Beneficial and Detrimental Effects of Earthquake Soil Structure Interaction

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Outline

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Motivation

Improve modeling and simulation for infrastructure objects

Use select fidelity (high $\leftrightarrow$ low) numerical models to analyze static and dynamic behavior of soil/rock structure fluid systems

Reduction of modeling uncertainty, ability to perform desired level of sophistication modeling and simulation

Accurately follow the flow of input and dissipation of energy in a soil structure system

Development of an expert system for modeling and simulation of Earthquakes, Soils, Structures and their Interaction, Real-ESSI: **http://real-essi.info/**

Predictive Capabilities

- Prediction under Uncertainty: use of computational model to predict the state of SSI system under conditions for which the computational model has not been validated.
- Verification provides evidence that the model is solved correctly. Mathematics issue.
- Validation provides evidence that the correct model is solved. Physics issue.
- Modeling and parametric uncertainties are always present, need to be addressed
- Goal: Predict and Inform rather than (force) Fit

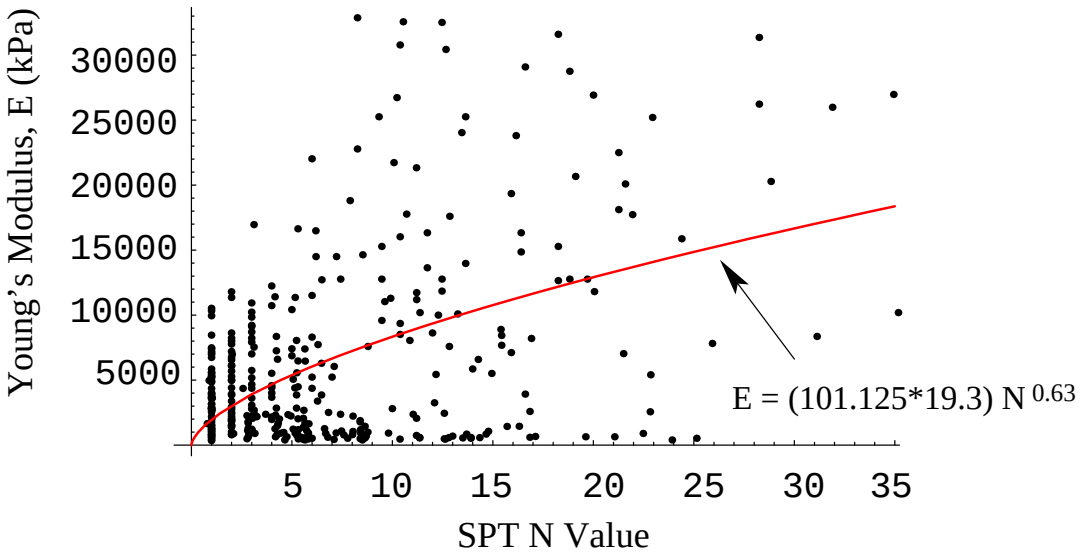
Hypothesis

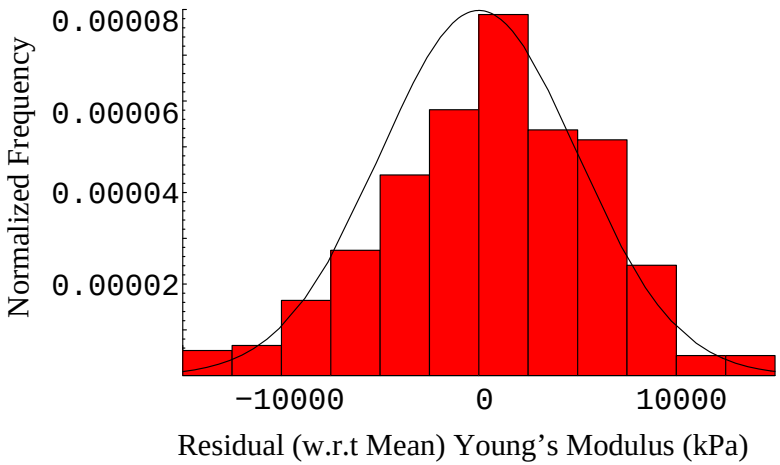
- Interplay dynamic characteristics of the Dynamic Forcing / Earthquake, Soil/Rock and Structure in time domain, plays a decisive role in successes and failures
- Timing and spatial location of energy dissipation determines location and amount of damage
- If timing and spatial location of the energy dissipation can be controlled (directed), we could optimize soil structure system for
  - Safety and
  - Economy

Uncertainties

- Modeling uncertainty, introduced by simplifying assumptions
  - low sophistication modeling and simulation
  - medium sophistication modeling and simulation
  - high sophistication modeling and simulation
  - choice of sophistication level for confidence in analysis results
- Parametric uncertainty, $M\ddot{u}_i + C\dot{u}_i + K^{ep}u_i = F(t)$,
  - propagation of uncertainty in material, K^{ep},
  - propagation of uncertainty in loads, $F(t)$,
  - results are PDFs and CDFs for σ_{ij}, ϵ_{ij}, u_i, $\dot{u}_i$, $\ddot{u}_i$

Parametric Uncertainty: Soil Stiffness





Transformation of SPT *N*-value: 1-D Young's modulus, *E* (cf. Phoon and Kulhawy (1999B))

Outline

Energy Input and Dissipation

Energy input, static and dynamic forcing

Energy dissipation outside SSI domain:

- SSI system oscillation radiation
- Reflected wave radiation

Energy dissipation/conversion inside SSI domain:

- Inelasticity of soil, contact zone, structure, foundation, dissipators
- Viscous coupling with internal/pore fluids, and external fluids

