

Release Note

Release Date : December 2023

Product Ver. : FEA NX 2024 (v1.1)



ADVANCED NONLINEAR AND DETAIL ANALYSIS

New Paradigm in Advanced Structural Analysis

Enhancements

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2. Bowl Model Element Simulation
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1. Variable Deformation Fitting Function

- During ground motion analysis, a tool is installed to obtain the standard strain rate and maximum damping coefficient from the material models R-O and H-D by fitting the dynamic properties with experimental results or proposed equations.

▪ Dynamic Analysis > Tools > Material Evaluator > R-O/ H-D Model

RO-HD Material Evaluator
✕

Case Name

Name:

Description:

Input Table

<input type="checkbox"/> Name	Result
<input checked="" type="checkbox"/> RO-HD-1	O
<input type="checkbox"/> RO-HD-2	X

Input Table		Result Table	
γ	G/Gmax	γ	h
1e-006	1	1e-006	0.013
2e-006	1	2e-006	0.013
5e-006	1	5e-006	0.013
1e-005	1	1e-005	0.013
2e-005	0.978	2e-005	0.013
5e-005	0.924	5e-005	0.014
0.0001	0.871	0.0001	0.017
0.0002	0.775	0.0002	0.021
0.0005	0.585	0.0005	0.03
0.001	0.406	0.001	0.04
0.002	0.266	0.002	0.053
0.005	0.165	0.005	0.083
0.01	0.076	0.01	0.123
0.02	0.045	0.02	0.161
0.05	0.02	0.05	0.198

γ	h
1e-006	0.013
2e-006	0.013
5e-006	0.013
1e-005	0.013
2e-005	0.013
5e-005	0.014
0.0001	0.017
0.0002	0.021
0.0005	0.03
0.001	0.04
0.002	0.053
0.005	0.083
0.01	0.123
0.02	0.161
0.05	0.198

Input Data

RO-HD Type: Hardin-Drnevich Fitting Range: ~

γ (G/G0=0.5): Hmax Scale:

Result

Reference Strain:

Maximum Damping:

1. Variable Deformation Fitting Function

- During ground motion analysis, a tool is installed to obtain the standard strain rate, maximum damping coefficient, and parameters used during analysis in the material model GHES by fitting dynamic properties with experimental results or proposed equations.

Dynamic Analysis > Tools > Material Evaluator > GHE-S Model

GHE-S Material Evaluator

Case Name: Name: GHE-S-2, Description:

Input Table: Database..., Import..., Using Dynamic Strain Compatible Soil Equation, Export..., Reset

Name Result
 GHE-S-1 0

G/Gmax~ $\dot{\gamma}$ $h \sim \dot{\gamma}$

Input Table		Fitting Table	
$\dot{\gamma}$	G/Gmax	$\dot{\gamma}$	G/Gmax
1e-006	1	1e-006	0.99876
2e-006	1	1.2e-006	0.99852
5e-006	1	1.4e-006	0.99827
1e-005	1	1.6e-006	0.99802
2e-005	0.978	1.8e-006	0.99777
5e-005	0.924	2e-006	0.99752
0.0001	0.871	2.2e-006	0.99727
0.0002	0.775	2.4e-006	0.99702
0.0005	0.585	2.6e-006	0.99677
0.001	0.406	2.8e-006	0.99652
0.002	0.266	3e-006	0.99627
0.005	0.165	3.2e-006	0.99602
0.01	0.076	3.4e-006	0.99577
0.02	0.045	3.6e-006	0.99552
0.05	0.027	3.8e-006	0.99527

GHE-S Parameter

Type: G/Gmax~ $\dot{\gamma}$ Reference: 0.0005
 Error Norm for Fit: Absolute Error Tolerance: 1e-008

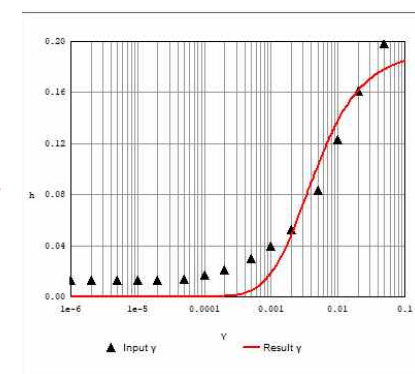
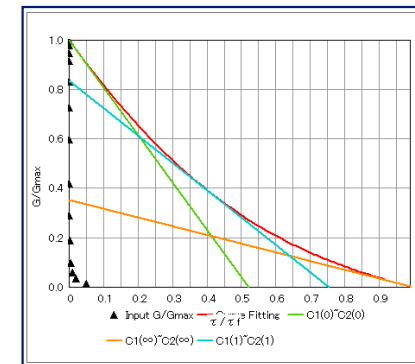
Result

C1(0)	1	C2(0)	1.6	alpha	0.522
C1(∞)	0.86	C2(∞)	1	beta	2.12e+058

Add Modify Delete Calculate Create Material Excel Export... Close

GHE-S Parameter

Type: Normalization
 Error Norm for Fit: Absolute Error



Result

Hmax: 0.19 beta1: 4.2

2. Bowl Model Element Simulation

- A tool for determining liquefaction parameters is installed. Liquefaction parameters can be set through single element analysis by fitting the relationship between liquefaction strength and loading recovery in repeated shear experiments.

Dynamic Analysis > Tools > Material Evaluator > Bowl Model

Density Sand

Bowl Model Parameter Setting

Case Name

Name:

Description:

<input type="checkbox"/>	Name	Result
<input checked="" type="checkbox"/>	Bowl-1	0

Bowl Model Parameter | Liquefaction Strength

Model

Bowl Model with RO

Analysis Parameters

Incremental Shear Strain:

Interrupted Shear Strain:

Initial Condition

Initial Mean Effective Stress: kN/m²

Initial Shear Stress: kN/m²

Initial Shear Strain:

Base Model Parameters

Ref. Mean Effective Stress: kN/m²

Goi: kN/m²

yoi:

hmax:

n1:

n2:

Stress Condition

Stress Ratio	
	0.3
	0.25
	0.2

+

Base Model Parameters

A:

B:

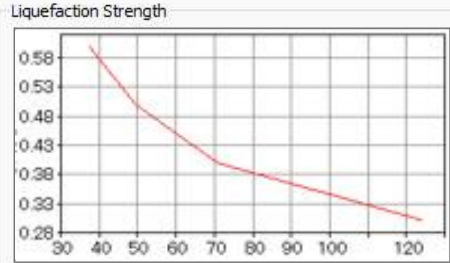
C:

D:

Cs/(1+e0):

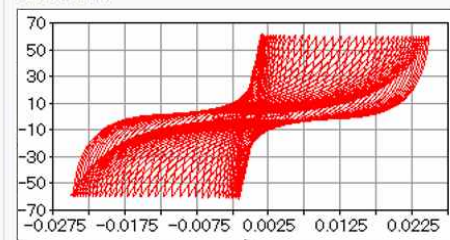
Cc/(1+e0):

Xl:

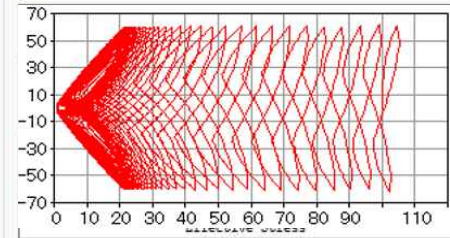


Liquefaction Strength

Stress Ratio: ▾



Stress-Strain



Effective Stress Path

Add
Modify
Delete
Calculate
Create Material
Excel Export...
Close

3. HD/ RO/ GHE-S Function (Confining Pressure)

- An input item has been added to allow input of the standard confining pressure. Under the standard confining pressure used in the 3-axis compression experiment
- You can directly enter shear stiffness and reference strain rate.

▪ Mesh > Material > Isotropic > Modified Ramberg-Osgood > Nonlinear

The screenshot shows the 'Material' dialog box with the 'Non-Linear' tab selected. The 'Reference Pressure (Pref)' field is highlighted with a red box. The values for the fields are as follows:

Field	Value	Unit
ID	6	
Name	Dc_d	
Color	[Green]	
Model Type	Modified Ramberg-Osgood	
Structure	<input type="checkbox"/>	
Initial Shear Modulus	124040393	kN/m ²
Reference Strain	0.000335	
Maximum Damping	0.23	
Reference Pressure (Pref)	9.80665	kN/m ²
Poisson's Ratio (For Dynamic)	0.488	
Consider Shear Stress Only	<input checked="" type="checkbox"/>	
Constraint pressure dependence		
n1	0.5	
n2	0.5	
Update Young's Modulus	<input type="checkbox"/>	

4. Initial Equilibrium Force and Initial Stress Table Functions

- Provides the ability to reflect Initial Force on various elements (Truss/Embedded Truss , Beam/Embedded Beam , Plane Strain/Plane Stress , Axisymmetric , Solid , Shell)
- These Initial Forces can be further used to obtained dynamic analysis results (Eigenvalue , Time History Analysis)

▪ **Static Analysis > Static Load > Initial Equilibrium Force**

Initial Equilibrium Force dialog box configuration:

- From Result: [From Result]
- Name: Initial Equilibrium Force
- Element Type: Plane Strain/Plane Stress
- Object Type: 2D Element
- Ref. CSys: CORD_ID=1
- Components:
 - Sxx: 0 kN/m², Base Function: None
 - Syy: 0 kN/m², Base Function: None
 - Szz: 0 kN/m², Base Function: None
 - Sxy: 0 kN/m², Base Function: None
- Self-Weight Consideration:
- Result Set: SoilPlus
- Analysis Set: SoilPlus
- Step: Linear Time History(Moda)
- Load Set: Load Set-1

Initial Equilibrium Force dialog box configuration (continued):

- From Result: [From Result]
- Type: [Type]
- Element Type: Plane Strain/Plane Stress
- Ref. CSys: CORD_ID=1
- Self-Weight Consideration:
- Result Set: [Result Set]
- Analysis Set: SoilPlus
- Step: Linear Time History(Moda)
- Tension(+), Compression(-)
- Load Set: Load Set-1

Transfer Initial Force

Element	Sxx (kN/m ²)	Syy (kN/m ²)	Szz (kN/m ²)	Sxy (kN/m ²)	Self-Weight Consideration	Load Set	Ref. CSys	Base Func. Sxx	Base Func. Syy	Base Func. Szz	Base Func. Sxy
1	-2.723e+00	-5.359e+00	-2.723e+00	0.000e+00	No	初期力	全体直交	None	None	None	None
2	-2.514e+00	-5.866e+00	-2.514e+00	0.000e+00	No	初期力	全体直交	None	None	None	None
3	-2.314e+00	-5.398e+00	-2.314e+00	0.000e+00	No	初期力	全体直交	None	None	None	None
4	-2.113e+00	-4.931e+00	-2.113e+00	0.000e+00	No	初期力	全体直交	None	None	None	None
5	-1.920e+00	-4.481e+00	-1.920e+00	0.000e+00	No	初期力	全体直交	None	None	None	None
6	-1.742e+00	-4.066e+00	-1.742e+00	0.000e+00	No	初期力	全体直交	None	None	None	None
7	-1.580e+00	-3.686e+00	-1.580e+00	1.304e-012	No	初期力	全体直交	None	None	None	None
8	-1.434e+00	-3.345e+00	-1.434e+00	1.117e-012	No	初期力	全体直交	None	None	None	None
9	-1.301e+00	-3.036e+00	-1.301e+00	0.000e+00	No	初期力	全体直交	None	None	None	None
10	-1.181e+00	-2.757e+00	-1.181e+00	0.000e+00	No	初期力	全体直交	None	None	None	None
11	-1.090e+00	-2.543e+00	-1.090e+00	0.000e+00	No	初期力	全体直交	None	None	None	None
12	-1.018e+00	-2.375e+00	-1.018e+00	0.000e+00	No	初期力	全体直交	None	None	None	None
13	-9.476e+00	-2.211e+00	-9.476e+00	0.000e+00	No	初期力	全体直交	None	None	None	None
14	-8.793e+00	-2.052e+00	-8.793e+00	0.000e+00	No	初期力	全体直交	None	None	None	None
15	-8.163e+00	-1.905e+00	-8.163e+00	0.000e+00	No	初期力	全体直交	None	None	None	None

4. Initial Equilibrium Force and Initial Stress Table Functions

■ Static Analysis > Static Load > Initial Equilibrium Force

初期応力

Truss/Embedded Truss Beam/Embedded Beam Plane Strain/Plane Stress Axisymmetric Solid Shell

Element	Fx_i (tonf)	Fy_i (tonf)	Fz_i (tonf)	Mx_i (tonfm)	My_i (tonfm)	Mz_i (tonfm)	Fx_j (tonf)	Fy_j (tonf)	Fz_j (tonf)	Mx_j (tonfm)	My_j (tonfm)	Mz_j (tonfm)	自重考慮
2001	-2.291e+001	-3.861e+001	0.000e+000	0.000e+000	0.000e+000	-3.976e+001	-2.291e+001	-3.383e+001	0.000e+000	0.000e+000	0.000e+000	-2.346e+001	No
2002	-2.291e+001	-3.383e+001	0.000e+000	0.000e+000	0.000e+000	-2.346e+001	-2.291e+001	-2.957e+001	0.000e+000	0.000e+000	0.000e+000	-1.078e+001	No
2003	-2.291e+001	-2.957e+001	0.000e+000	0.000e+000	0.000e+000	-1.078e+001	-2.291e+001	-2.159e+001	0.000e+000	0.000e+000	0.000e+000	8.400e+000	No
2004	-2.291e+001	-2.159e+001	0.000e+000	0.000e+000	0.000e+000	8.400e+000	-2.291e+001	-1.361e+001	0.000e+000	0.000e+000	0.000e+000	2.161e+001	No
2005	-2.291e+001	-1.361e+001	0.000e+000	0.000e+000	0.000e+000	2.161e+001	-2.291e+001	-5.630e+000	0.000e+000	0.000e+000	0.000e+000	2.862e+001	No
2006	-2.291e+001	-5.630e+000	0.000e+000	0.000e+000	0.000e+000	2.862e+001	-2.291e+001	7.500e-001	0.000e+000	0.000e+000	0.000e+000	3.028e+001	No
2007	-2.291e+001	7.500e-001	0.000e+000	0.000e+000	0.000e+000	3.028e+001	-2.291e+001	7.670e+000	0.000e+000	0.000e+000	0.000e+000	2.755e+001	No
2008	-2.291e+001	7.670e+000	0.000e+000	0.000e+000	0.000e+000	2.755e+001	-2.291e+001	1.405e+001	0.000e+000	0.000e+000	0.000e+000	2.103e+001	No
2009	-2.291e+001	1.405e+001	0.000e+000	0.000e+000	0.000e+000	2.103e+001	-2.291e+001	2.203e+001	0.000e+000	0.000e+000	0.000e+000	7.500e+000	No
2010	-2.291e+001	2.203e+001	0.000e+000	0.000e+000	0.000e+000	7.500e+000	-2.291e+001	3.001e+001	0.000e+000	0.000e+000	0.000e+000	-1.202e+001	No
2011	-2.291e+001	3.001e+001	0.000e+000	0.000e+000	0.000e+000	-1.202e+001	-2.291e+001	3.746e+001	0.000e+000	0.000e+000	0.000e+000	-3.564e+001	No
2012	-2.291e+001	3.746e+001	0.000e+000	0.000e+000	0.000e+000	-3.564e+001	-2.291e+001	4.597e+001	0.000e+000	0.000e+000	0.000e+000	-4.875e+001	No
2013	-2.291e+001	4.597e+001	0.000e+000	0.000e+000	0.000e+000	-4.875e+001	-2.291e+001	4.810e+001	0.000e+000	0.000e+000	0.000e+000	-6.842e+001	No
2014	-2.291e+001	4.810e+001	0.000e+000	0.000e+000	0.000e+000	-6.842e+001	-2.291e+001	-4.597e+001	0.000e+000	0.000e+000	0.000e+000	-4.875e+001	No
2015	-2.291e+001	-4.597e+001	0.000e+000	0.000e+000	0.000e+000	-4.875e+001	-2.291e+001	-3.746e+001	0.000e+000	0.000e+000	0.000e+000	-3.564e+001	No
2016	-2.291e+001	-3.746e+001	0.000e+000	0.000e+000	0.000e+000	-3.564e+001	-2.291e+001	-3.001e+001	0.000e+000	0.000e+000	0.000e+000	-1.202e+001	No
2017	-2.291e+001	-3.001e+001	0.000e+000	0.000e+000	0.000e+000	-1.202e+001	-2.291e+001	-2.203e+001	0.000e+000	0.000e+000	0.000e+000	7.500e+000	No
2018	-2.291e+001	-2.203e+001	0.000e+000	0.000e+000	0.000e+000	7.500e+000	-2.291e+001	-1.405e+001	0.000e+000	0.000e+000	0.000e+000	2.103e+001	No
2019	-2.291e+001	-1.405e+001	0.000e+000	0.000e+000	0.000e+000	2.103e+001	-2.291e+001	-1.670e+001	0.000e+000	0.000e+000	0.000e+000	2.755e+001	No

