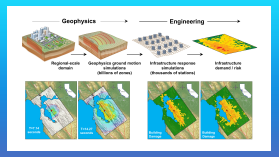

PEER International Pacific Rim Forum
June 16-17, 2021

Towards Modeling Three-Dimensional Shallow Crust Nonlinearity in Broadband Deterministic Earthquake Simulations

Elnaz Seylabi, University of Nevada Reno

In Collaboration with: Domniki Asimaki (Caltech)
Doriam Restrepo, Ricardo Taborda (EAFIT)

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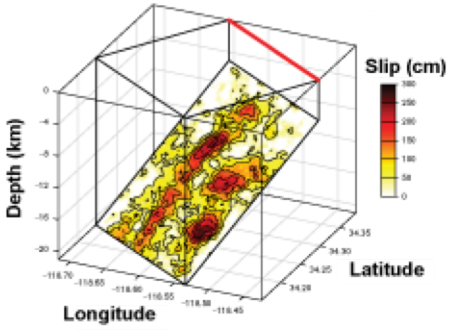
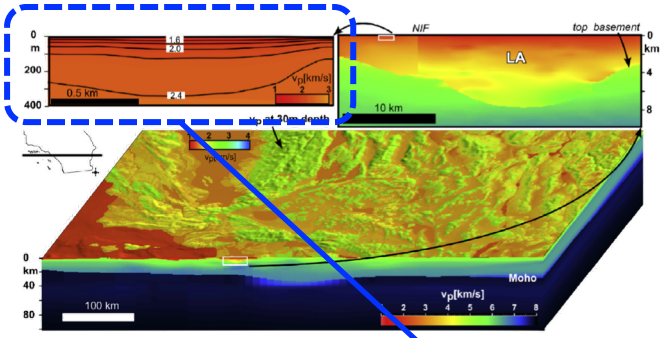
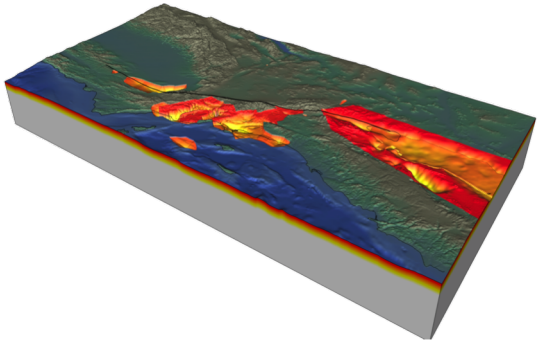
Ingredients for broadband deterministic earthquake simulations

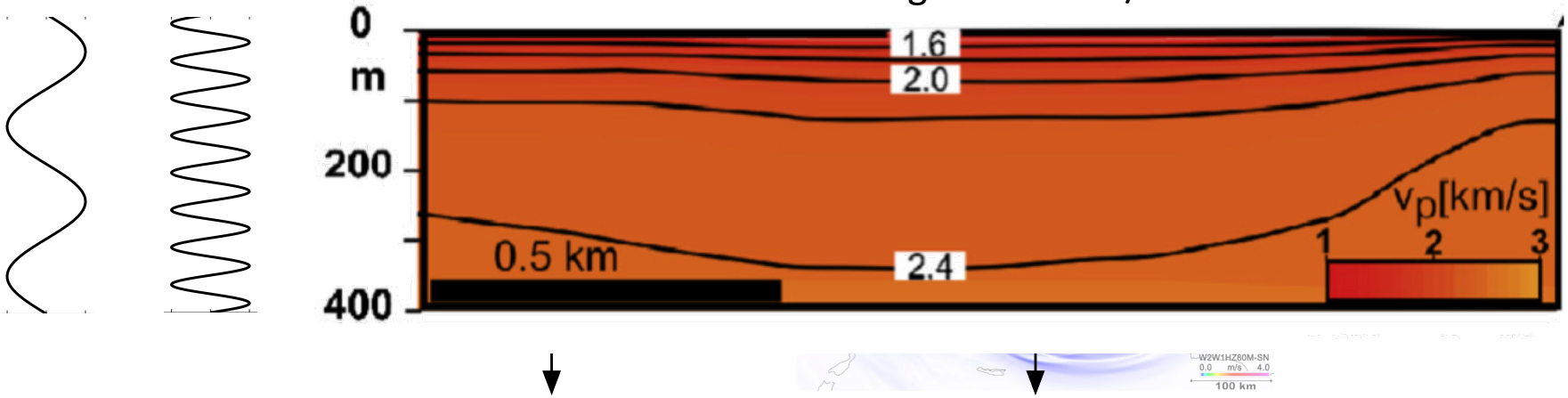






https://www.scec.org

Near surface geomaterial / shallow crust



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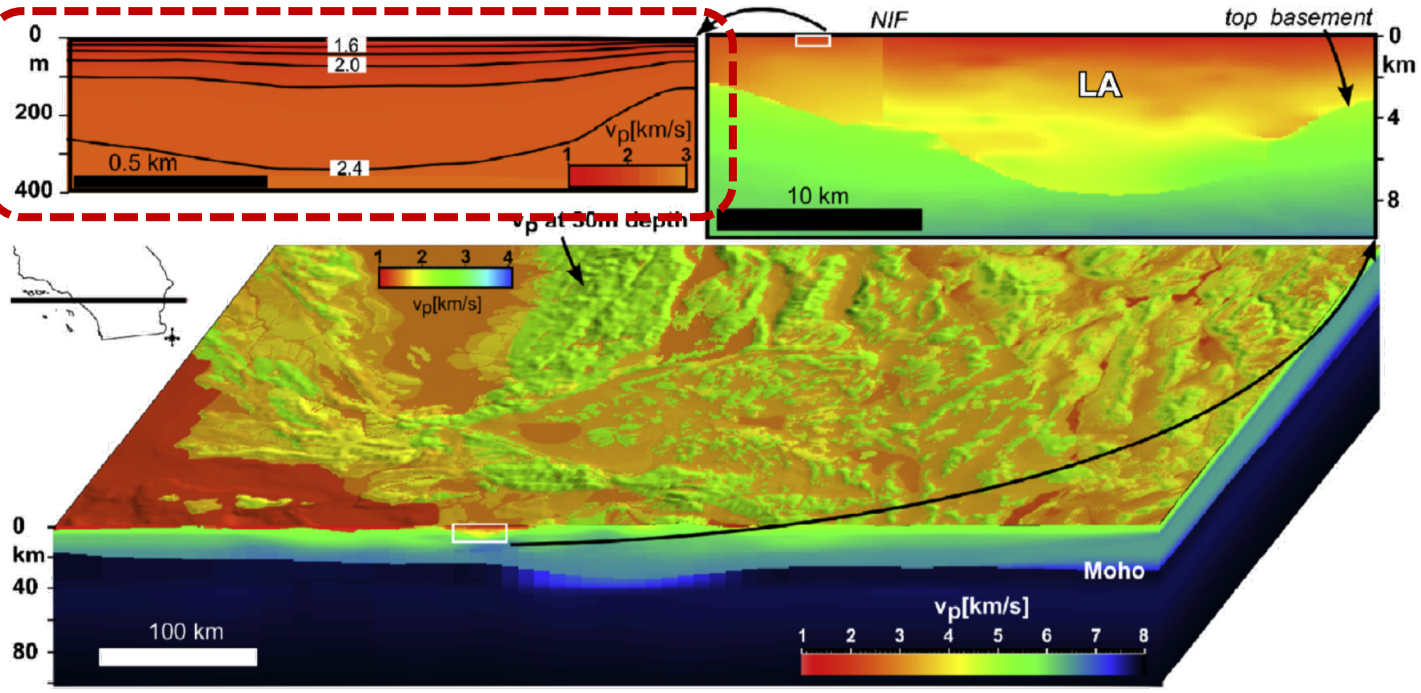
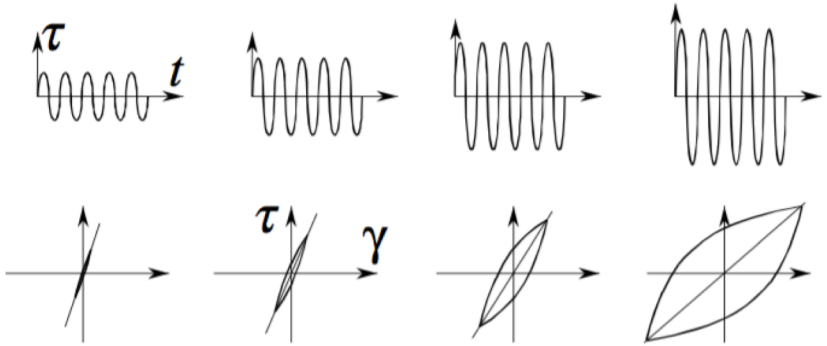
Primary effects of shallow crust nonlinearity



https://www.scec.org

Primary effects of nonlinearity:

- Reduction in shear modulus
- Increase in material damping
- Reduction in site amplification factors
- Increase in residual deformations



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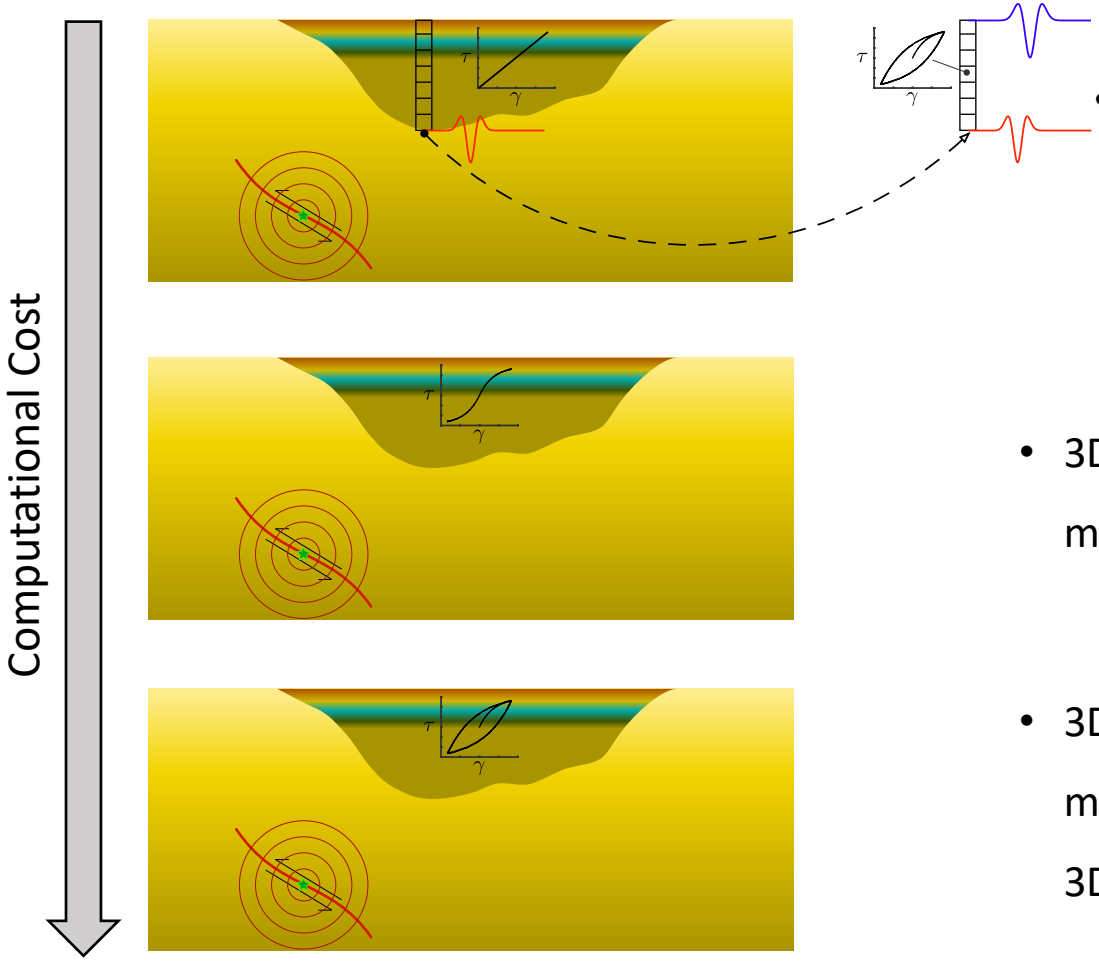
Different proxies for modeling shallow crust nonlinearity at the regional-scale



- Hybrid 3D-1D analysis: Blind to 3D nonlinear scattering effects

- 3D equivalent linear analysis: Incapable of modeling residual deformations

- 3D nonlinear analysis: Capable of modeling both residual deformations and 3D nonlinear scattering effects

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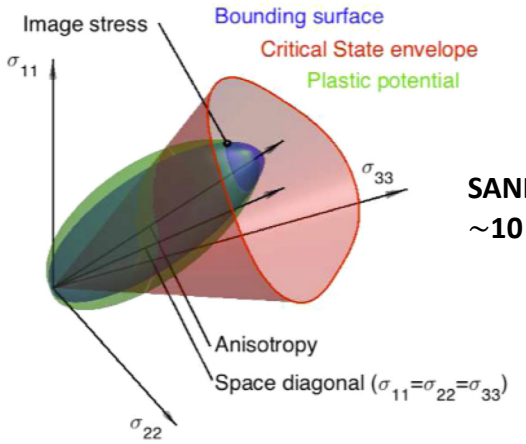
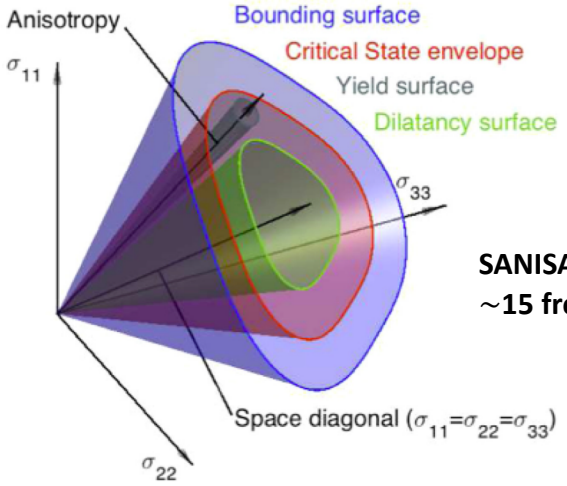
Today we have a rich library of constitutive models for geotechnical engineering applications. Which ones are suitable for regional scale simulations?

Constitutive models for soils (Lade 2005)

- Simple Elastic Plastic Models
- Single Yield Surface Models
- Bounding Surface Models
- Multiple Surfaces Models
- Incrementally Nonlinear Models
- Double Hardening Models
- Critical State Models



SANICLAY
~10 free parameters



SANISAND
~15 free parameters

Yang et al. (2019)

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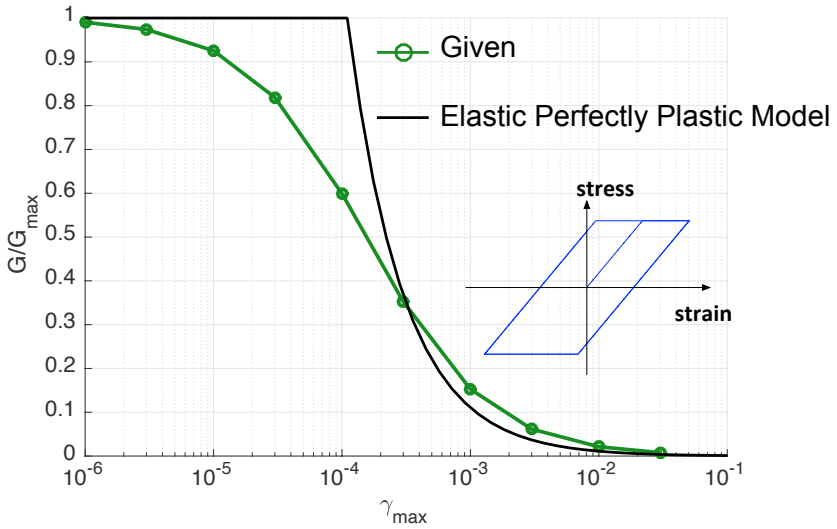
Elastic perfectly plastic models can overestimate an increase in residual displacements and a reduction in site amplification factors.