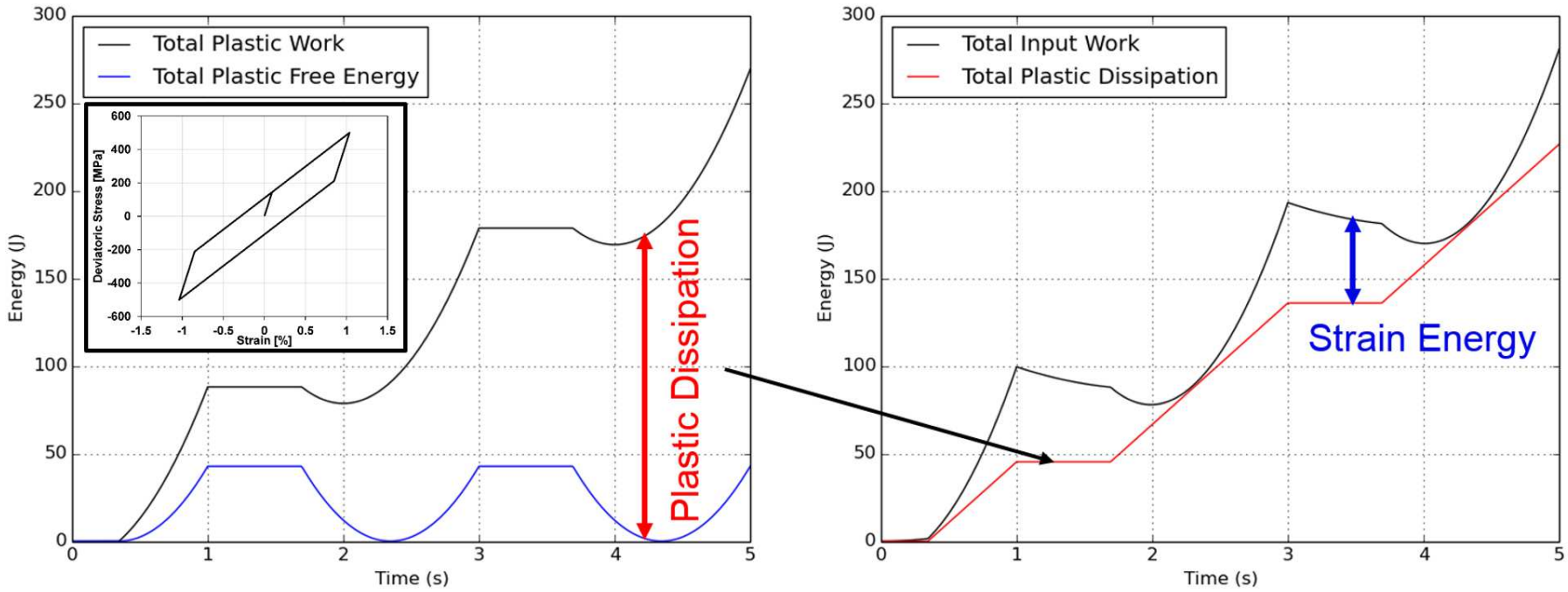
Numerical energy dissipation/production

Energy Dissipation due to Elasto-Plasticity

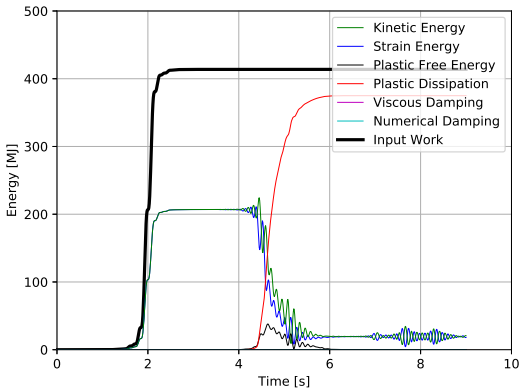
Single elastic-plastic element under cyclic shear loading

Difference between plastic work and dissipation

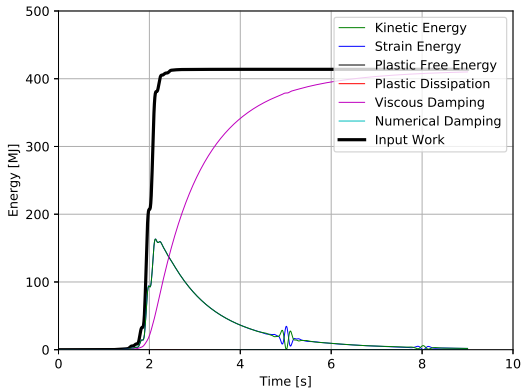
Plastic work can decrease, dissipation always increases



