Verification for the Real ESSI Simulator

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Outline

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Goal

Improve seismic modeling and simulation for infrastructure objects

Use of high fidelity numerical models to analyze seismic behavior of soil structure nuclear facilities

Reduction of modeling uncertainty, ability to perform high(er) level sophistication modeling and simulation

Accurately follow the flow of seismic energy in a soil structure system

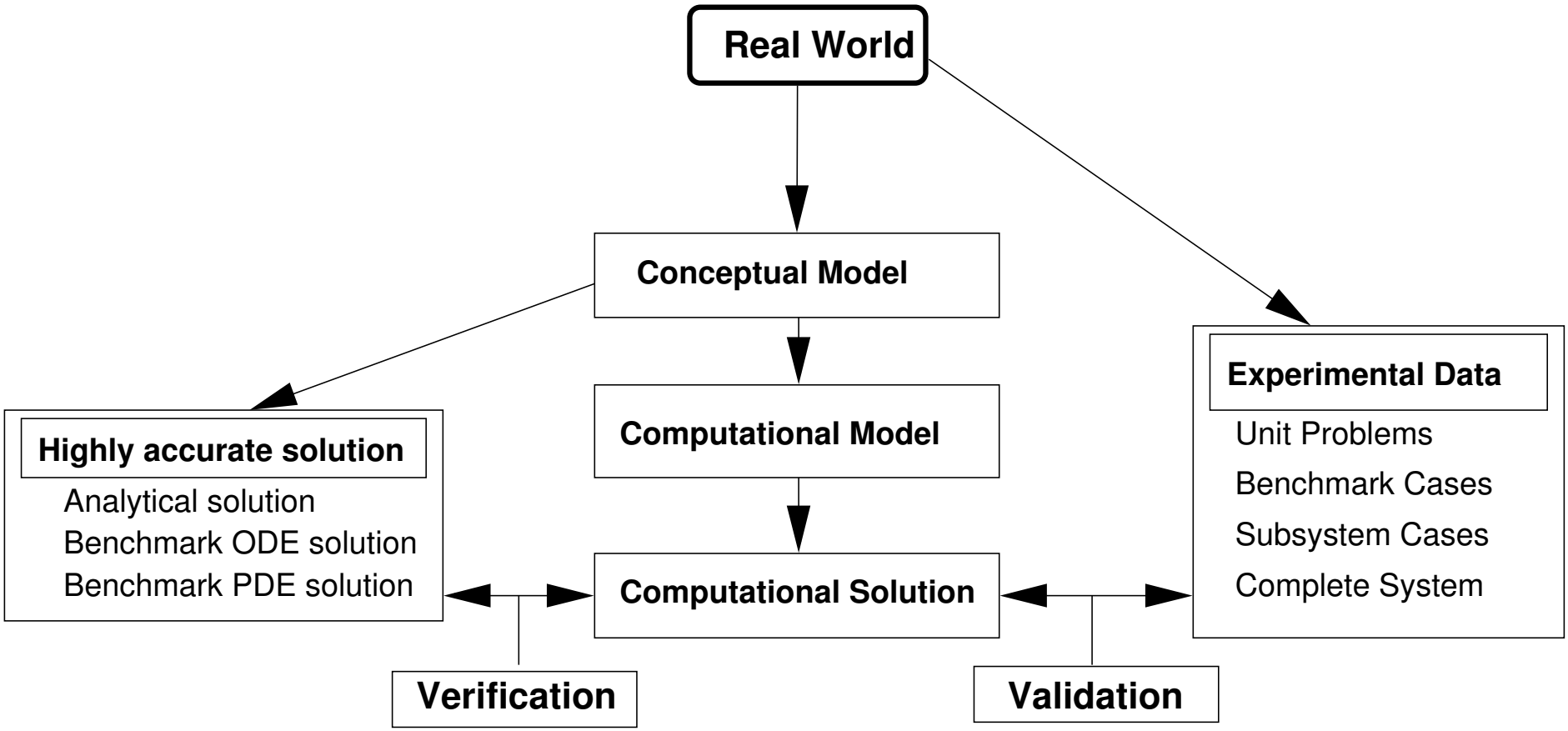
V & V Motivation

- How much can (should) we trust model implementations (verification)?
- How much can (should) we trust numerical simulations (validation)?
- How good are our numerical predictions?
- Can simulation tools be used for improving safety and economy?
- V & V procedures are the primary means of assessing accuracy in modeling and computational simulations
- V & V procedures are the tools with which we build confidence and credibility in modeling and computational simulations

Predictive Capabilities

- Verification: provides evidence that the model is solved correctly. Mathematics issue. Well developed for the Real ESSI Simulator.
- Validation: provides evidence that the correct model is solved. Physics issue. Work in progress, US-DOE project.
- Prediction: use of computational model to foretell the state of a physical system under consideration under conditions for which the computational model has not been validated.

Fundamentals of Verification and Validation



Important Sources

- W. L. Oberkampf, T. G. Trucano, and C. Hirsch. Verification, validation and predictive capability in computational engineering and physics. In *Proceedings of the Foundations for Verification and Validation on the 21st Century Workshop*, pages 1–74, Laurel, Maryland, October 22-23 2002. Johns Hopkins University / Applied Physics Laboratory.
- P. J. Roache. *Verification and Validation in Computational Science and Engineering*. Hermosa publishers, 1998. ISBN 0-913478-08-3.
- Material from *Verification and Validation in Computational Mechanics* web site `http://www.usacm.org/vnvcsm/` at the USACM.