OK 閉じる 適用

Initial Equilibrium Force of Beam Element

Initial Equilibrium Force

Truss/Embedded Truss Beam/Embedded Beam Plane Strain/Plane Stress Axisymmetric Solid Shell

Element	Sxx (kN/m ²)	Syy (kN/m ²)	Szz (kN/m ²)	Sxy (kN/m ²)	Self-Weight Consideration	Load Set	Ref. CSys	Base Func. Sxx	Base Func. Syy	Base Func. Szz	Base Func. Sxy
1	-2.723e+00	-6.353e+00	-2.723e+00	0.000e+000	No	初期力	全体直交	None	None	None	None
2	-2.514e+00	-5.866e+00	-2.514e+00	0.000e+000	No	初期力	全体直交	None	None	None	None
3	-2.314e+00	-5.398e+00	-2.314e+00	0.000e+000	No	初期力	全体直交	None	None	None	None
4	-2.113e+00	-4.931e+00	-2.113e+00	0.000e+000	No	初期力	全体直交	None	None	None	None
5	-1.920e+00	-4.481e+00	-1.920e+00	0.000e+000	No	初期力	全体直交	None	None	None	None
6	-1.742e+00	-4.066e+00	-1.742e+00	0.000e+000	No	初期力	全体直交	None	None	None	None
7	-1.580e+00	-3.686e+00	-1.580e+00	1.304e-012	No	初期力	全体直交	None	None	None	None
8	-1.434e+00	-3.345e+00	-1.434e+00	1.117e-012	No	初期力	全体直交	None	None	None	None
9	-1.301e+00	-3.036e+00	-1.301e+00	0.000e+000	No	初期力	全体直交	None	None	None	None
10	-1.181e+00	-2.757e+00	-1.181e+00	0.000e+000	No	初期力	全体直交	None	None	None	None
11	-1.090e+00	-2.543e+00	-1.090e+00	0.000e+000	No	初期力	全体直交	None	None	None	None
12	-1.018e+00	-2.375e+00	-1.018e+00	0.000e+000	No	初期力	全体直交	None	None	None	None
13	-9.476e+00	-2.211e+00	-9.476e+00	0.000e+000	No	初期力	全体直交	None	None	None	None
14	-8.793e+00	-2.052e+00	-8.793e+00	0.000e+000	No	初期力	全体直交	None	None	None	None
15	-8.163e+00	-1.905e+00	-8.163e+00	0.000e+000	No	初期力	全体直交	None	None	None	None

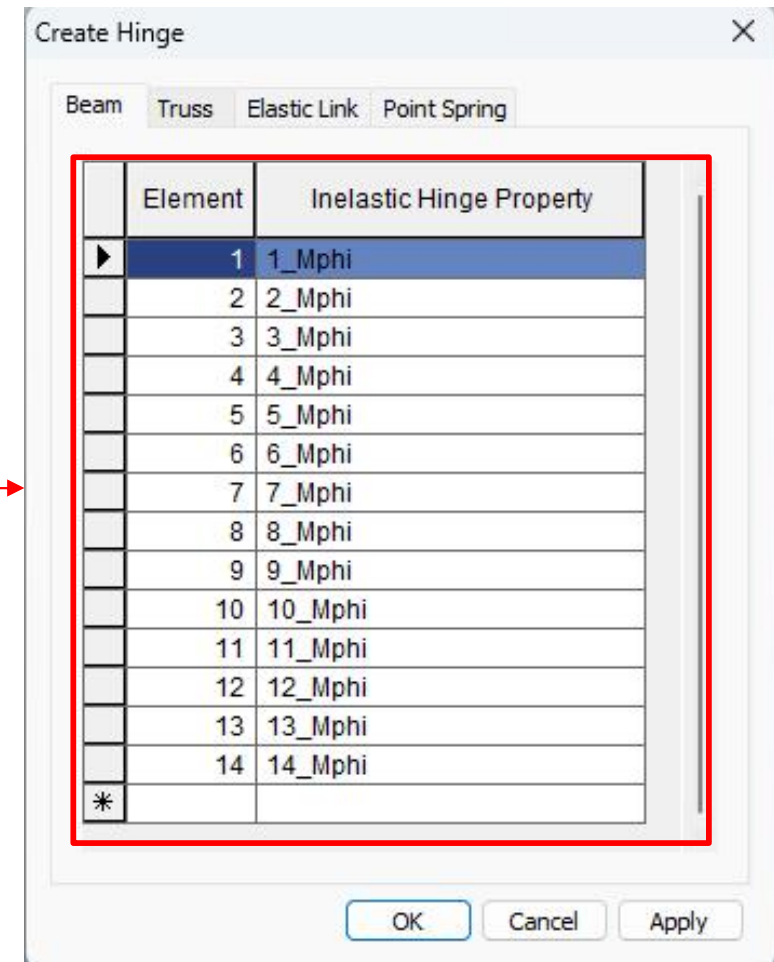
OK Cancel Apply

Initial Stress of Plane Strain/ Plane Stress Element

5. Hinge (M- Φ Data) Assign Table

- Provide a convenient function to define Hinge property as a Table.

- **Mesh > Element > Hinge Table**



6. Hinge (M-Φ Data) Import

- Provide a convenient function to export or import Hinge Property data in CSV file format.

▪ Mesh > Prop./ Csys./ Func. > Hinge > CSV Import

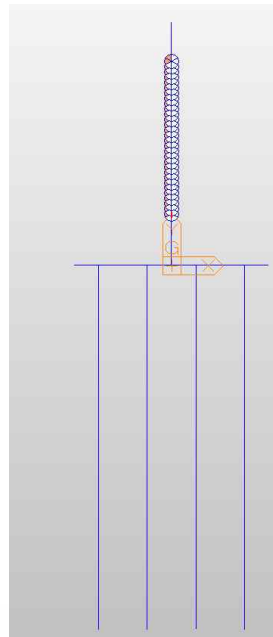
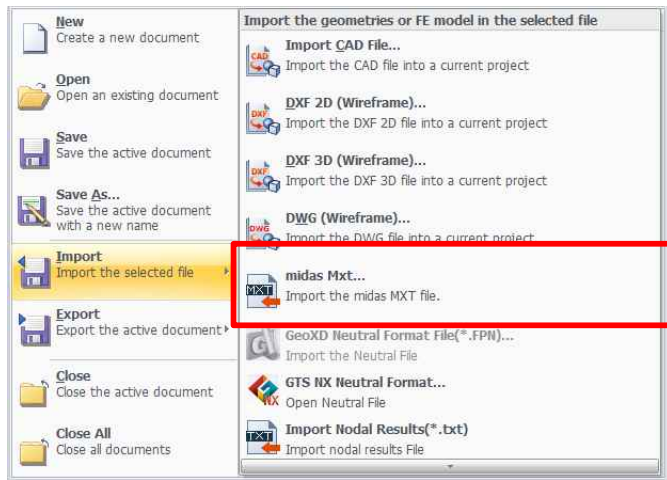
The screenshot displays the 'Add/Modify Property' dialog box in the foreground, which is used for managing hinge properties. The dialog lists 14 properties, all of type 'Beam'. The 'CSV Import' and 'CSV Export' options are highlighted with a red box. A red arrow points from the 'Import...' button in the dialog to the Microsoft Excel window in the background. The Excel window shows a spreadsheet with columns labeled F through S, containing numerical data in scientific notation, representing the imported hinge property data.

No	Name	Type
1	1_Mphi	Beam
2	2_Mphi	Beam
3	3_Mphi	Beam
4	4_Mphi	Beam
5	5_Mphi	Beam
6	6_Mphi	Beam
7	7_Mphi	Beam
8	8_Mphi	Beam
9	9_Mphi	Beam
10	10_Mphi	Beam
11	11_Mphi	Beam
12	12_Mphi	Beam
13	13_Mphi	Beam
14	14_Mphi	Beam

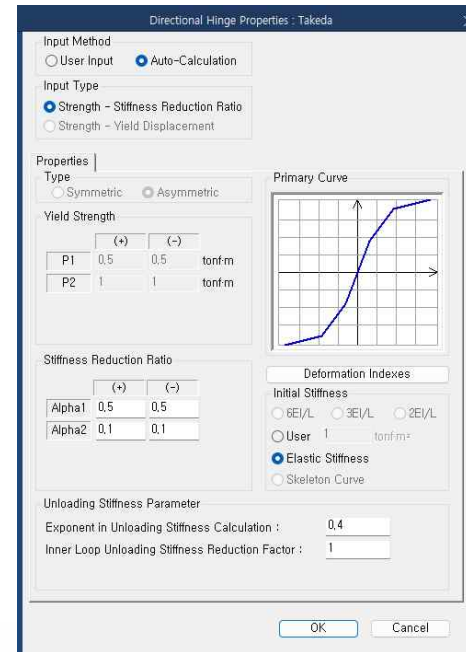
6. Hinge (M-Φ Data) Import

- Provide a convenient function to Import midas Civil mxt file format(Automatically calculated Hinge Property)

▪ File > Import > midas Mxt...

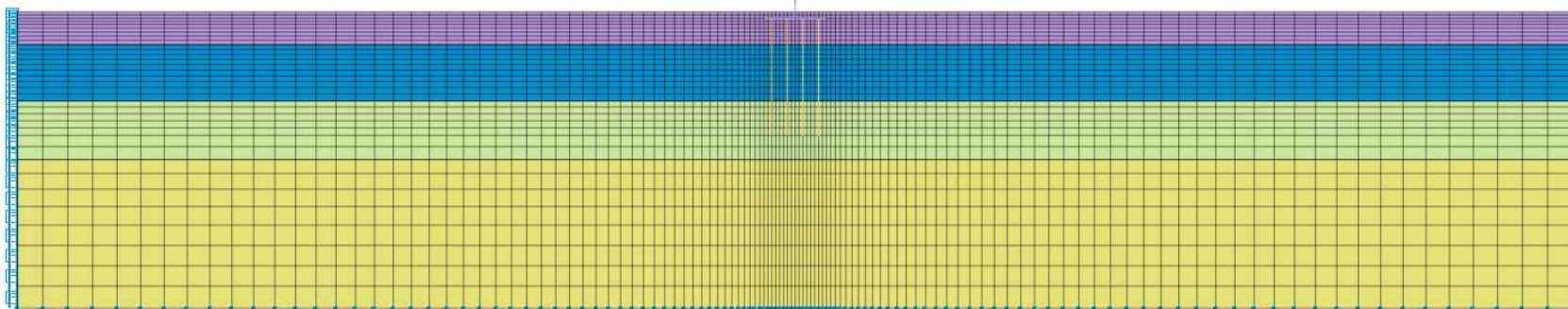
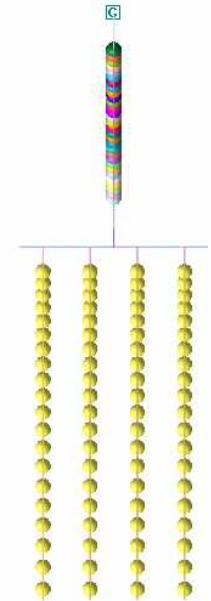


Midas civil



M-φ Hinge (Auto Calculation)

*.mxt

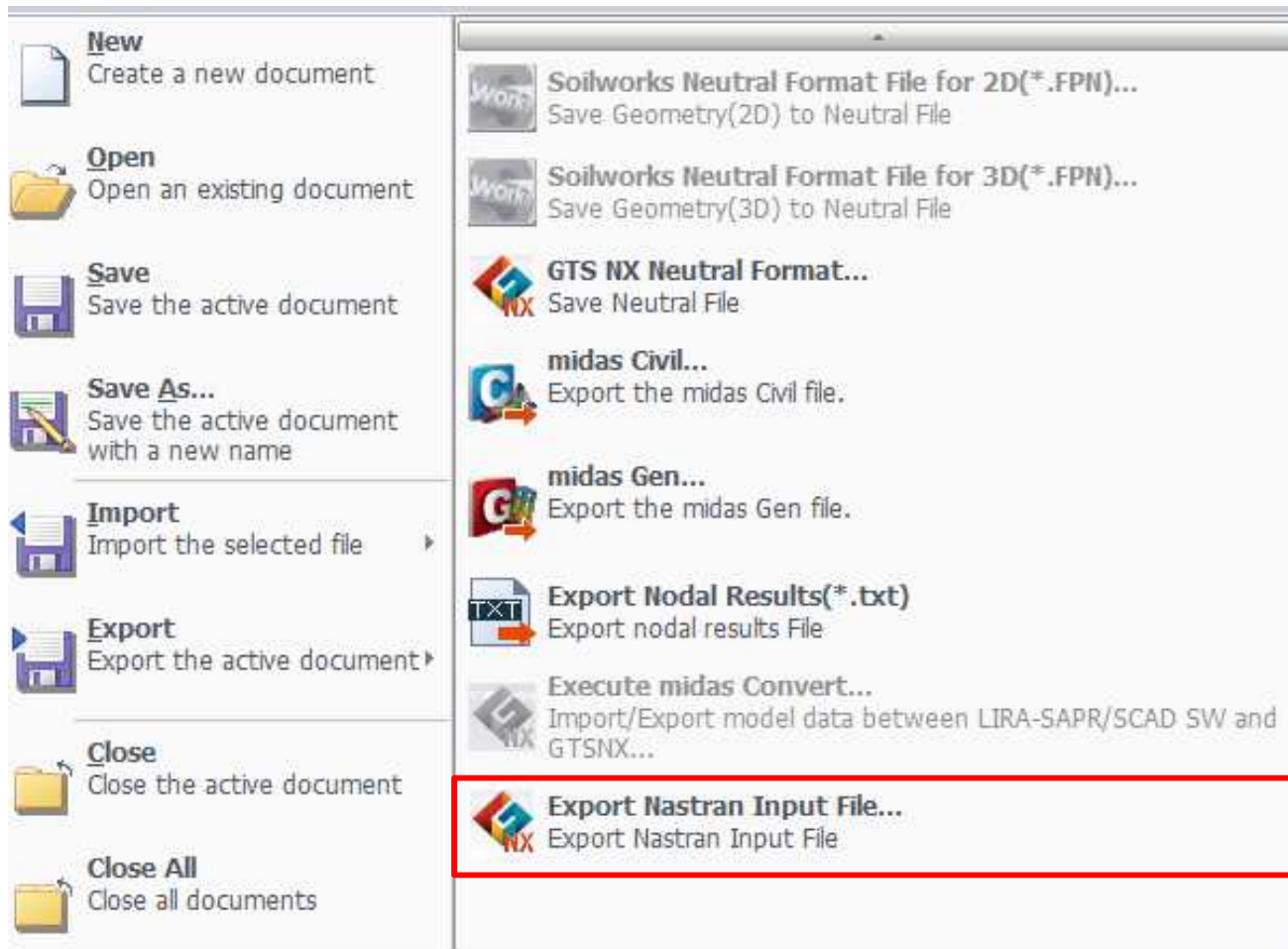


Structure + Ground Connection Analysis

7. Nastran file Export

- Provide a convenient function to export to a format that can be used as an Input file in Nastran.

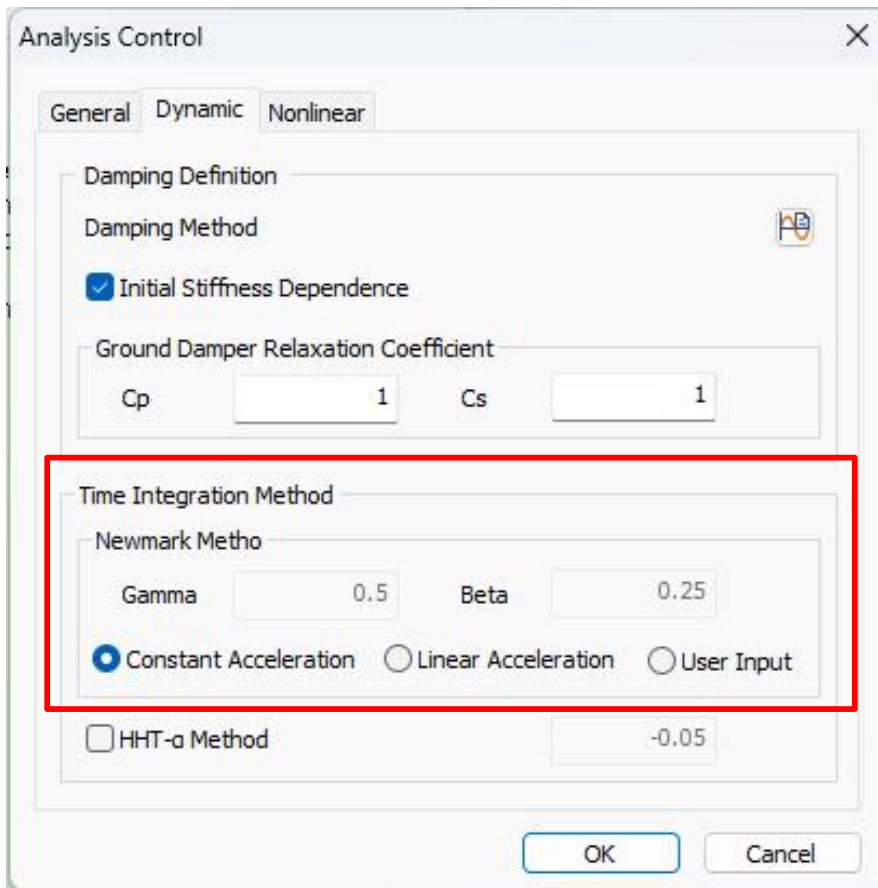
- **File > Export > Nastran file export**




8. Newmark- β Method

- Provide the Newmark Method used in the Direct Integration Method of dynamic analysis.
- Three Input methods are provided, of which Constant Acceleration is recommended as it provides the most stable analysis.