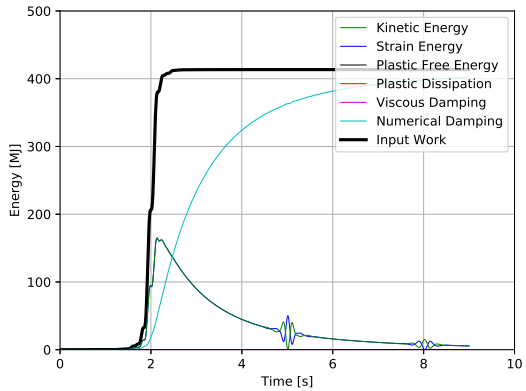
Energy Dissipation Control Mechanisms



Plasticity

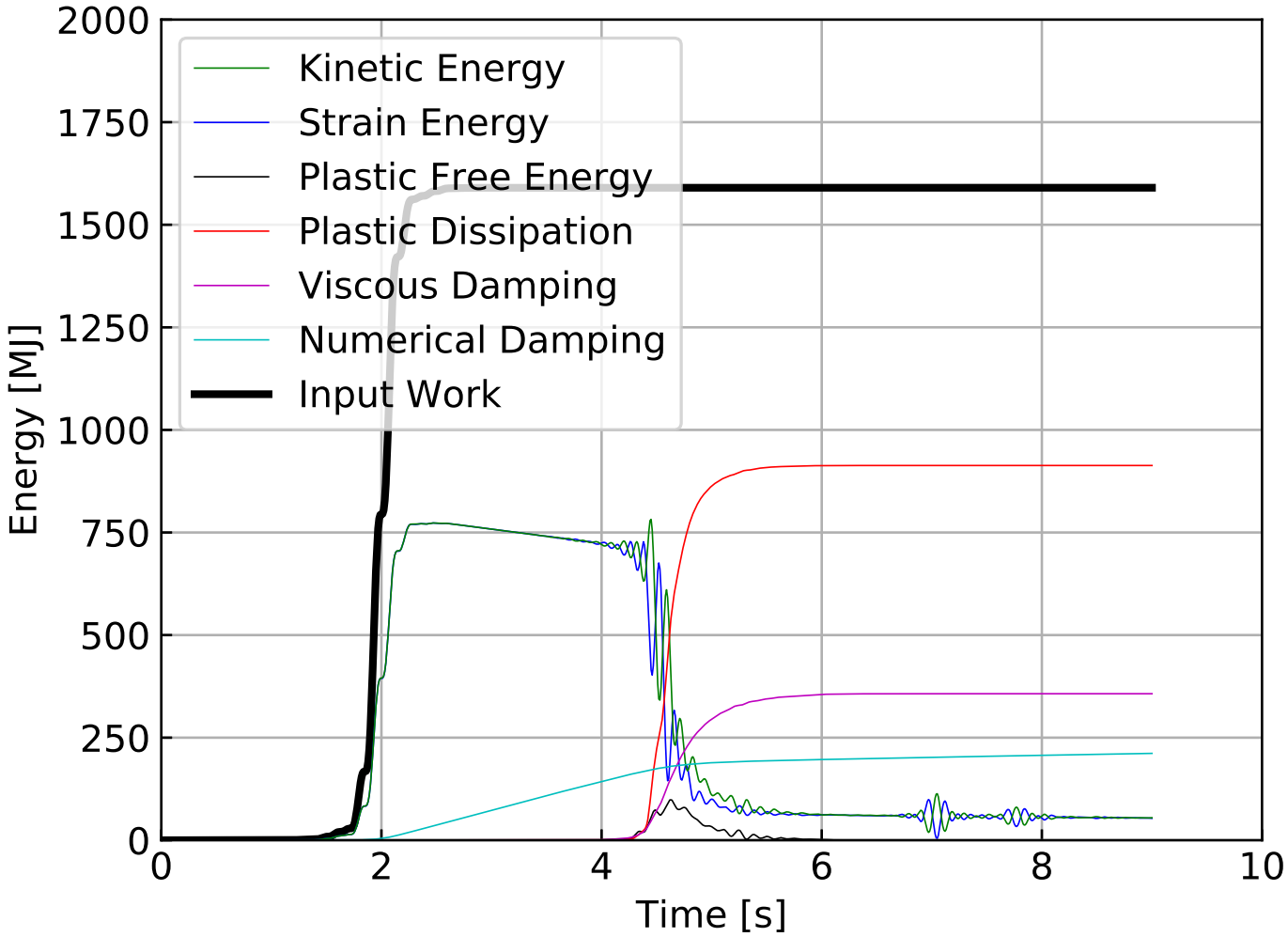


Viscous



Numerical

Energy Dissipation Control

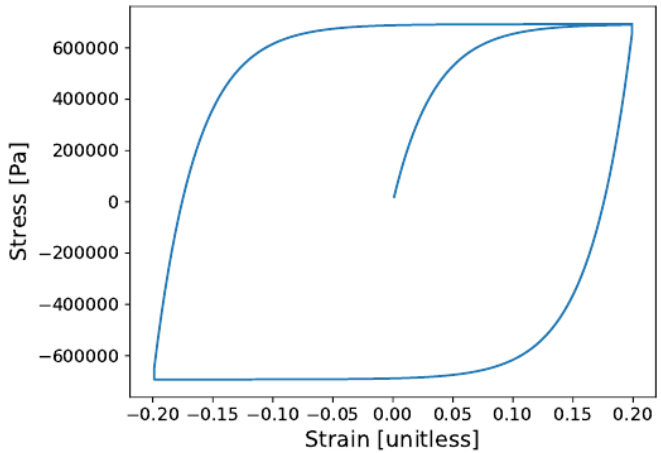


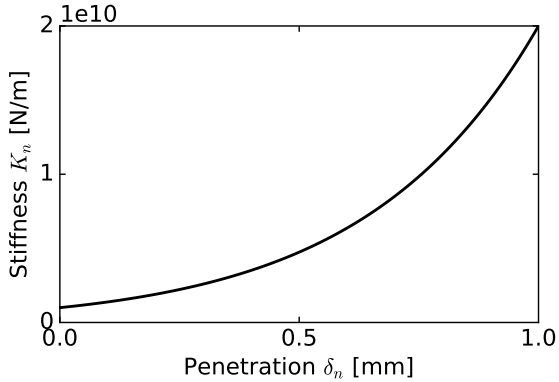
Inelastic Modeling for Components

- Soil elastic-plastic
  - Dry, single phase
  - Unsaturated (partially saturated)
  - Fully saturated
- Contact, inelastic, soil/rock – foundation
  - Dry, single phase, Normal (hard and soft, gap open/close), Friction (nonlinear)
  - Fully saturated, suction and excess pressure (buoyant force)
- Structural inelasticity/damage
  - Nonlinear/inelastic 1D fiber beam
  - Nonlinear/inelastic 2D wall element

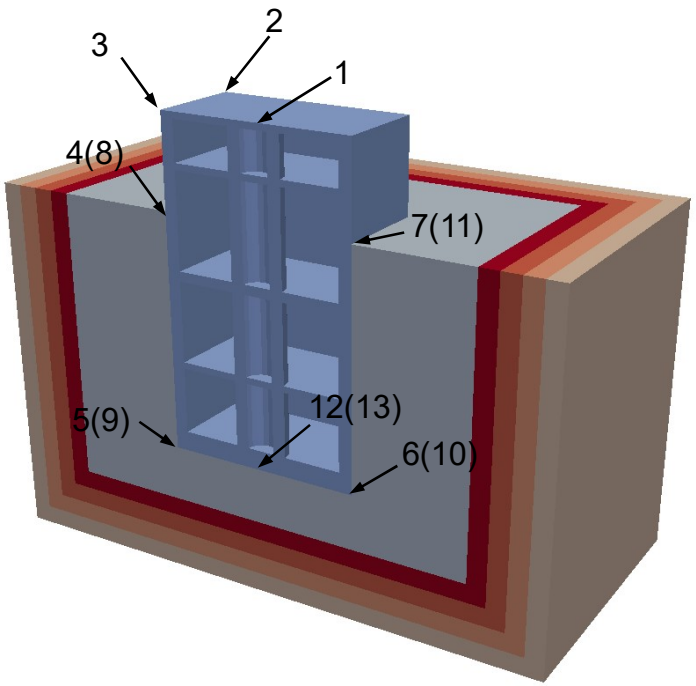
Soil Modeling Parameters

Material parameters	shear wave velocity [m/s]	500
	Young's modulus [GPa]	1.25
	Poisson ratio	0.25
	von Mises radius [kPa]	60
	linear hardening parameter [MPa]	30
	nonlinear hardening parameter	25
Contact parameters	initial normal stiffness [N/m]	1e9
	hardening rate [/m]	1000
	maximum normal stiffness [N/m]	1e12
	tangential stiffness [N/m]	1e7
	normal damping [N/(m/s)]	100
	tangential damping [N/(m/s)]	100
	friction ratio	0.25
Damping parameters	structure layer	5%
	surrounding soil	15%
	DRM layer	20%
	outside layer 1	20%
	outside layer 2	40%
	outside layer 3	60%