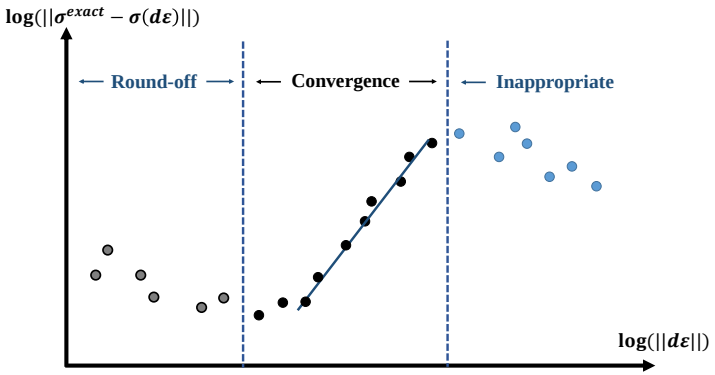
Outline

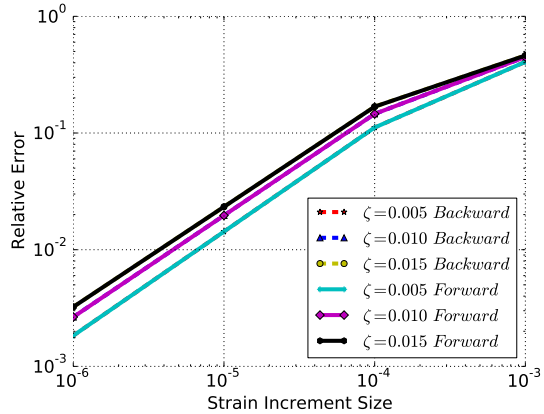
Verification

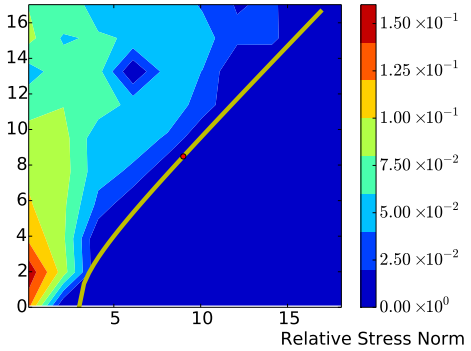
- Source code management
- Source code verification
- Constitutive problems
- Static and dynamic behavior of single phase solids
- Static and dynamic behavior of fully and partially saturated, fully coupled, porous solid - pore fluid problems
- Static and dynamic behavior of structural elements
- Static and dynamic behavior of special elements (contacts/gap-frictional/dry-saturated, isolators/dissipators)
- Static and dynamic FEM soln. advancement algorithms
- Seismic wave propagation problems
- Model verification, hierarchy of models

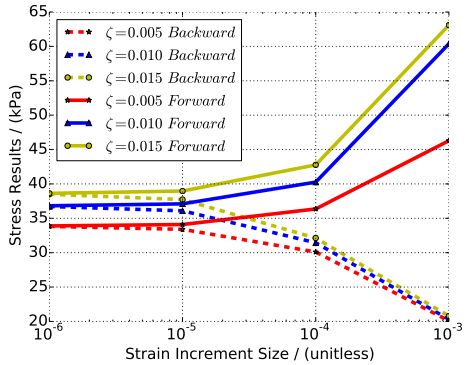
Constitutive Integration Verification

- Asymptotic regime of convergence
- Richardson extrapolation
- Grid convergence index

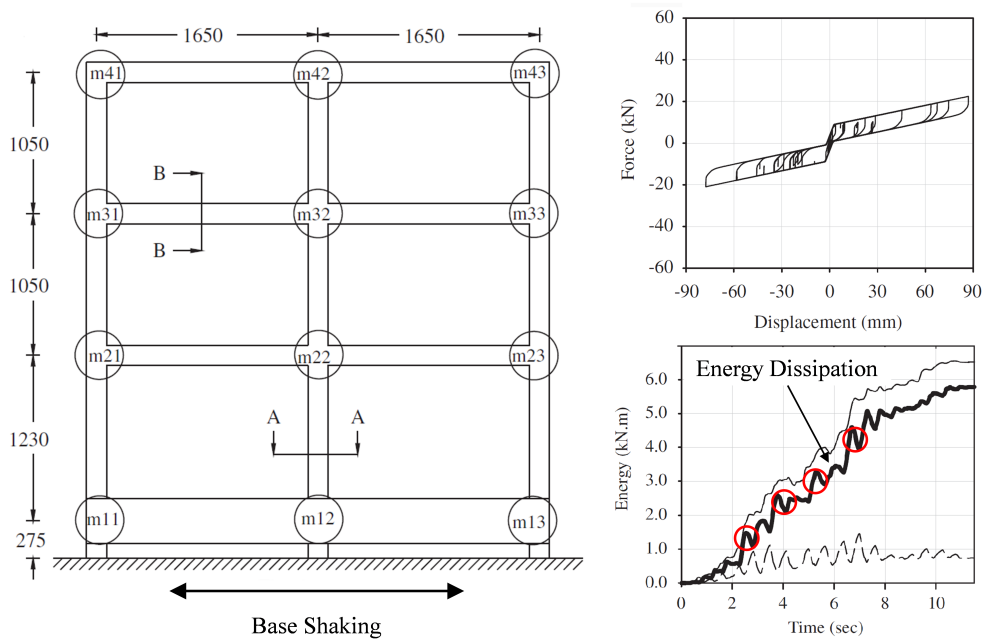








Energy Dissipation Verification: Plastic Work $\neq$ Plastic Dissipation



From a paper on *Soil Dynamics and Earthquake Engineering* (2011)

