SSI and SSSI in Highly Seismic Urban Regeneration Zones

Ibbi Almufti
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New Transbay Transit Center (TTC)

185ft wide x 65ft deep excavation x 1400 ft long

Transbay Bus Ramps

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Transbay Redevelopment Area – Current View

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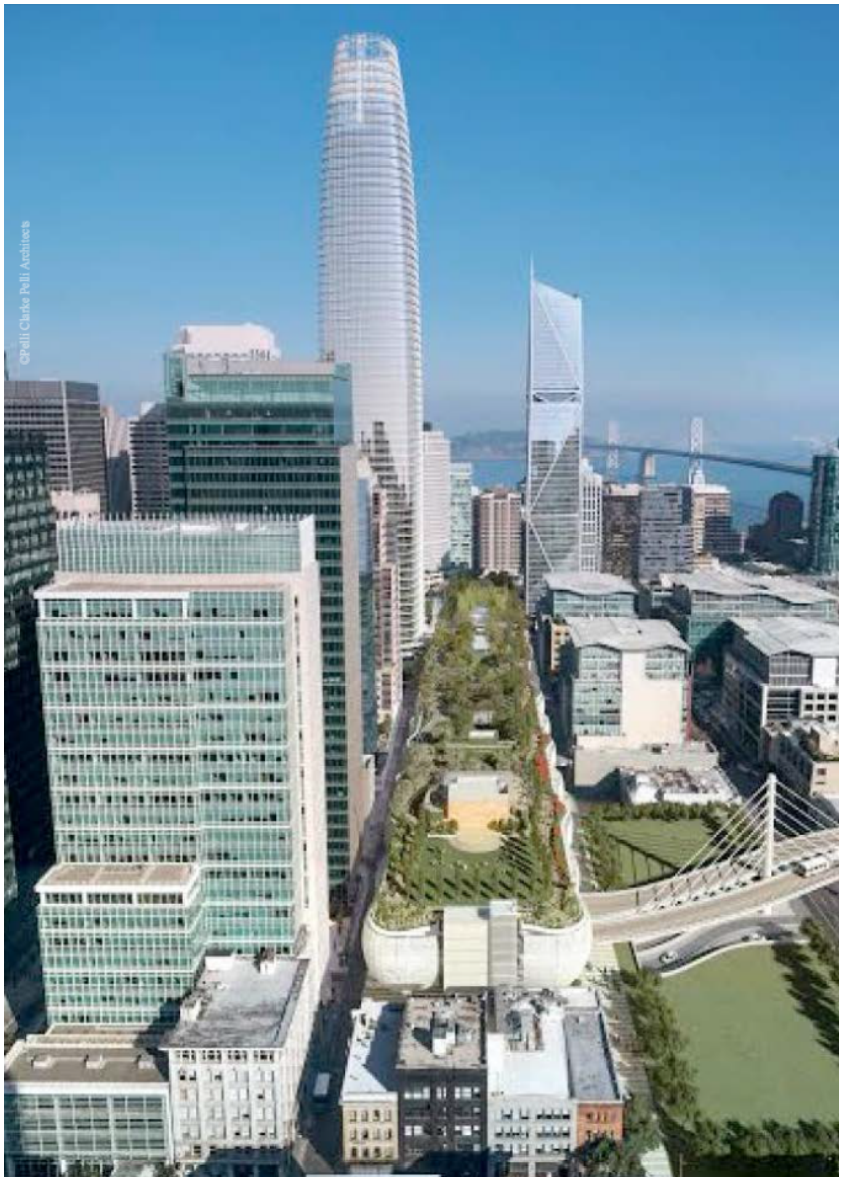
Transbay Redevelopment Area – Future View (~2017)



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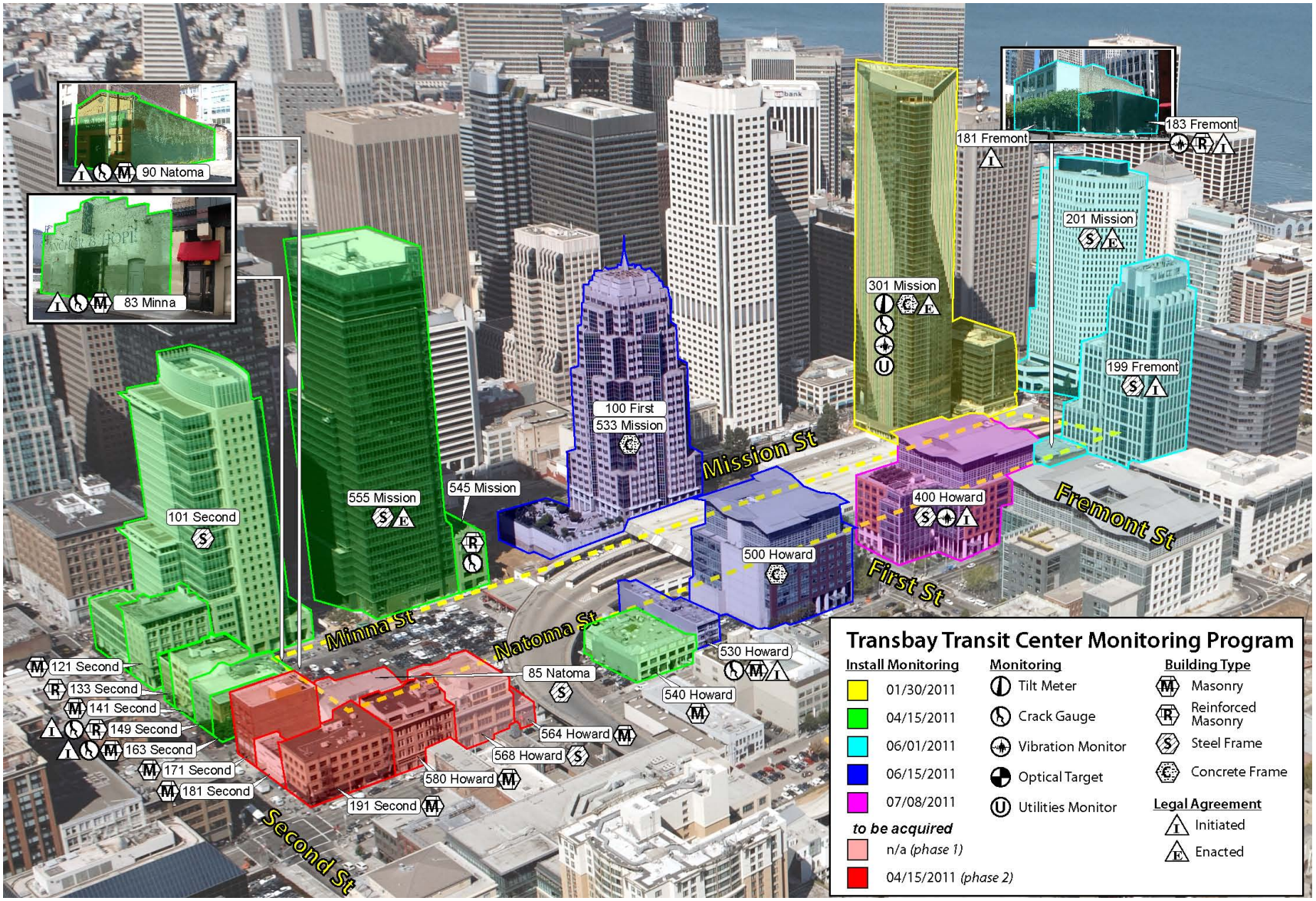
Adjacent Existing Buildings



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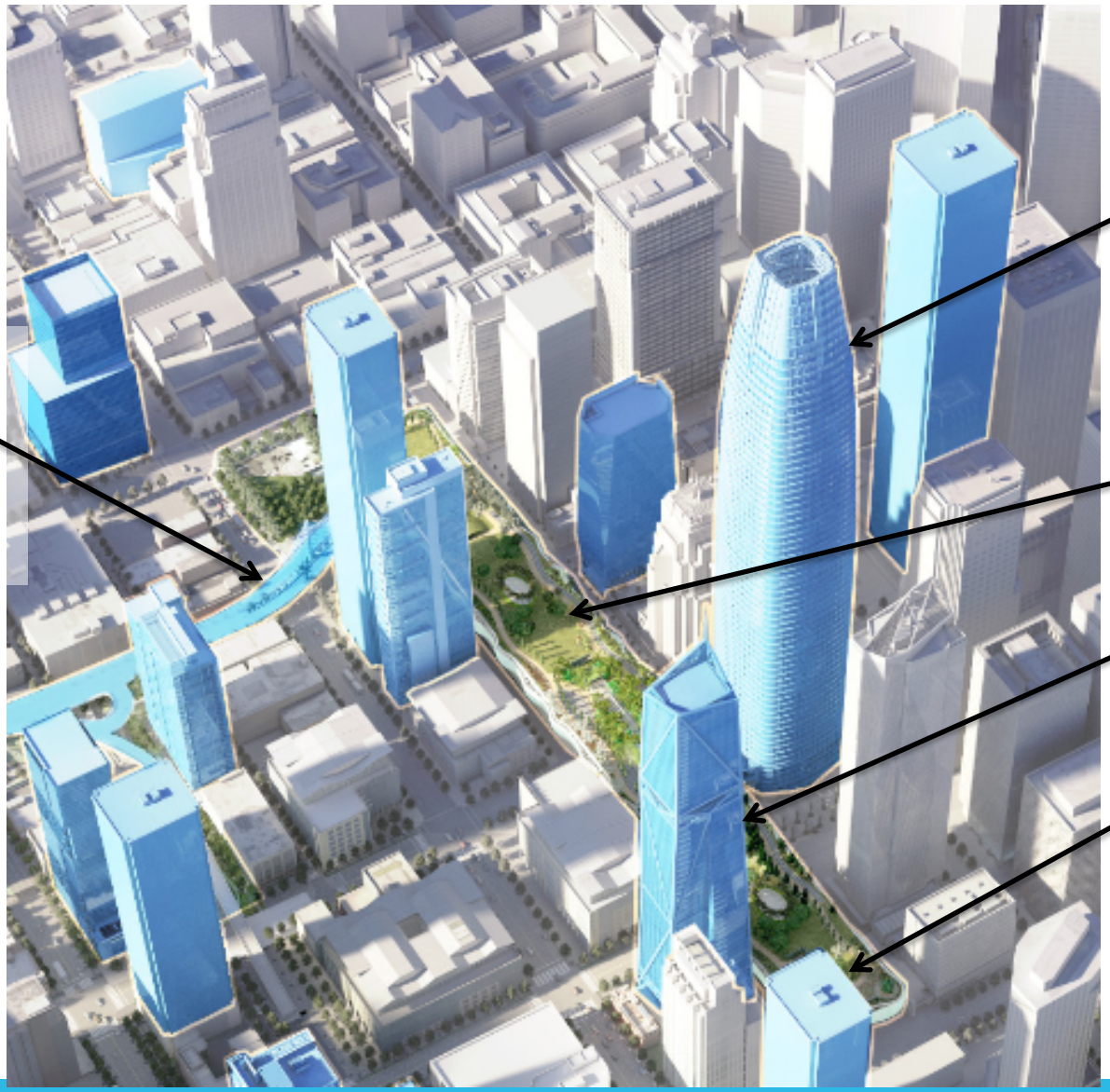
Adjacent New Structures