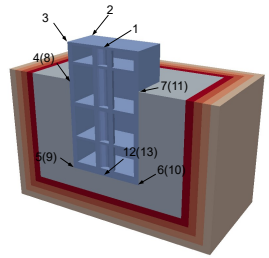
Representative points

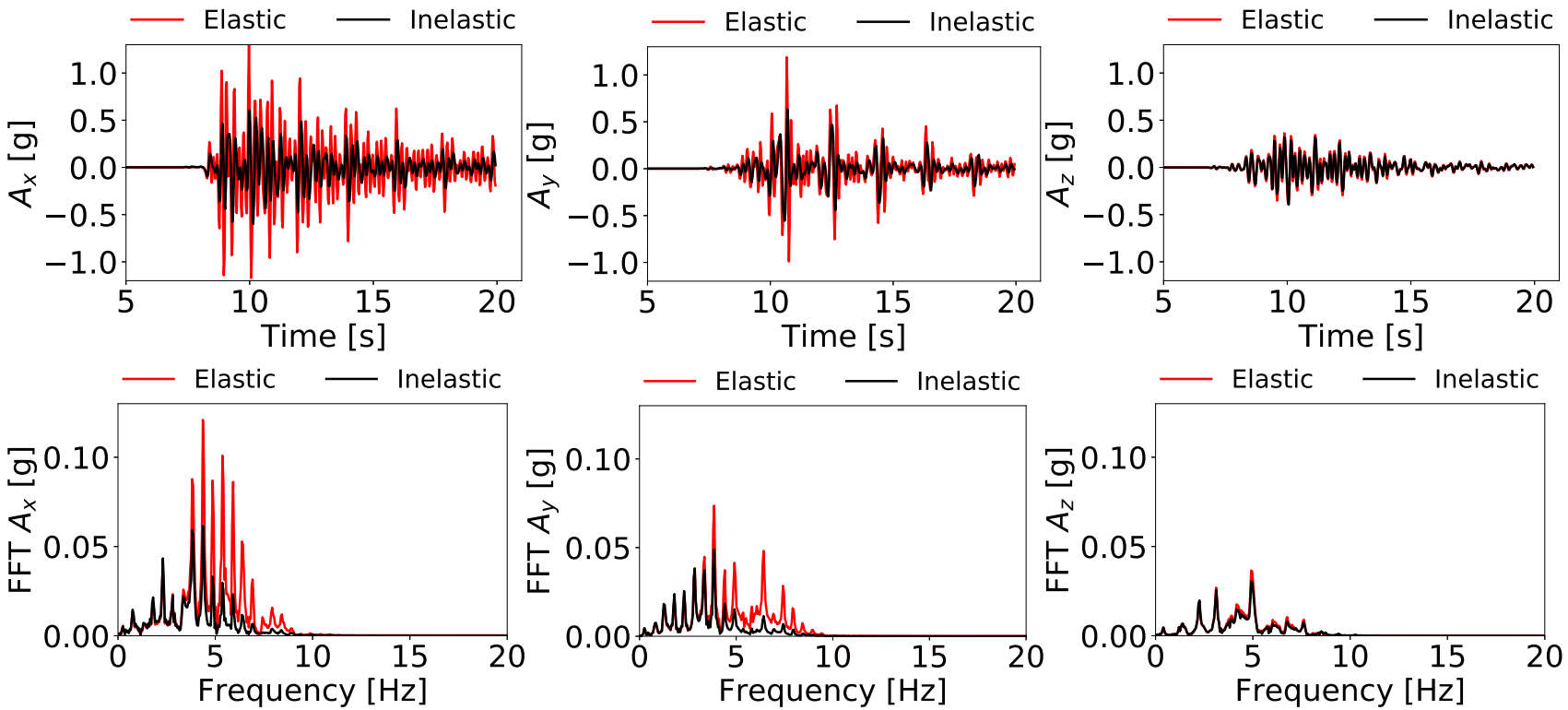


Location of points

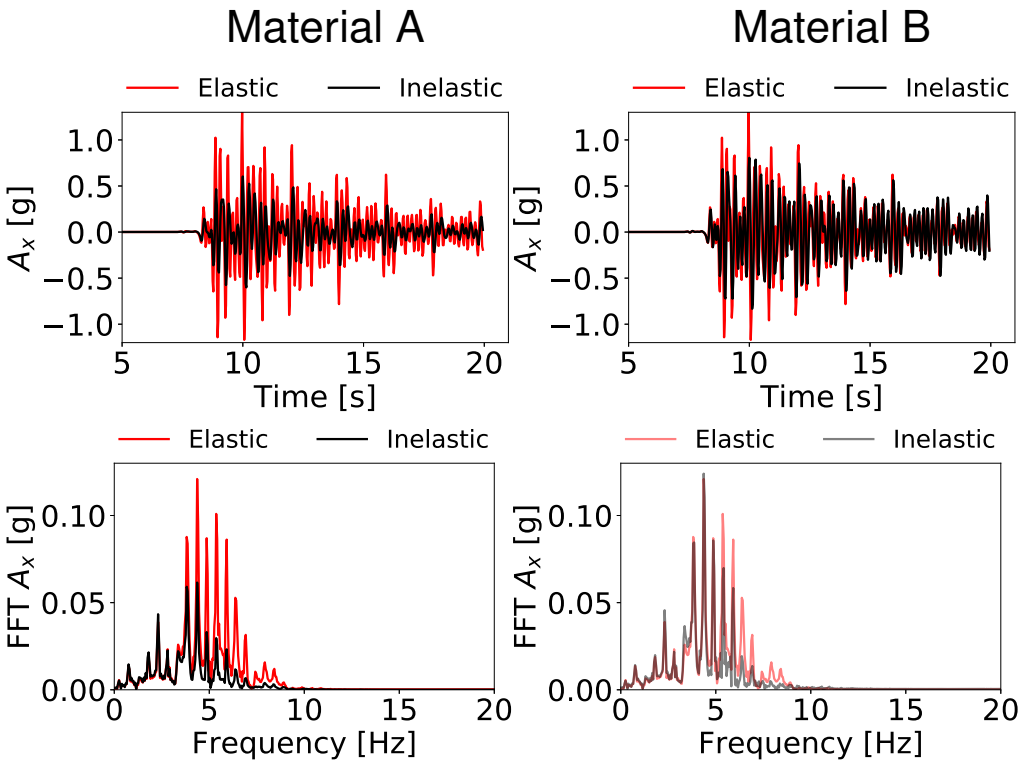
Point ID	X (m)	Y (m)	Z (m)	layer
1	0	0	14	structure
2	15	15	14	structure
3	0	15	14	structure
4	0	15	0	structure
5	0	15	-36	structure
6	0	-15	-36	structure
7	0	-15	0	structure
8	0	15	0	surrounding soil
9	0	15	-36	surrounding soil
10	0	-15	-36	surrounding soil
11	0	-15	0	surrounding soil
12	0	0	-36	structure
13	0	0	-36	surrounding soil