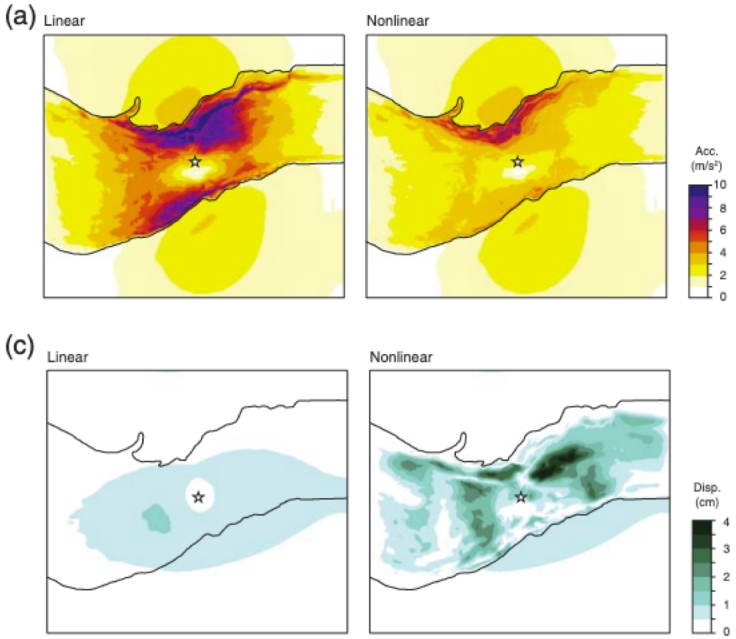


RESEARCH ARTICLE | NOVEMBER 01, 2012

Earthquake Ground-Motion Simulation including Nonlinear Soil Effects under Idealized Conditions with Application to Two Case Studies

R. Taborda; J. Bielak; D. Restrepo

Seismological Research Letters (2012) 83 (6): 1047–1060.
https://doi.org/10.1785/0220120079 Article history



Disadvantages:

- Do not accurately reproduce the behavior of most geomaterials
- Artificially large hysteresis loops at large strains; overestimation of residual deformations and attenuation.
- Blind to the effects of geomaterial nonlinearity at small to moderate strain ranges

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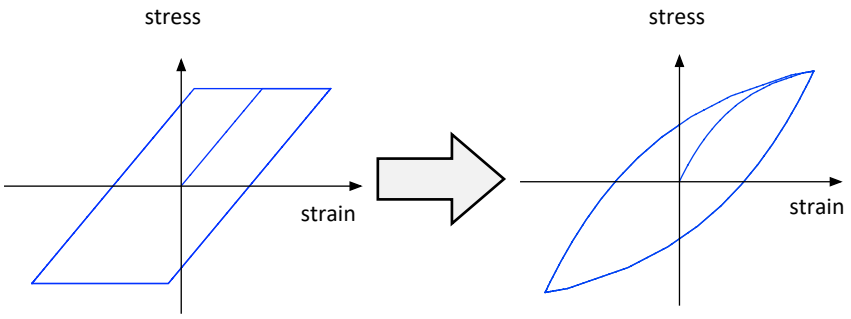
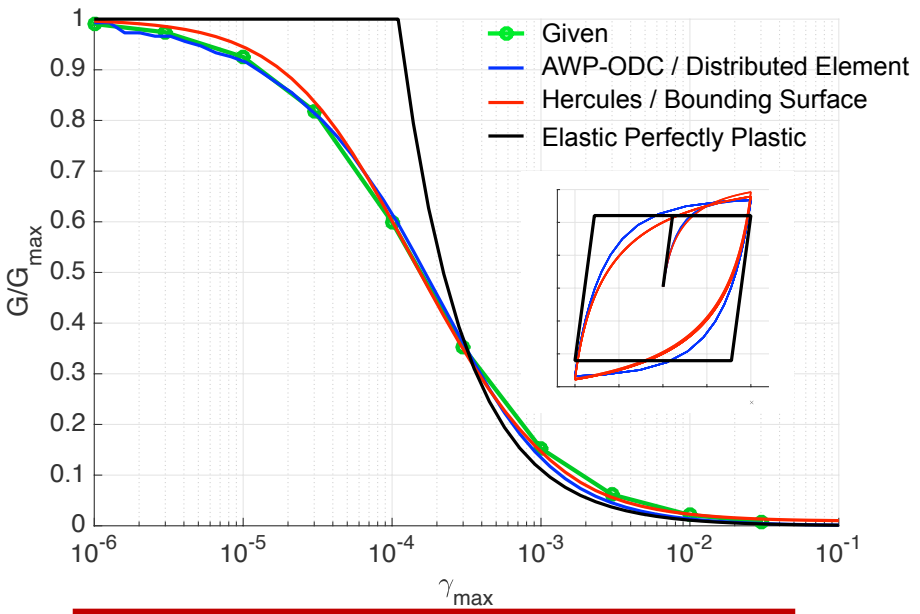
Going beyond perfect plasticity in large scale simulations

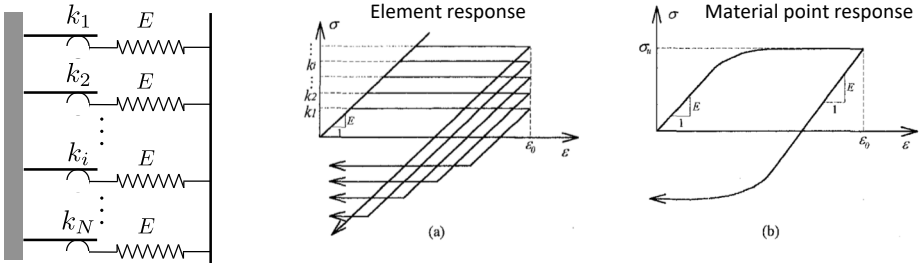




Necessary considerations:

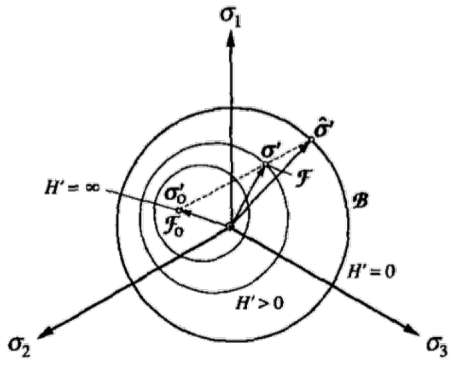
- Rigorous but computationally efficient
- Small number of free model parameters

AWP-ODC (Olsen, Day, and Cui @ SDSU)



Iwan (1966), Chiang (1997)

Hercules (Quake/Bielak Group @ CMU)



Borja & Amies (1994)