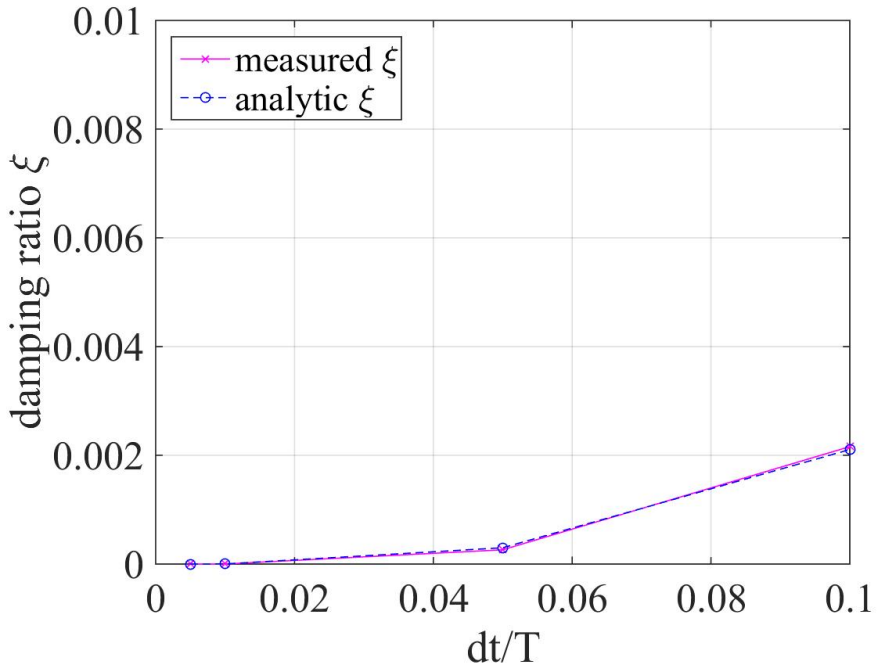
Direct violation of the second law of thermodynamics

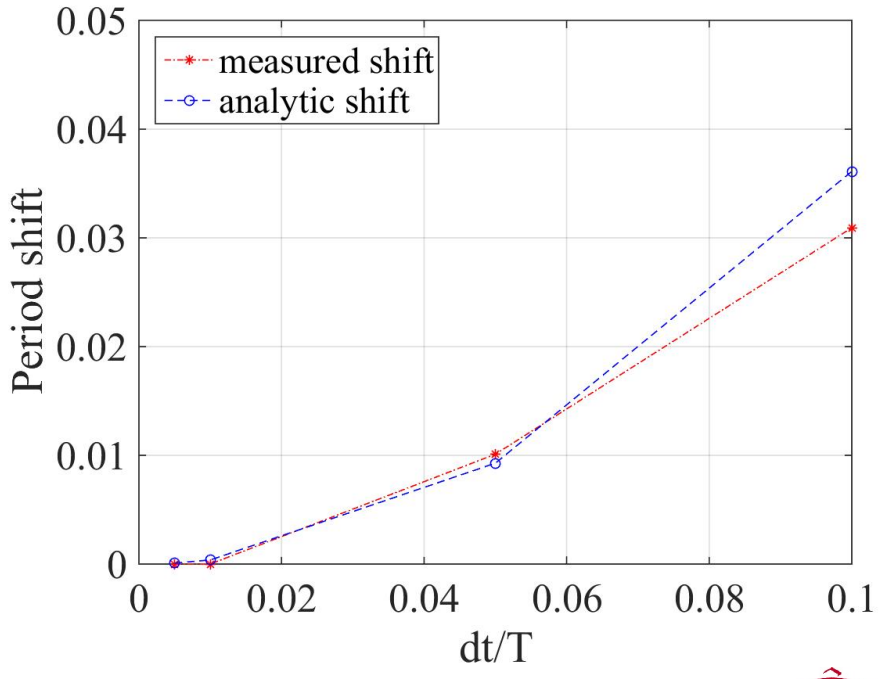
600 papers since 1990 (!?!) repeat this error

Dynamic Time Stepping Verification

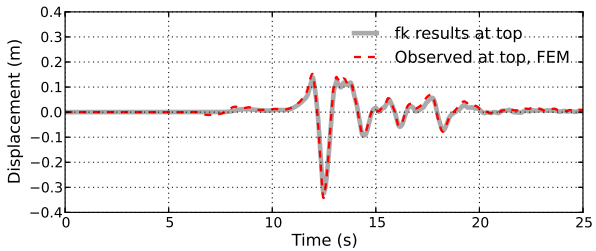
Based on the amplification matrix **A**, to calculate the analytical solution of damping ratios and period shift.