▪ **Analysis Case > Analysis Control**



The screenshot shows the 'Analysis Control' dialog box with the 'Dynamic' tab selected. The 'Time Integration Method' section is highlighted with a red box. It contains the following settings:

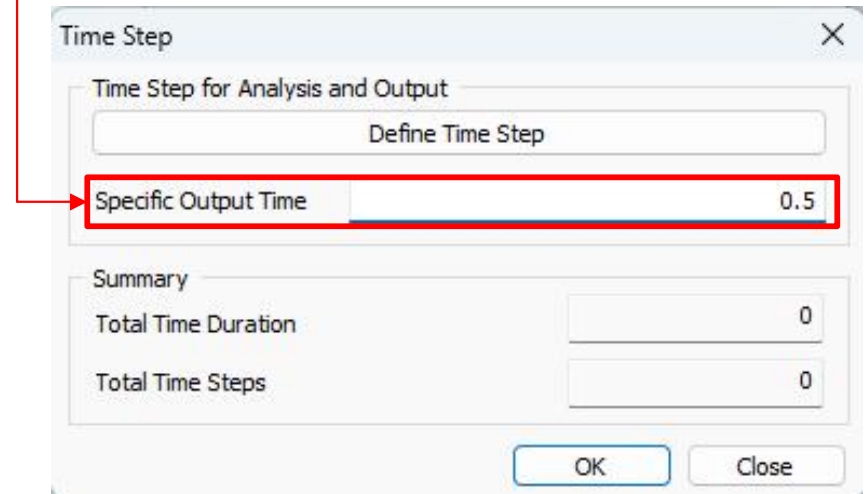
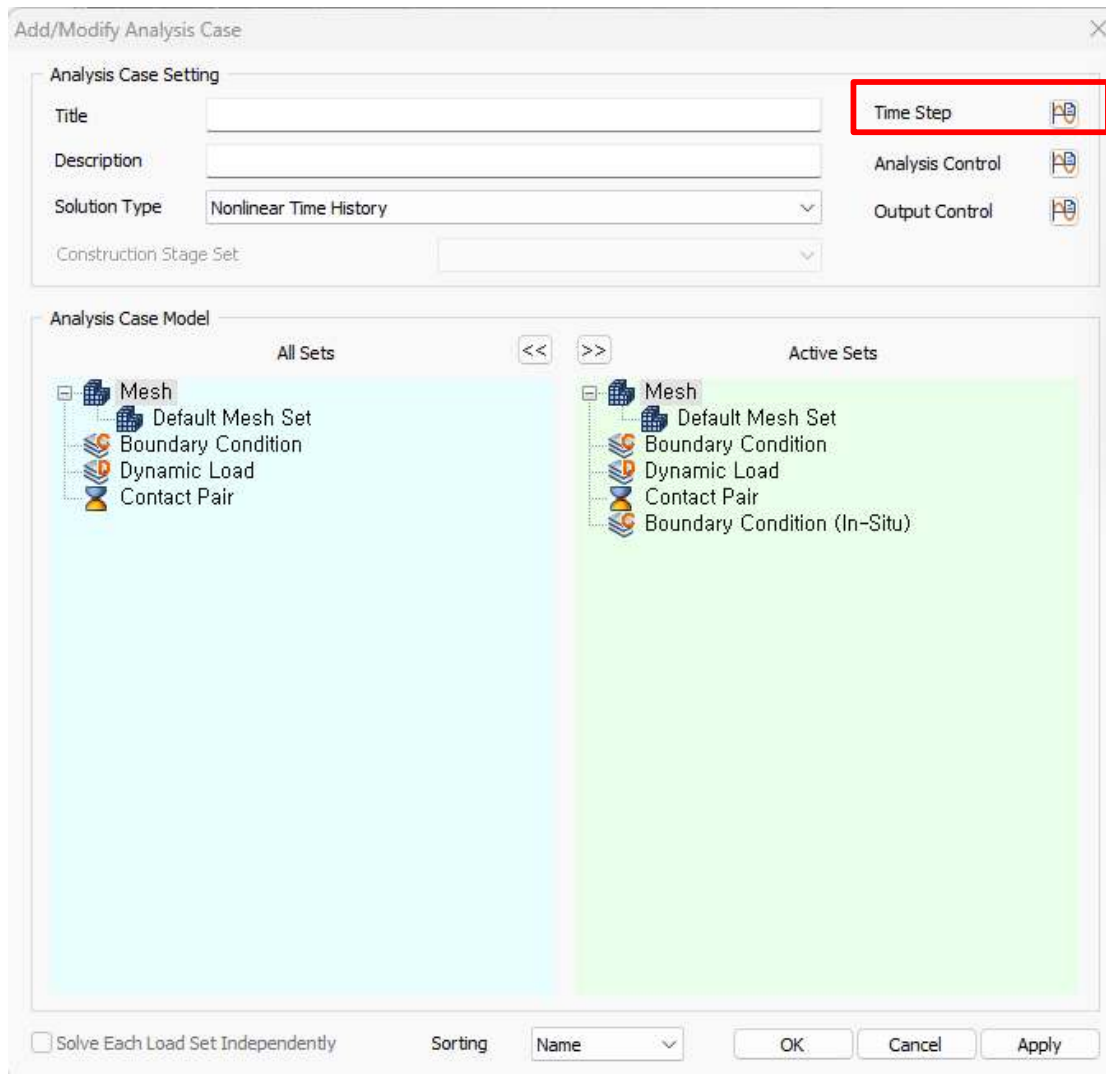
- Damping Definition**
 - Damping Method: 
 - Initial Stiffness Dependence
 - Ground Damper Relaxation Coefficient
 - Cp:
 - Cs:
- Time Integration Method**
 - Newmark Metho
 - Gamma:
 - Beta:
 - Constant Acceleration Linear Acceleration User Input
 - HHT- α Method

Buttons: OK, Cancel

9. Random Setting of Dynamic Analysis Output Time

- The Output time interval for dynamic analysis can be set arbitrarily, facilitating result output only at required time steps.

▪ Analysis Case > Analysis Case Setting > Time Step

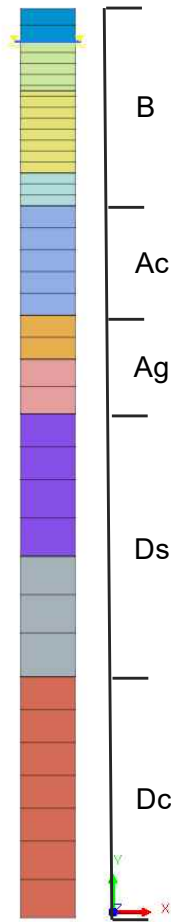


10. Bowl Model

- The Bowl Model, a material model capable of liquefaction analysis, has been added. Compared to other material models, it has fewer parameters, can be easily determined from experimental values and estimated values. The analysis time is also low, making it the ideal choice for liquefaction model that can be easily used in practice.

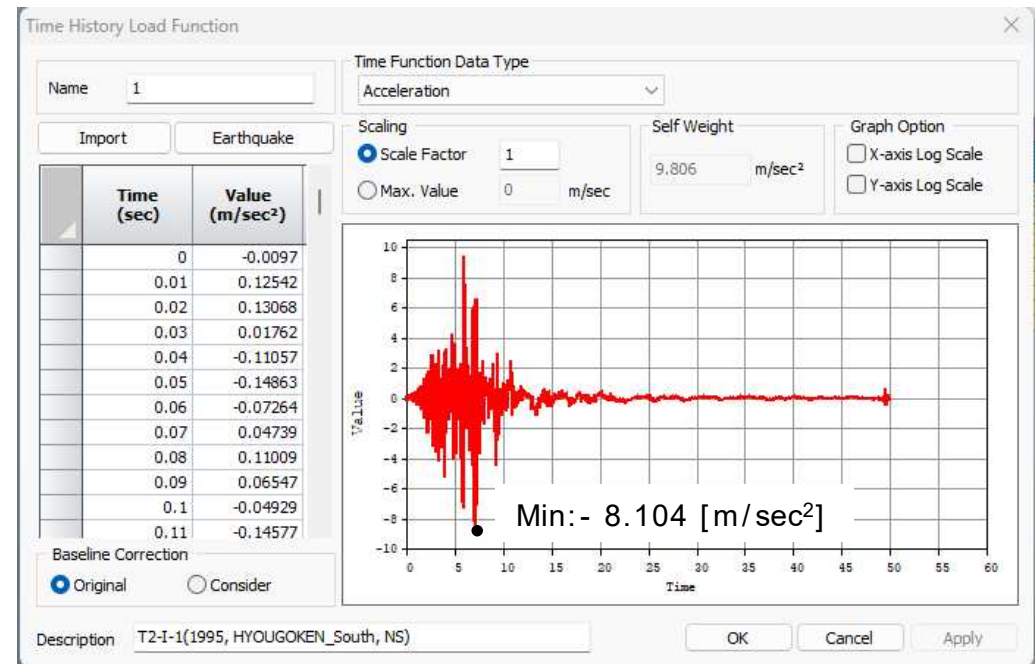
▪ Mesh > Prop./ Csys./ Func. > Material

GL(m)	Soil Layer	Wave (m/s)	Unit vol. weight (kN/m ³)	
0	Back Fill	140	18.53	
-3		170	21.28	
-7.5		200	21.18	
-15		220	21.57	
-18	Clay	Ac	180	15.69
-28	Sand	245	17.65	
-32		305	17.65	
-37	Sand	305	18.14	
-50		350	18.14	
-61	Clay	Dc	303	17.65



Fixed End(E+ F 입력)

B, Ag Layers → Modified Ramberg-Osgood+ Bowl Model
Ac, Ds, Dc Layers → Modified Ramberg-Osgood Model

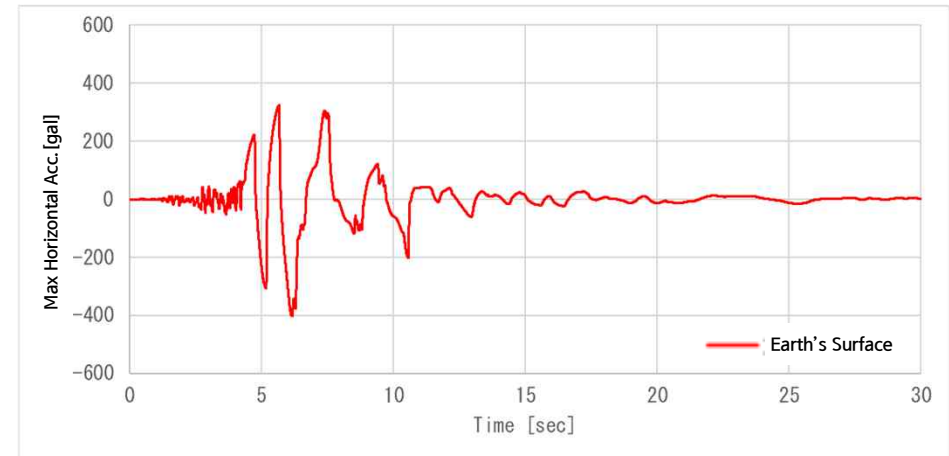
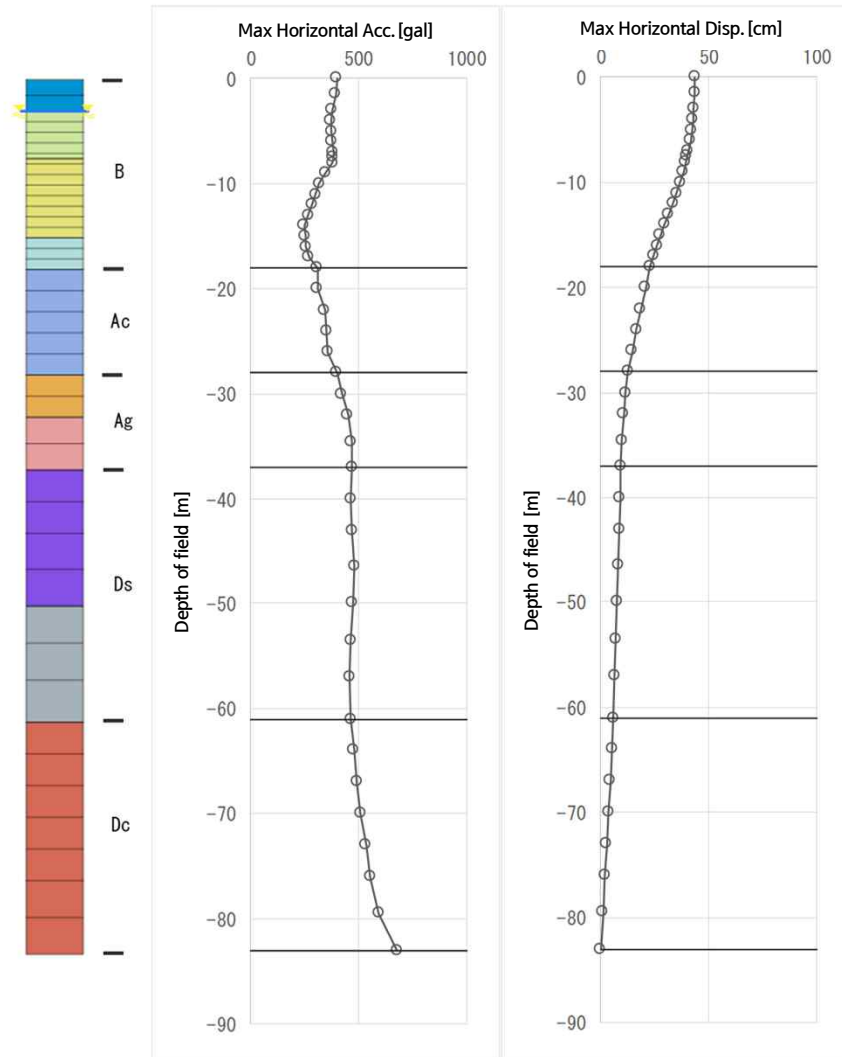


Ground Acceleration

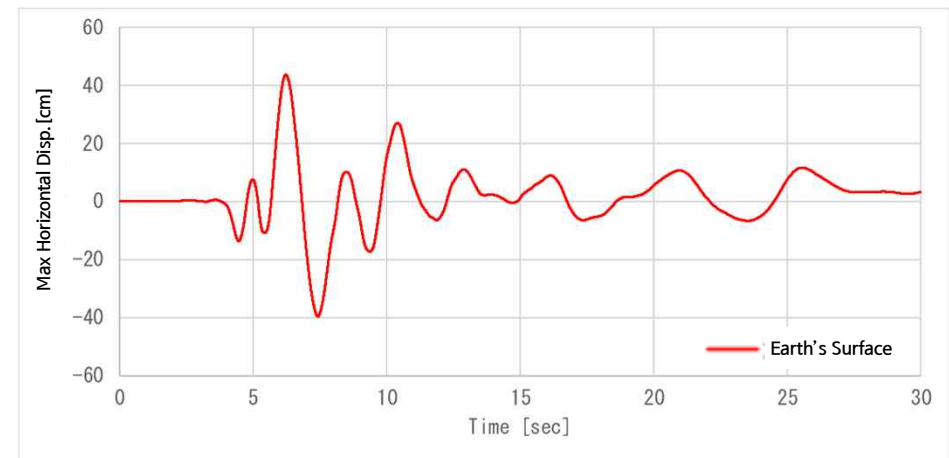
10. Bowl Model

- During an earthquake in the depth direction, it can be confirmed that the acceleration is attenuated and the displacement increases through the response on the maximum acceleration and maximum displacement indicators.

