Bridge 3D Soil Structure Interaction Methods Comparison

Soil Structure Interaction using midas Civil & midas GTS NX for the Structural & Geotechnical Engineers

Integrated Solver Optimized for the next generation 64-bit platform

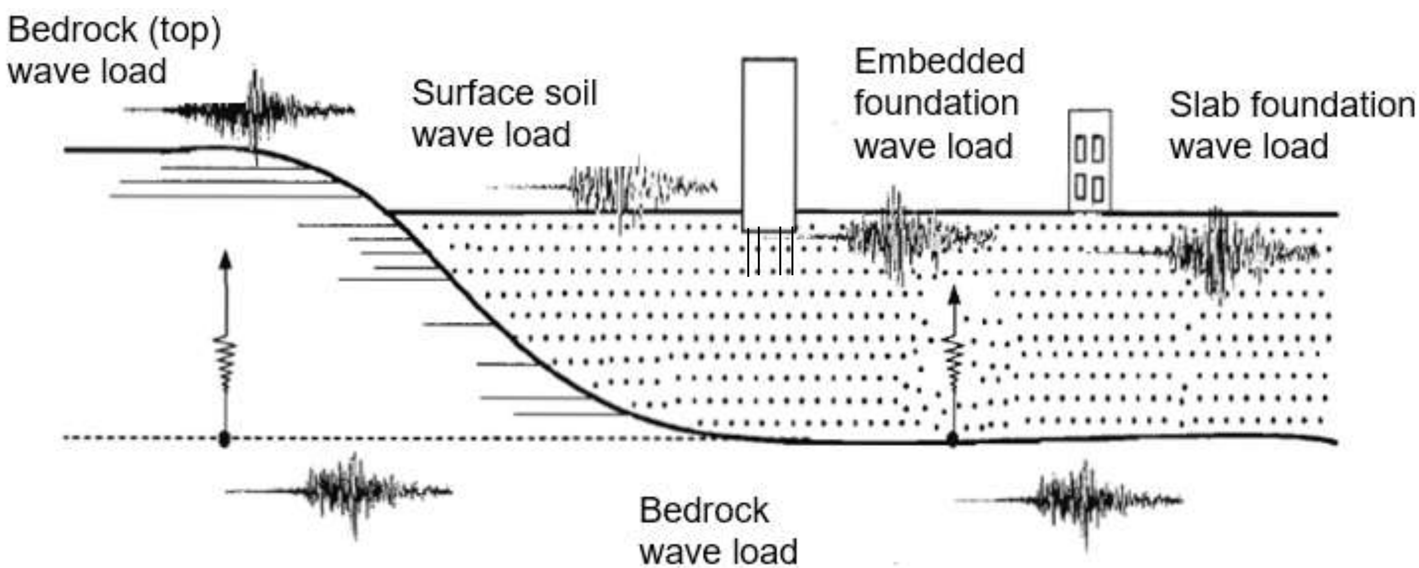
Finite Element Solutions for Geotechnical Engineering

MIDAS

Contents

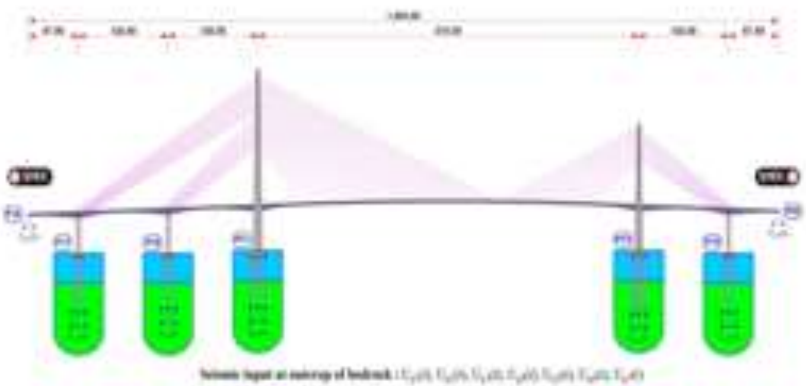
Soil Structure Interaction

SSI: The phenomenon in which the response of soil and movement of the structure influence each other. When external forces, such as earthquakes, act on these systems, neither structural displacements nor ground displacements are independent of each other. Unlike an above-ground structure, the response of an underground structure subjected to an earthquake is mainly controlled by the ground displacement. The ground displacement in turn is largely influenced by the dynamic properties of the ground and its modeling method. The ground exhibits a complete nonlinear behavior depending on the strains developed in the ground due to the dynamic load. It is therefore important to closely examine the nonlinearity of the ground relative to strains.



Dynamic SSI

Substructure Method



Based on superposition of events, it separates the problem into two simpler parts.

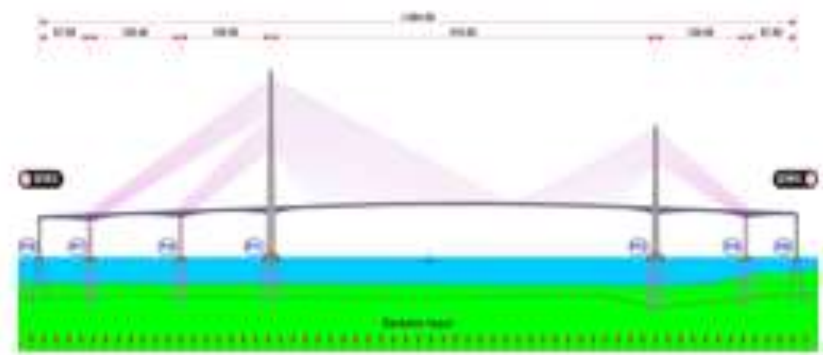
1) Free Field Analysis: The reaction / response of the soil is determined (mainly where the structure will be)

2) Structural Analysis

-The soil can be modeled as spring damper system (impedance) with that response.

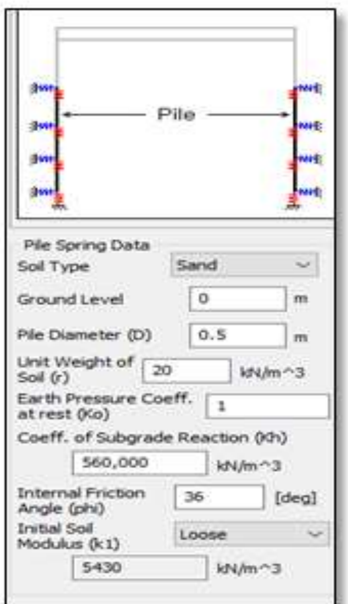
- The detailed structure is designed with the idealization of soil as independent damper springs.

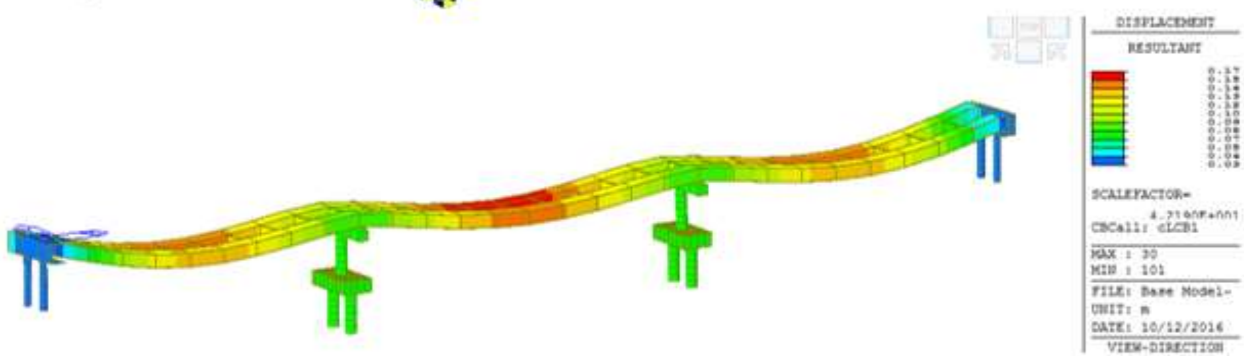
Direct Method



- The soil-structure system is modeled and analyzed in one step directly
- Get response with the two simultaneously.
- Numerical methods: FEM, FDM

Soil Structure Interaction
by Substructure Method



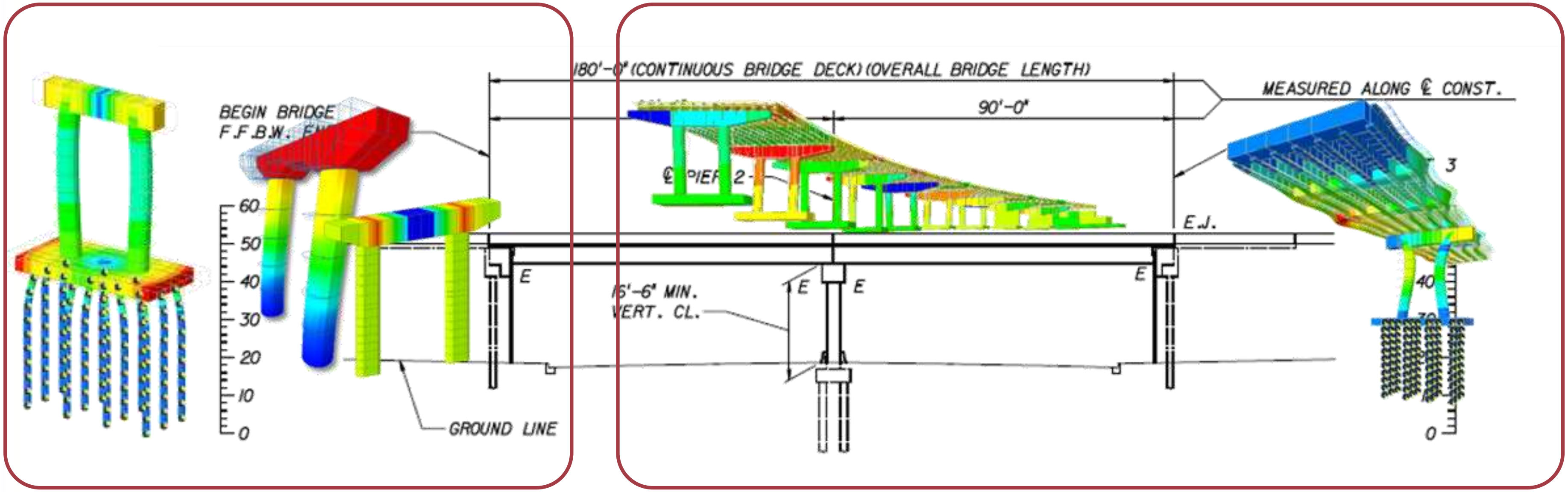


Substructure/Indirect Method

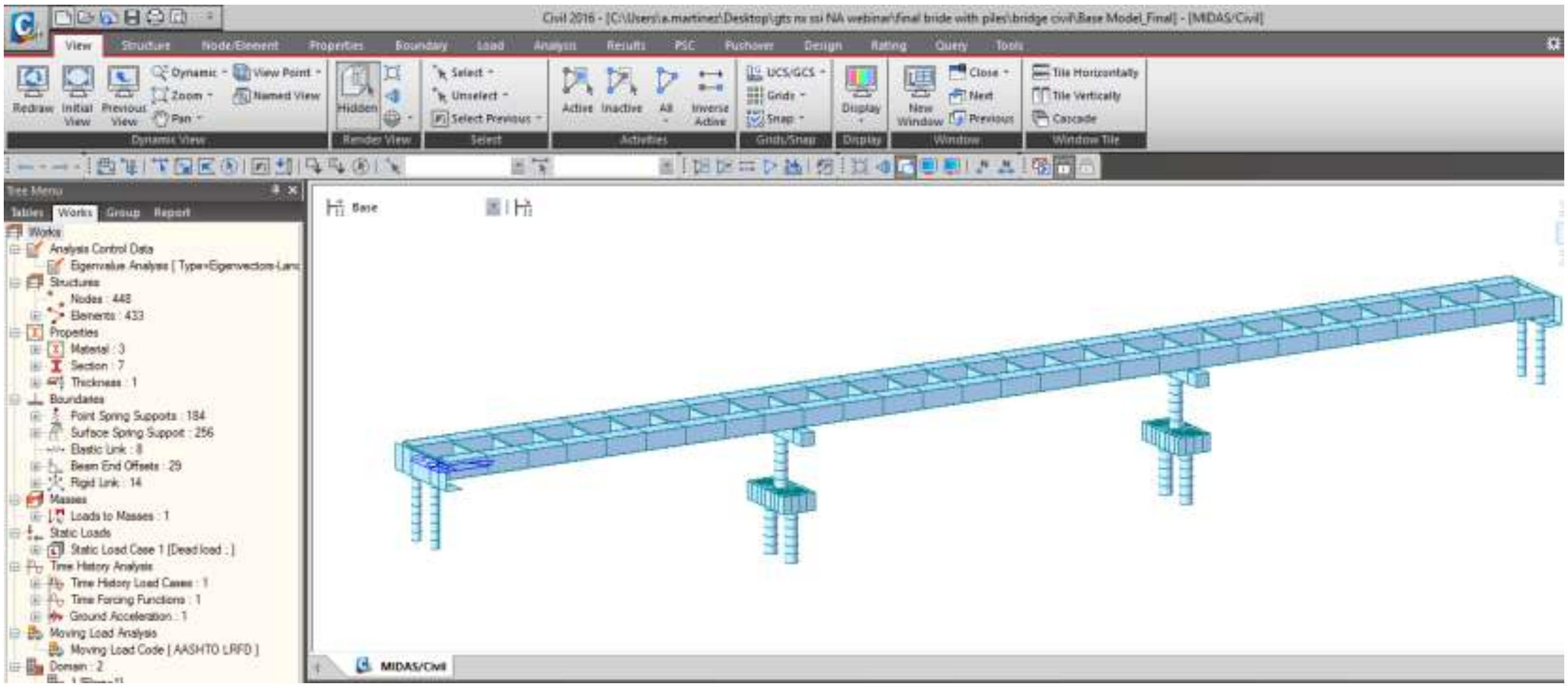
GTS NX

The soil-structure interaction is reflected with soil spring data.

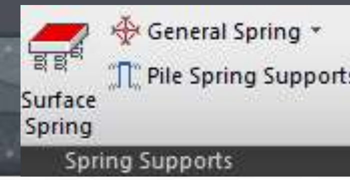
- The soil spring data may be applied to the **substructure-only model** with the superstructure load applied.
- The soil spring data may be applied to the **entire structure model** with both the super and substructure.



Initial Civil model dimensions

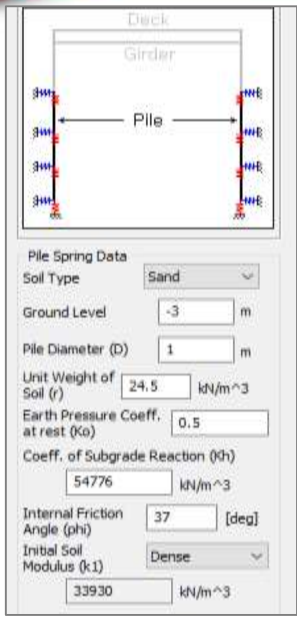


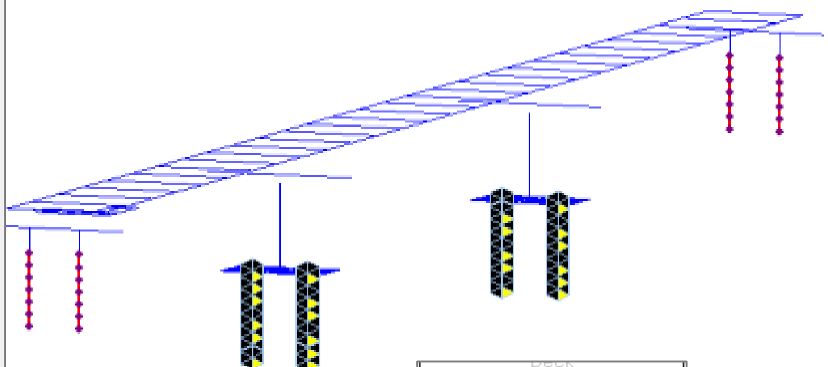
Add Soil Springs Supports

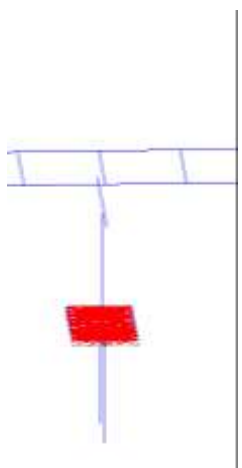


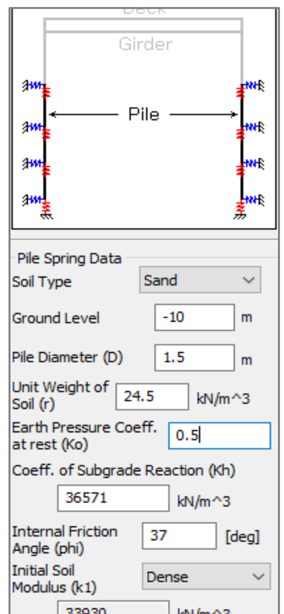
① Use of the modulus of elasticity of ground

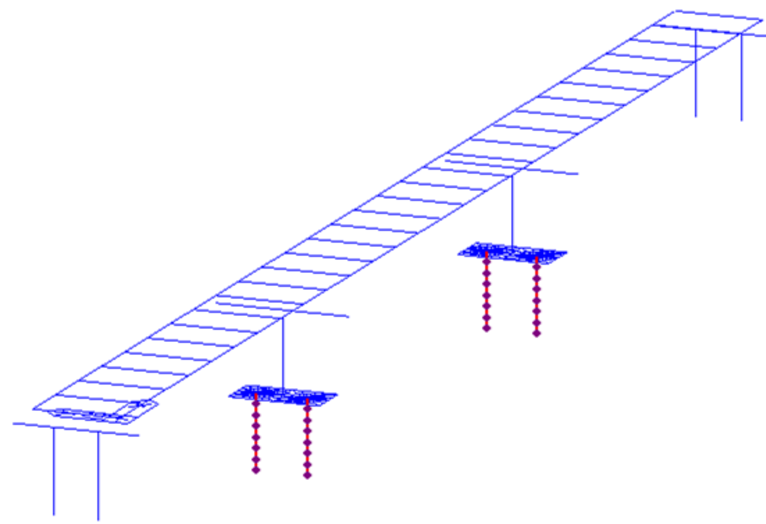
Circular Pile	Kh = 0.56 Es / D	Es: modulus of elasticity



