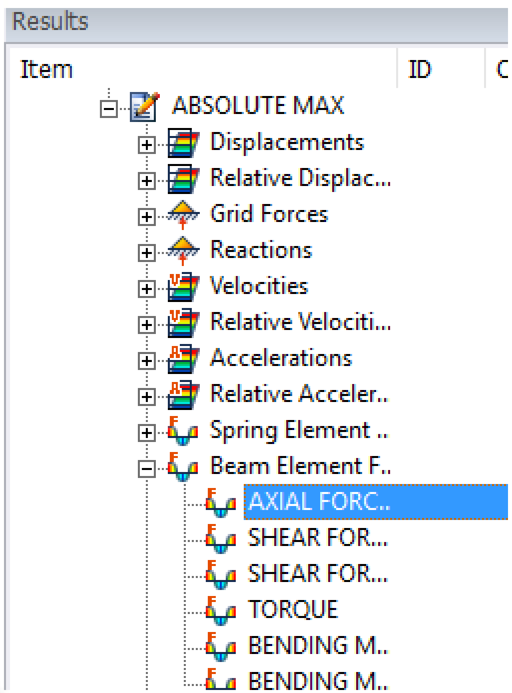


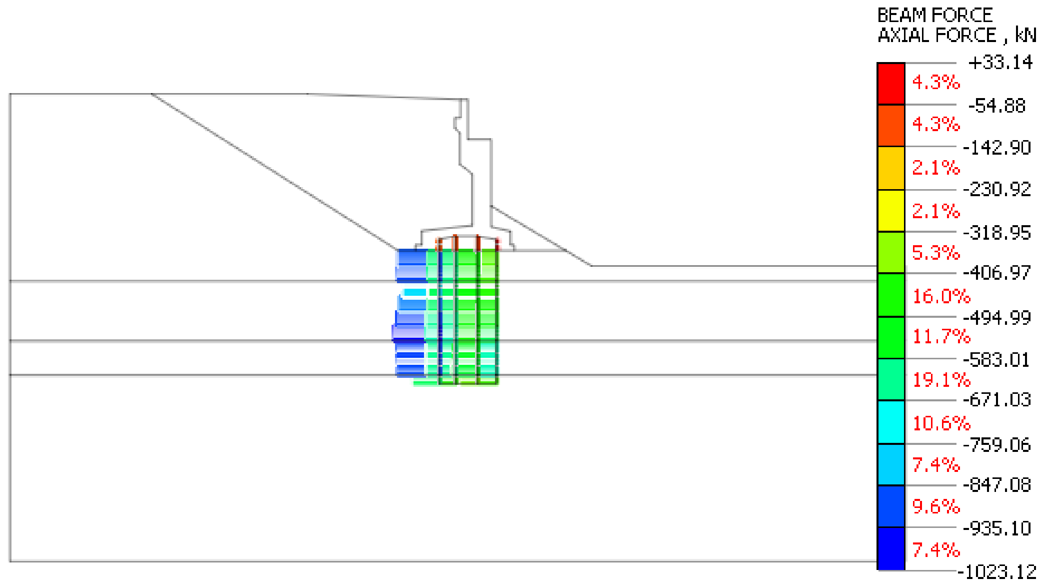
Step 16 Results > Beam Element Forces

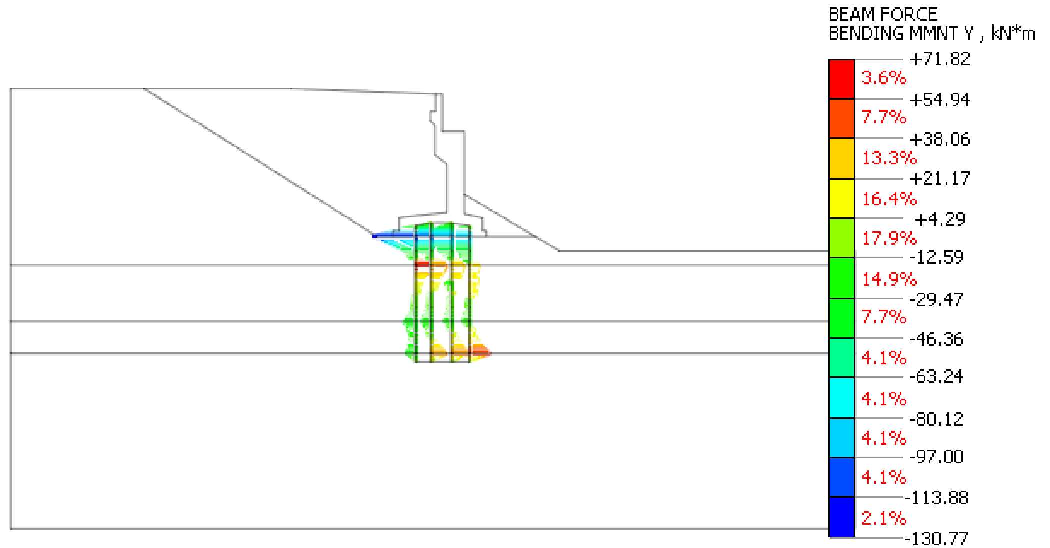
GTS NX

Procedure

1. **Post Works Tree > Time History > Absolute Max > Beam Force Element> Axial Force**