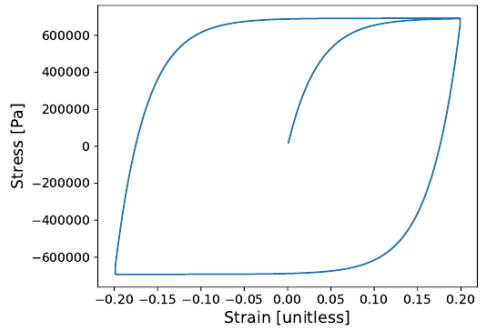
SMR: Inelastic ESSI Effects, Top Center



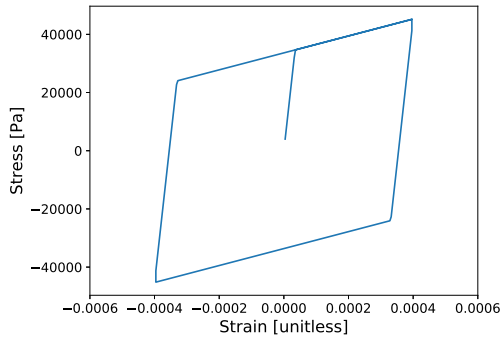


SMR: ESSI Effects, Material Modeling



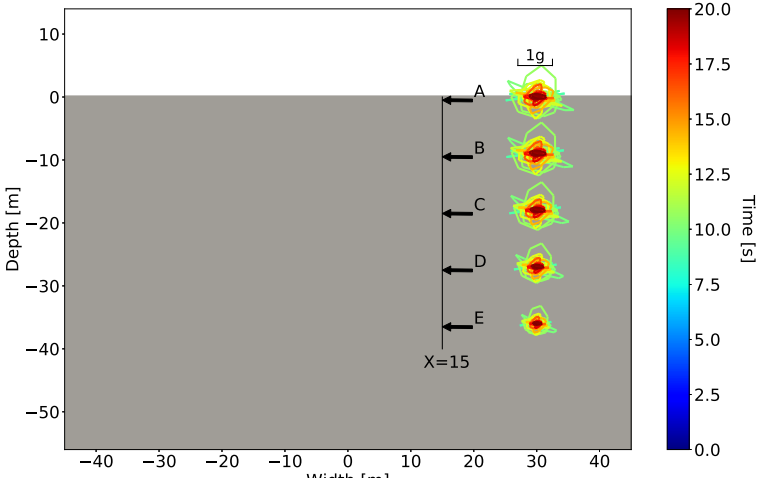


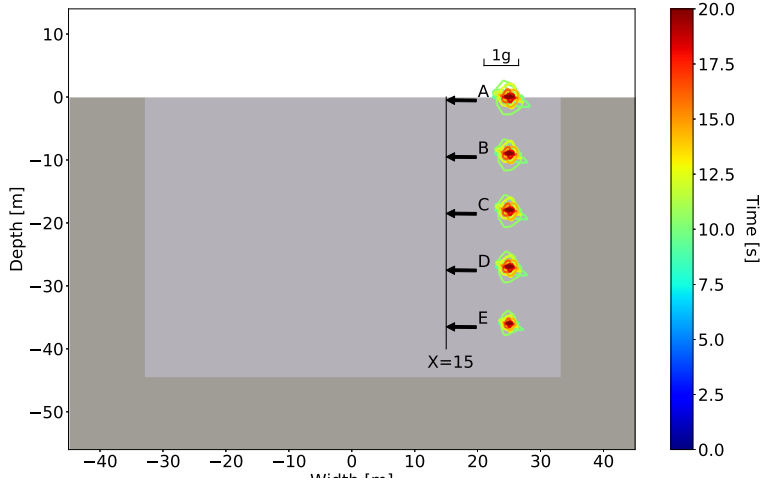
Material A: nonlinear, vM - AF



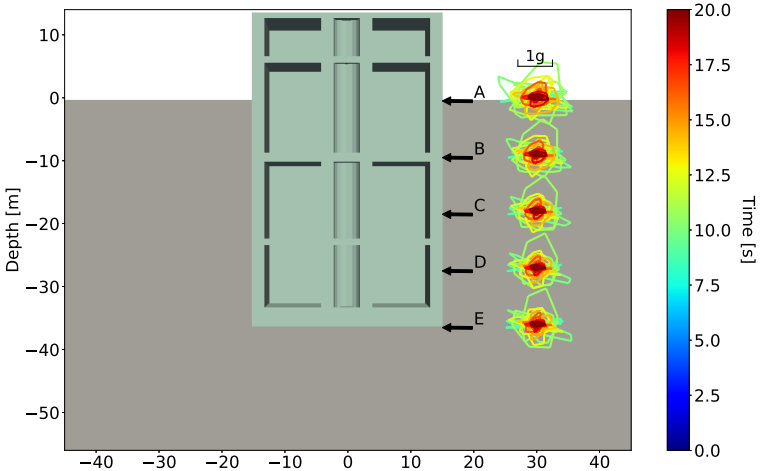
Material B: Bilinear

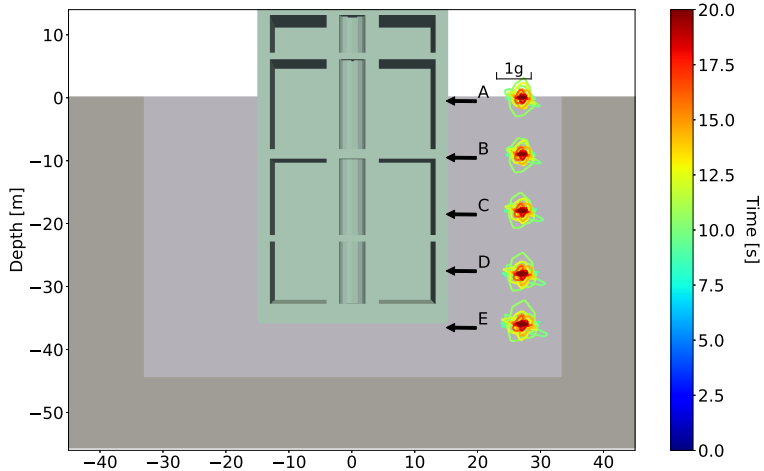
SMR: Accelerations Along Depth





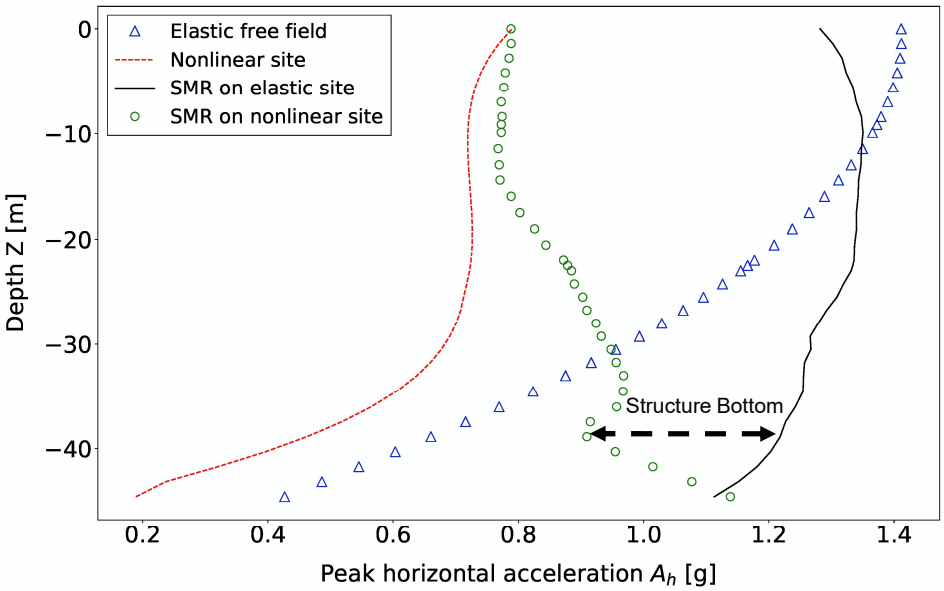
Nonlinear site effects

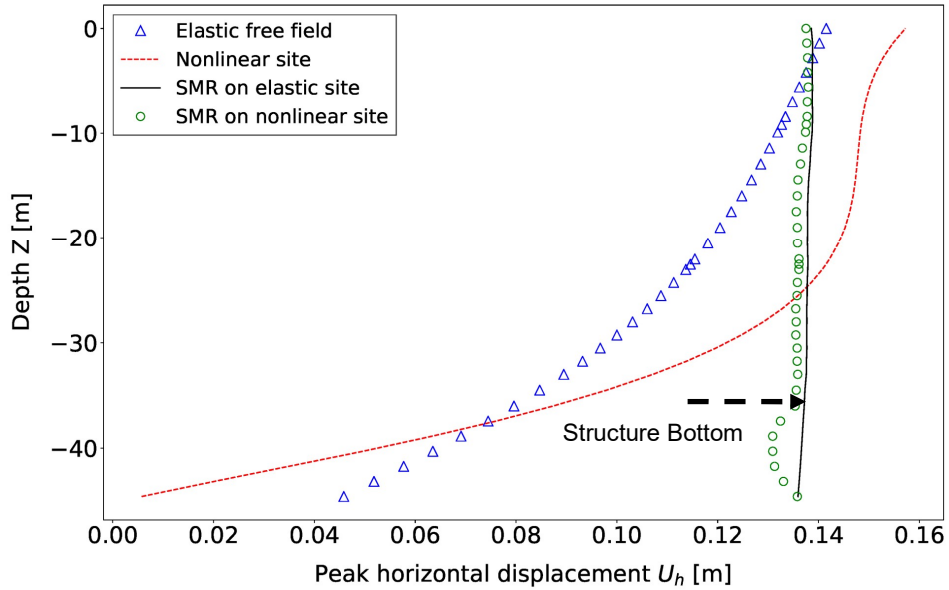




SSI effects

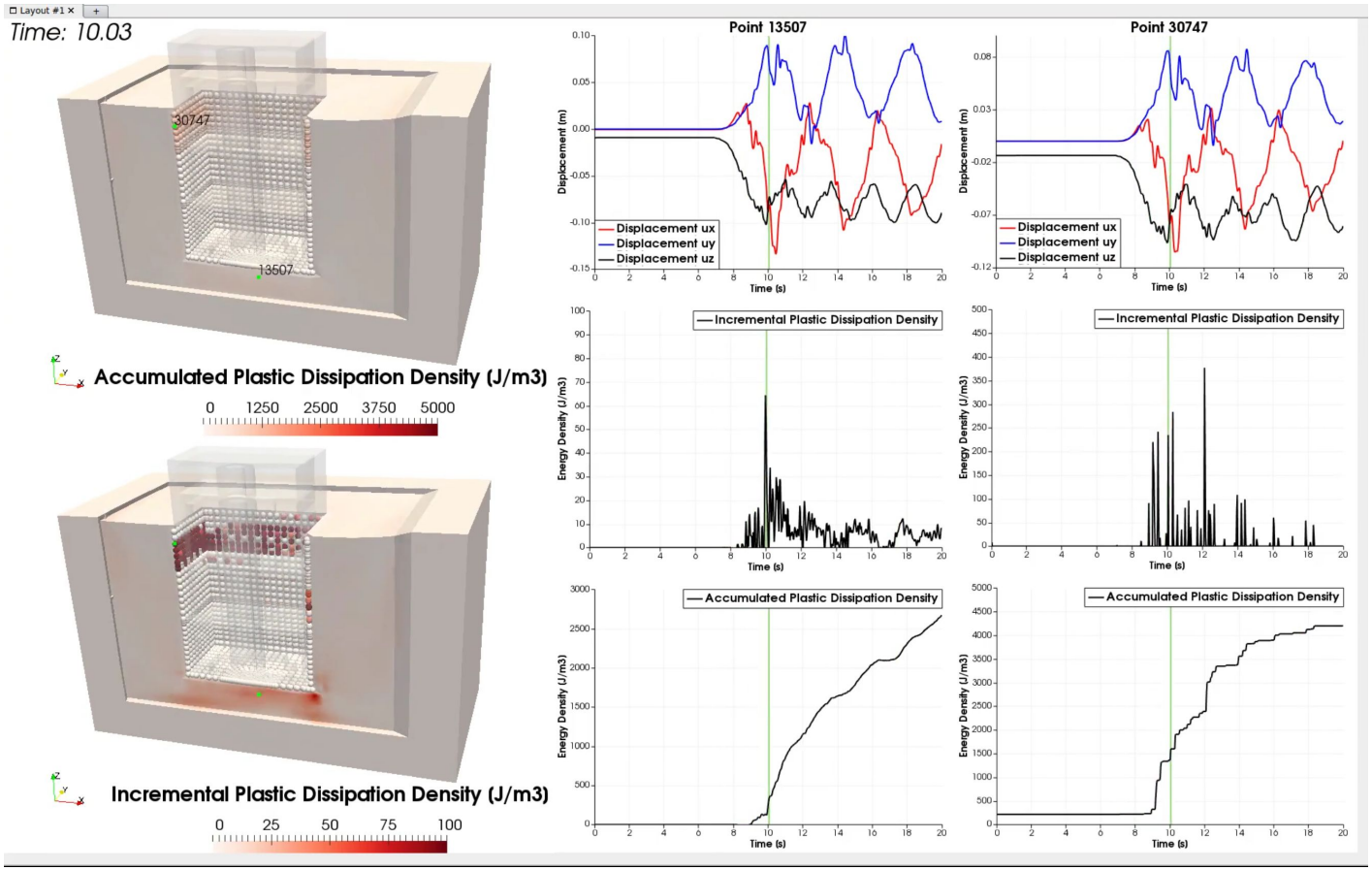