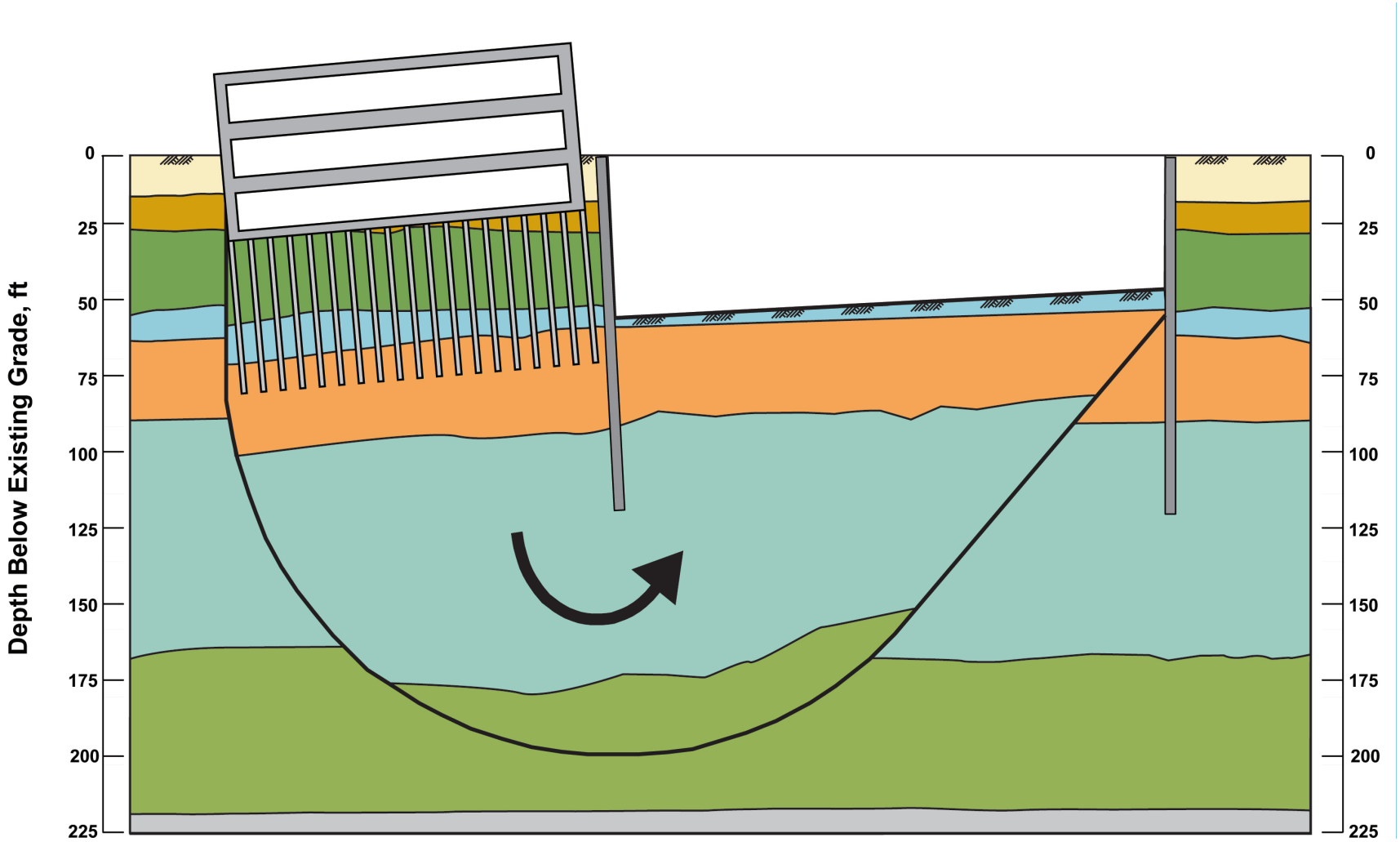
Arup's Scope

- GEOR and SEOR for several buildings
- Major construction monitoring instrumentation system

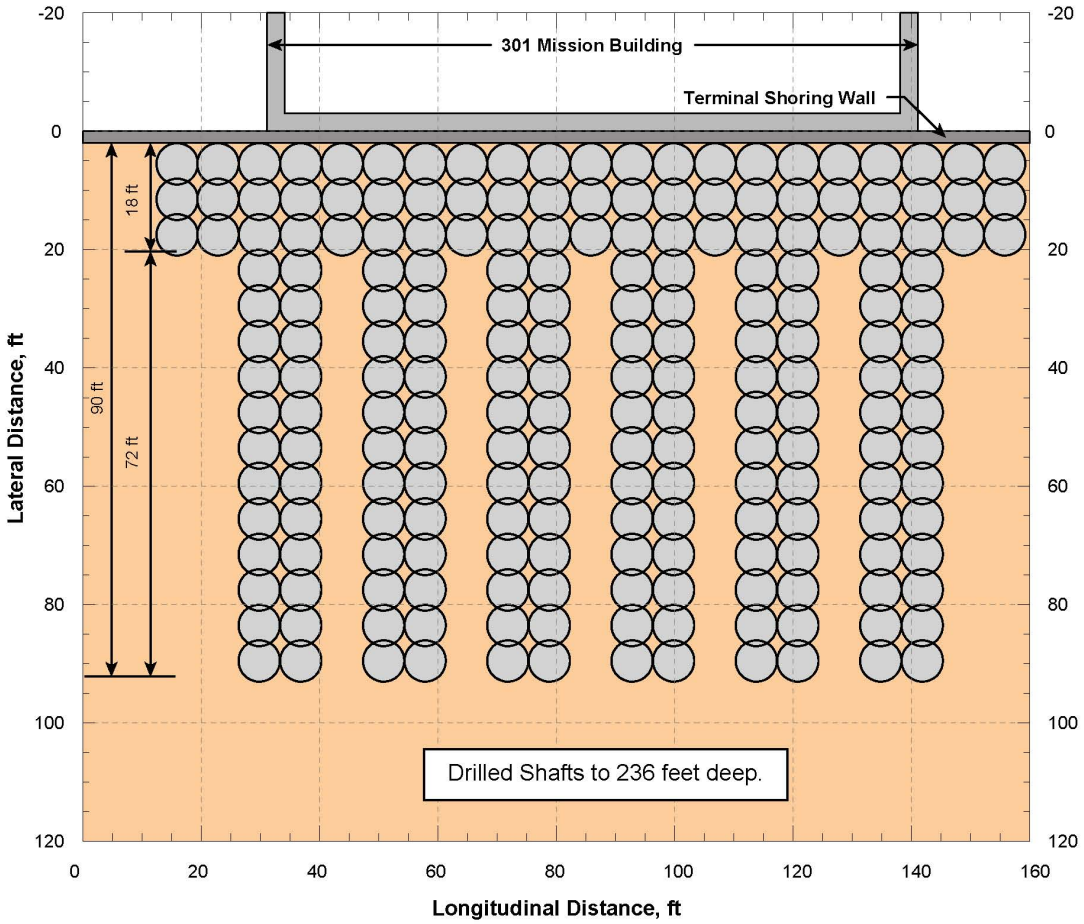
- Ground motion development:
  - Developed bedrock motions explicitly incorporating velocity pulses using a "pulse-included" CMS approach (Almufti et al., Earthquake Spectra, online)
  - Non-linear site response analysis
  - Kinematic effects on deep basements (SSI)

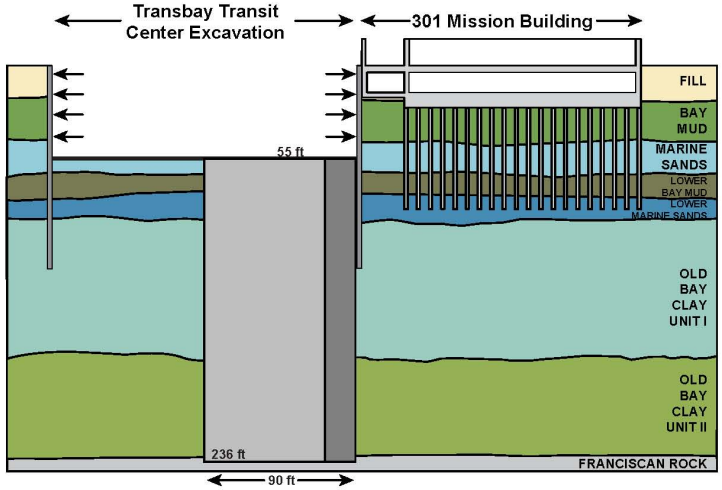
- SSSI scope includes:
  - Prediction of excavation-induced movements of adjacent *existing* buildings
  - Assurance that *new* towers do not invalidate earthquake performance requirements of TTC
  - Quantifying static and seismic load-paths between soils, piles and adjacent basements - for structural design

Excavation Near Heavy Things



301 Mission Buttress Plan





Buttress Elevation

Total Number of Shafts = 207 shafts
Depth of all Shafts = 236 ft
Primary Shafts = 93 shafts
Secondary Shafts = 114 shafts