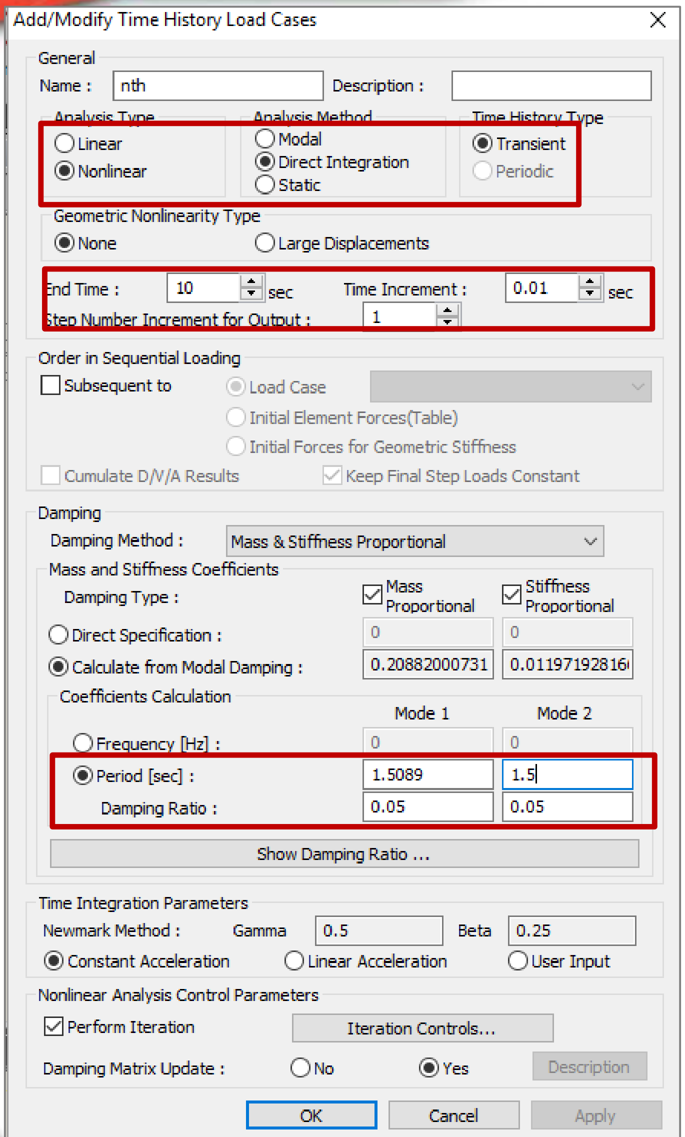


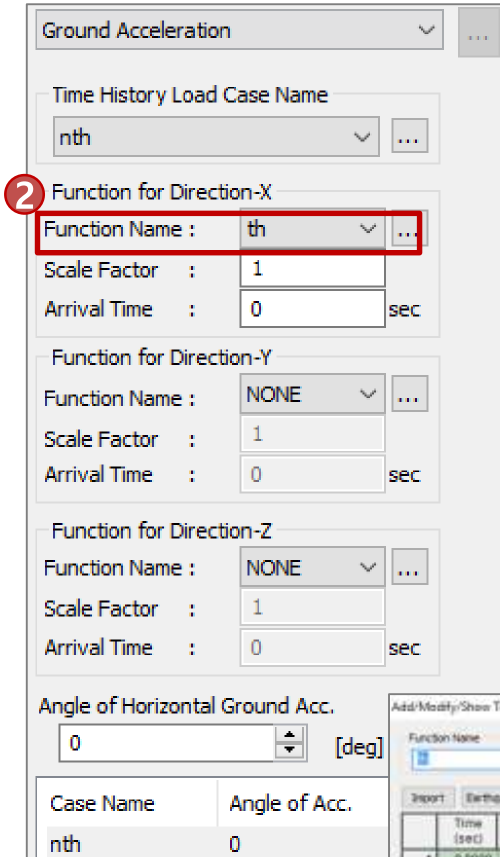


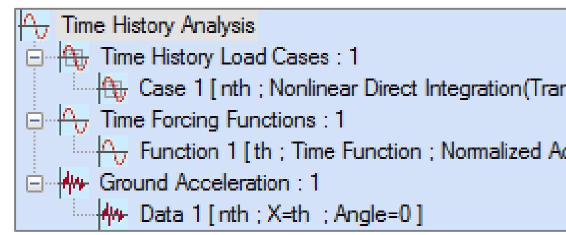


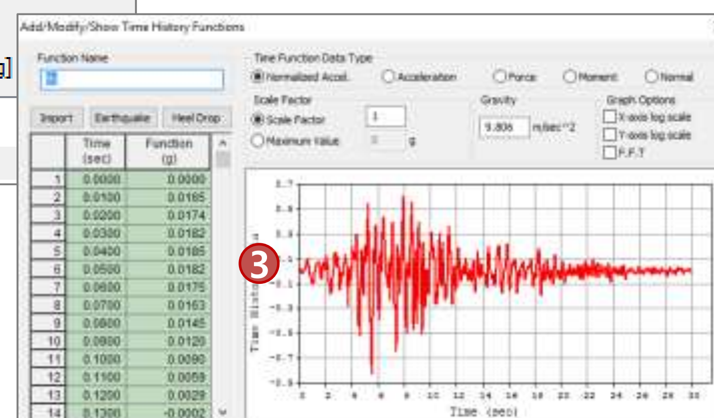


Time History Analysis Case

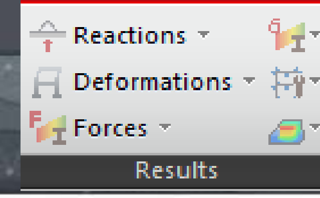


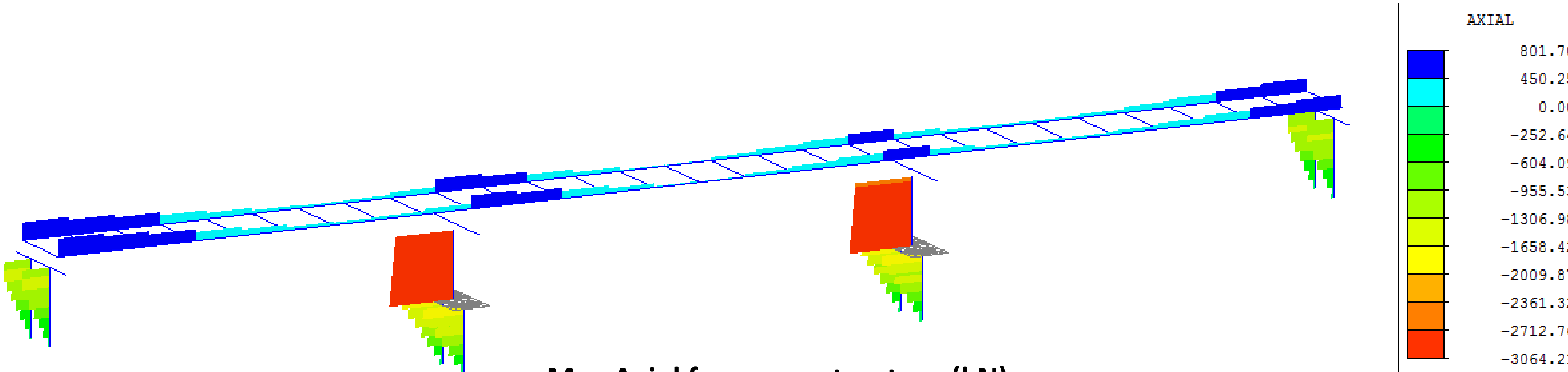




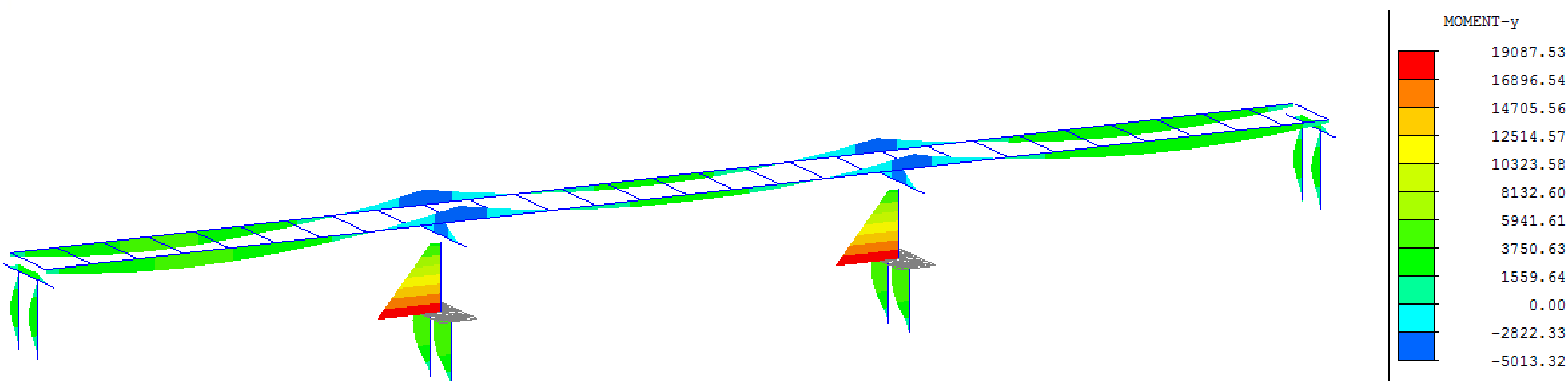


Results for TH in Civil using PY springs



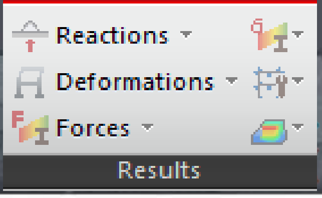


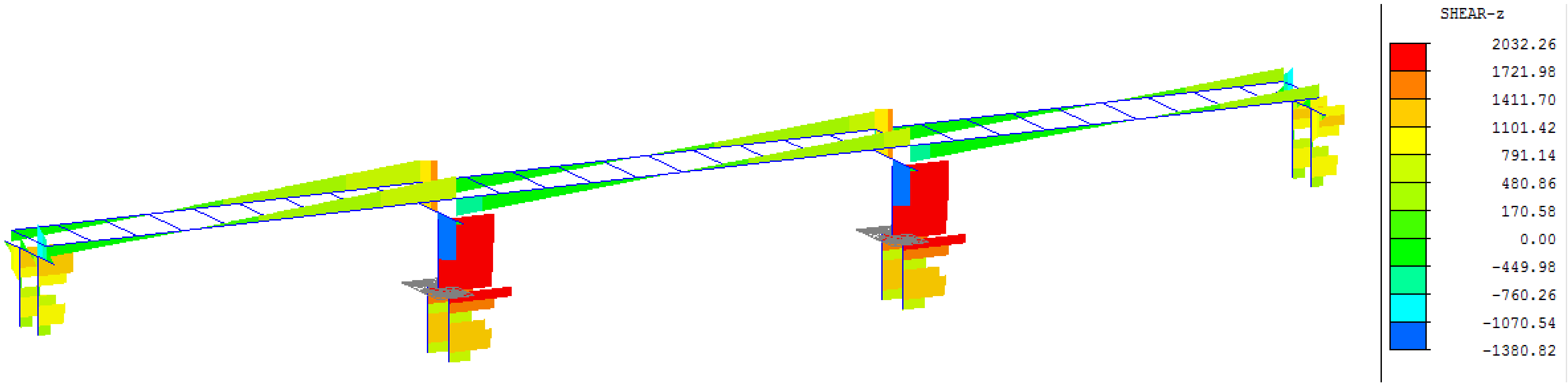
Max Axial forces on structure (kN)



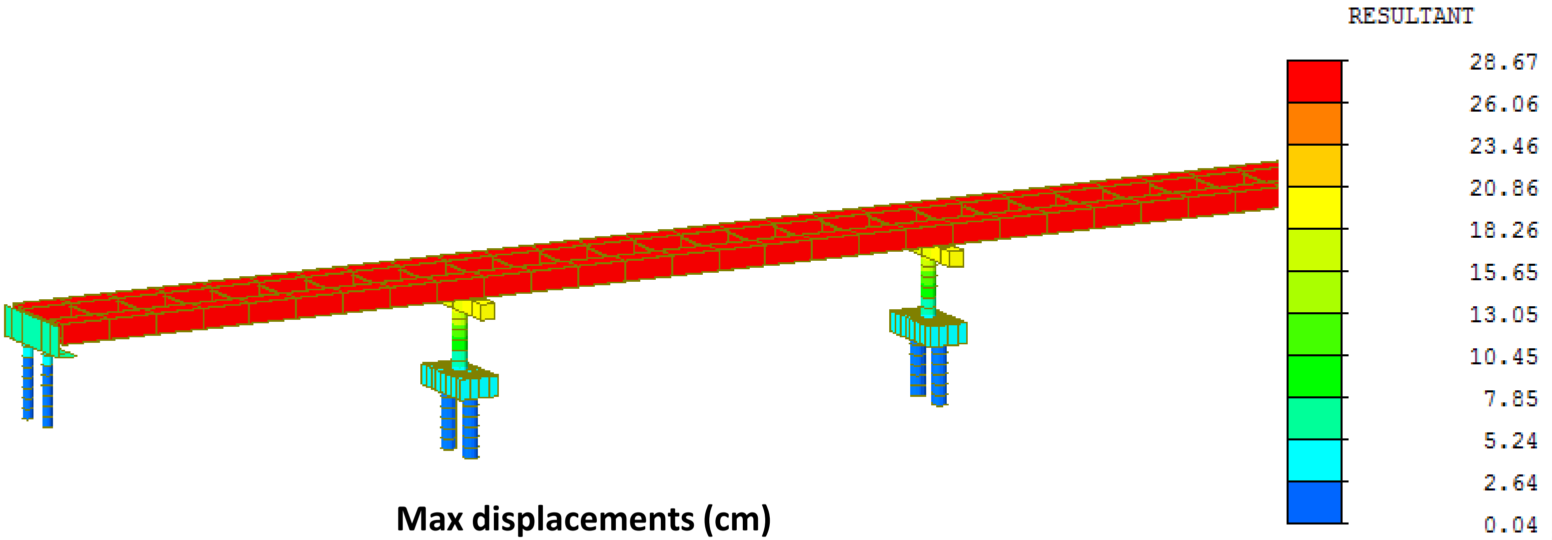
Max moments on structure (kN/m)

Results for TH in Civil using PY springs





Max Shear Forces (Kn)



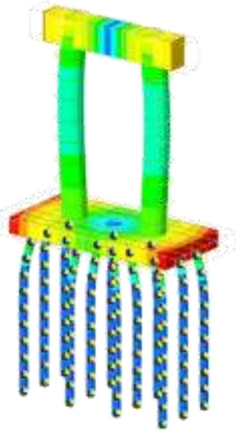
Max displacements (cm)

