

State of Practice for Seismic Structure-Soil-Structure Interaction (SSSI) Analysis in California

Los Angeles Geo-Institute Spring Seminar

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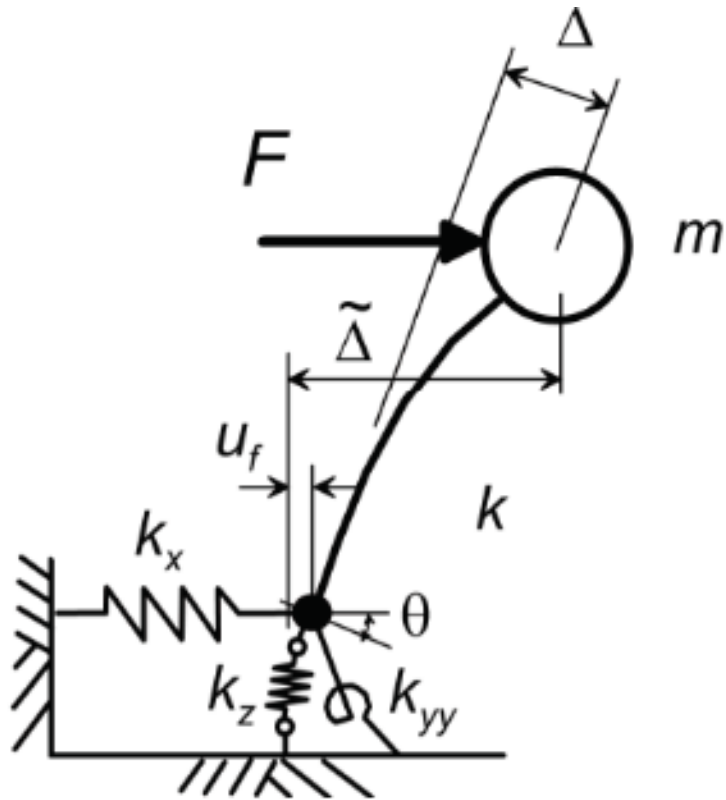
May 7th, 2026

Introduction: SSI vs SSSI



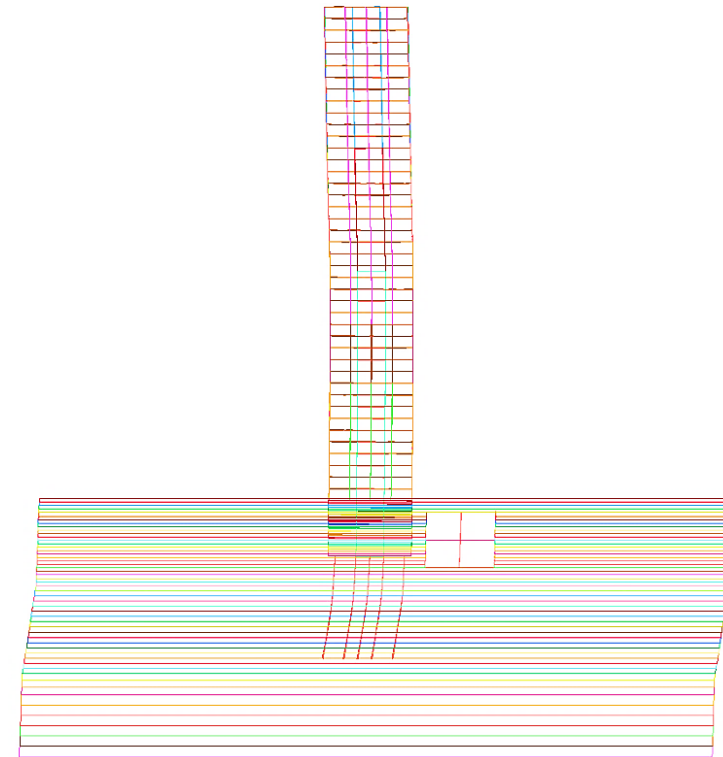
Introduction

SSI vs SSSI: Inertial Effects



SSI

Reference: NIST (2012)

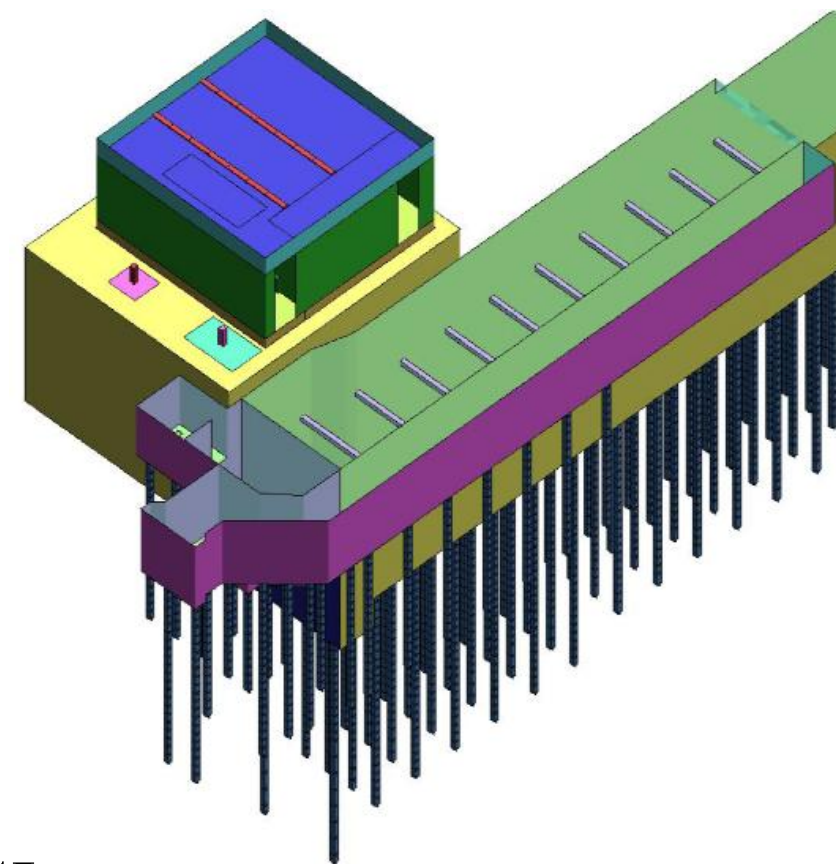
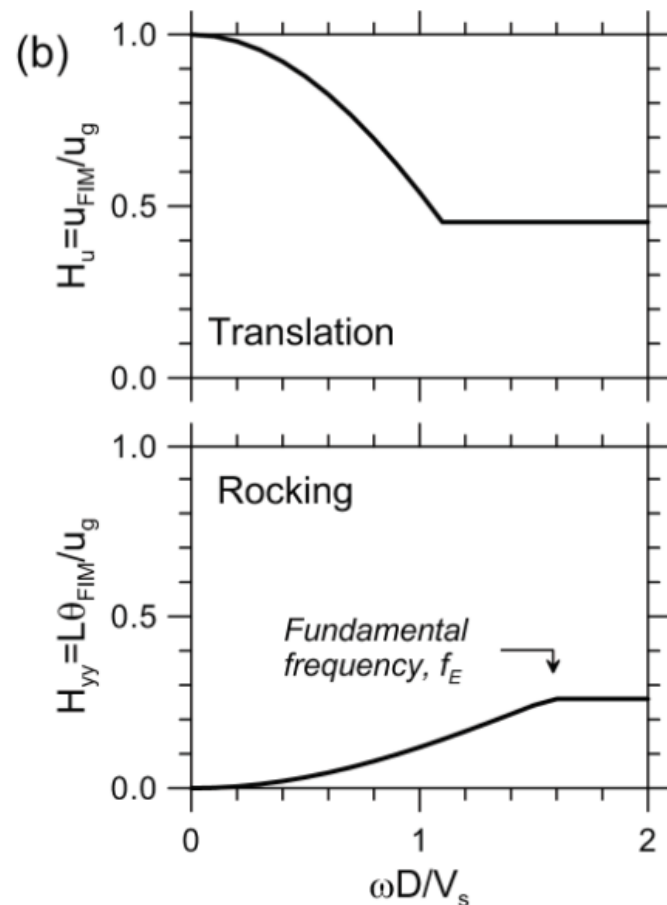
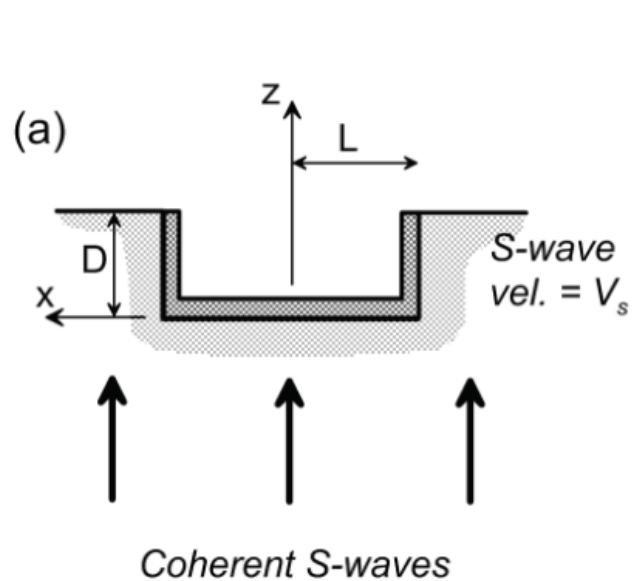


SSSI

Reference: Basarah (2021)

Introduction

SSI vs SSSI: Kinematic Effects



SSI

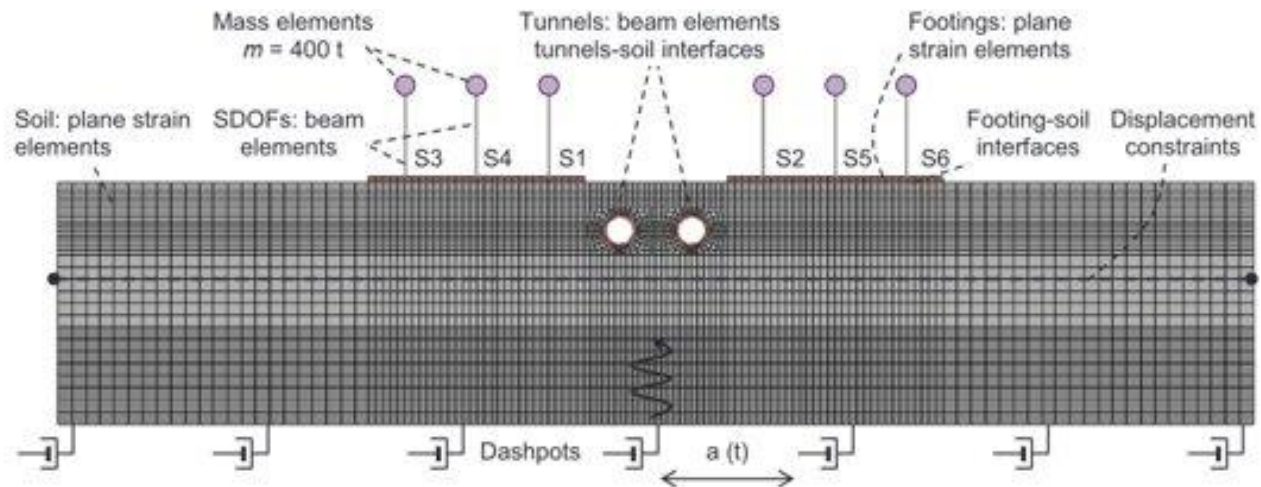
Reference: NIST (2012)

SSSI

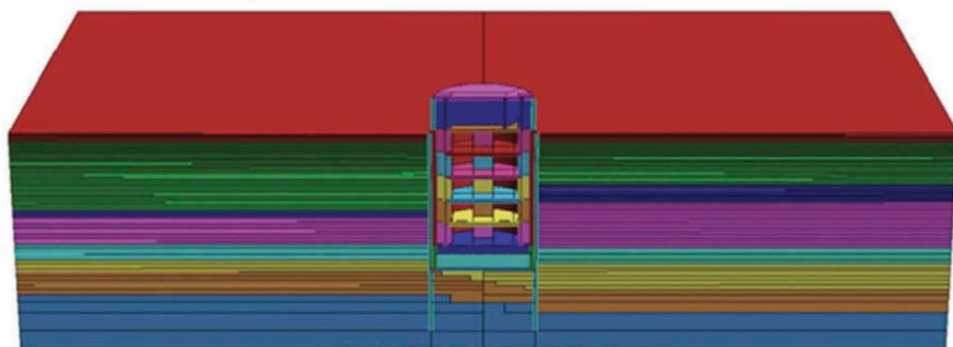
Reference: Ellison et al (2018)

Introduction

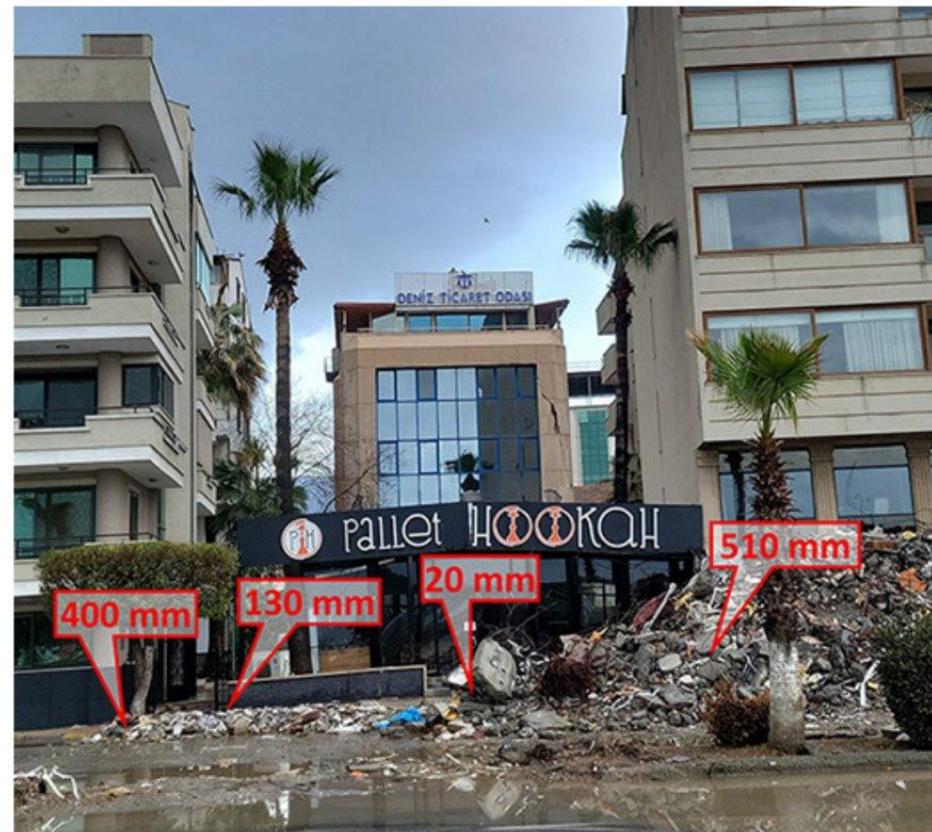
A few more SSSI examples



Reference: Tsinidis et al (2018)



Reference: Ellison et al (2019)



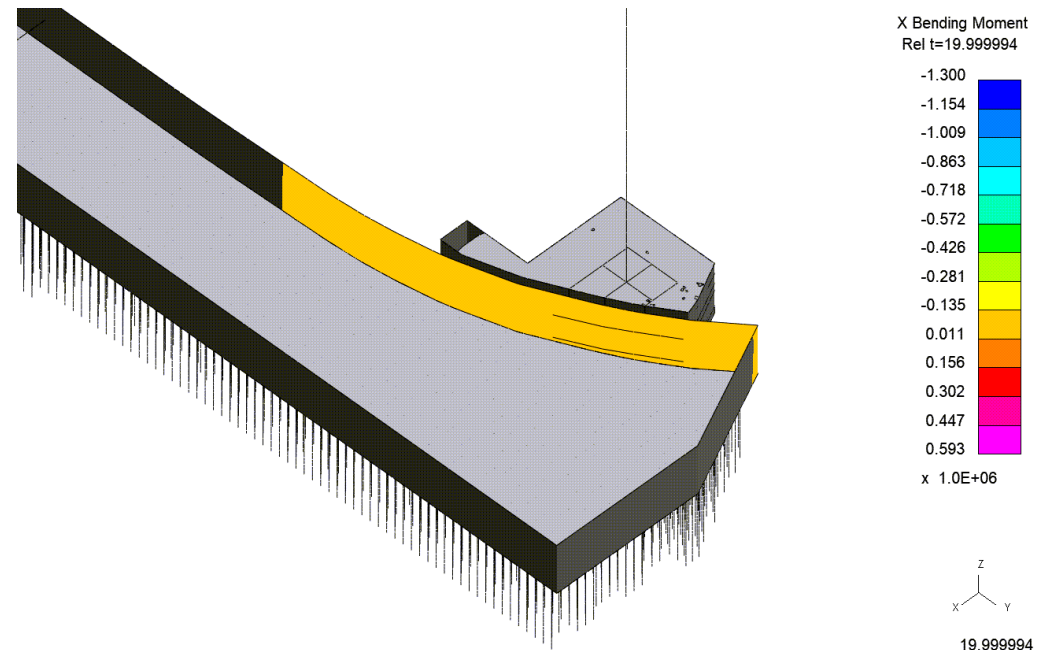
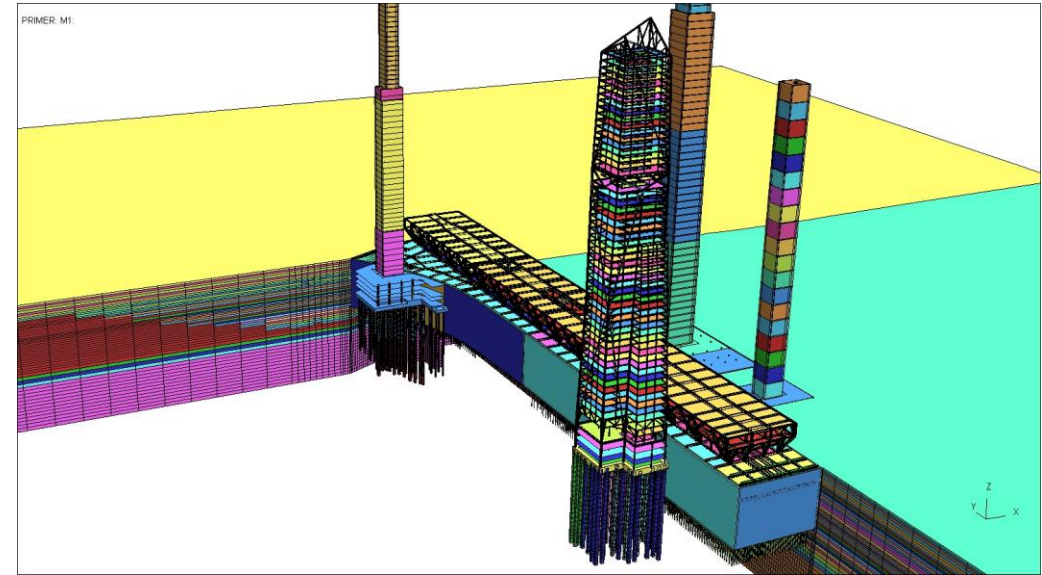
Reference: Moug et al (2024)