Depth variation - PGA & PGD





- The PGA & PGD of SSI systems are (very) different from free field motions,
- Material nonlinearity has significant effect on acceleration response.

Energy Dissipation for an SMR

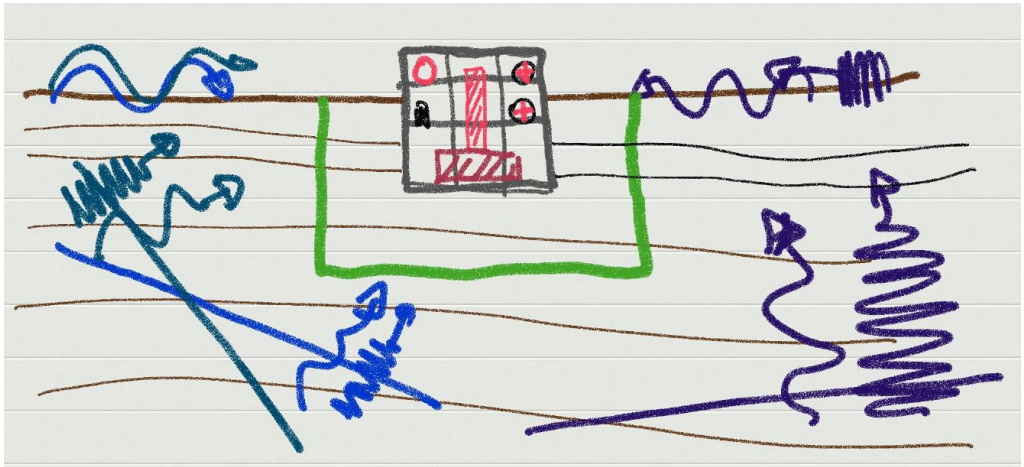


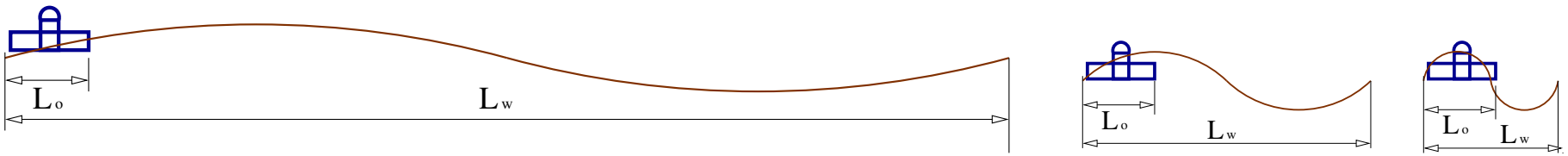
(MP4)

Outline

Stress Testing SSI Systems

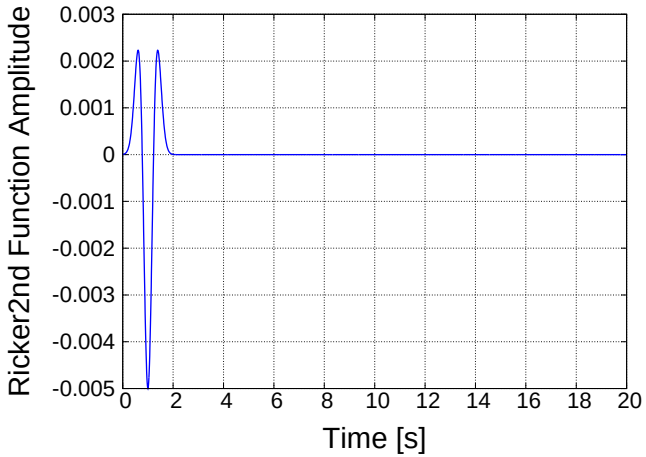
- Excite SSI system with a suite of seismic motions
- Waves: P, SV, Sh, Surface (Rayleigh, Love, etc.)
- Variation in inclination, frequency, energy and duration
- Try to "break" the system, shake-out strong and weak links