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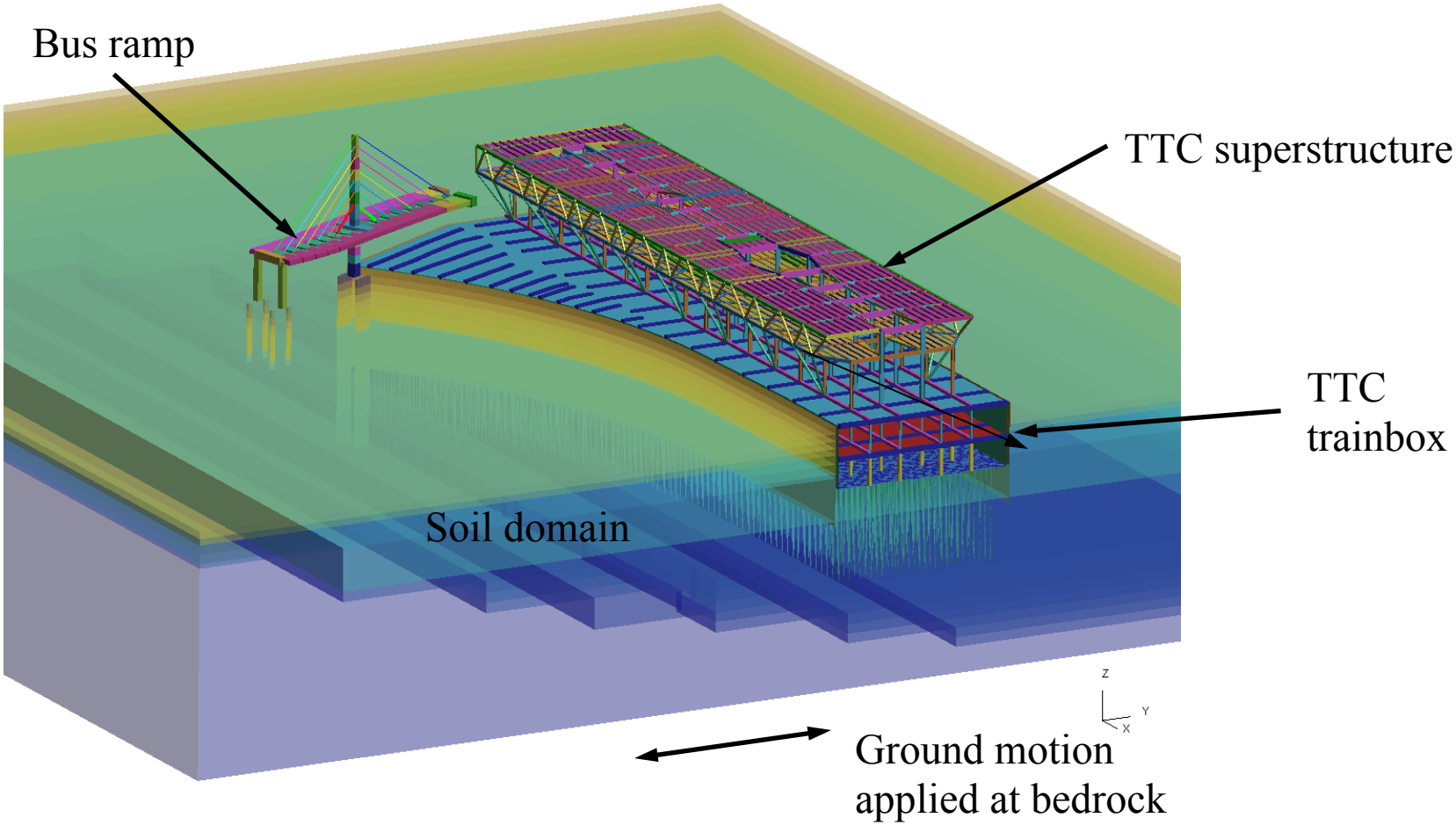
Advanced Numerical Simulation using LS-DYNA

- Large (non uniform) 3D non-linear soil domain to bedrock
- Construction sequence followed by earthquake response
- Extensively validated LS-DYNA modeling techniques



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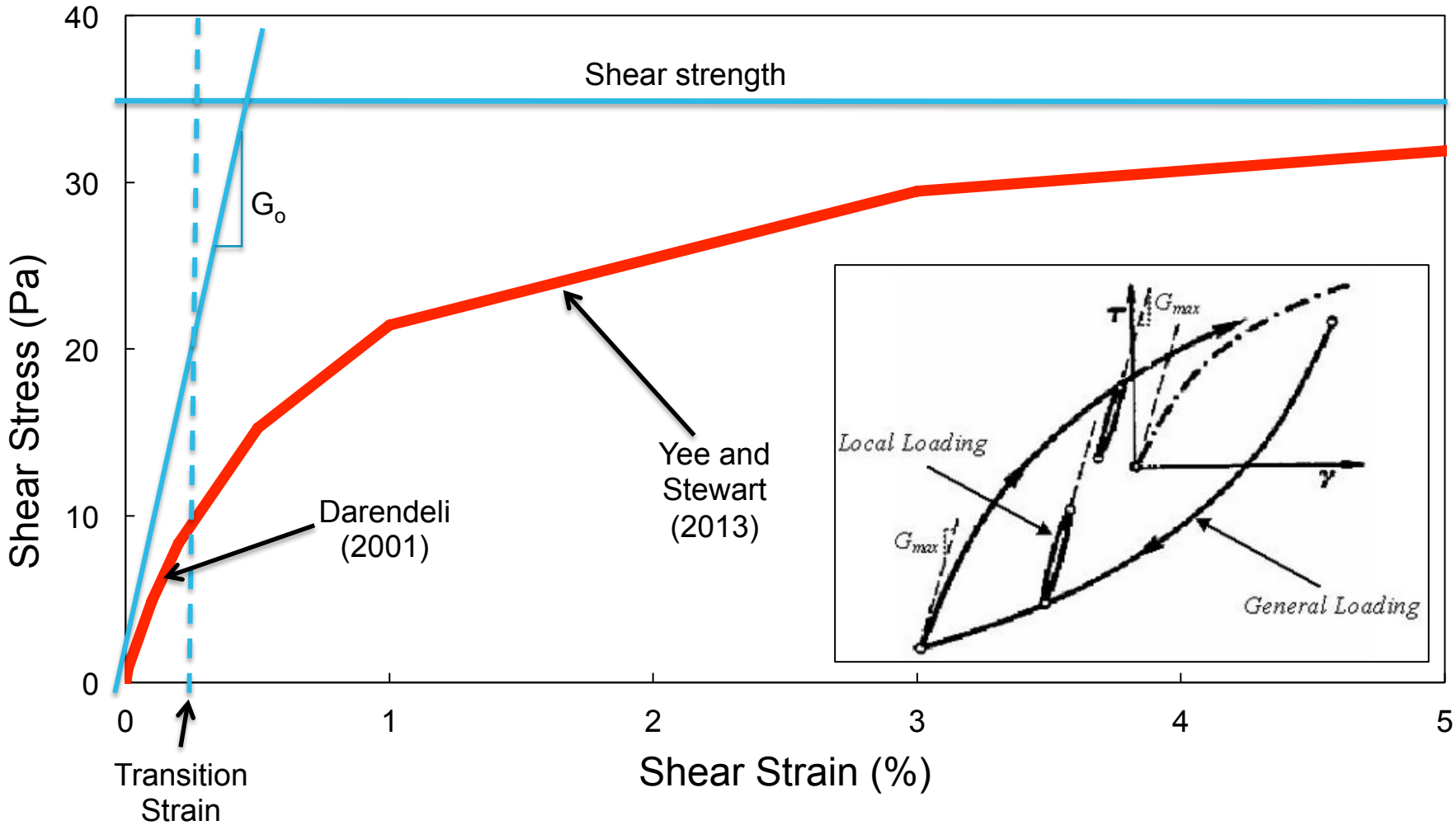
Constitutive Soil Behavior



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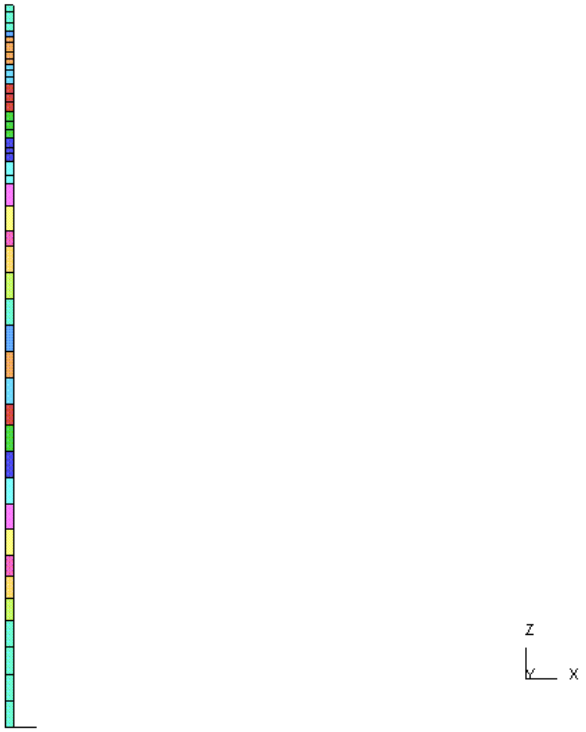
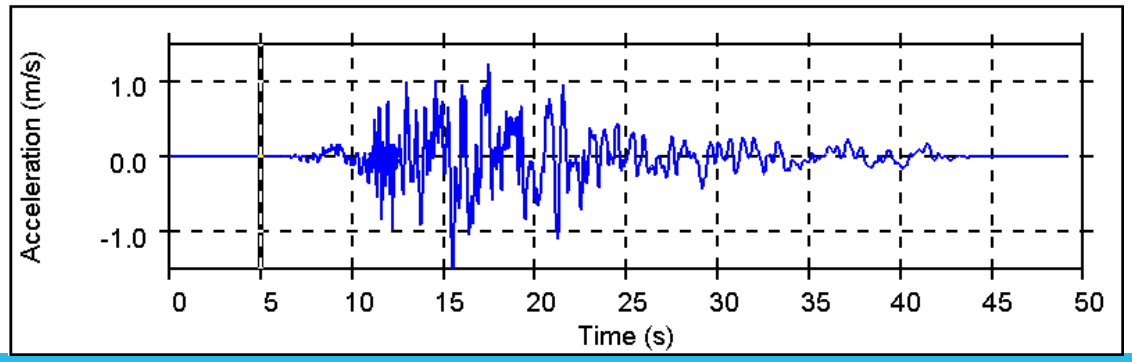
Non-linear Site Response Analyses in LS-DYNA

Reference: Bolisetti, C., Whittaker, A. S., Mason B., Almufti, I, Willford, M. *Equivalent linear and nonlinear site response analysis for design and risk assessment of safety-related nuclear structures*. Nuclear Engineering and Design. 2014.