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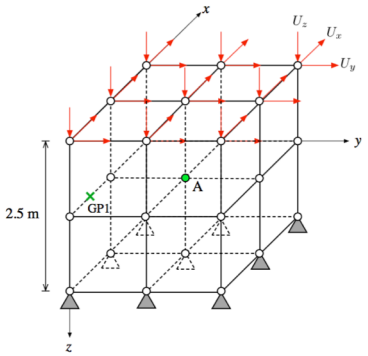
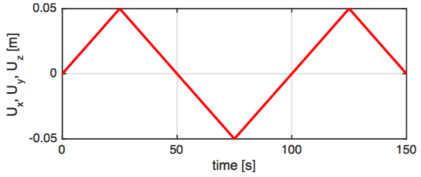
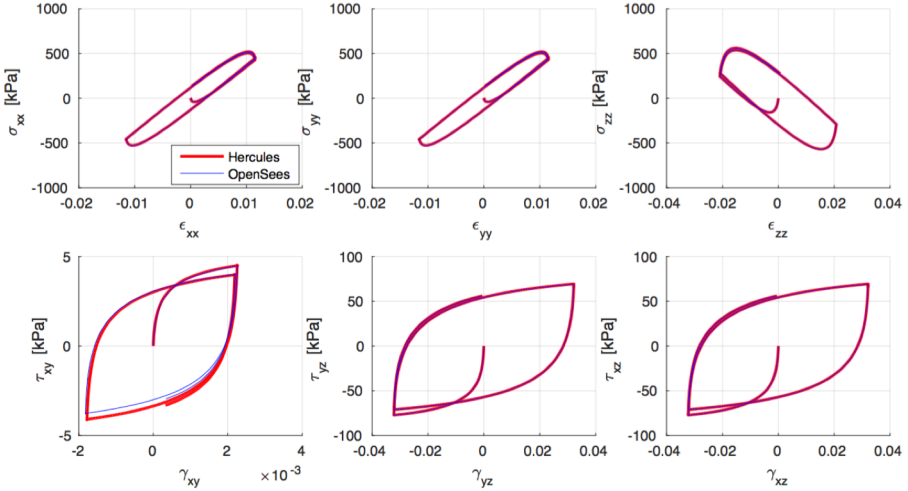
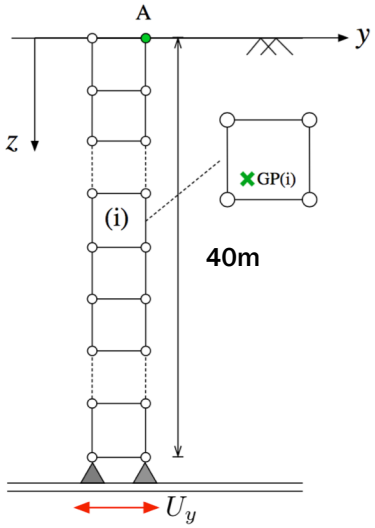
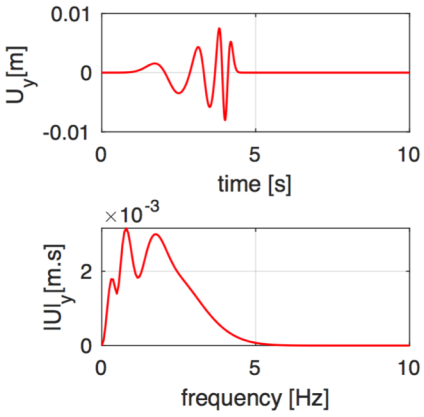
Verification of Hercules BSP model at different scales

