Bridge 2D Soil Structure Interaction

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





- 1. Introduction
- 2. Soil Structure Interaction Substructure Method
- 3. Ground Response Analysis for Calibration
- 4. Soil Structure Interaction Direct Method
- 5. Results Comparison Between SSI Methods



Integrated Solver Optimized for the next generation 64-bit platform Finite Element Solutions for Geotechnical Engineering





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.

 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



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.

GTS N



Initial Civil model dimensions



CIVIL

Add Soil Springs Supports

🕀 General Spring * 336 Pile Spring Supports Surface Spring

Spring Supports



Time History Analysis Case

Add/Modify Time History Load Cases X	Cround Acceleration
General	Ground Acceleration
Name : Inth Description : Apalysis Type Analysis Method Time History Type O Linear O Modal Transient	Time History Load Case Name
Nonlinear Ostatic	Eurotion for Direction-X
Geometric Nonlinearity Type	Eurotion Name : th
None O Large Displacements	Scale Factor 1
End Time : 10 = sec Time Increment : 0.01 = sec Step Number Increment for Output : 1 =	Arrival Time : 0 sec
Order in Sequential Loading	Function for Direction-Y
Subsequent to O Load Case	Function Name : NONE V
Initial Element Forces(Table)	Scale Factor : 1
Cumulate D/V/A Results Keep Final Step Loads Constant	Arrival Time : 0 sec
	Ime History Load Cases : 1
Damping Method : Mass & Stiffness Proportional V	Function for Direction-Z
Mass and Stiffness Coefficients	Function Name : NONE
Damping Type :	Scale Factor : 1
O Direct Specification : 0 0	Arrival Time : 0 sec
Calculate from Modal Damping : 0.20882000731 0.01197192816	
Coefficients Calculation Mode 1 Mode 2	Angle of Horizontal Ground Acc. Add/Modify/Show Time History Functions
O Frequency [Hz] : 0 0	0 [deg] Function Name Three Function Data Type Rectangle Lange Character Ch
Period [sec] : 1.5089 1.5	Lose Factor Gravity Gravity Gravity
Damping Ratio : 0.05 0.05	Case Name Angle of Acc.
Show Damping Ratio	nth 0 (sec) (a)
Time Integration Parameters Newmark Method : Gamma O.5 Beta Oconstant Acceleration O User Input	2 0.0100 0.0165 3 0.0200 0.0162 4 0.0300 0.0162 5 0.0400 0.0165 6 0.0500 0.0162 7 0.0500 0.0162 3 1 0.0500 0.0162 6 0.0500 0.0162
Nonlinear Analysis Control Parameters	8 0.0710 0.0163
Perform Iteration Iteration Controls	9 0.0000 0.0100 h
Damping Matrix Update : ONo OYes Description	11 0.1000 0.0009 12 0.1500 0.0009 13 0.1220 0.0029 8 2 4 9 50 12 34 36 58 52 52 24 56 55 14 8.1500 0.0029 9 The (see)
OK Cancel Apply	9

CIVIL GTS

Results for TH in Civil using PY springs



🔶 Reactions 👻

👎 Forces 🗵

H

Deformations

Results

11-

Fi-

<u>-</u>-

Results for TH in Civil using PY springs





Substructure/Indirect Method

The substructure-only approach:

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





GTS N

Soil Structure Interaction by Direct Method



Interaction with other software





Tools to check or verify mesh quality





Mesh quality check .

Mesh check (Free Face) A

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.