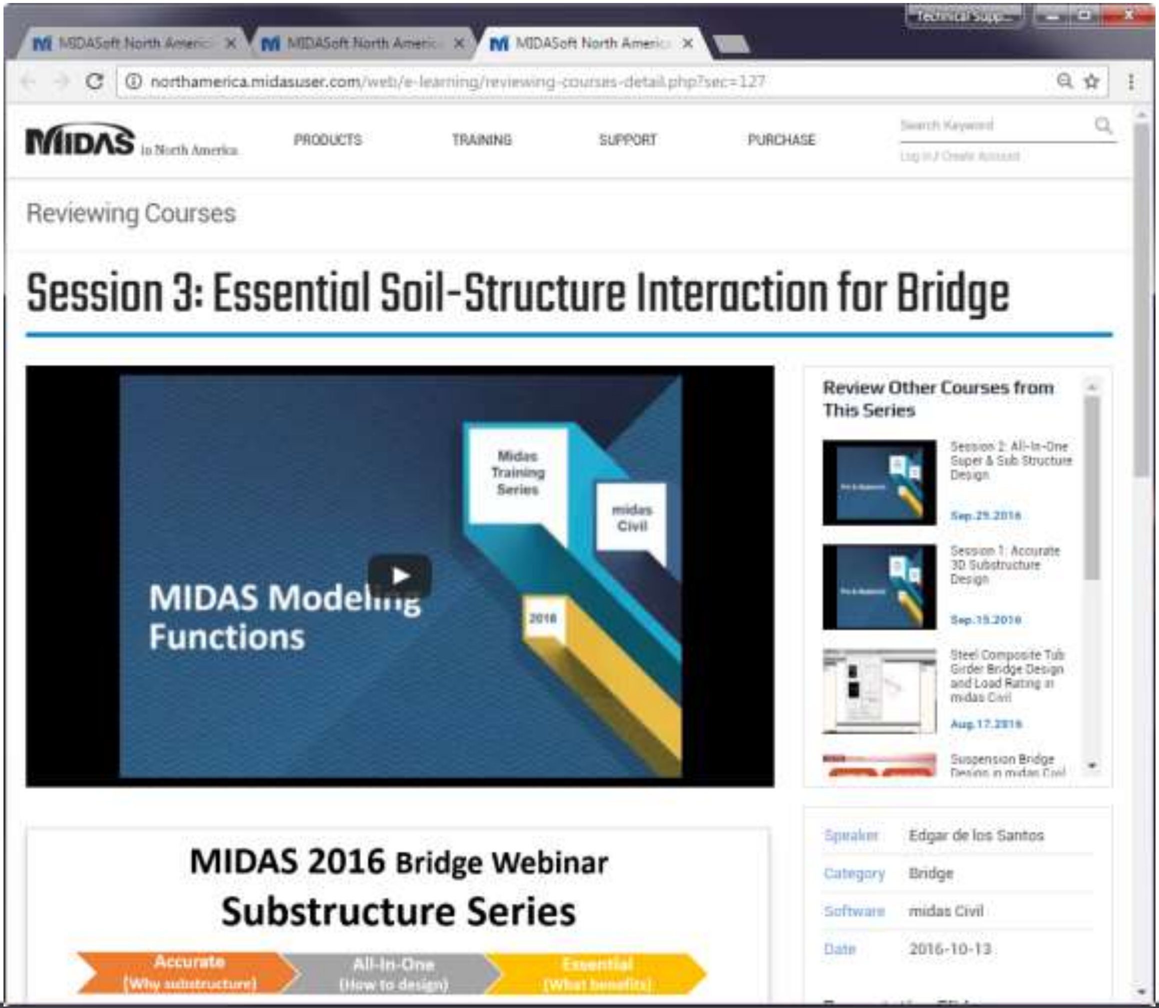
Substructure/Indirect Method

GTS NX

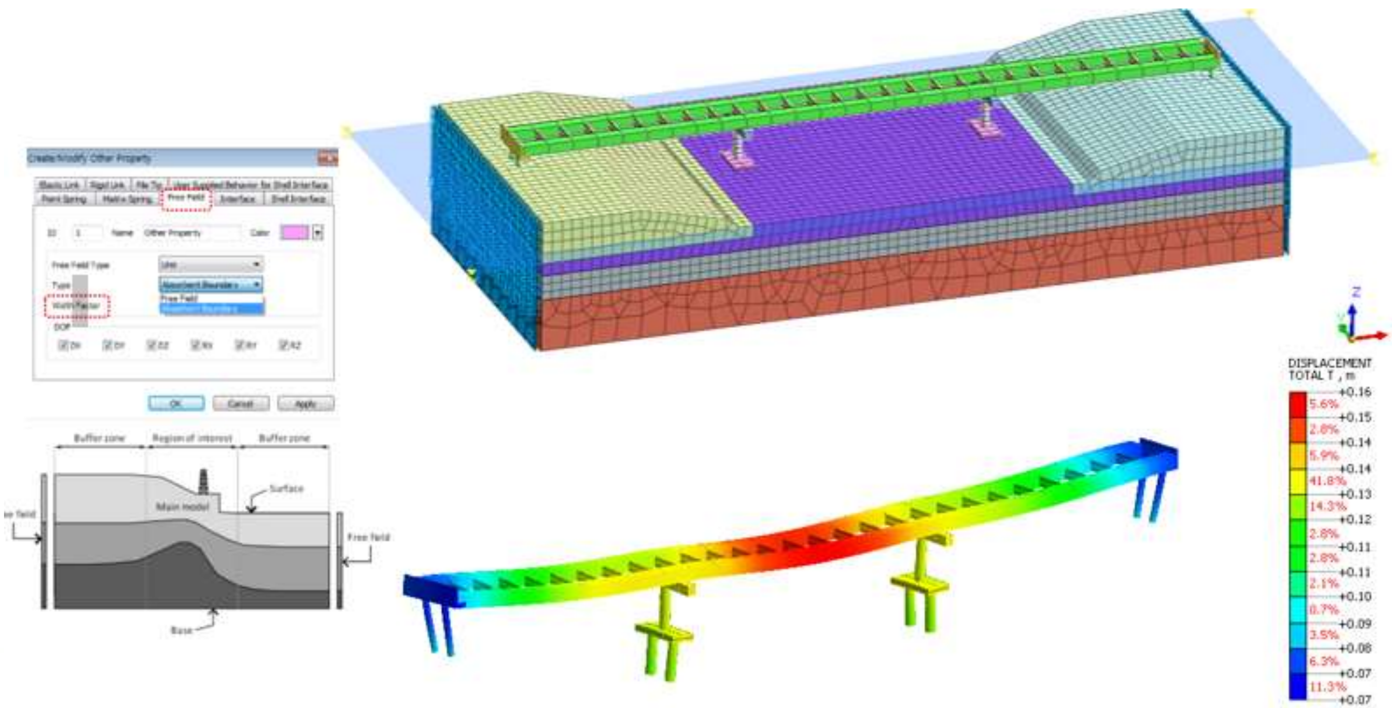
The substructure-only approach:

http://Northamerica.midasuser.com > Training > Review Courses

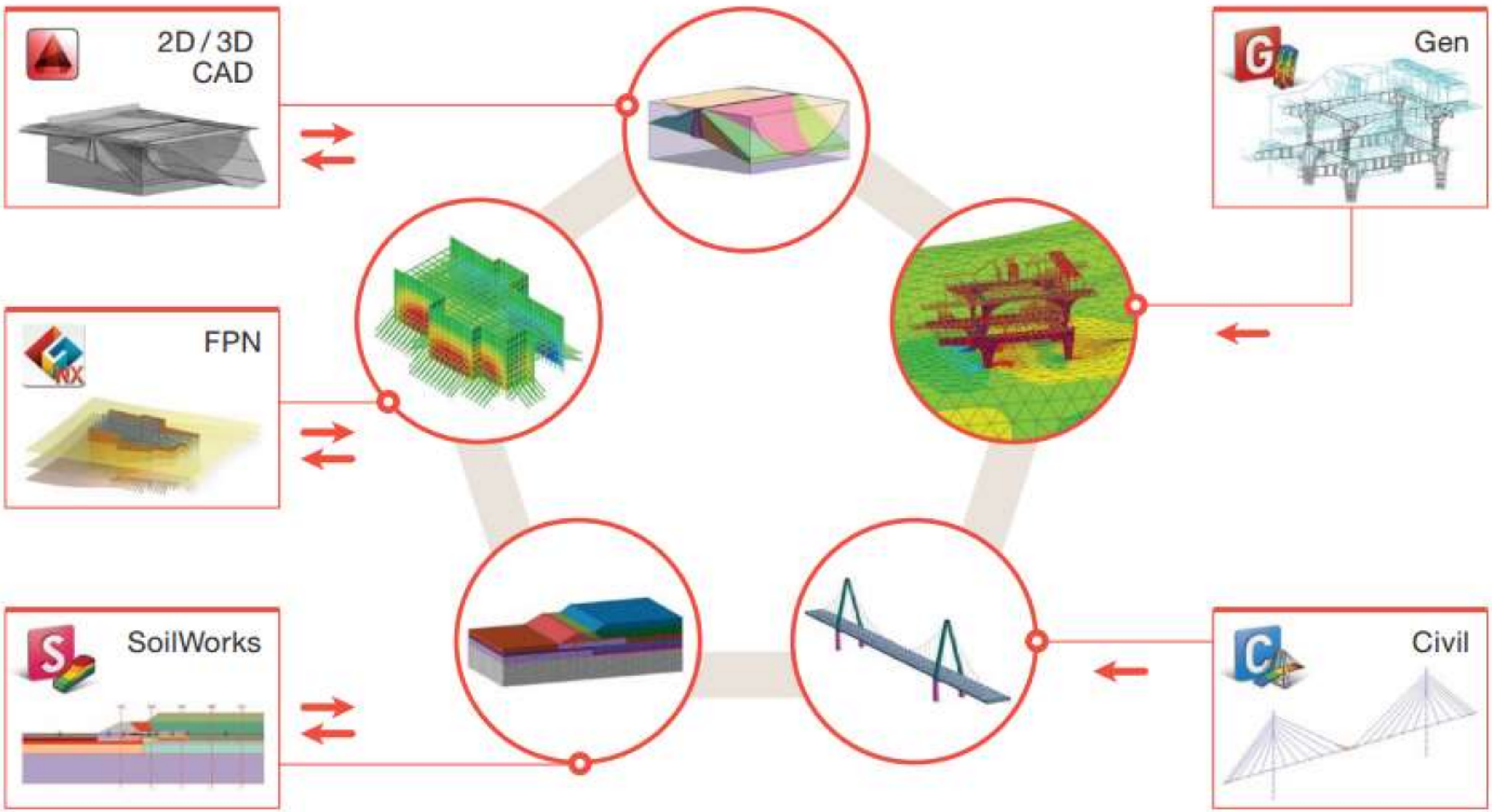




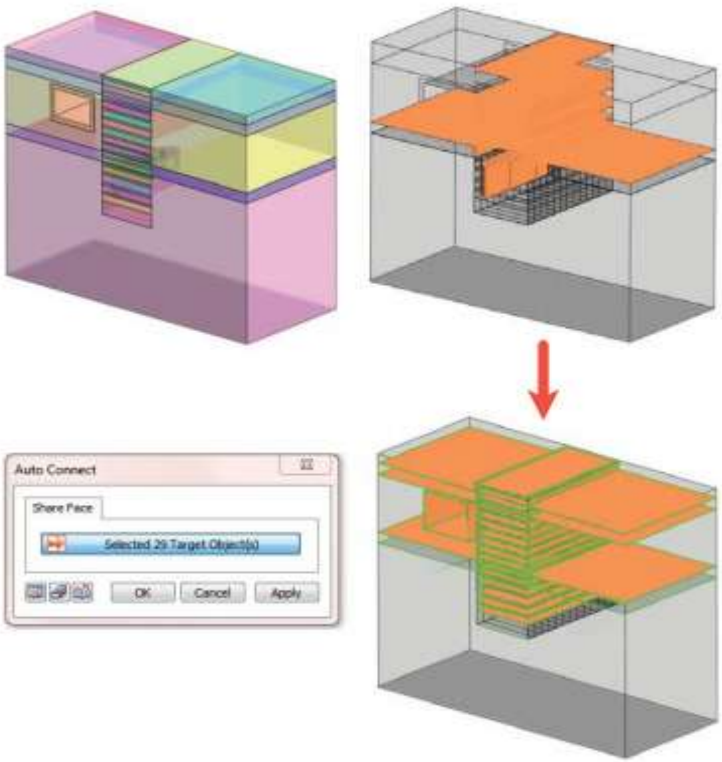
Soil Structure Interaction
by Direct Method

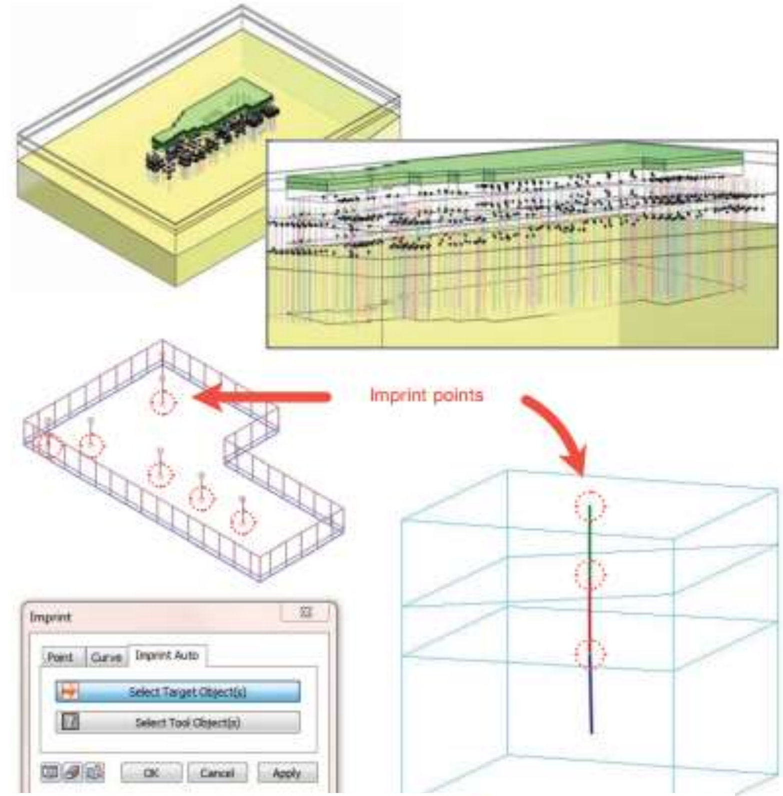


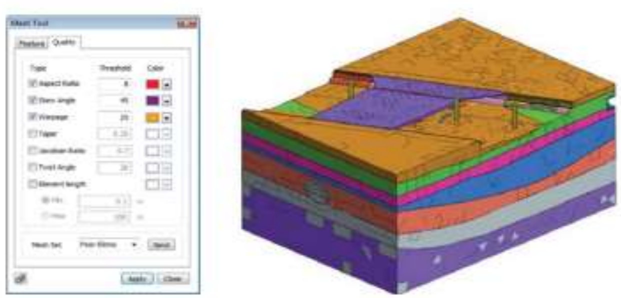
Interaction with other software



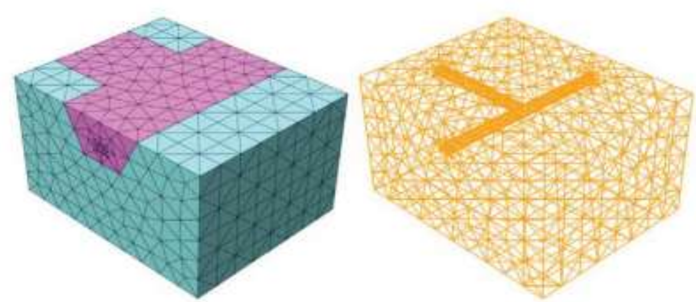
Tools to check or verify mesh quality







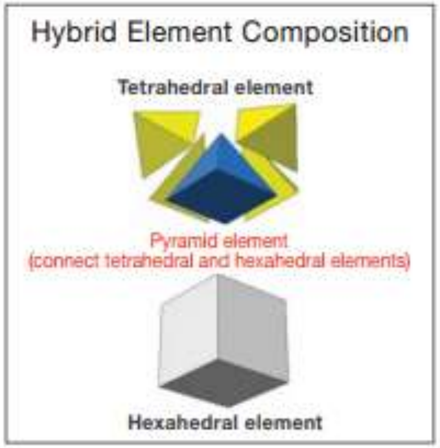
Mesh quality check ▲

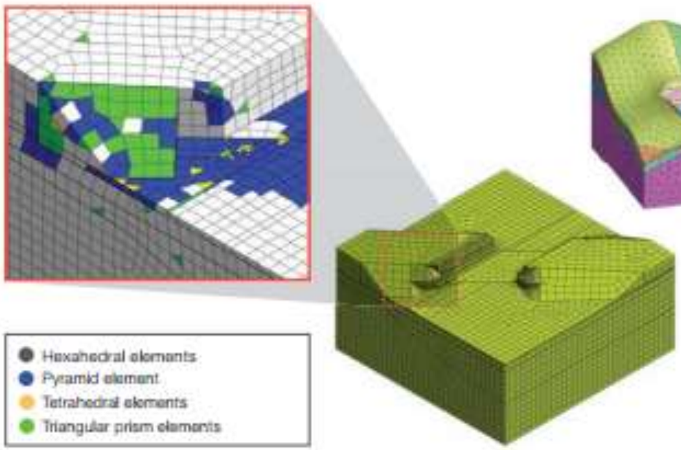


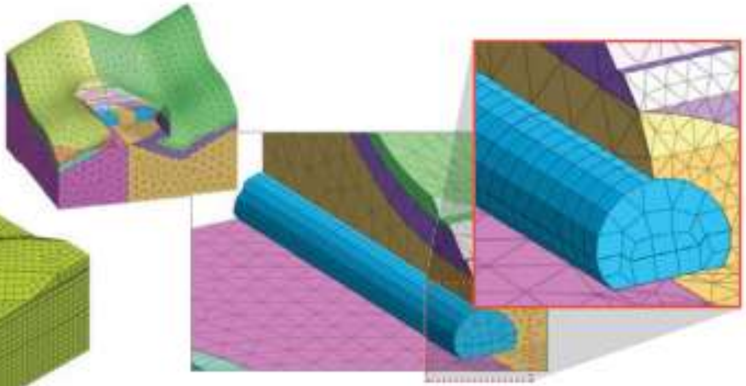
Mesh check (Free Face) ▲

Hybrid Mesher

To provide more reliable analysis results, GTS NX can automatically generate hexahedral centered hybrid mesh. Hexahedral elements are the most stable for stress and displacement results.