▪ Mesh > Prop./ Csys./ Func. > Material



Surface Horizontal Acceleration – Time Graph

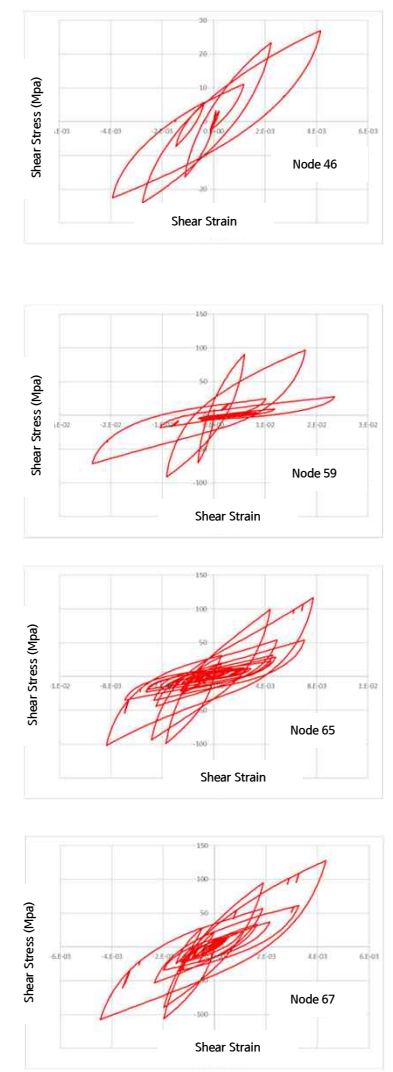
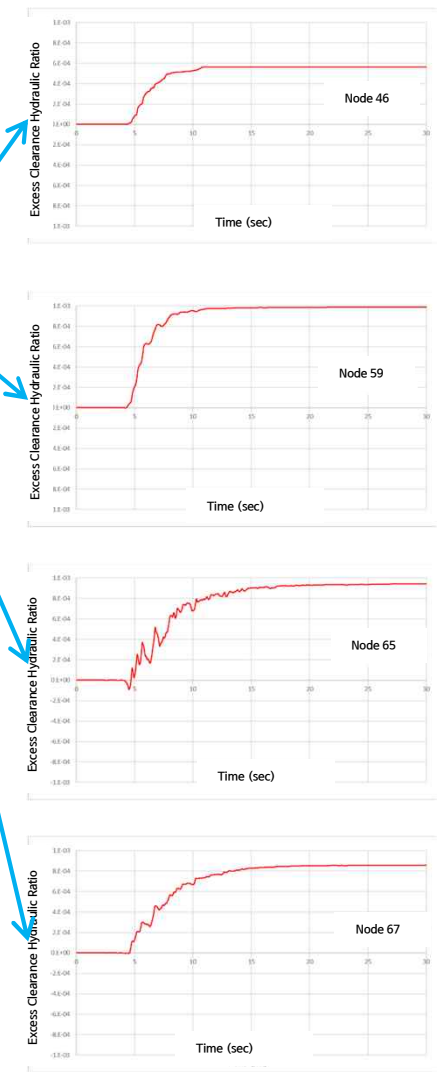
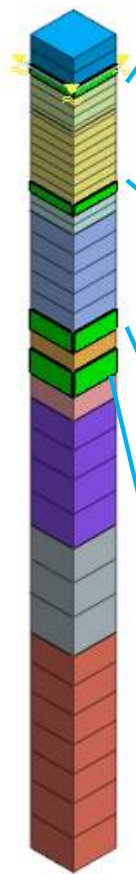
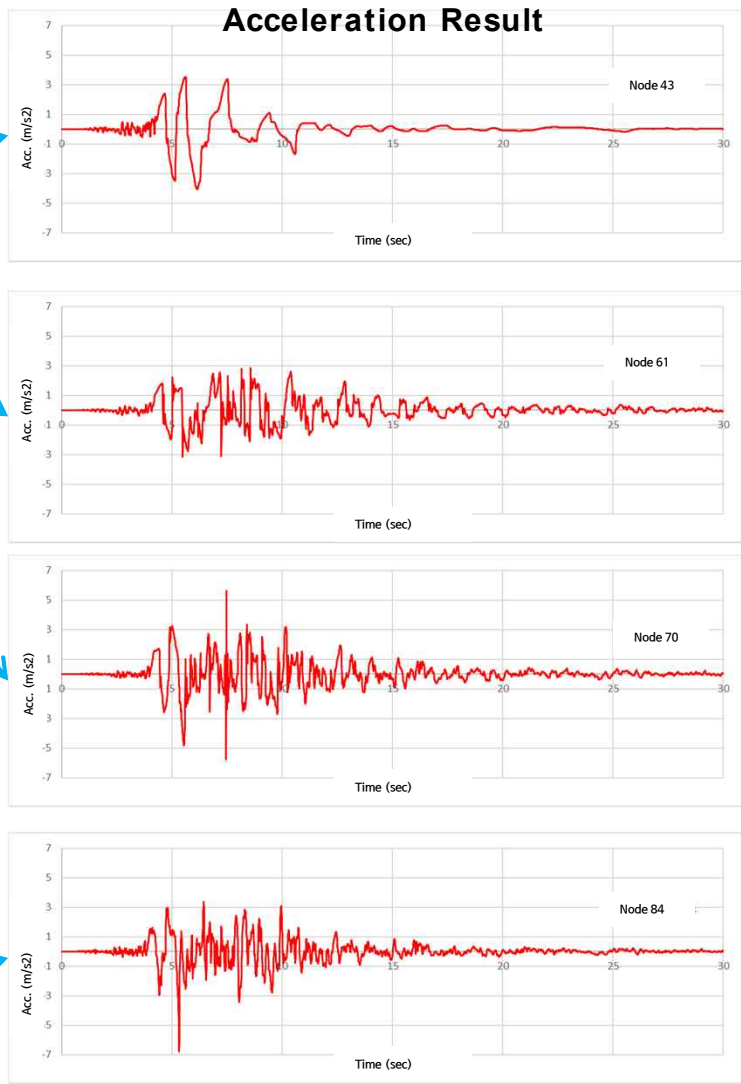
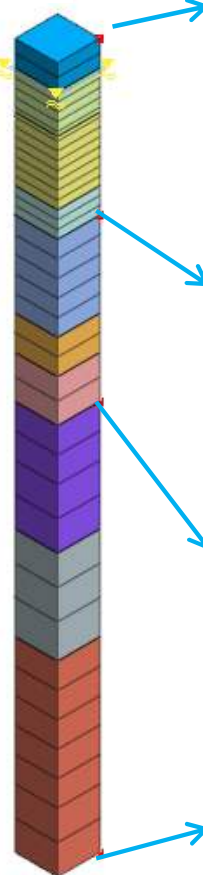
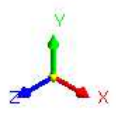


Surface Horizontal Displacement – Time Graph

10. Bowl Model

- As the acceleration of the focal point is transmitted to the surface, In the liquefaction layer, excess pore water pressure increases and shear stiffness decreases.
- This can be confirmed from the shear stress-shear strain relationship.

▪ **Mesh > Prop./ Csys./ Func. > Material**



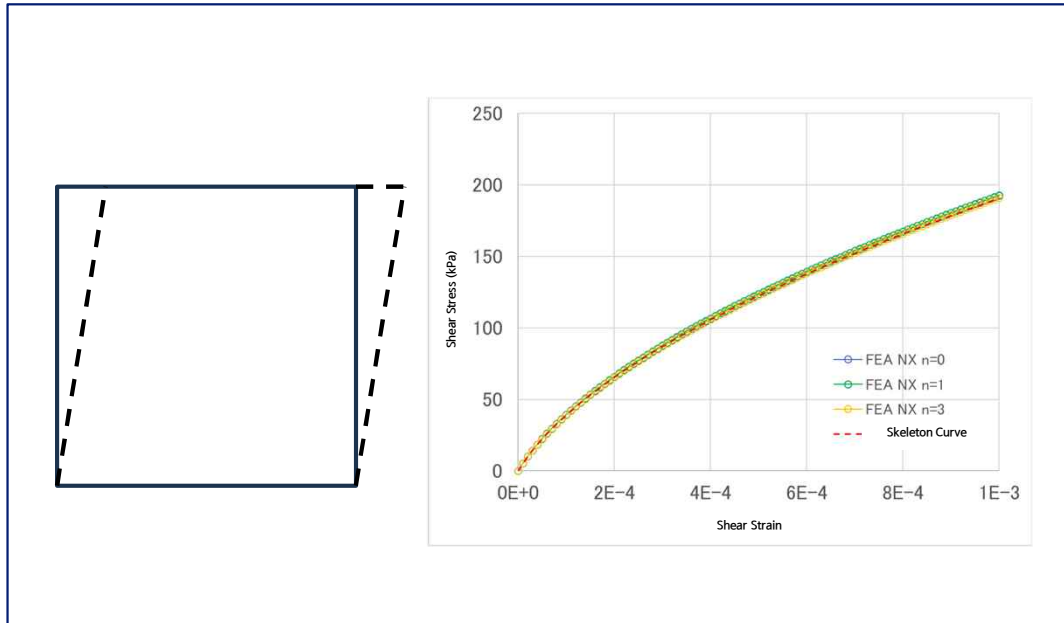
Excess Pore Water Pressure Shear Stress – Shear Strain

11. Multi-Spring(Multi Shear Spring)

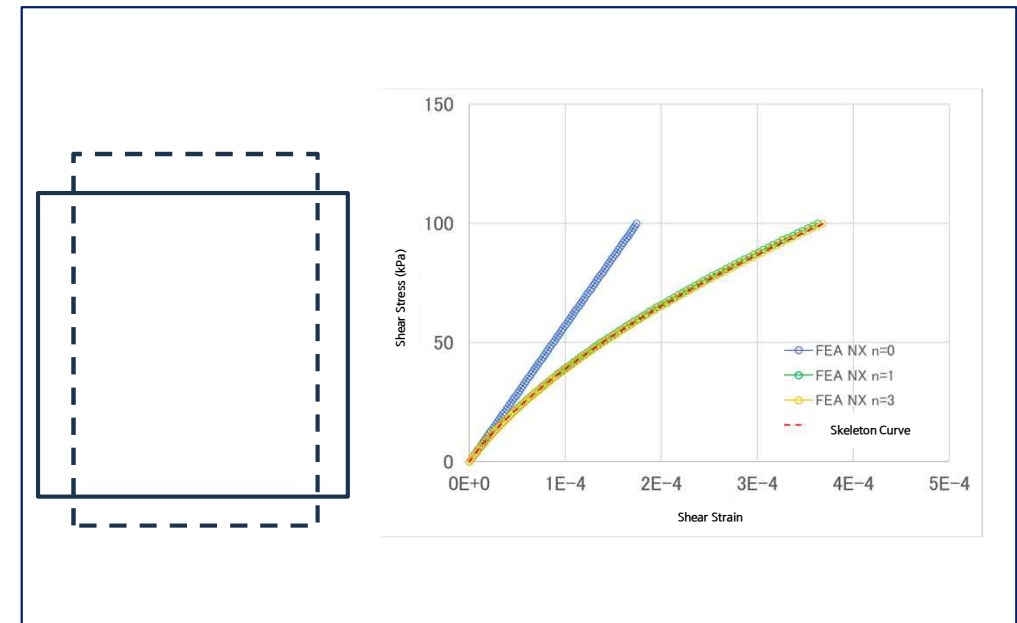
- The existing dynamic analysis material model was developed with focus on horizontal behavior for underground structures. By adding multi-spring elements, sequential shear was introduced. This is an expanded function that can predict displacement in the vertical direction during an earthquake.

Modified RO/ HD , GHE - S Model , Multi Spring

Multi-Spring(Multi Shear Spring) Can be considered when using Modified Ramberg-Osgood Model , Modified Hardin-Drnevich Model / GHE-S Model.



Simple Shear



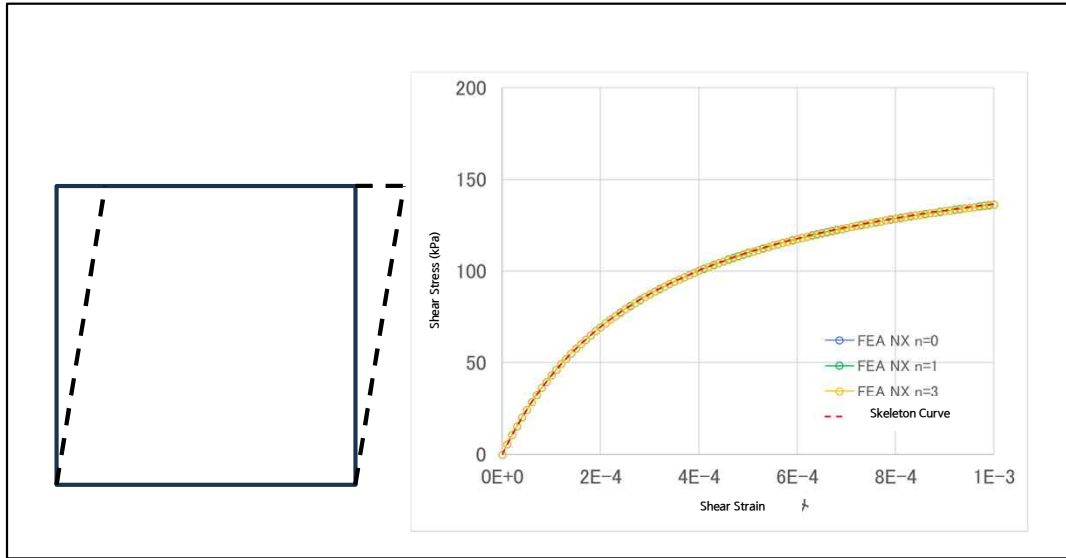
Sequential Shear

Modified Ramberg-Osgood Model

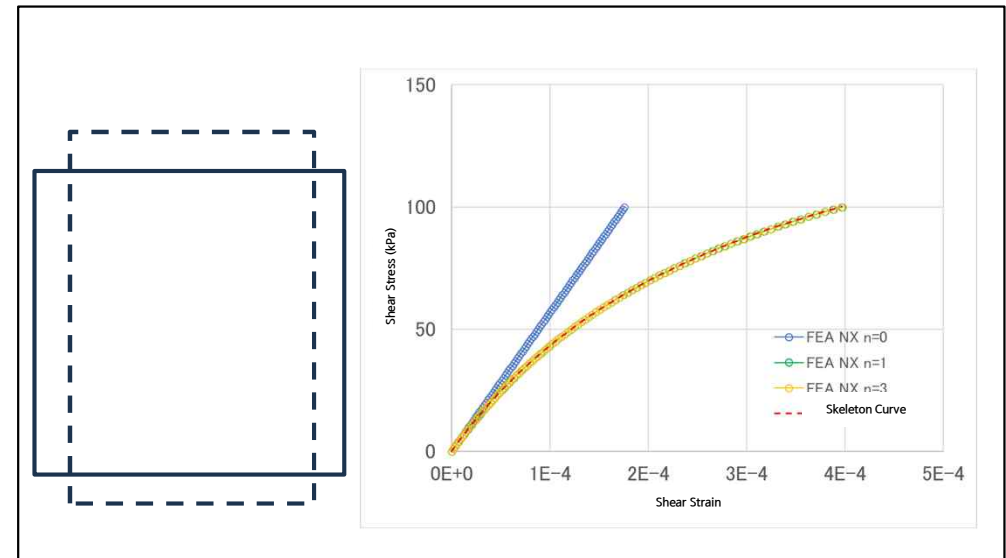
11. Multi-Spring(Multi Shear Spring)