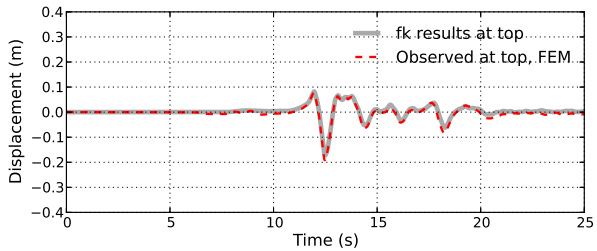
Example: Hilber-Hughes-Taylor $\alpha = -0.1$

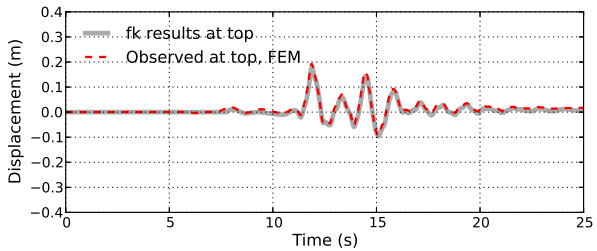


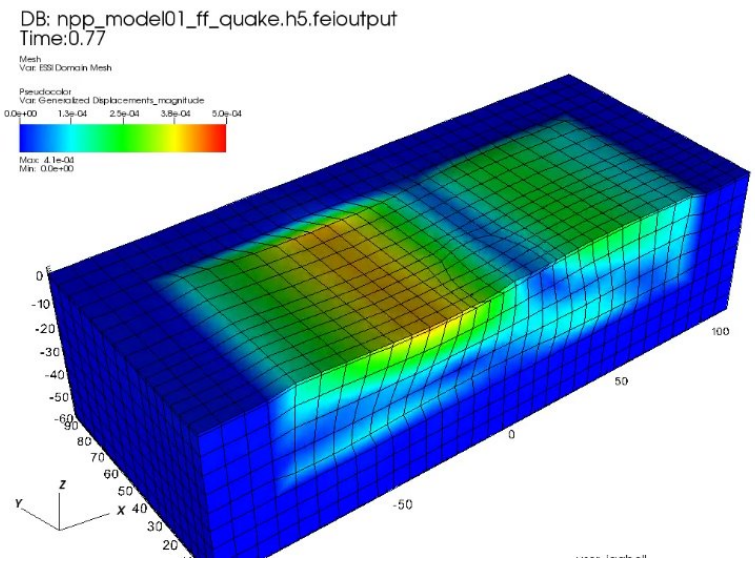


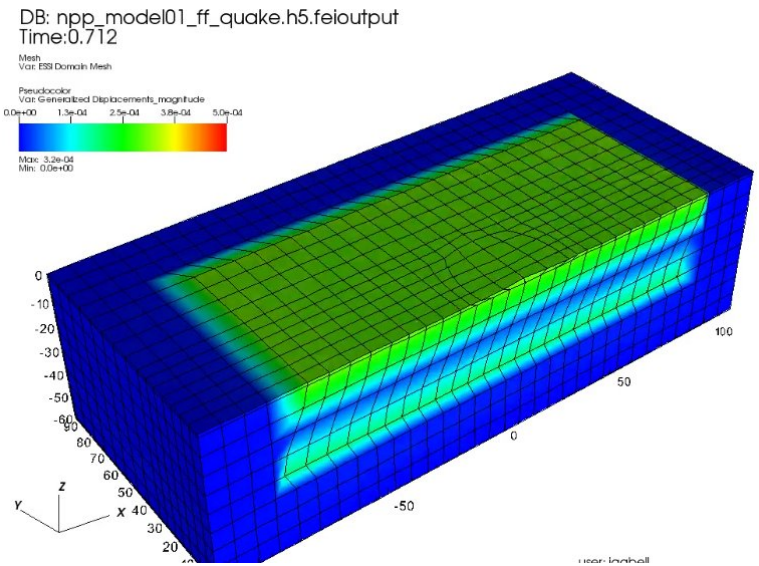
Seismic Input Verification, DRM



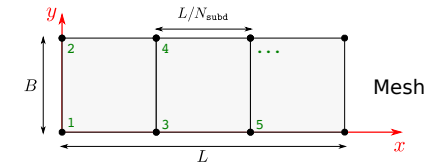


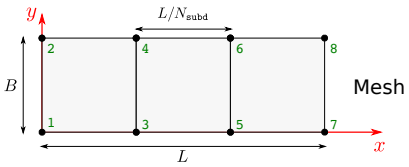


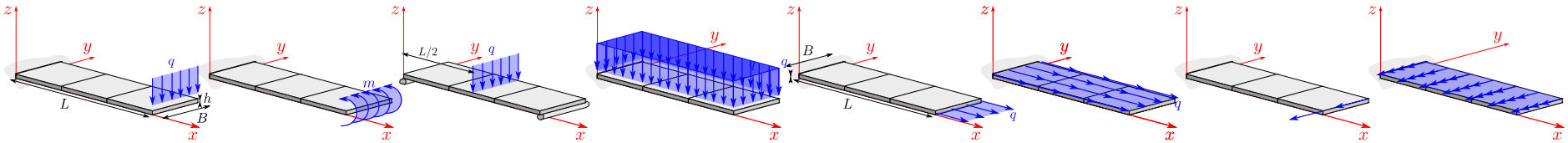




Verification: ANDES Shell