Introduction

Industry Trend in California

3D Seismic SSSI evaluations are often requested by Agencies such as:

- TJPA
- Caltrans
- SFPUC
- LA Metro
- Valley Transit Authority
- BART



Introduction

Why I use LS-DYNA

- Easy to match results from nonlinear SRA software using *MAT_HYSTERETIC_SOIL or ISOIL constitutive models
- Large library of advanced structural materials
- Robust contact algorithms
- Parallel processing

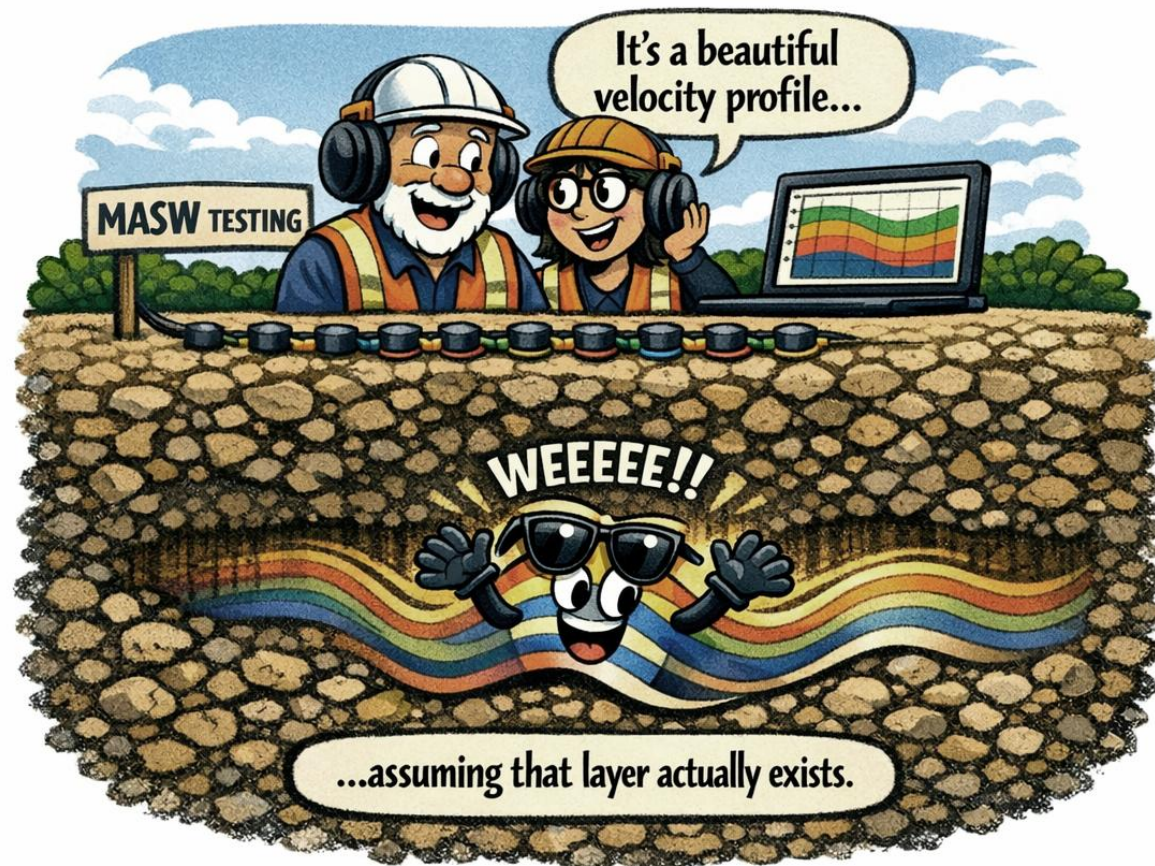


- 19th Century European Church
- Timber piles
- Unreinforced masonry
- Soft soil
- Steel ties
- Timber roof

Introduction

Key GI Data Needed for SSSI Analysis

- Shear wave velocity into hard layer
- Shear strength / friction angle
- Index testing
- Pore pressure profile
- 3D stratigraphy
- Sometimes cyclic DSS/TXC (if liquefaction/softening/rate effects)



Outline

- The Past

 - Case Study #1: 181 Fremont (circa 2014)

 - Interlude #1: Contact Modeling for SSSI

 - Case Study #2: Mariposa Pump Station (circa 2017)

 - Interlude #2: Quick thoughts about simplified methods for SSSI Analysis

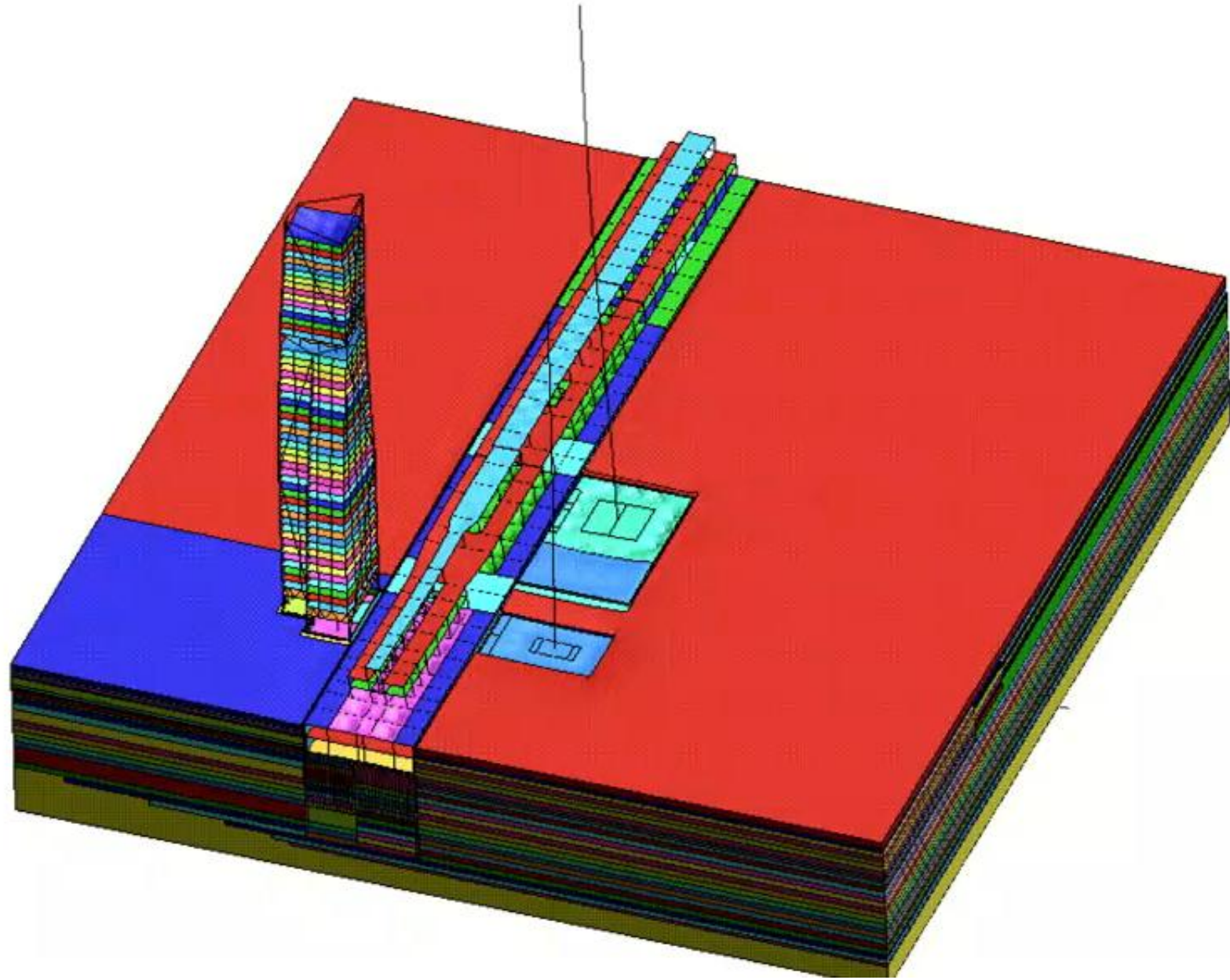
- The Present

 - Case Study #3: Lower Alemany Sewer Tunnel (circa 2025)

- The Near Future

Case Study #1

181 Fremont
(~2014)



The challenge:

Evaluate impact of new construction on seismic performance of existing structures

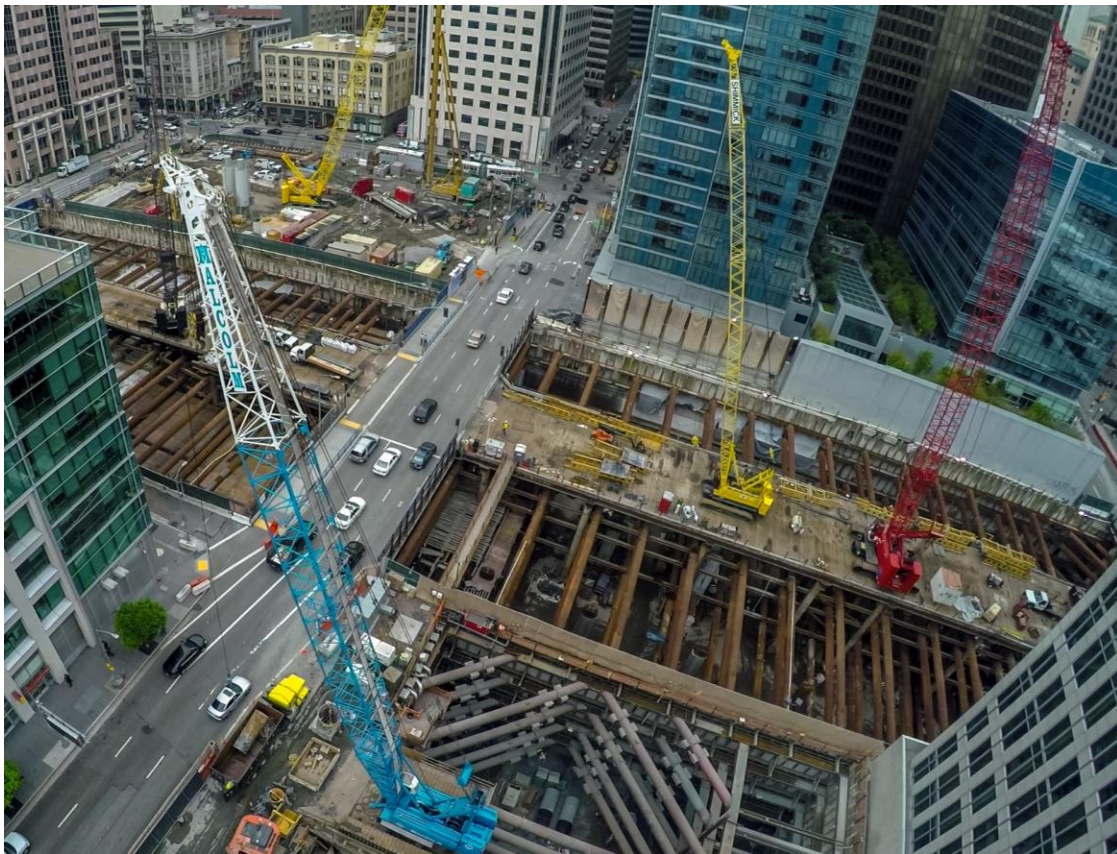
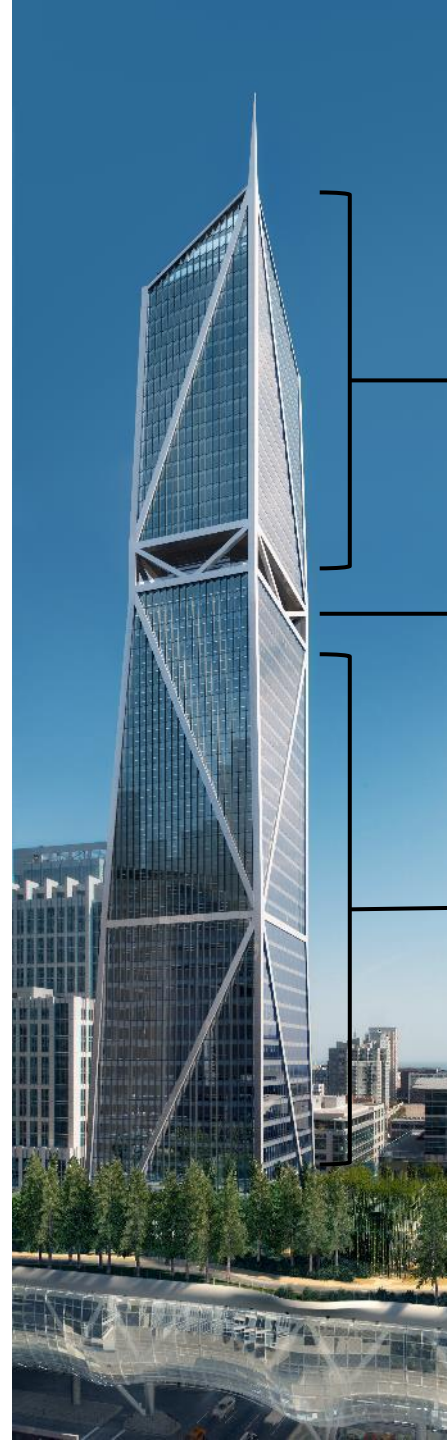


Photo Credit: Malcolm Drilling



Between Level 39 and 55
Condominiums

Amenity Level
Open air terrace

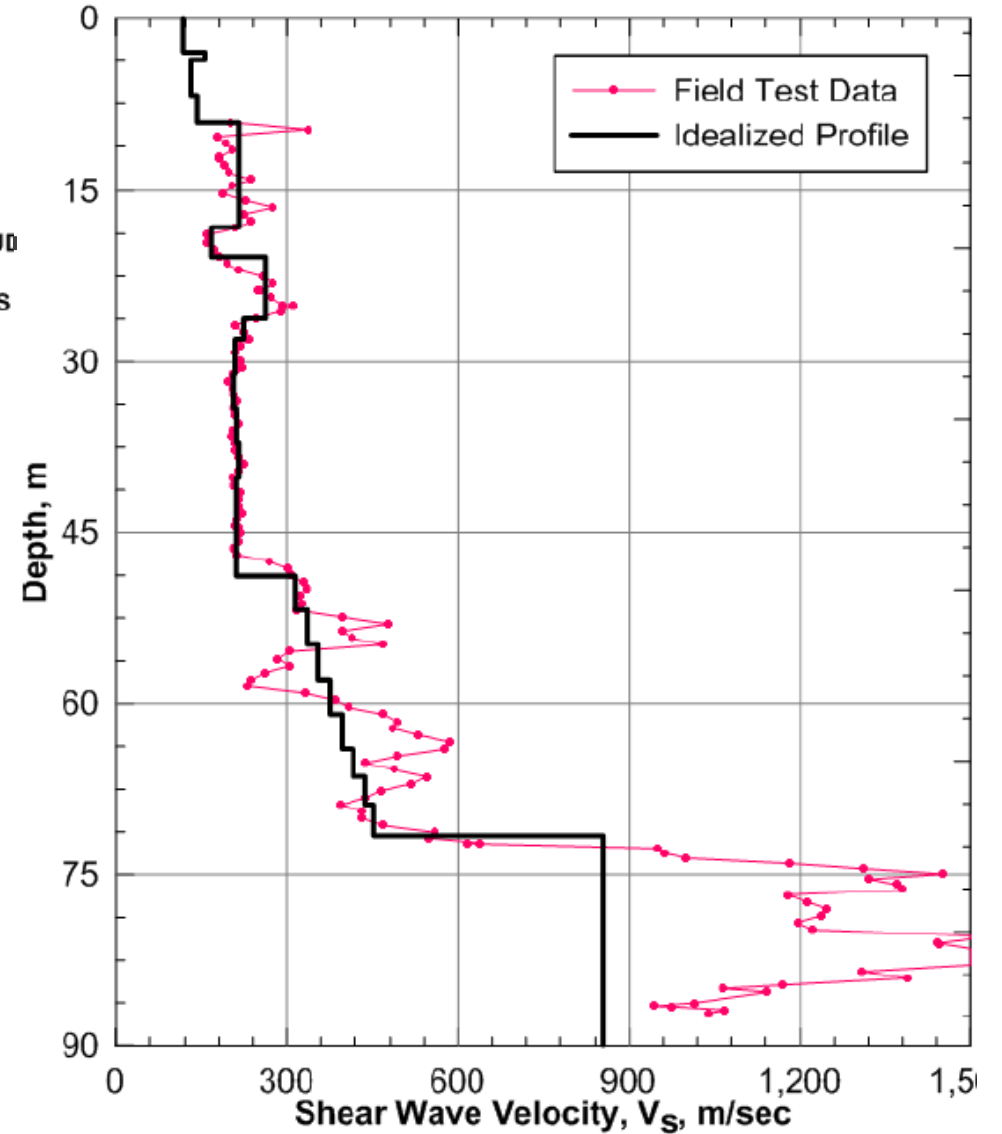
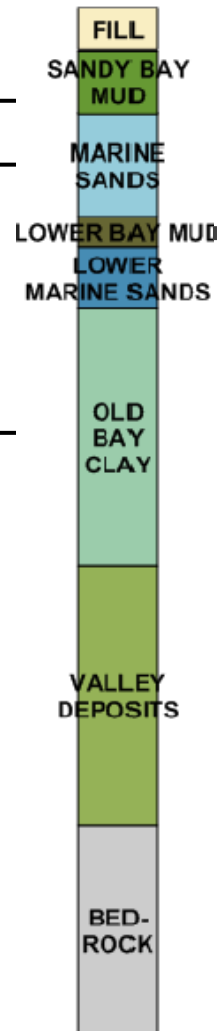
Between Level 2 and 36
Office space