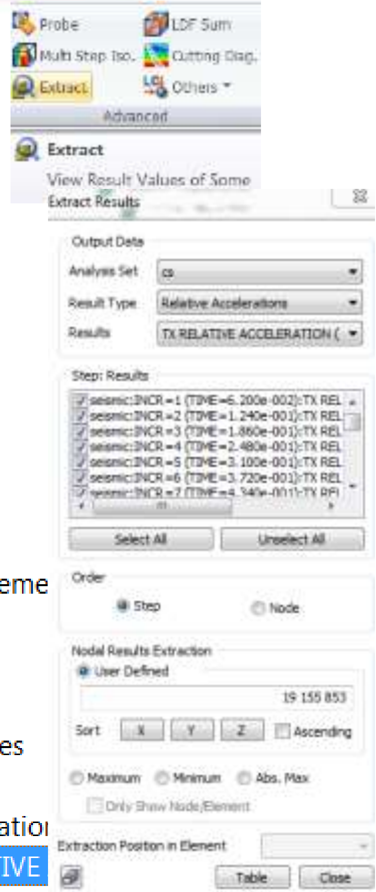


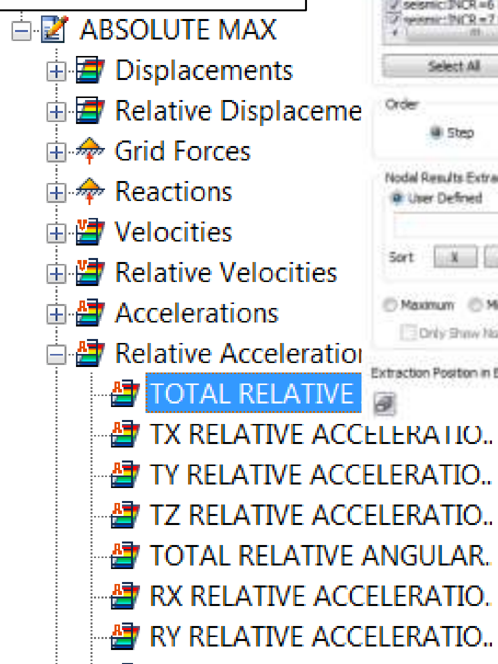
Step 16 Results > Accelerations

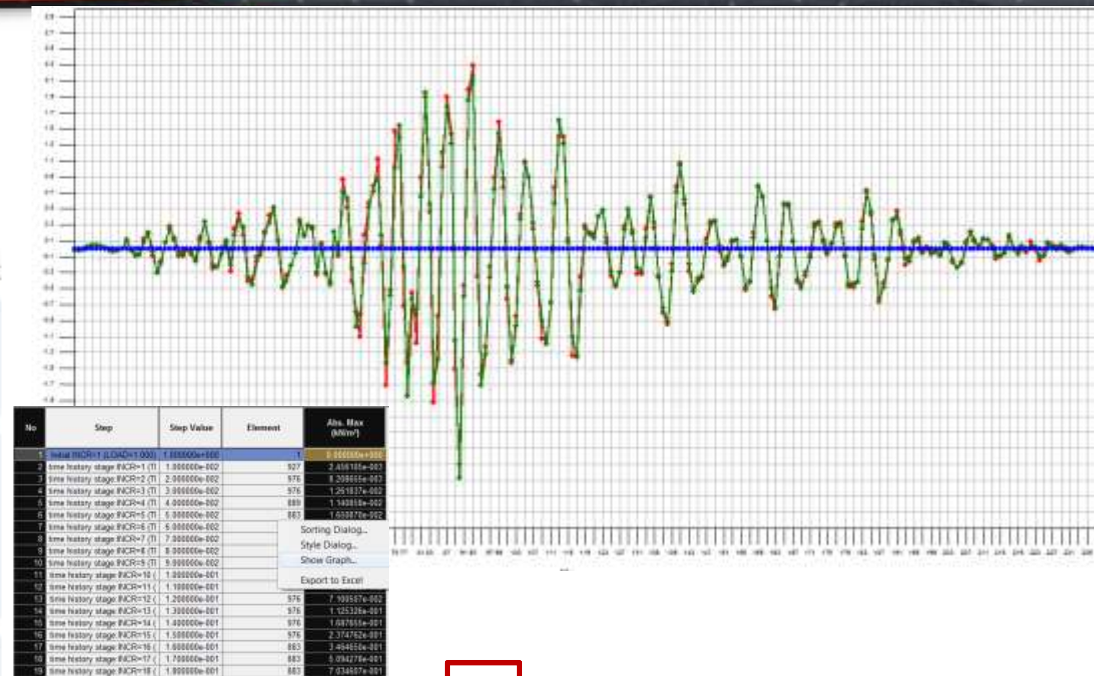
GTS NX

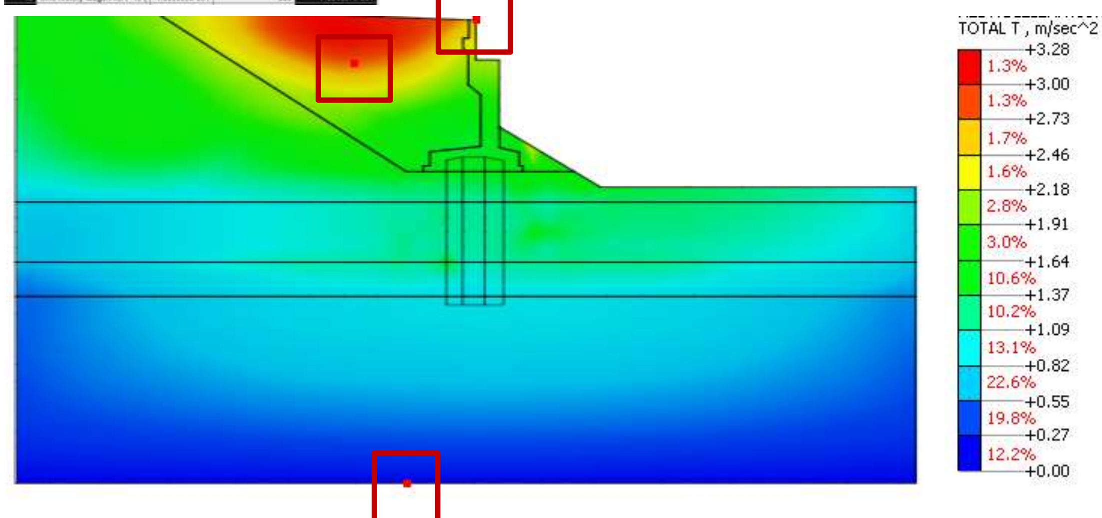
Procedure

Post Works Tree > Time History > Absolute Max > Relative Accelerations > Total
Results > Extract > Relative Acc TX > nodes 19, 129, 849 > Table > Graph