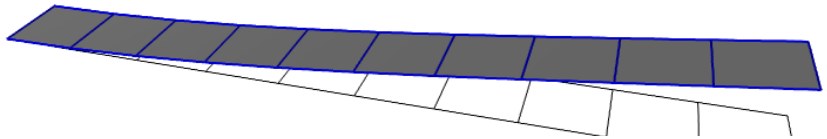




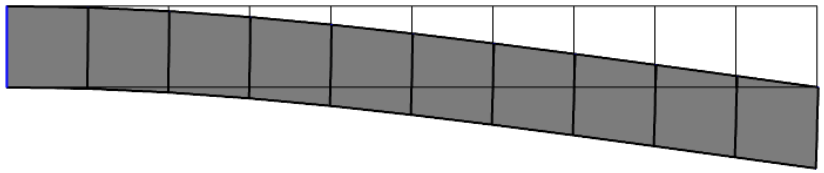


$N_{\mathtt{subd}}$	u_z
2	96.2118
7	100.096
101	100.002

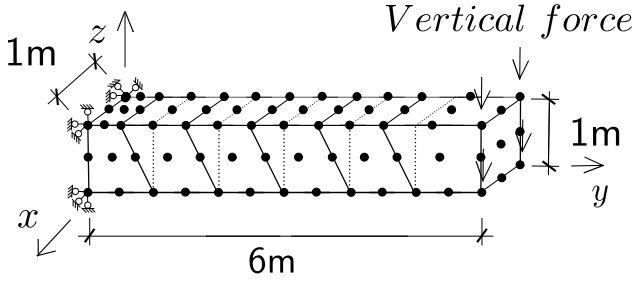
Mode 1, T = 0.999959s

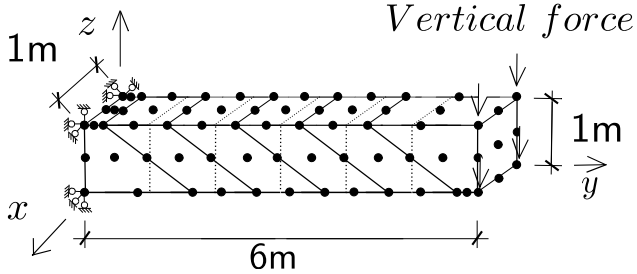


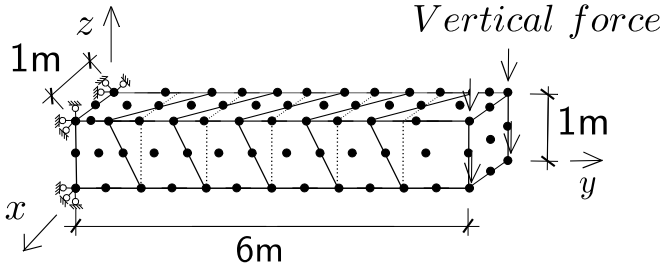
Mode 1, T = 0.998022s



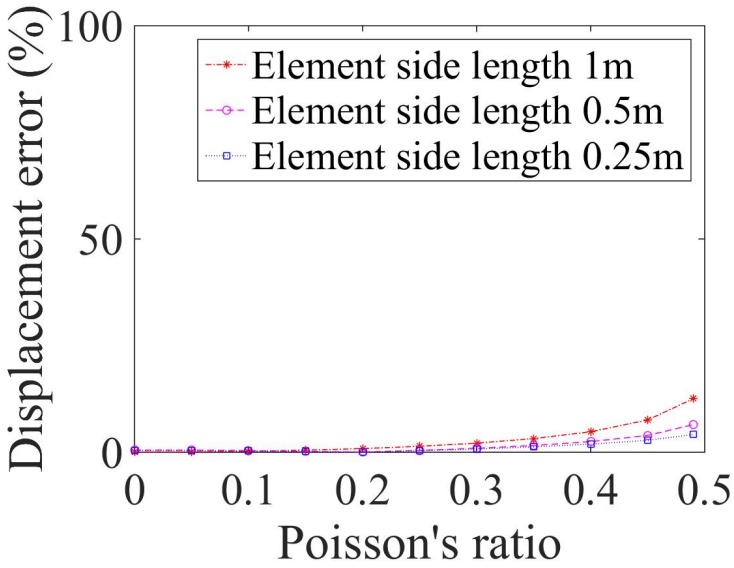
Verification: Irregular Solids and Poisson's Ratio