Modified Hardin-Drnevich Model

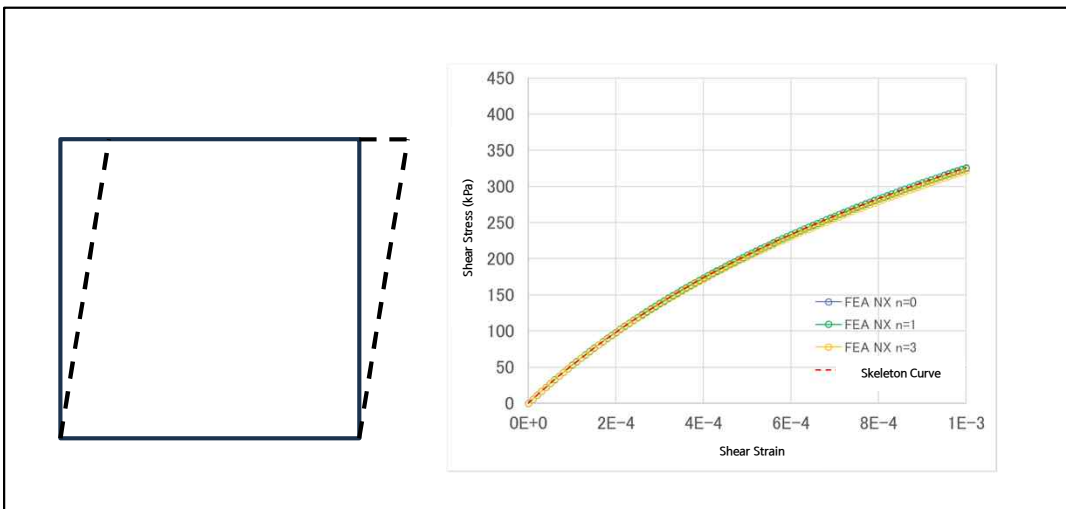
Simple Shear



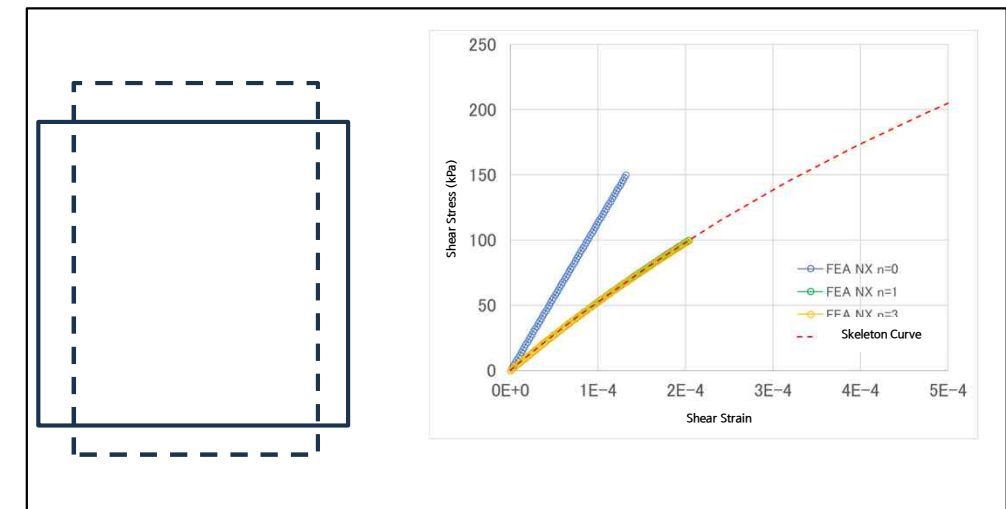
Sequential Shear



Simple Shear



GHE-S Model

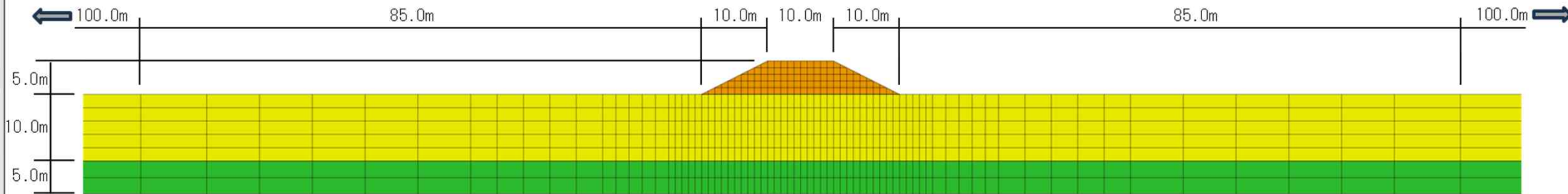


Sequential Shear

11. Multi-Spring(Multi Shear Spring)

- Modified RO/ HD , GHE- S Model , Multi Spring

Analysis Model (2D)

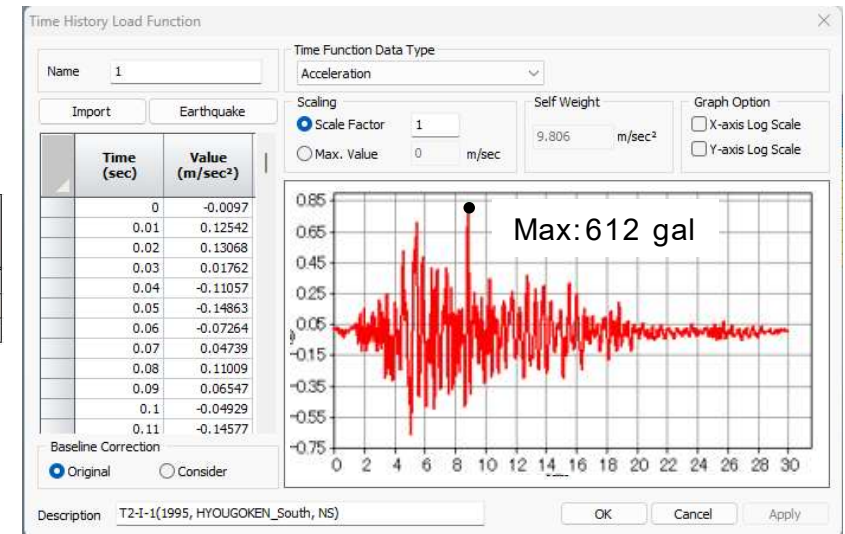


Side : Horizontal Roller

Fixed End(E+ F Input)

Ground Material Properties

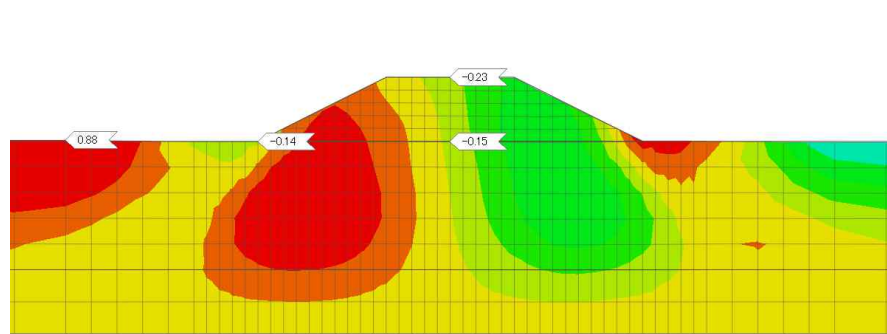
	Ground Model	Unit vol. weight [kN/m ²]	Standard Confining Pressure [kN/m ²]	Shear modulus of E [kN/m ²]	Refer. Strain	Confining Pressure Dependence Coff.	Poisson's Ratio	Max. Damping Ratio
Fill Layer	Modified R-O	17.00	28.00	84000.00	4.29E-04	0.50	0.33	0.24
Sand Layer	Modified R-O	18.00	60.00	60000.00	1.27E-03	0.50	0.33	0.24
Clay Layer	Modified R-O	20.00	152.00	128000.00	1.51E-03	0.50	0.33	0.20



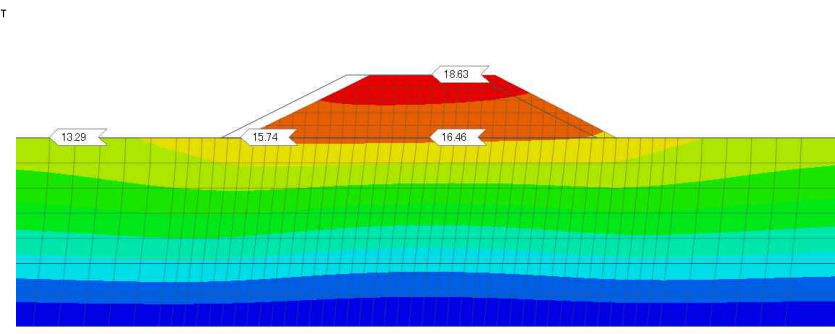
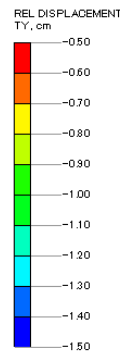
Ground Acceleration

11. Multi-Spring(Multi Shear Spring)

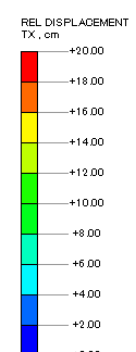
- Modified RO/ HD , GHE- S Model , Multi Spring



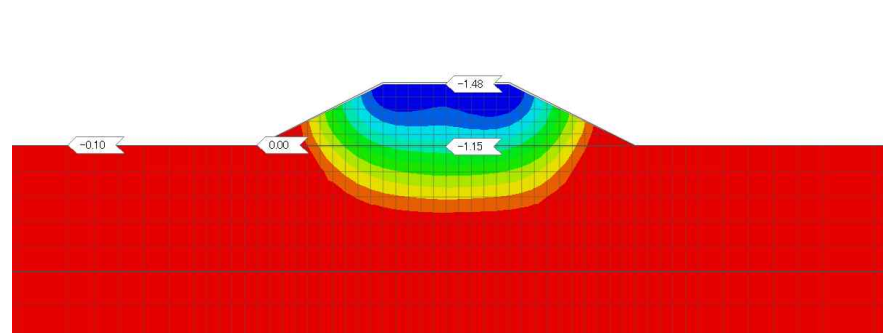
Residual Vertical Displacement



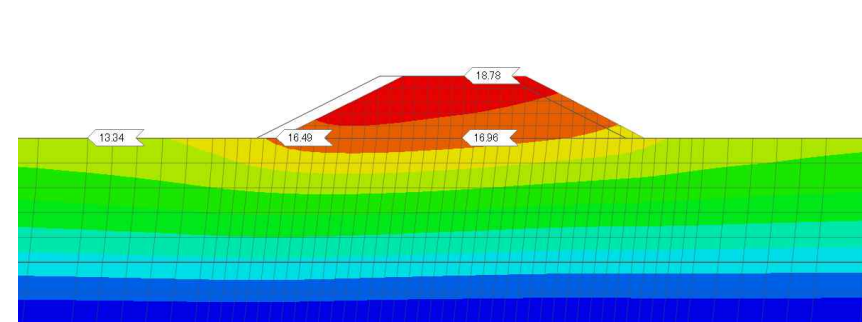
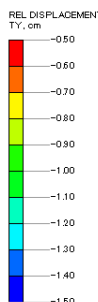
Maximum Horizontal Displacement



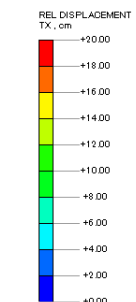
No Multi Spring



Residual Vertical Displacement



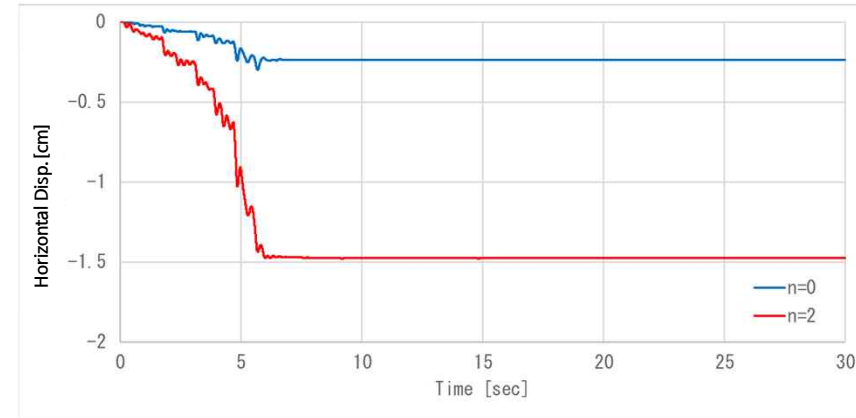
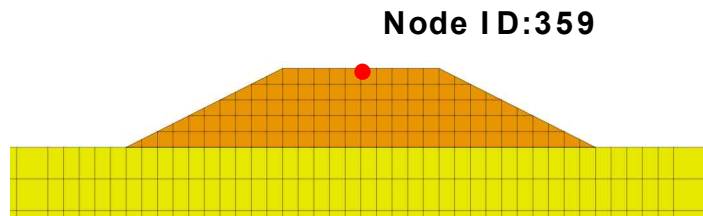
Maximum Horizontal Displacement



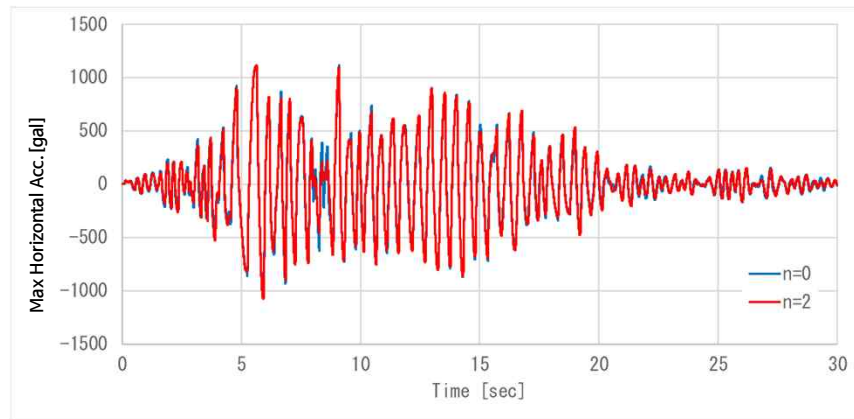
Multi Spring n=2

11. Multi-Spring(Multi Shear Spring)

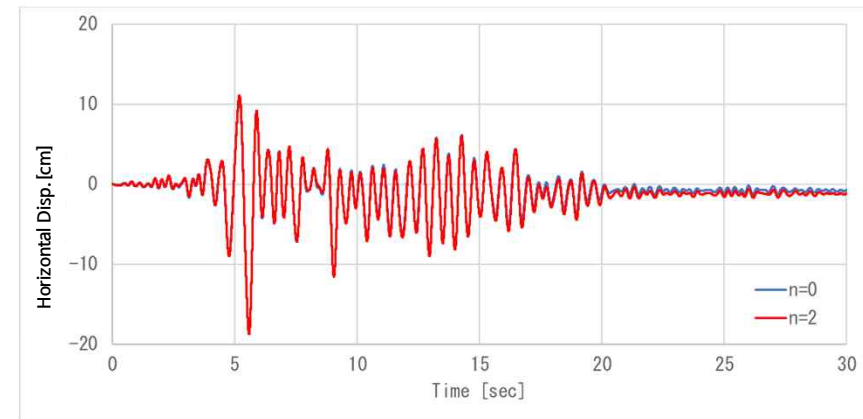
- Modified RO/ HD , GHE- S Model , Multi Spring



Vertical Displacement Time History



Horizontal Acceleration - Time



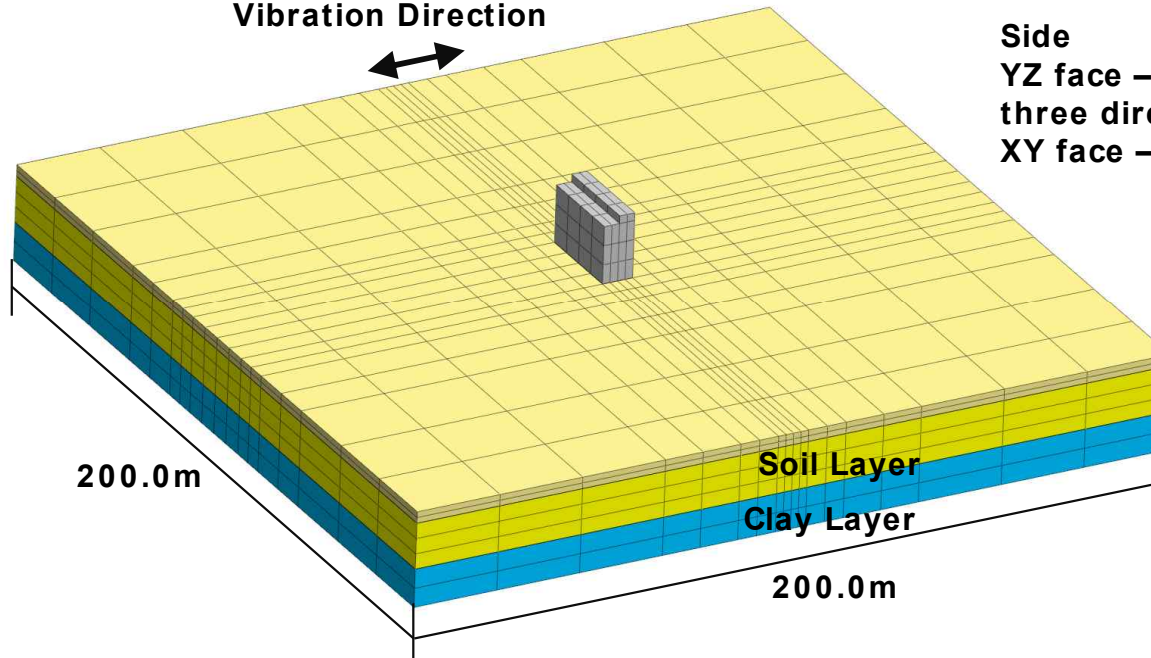
Horizontal Displacement - Time History

11. Multi-Spring(Multi Shear Spring)

- Modified RO/ HD , GHE- S Model , Multi Spring

Analysis Case (3D)