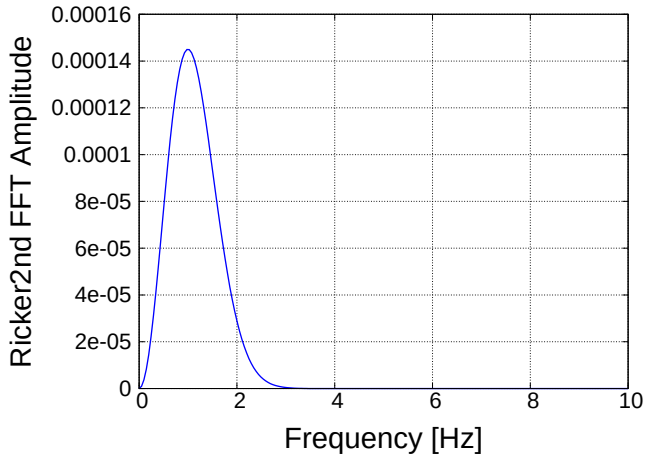




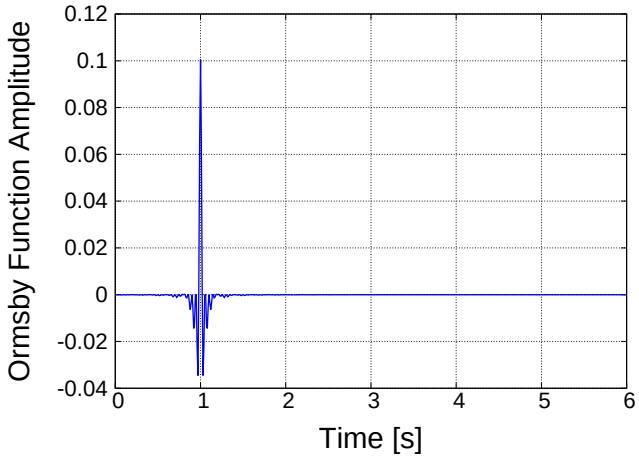
Stress Test Wavelet Signals

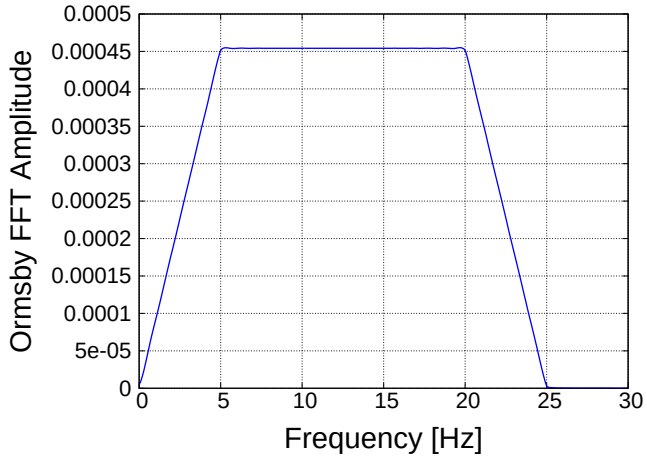
- Ricker



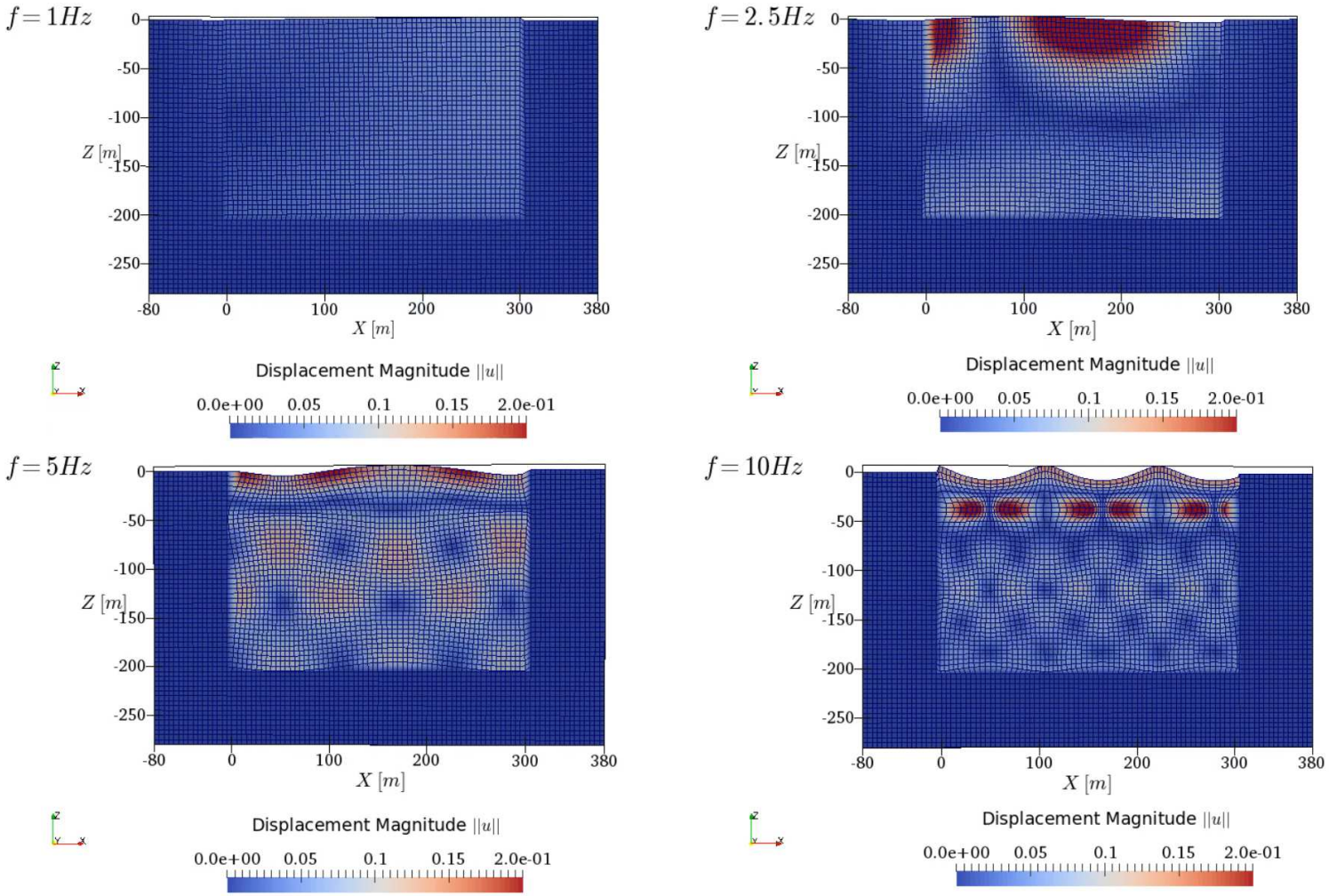


- Ormsby





Free Field, Variation in Input Frequency, $\theta = 60^o$



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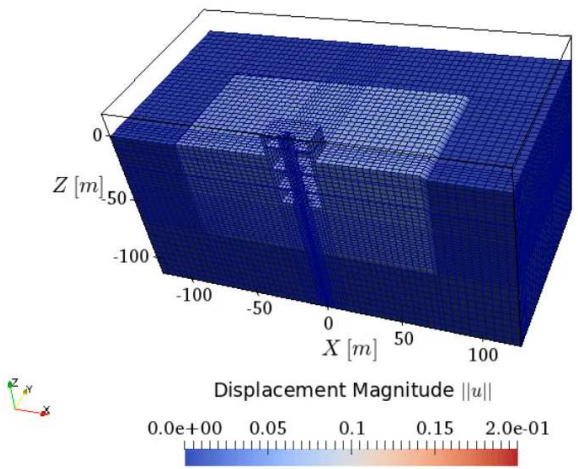
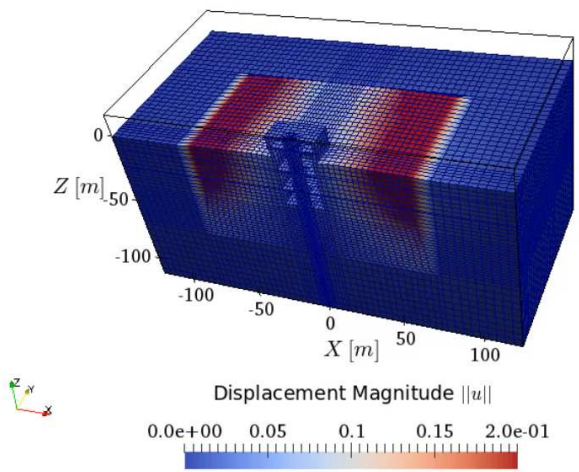
SMR ESSI, Variation in Input Frequency, $\theta = 60^o$