CIVIL GTS



Extensive Constitutive Model Data Base



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

Plastic Materials

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





Undrained Materials

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

Functions

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



Strain compatibility A







Unsaturated property (Individual)



Unsaturated property (Relation) A

Dynamic Analysis





Linear Equivalent 1D and 2D





Dynamic Curve





Free Field





2D Linear Equivalent





Linear EQ (Free Field)



Max acceleration (12 m/sec^2)



CIVIL GTS



Add embankment to soil layer

Short Time History Function (2 sec Analysis)

Max acceleration (14.3 m/sec^2)



REL ACCELERATION TOTAL T , m/sec^2 +14.386941,2% +13.1880316.4% +11.98911 18.5% +10.79020 13.9% +9.59129 8.8% +8.39238 6.6% +7.19347 5.9% +5.99456 5.0% -+4.79565 5.2% +3.596735.5% +2.397823.9% +1.198913.1% +0.00000

CIVIL GTS



3D Time History Analysis





Integrated Solver Optimized for the next generation 64-bit platform Finite Element Solutions for Geotechnical Engineering



Dynamic SSI





Use same dynamic curve and time history function





Free Field 1D





HANE STRAIN STREES S-MAX SHEAR , MANY





+9.30803

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	10.1104

CIVIL GTS

ID 1	Name	weathered rock	Color	
Model Type	Mohr-Coul	lomb	~	Structure
Seneral Po	rous Non-Li	near Time Depender	vt	
Cohesion	(C)		375	kð\/m²
Inc. of Co	ohesion		0	ktN/mª
Inc. of Co	hesion Ref. H	leight	0	m
Frictional	Angle (Phi)		37	[deg]
Dilata	ncy Angle		36	[deg]
Tensi	e Strength		0	k0Mm12



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

1.4%

6.5%

9.7%

9.4%

8.6%

1.1%

1.1%







Max: 14.8785 <





REL ACCELERATION TOTAL T, m/sec~2 +14.87854 5.6% +13.63866 4.9% +12.39878 4.1% +11.15890 +9.91903 6.6% +8.67915 14.1% +7.43927 11.3% +6.19939 -+4.95951 8.8% +3.71963 8.4% +2.47976 7.3% +1.23988 10.1% +0.00000