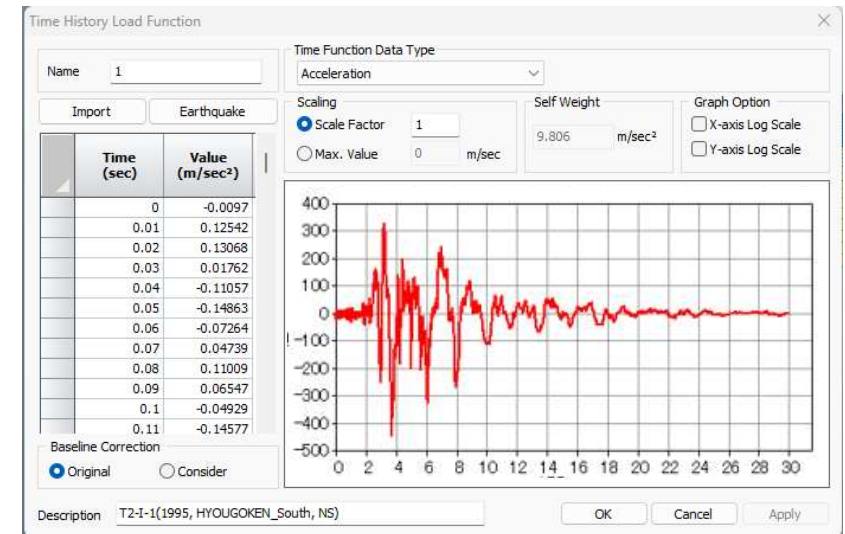
Bottom Viscous Boundary (2E Input)
Vibration Direction



Side
YZ face – Repeated BC (Equal Displacement constraint in all three directions for nodes at the same depth)
XY face –Z Direction Fixed

Ground Material Properties

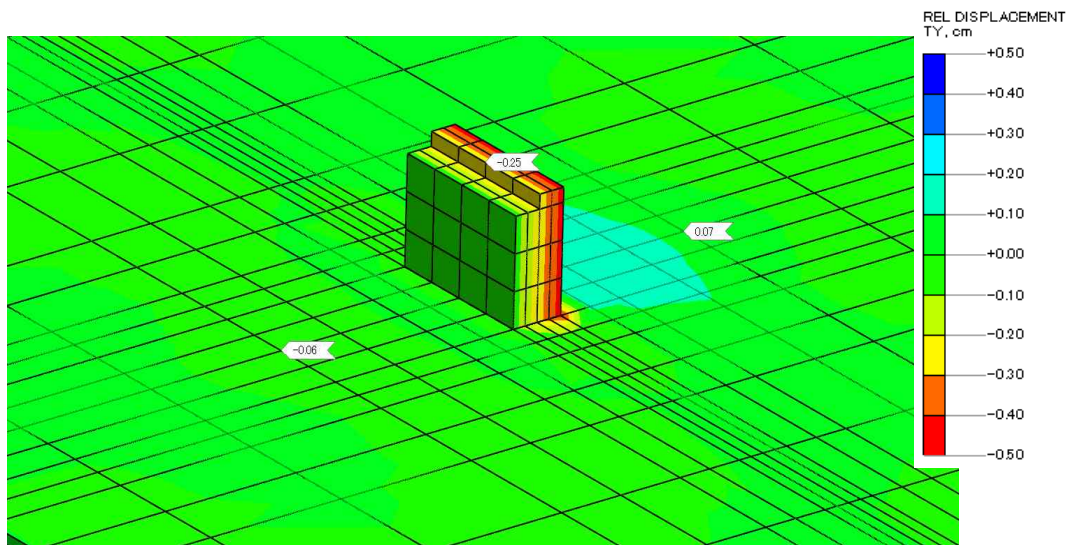
	Ground Model	Unit vol. weight [kN/m ³]	Standard Confining Pressure [kN/m ²]	Shear modulus of E [kN/m ²]	Refer. Strain	Confining Pressure Dependence Coff.	Poisson's Ratio	Max. Damping Ratio
Fill Layer	Modified R-O	17.60	18.00	64980.00	3.39E-04	0.50	0.33	0.30
Sand Layer	Modified R-O	17.60	66.00	64980.00	1.29E-03	0.50	0.33	0.30
Clay Layer	Modified R-O	16.70	120.00	38250.00	3.97E-03	0.50	0.33	0.20



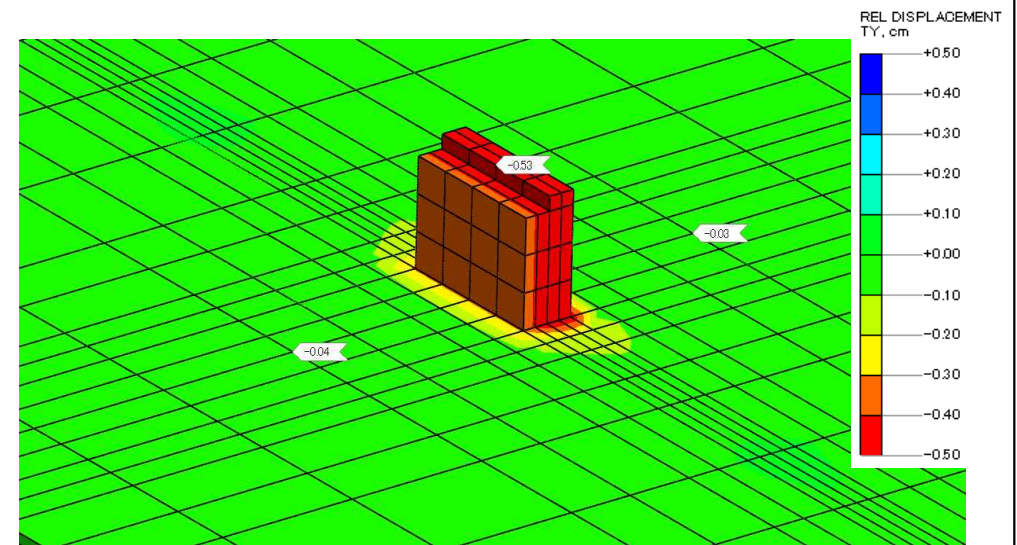
Ground Acceleration

11. Multi-Spring(Multi Shear Spring)

- Modified RO/ HD , GHE- S Model , Multi Spring



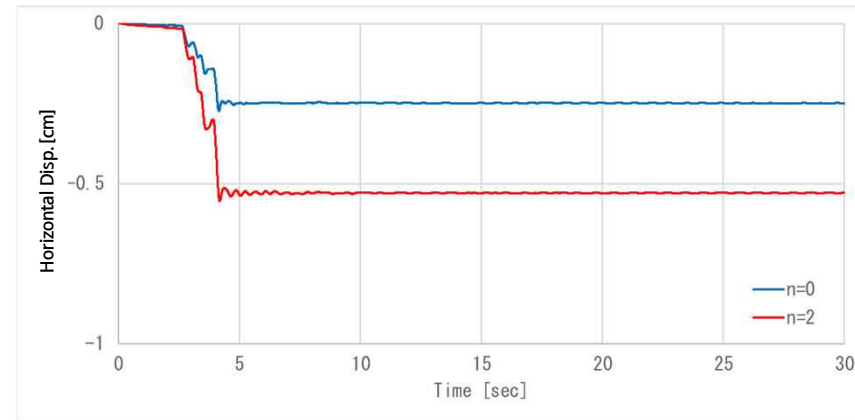
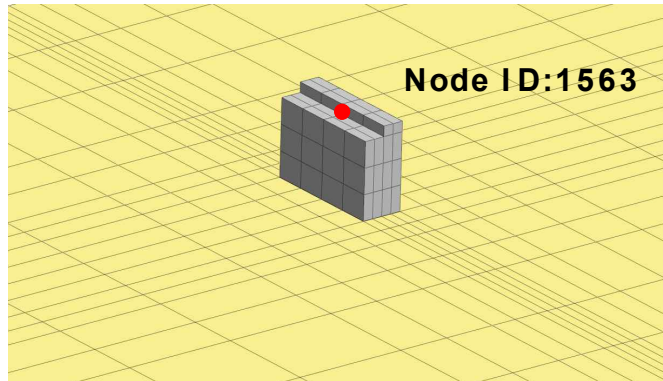
**Residual Vertical Displacement
Multi Spring X**



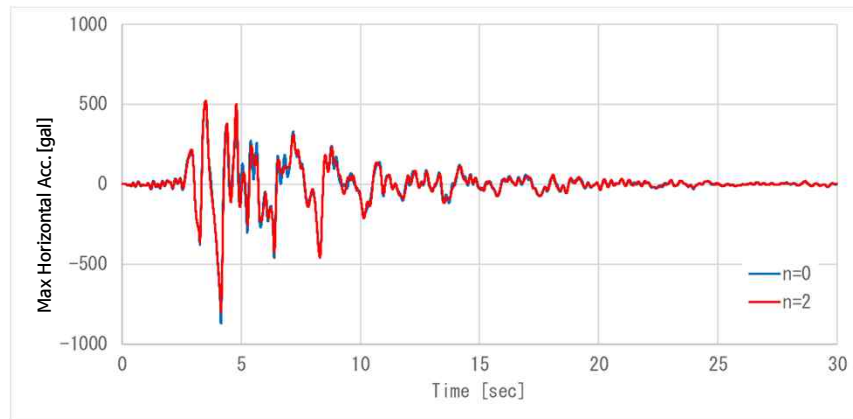
**Residual Vertical Displacement
Multi Spring n= 2**

11. Multi-Spring(Multi Shear Spring)

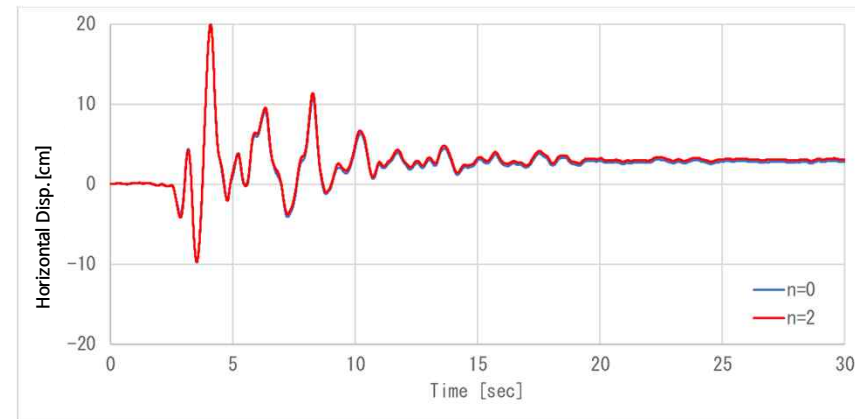
- Modified RO/ HD , GHE- S Model , Multi Spring



Vertical Displacement – Time Graph



Horizontal Acceleration – Time Graph



Horizontal Displacement – Time Graph

12. Rayleigh Damping by Element(Material)

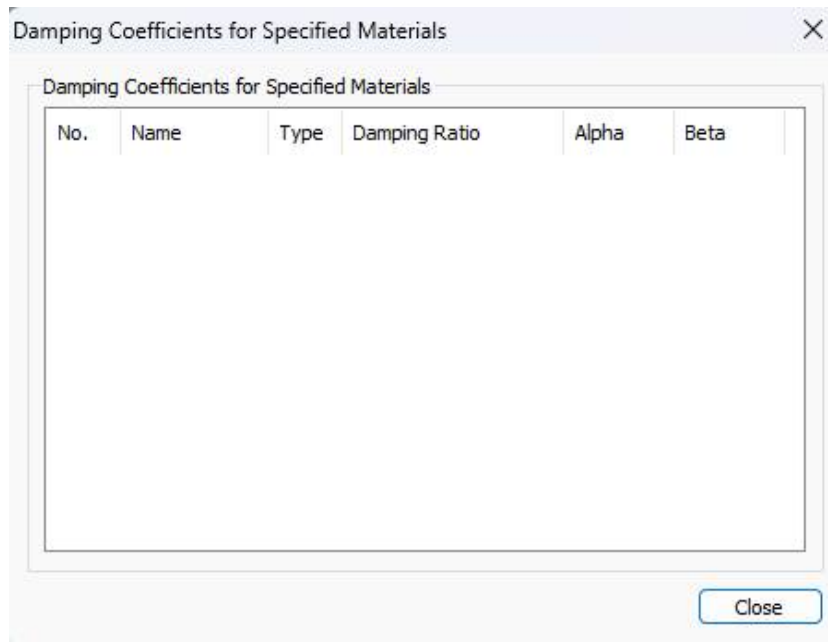
- During seismic analysis, the superstructure, substructure, and ground all have different attenuation coefficients
- Therefore, in the analysis, a function is installed to calculate the attenuation coefficients α and β for each material.

▪ *Analysis > Analysis Control > Dynamic > Damping Method*

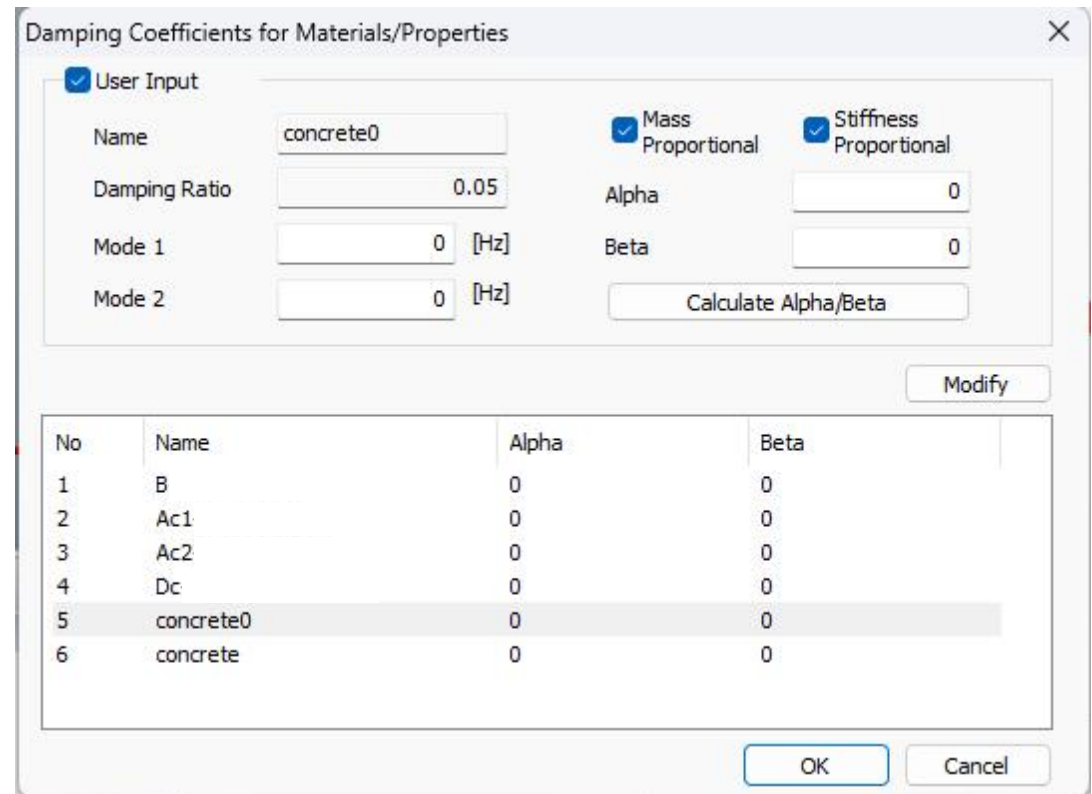
Previously, Only approximate Settings could be made by inputting the period and frequency and using internally calculated α and β .

Now it is possible to directly input α and β .