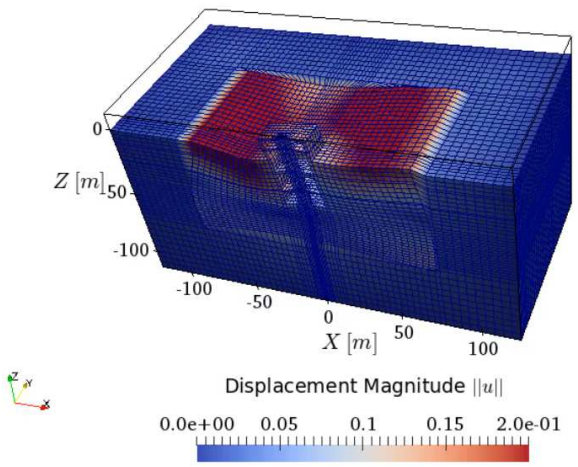
$f = 1Hz$



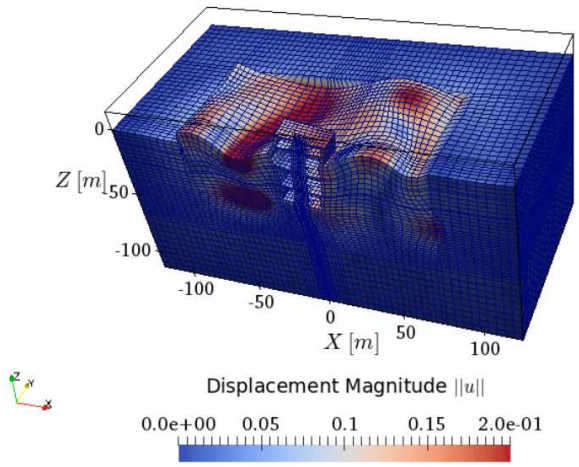
$f = 2.5Hz$



$f = 5Hz$



$f = 10Hz$



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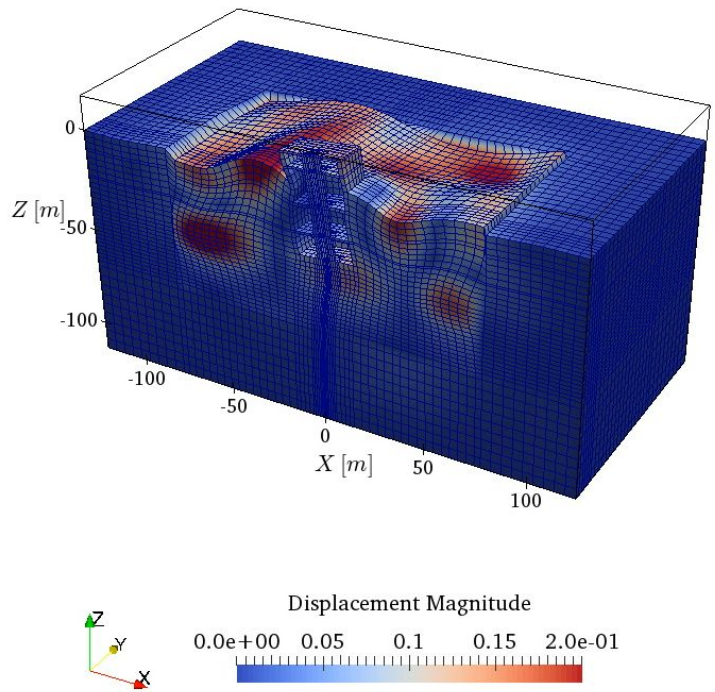
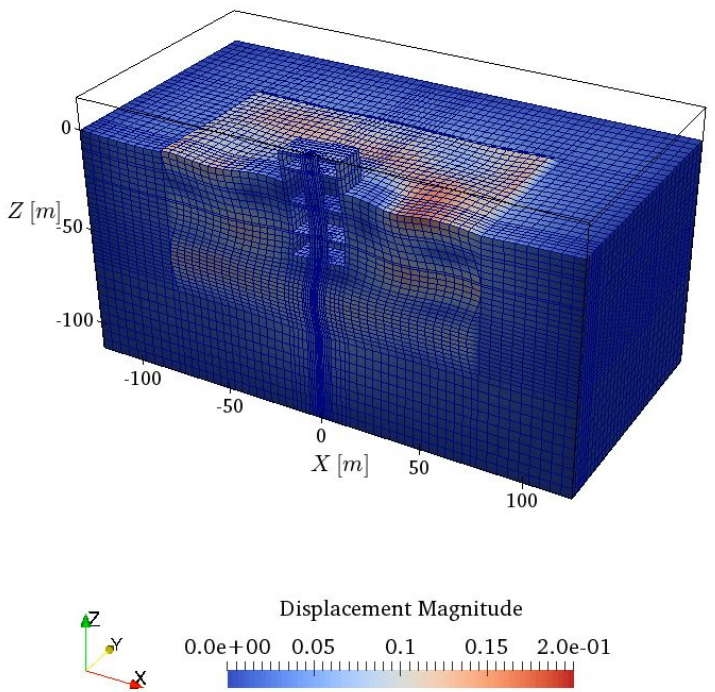
SMR ESSI, 3C vs 3×1C

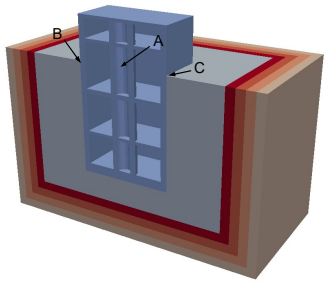
$3C$



$3 \times 1C$



(OGV)

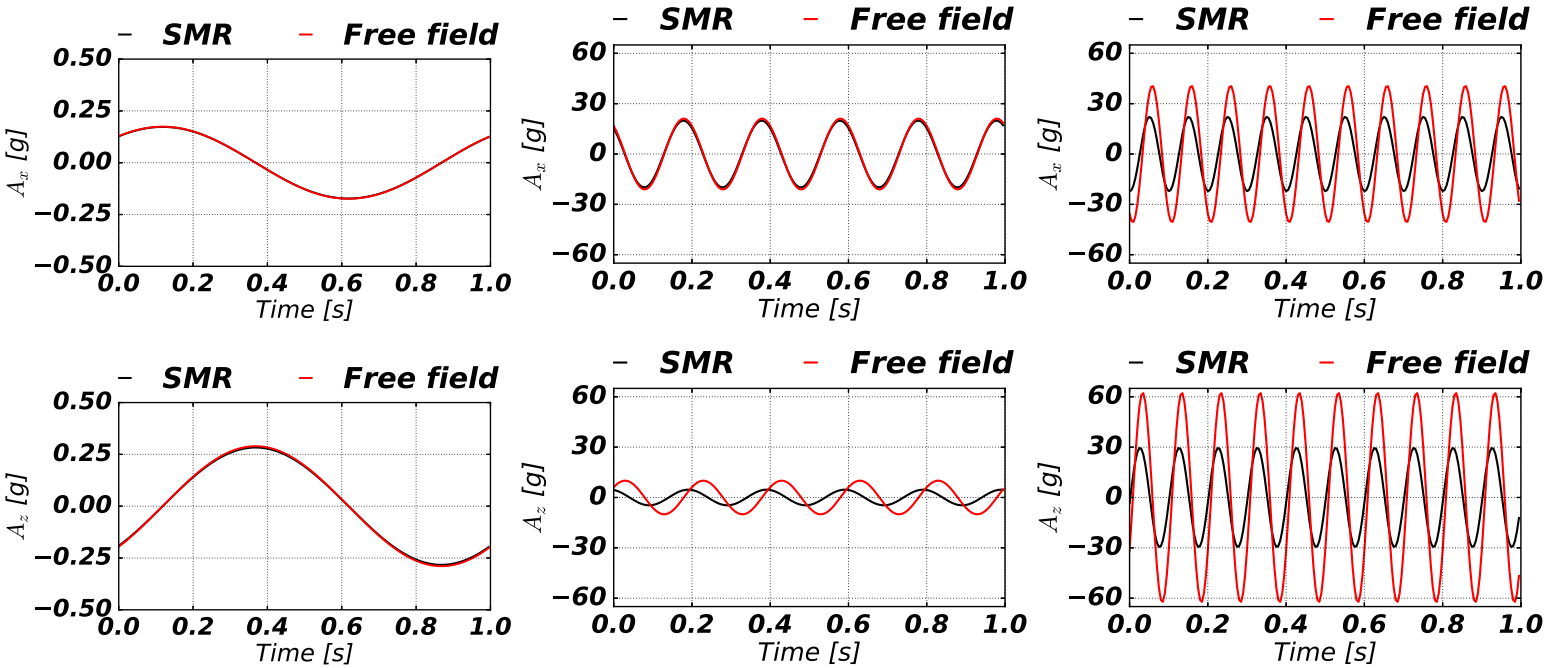


Free Field vs ESSI - Different Frequencies

Acceleration response - Surface center point A

X direction

Z direction



(a) $f = 1Hz \;\; \theta = 60^o$ (b) $f = 5Hz \;\; \theta = 60^o$ (c) $f = 10Hz \;\; \theta = 60^o$

Summary

- Numerical modeling to predict and inform, rather than fit
- Education and Training is the key!
- Funding from and collaboration with the US-DOE, US-NRC, US-NSF, CNSC-CCSN, UN-IAEA, and Shimizu Corp. is greatly appreciated,
- Real-ESSI/MS-ESSI Simulator System:
  http://real-essi.info/
  http://ms-essi.info/
- Lecture Notes, Book:
  http://sokocalo.engr.ucdavis.edu/~jeremic/LectureNotes/