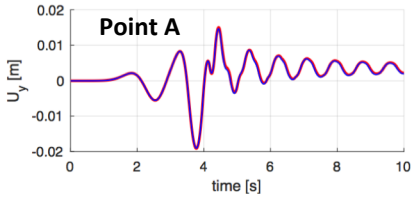


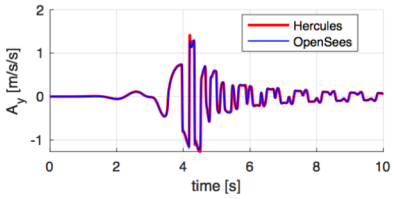


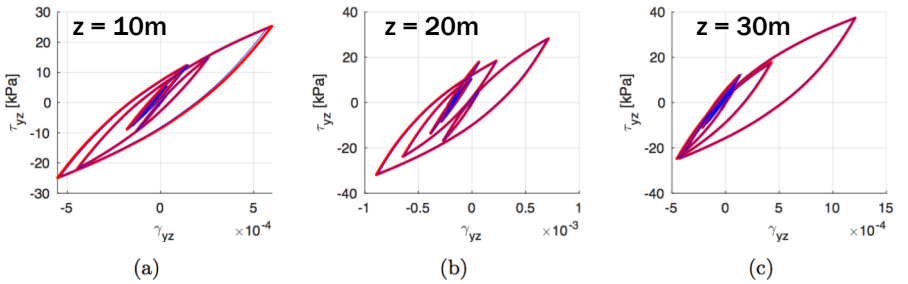




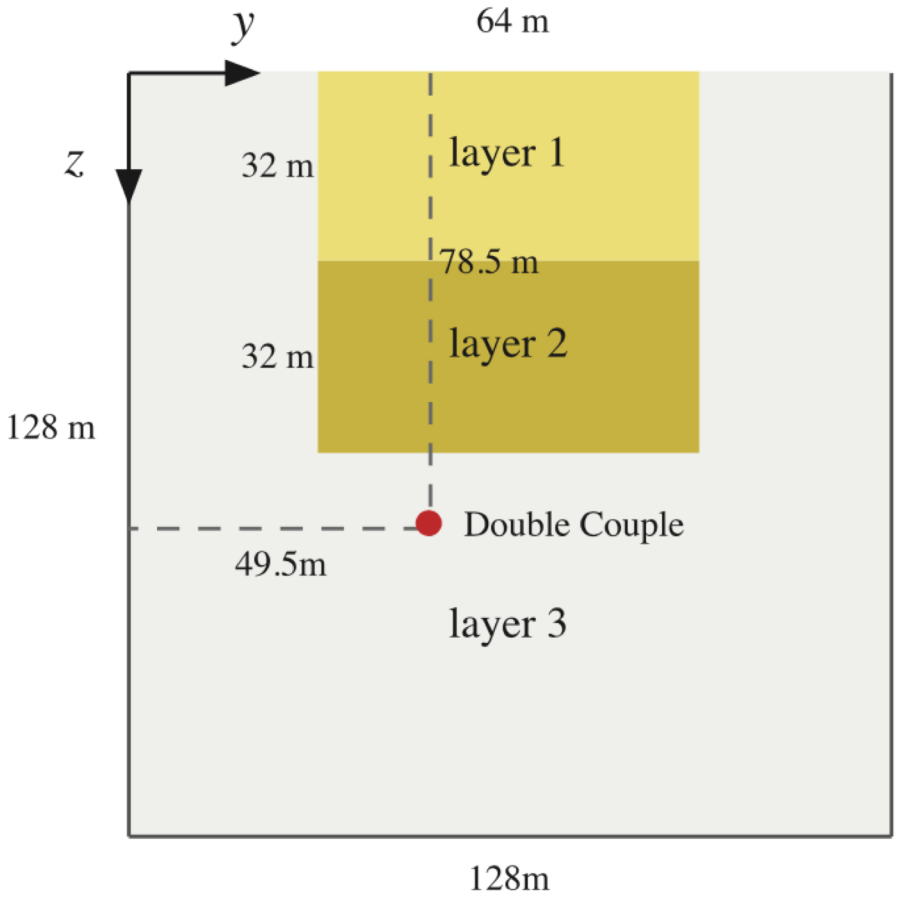


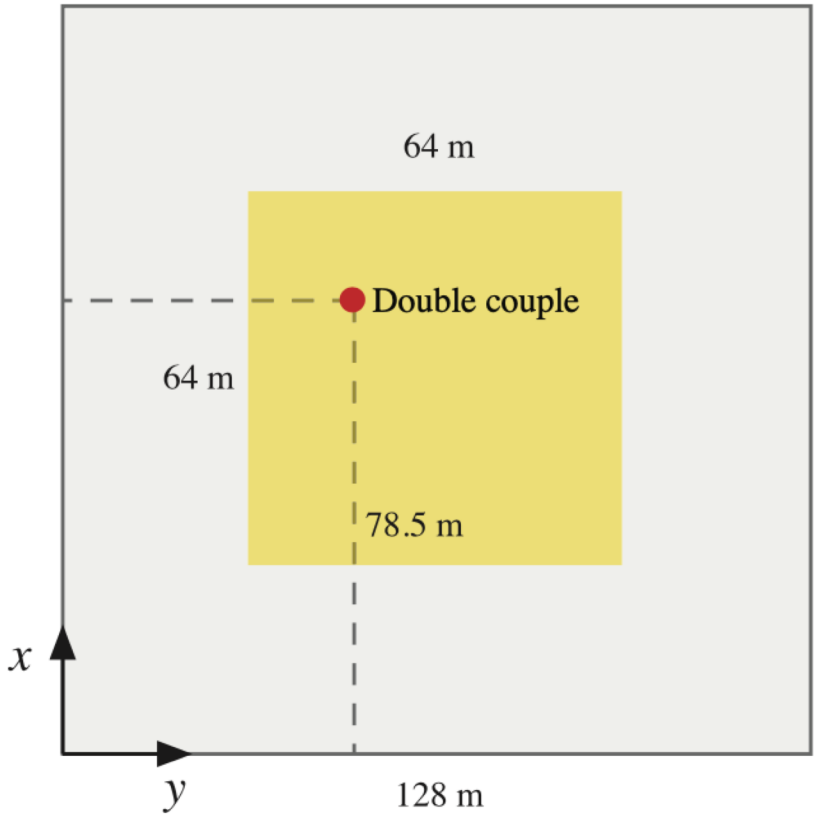






Verification of Hercules BSP model at different scales





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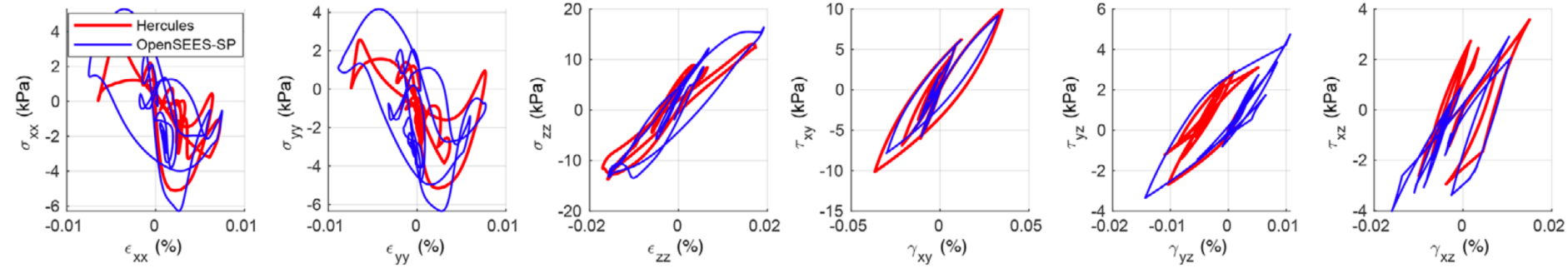
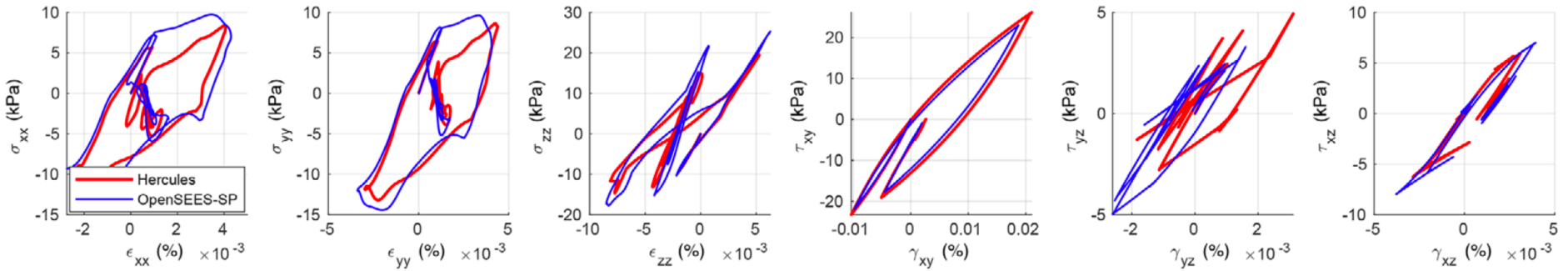
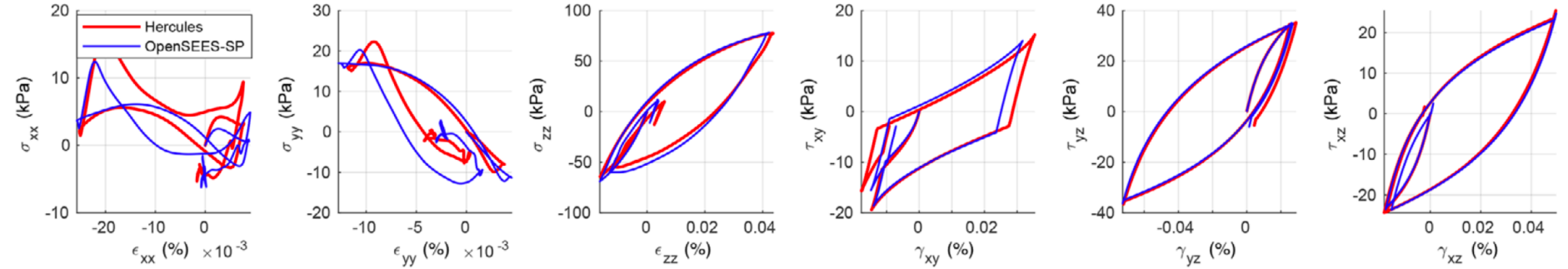


(A) z = 14 m



(B) z = 34 m



(C) z = 54 m

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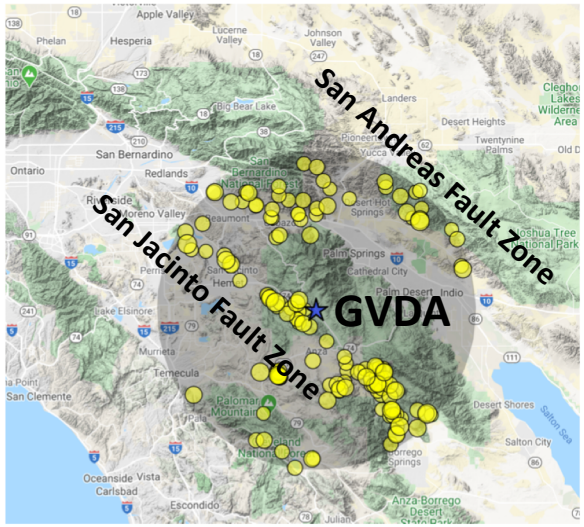
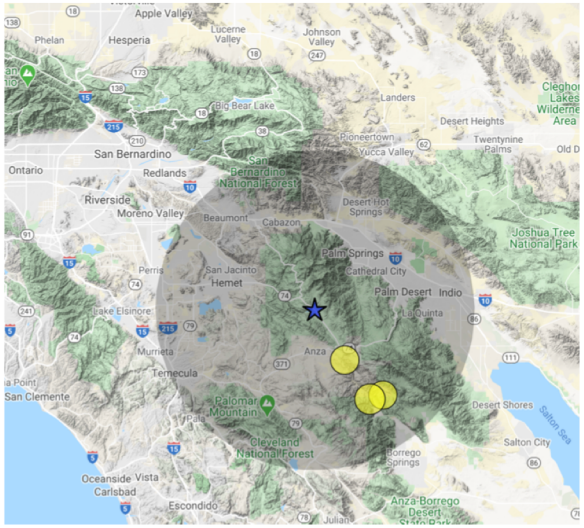
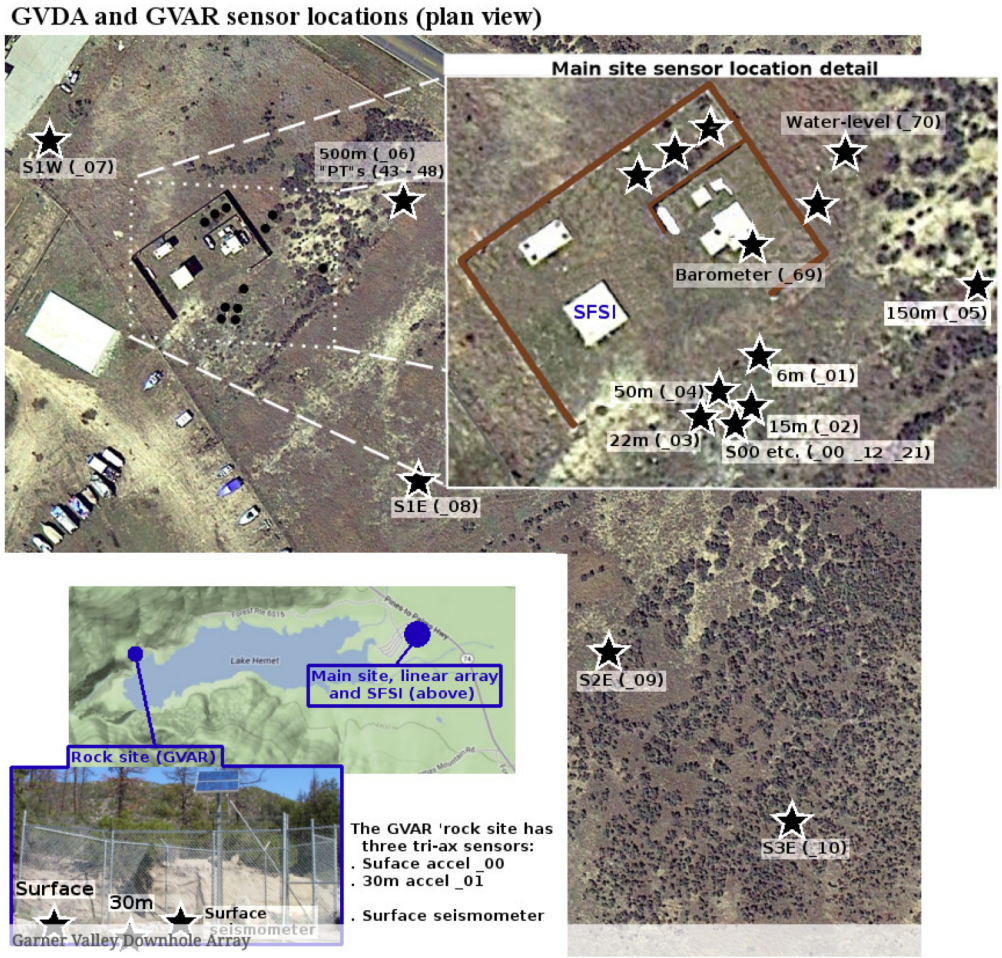
Garner Valley: Our testbed for broadband nonlinear simulations