Previous Version

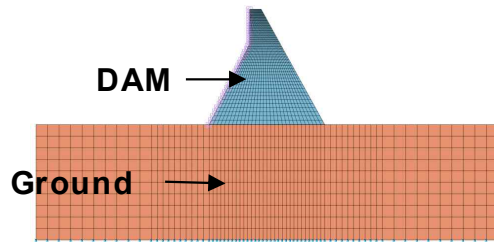


New Version

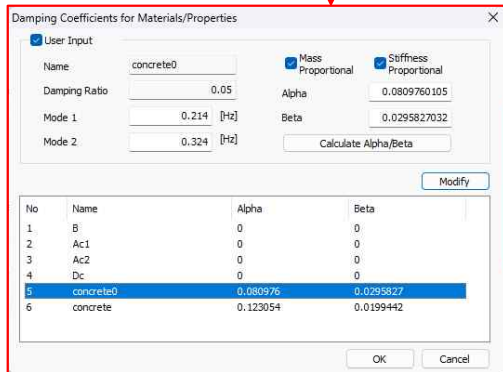
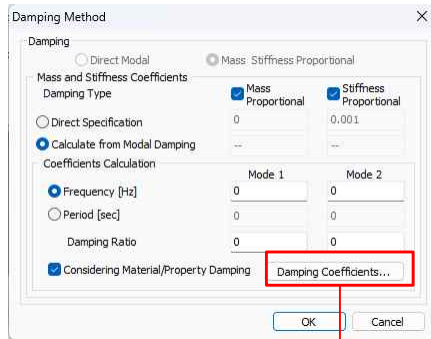


12. Rayleigh Damping by Element(Material)

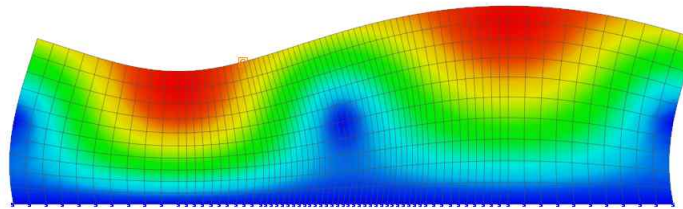
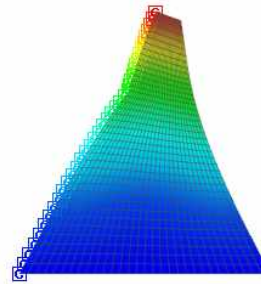
- Analysis > Analysis Control > Dynamic > Damping Method



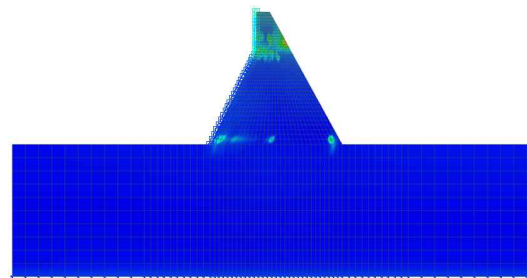
① Analysis Model



④ Damping Coefficients for Material

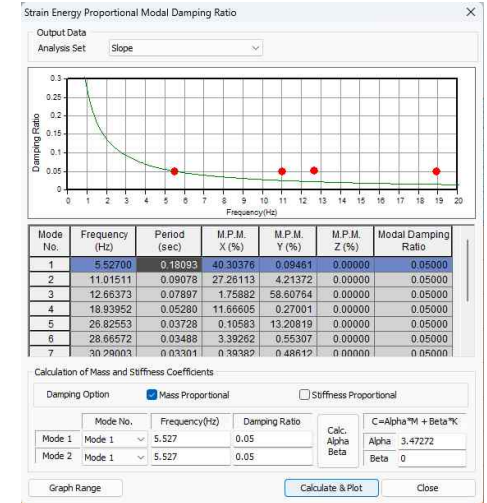


② Eigenvalue Analysis of Structures and Ground

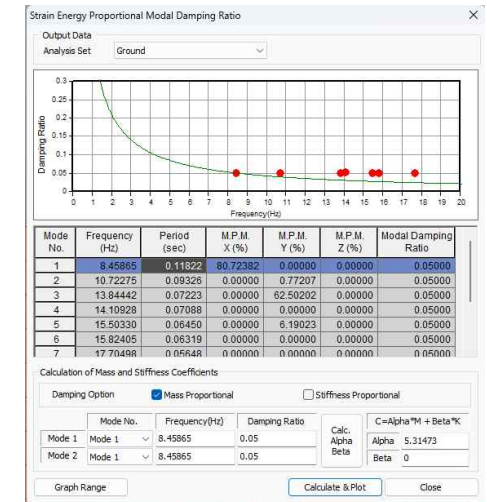


⑤ Perform Dynamic Analysis

Damping Constant of DAM



Damping Constant of the Ground



③ Damping Constant for each mode

13. Fluid Element (Sloshing)

- A liquid element that can simulate the water in the structure and the liquid gas contained in LNG tank has been added. This is a function that calculates the wave height and pressure results during an earthquake and predicts through analysis how much pressure will be generated.

▪ **Mesh > Prop./ CSys./ Func. > Material**

Add/Modify Material

No	Name	Type
1	MAT M1	Isotropic-Elastic
2	MAT M2	Isotropic-Elastic
4	MAT M4	Sloshing Medium
10	MAT M10	Isotropic-Elastic

Material

Material

ID 4 Name MAT M4 Color [Green]

Inviscid

Bulk Modulus (k) 2200000 kN/m²

Unit Weight(γ) 9.80665 kN/m³

Add/Modify Property

No	Name	Type	Sub-Type
1	ATT 1	2D	Shell
2	ATT 2	2D	Shell
3	ATT 3	Other	Fluid Boun...
4	ATT 4	3D	Sloshing Fluid
5	ATT 5	Other	Fluid Boun...
6	ATT 6	Other	Point Spring

Property

Create/Modify 2D Property

Shell Plane Stress Plane Strain Geogrid(2D) Plot Only(2D)

Gauging Shell Axisymmetric Composite Shell

Sloshing Fluid(2D) Sloshing Fluid(Axisym.)

ID 7 Name 2D Property Color [White]

Material 4: MAT M4

Thickness 1 m

Create/Modify 3D Property

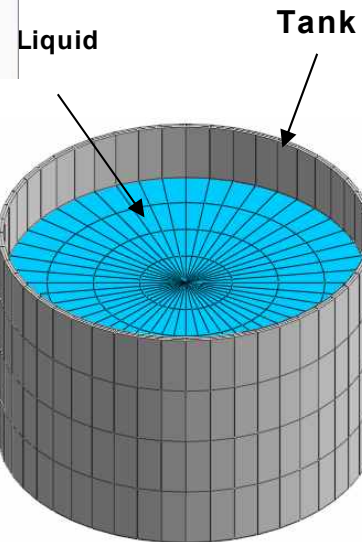
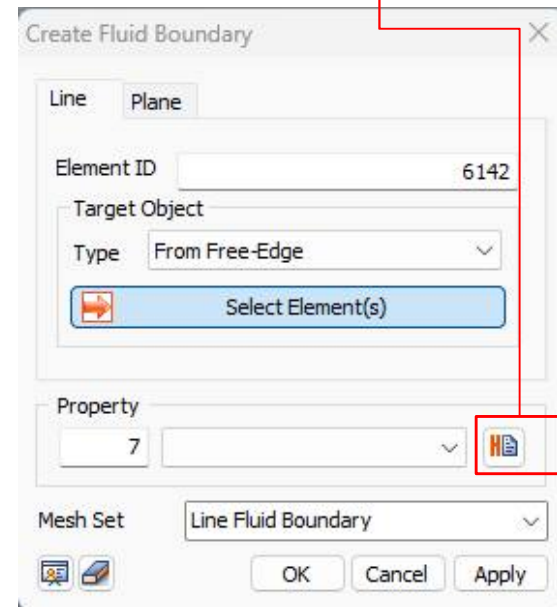
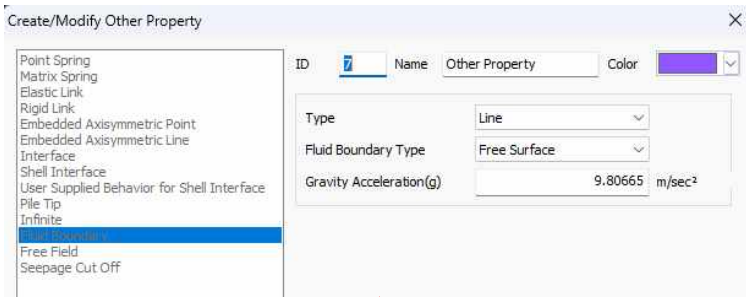
Sloshing Fluid

ID 4 Name ATT 4 Color [Brown]

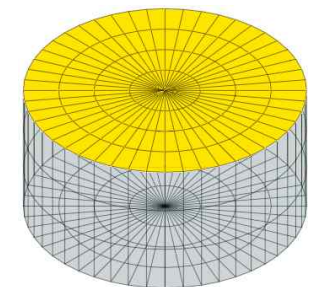
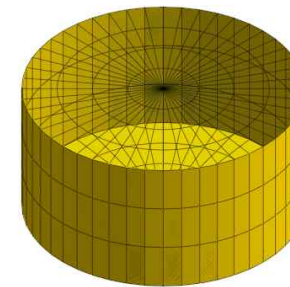
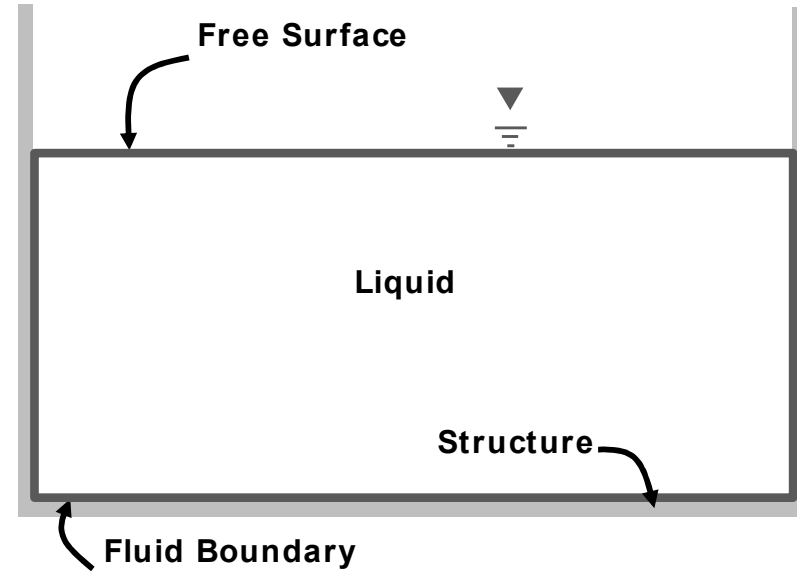
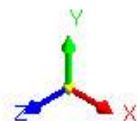
Material 4: MAT M4

13. Fluid Element (Sloshing)

▪ **Mesh > Element > Fluid Boundary**



Analysis Model

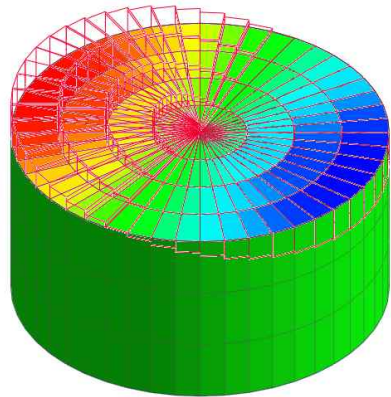


**Fluid Boundary
(Interface between
Structure and liquid)**

Set Boundary element on the part in contact with the object and on the top of the liquid

13. Fluid Element (Sloshing)

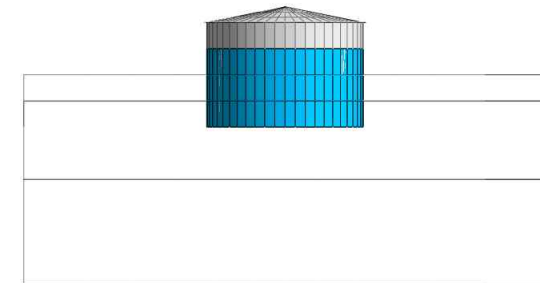
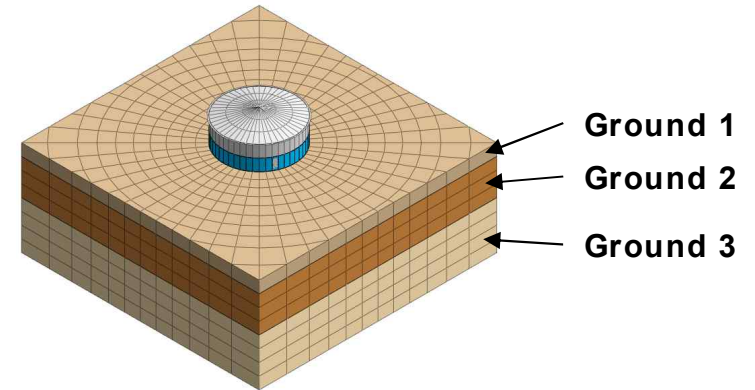
- Mesh > Prop./CSys./Func. > Material



Velocity Potential Theory

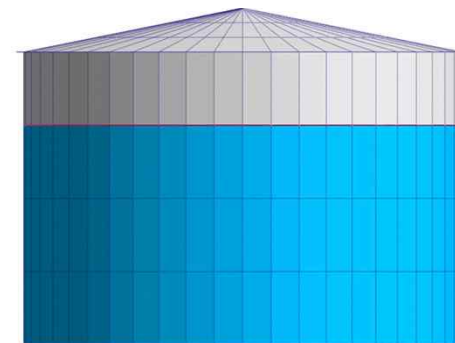
Natural Cycle $T_{si} = \frac{2\pi}{\omega_i} = 2\pi \sqrt{\frac{R}{\epsilon_i g} \coth\left(\epsilon_i \frac{H}{R}\right)}$

Natural Frequency $f(\text{Hz}) = \frac{1}{2\pi} \cdot \sqrt{\frac{(2n-1) \cdot \pi \cdot g}{L} \cdot \tanh\left(\frac{(2n-1) \cdot \pi \cdot H}{L}\right)}$



Perform an eigenvalue Analysis including liquid elements and compare the natural frequency and natural period as follows. ϵ_i is the i th root of $dJ_1(r)/dr=0$, and is calculate as $\epsilon_1=1.84118$.

	Ts(s)	f(Hz)
Theoretical value	6.43	0.141
Analysis value	6.35	0.157



14. Dynamic Analysis Min/ Max value occurrence time output

- Occurrence time of the dynamic analysis min/max results can now be obtained in a tabular format.

▪ Results Tree > MIN, MAX, ABSOLUTE MAX (Occurrence time output)

dy
 Nonlinear Time History
 INCR=3000 (TIME=3.000e+001)
 MIN
 MAX
 Displacements
 TOTAL TRANSLATION (V)
TX TRANSLATION (V)
 TY TRANSLATION (V)
 TZ TRANSLATION (V)
 TOTAL ROTATION (V)
 RX ROTATION (V)
 RY ROTATION (V)
 RZ ROTATION (V)
 TXY TRANSLATION (V)
 TYZ TRANSLATION (V)
 TZX TRANSLATION (V)
 Relative Displacements
 Reactions
 Grid Forces
 Velocities
 Relative Velocities
 Accelerations
 Relative Accelerations
 Beam Element Forces
 AXIAL FORCE
 SHEAR FORCE Y
 SHEAR FORCE Z
 TORQUE
BENDING MOMENT Y
 BENDING MOMENT Z

Node	TX TRANSLATION (V) (m)	
	Value	Time (sec)
1	3.480e-001	5.510e+000
2	3.480e-001	5.510e+000
3	3.480e-001	5.510e+000
4	3.480e-001	5.520e+000
5	3.482e-001	5.520e+000
6	3.483e-001	5.520e+000
7	3.487e-001	5.530e+000
8	3.494e-001	5.540e+000
9	3.504e-001	5.550e+000
10	3.518e-001	5.560e+000
11	3.562e-001	5.580e+000
12	3.634e-001	5.620e+000
13	3.617e-001	5.650e+000
14	3.270e-001	5.690e+000
15	4.405e-001	2.105e+001
16	4.887e-001	2.104e+001
17	3.480e-001	5.510e+000