Hybrid + Bonded contact element generation ▲

Extensive Constitutive Model Data Base

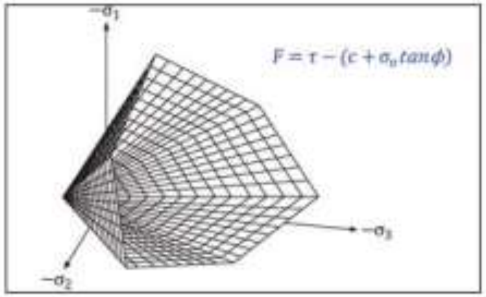
CIVIL GTS NX

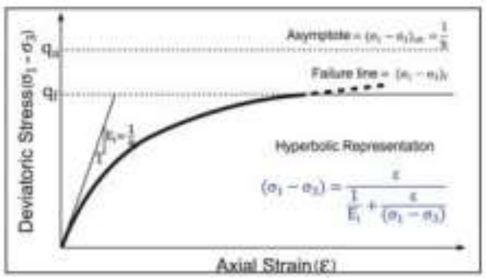
Elastic Materials

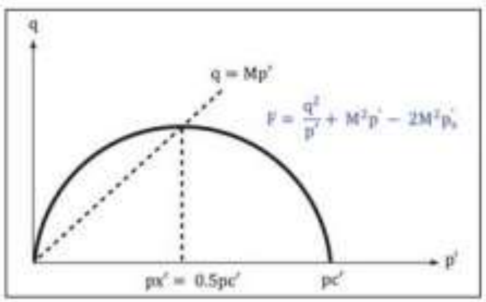
- Linear Elastic Isotropic
- Linear Elastic
- Transversely Isotropic
- Interface Elastic
- Nonlinear Elastic (1D)
- Jardine
- D-Min
- Hyperbolic (Duncan-Chang)

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





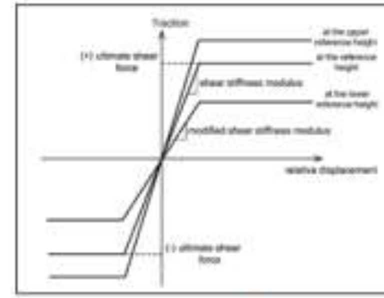


Undrained Materials

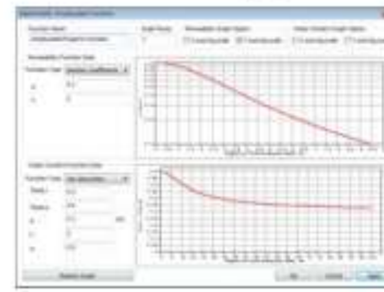
- Effective Stiffness / Effective Strength
- Effective Stiffness / Undrained Strength
- Undrained Stiffness / Undrained Strength

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)

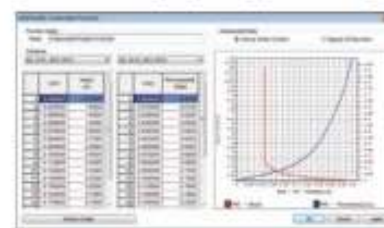


Pile bearing ▲



Unsaturated property (Individual) ▲

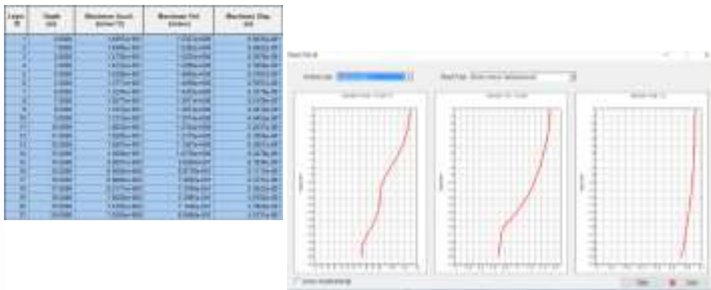
Strain compatibility ▲

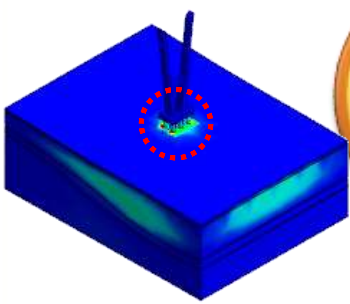


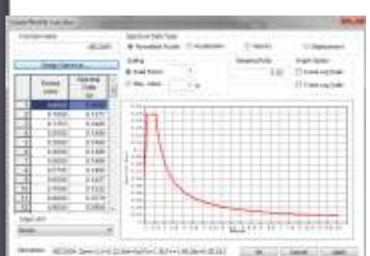
Unsaturated property (Relation) ▲

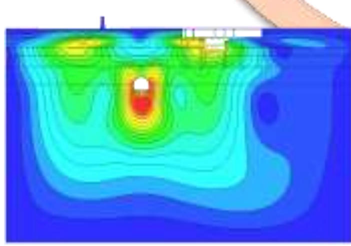
Dynamic Analysis

- Free Field









Linear Equivalent

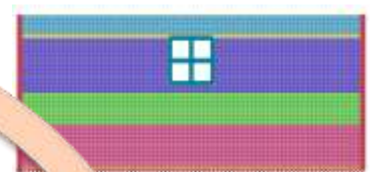
Eigen Value

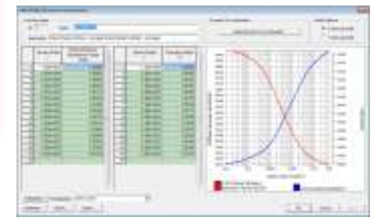
GTS NX & Civil

Time History

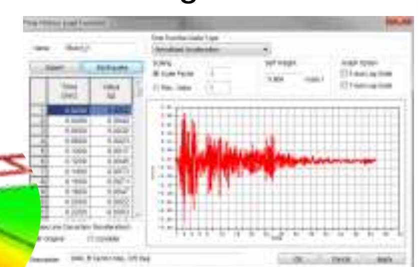
Response Spectrum

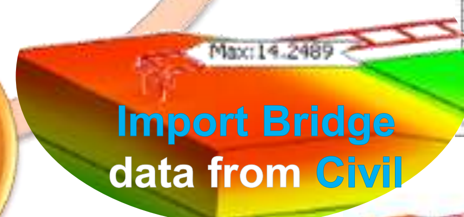
- 2D Linear Equivalent

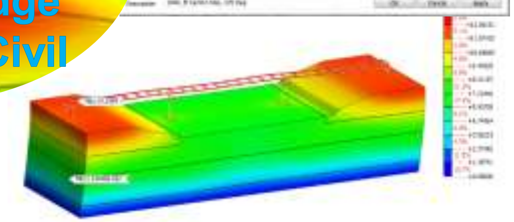




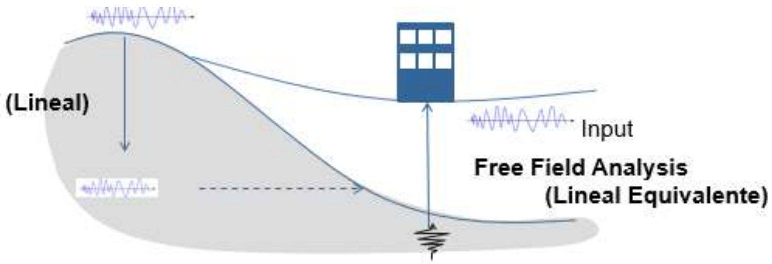
- Linear (Direct)
- Linear (Modal)
- Non linear (Direct)
- Non linear + SRM
- Liquefaction
- Moving Load



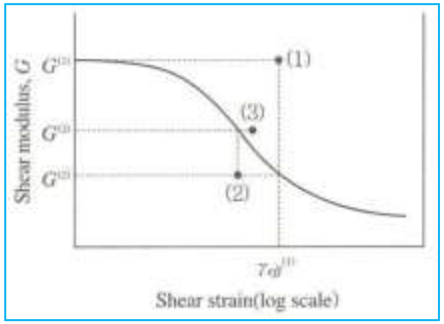


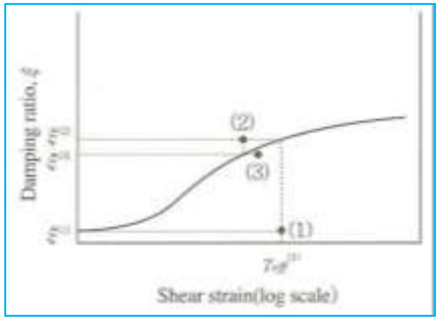


Linear Equivalent 1D and 2D

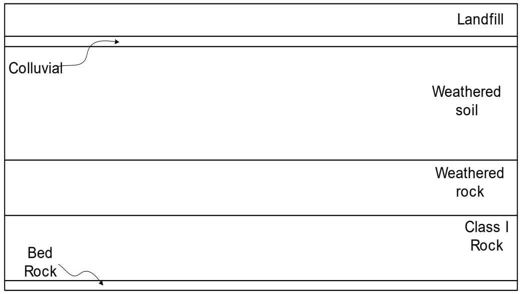


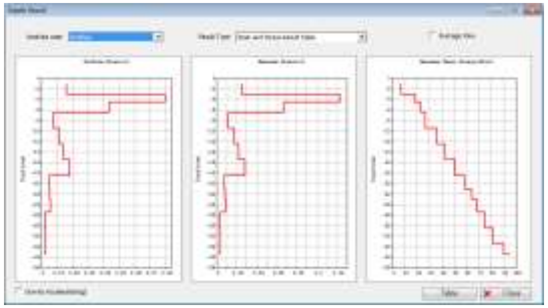
Dynamic Curve



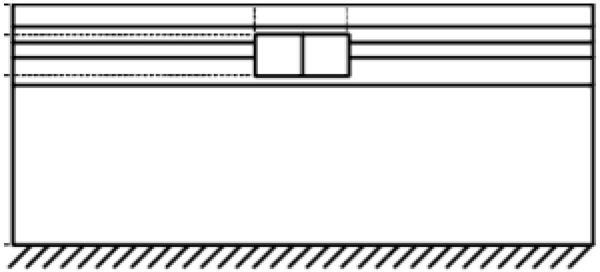


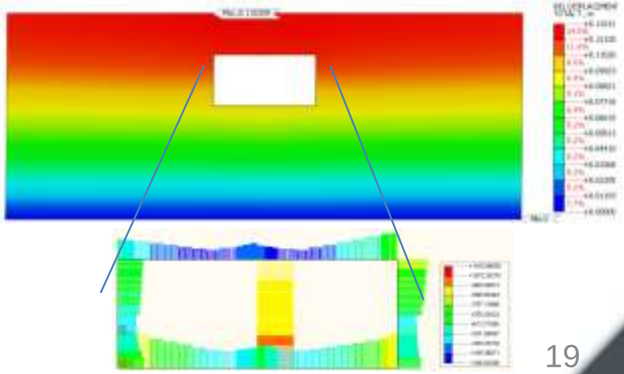
Free Field





2D Linear Equivalent

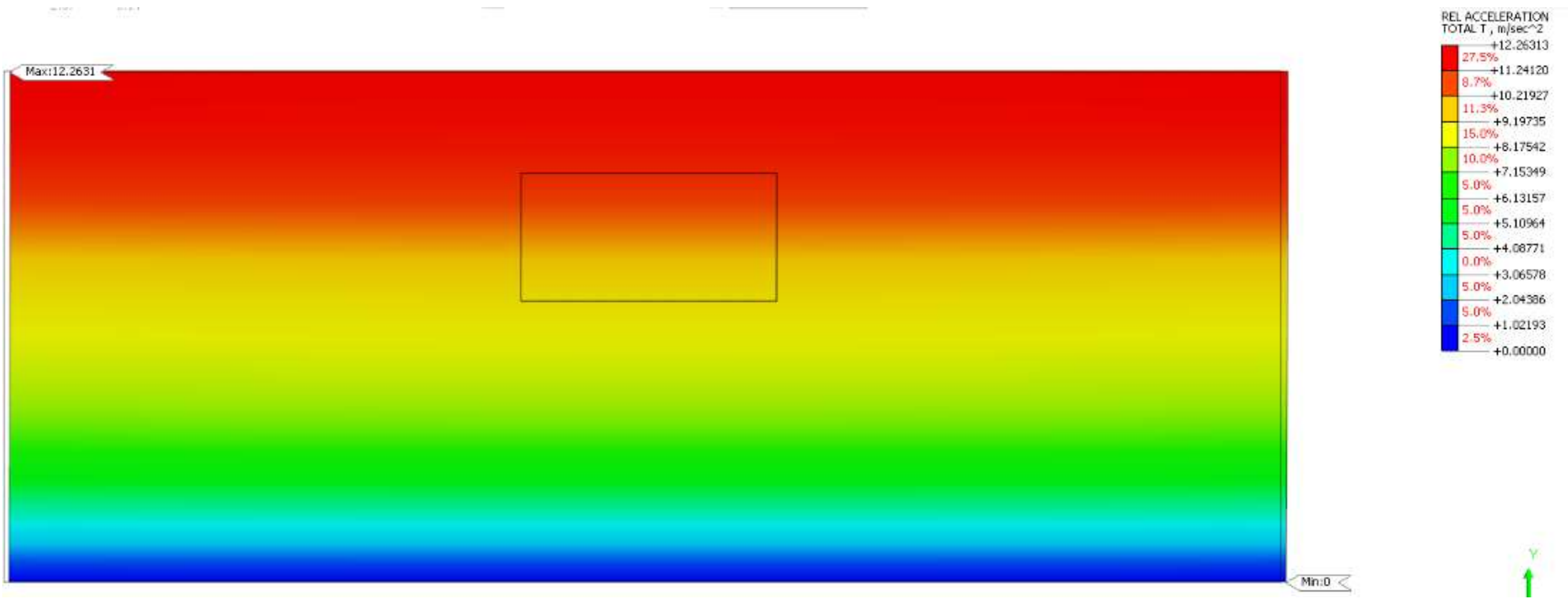




Linear EQ (Free Field)

Short Time History Function (2 sec Analysis)

Max acceleration (12 m/sec^2)

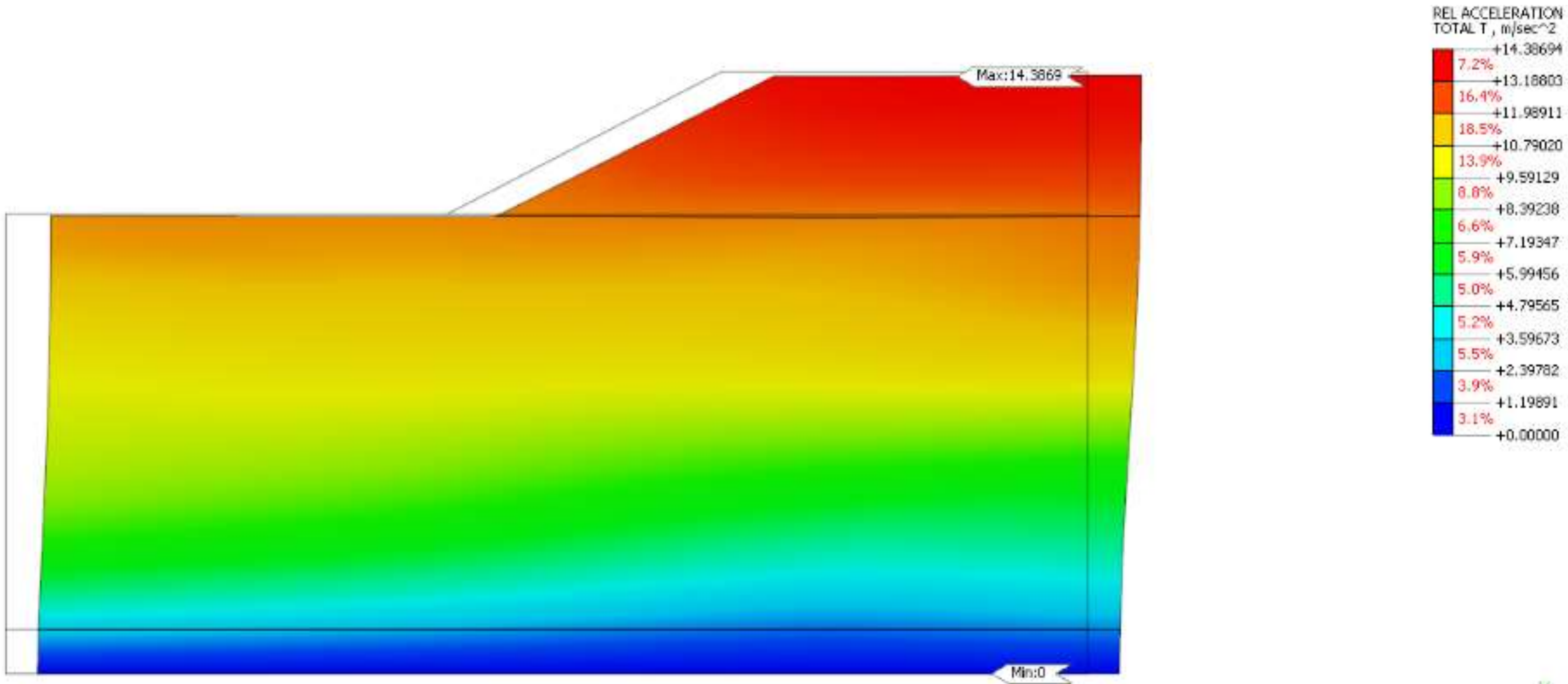


Linear EQ

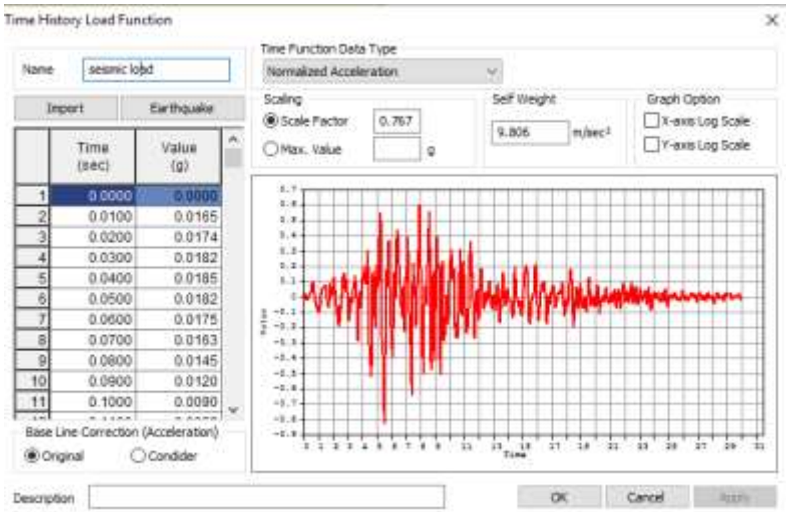
Add embankment to soil layer

Short Time History Function (2 sec Analysis)

Max acceleration (14.3 m/sec^2)



3D Time History Analysis



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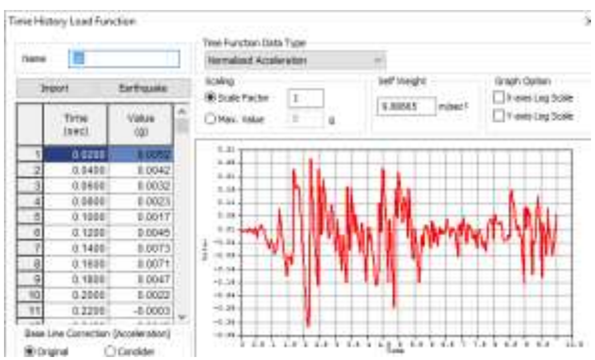
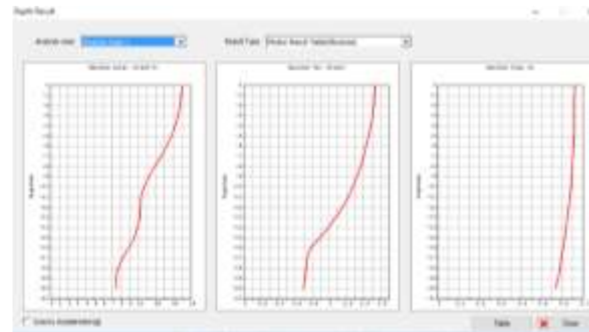
Finite Element Solutions for Geotechnical Engineering