Deformations Magnified x50



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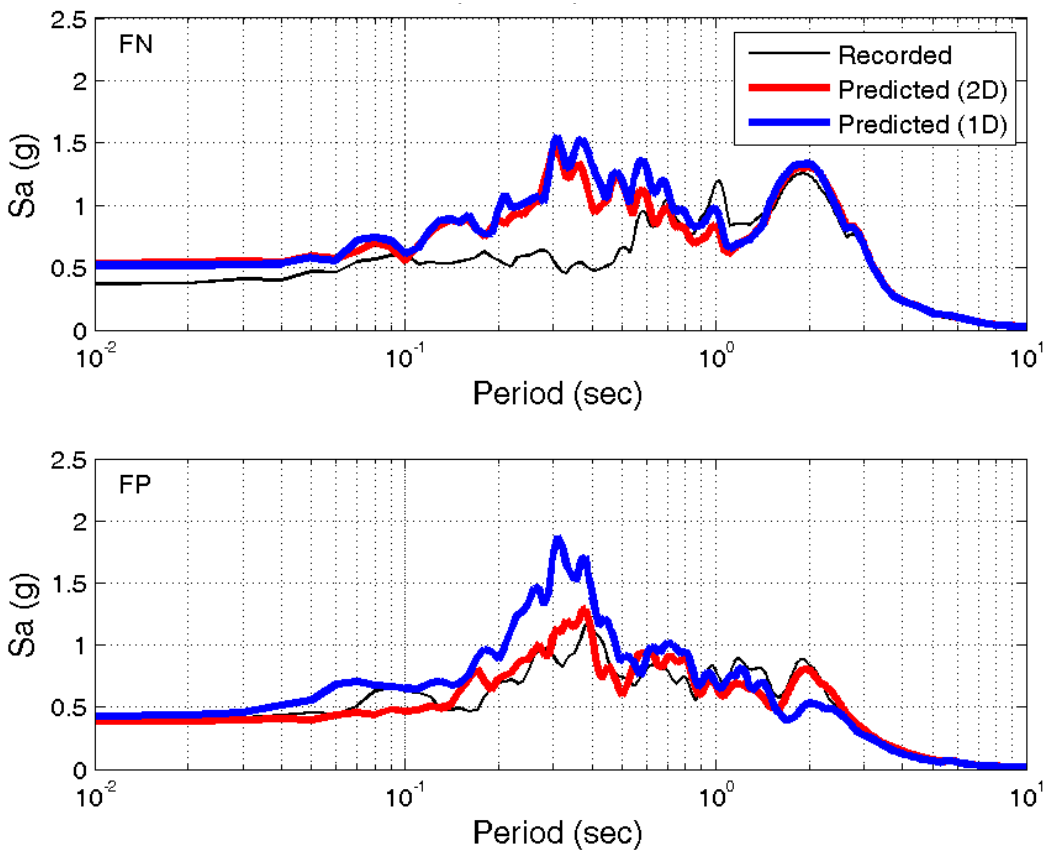
Validation of Non-linear Site Response Analyses: Service Hall Array, Japan

- Bi-directional shaking
- Explicit consideration of strain-rate effect
- Added damping: 2%



Upcoming reference: Motamed, R., Stanton, K. Almufti, I., Ellison, K. and Willford, M. *An Evaluation of Site Response Analysis Methods: Case Study of the Service Hall Array in Japan*. Earthquake Spectra. In Review.

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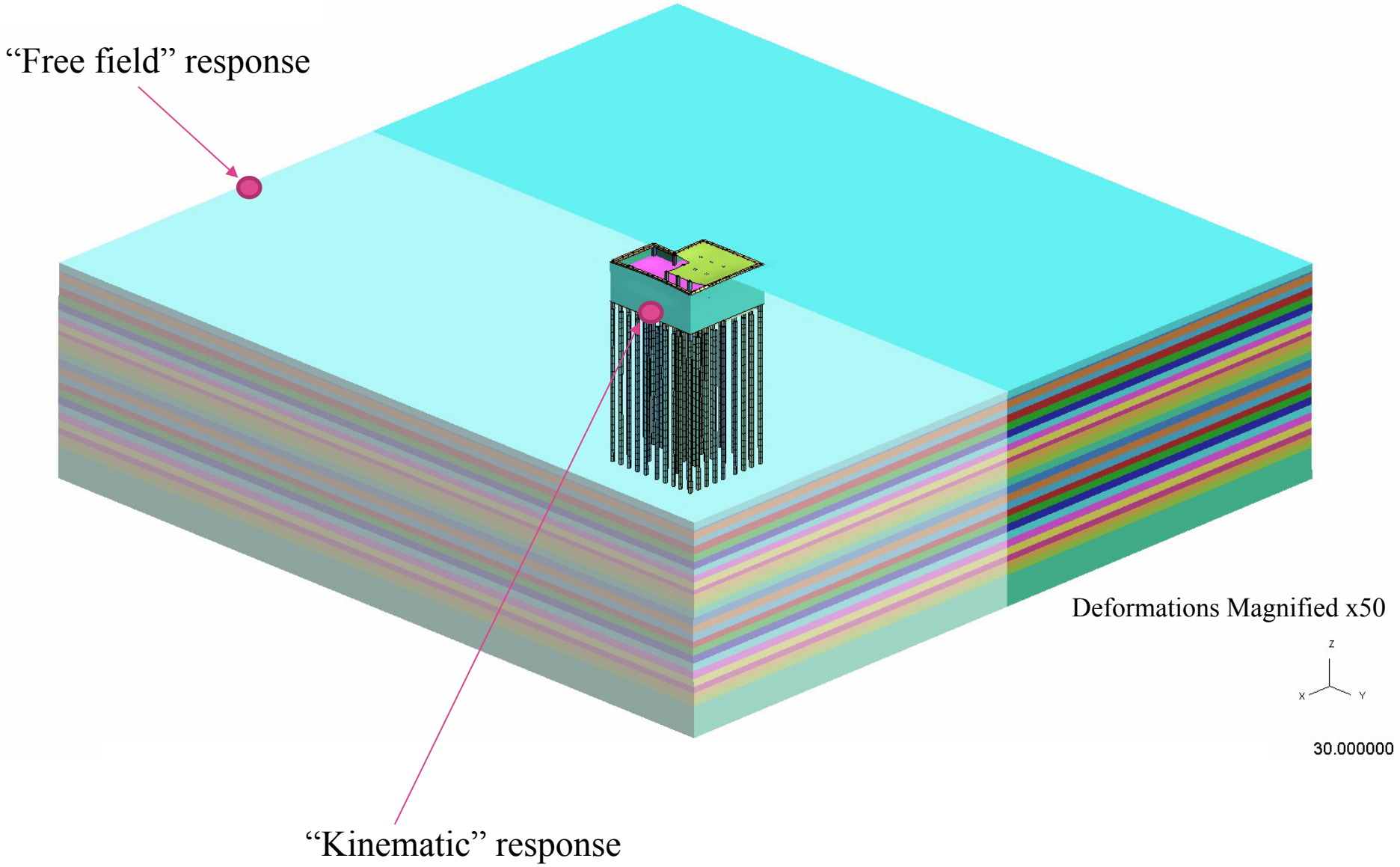
3D SSI Analysis to Assess Kinematic Effects



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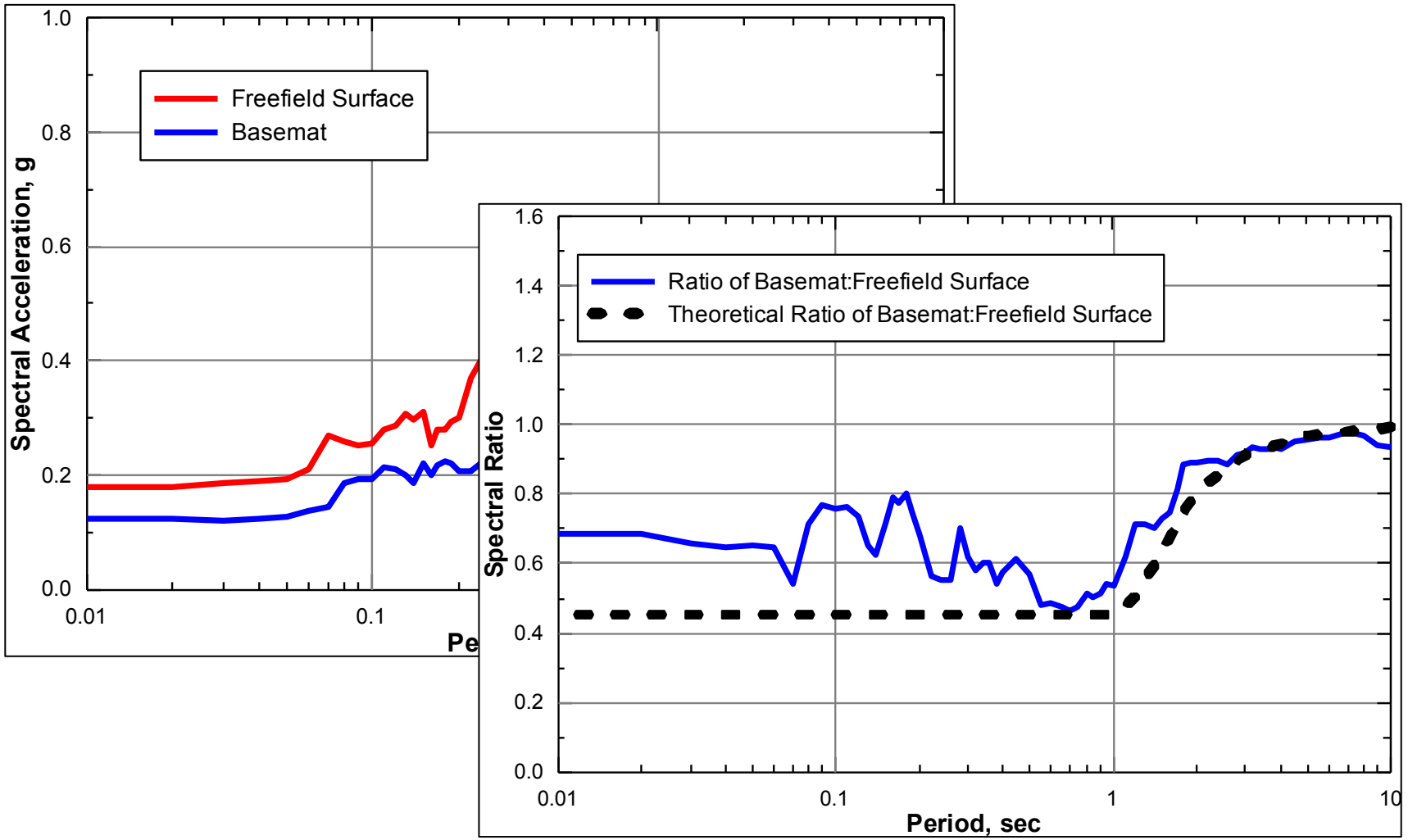
Kinematic Effects



Reference: Stewart, J.P., Tileylioglu, S. *Input Ground Motions for Tall Buildings with Subterranean Levels*. PEER Tall Buildings Initiative, Task 8