~800 ft tall, 56 stories

Ground conditions



Idealized Soil Profile



Drilled shaft layout

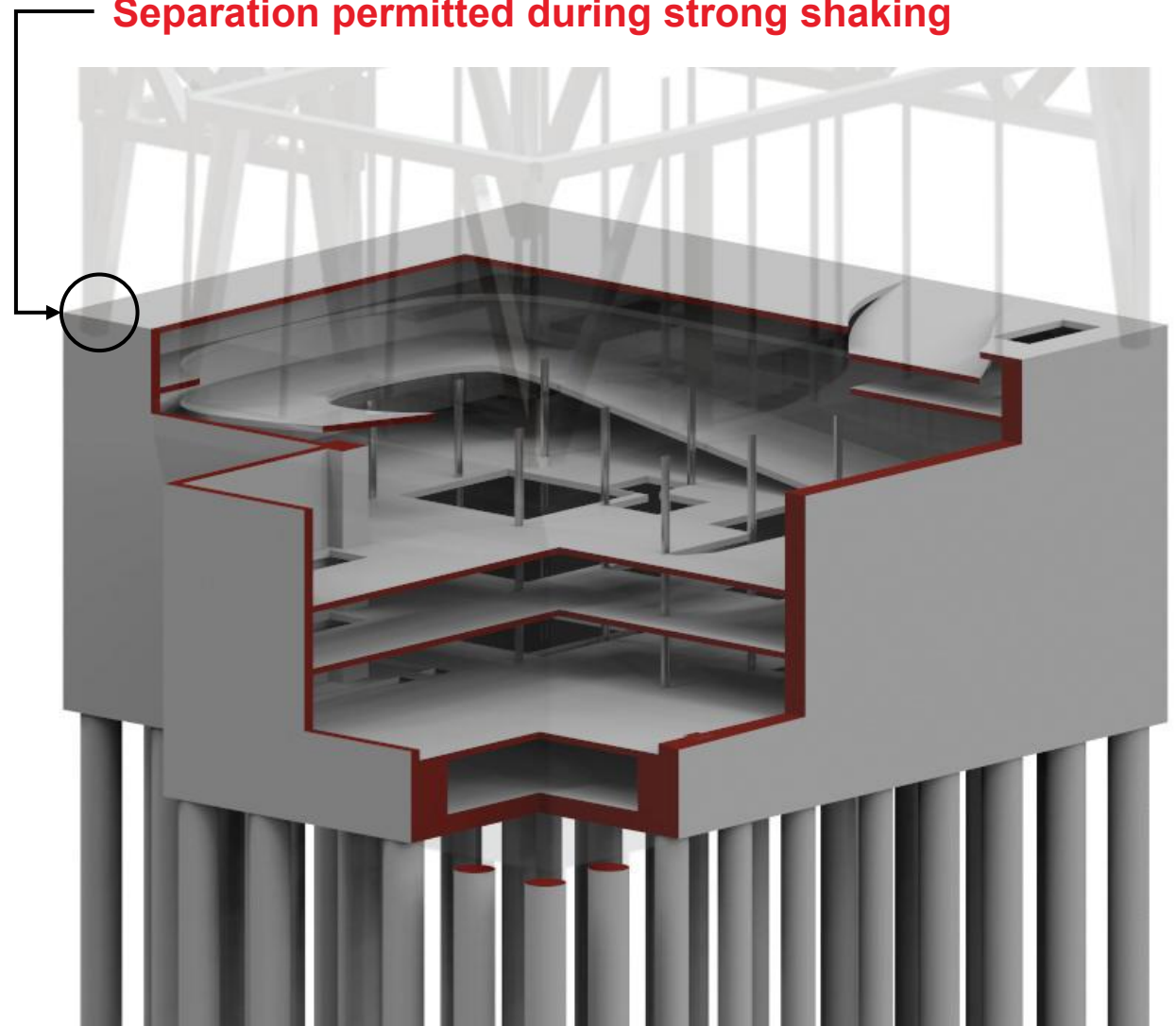
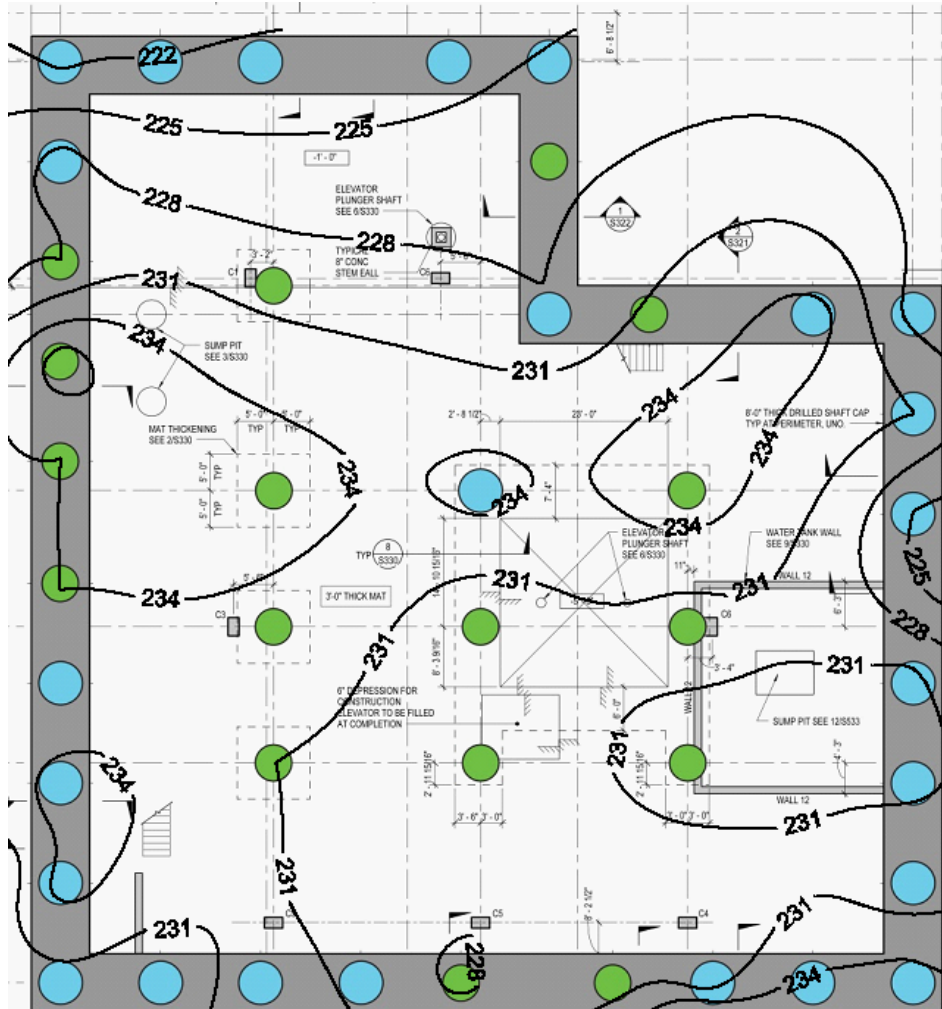
Max compression: 48 MN

Max shear: 2.6 MN

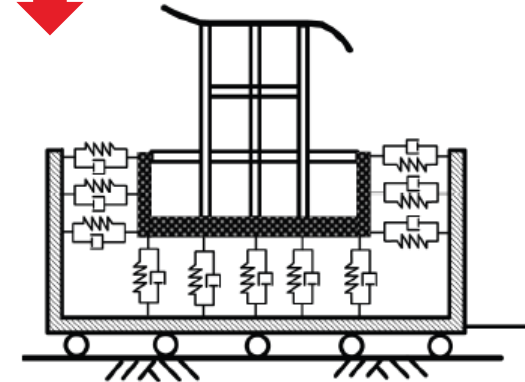
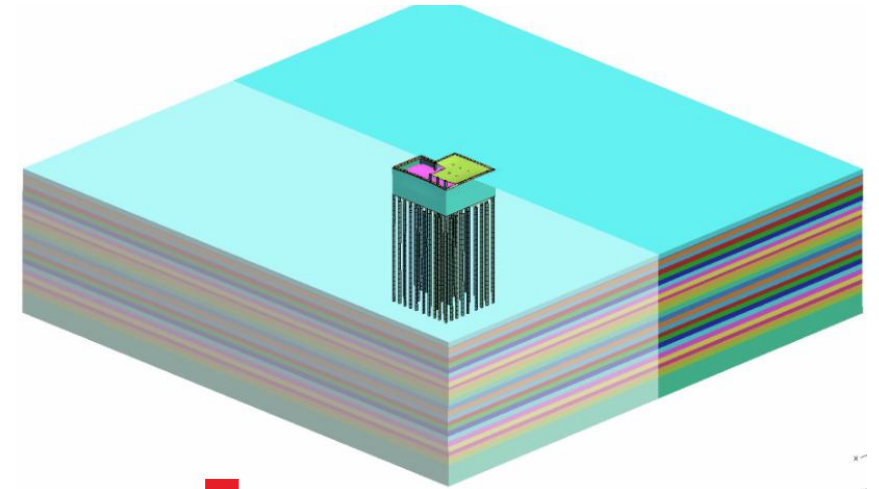
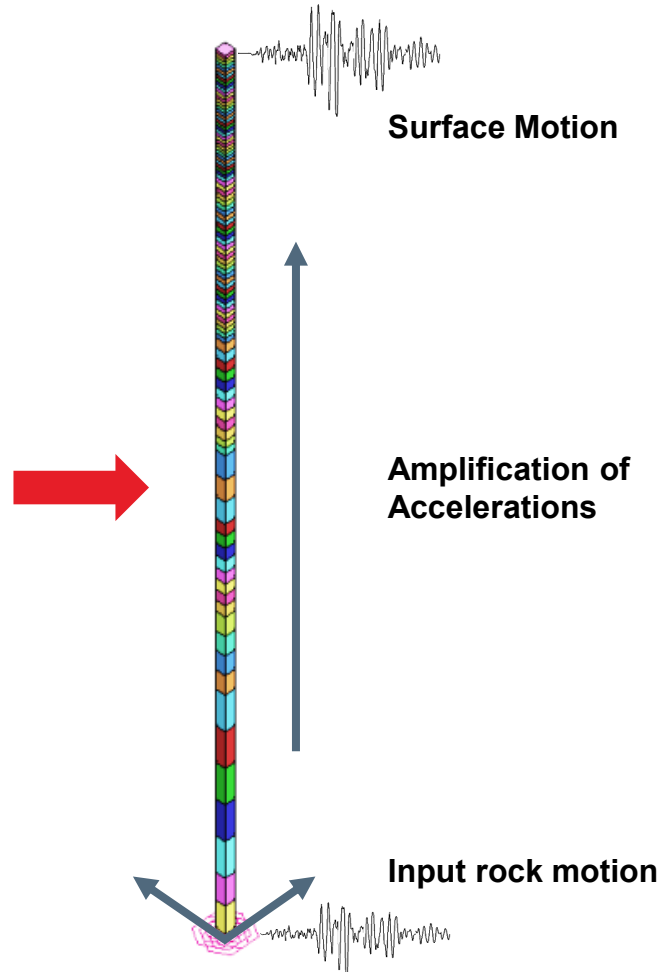
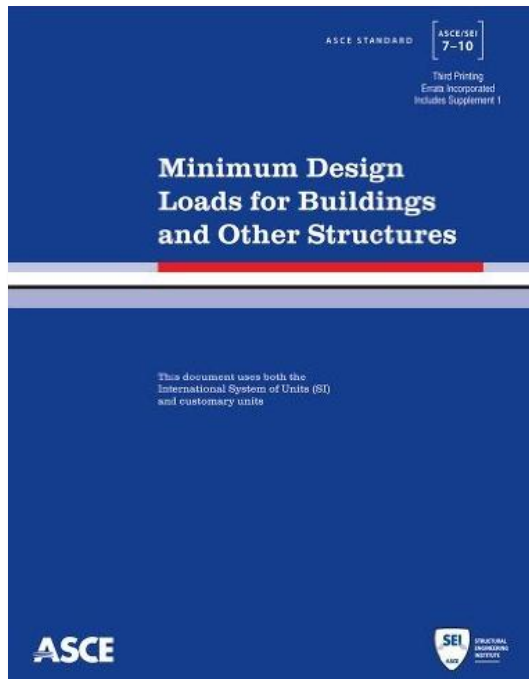
Max tension: 36 MN

Max moment: 9.0 MN-m

Separation permitted during strong shaking

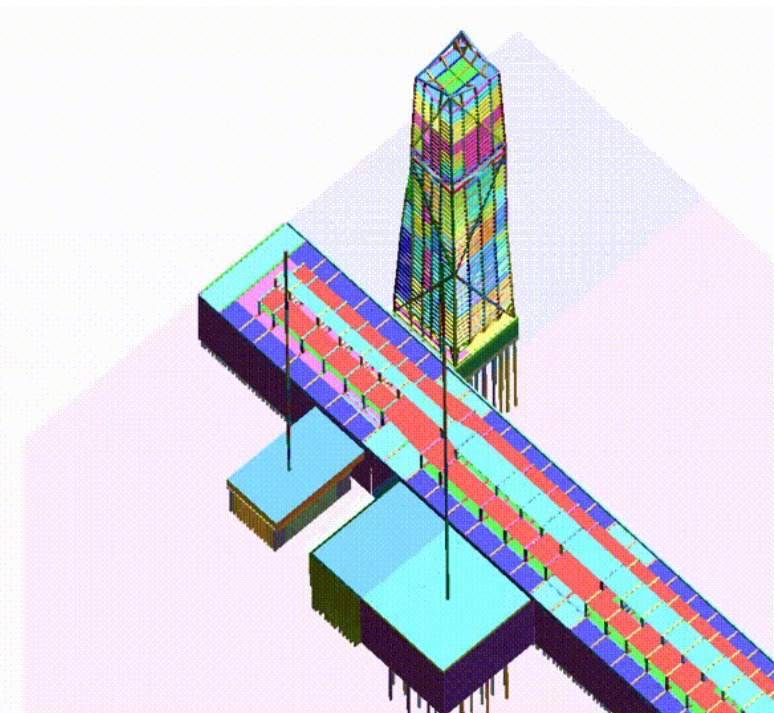
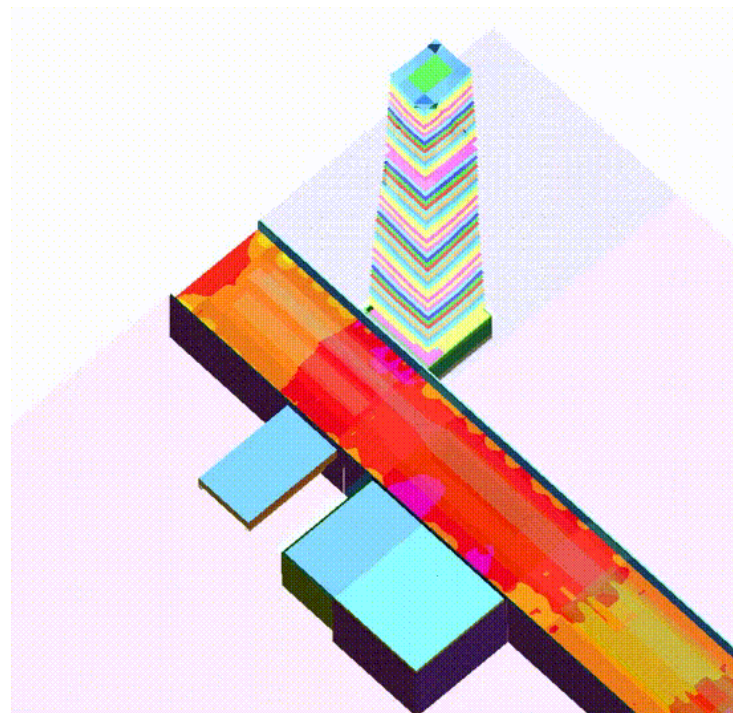


KSSI for structural design

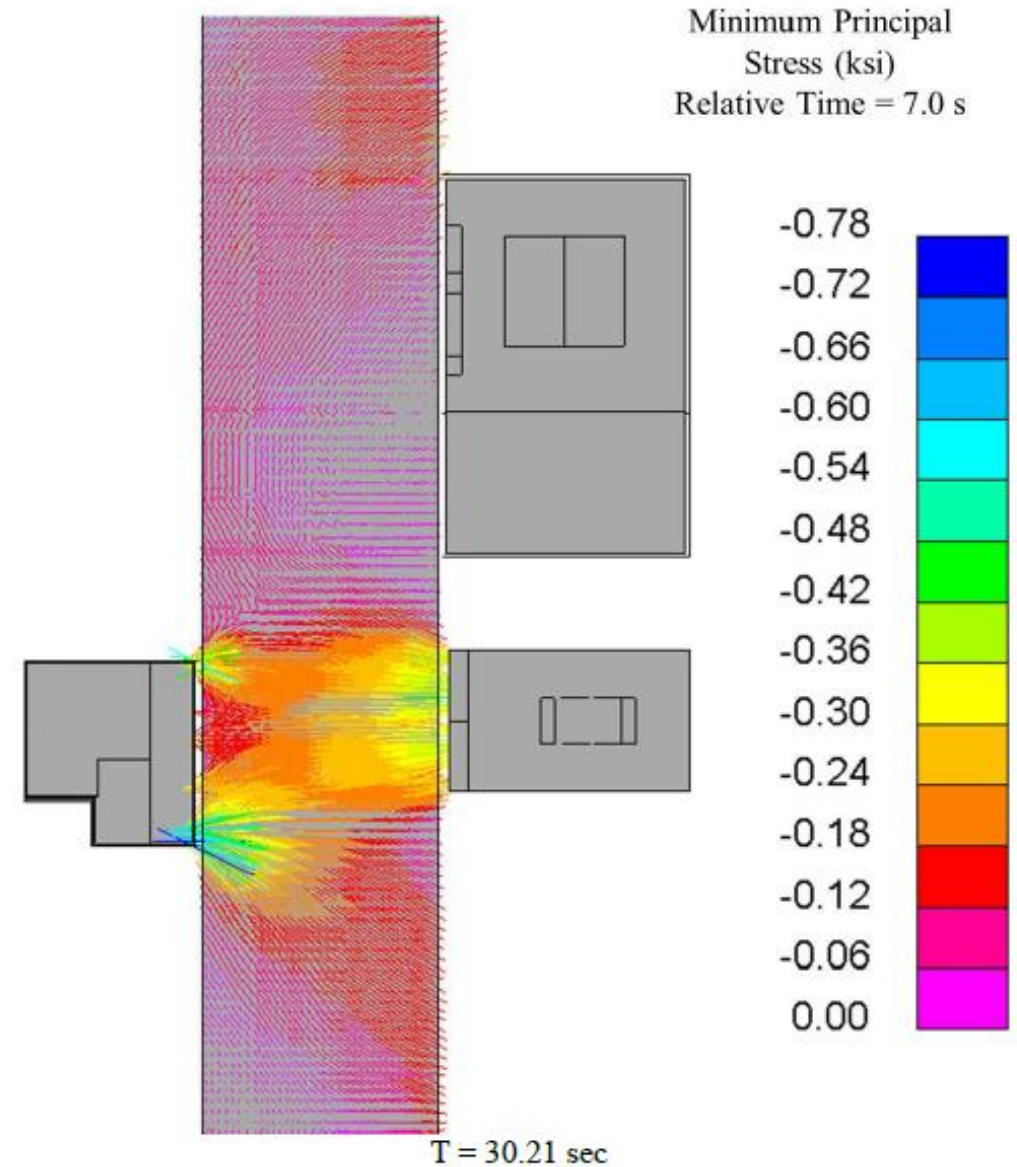
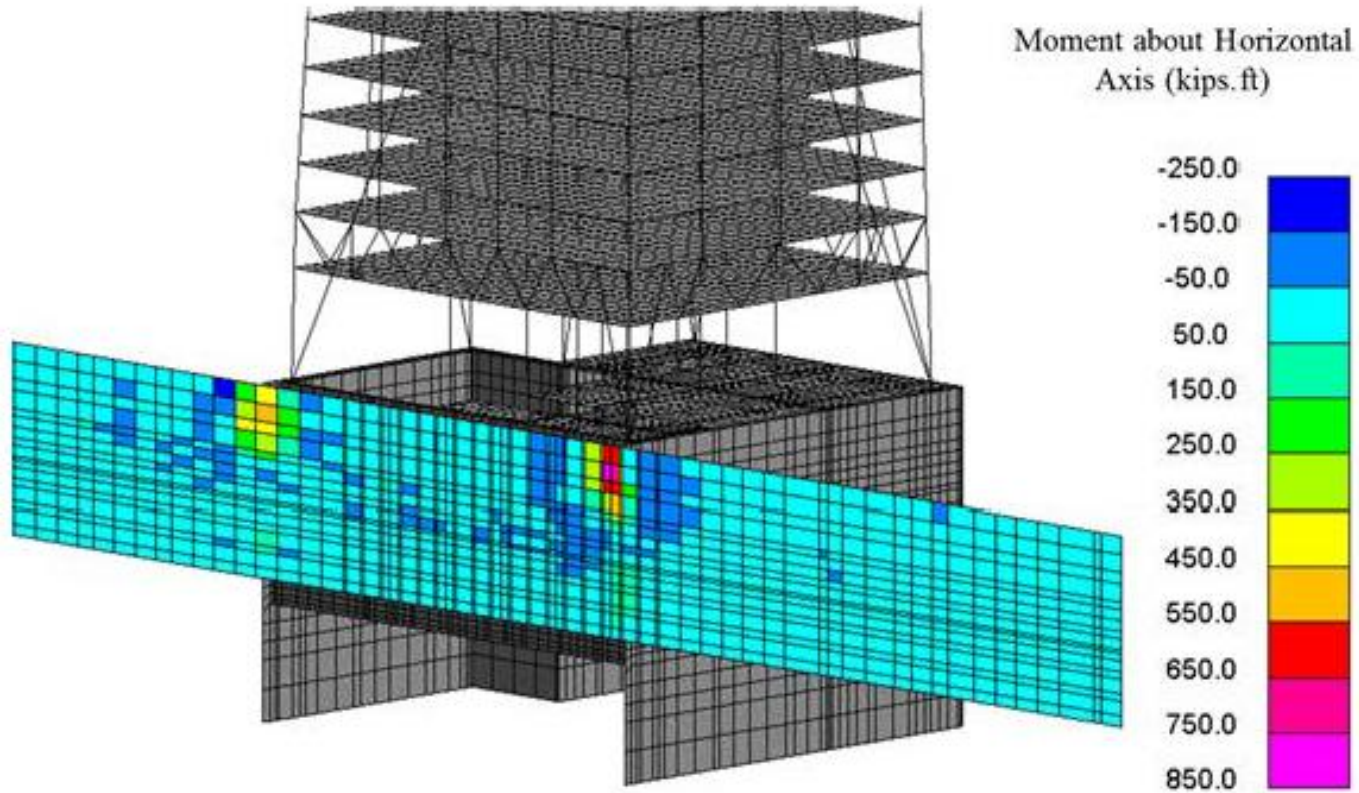


