Practical Methods for
Verifying Computational Models

Boris Jeremić and Farzad Abedzadeh Anaraki

University of California, Davis, CA
Stantec, Boulder, CO

USSD Annual Conference Seattle, WA
April 2024

# Outline

Introduction

Verification and Validation

Summary

Verification

- Source code management
- Source code verification
- Constitutive integration
- 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-interface/gap-frictional/dry-saturated, isolators/dissipators)
- Static and dynamic FEM solution advancement
- Seismic wave propagation problems
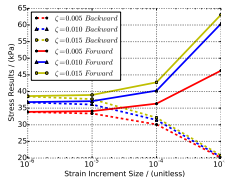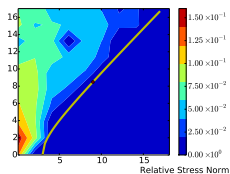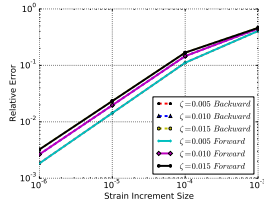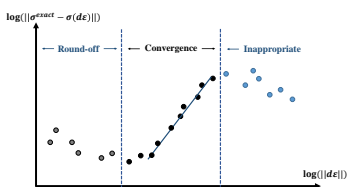- FEM Model verification, hierarchy of models

Numerical Analysis Components

- Model physical components, <u>ALL</u>

- Solids and fluids

- Materials

- Static loads
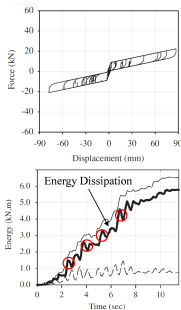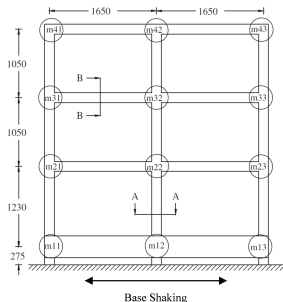
- Dynamic loads

- Response quantities
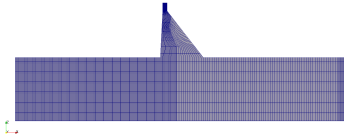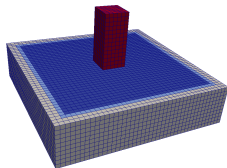
Constitutive Integration Verification

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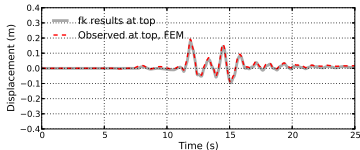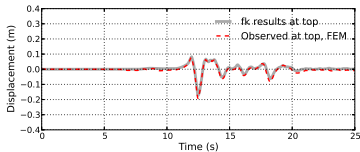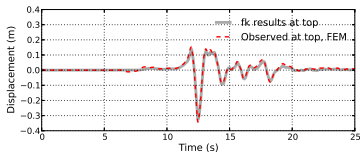
600 papers since 1990 (!?!) repeat this error

Dynamic Time Stepping Verification

Based on the amplification matrix **A**, to calculate the analytical solution of damping ratios and period shift.
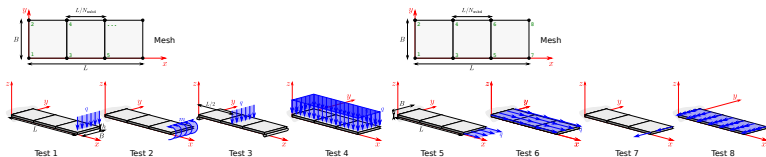Example: Hilber-Hughes-Taylor $\alpha = -0.1$
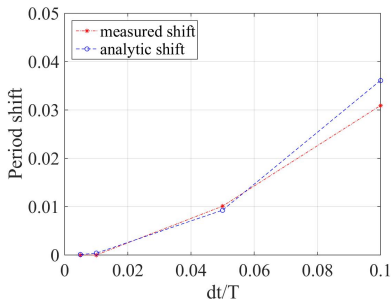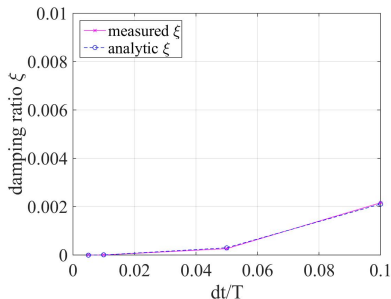
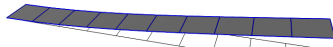# Seismic Input Verification, DRM
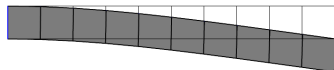
Verification: ANDES Shell

Test 1 Test 2 Test 3 Test 4 Test 5 Test 6 Test 7 Test 8

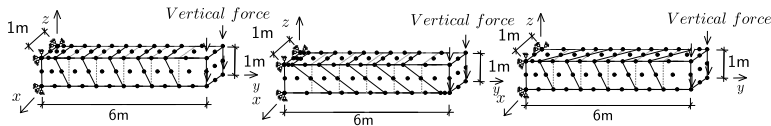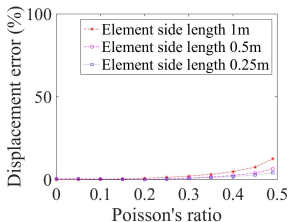| N_{subd}	u_z
2	96.2118
7	100.096
101	100.002