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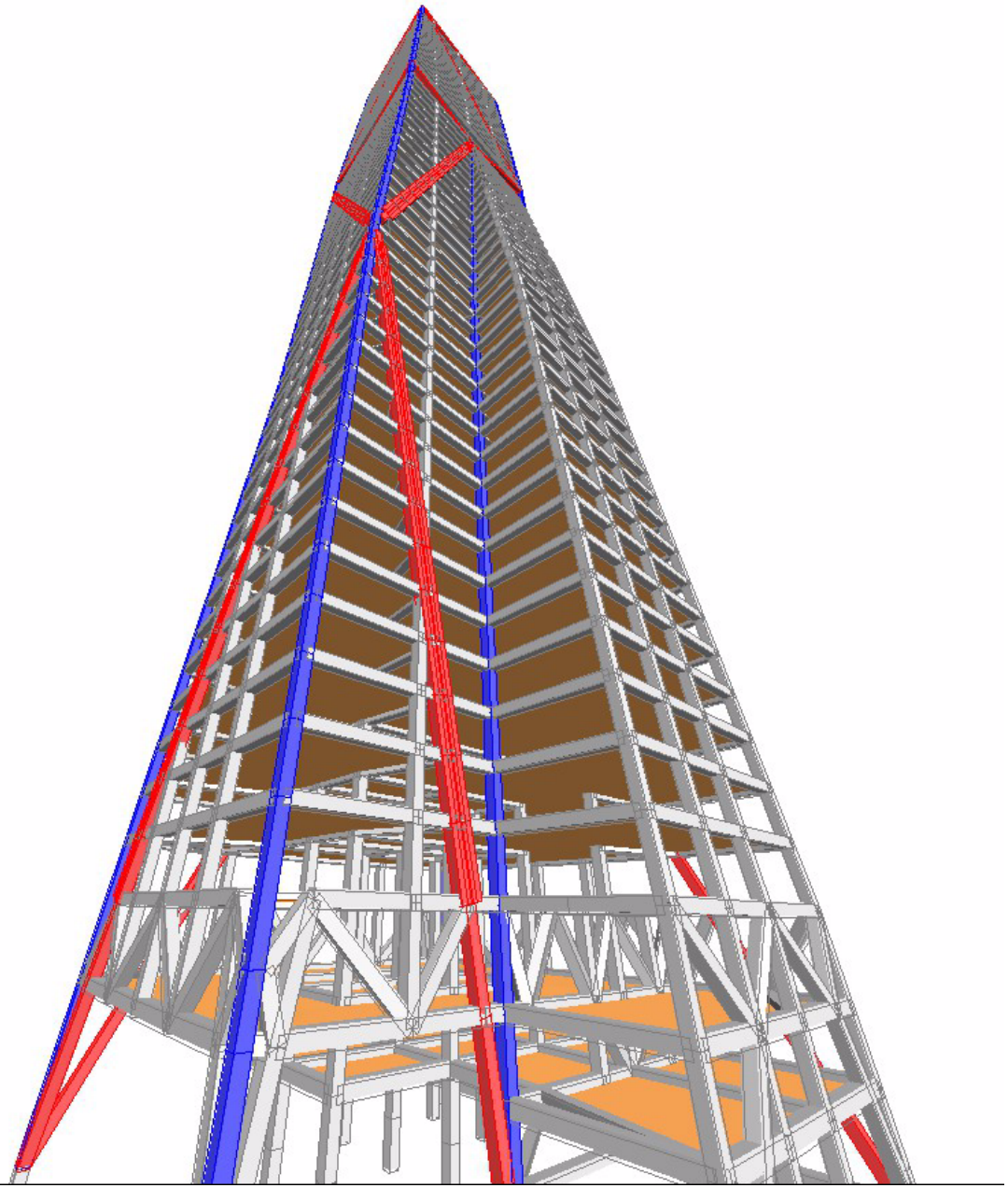
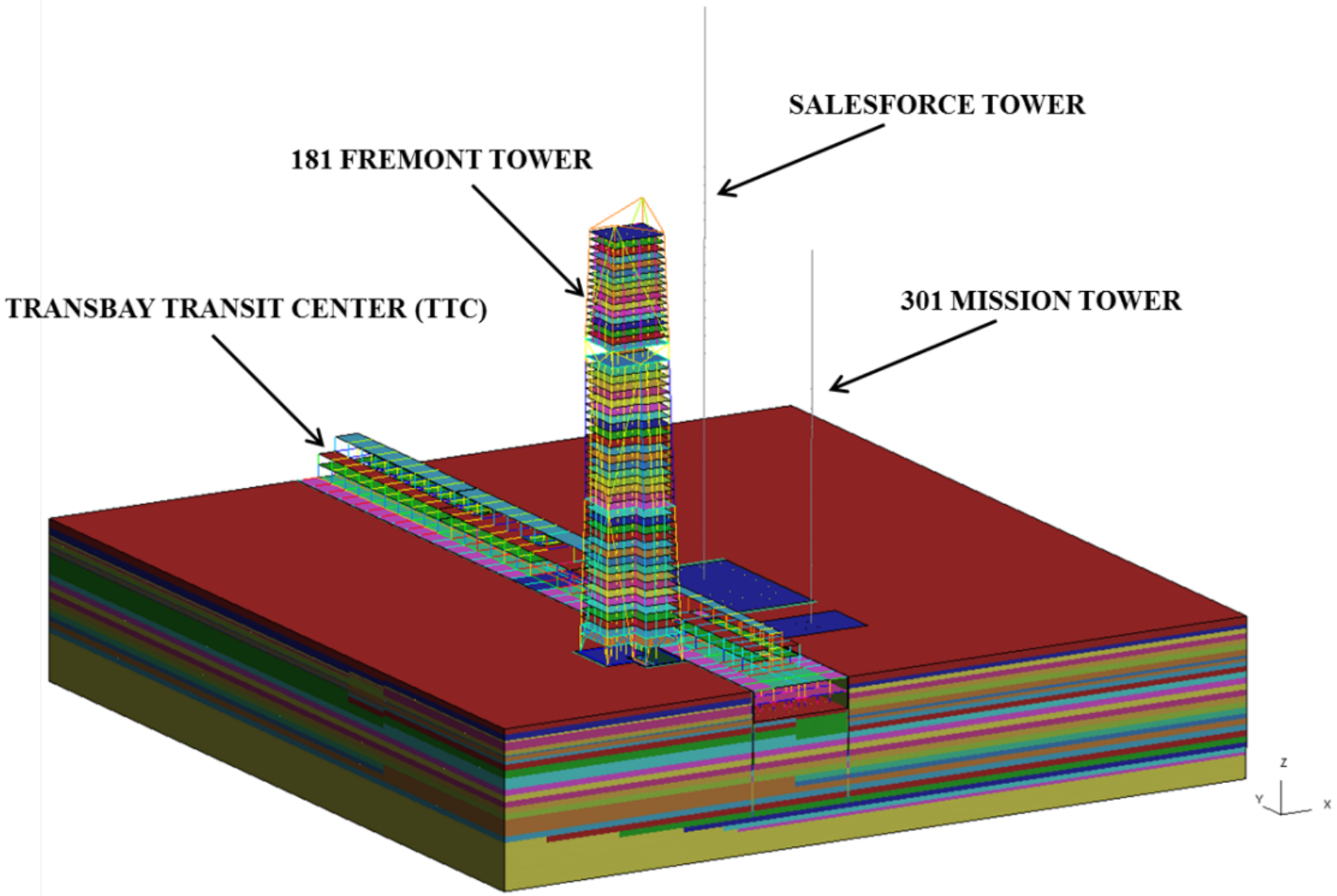
Structural Modeling in LS-DYNA

- Non-linear materials including cracking, yield, degradation
- Energy dissipating devices including BRB's, dampers and isolators
- Uplift
- Contact surfaces
- Non-linear geometry captured explicitly



Extents of LS-DYNA Model



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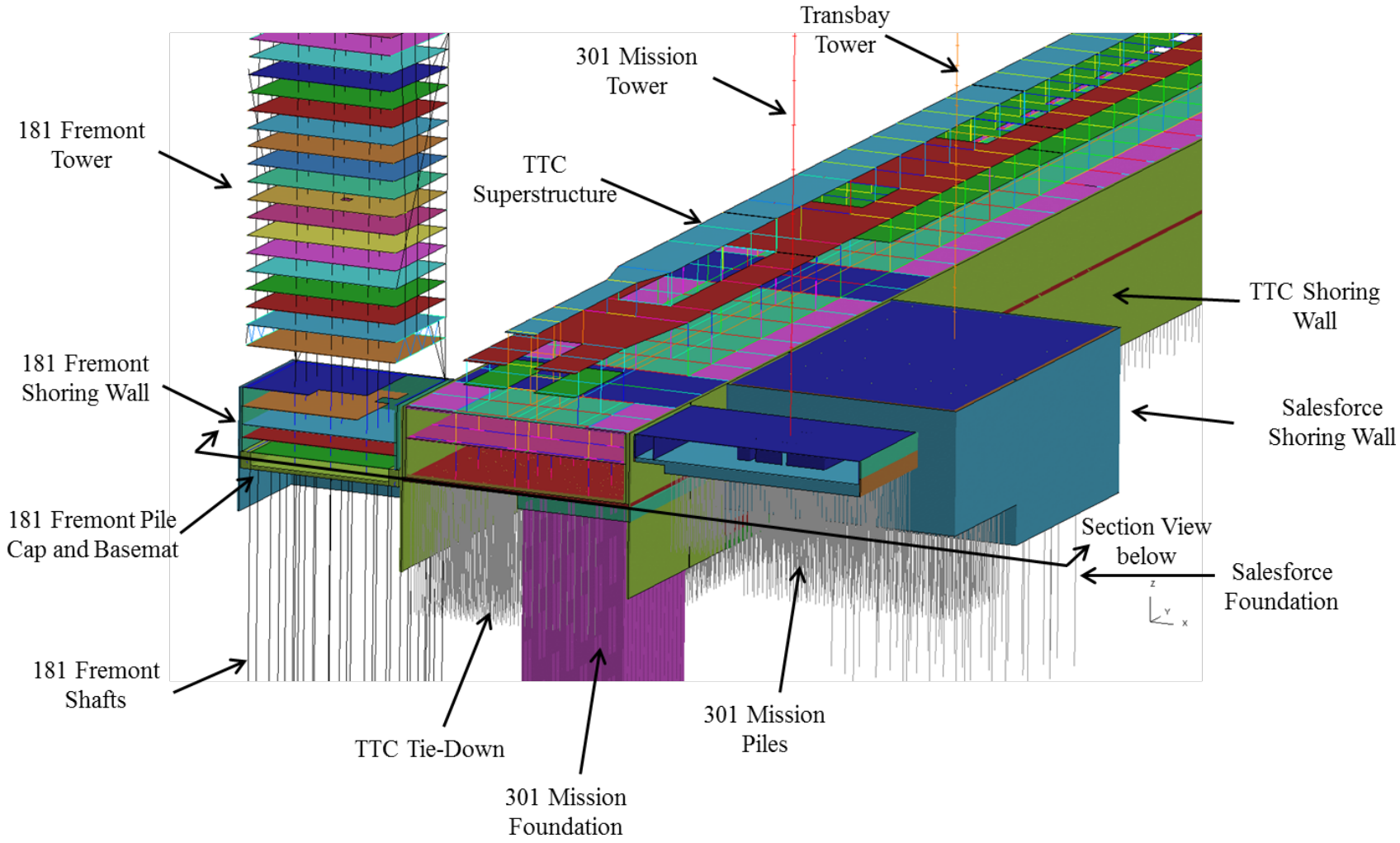
Structural Elements in LS-DYNA Model