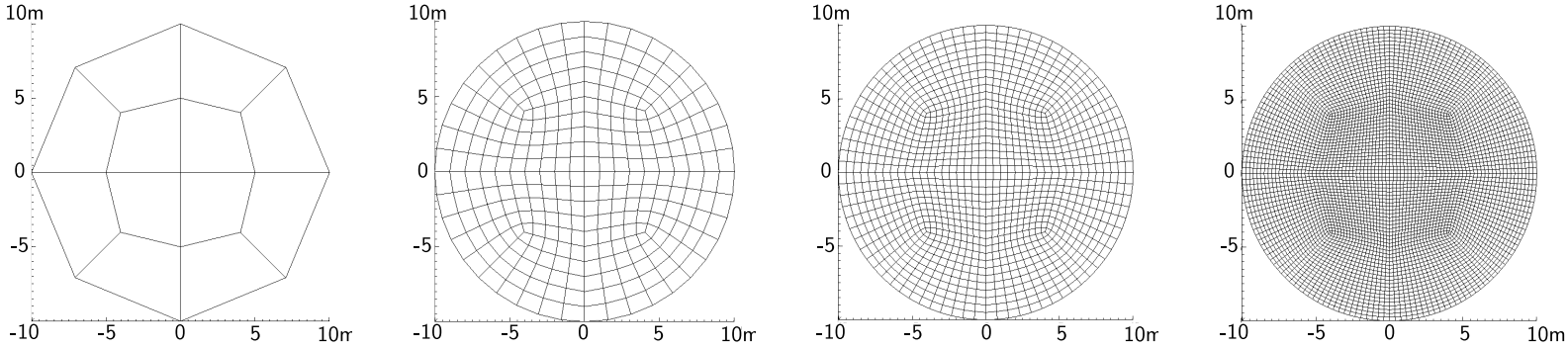


Force direction	Shape 1	Shape 2	Shape 3
Vertical (z)	0.40%	0.85%	0.60%
Transverse (y)	0.54%	3.67%	0.46%

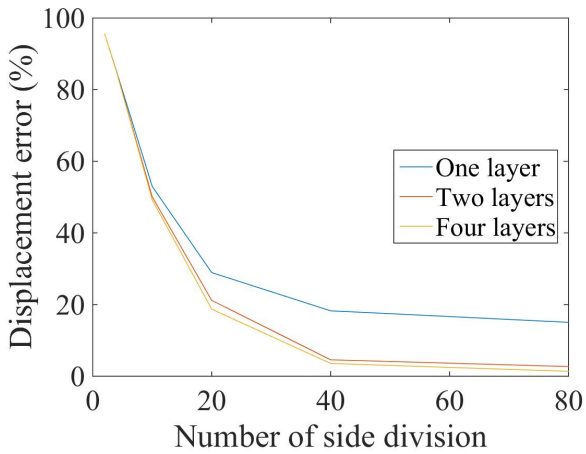


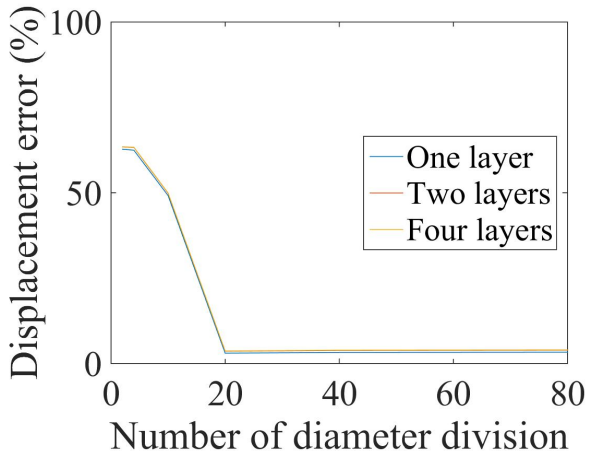
Poisson's ratio	27NodeBrick displacement	Theory displacement	Error
0.00	8.797E-04 m	8.784E-04 m	0.15%
0.05	8.801E-04 m	8.791E-04 m	0.11%
0.10	8.799E-04 m	8.799E-04 m	0.01%
0.15	8.792E-04 m	8.806E-04 m	0.16%
0.20	8.778E-04 m	8.813E-04 m	0.40%
0.25	8.758E-04 m	8.821E-04 m	0.71%
0.30	8.730E-04 m	8.828E-04 m	1.12%
0.35	8.692E-04 m	8.836E-04 m	1.63%
0.40	8.641E-04 m	8.844E-04 m	2.29%
0.45	8.567E-04 m	8.851E-04 m	3.21%
0.49	8.452E-04 m	8.857E-04 m	4.58%

Verification of Solid Shell/Plate

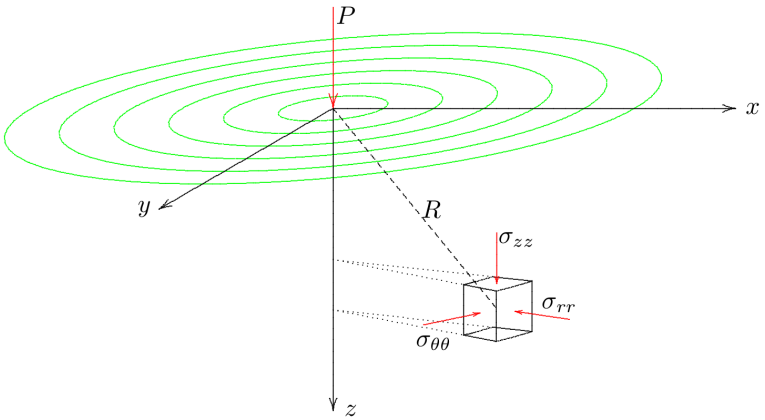


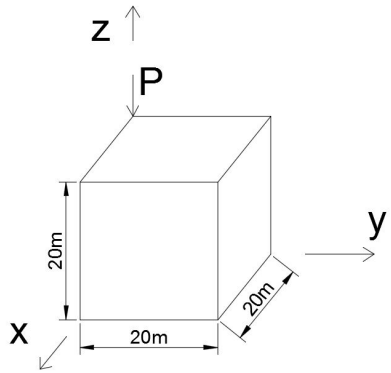
- Simply supported and clamped ends
- Timoshenko's analytic solutions