Interaction with other software





3D SSI





Import model to GTS NX





CIVIL GTS

Mesh CAD in 3D elements



Mesh Generation in Progress

112 Extrude(1)(1)(1) Mesting Sold 51 259 Extrude(1)(1)(2) Mesting Sold 51 259 Extrude(1)(1)(2) Mesting Sold 51 250 Extrude(1)(1)(2) Mesting Sold 51 250 Extrude(1)(1)(2) Mesting Sold 52 260 Extrude(1)(1)(2) Mesting Sold 52 260 Extrude(1)(1)(2)(1)(0) Extrude(1)(1)(2)(1)(0) 50 270 Extrude(1)(1)(2)(1)(0) Geometri-Mest Relation 71 51 277 Extrude(1)(1)(2)(1)(0) Geometri-Mest Relation 71 51 51 277 Extrude(1)(1)(2)(1)(0) Extrude(1)(1)(2)(1)(0) 51 51 51 277 Extrude(1)(1)(2)(1)(0) Extrude(1)(1)(2)(1)(0) 51 51 51 277 Extrude(1)(1)(2)(1)(0) Start 0 55 51 275 Extrude(1)(1)(2)(1)(0) Start 0 55 274 Extrude(1)(1)(2)(1)(0) Start 0 55		ID.	Name	Current Step	Progress	
399 Extrude (1)(1)(1) Meeting Solid 11 399 Extrude (1)(1)(2) Meeting Solid 31 14 362 Extrude (1)(1)(2) Meeting Solid 31 14 360 Extrude (1)(1)(2)(1)(1) Meeting Solid 32 15 360 Extrude (1)(1)(2)(1)(2) Meeting Solid 32 15 370 Extrude (1)(1)(2)(1)(2) Reating Solid 33 16 371 Extrude (1)(1)(1)(2) Geometrix - Meetin Rolston 91 16 372 Extrude (1)(1)(1)(1)(2) Bart 0 16 17 373 Extrude (1)(1)(2)(1)(2) Bart 0 16 35 16 374 Extrude (1)(1)(2)(1)(2) Start 0 16 37 37 Extrude (1)(1)(3)(1)(2) Start 0 16 376 Extrude (1)(1)(3)(1)(2) Start 0 16	1	112	Extrude(1)(1)(1)(1)	Meshing Solid	511%	
209 Extrade(1)(1)(2) Meeting Sold 31 % 262 Extrade(1)(1)(2)(1)(1) Meeting Sold 32 % 369 Extrade(2)(1)(2)(1)(1) Meeting Sold 32 % 370 Extrade(2)(1)(2)(1)(1) Meeting Sold 33 % % 370 Extrade(2)(1)(1)(1)(7) Georet = Alexing Sold 33 % % 372 Extrade(1)(1)(1)(1)(1)(7) Meeting Sold 34 % % 373 Extrade(1)(1)(1)(1)(1)(7) Bart 0.% % % % 374 Extrade(1)(1)(1)(1)(1)(7) Extrade(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)(2	358	Extrude(1)(1)(1)(1)	Neshing Solid	11.75	
302 Extrude (1(1)(1)(1)(1)) Meating Sold 31 % 369 Extrude (1(1)(1)(1)(1)) Meating Sold 53 % 370 Extrude (1(1)(1)(1)(1)) Geometry-Mean Robitson 9.1 % 371 Extrude (1(1)(1)(1)(1)) Geometry-Mean Robitson 9.1 % 372 Extrude (1(1)(1)(1)(1)) Geometry-Mean Robitson 9.1 % 372 Extrude (1(1)(1)(1)(1)) Beart 0.% % 373 Extrude (1(1)(1)(1)(1)(2)) Extrude (1)(1)(1)(1)(1)(2) % % 374 Extrude (1)(1)(1)(1)(2) Extru 0.% % 375 Extrude (1)(1)(1)(2)(1)(2) Start 0.% % 376 Extrude (1)(1)(1)(2)(1)(2) Start 0.% %	3	359	Extrude(1)(1)(2)	Meating Sold	21 %	
369 Extrade(1)(1)(2)(1)(10) 60 2 370 Extrade(1)(1)(2)(1)(1) Heating Solid 33 1 371 Extrade(1)(1)(1)(1)(1) Meating Solid 33 1 372 Extrade(1)(1)(1)(1)(1) Meating Solid 31 1 373 Extrade(1)(1)(1)(1)(1) Meating Solid 31 1 373 Extrade(1)(1)(1)(1)(1)(2) Bart 0 % 374 Extrade(1)(1)(1)(1)(1)(2) Start 0 % 375 Extrade(1)(1)(1)(1)(2) Start 0 % 376 Extrade(1)(1)(1)(1)(2) Start 0 %	4	362	Estrude(1)(1)(1)(1)(1)	Mesterg Sold	11 15	
370 Extrude (21(1)(21)(2)) Meshing Solid 52 % 371 Extrude (21(1)(21)(2)) Genre tri - Kesh Relation 310 51 372 Extrude (10(1)(2)) Mering Solid 61 64 373 Extrude (11(1)(2)) Bart 0.% 54 374 Extrude (11(1)(2)) Bart 0.% 54 375 Extrude (11(1)(2)) Start 0.% 35 376 Extrude (11(1)(3)(3)(2) Start 0.% 36	5	369	Extrude(1)(1)(1)(1)(0)		6.5	
371 Evenue(1)(1)(1)(1) Geometry-Meet Relation 91.0% 372 Evenue(1)(1)(1)(1) Meeting Sold 11 373 Evenue(1)(1)(1)(1)(1) Meeting Sold 11 374 Evenue(1)(1)(1)(1)(1)(2) Elart 0.% 374 Evenue(1)(1)(1)(1)(2) Elart 0.% 374 Evenue(1)(1)(1)(1)(2) Elart 0.% 375 Evenue(1)(1)(1)(1)(2) Start 0.% 376 Evenue(1)(1)(1)(1)(2) Start 0.%	6	370	Extrude(1)(1)(1)(1)(8)	Neshing Solid	B1 %	
372 Datude (1) (U,U) (10) Meating Sold 11 271 Extrude (1) (U,U) (10) Elsert 0.% 374 Extrude (1) (U,U) (10) Elsert 0.% 374 Extrude (1) (U,U) (10) Elsert 0.% 375 Extrude (1) (U,U) (10) Elsert 0.% 376 Extrude (1) (U,U) (102) Start 0.%	7	371	Extrude(E)(1)(1)(1)(7)	Geometry-Mesh Relation	91.5	
273 Extrude(1)(1)(1)(1)(0) East 0.% 274 Extrude(1)(1)(1)(1)(0) East 0.% 375 Extrude(1)(1)(1)(1)(0) Start 0.% 376 Extrude(1)(1)(1)(1)(2) Start 0.%	8	372	Extrude(1)(1)(1)(1)(0)	Meeting Solid	11.74	
224 Extrude(1)(1)(1)(1)(4) Start 0.% 375 Extrude(1)(1)(1)(2) Start 0.% 376 Extrude(1)(1)(1)(2) Start 0.%	9	373	fatrude(1)(1)(1)(1)(5)	Start	0.%	
375 Extrude (1)(1)(1)(1)(1) Start 0.% 376 Extrude (1)(1)(1)(1)(2) Start 0.%	10	374	Extrude(1)(1)(1)(1)(4)	Start.	0.%	
376 Extrude(1)(1)(1)(2) Start 0.%	11	375	Extrude(1)(1)(1)(1)(3)	Start.	0.%	
	12	376	Extrude(1)(1)(1)(1)(2).	Start	0.56	
	12	376	Extrude(1)(1)(1)(1)(2) Extrude(1)(1)(1)(1)(2)	Start	0.56	
	900 - L					