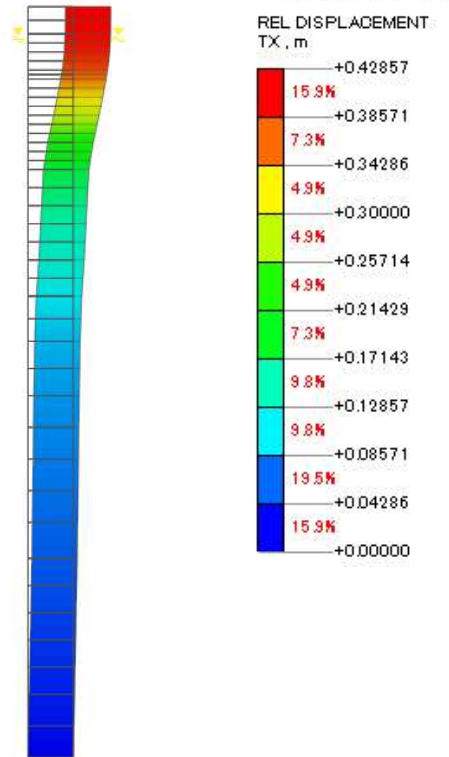
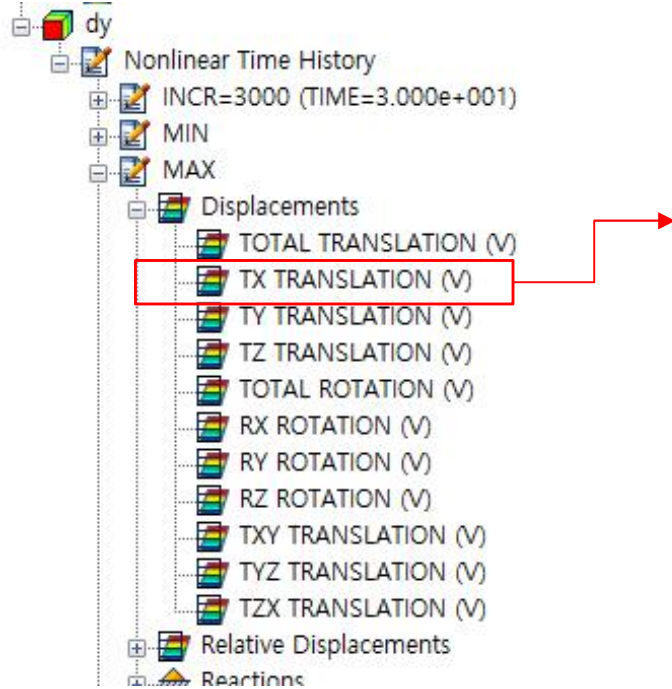
No.	BENDING MOMENT Y 0/4 (kN-m)		BENDING MOMENT Y 1/4 (kN-m)		BENDING MOMENT Y 1/4 (kN-m)		BENDING MOMENT Y 2/4 (kN-m)		BENDING MOMENT Y 2/4 (kN-m)		BENDING MOMENT Y 3/4 (kN-m)		BENDING MOMENT Y 3/4 (kN-m)		BENDING MOMENT Y 4/4 (kN-m)	
	Value	Time (sec)	Value	Time (sec)	Value	Time (sec)	Value	Time (sec)	Value	Time (sec)	Value	Time (sec)	Value	Time (sec)	Value	Time (sec)
1	4.561e+004	6.350e+000	4.510e+004	6.350e+000	4.510e+004	6.350e+000	4.459e+004	6.350e+000	4.459e+004	6.350e+000	4.409e+004	6.350e+000	4.409e+004	6.350e+000	4.358e+004	6.350e+000
2	4.351e+004	6.350e+000	4.299e+004	6.350e+000	4.299e+004	6.350e+000	4.247e+004	6.350e+000	4.247e+004	6.350e+000	4.194e+004	6.350e+000	4.194e+004	6.350e+000	4.145e+004	6.360e+000
3	4.138e+004	6.360e+000	4.087e+004	6.360e+000	4.087e+004	6.360e+000	4.036e+004	6.360e+000	4.036e+004	6.360e+000	3.986e+004	6.360e+000	3.986e+004	6.360e+000	3.935e+004	6.360e+000
4	3.927e+004	6.360e+000	3.875e+004	6.360e+000	3.875e+004	6.360e+000	3.822e+004	6.360e+000	3.822e+004	6.360e+000	3.770e+004	6.360e+000	3.770e+004	6.360e+000	3.717e+004	6.360e+000
5	3.711e+004	6.360e+000	3.657e+004	6.370e+000	3.657e+004	6.370e+000	3.607e+004	6.370e+000	3.607e+004	6.370e+000	3.556e+004	6.370e+000	3.556e+004	6.370e+000	3.505e+004	6.370e+000
6	3.495e+004	6.370e+000	3.388e+004	6.370e+000	3.388e+004	6.370e+000	3.281e+004	6.380e+000	3.281e+004	6.380e+000	3.182e+004	6.380e+000	3.182e+004	6.380e+000	3.083e+004	6.380e+000
7	3.067e+004	6.380e+000	2.965e+004	6.390e+000	2.965e+004	6.390e+000	2.868e+004	6.390e+000	2.868e+004	6.390e+000	2.776e+004	6.400e+000	2.776e+004	6.400e+000	2.689e+004	6.400e+000
8	2.862e+004	6.410e+000	2.576e+004	6.410e+000	2.576e+004	6.410e+000	2.494e+004	6.420e+000	2.494e+004	6.420e+000	2.418e+004	6.420e+000	2.418e+004	6.420e+000	2.342e+004	6.420e+000
9	2.316e+004	6.430e+000	2.242e+004	6.430e+000	2.242e+004	6.430e+000	2.177e+004	6.440e+000	2.177e+004	6.440e+000	2.121e+004	6.450e+000	2.121e+004	6.450e+000	2.072e+004	6.460e+000
10	2.040e+004	6.470e+000	1.956e+004	6.480e+000	1.956e+004	6.480e+000	1.921e+004	6.500e+000	1.921e+004	6.500e+000	1.915e+004	6.510e+000	1.915e+004	6.510e+000	1.936e+004	6.540e+000
11	1.896e+004	6.560e+000	2.031e+004	6.700e+000	2.031e+004	6.700e+000	2.273e+004	6.700e+000	2.273e+004	6.700e+000	2.516e+004	6.700e+000	2.516e+004	6.700e+000	2.758e+004	6.700e+000
12	2.758e+004	6.700e+000	2.861e+004	6.700e+000	2.861e+004	6.700e+000	2.965e+004	6.700e+000	2.965e+004	6.700e+000	3.074e+004	6.690e+000	3.074e+004	6.690e+000	3.183e+004	6.690e+000
13	3.189e+004	6.690e+000	3.020e+004	6.680e+000	3.020e+004	6.680e+000	2.858e+004	6.680e+000	2.858e+004	6.680e+000	2.706e+004	6.670e+000	2.706e+004	6.670e+000	2.566e+004	6.660e+000
14	2.575e+004	6.660e+000	2.068e+004	6.650e+000	2.068e+004	6.650e+000	1.571e+004	6.640e+000	1.571e+004	6.640e+000	1.110e+004	6.060e+000	1.110e+004	6.060e+000	6.601e+003	6.070e+000
15	6.680e+003	6.060e+000	5.010e+003	6.060e+000	5.010e+003	6.060e+000	3.340e+003	6.060e+000	3.340e+003	6.060e+000	1.670e+003	6.060e+000	1.670e+003	6.060e+000	1.140e+003	6.690e+000

15. Improve Dynamic Analysis ABSOLUTE MAX(Absolute value output)

- For Dynamic Analysis, the results for max/min (+/-) can now be viewed in absolute value form.

Results Tree > ABSOLUTE MAX

Positive/ Negative Result → Change Output format(ABS)



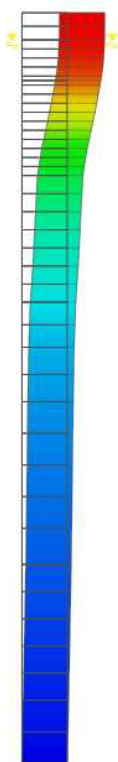
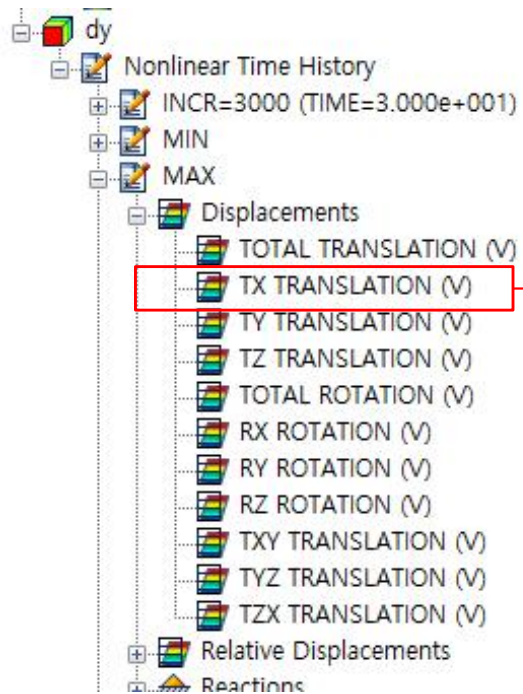
1	4.286e-001	6.210e+000
2	4.273e-001	6.210e+000
3	4.244e-001	6.210e+000
4	4.211e-001	6.210e+000
5	4.151e-001	6.215e+000
6	4.054e-001	6.215e+000
7	3.915e-001	6.215e+000
8	3.828e-001	6.210e+000
9	3.739e-001	6.210e+000
10	3.542e-001	6.210e+000
11	3.356e-001	6.210e+000
12	3.151e-001	6.210e+000
13	2.937e-001	6.215e+000
14	2.718e-001	6.220e+000
15	2.497e-001	6.230e+000
16	2.280e-001	6.230e+000
17	2.105e-001	6.230e+000
18	1.937e-001	6.230e+000
19	1.779e-001	6.240e+000
20	1.667e-001	6.240e+000
21	1.559e-001	6.240e+000
22	1.454e-001	6.245e+000
23	1.352e-001	6.245e+000
24	1.250e-001	6.240e+000
25	1.102e-001	6.230e+000
26	9.622e-002	6.215e+000
27	8.688e-002	6.200e+000
28	7.814e-002	6.190e+000
29	7.277e-002	6.180e+000
30	6.754e-002	6.180e+000
31	6.316e-002	5.700e+000
32	5.849e-002	5.690e+000
33	5.447e-002	5.690e+000
34	5.002e-002	5.680e+000
35	4.441e-002	5.680e+000
36	3.879e-002	5.680e+000
37	3.296e-002	5.680e+000
38	2.700e-002	5.680e+000
39	2.099e-002	5.680e+000
40	1.498e-002	5.680e+000
41	7.626e-003	5.670e+000
42	0.000e+000	1.000e-002
43	4.286e-001	6.210e+000
44	4.273e-001	6.210e+000
45	4.244e-001	6.210e+000
46	4.211e-001	6.210e+000

16. Customization of Results Display

- Set so that only the necessary parts of the output results are displayed in the result tree
- Output generation time can be reduced significantly in models with many large steps and stages, such as nonlinear time history analysis.

▪ Results Tree > ABSOLUTE MAX

Positive/ Negative Result → Change Output format(ABS)

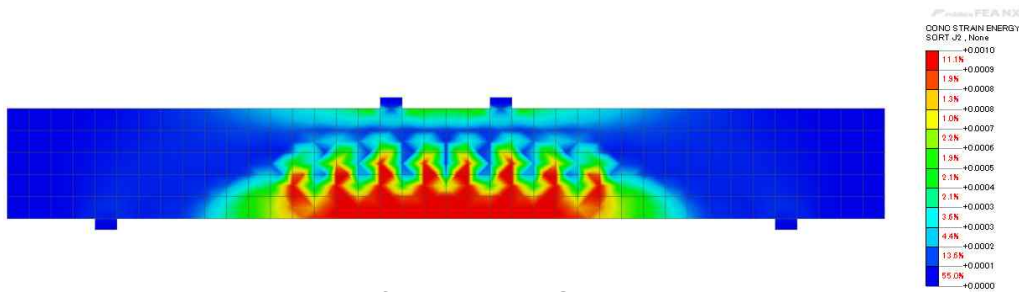


1	4.286e-001	6.210e+000
2	4.273e-001	6.210e+000
3	4.244e-001	6.210e+000
4	4.211e-001	6.210e+000
5	4.151e-001	6.215e+000
6	4.054e-001	6.215e+000
7	3.915e-001	6.215e+000
8	3.828e-001	6.210e+000
9	3.739e-001	6.210e+000
10	3.542e-001	6.210e+000
11	3.356e-001	6.210e+000
12	3.151e-001	6.210e+000
13	2.937e-001	6.215e+000
14	2.718e-001	6.220e+000
15	2.497e-001	6.230e+000
16	2.280e-001	6.230e+000
17	2.105e-001	6.230e+000
18	1.937e-001	6.230e+000
19	1.779e-001	6.240e+000
20	1.667e-001	6.240e+000
21	1.559e-001	6.240e+000
22	1.454e-001	6.245e+000
23	1.352e-001	6.245e+000
24	1.250e-001	6.240e+000
25	1.102e-001	6.230e+000
26	9.622e-002	6.215e+000
27	8.688e-002	6.200e+000
28	7.814e-002	6.190e+000
29	7.277e-002	6.180e+000
30	6.754e-002	6.180e+000
31	6.316e-002	5.700e+000
32	5.849e-002	5.690e+000
33	5.447e-002	5.690e+000
34	5.002e-002	5.680e+000
35	4.441e-002	5.680e+000
36	3.879e-002	5.680e+000
37	3.296e-002	5.680e+000
38	2.700e-002	5.680e+000
39	2.099e-002	5.680e+000
40	1.498e-002	5.680e+000
41	7.626e-003	5.670e+000
42	0.000e+000	1.000e-002
43	4.286e-001	6.210e+000
44	4.273e-001	6.210e+000
45	4.244e-001	6.210e+000
46	4.211e-001	6.210e+000

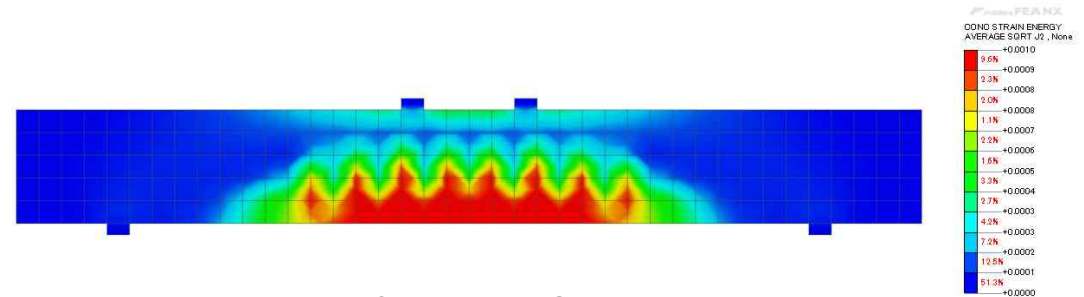
17. Concrete Result item

- Concrete damage evaluation items proposed in concrete standard specifications
- Deviation transformation second invariant, Formalized by transformation energy

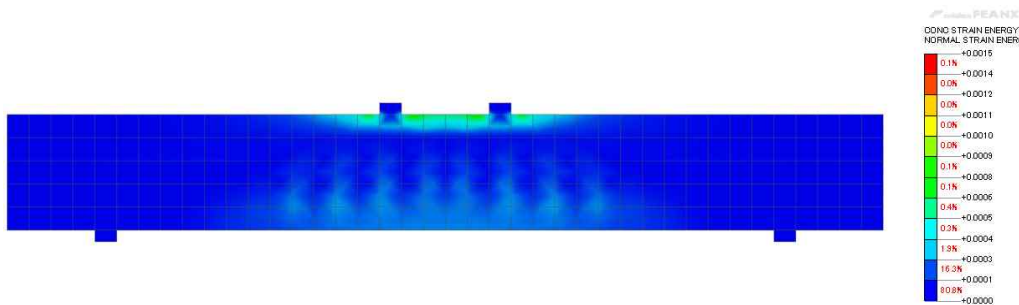
- **Tools > Option > Analysis Result**



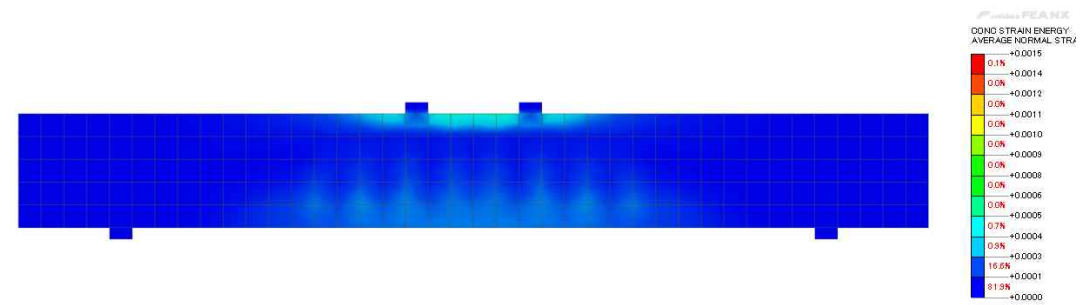
Deviation Transformation Second Invariant



Deviation Transformation Second Invariant (Average)



Formulated Cumulative Strain Energy



Formulated Cumulative Strain Energy (Average)

18. Convert to Load Sets using Load Combination Function

- By utilizing the load combination function, a new load set can be created considering the scale factor of each load set.

Convert to Load Sets

Create Load Set with Combined Load Sets

Combined Load Sets

Name: LC1

Load	Factor
1:Self Weight	1.25
2:2nd Load	1.30
4:Temp gradient	0.90

Convert to Loadsets

OK Cancel Apply

Analysis

- Item ID Color
- Function
- History Output Probe
- Boundary Condition
- Static Load
 - Self Weight 1
 - 2nd Load 2
 - Temp gradient 4
 - Prestress 5
 - LL1-3 6
 - LL1-1 7
 - LL1-2 8
 - LL2 9
 - LL3-1 10
 - LL3-2 11
 - LC1 12
- Dynamic Load
- Thermal Load
- Response Spectrum Load
- Combined Loadsets
 - LC1
- Stage Set
- Analysis Case
 - Transverse - Linear Static
 - Parametric Analysis
 - Partial Factor