SSSI for impact on Salesforce Transit Center

- Mitigation of SSSI effects due to future projects not anticipated in original STC design
- 1D shaking
- Masing damping
- Simplified stratigraphy
- Software unfamiliar to client and peer reviewers



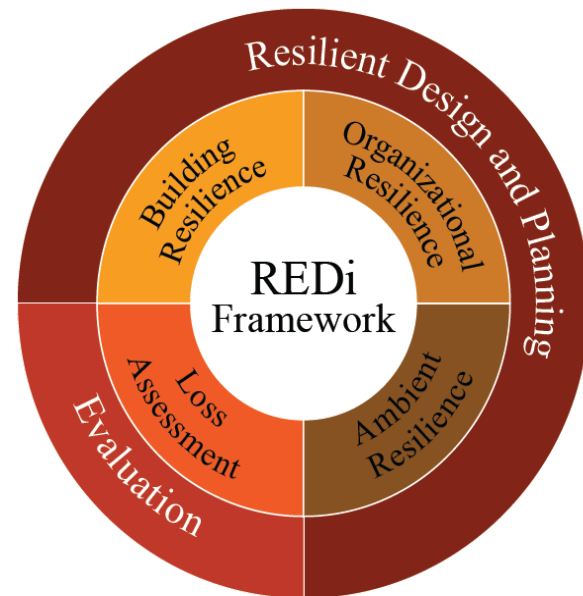
SSSI results (181 Fremont)



Commentary on savings

SSI and structural innovations helped **improve resilience** and achieve a **reduction of ~2,700 tons of steel.**

Enough steel to build a 20-story tower!



2018 Structural Project of the Year: ASCE Region 9

2018 Outstanding Project Award: Deep Foundations Institute

2019 Outstanding Project Award (Private, Large Budget): The California Geotechnical Engineering Association

2019 Best in Geotechnical Engineering: Council on Tall Buildings and Urban Habitat

2019 Best in Structural Engineering: Council on Tall Buildings and Urban Habitat

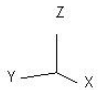
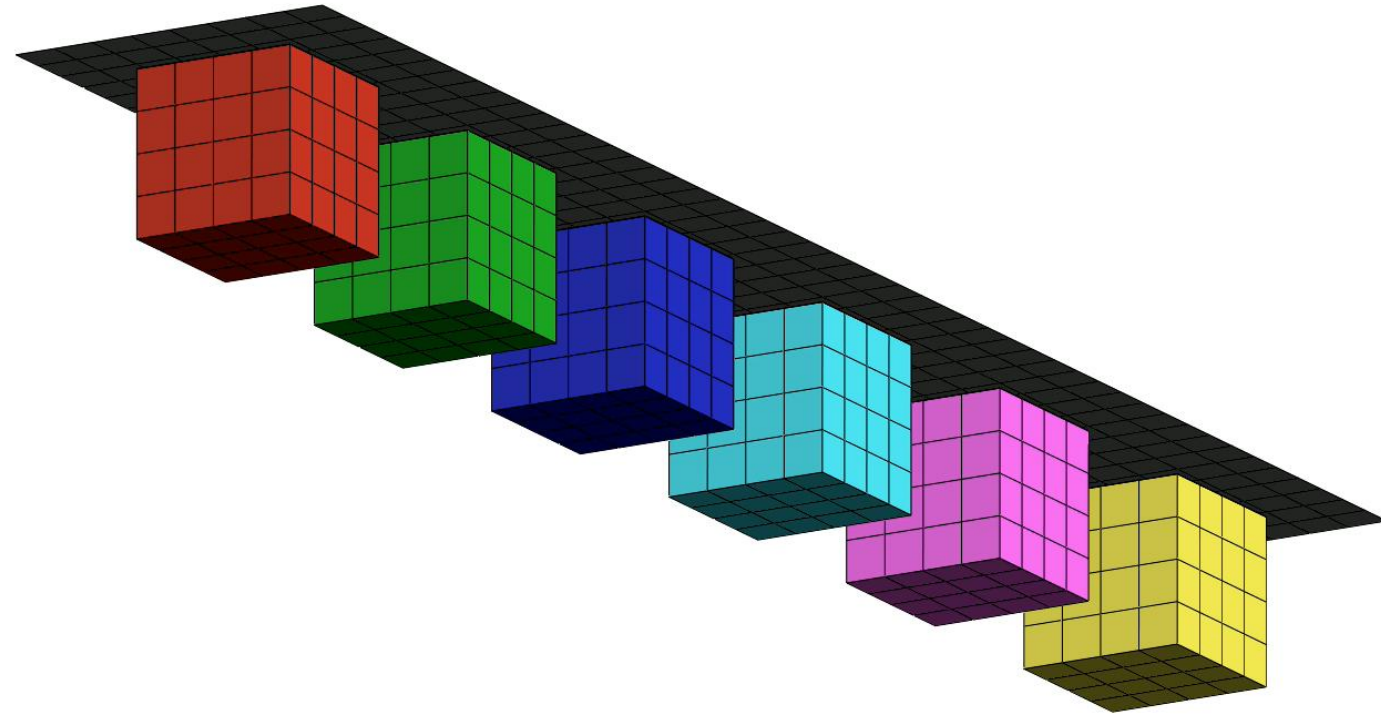
2019 Award of Excellence in Best Tall Building 200-299 meters: Council on Tall Buildings and Urban Habitat

2019 IDEAS² Award for projects greater than \$75 million: American Institute of Steel Construction



Interlude #1

Contact modeling for SSI vs SSSI



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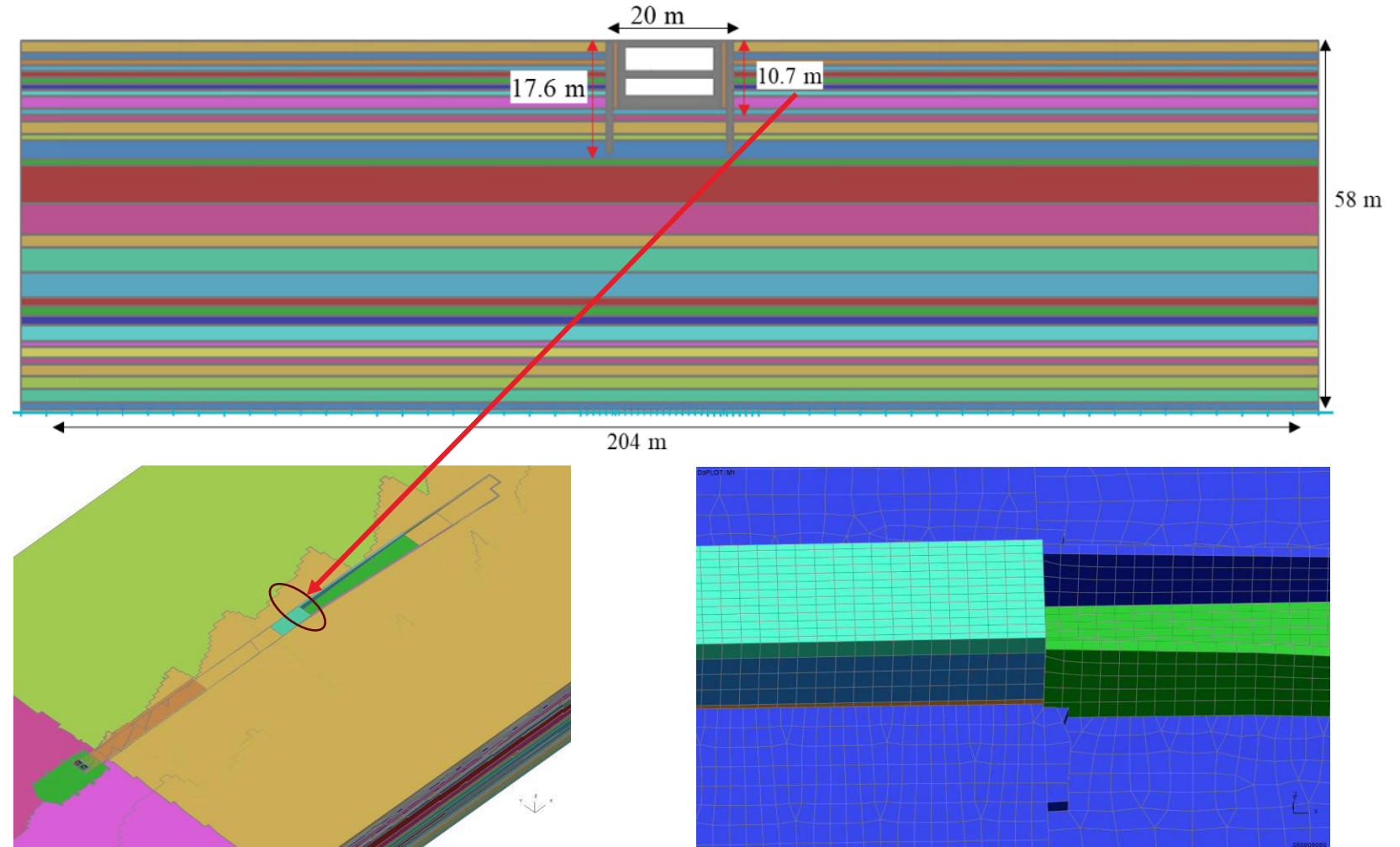
Contact modeling for SSI vs SSSI

Recent Study: Overview

Scenario: CLSM between shoring/cut and cover tunnel

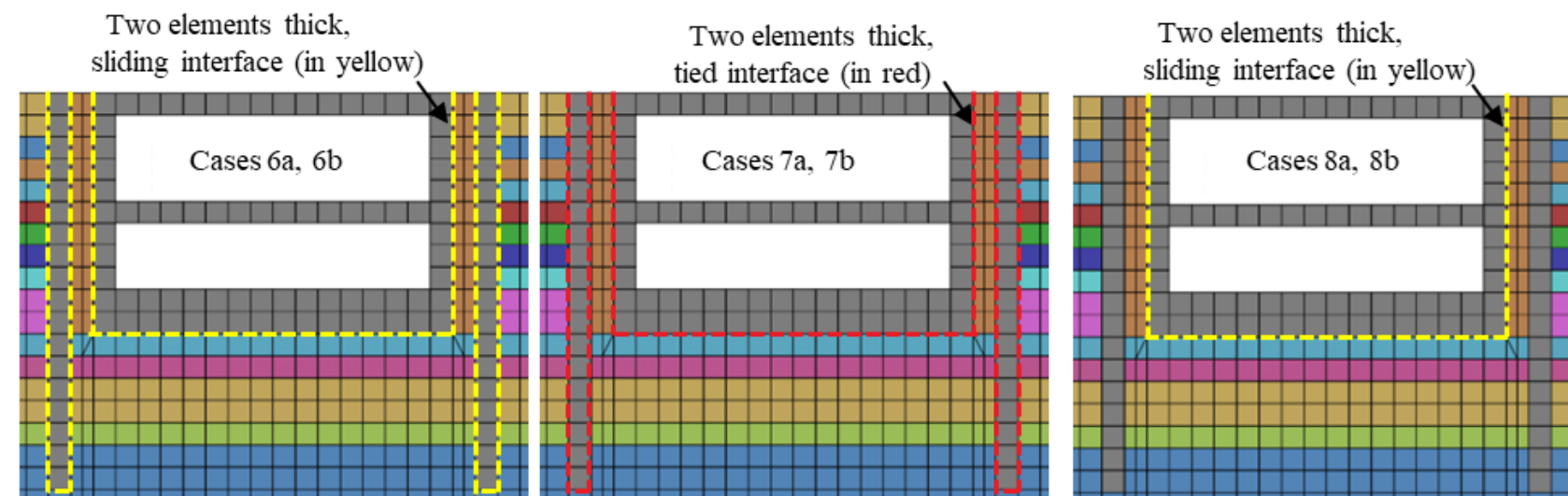
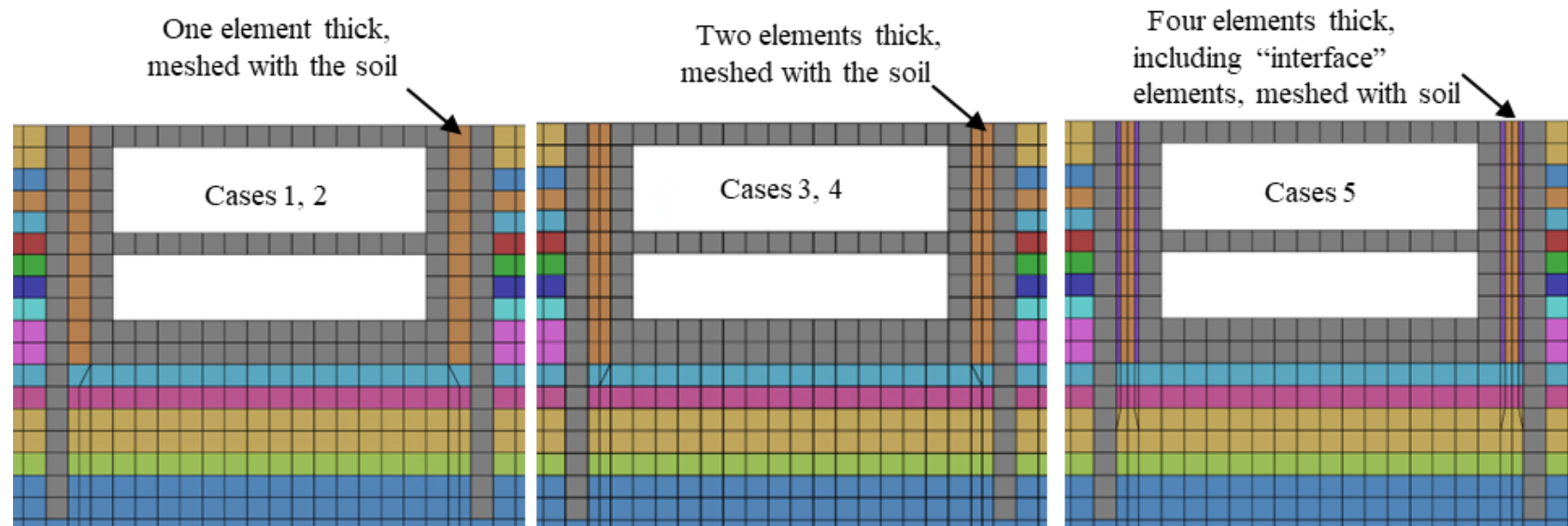
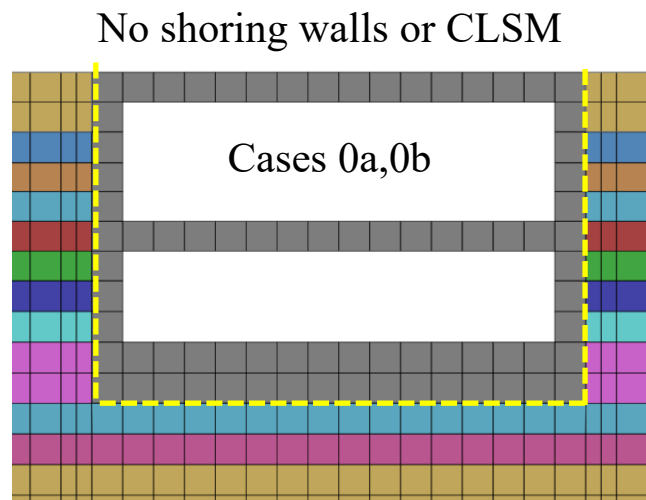
Soils: Over-consolidated clay with interbedded sand and gravel layers

Question: How sensitive are demands to the contact modeling?