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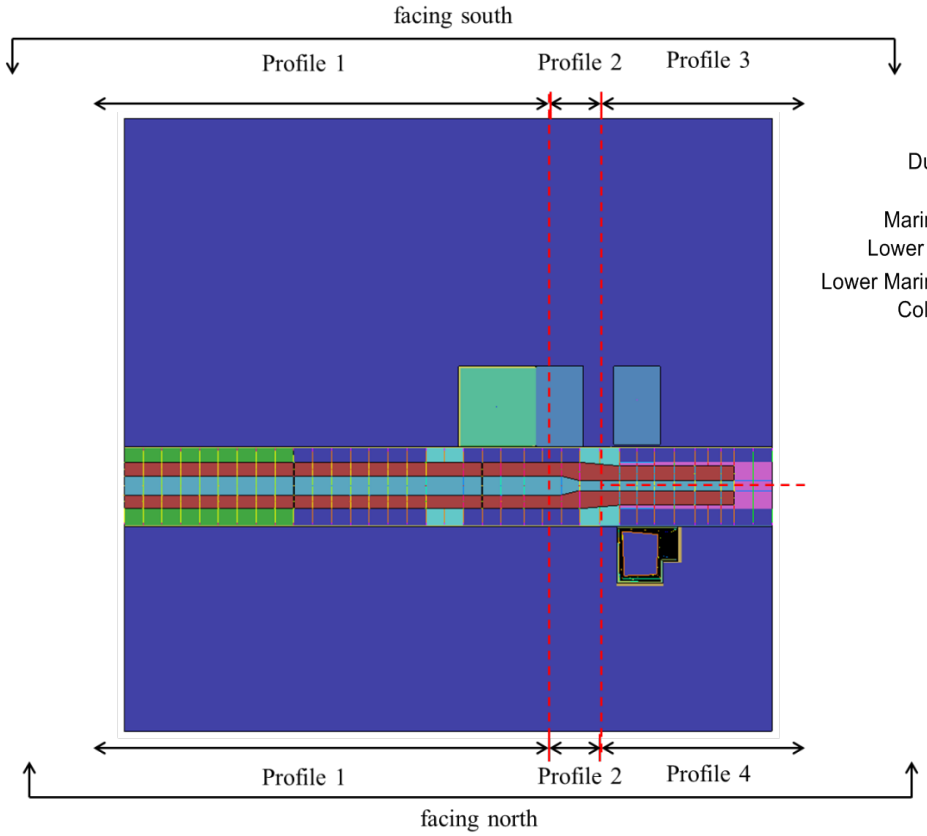
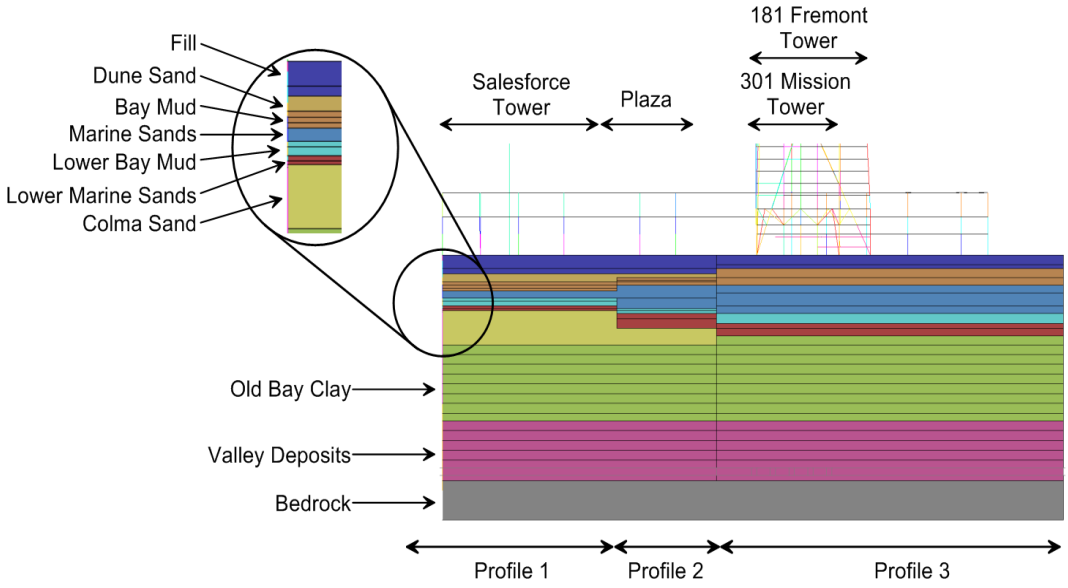
Stratigraphy





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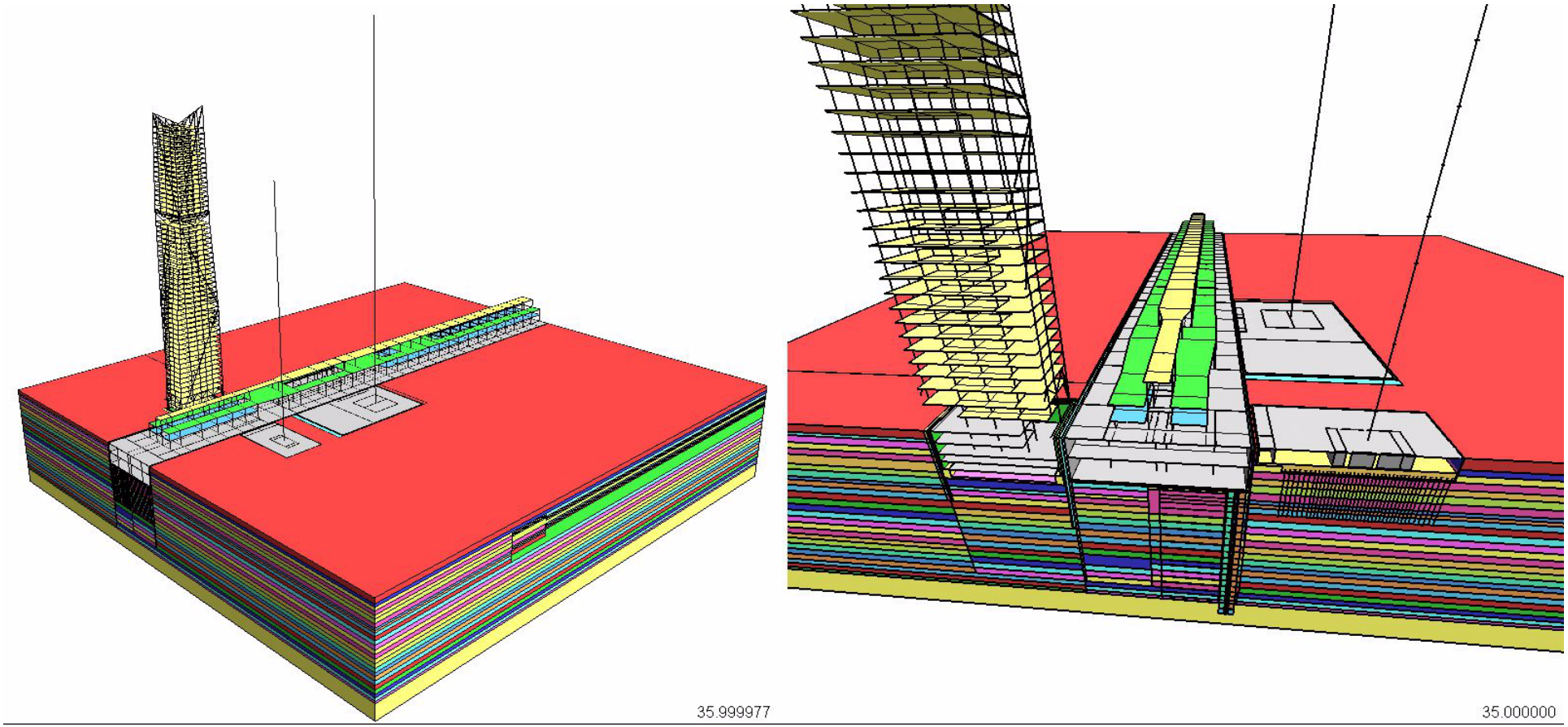
3D SSSI Analysis of Transbay Area



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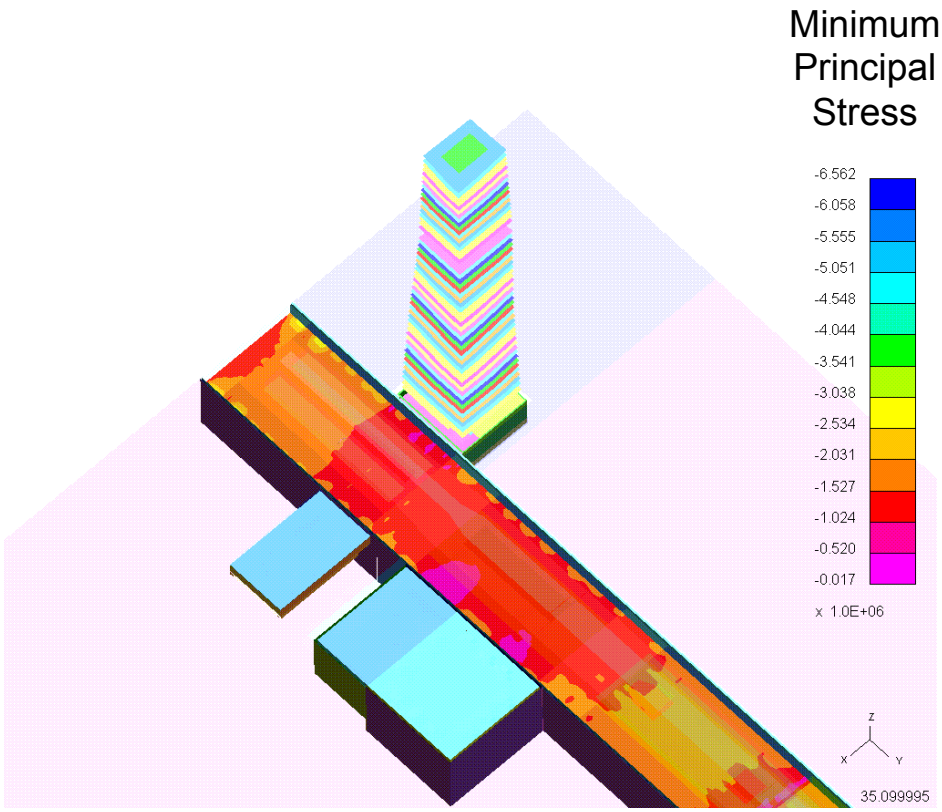
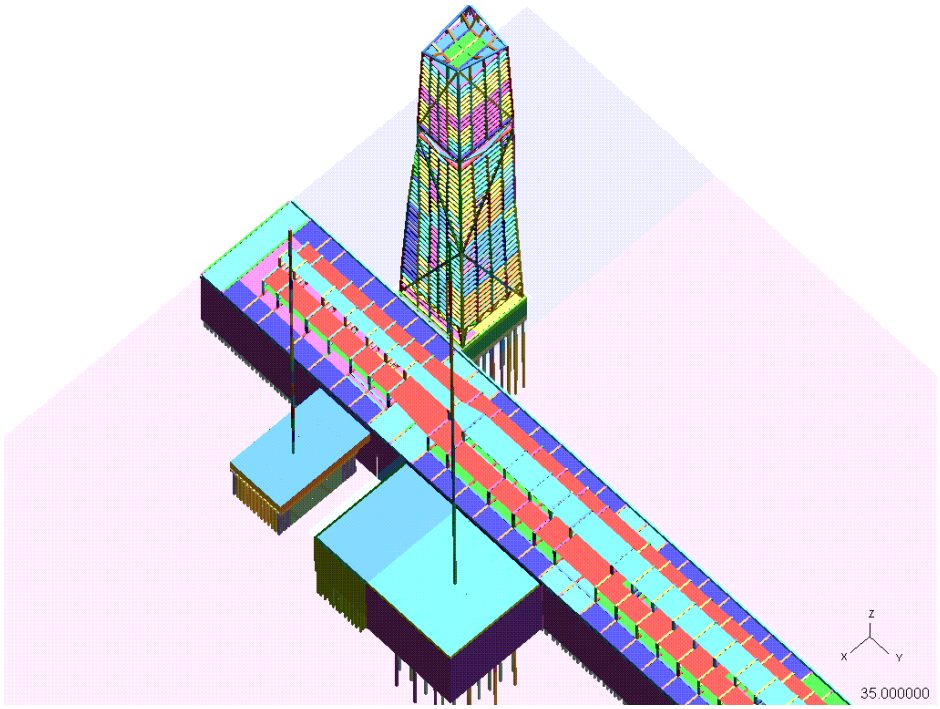
Stress Induced in TTC Mezzanine Diaphragm