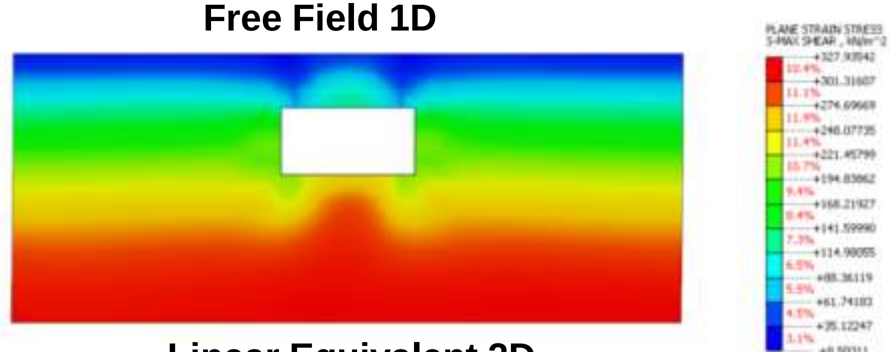
Dynamic SSI

Use same dynamic curve and time history function

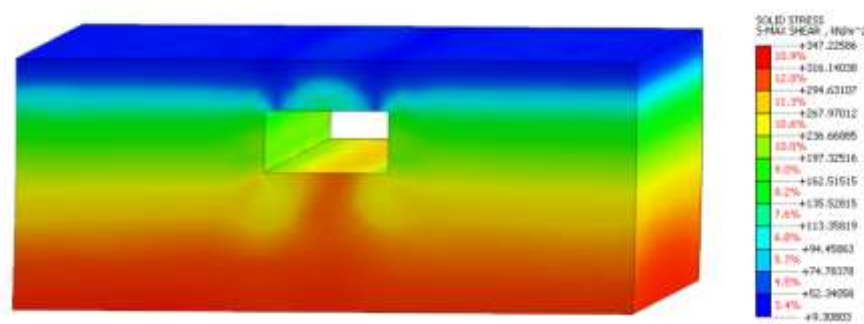




Free Field 1D

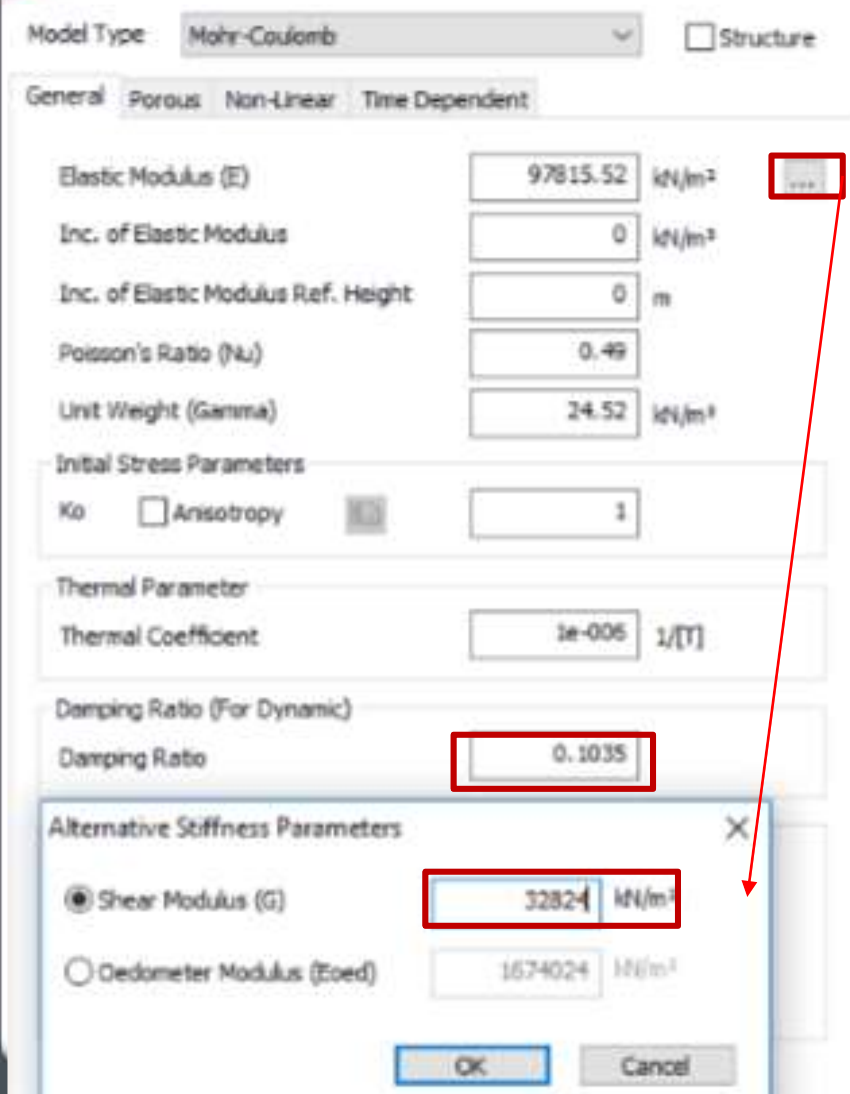


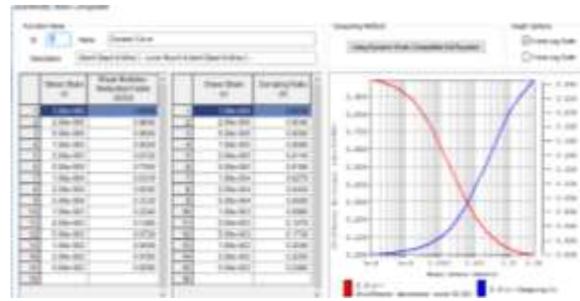
Linear Equivalent 2D



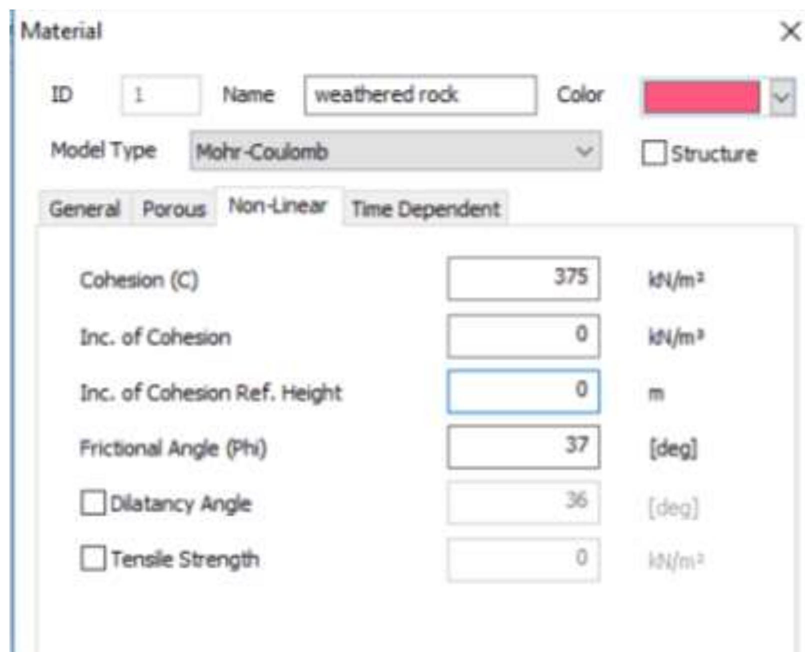
Time History 3D

Define 3D LTH Material (Ground Only)

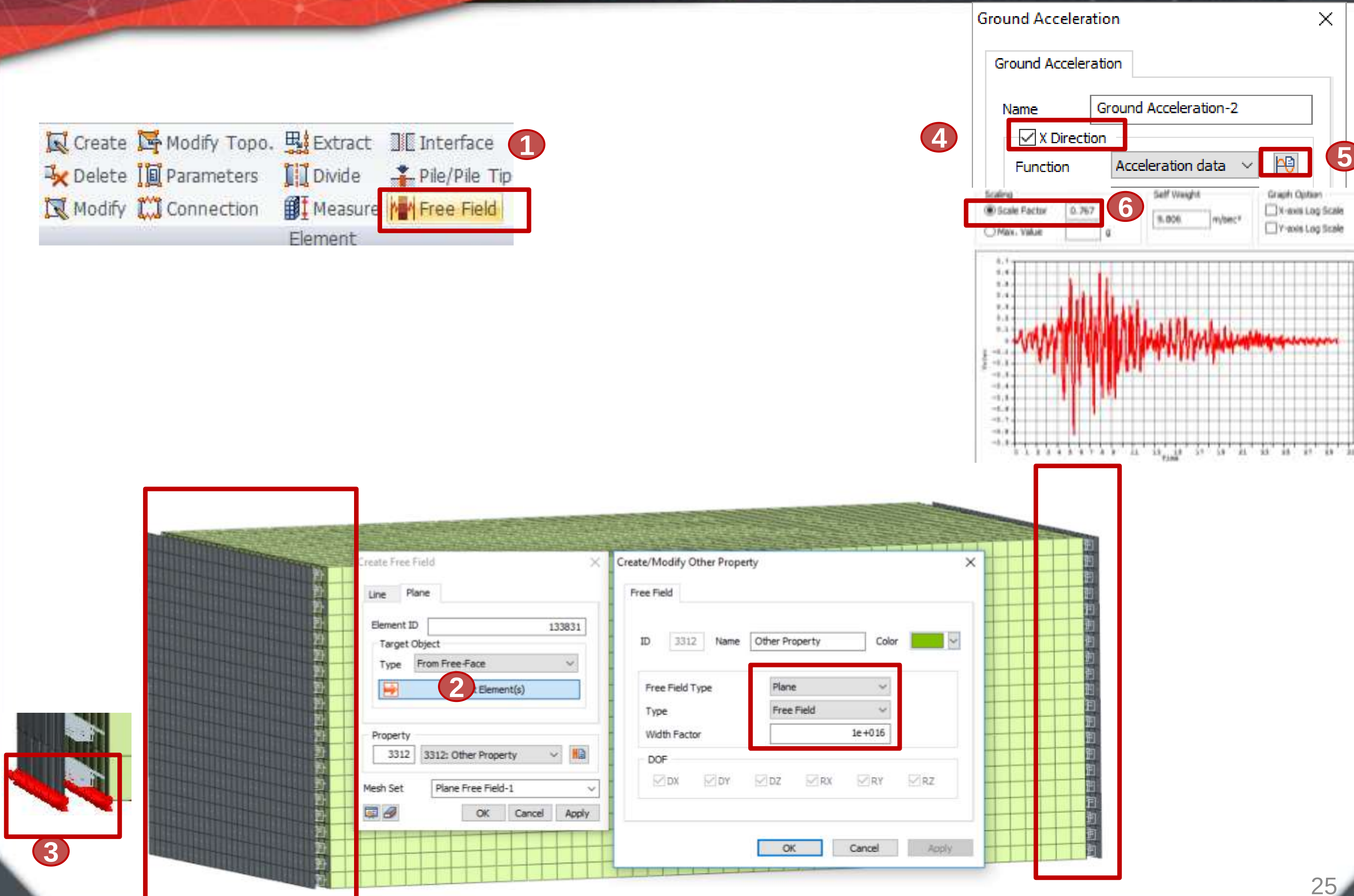




Shear Strain	G/G0	New G	D
0.01	0.3257	34,459	0.1012
0.0124	0.31025	32,824	0.1035
0.02	0.2639	27920	0.1104

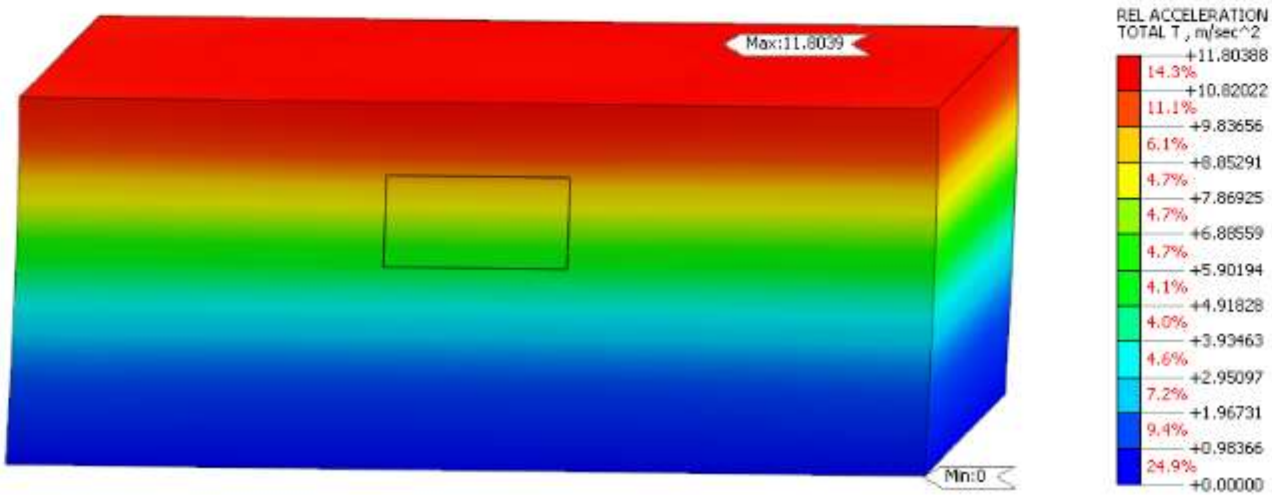


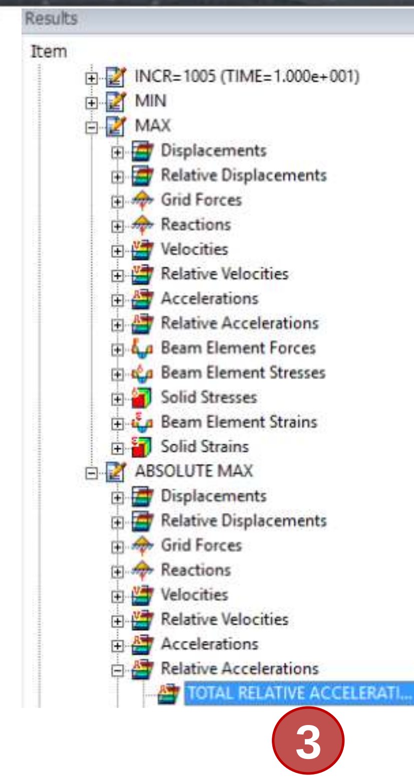
3D LTH Loads and Boundaries (ground only)



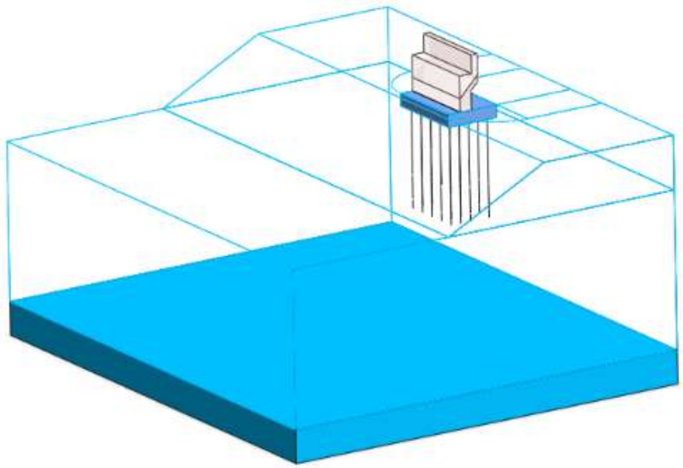
3D Linear Time History Results (ground only)

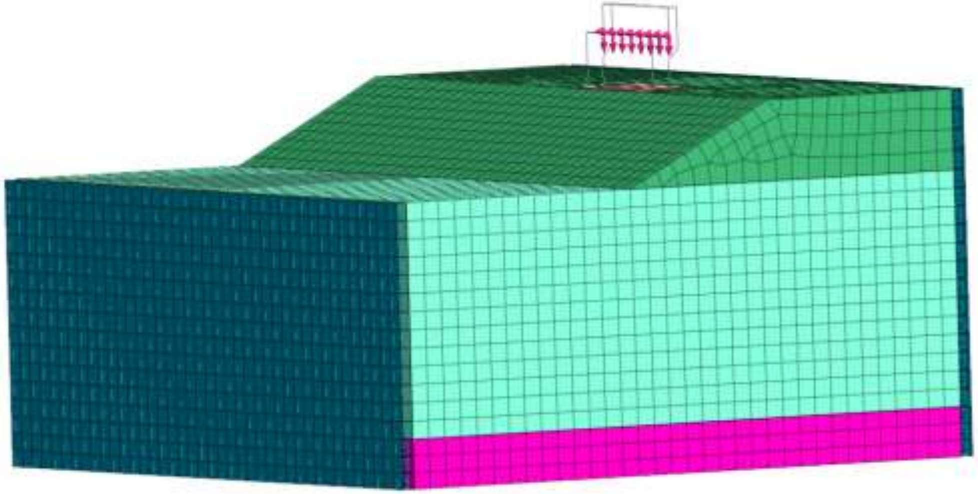
Results for Linear Time History is within 5%. Max of 11.8 m/sec^2
2 sec Analysis*