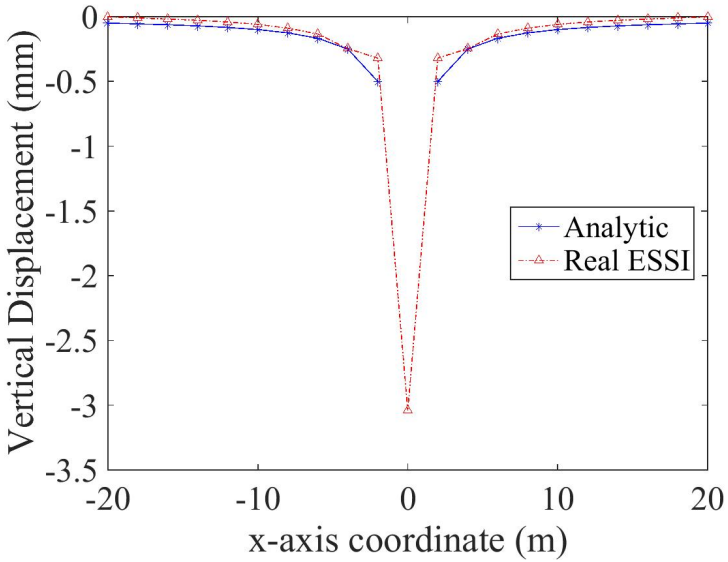


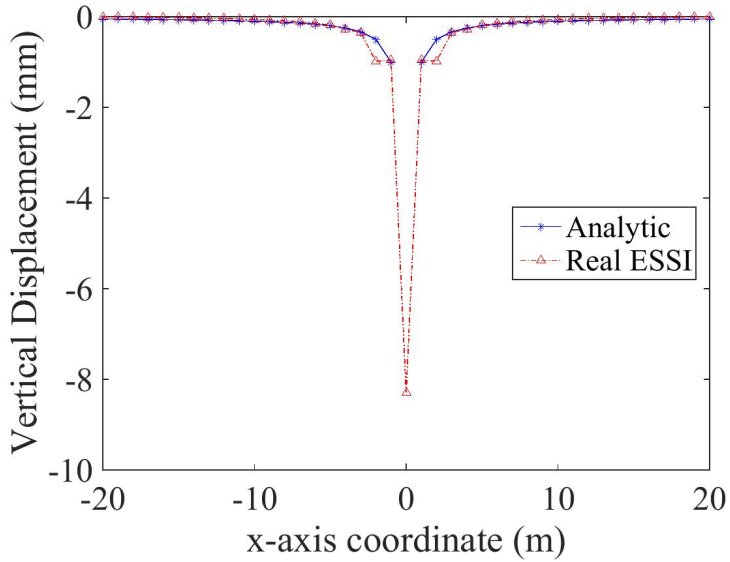


Verification of Boussinesq Problem

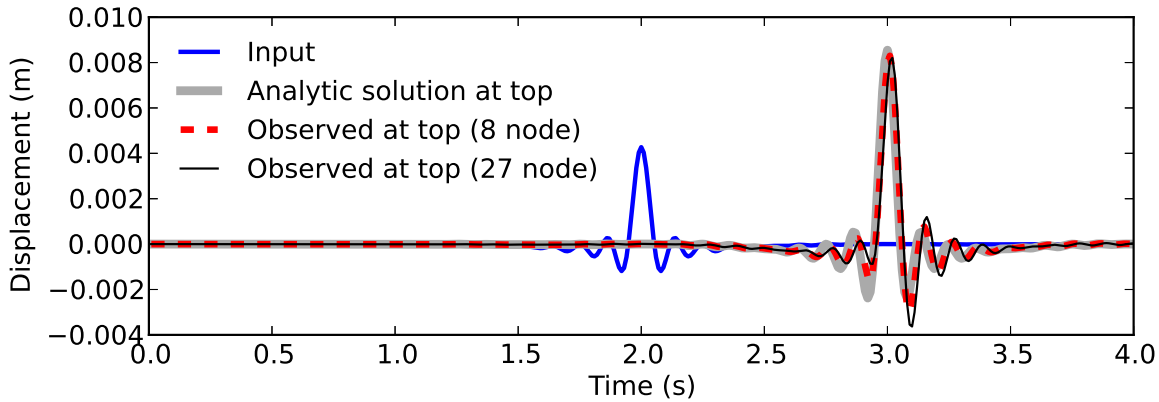


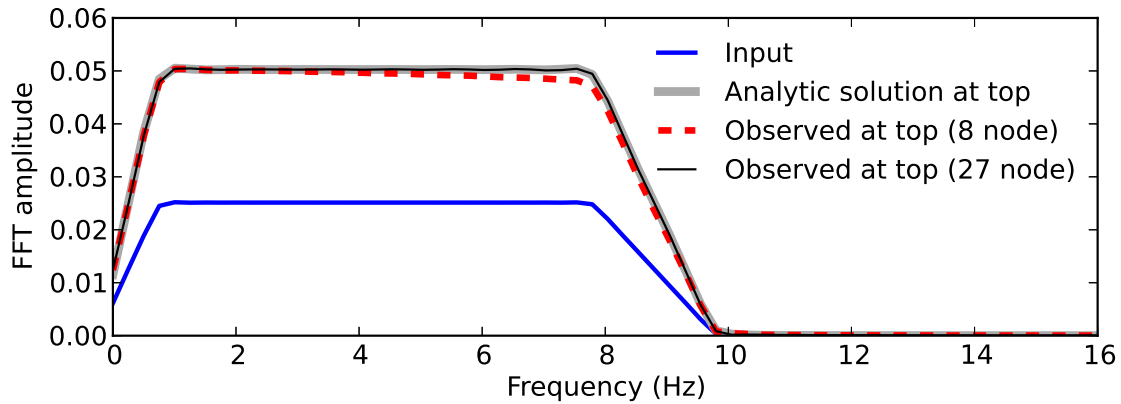






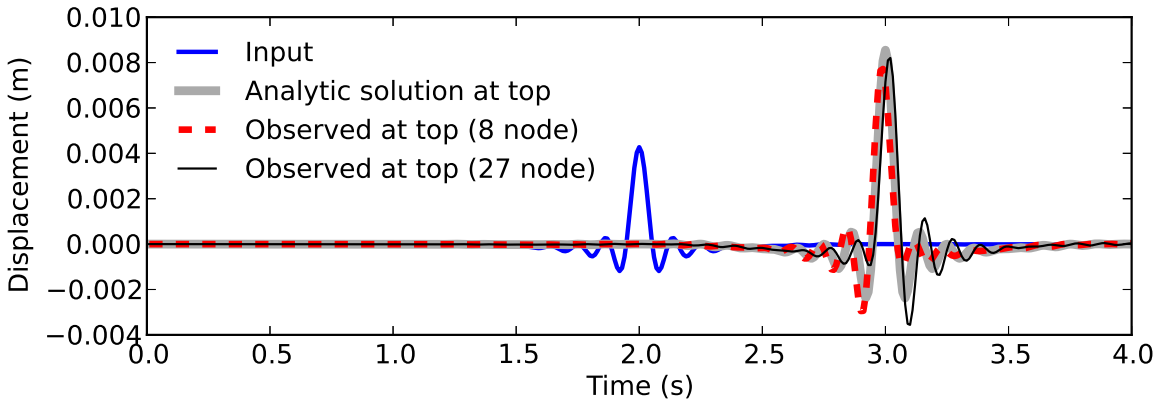
Wave Propagation, Mesh Size Effects

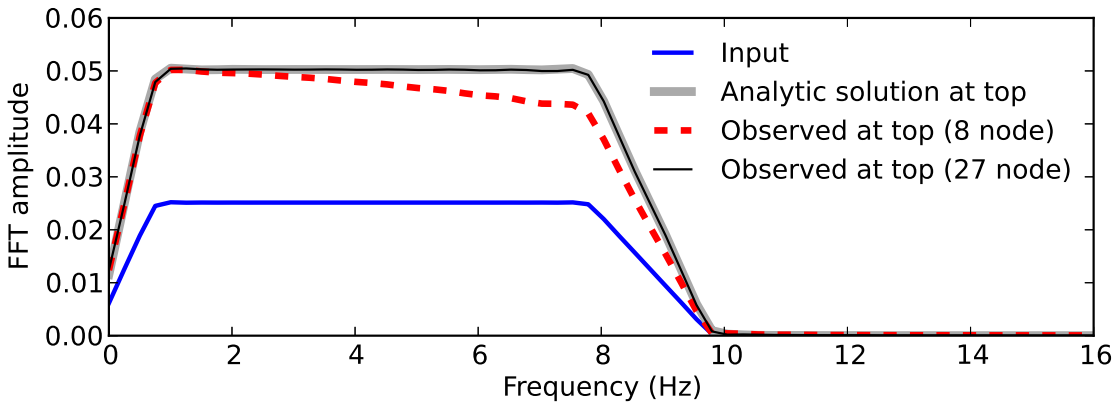




(Case 1, Vs = 1000 m/s, Cutoff Fq. = 8 Hz, E. Size = 10 m)

Wave Propagation, Mesh Size Effects





(Case 1, Vs = 1000 m/s, Cutoff Fq. = 8 Hz, E. Size = 20 m)

Outline

Summary

- V&V most important for providing confidence in results
- Numerical modeling program(s) should not be used without extensive/full V&V
- V&V of models is also essential
- Real ESSI Simulator has an extensive Verification database, and a significant Validation database that is being enhanced through our DOE project experiments
- Funding/support from and collaboration with the US-DOE, US-NRC, CNSC-CCSN, US-NSF, UN-IAEA, and Shimizu Corp. is greatly appreciated,
- More on Verification and Validation at the: Nonlinear/Inelastic Earthquake Soil Structure Interaction (ESSI) short course, this fall in San Francisco, more info at http://real-essi.info