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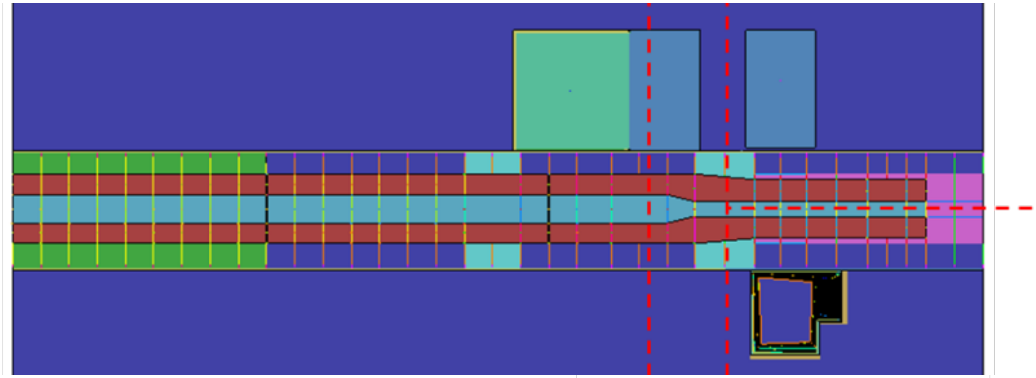
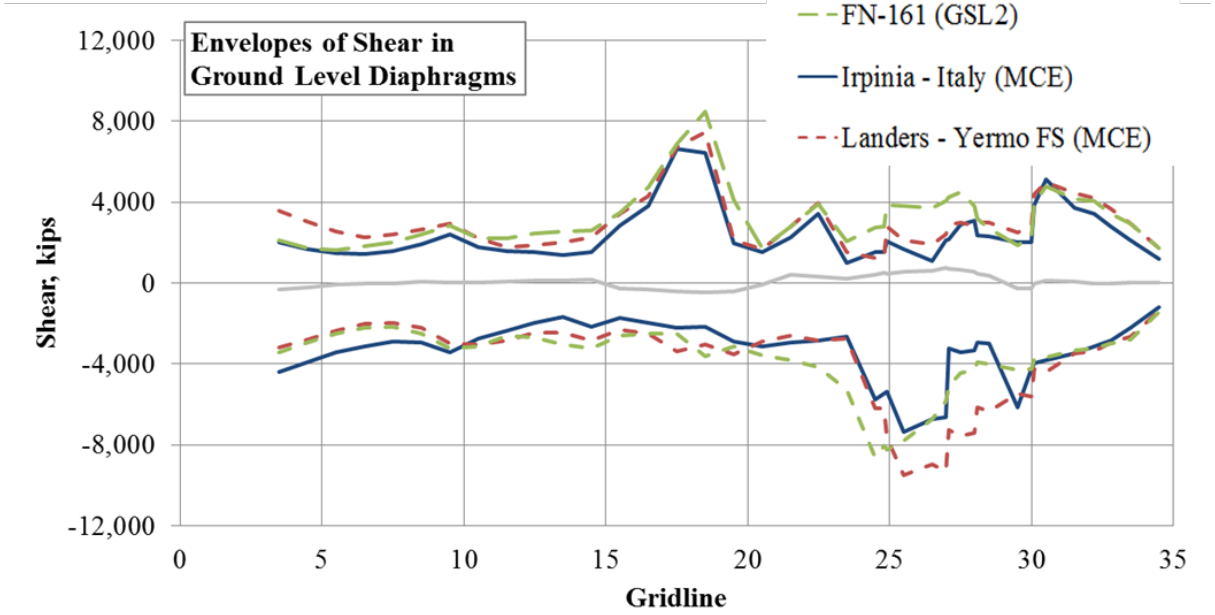
Shear Forces in TTC Ground Level Diaphragm





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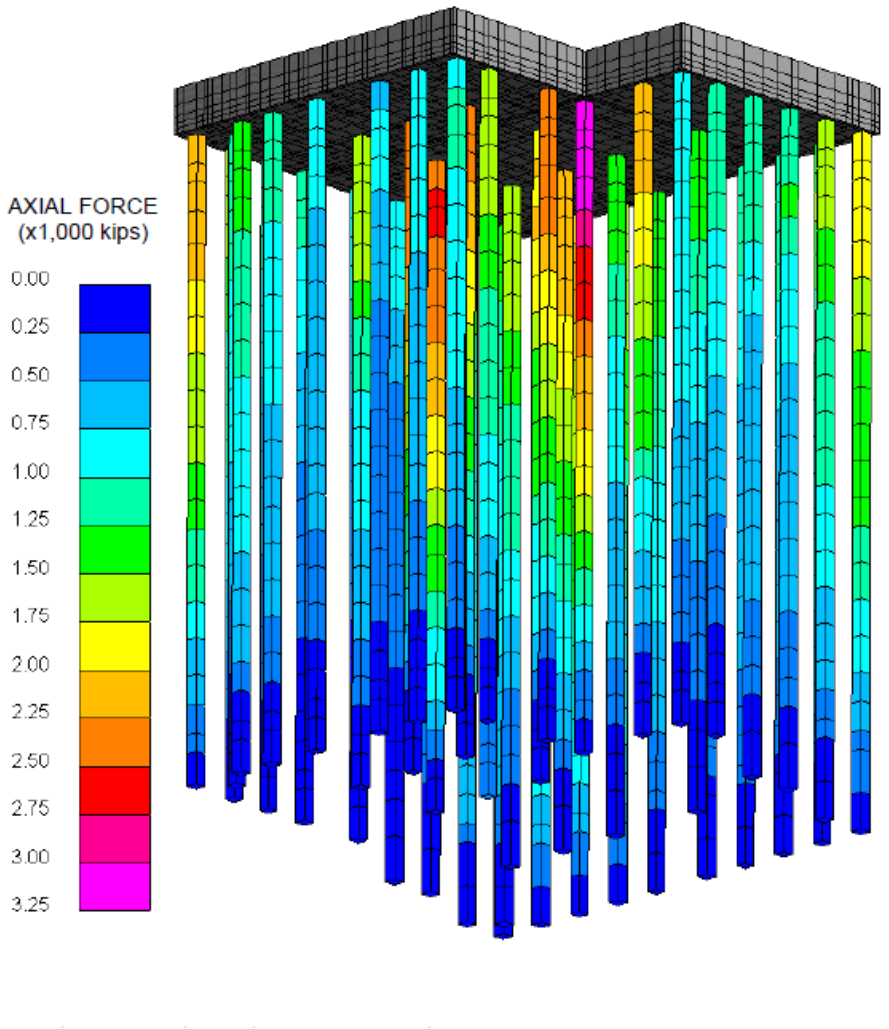
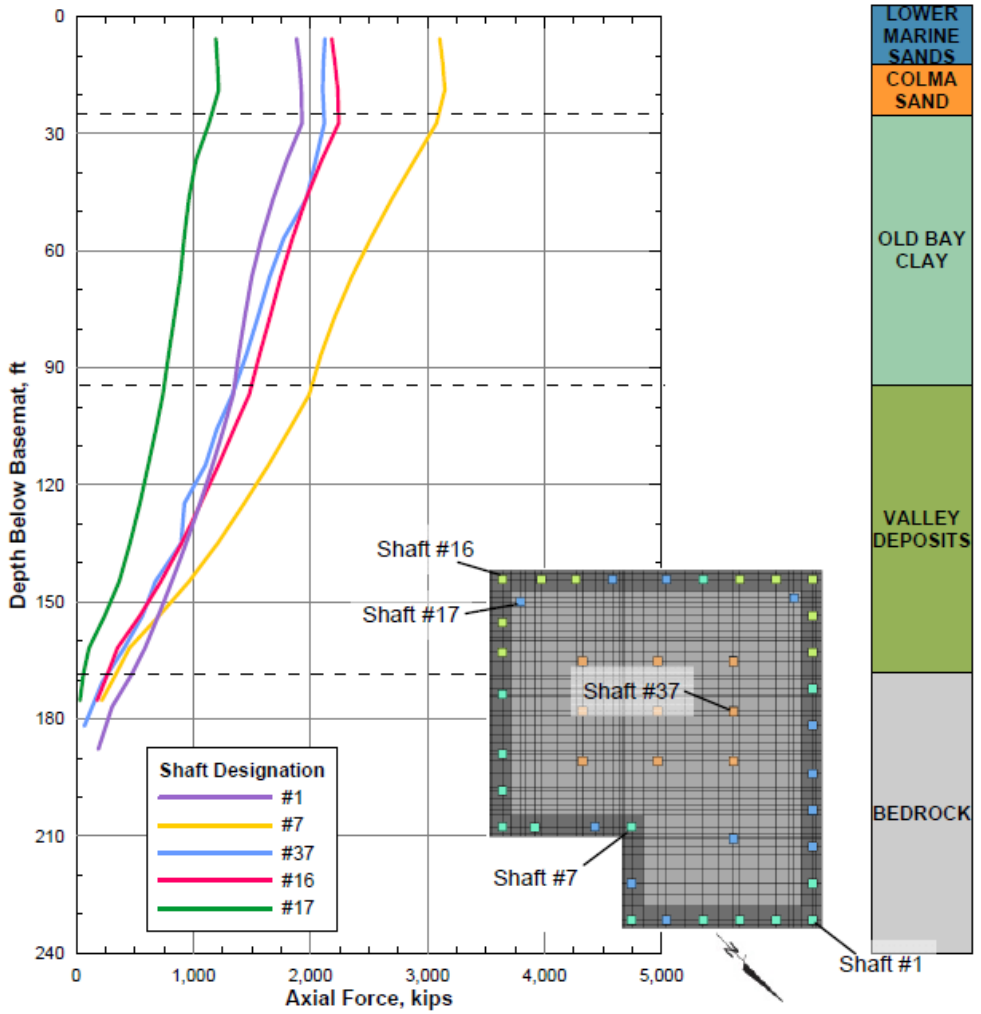
Forces in 181 Fremont Shafts