Contact modeling for SSI vs SSSI

Recent Study: Scenarios



- Cases 1 & 3: constant stress elements
- Cases 2 & 4: quadratic elements
- a: default contact stiffness
- b: higher contact stiffness

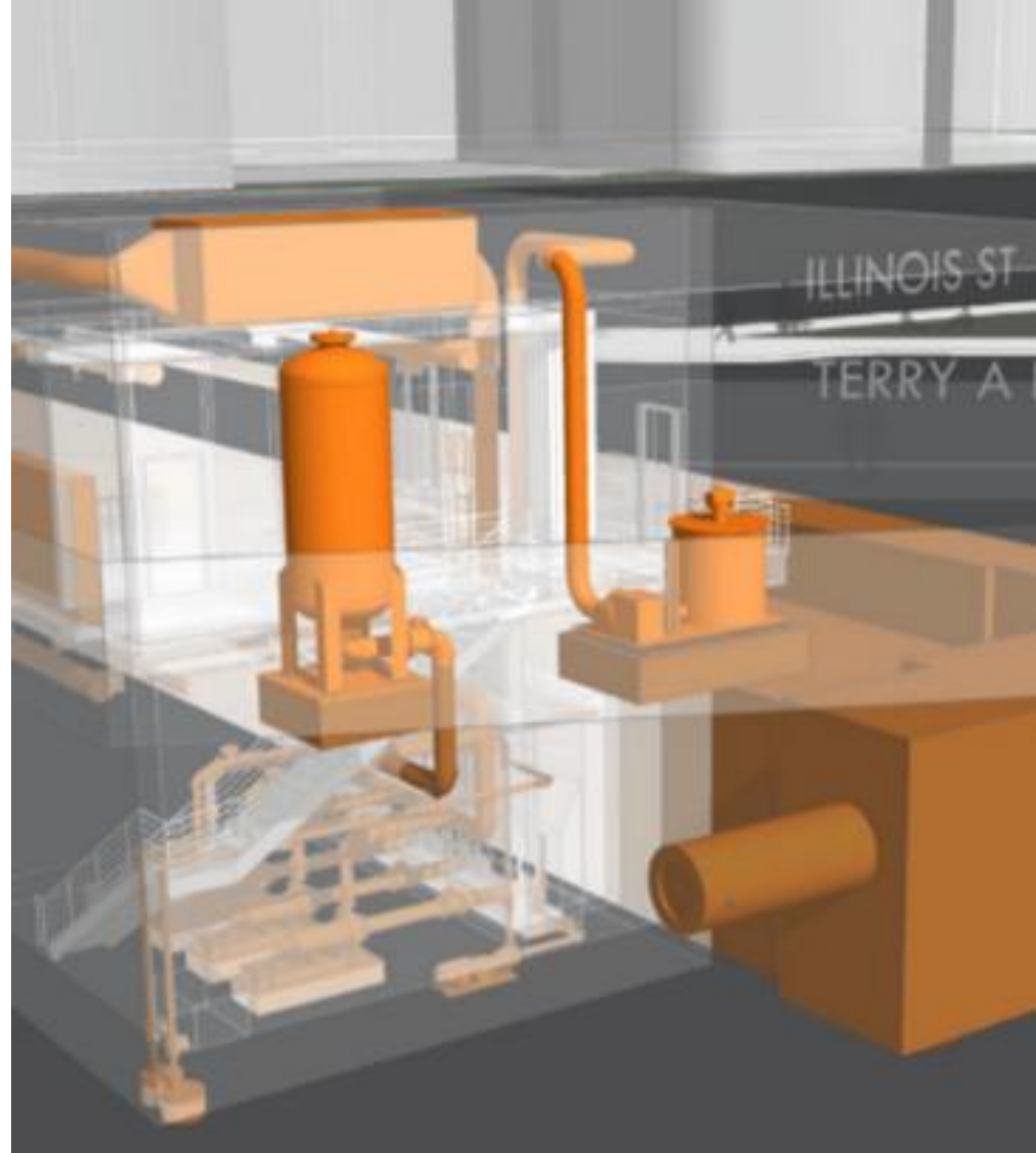
Contact modeling for SSI vs SSSI

Recent Study: Conclusions

- SSSI systems may be more sensitive to contact modelling decisions
- Relatively compressible layers should be at least two (preferably more) elements thick
- Avoid tied contacts if possible
- Realistic responses were achieved using meshed interface elements (Case 5) or sliding interfaces (Case 6b).
- If sliding contacts are used, careful selection of the contact stiffness is needed.

Case study #2

Mariposa Pump Station (~2017)





Transbay Terminal

Project Site



Image © 2025 Airbus

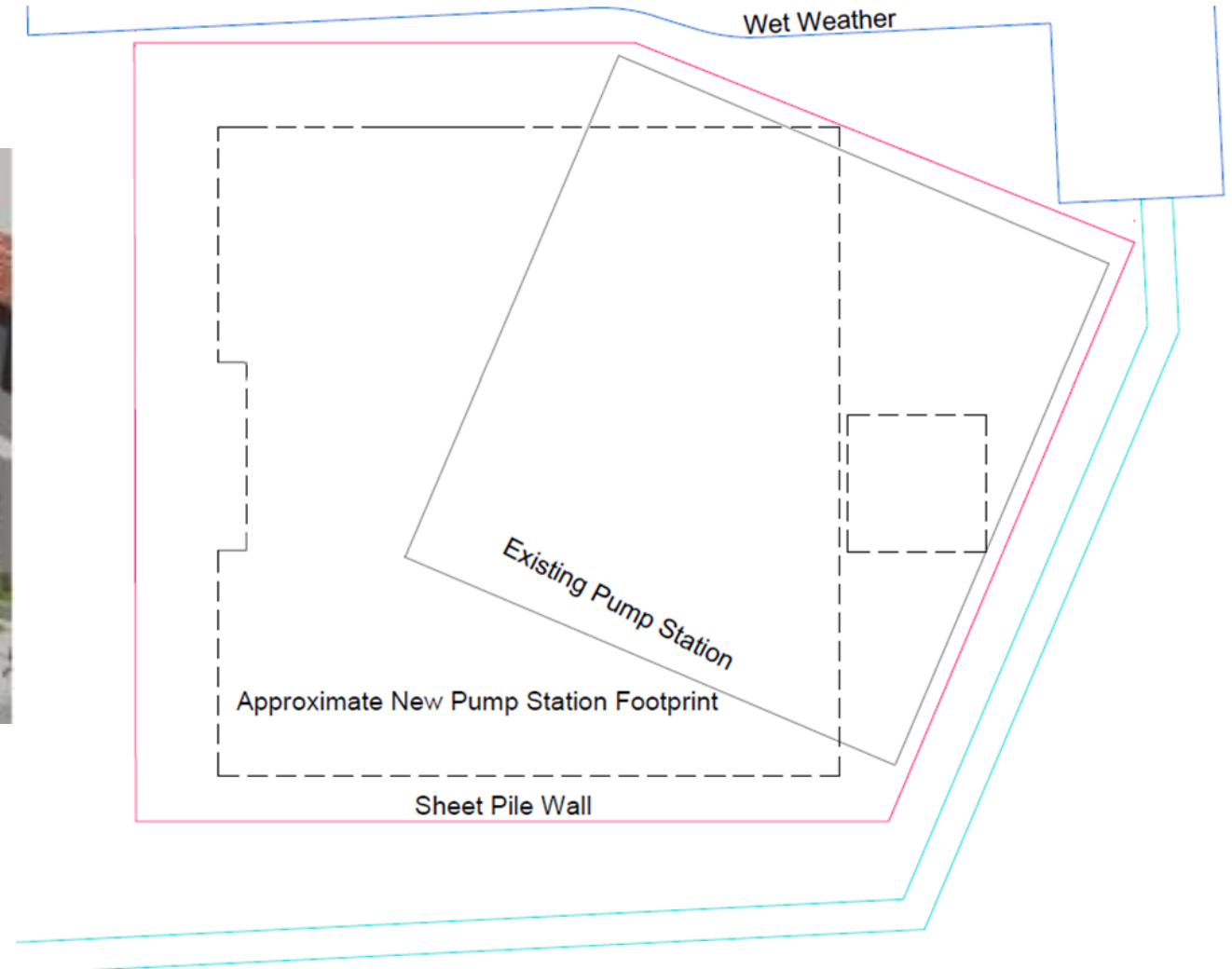
Google Earth

Imagery Date: 4/9/2024 37°46'59.58" N 122°23'37.21" W elev 0 ft eye alt 22652 ft

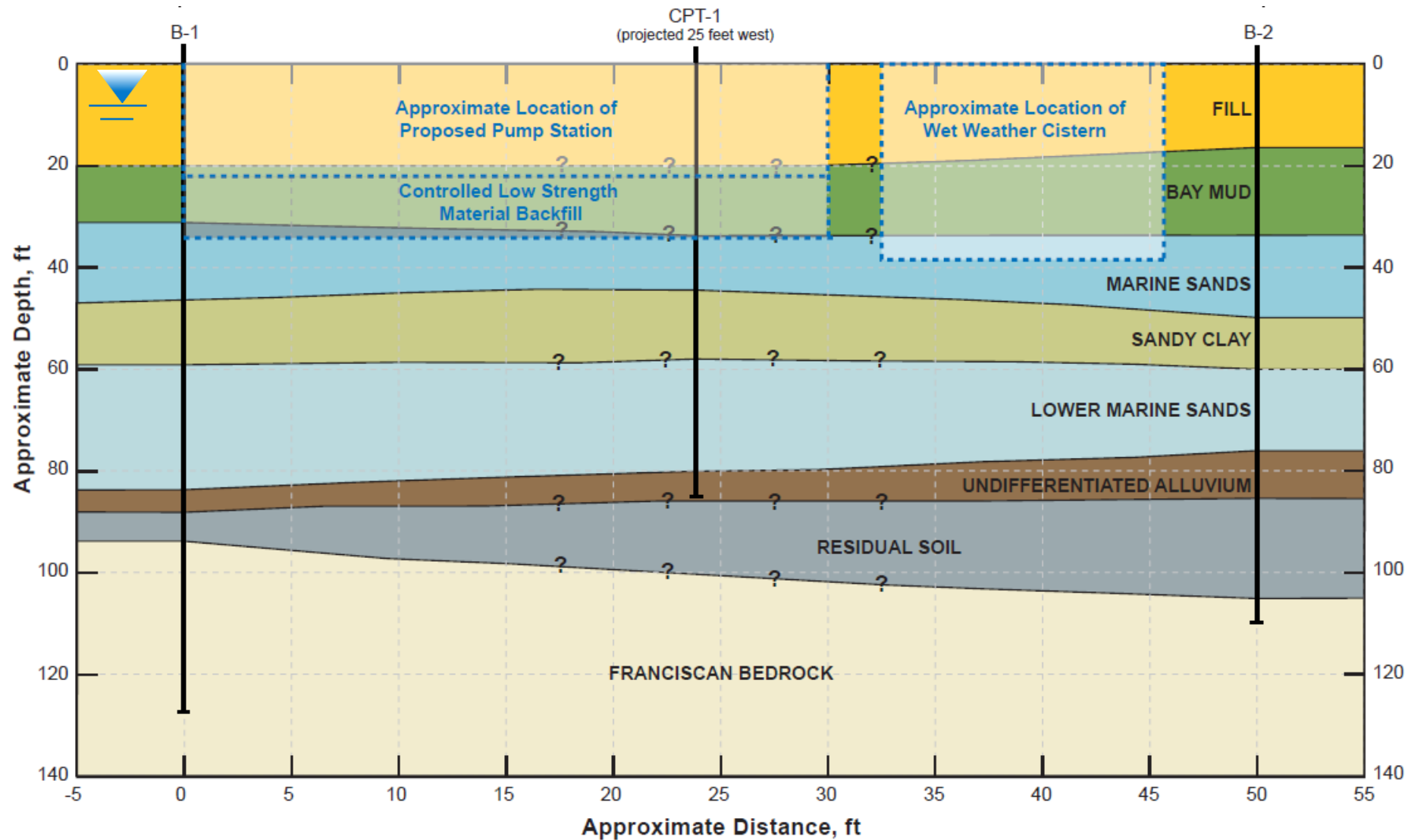
1985

New Pump Station Layout

T/S
Box

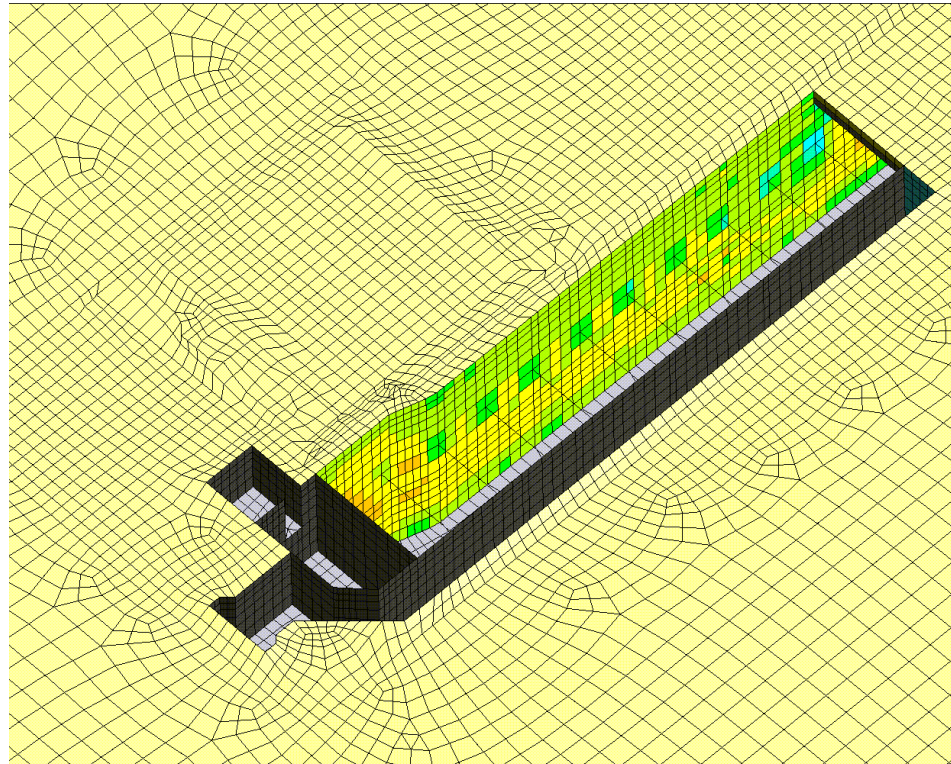


Stratigraphy

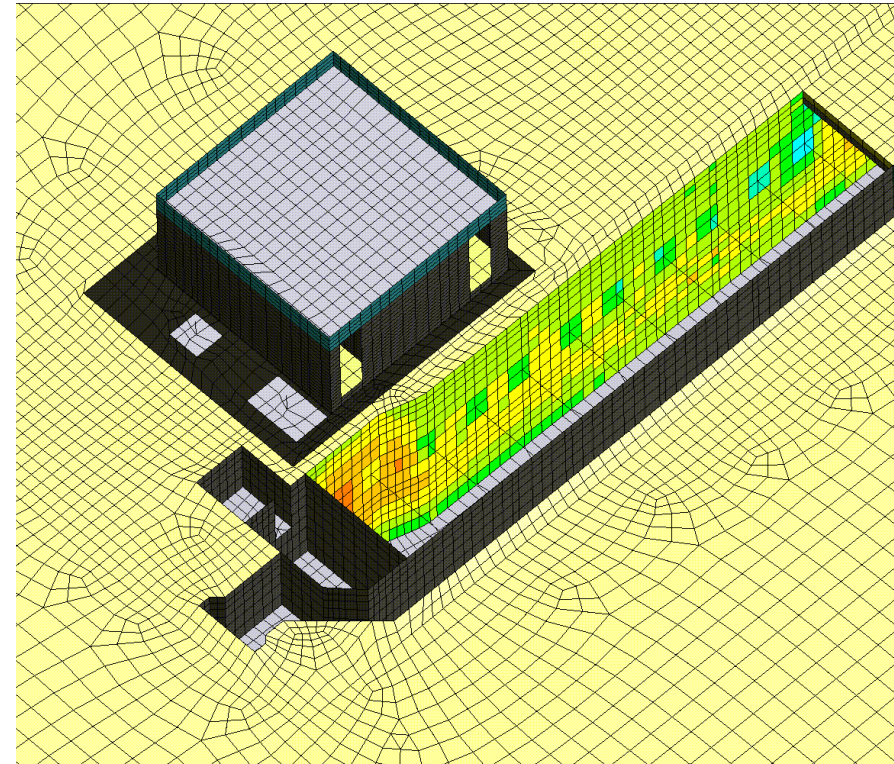


SSSI check on T/S box

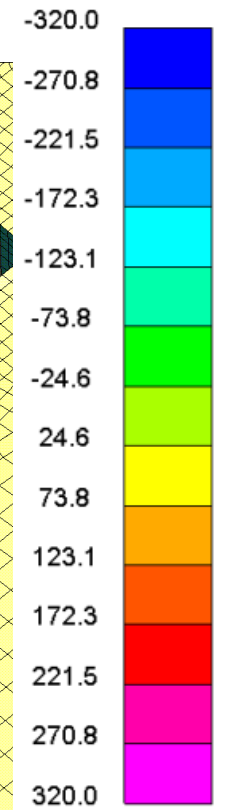
No New Station



Strong CLSM

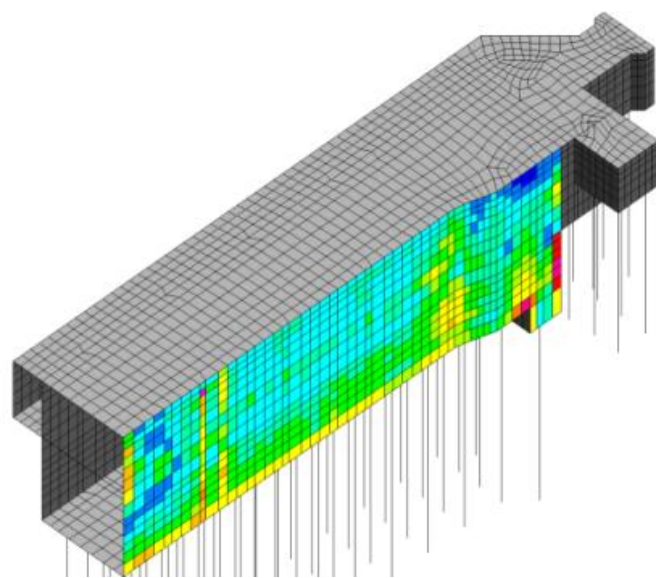
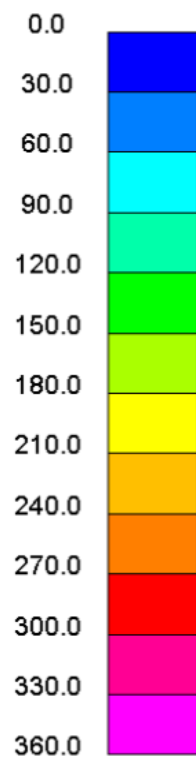


Moment
(kN-m/m)