$3 \leq Mw \leq 4$



$Mw \geq 5$



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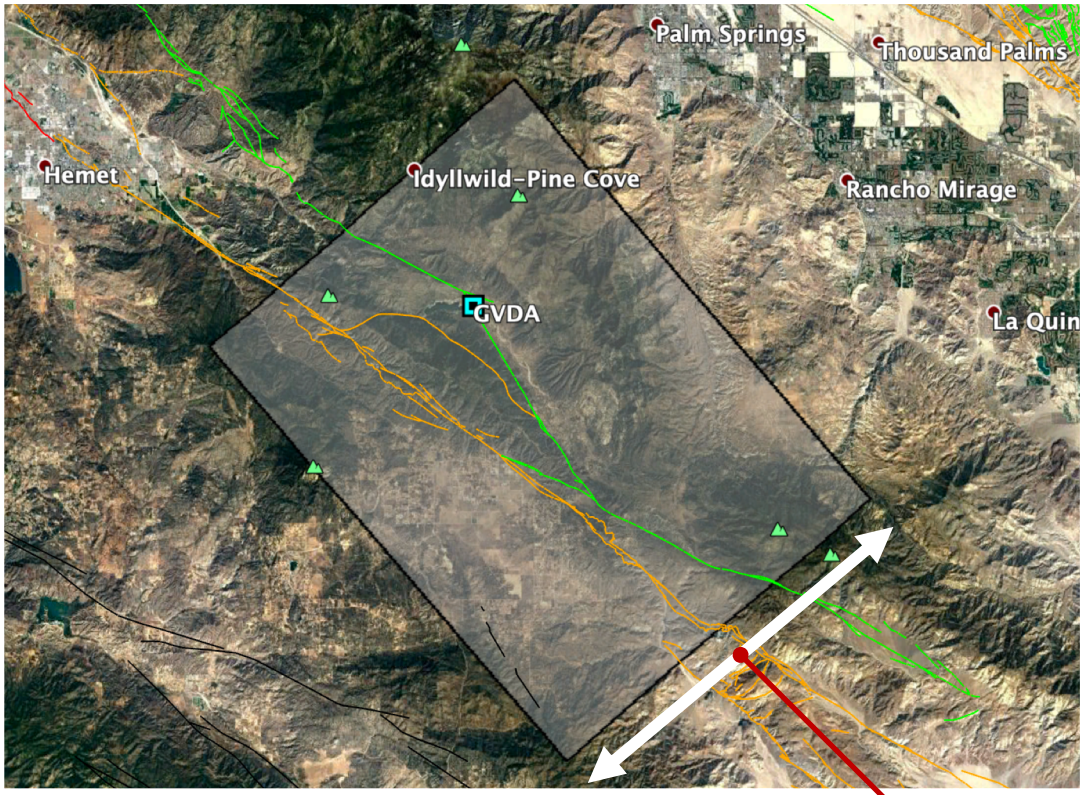
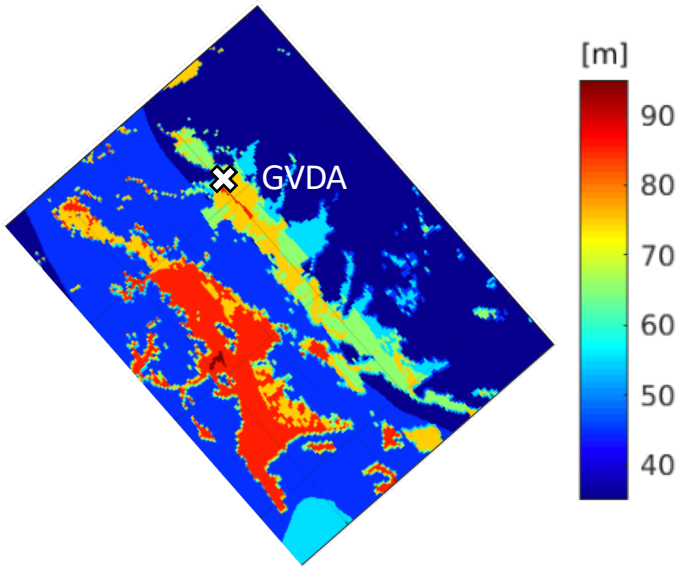
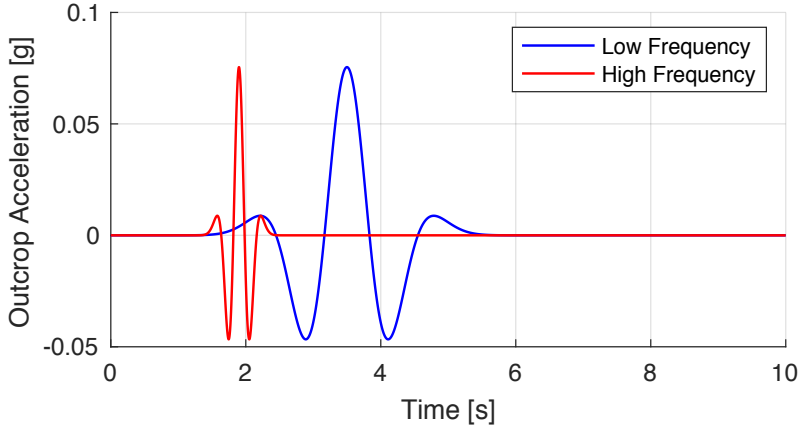
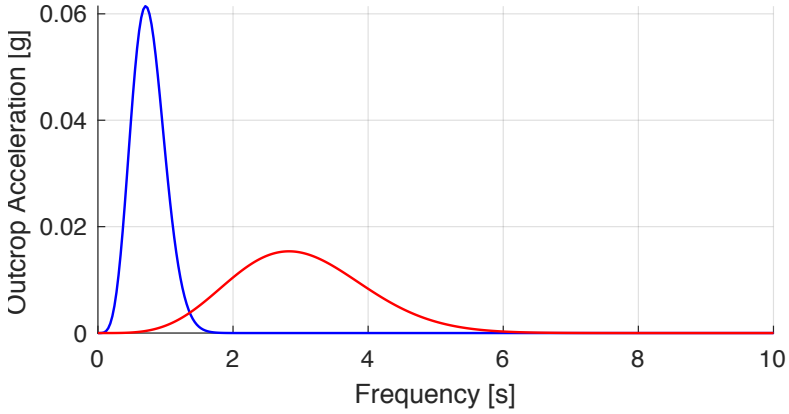
Garner Valley: Plane wave simulations