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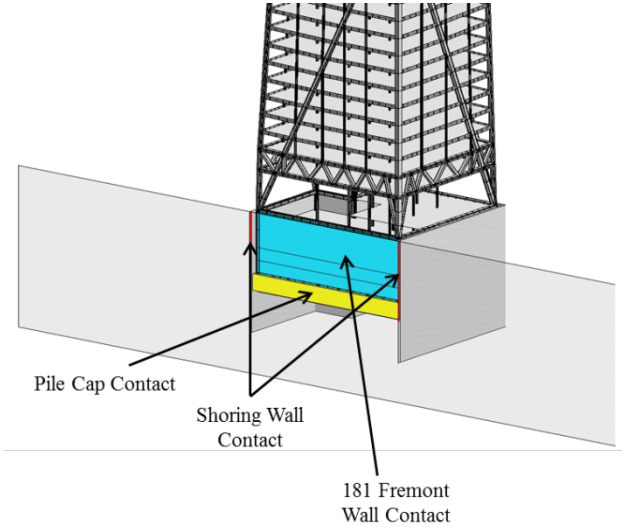
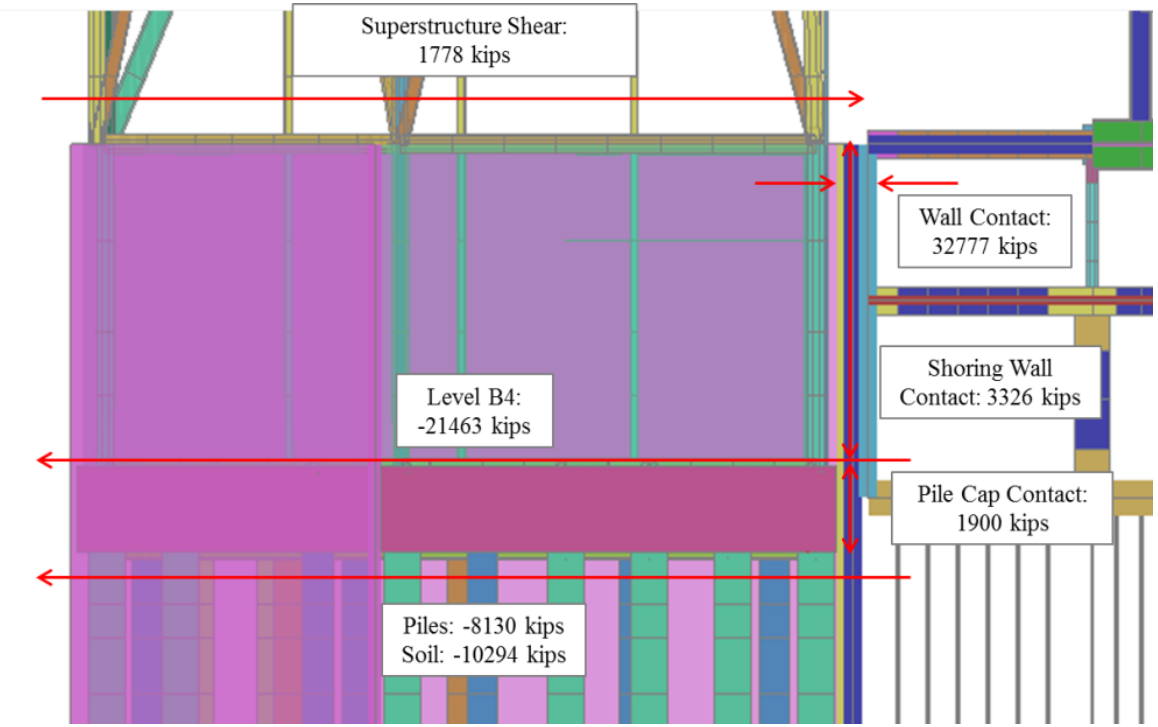
Instantaneous Shear Stresses in the 181 Fremont Below Grade Structure



Forces at t=17.6 sec



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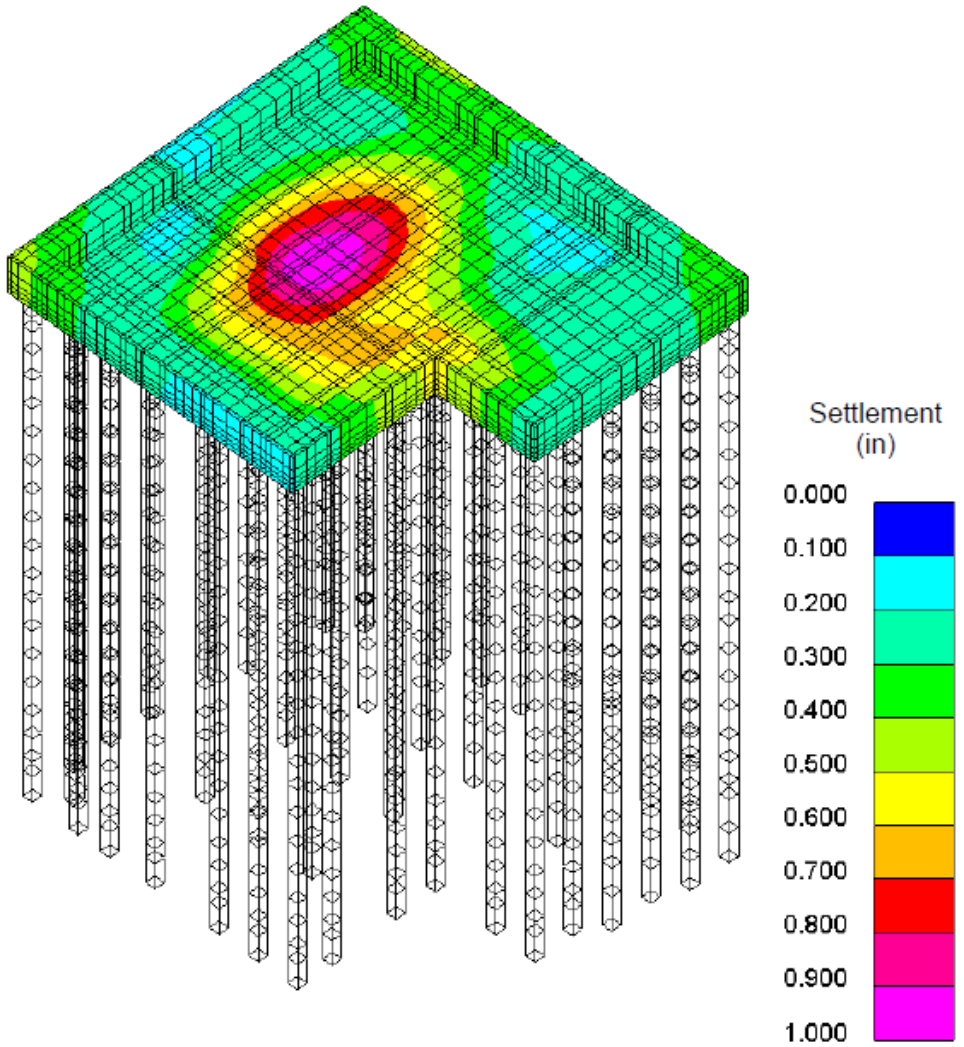
Settlement of 181 Fremont Tower



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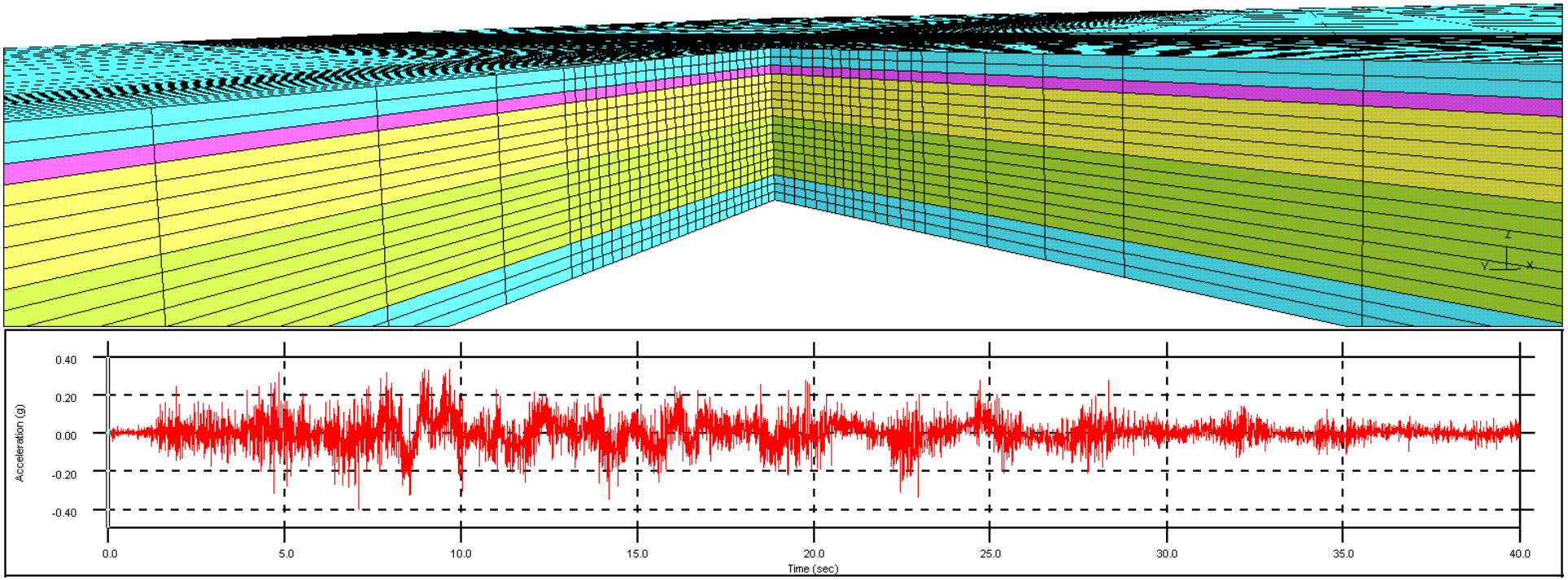
Summary

- Major urban development with many stakeholders concerned about interactions between their properties
- Detailed 3D geometry and fully non-linear modeling reduces the number of judgment calls required
- These types of simulation always provide insights into complex behaviors that are valuable in making effective and economical designs.
- Extensive validation is essential, and Peer Review necessary

Thank You

D3PLOT: Nonlinear BRB's - Liquefaction



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