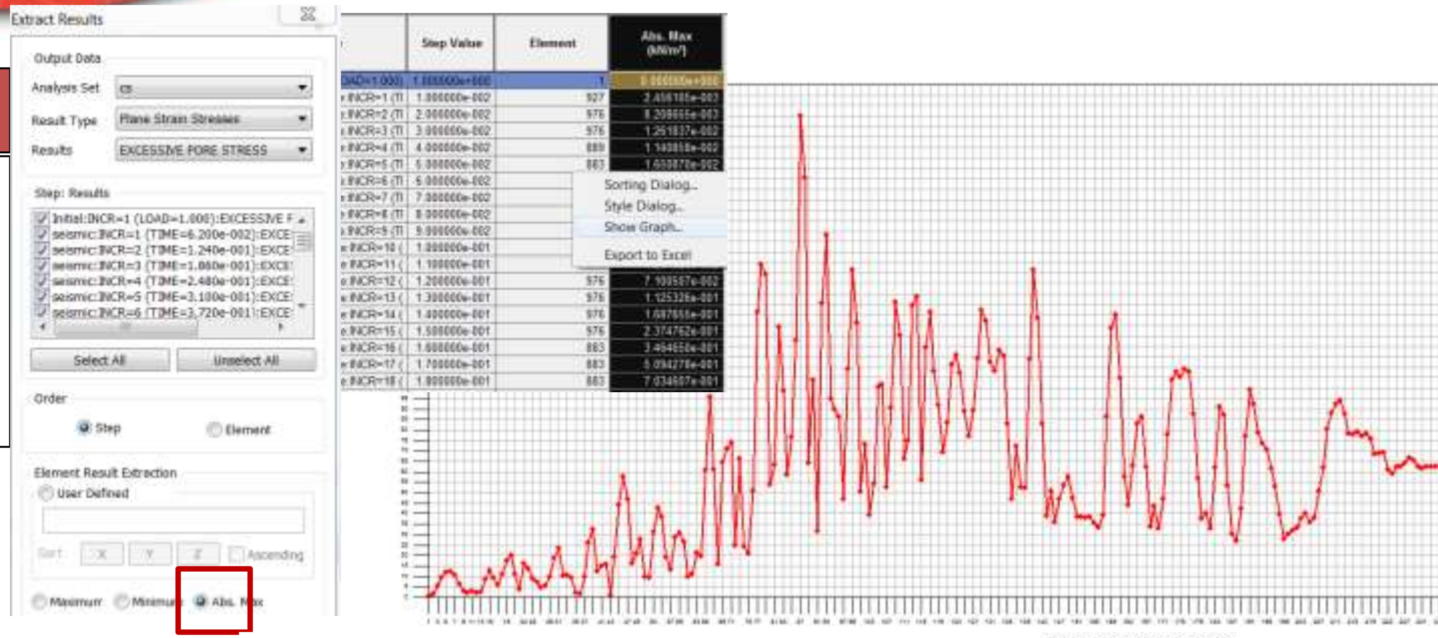


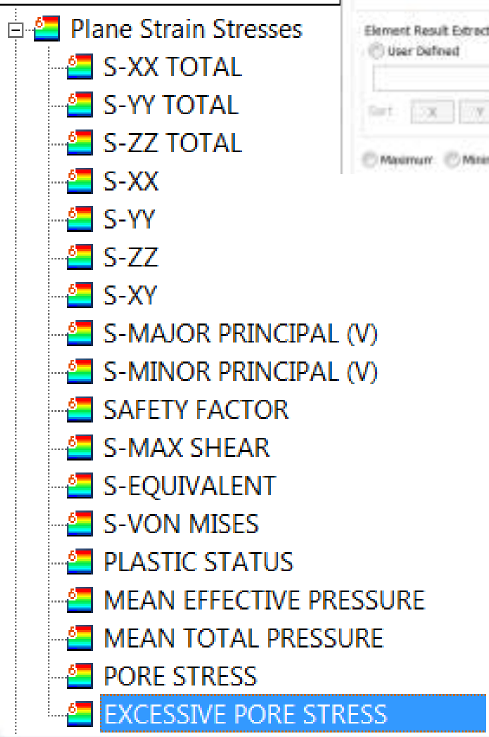
Step 16 Results > Excessive Pore Stress

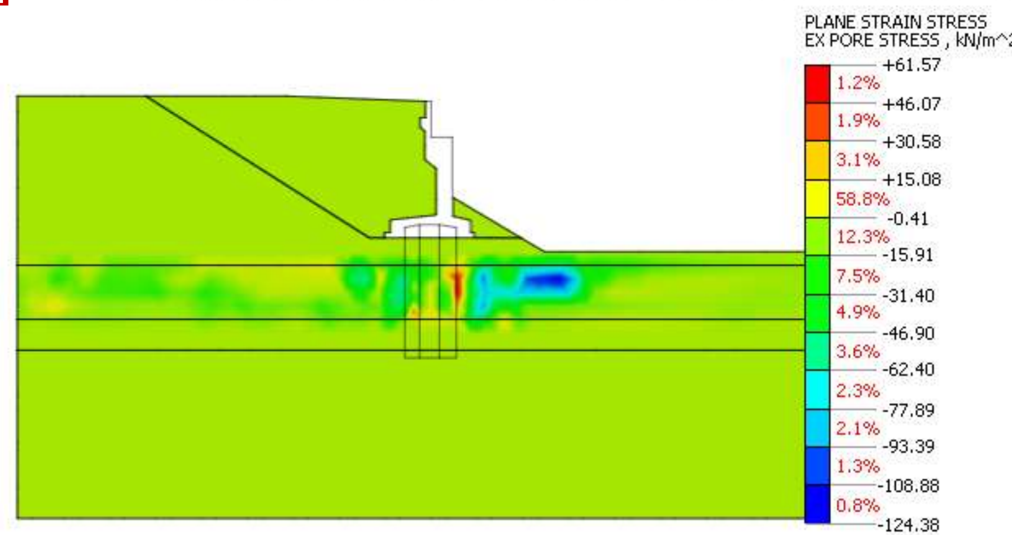
GTS NX

Procedure

Post Works Tree > Time History > Absolute Max > Plane Strain Stresses > Excessive Pore Stress Results > Extract > Excess Pore Stress > Abs Max > Table > Graph