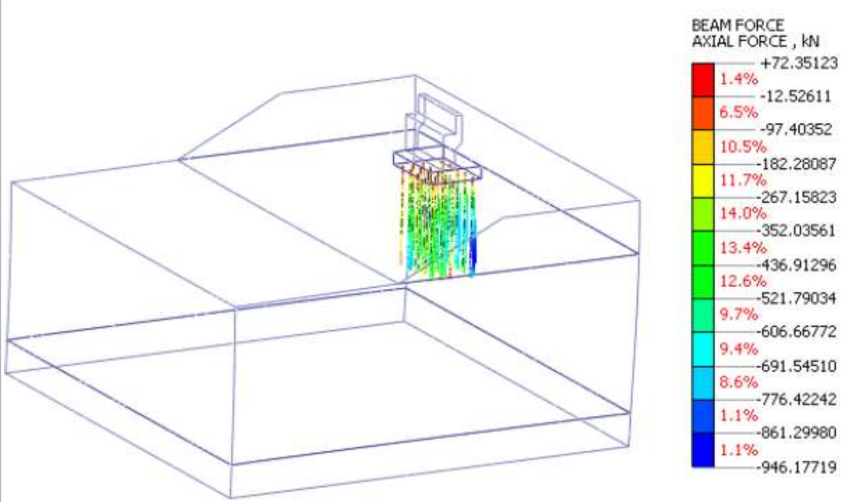


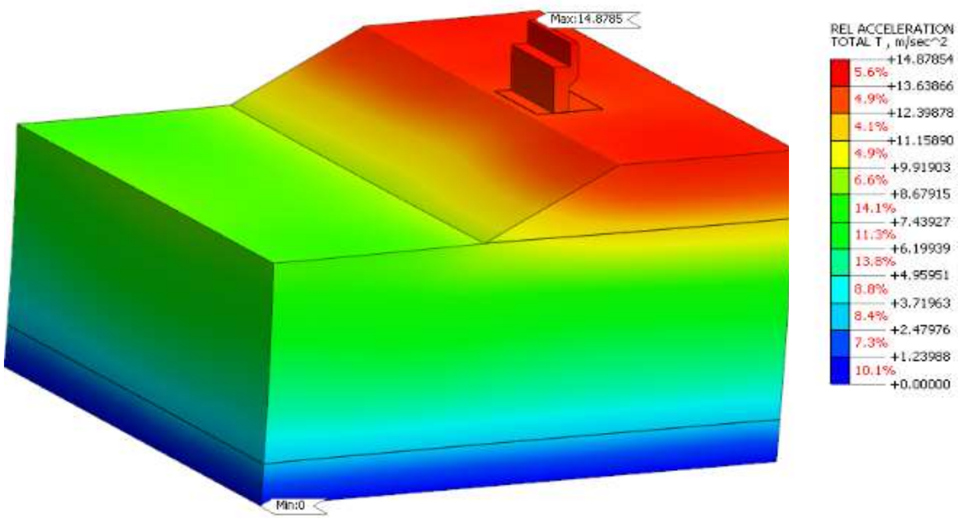


3D Linear Time History Results

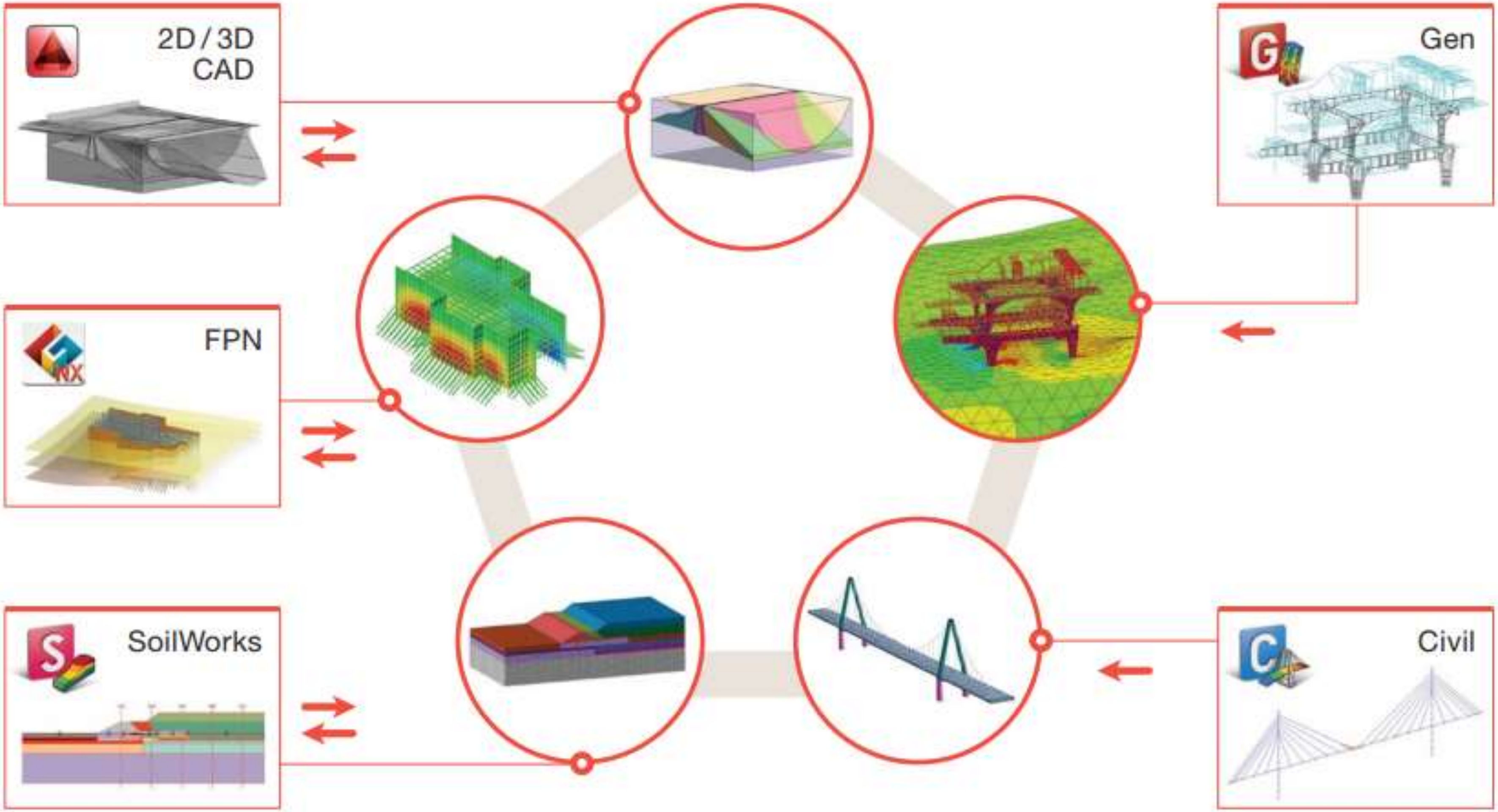




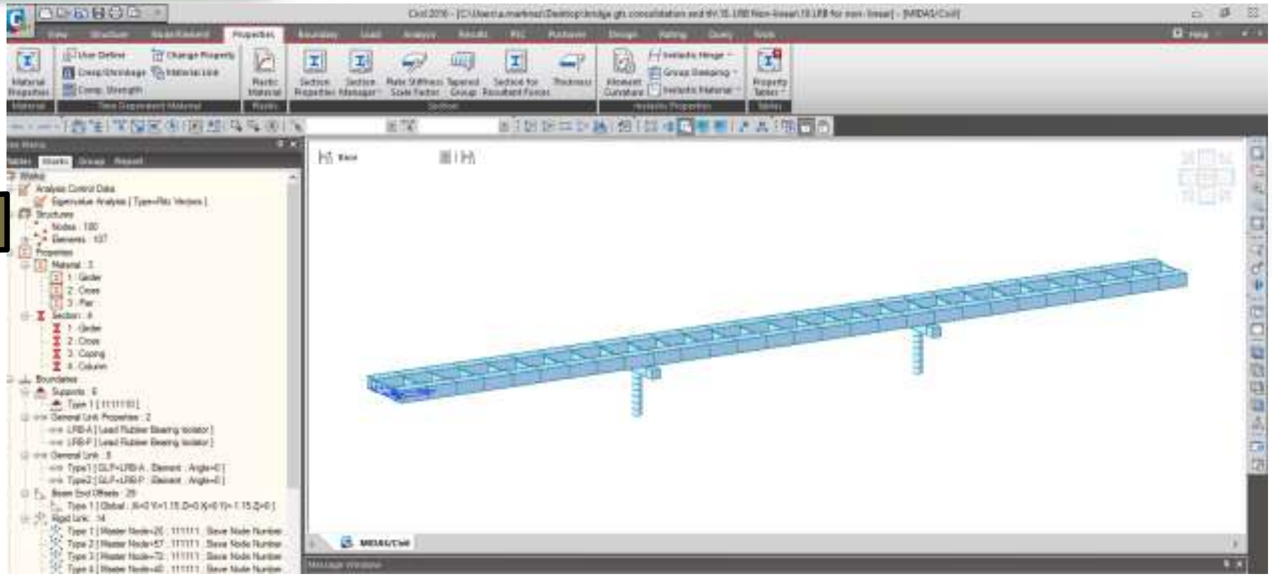




Interaction with other software

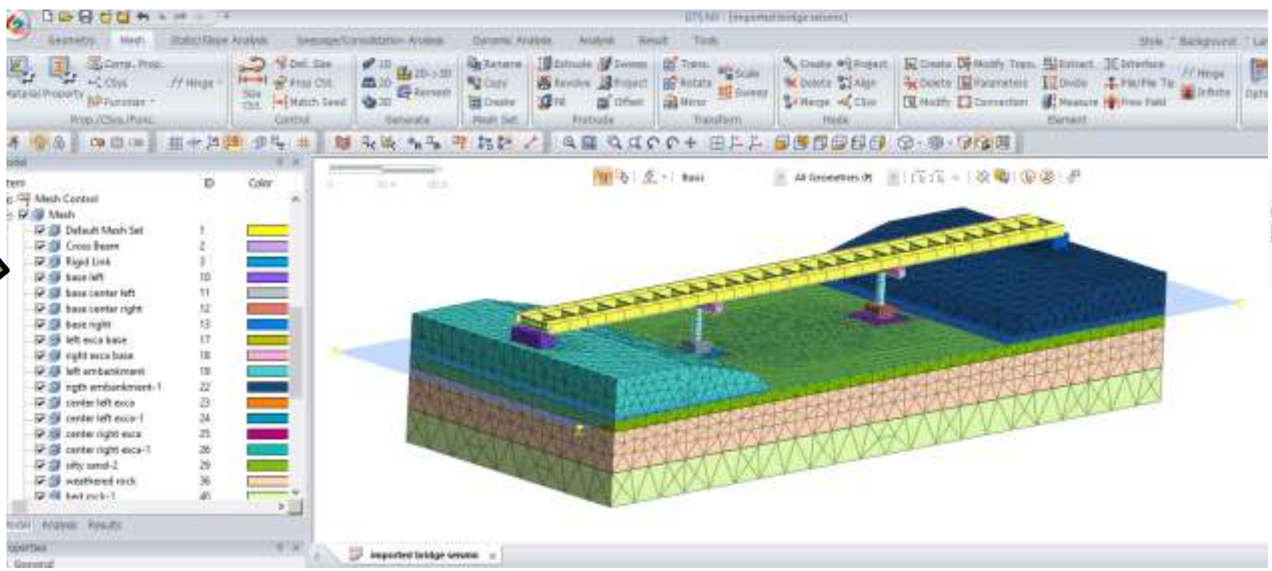


3D SSI



BRIDGE ENGINEERING

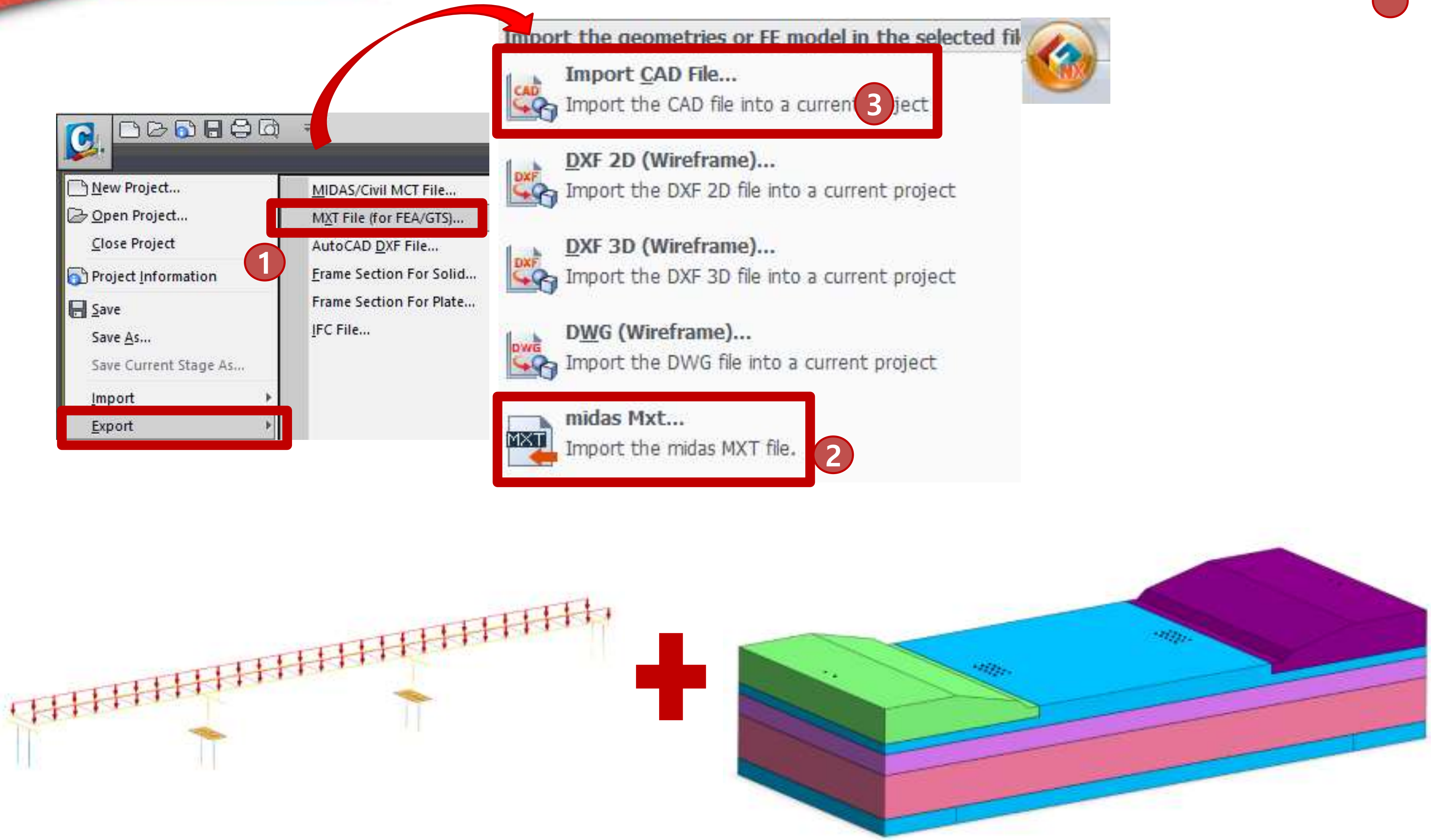
midas Civil



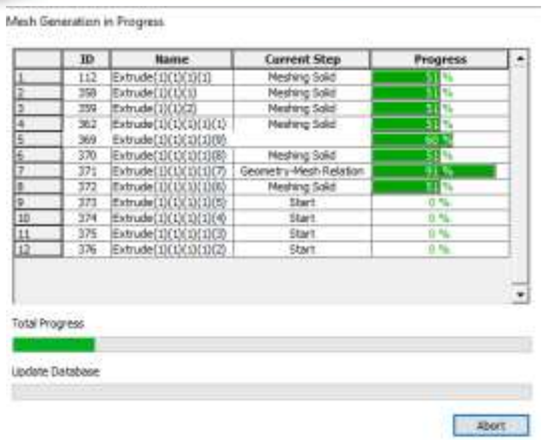
GEOTECHNICAL ENGINEERING

GTS NX

Import model to GTS NX



Mesh CAD in 3D elements

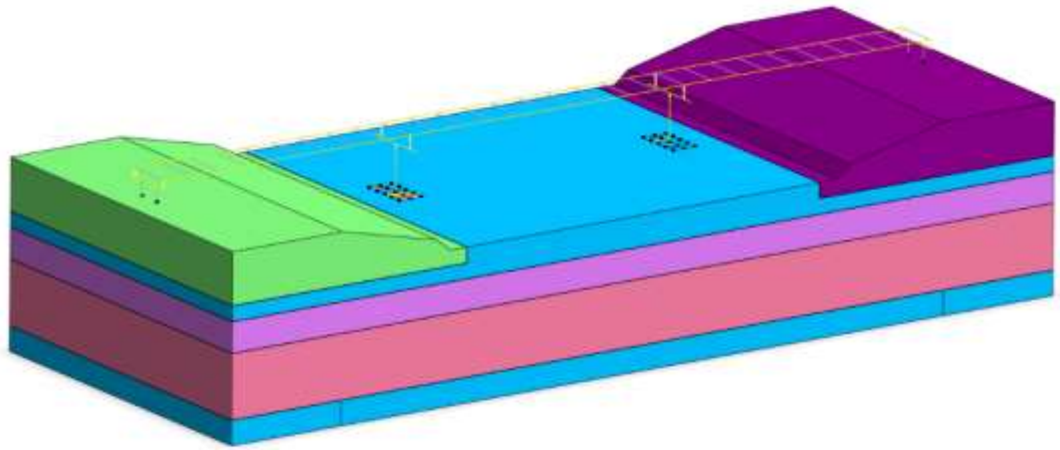

Mesh Generation in Progress

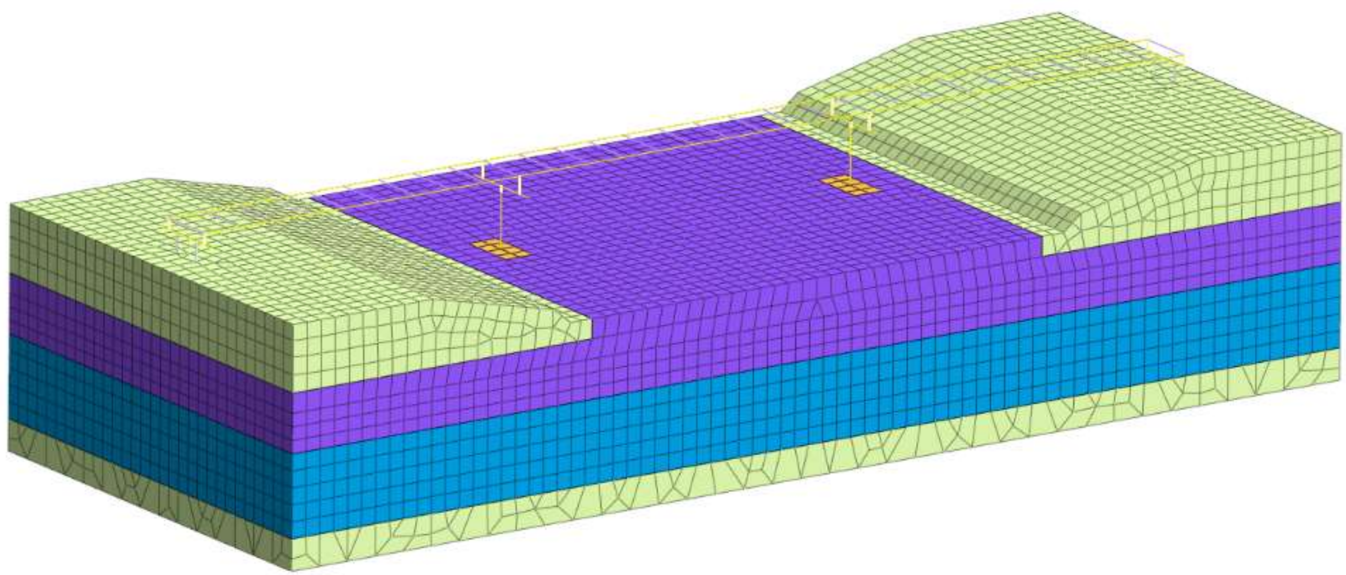
	ID	Name	Current Step	Progress
1	112	Extrude[1](1)(1)[1]	Meshing Solid	51 %
2	358	Extrude[1](1)(1)	Meshing Solid	51 %
3	359	Extrude[1](1)(2)	Meshing Solid	51 %
4	362	Extrude[1](1)(1)[1](1)	Meshing Solid	51 %
5	369	Extrude[1](1)(1)[1](9)		60 %
6	370	Extrude[1](1)(1)[1](8)	Meshing Solid	51 %
7	371	Extrude[1](1)(1)[1](7)	Geometry-Mesh Relation	91 %
8	372	Extrude[1](1)(1)[1](6)	Meshing Solid	51 %
9	373	Extrude[1](1)(1)[1](5)	Start	0 %
10	374	Extrude[1](1)(1)[1](4)	Start	0 %
11	375	Extrude[1](1)(1)[1](3)	Start	0 %
12	376	Extrude[1](1)(1)[1](2)	Start	0 %