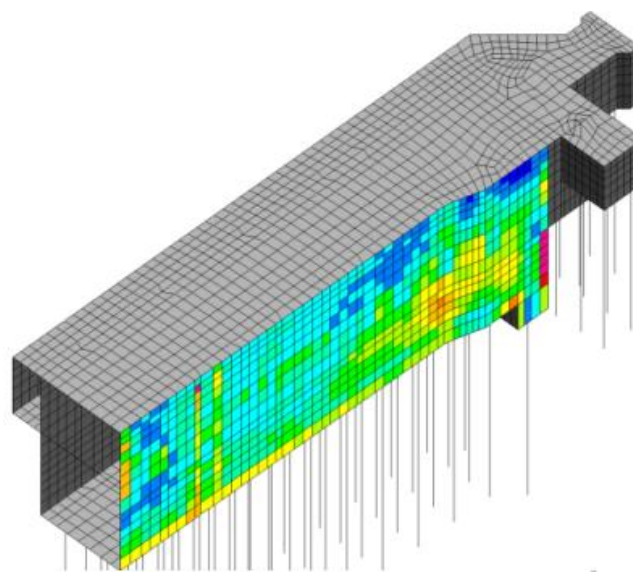


Moment about vertical axis in T/S box wall

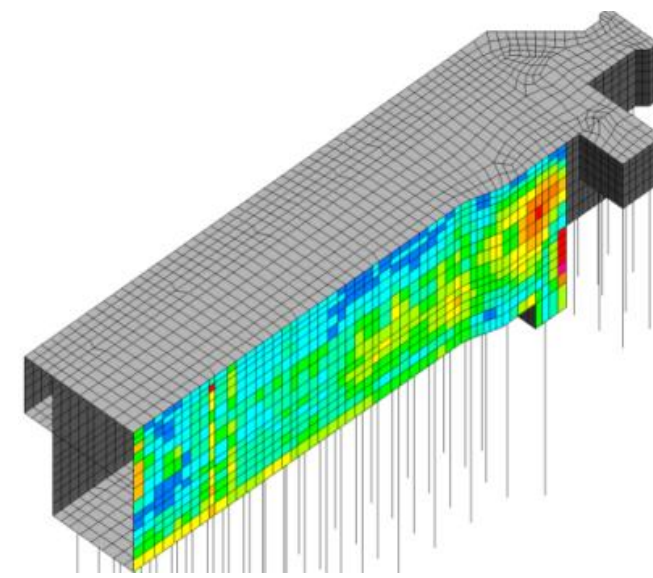
Moment
(kN-m/m)



No New
Station

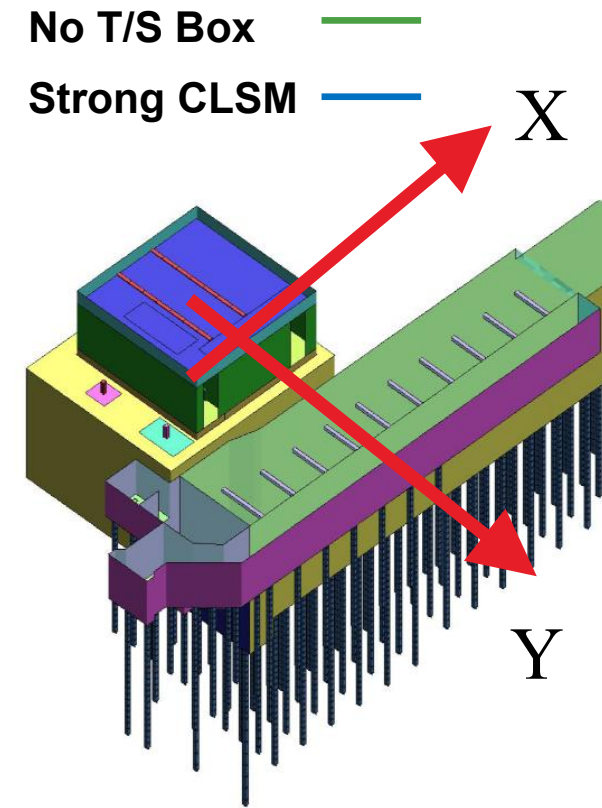
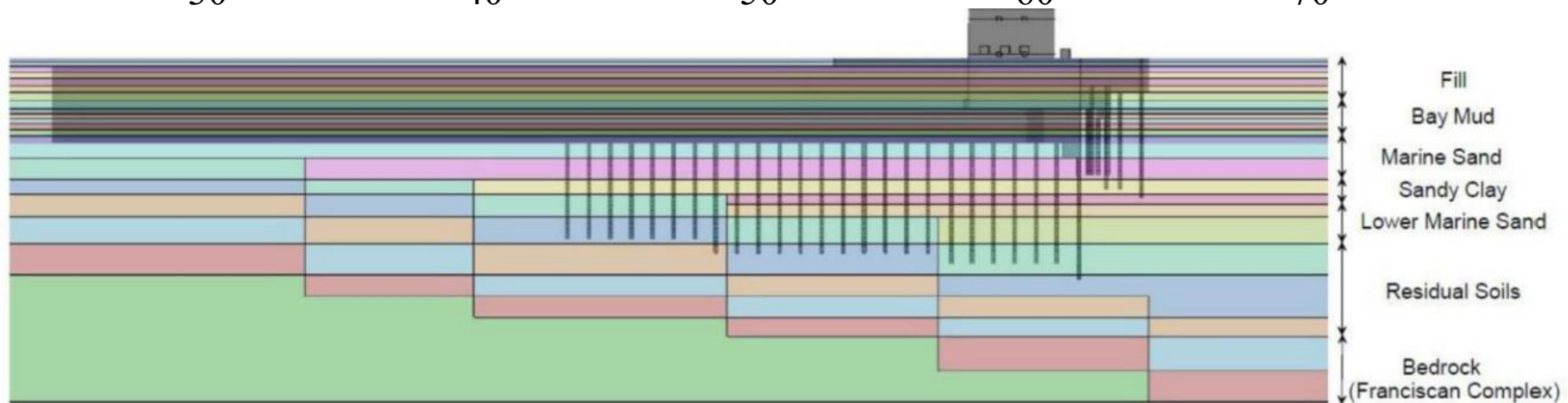
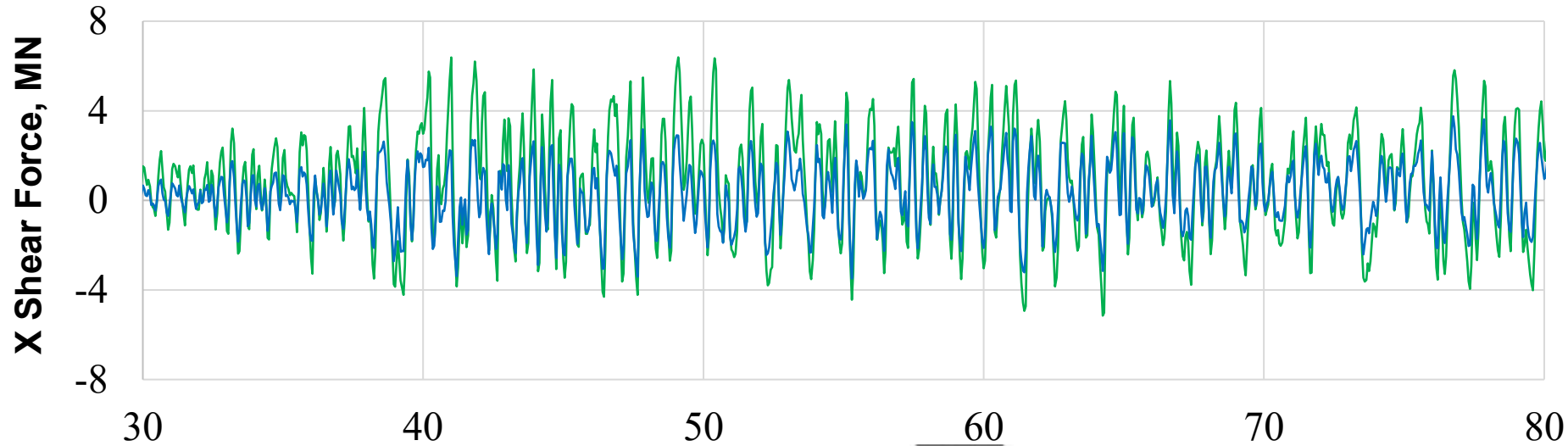


Lower Range
CLSM



Upper Range
CLSM

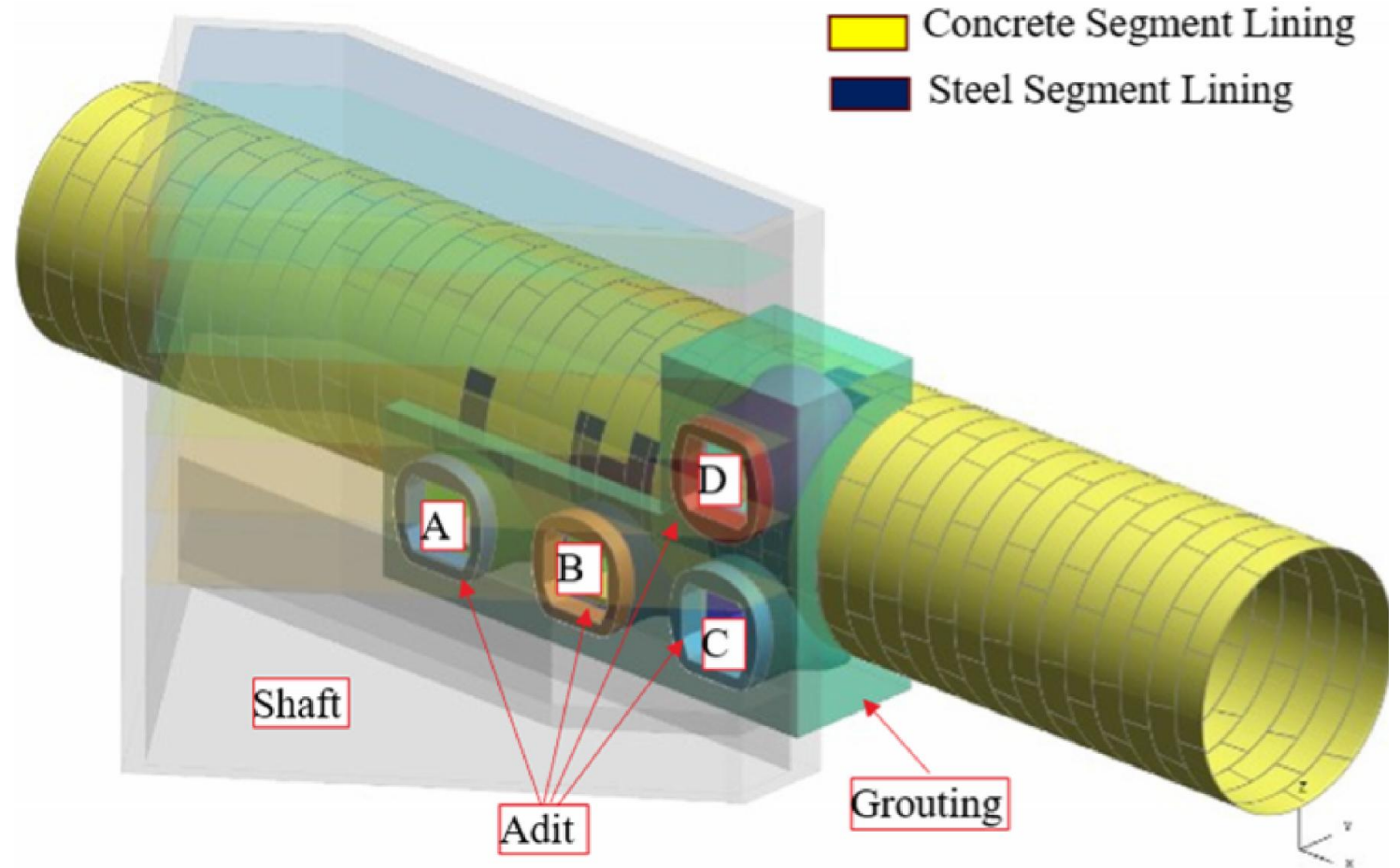
An interesting observation....



Ellison, K., Masroor, A., Chen, S., Liang, W., Kwan, T., Tam, B., Walker, M. SSI versus SSSI for Adjacent Pump Stations. Geotechnical Earthquake Engineering and Soil Dynamics V. 2018.

Interlude #2

Quick Thoughts about Simplified Methods for SSSI Analysis

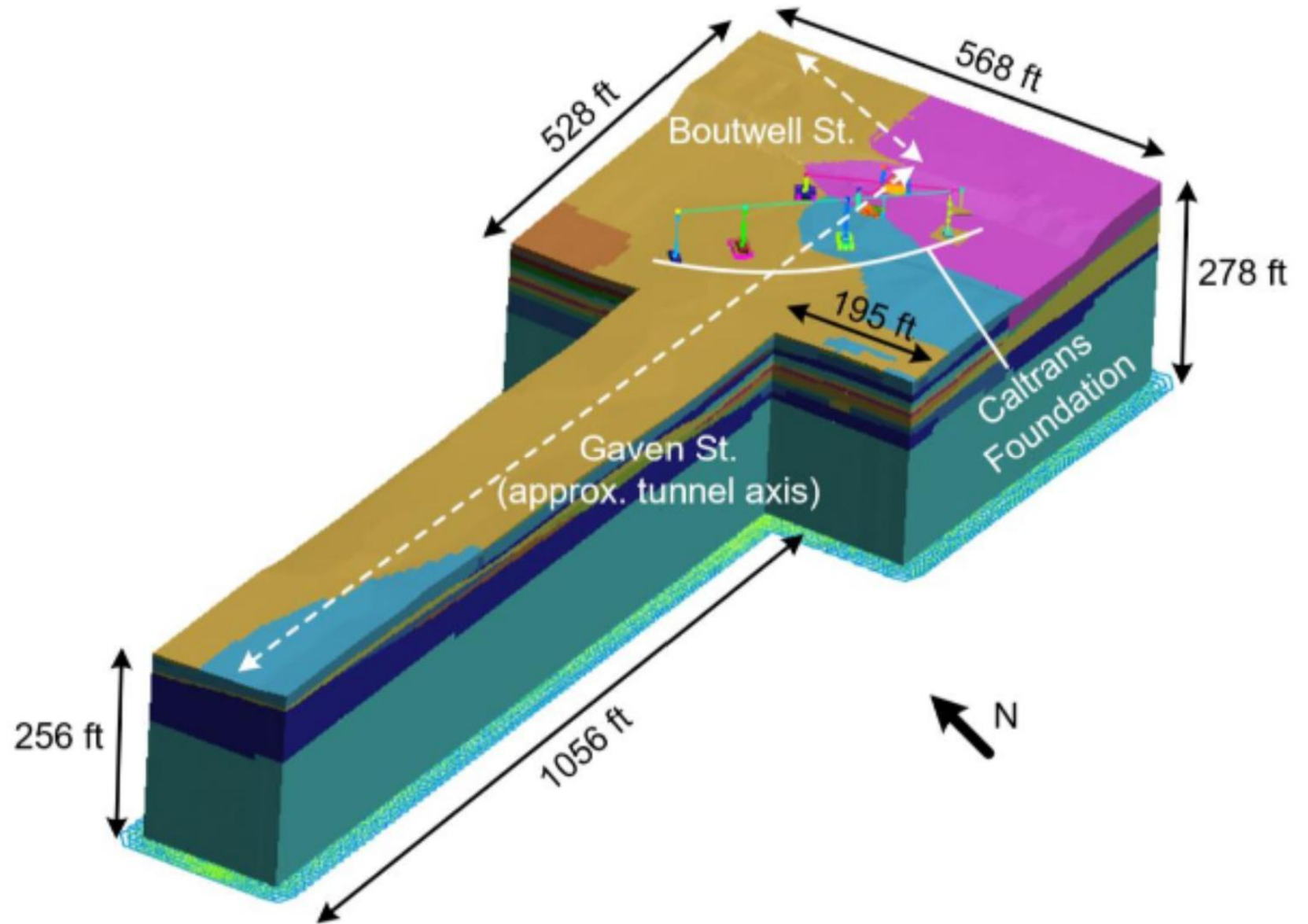


Quick thoughts about Simplified Methods

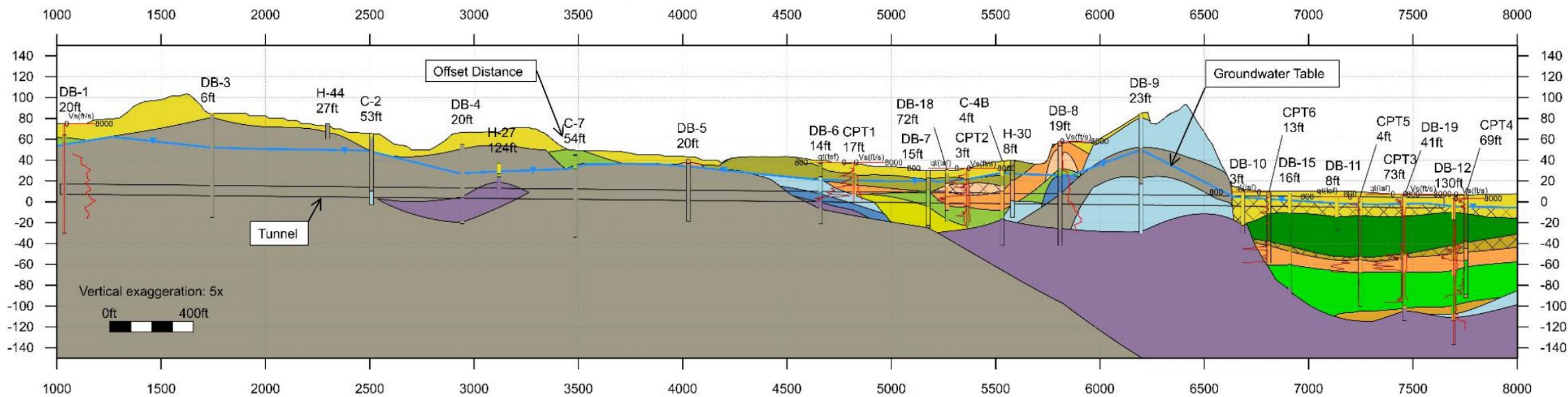
- **Empirical methods:** Not many out there.
- **Pushover analyses:** Limited use cases for screening, e.g.
 - Tower base shear force applied to rule out inertial effects
 - Body forces applied to soil and below-grade structures to rule out kinematic effects
- **Frequency domain analysis:** Inappropriate for nonlinear problems with below-grade structures.
- **Greenfield dynamic SSI analysis:** Great approach for screening.
- **2D dynamic SSSI analysis:** Very few real-world cases are 2D. Highest demands tend to be at edges/corners.