3D SSI Results





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

Dynamic results for imported bridge





33

Results Comparison





34

Bridge with updated substructure





Max Acceleration

Results for Bridge with updated substructure



36

CIVIL GTS

Results for Bridge with updated substructure



Conclusion



Мах	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)

	🖬 🖛 🖻 🍋	i⊾) ₹						GTS NX - [Imp	orted bridge with t	unnel final]
Geometry	Mesh Stati	c/Slope Analysis	See	page/Consolidation	on Analysis I	Dynamic Analysis A	nalysis Re	sult Tools		
+ 0 2 0 7 7	x 1 0 7 4 0 1 4 0	Compared and a c	edding Plane	Solid Surface	Solid Surface	Extrude Protrude	+ Translate ひ Rotate の Mirror	 Cale Sweep-Tra Project Transform 	nslate 📰 Attach	Super Super Sup Shape
	n n : ##4			1 M 4. 16.		P D > : @ I			15. 15. 1 🖂 🗃 6	
Model		4 X	at 1 m					× • Ш		
Rigid Link Rigid Link soft rock V tunnel 15 V tunnel-1 V tunnel-2 V tunnel-3 V tunnel-3 V tunnel-4 V tunnel-5 V tunnel-6 V tunnel-7 V tunnel-8 V tunnel-9 V tunnel-10 V tunnel-10	3 87 88 89 90 91 92 93 94 95 96 97 97 98		1.38							
tunnel-12	100 101									
tunnel 14	102									



Excavation stage 2

Final Excavation stage

Adjacent Structure consideration during excavation

+925.991

52,656

134.370

150.291

190.736

220.377

246.589

269.134

287.583

308.773

325.967

140.832

353.620

366.310

381.461

104.529

-135.049

5744.175

5911.705 6223.527 6391.057





Moments on bridge







Axial forces on rock bolts

DENDING PRIMITIY , 1971

+17944.803

-0412.015 +1606.534

+3482.762

2383.108

1303.54

+411.80 20.201

457,894

1248.04

2382,514

4063 552

5548 677 7980.763

0735.80

11156-086

13337.134

13536, 443

19966.262

22964.007

31466.137



Thank You