Total Progress

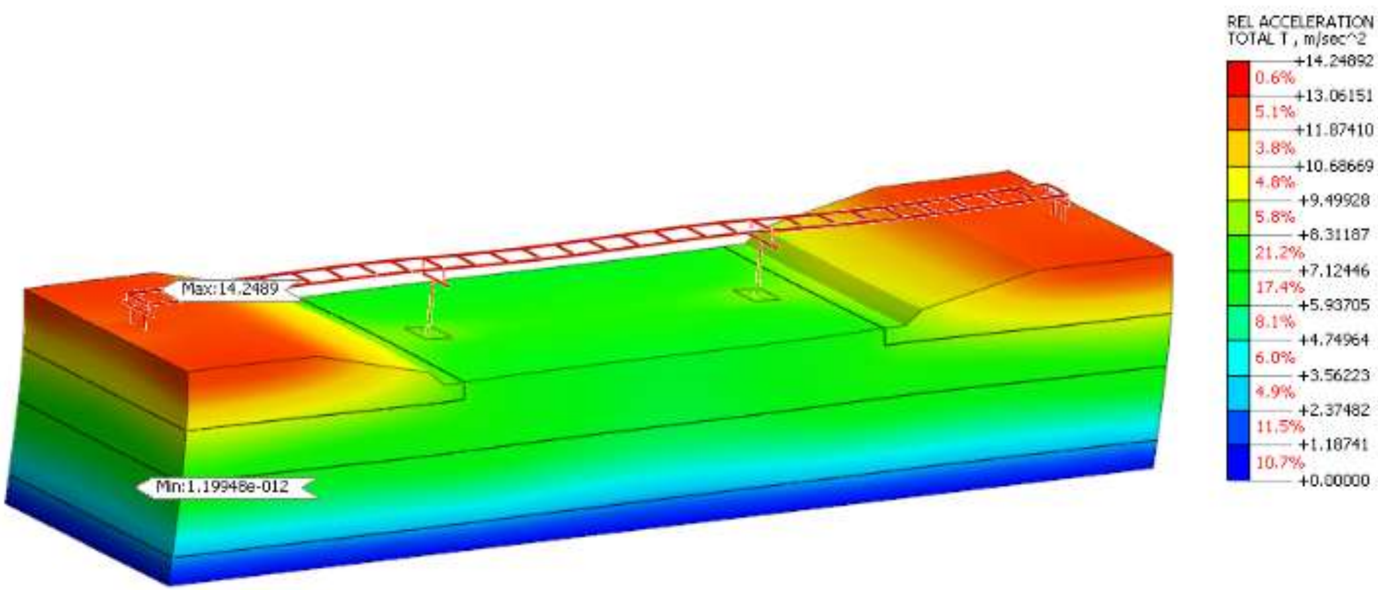
Update Database

Abort



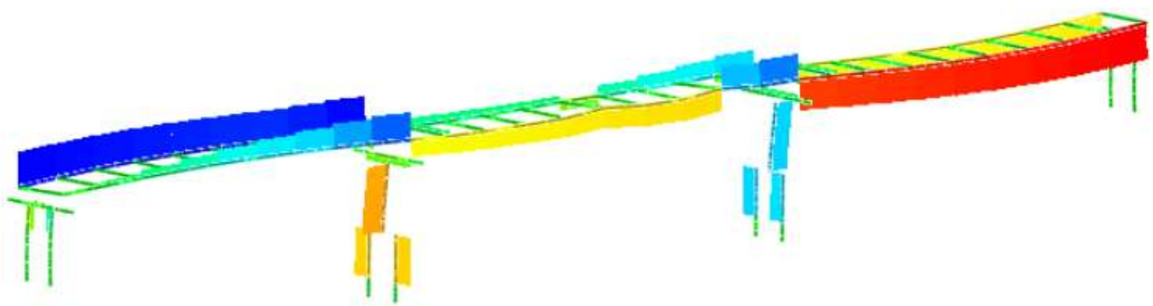


3D SSI Results

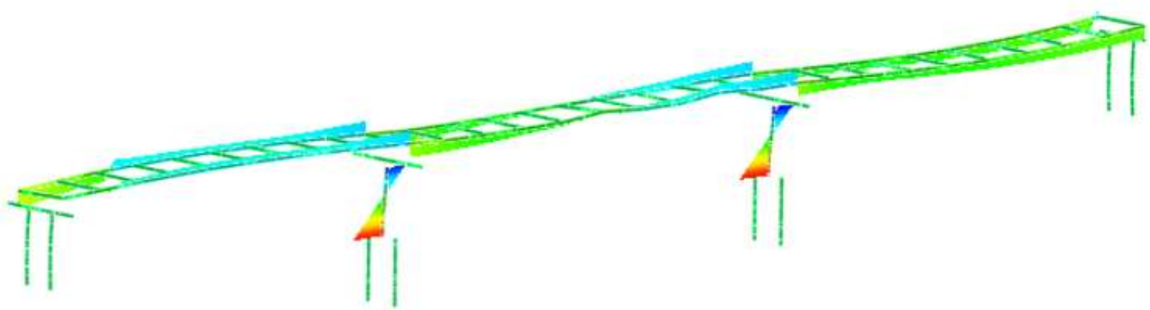


Results for Time History is within 5%. Max of 14.2 m/sec^2

Dynamic results for imported bridge

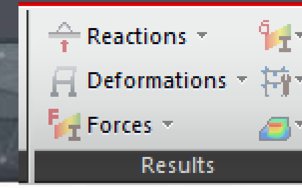


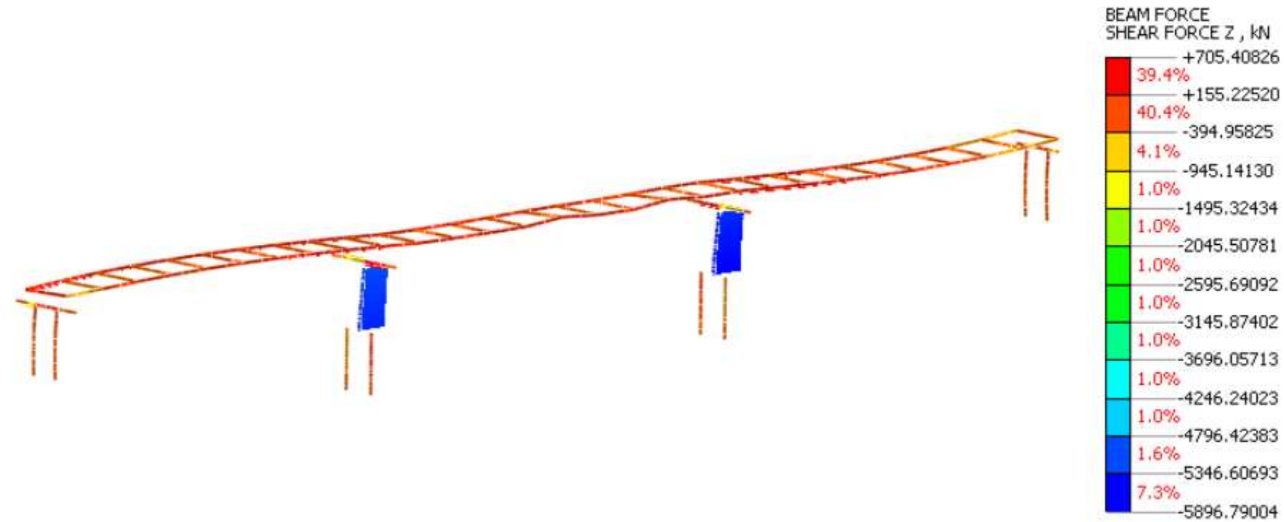
Max Axial forces on structure

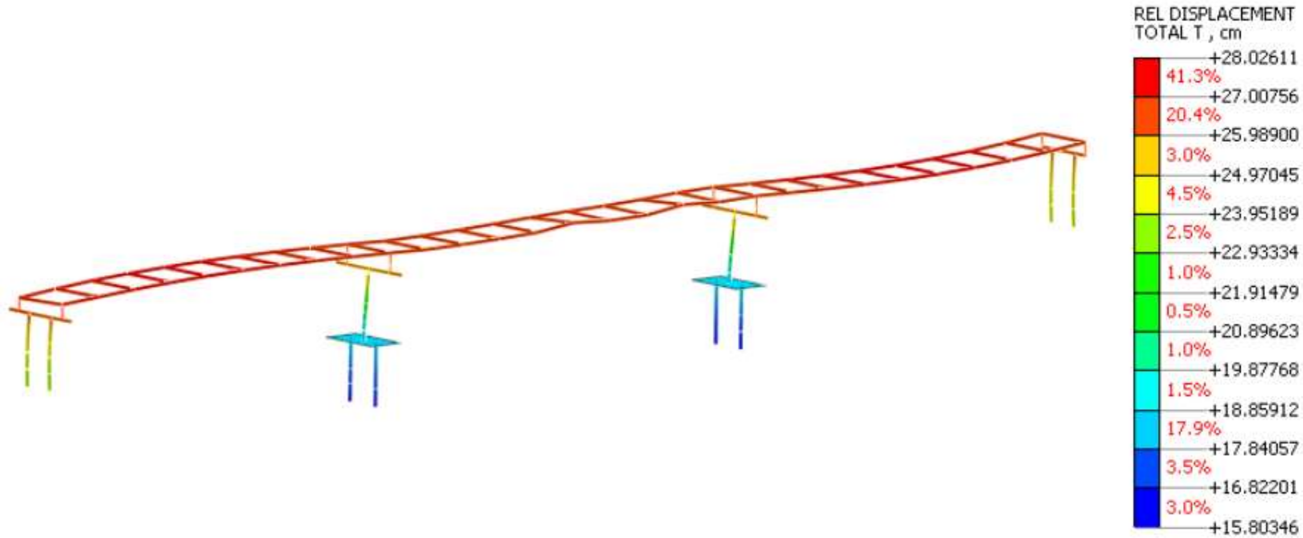


Max moments on structure

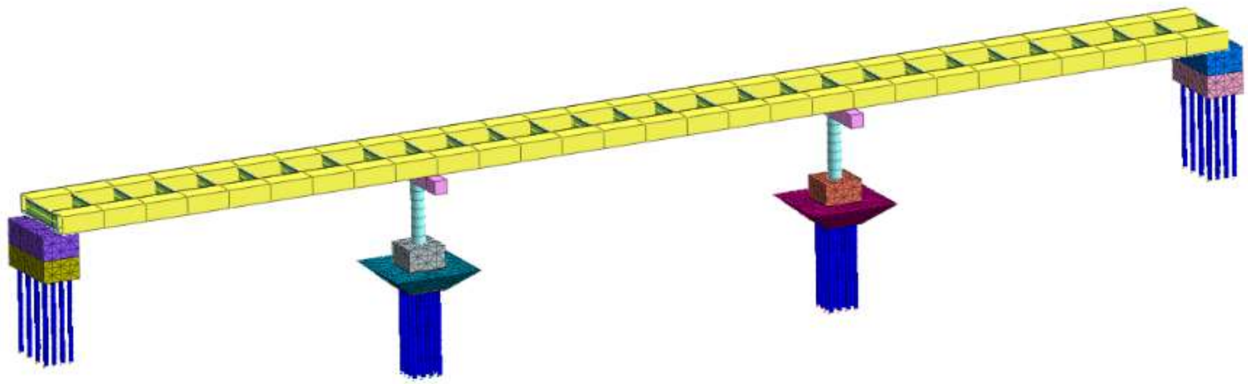
Results Comparison

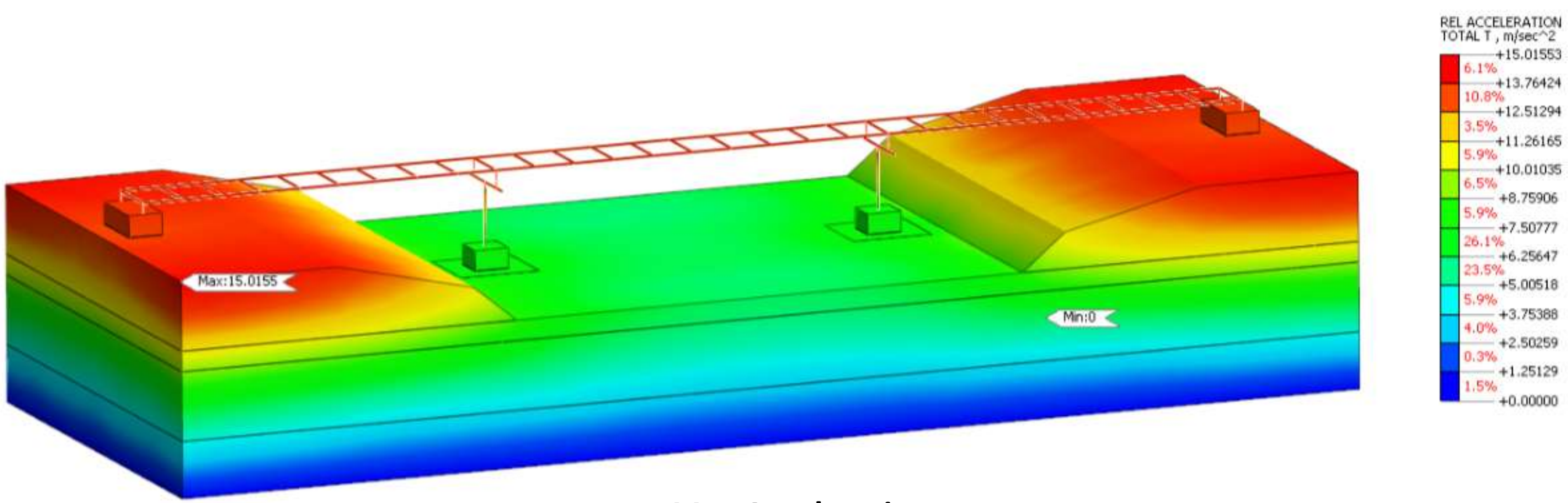






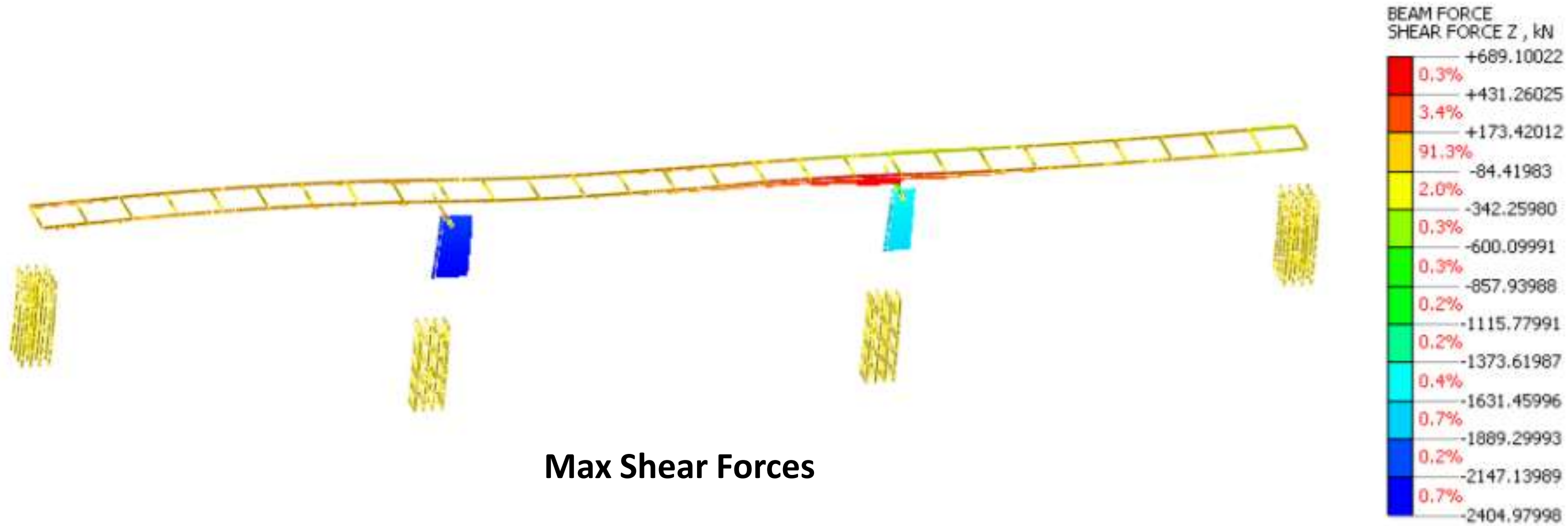
Bridge with updated substructure



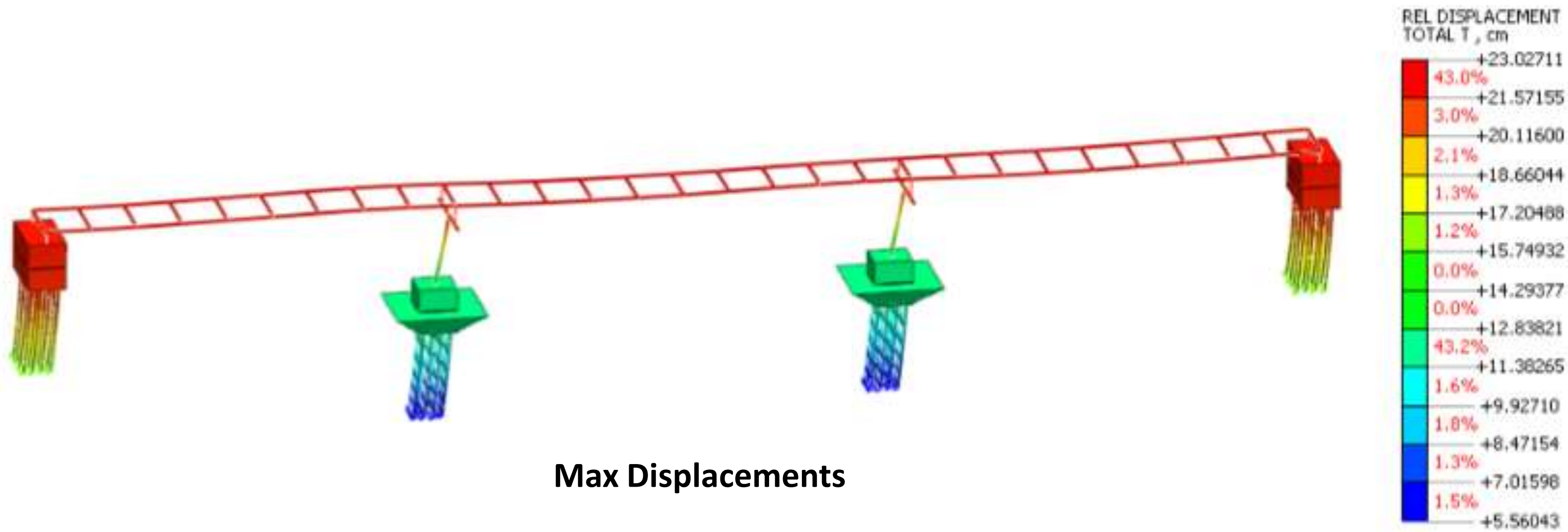


Max Acceleration

Results for Bridge with updated substructure



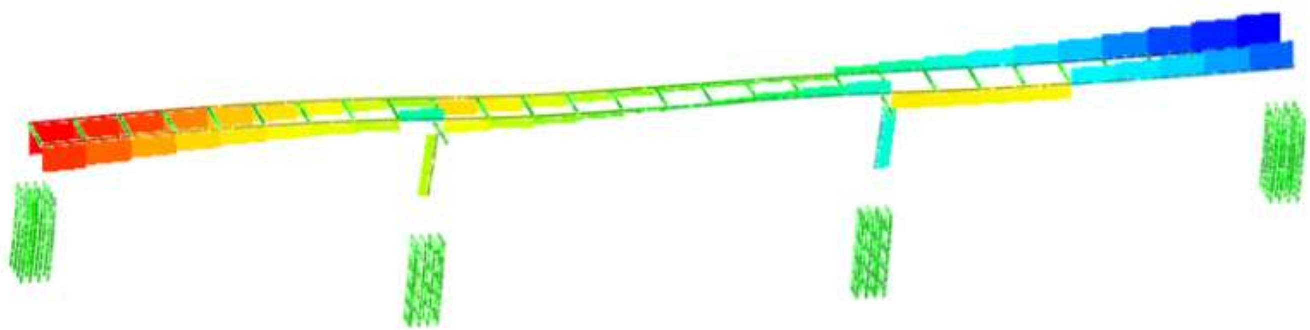
Max Shear Forces



Max Displacements

Results for Bridge with updated substructure

CIVIL GTS NX



Max Axial forces on structure

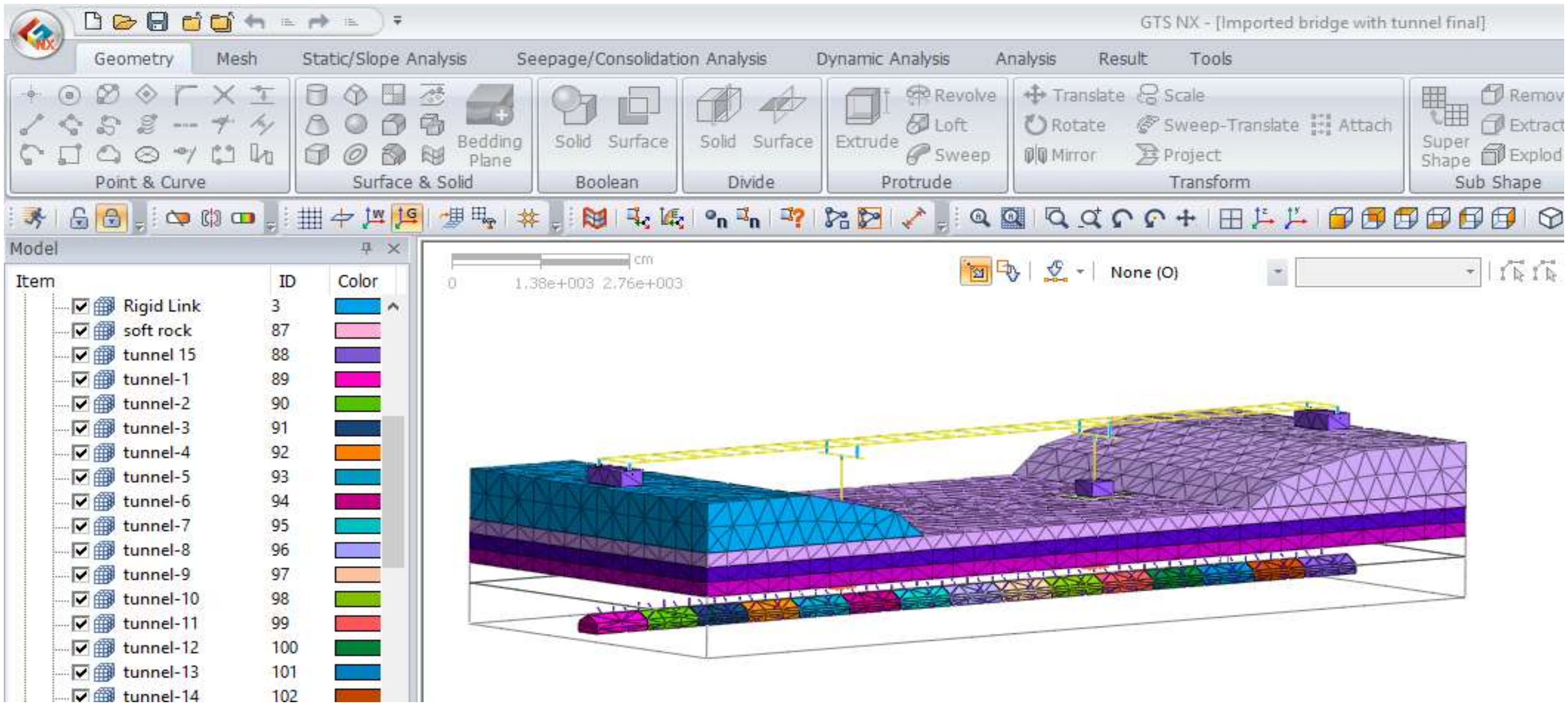
Max moments on structure

Conclusion

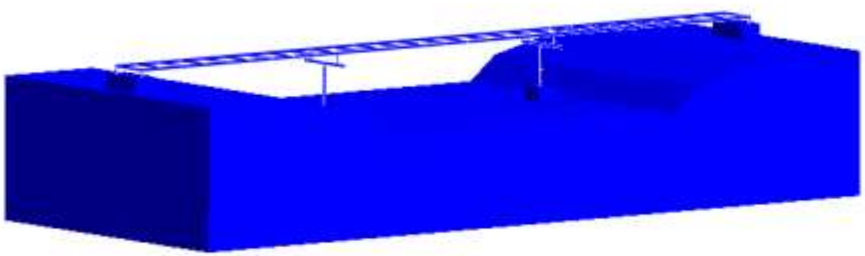
Max	Civil	GTS NX	Updated Base
Displacements (cm)	29	28	23
Axial Force (kN)	3,064	2,036	1,762
Moments Y (kN/m)	19,087	23,969	16,127
Shear Forces (kN)	2,032	5,838	2,404