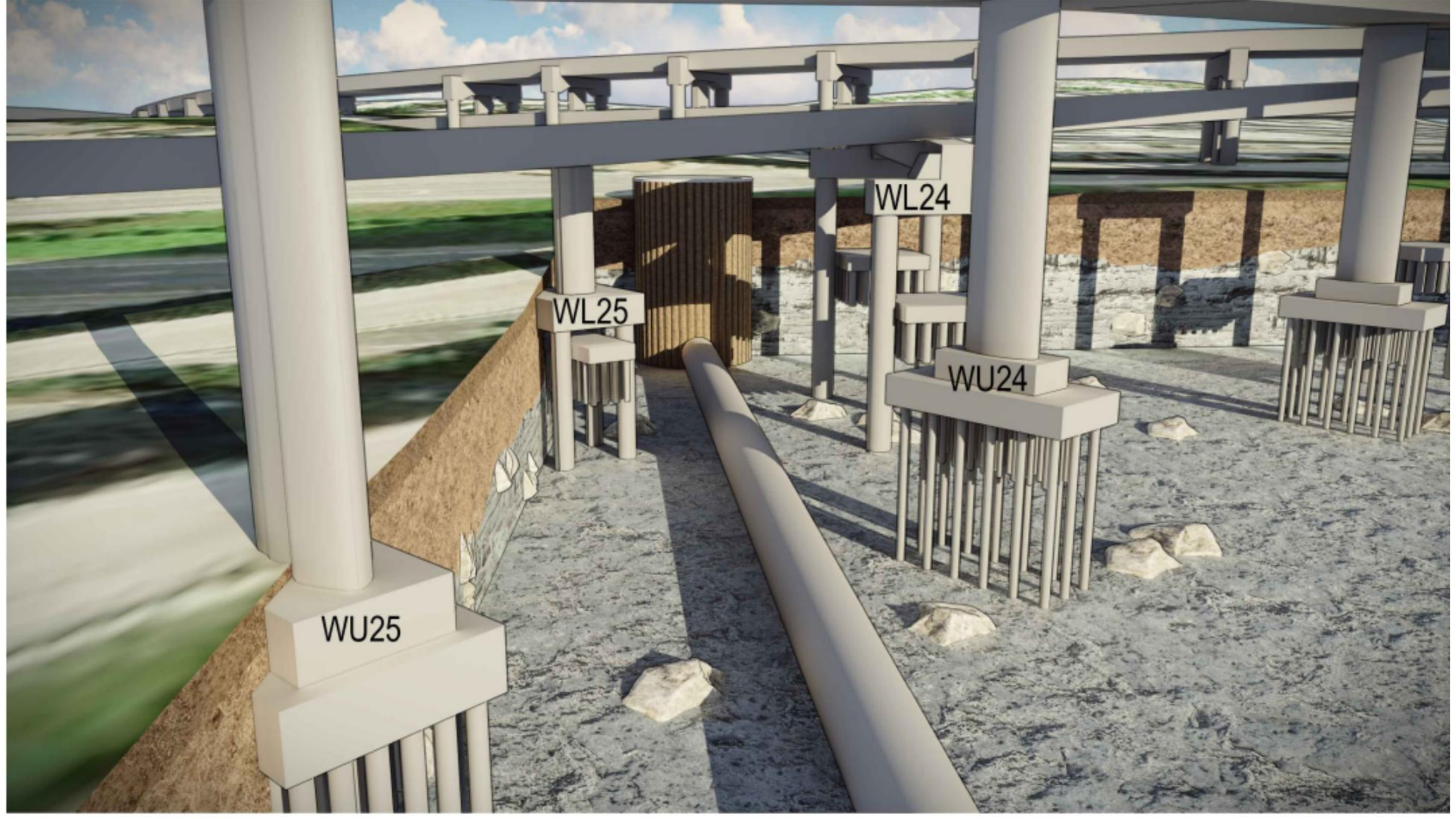
Case study #3

Lower Alemany Sewer Tunnel (~2025)



Overview





WL24

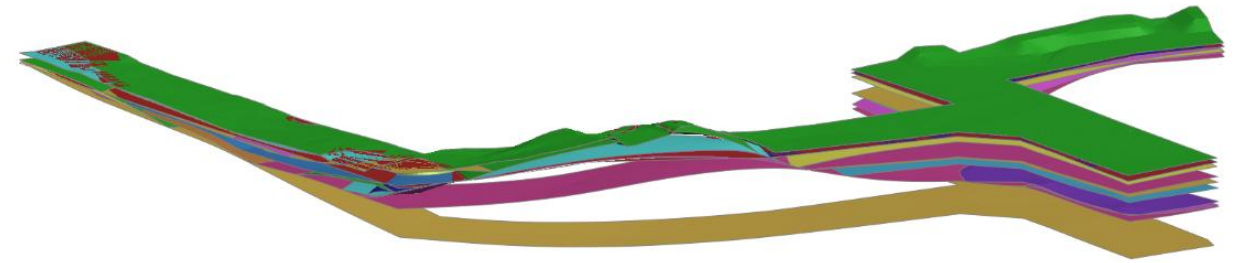
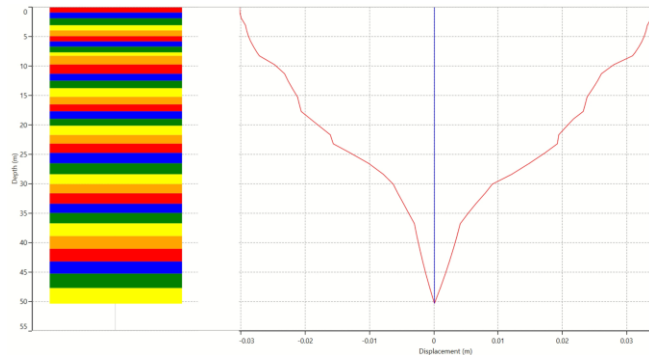
WL25

WU24

WU25

Automation for 3D site response analysis

Uni-directional site response analysis (SRA) in DEEPSOIL (now RS seismic)



Surfaces from Leapfrog

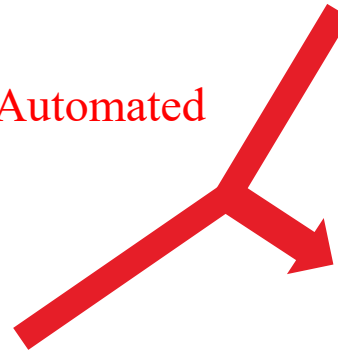
Automated



Automated



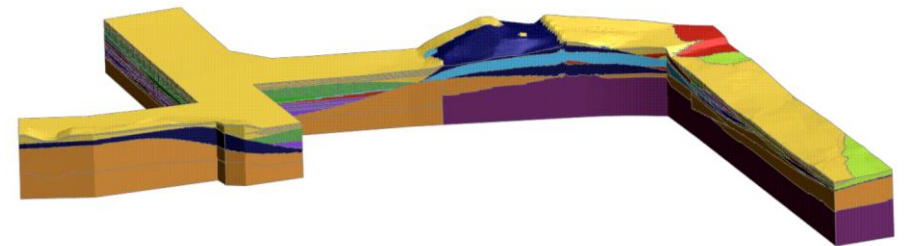
Automated



Uni-directional SRA in LS-DYNA (for validation)

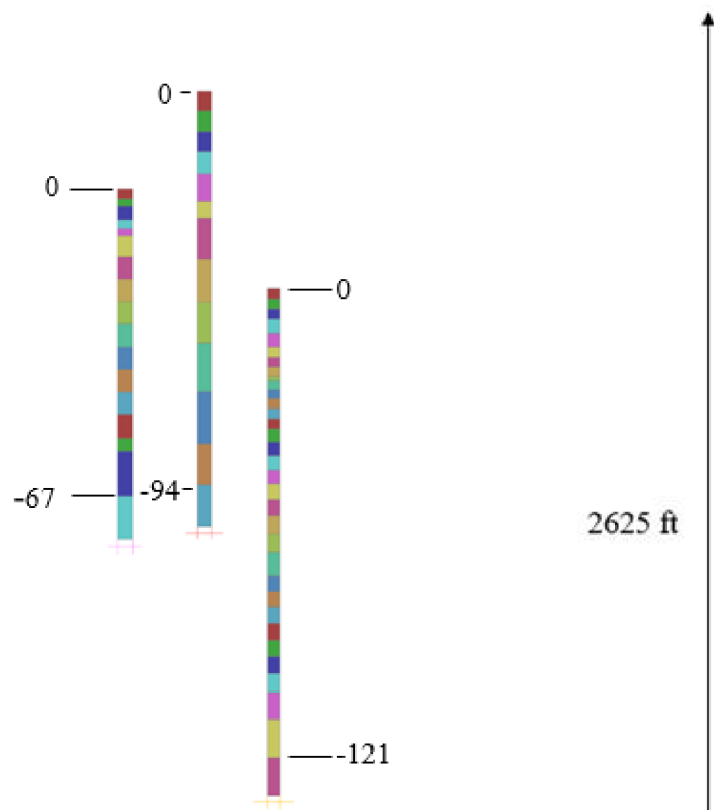


Multi-directional SRA in LS-DYNA

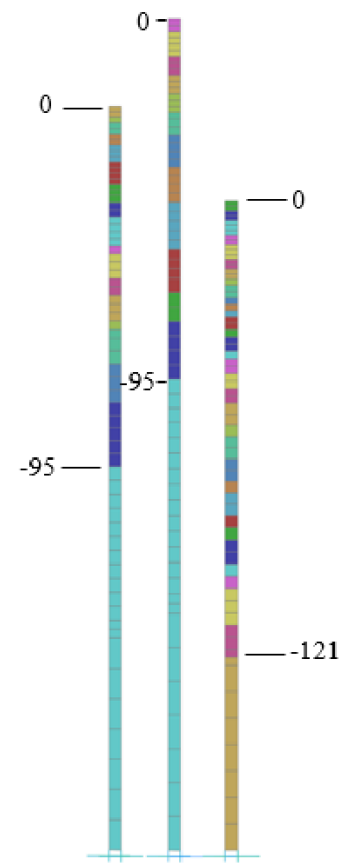
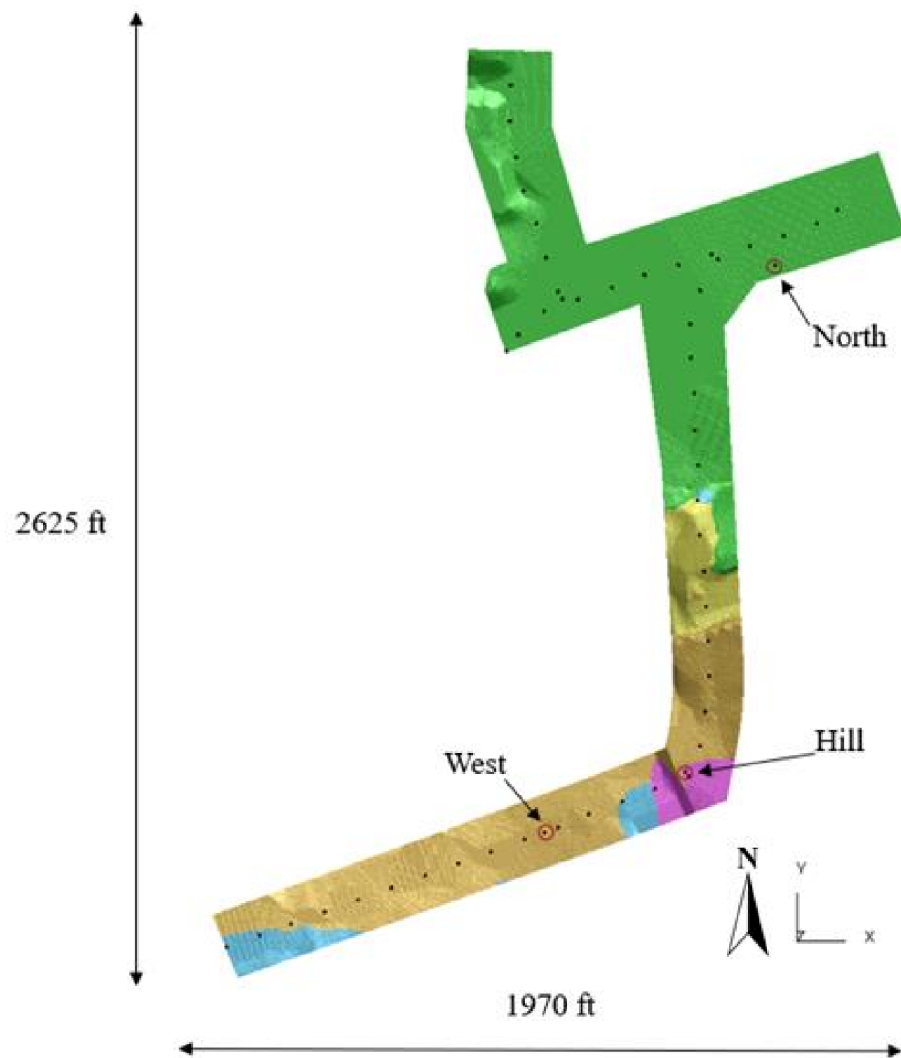


3D SRA

Validation for 3D site response analysis



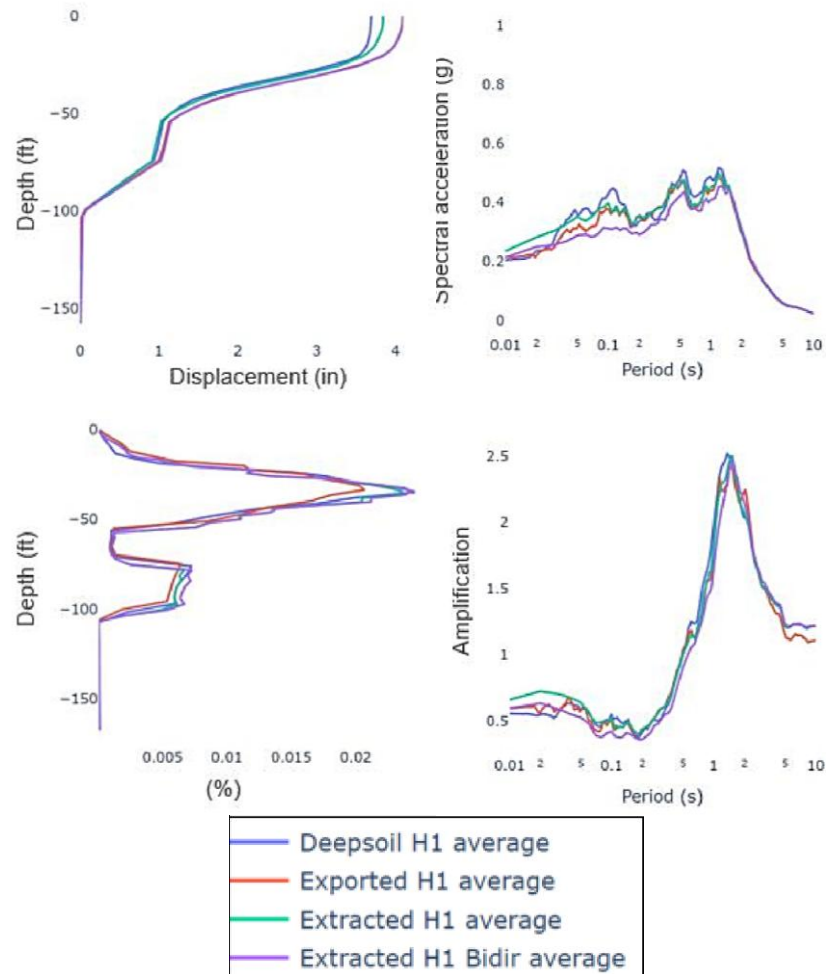
“Exported” Profiles



“Extracted” Profiles

Validation for 3D site response analysis

Do changes in response make sense at every step?



Identical?

DEEPSOIL uni-directional



“Exported” uni-directional



“Extracted” uni-directional

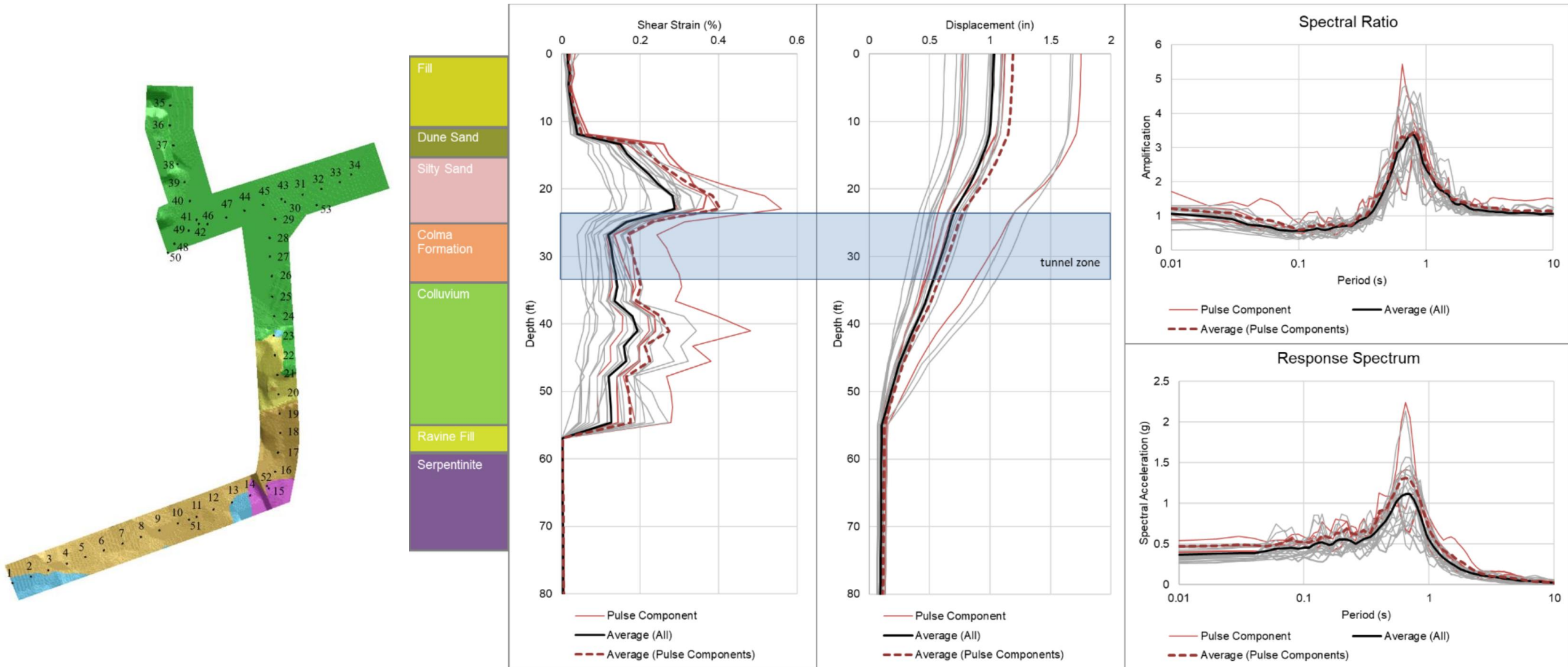


“Extracted” multi-directional

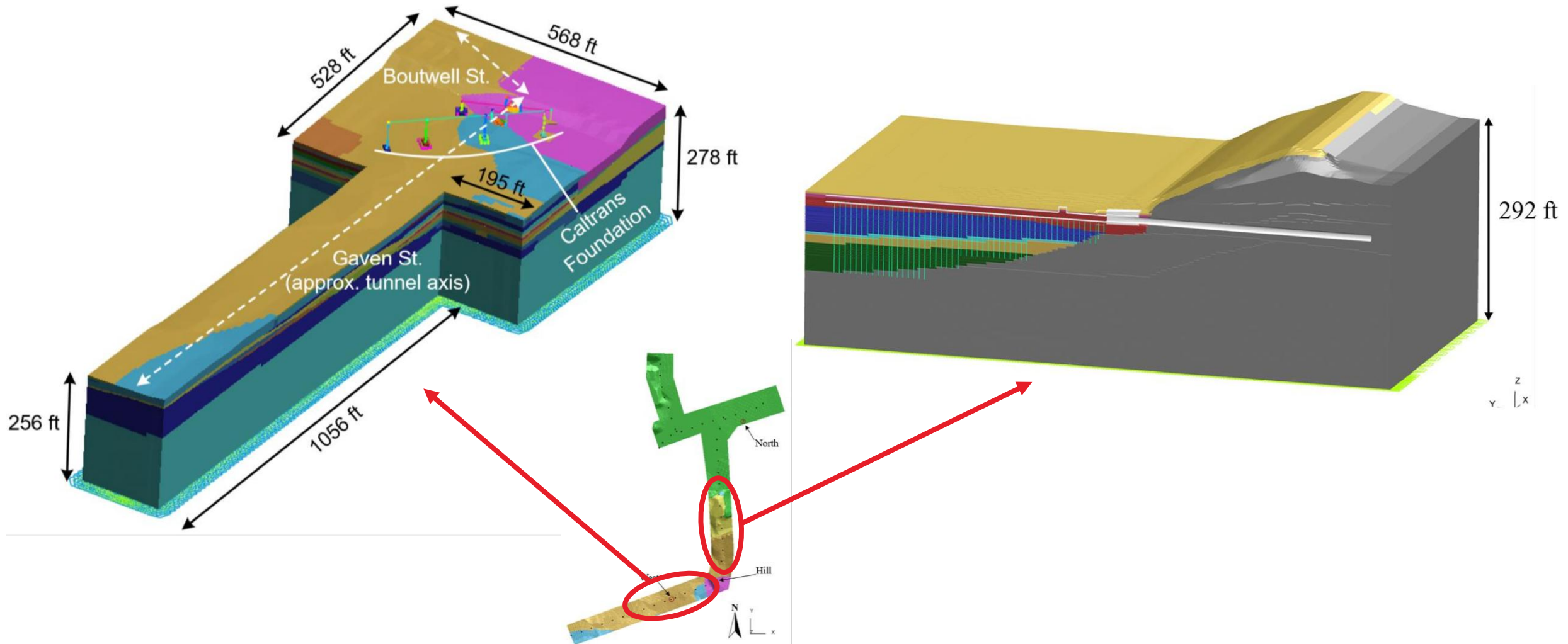


3D multi-directional

Sample 3D SRA results



SSI/SSSI models



2D SSI validation studies

Table 4-11 Comparison of seismic liner demands during GM1 from 2D SSSI (rotated component) and 3D SSSI at station 53+75 – 475 years