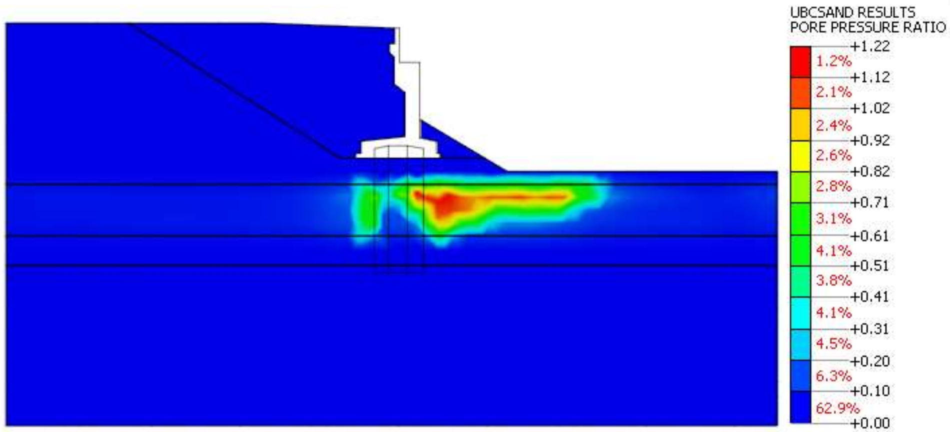






Step 16 Results > UBC Sand Results

GTS NX



- ***Pore Pressure Ratio (PPR)***
  - The ratio of excessive pore pressure change and the initial effective pressure

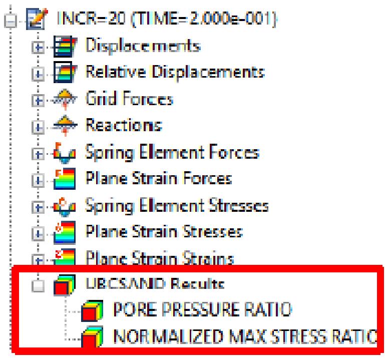
$$PPR = -\frac{\Delta p_w}{p'_{init}} = \frac{p'_{init} - p'_{current}}{p'_{init}}$$

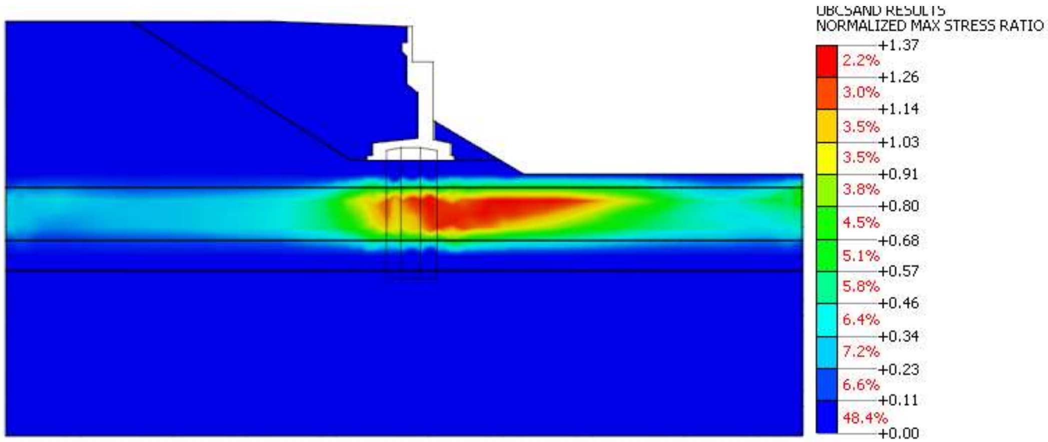
Δp_w	Excessive Pore Pressure Change
p'_{init}	Initial Effective Pressure
$p'_{current}$	Current Effective Pressure

- ***Normalized Max Stress Ratio***
  - The ratio of mobilized friction angle and the peak friction angle
  - When the Max stress ratio is reached, the mobilized friction angle is close to the peak friction angle, liquefaction is triggered (1 = Liquefaction)

$$\max\left(\frac{\sin\phi_m}{\sin\phi_p}\right)$$

ϕ_m	Mobilized Friction Angle
ϕ_p	Peak Friction Angle





End

Questions?

Global Help Desk
http://globalsupport.midasuser.com/helpdesk/