- **Midas Civil has internal PY curves in order to easily apply soil springs and run soil structure interaction through substructure method. For some soils, this is sufficient.**
- **Substructure Method cannot accurately capture the non linear behavior experienced by the foundation and surrounding ground during an earthquake.**
- **Midas GTS NX can import full structure from midas Civil to run SSI through Direct Method. However, since the ground is modeled in 3D, it must first be calibrated through comparison of ground response analysis like Free Field and Linear Equivalent.**

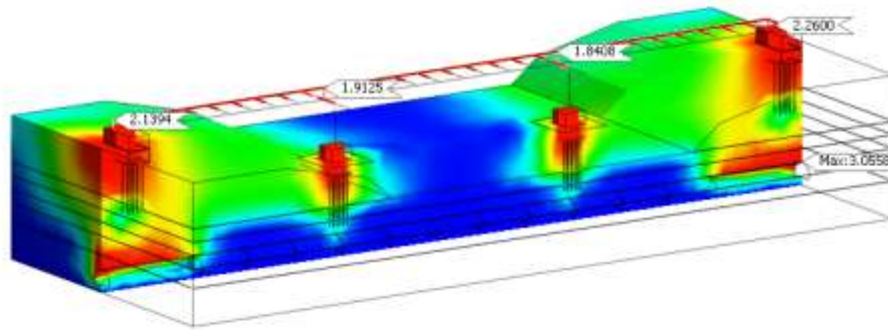
Other SSI problems (Adjacent Structure consideration)



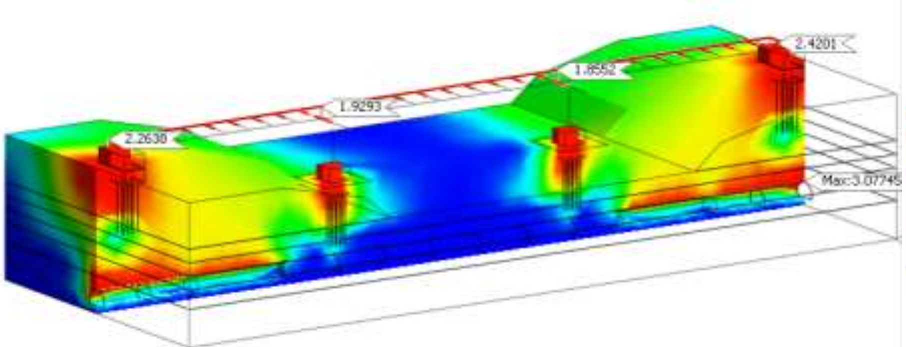
Adjacent Structure consideration during excavation



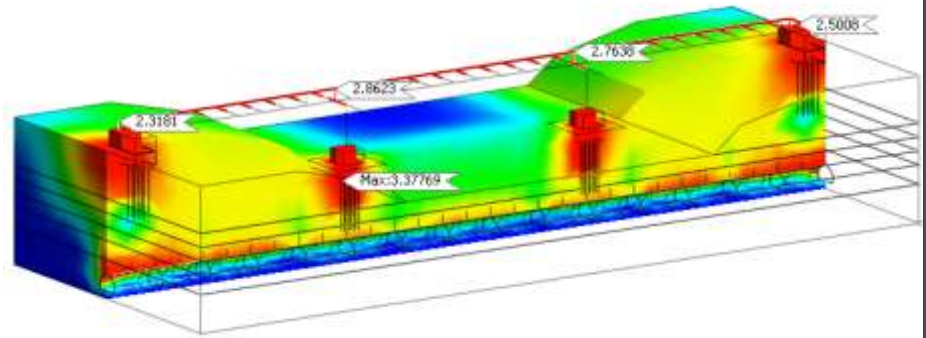
Initial Stage



Excavation stage 1

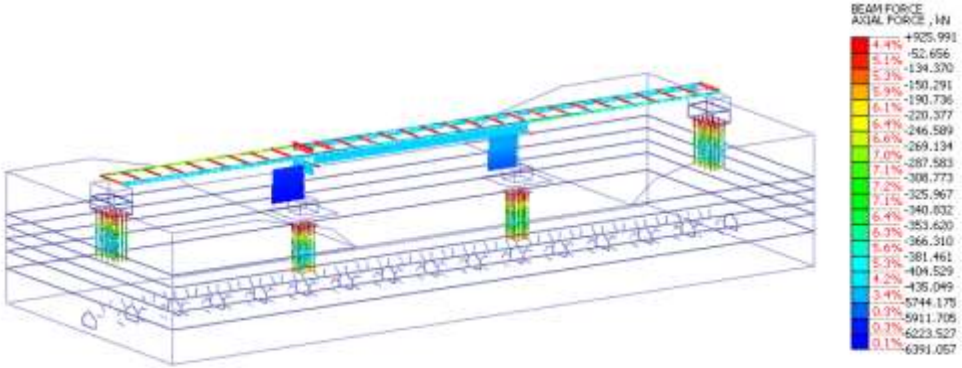


Excavation stage 2

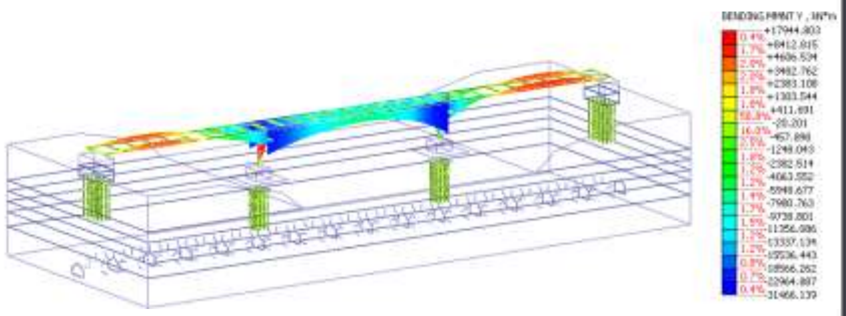


Final Excavation stage

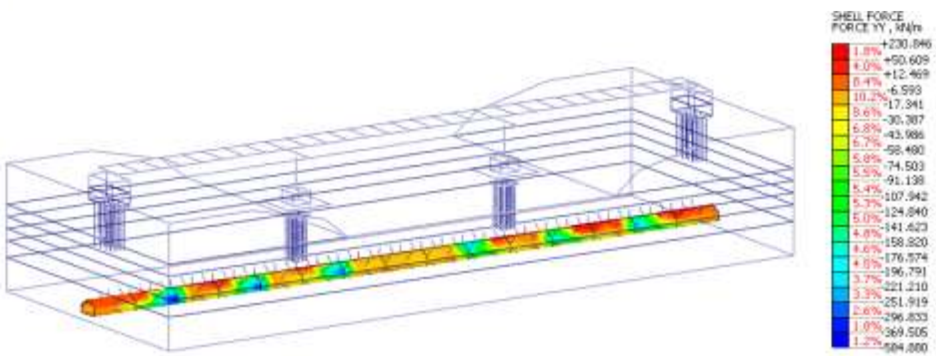
Adjacent Structure consideration during excavation



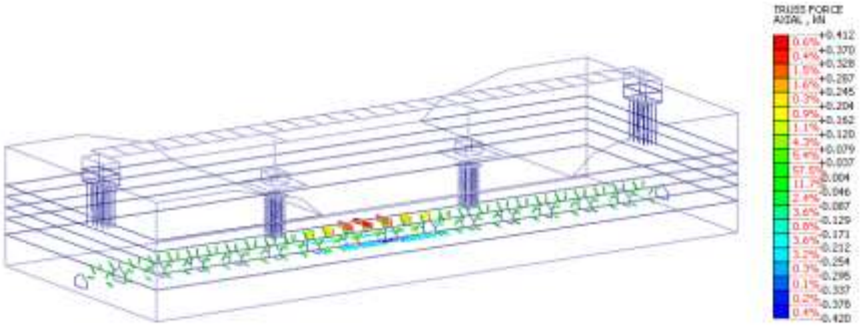
Axial forces on bridge



Moments on bridge



Moments on tunnel



Axial forces on rock bolts

Thank You