Analysis	Max bending moment (kip-ft/ft)	Max compressive force (kip/ft)	Max tensile force (kip/ft)	Max shear force (kip/ft)	Max change in diameter (ovalization) (in)
2D SSSI Model					
3D SSI Model, Friction =0.25					

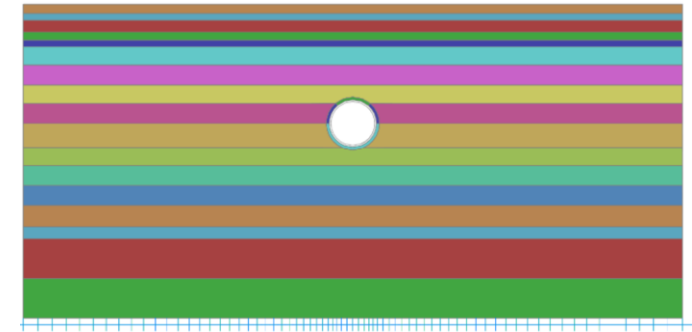
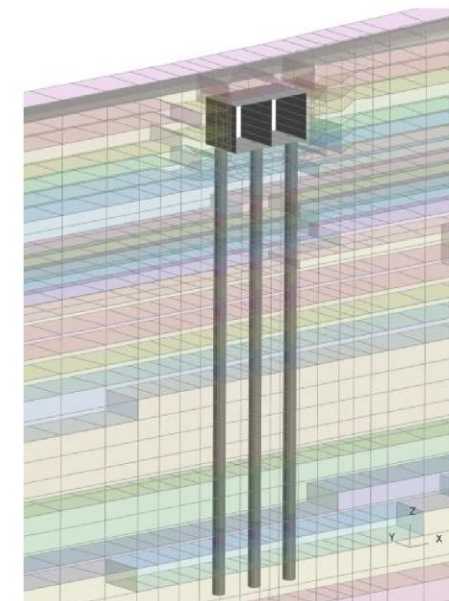
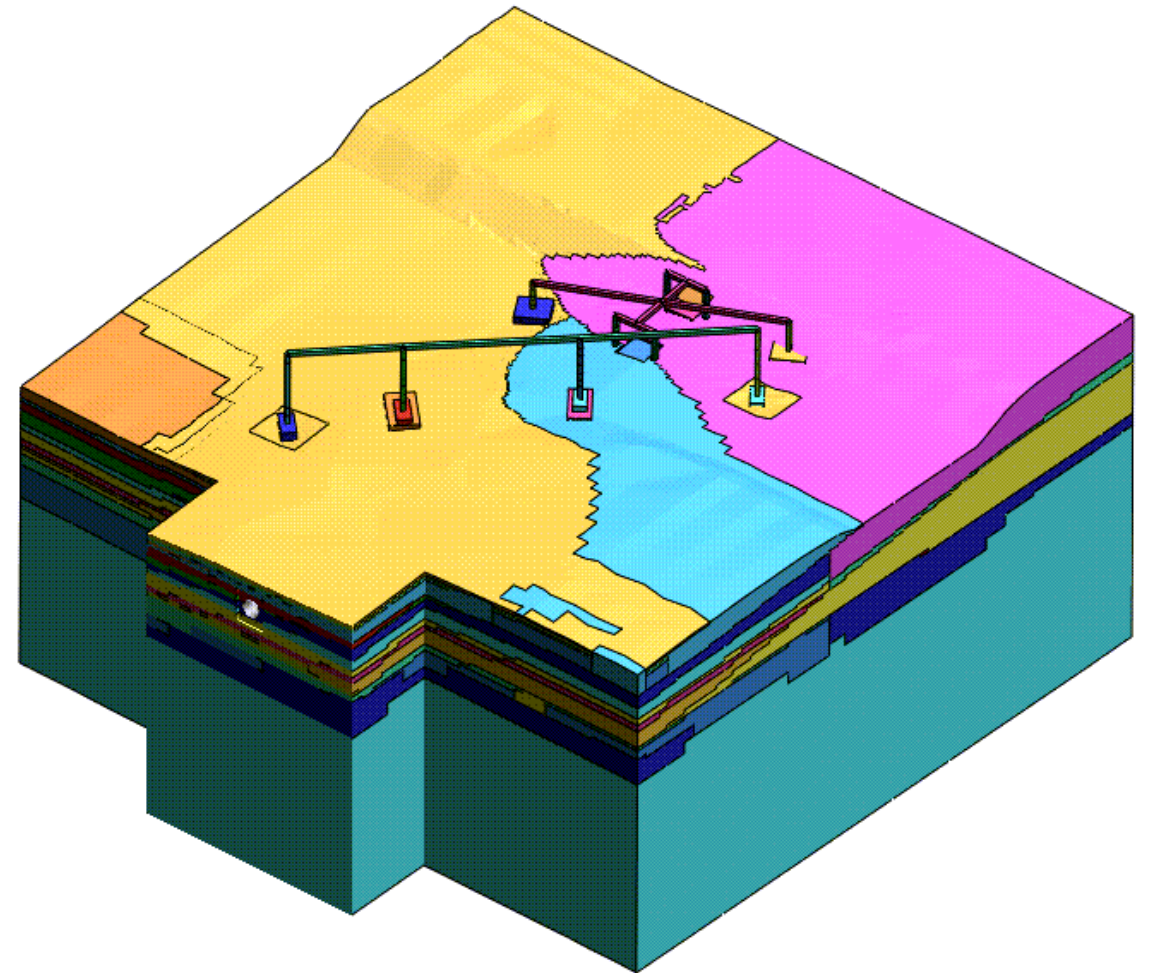
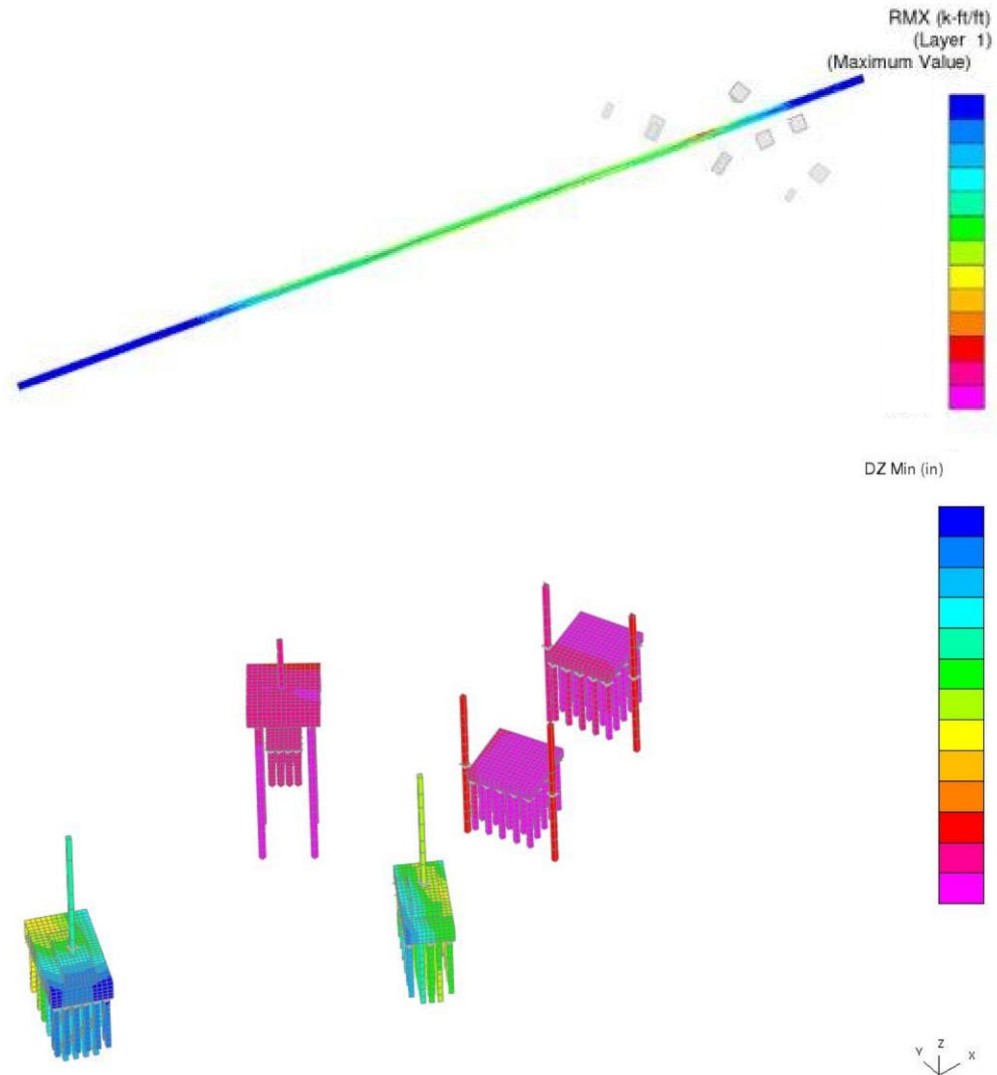


Table 5-8 Comparison of sewer box demands during GM1 from 2D SSSI (rotated component) and 3D SSSI at station 102+12

Analysis	Bending moment (kip-ft/ft)	Max compressive force (kip/ft)	Min compressive force (kip/ft)	Max shear force (kip/ft)	Max racking (in)
2D SSSI Model, GM1					
3D SSSI Model, GM1					



Sample 3D SSSI results



Sample 3D SSSI results

Moment demands for piers and piles

- difference <5%
- difference >5%

Pile or Pier Group	GM01				GM02				GM03				GM04				GM05				GM06				GM07			
	No Pipe	Pipeline	Diff	%Diff	No Pipe	Pipeline	Diff	%Diff	No Pipe	Pipeline	Diff	%Diff	No Pipe	Pipeline	Diff	%Diff	No Pipe	Pipeline	Diff	%Diff	No Pipe	Pipeline	Diff	%Diff	No Pipe	Pipeline	Diff	%Diff
WU25 Outer Piles				1%				1%				-1%				2%				0%				-1%				-1%
WU25 Inner Piles				2%				-2%				0%				2%				1%				-2%				-2%
WU25 Pier				-1%				-1%				0%				2%				0%				0%				0%
WL25 Outer Piles				-2%				1%				0%				0%				1%				0%				0%
WL25 Inner Piles				-2%				-2%				1%				1%				1%				-2%				1%
WL25 Pier				3%				0%				0%				1%				1%				-1%				2%
WU24 Outer Piles				-2%				1%				1%				3%				3%				-8%				6%
WU24 Inner Piles				-2%				0%				-3%				-2%				0%				-10%				-7%
WU24 Pier				0%				1%				0%				1%				-3%				0%				-1%
WL24S Inner Piles				0%				4%				0%				1%				0%				2%				0%
WL24S Piers				-1%				0%				-1%				0%				-1%				0%				0%
WL24N Inner Piles				-1%				-2%				-3%				-1%				-1%				-4%				-2%
WL24N Piers				0%				0%				-1%				0%				-1%				0%				0%

Pile or Pier Group	GM08				GM09				GM10				GM11				GM01 - Lower Range Soil				GM05 - Lower Range Soil				GM10 - Lower Range Soil			
	No Pipe	Pipeline	Diff	%Diff	No Pipe	Pipeline	Diff	%Diff	No Pipe	Pipeline	Diff	%Diff	No Pipe	Pipeline	Diff	%Diff	No Pipe	Pipeline	Diff	%Diff	No Pipe	Pipeline	Diff	%Diff	No Pipe	Pipeline	Diff	%Diff
WU25 Outer Piles				1%				1%				-1%				-2%				-1%				-4%				2%
WU25 Inner Piles				7%				-1%				3%				-3%				6%				0%				-8%
WU25 Pier				-1%				1%				0%				-2%				1%				1%				-1%
WL25 Outer Piles				1%				0%				0%				0%				-1%				1%				-1%
WL25 Inner Piles				1%				-2%				-3%				-3%				0%				0%				-3%
WL25 Pier				0%				0%				0%				0%				2%				1%				1%
WU24 Outer Piles				-7%				1%				3%				2%				-1%				-6%				-2%
WU24 Inner Piles				-2%				-3%				-1%				-2%				0%				-2%				0%
WU24 Pier				1%				-2%				1%				0%				-1%				0%				2%
WL24S Inner Piles				-2%				1%				-2%				-2%				2%				-1%				-2%
WL24S Piers				0%				0%				0%				0%				-1%				0%				-1%
WL24N Inner Piles				-1%				-1%				-2%				-2%				0%				-2%				-3%
WL24N Piers				0%				0%				0%				0%				-1%				-1%				-1%

2014 vs 2026

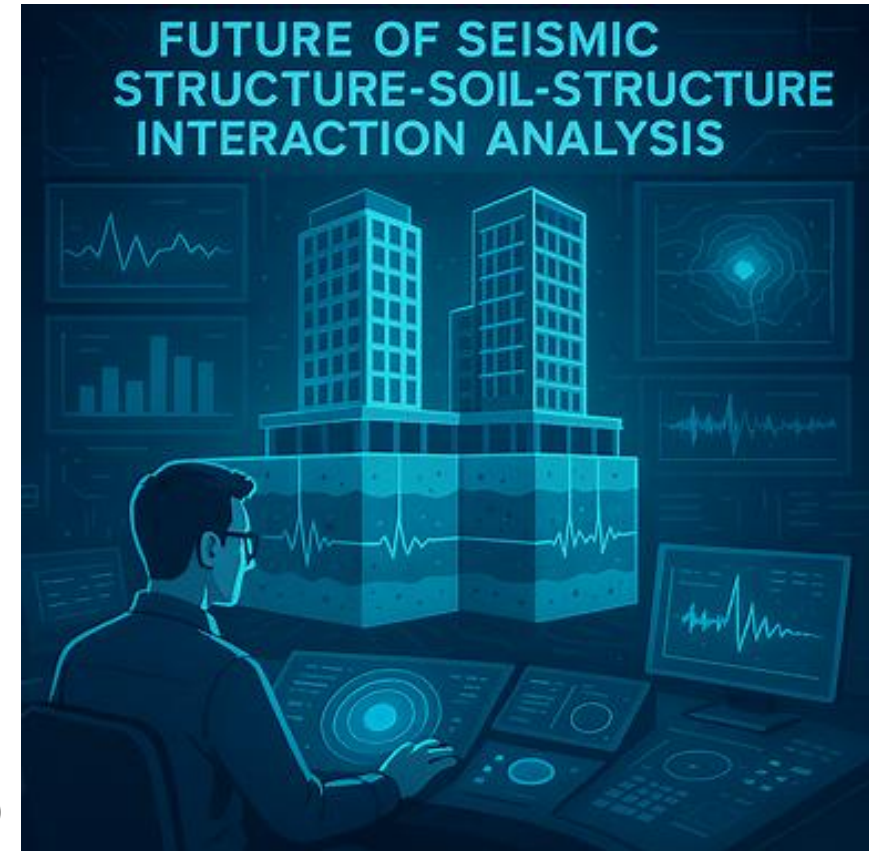
2014	2026
Uni-directional Shaking	Tri-directional Shaking
Simplified stratigraphy/topography	Complex stratigraphy/topography
Manual stratigraphy generation	Automated stratigraphy generation
Manual post-processing	More automated post-processing
Infrequent consideration of seismic SSSI effects	Knowledgeable clients/reviewers
	SSSI Analysis Requested/Expected
Cluster	Cloud
Masing Damping	Non-Masing Damping

The Future of Seismic SSSI Analysis



Copilot (January 2025)

Copilot (March 2026)



The Future of Seismic SSSI Analysis

My predictions

- Increasing demand from agencies to protect existing assets
- Decreasing engineering time to conduct SSSI analysis due to automation, industry experience, computing power and advances in AI
- Better guidance will be made available to practitioners

The Future of Seismic SSSI Analysis

Teaser for a forthcoming Guidance Document



1.	Introduction	1
1.1	Overview	1
1.2	Methods of SSSI evaluation	1
1.3	Examples of SSSI effects	3
1.4	Organization of the Guide	4
2.	Basis of Design	5
2.1	Jurisdictional Context	5
2.2	Basis of Design	5
3.	Discussion of Static SSSI Evaluation for Below-Grade Infrastructure	1
4.	Seismic SSSI Evaluation for Below-Grade Infrastructure	1
4.1	Summary of seismic SSSI effects for below-grade structures	1
4.2	Partial list of Influential Factors	1
4.3	Review of screening criteria from existing agency standards & available parametric studies?	2
4.4	Seismic SSSI screening flow chart	1
4.5	Greenfield Analysis Methods	2
4.6	SSSI Analysis	4
5.	Quality Control and Peer Review for Dynamic SSSI Analysis	1
5.1	Discussion of applications, strengths and limitations of Dynamic SSSI analysis	1
5.2	Discussion of best practice for dynamic SSSI	1
5.3	Discussion of software requirements	4
5.4	Checklist of information for peer review	5

ARUP