Depth to Vs = 800 m/s
[SCEC CVMS4.26 + Ely GTL]







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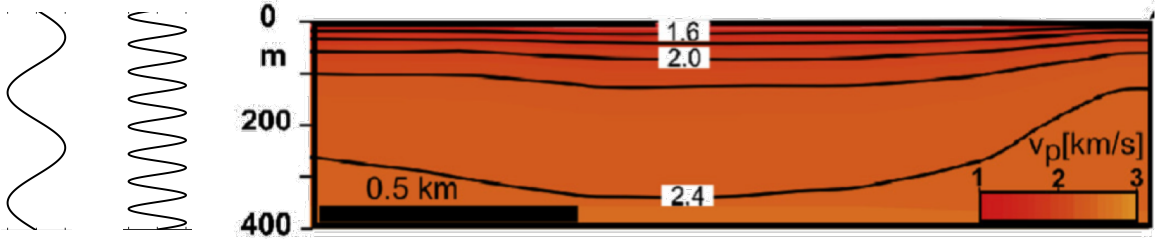
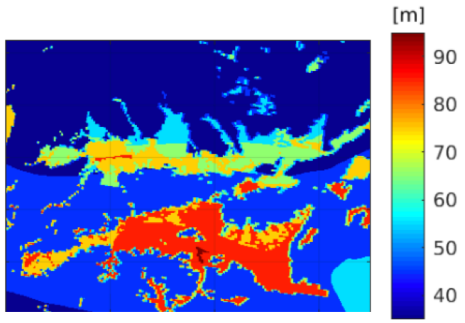
PGA Ratio Maps: PGA / Outcrop PGA

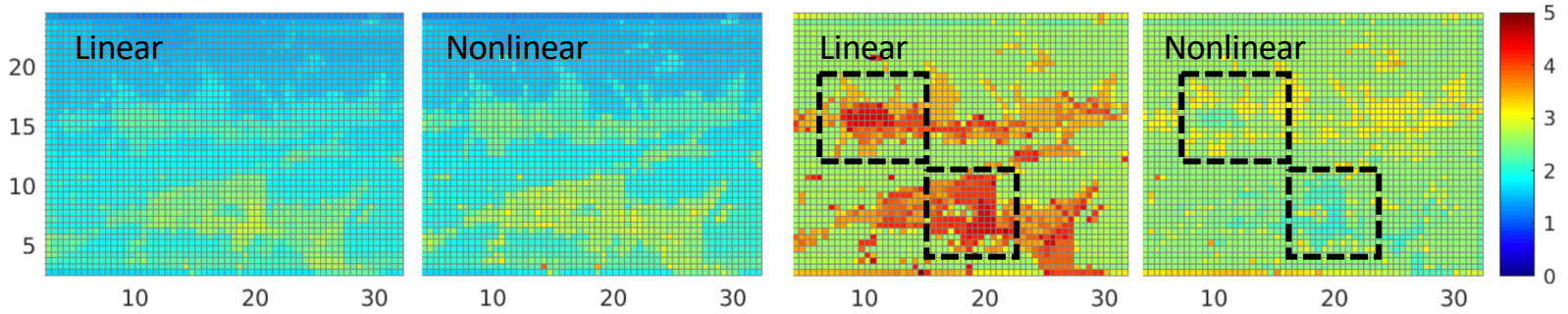




Low Frequency

High Frequency

3D



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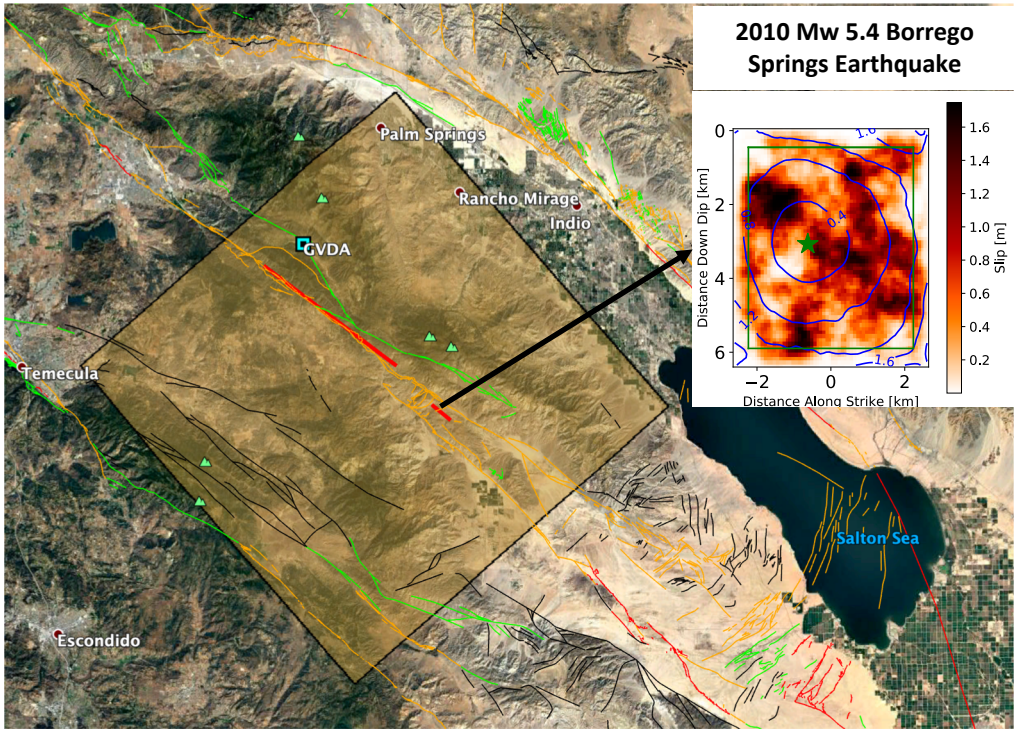
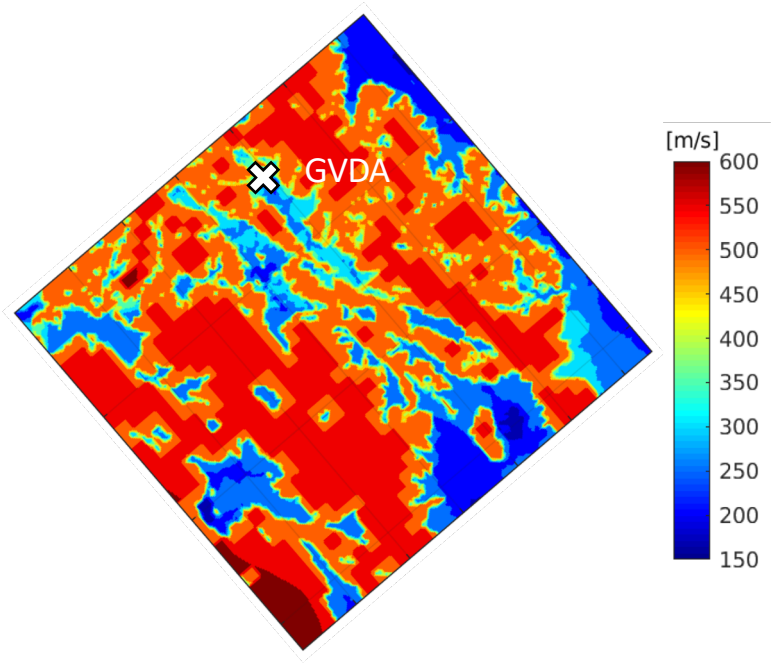
Garner Valley: Earthquake simulations



Vs at surface [SCEC CVMS4.26 + Ely GTL]



Simulation	Processors	Time [hrs]	Total # of Elements	Nonlinear Elements [%]	Maximum Frequency [Hz]
Linear	17,408	2.30	521,079,703	0	3.0
Nonlinear	17,408	28.5	521,079,703	19	3.0

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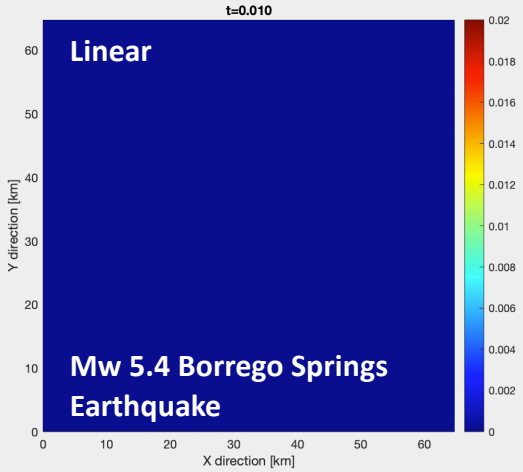
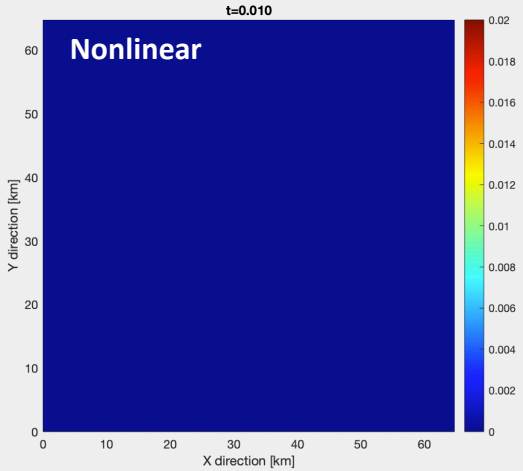
3D differential ground motions and shifts in predominant frequencies can change seismic risk to both distributed lifelines and buildings.

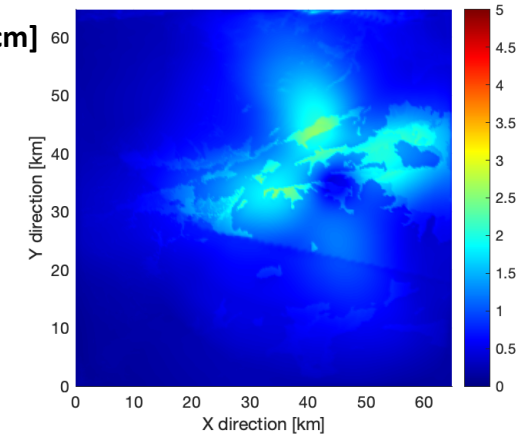


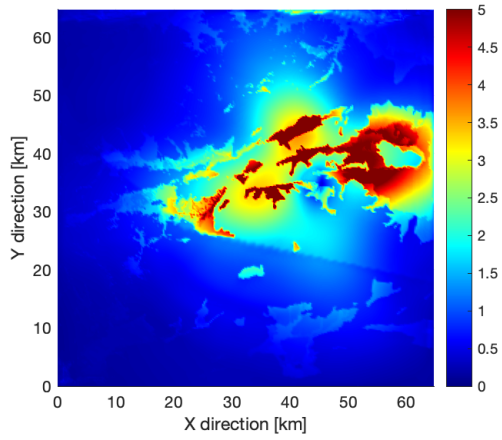


Linear Simulation

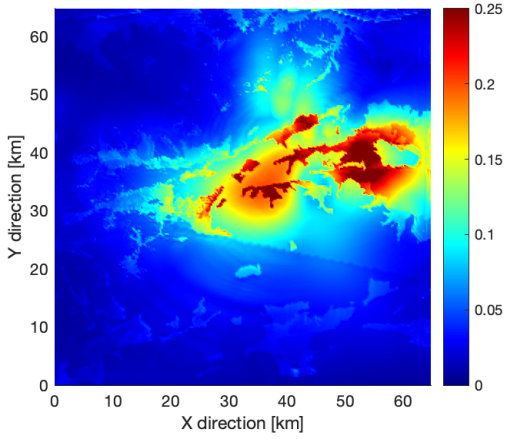
Nonlinear Simulation

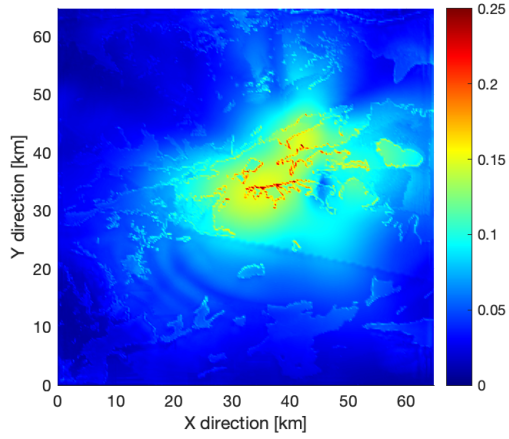
PGD [cm]





PGA [g]





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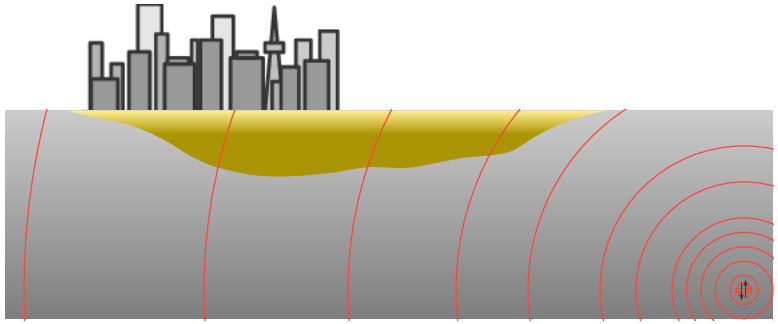
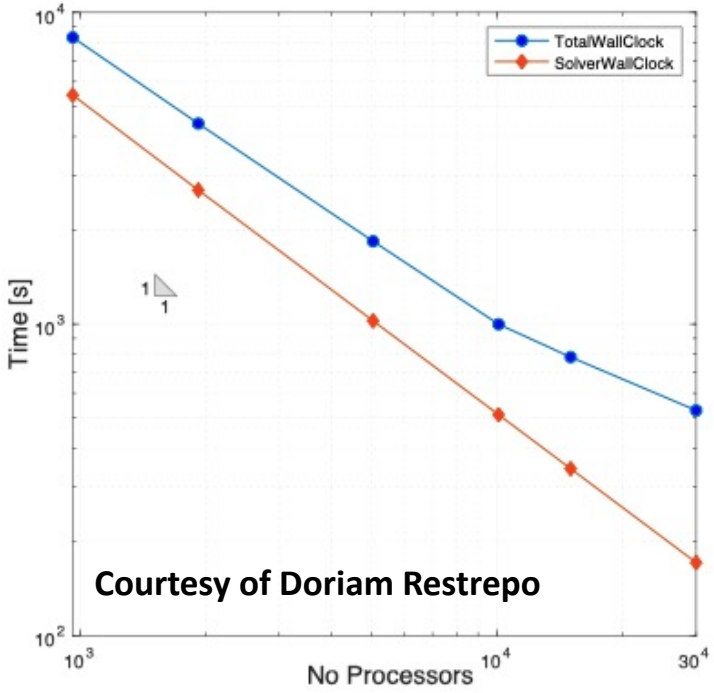
Existing gaps and next steps…



- Today, the accuracy of deterministic earthquake simulations is limited by our knowledge of the elastic and anelastic properties of earth materials.
- Enabling scalable nonlinear simulations.
- Enriching the library of computationally efficient but rigorous constitutive models.
- Enriching the existing velocity models to incorporate constitutive model and water table information.
- Enabling validation of 3D linear and nonlinear simulations at the large-scale.
- Revisiting the predictive capability of hybrid proxies.
- Enhancing modeling capabilities for using the outcome of nonlinear simulations in engineering applications, and in connection with large deformation problems.



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Acknowledgement

- Jorge Crempien > Kinematic Source Model Generation
- Philip Maechling and Mei-Hui Su > SCEC UCVM Support

Thank you for your attention!

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