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
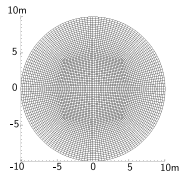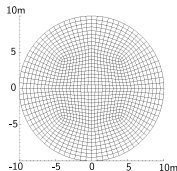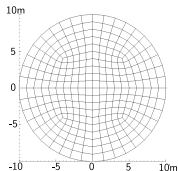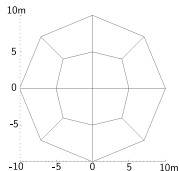
- Simply supported and clamped ends
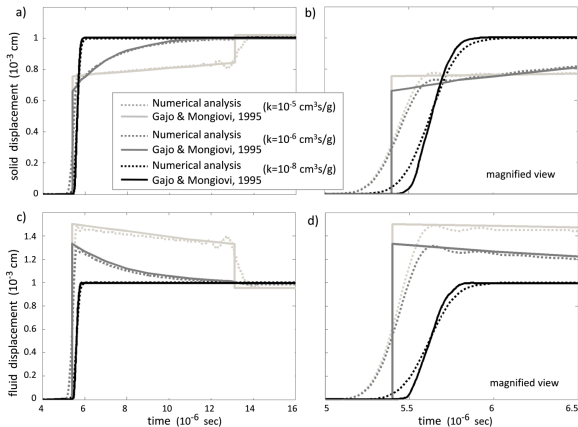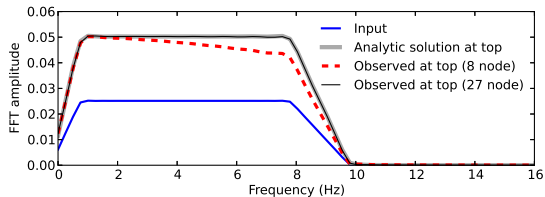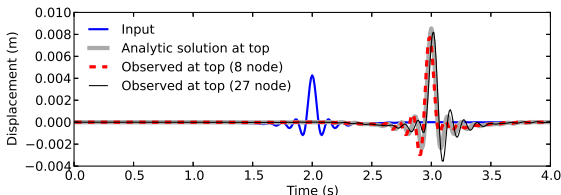- Timoshenko's analytic solutions
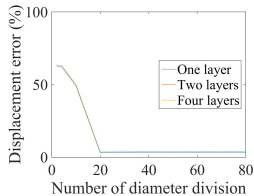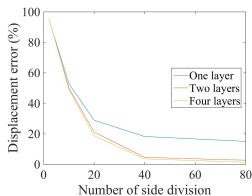
Verification of Boussinesq Problem
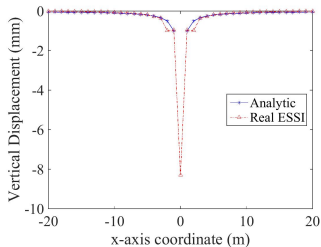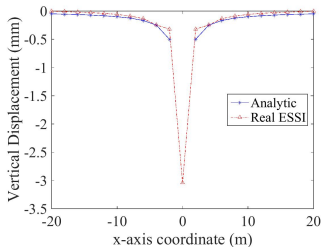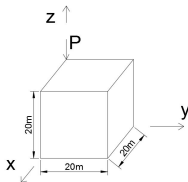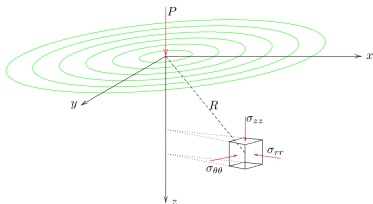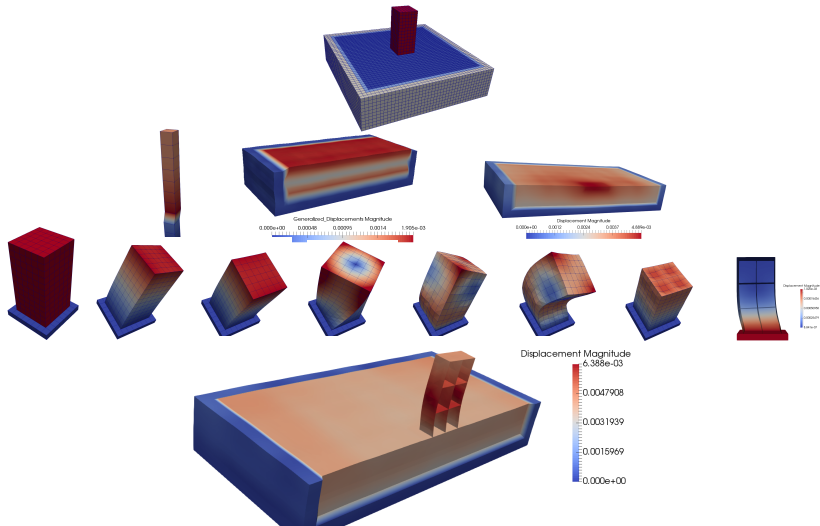
Verification for Fully Coupled Problems

Wave Propagation, Mesh Size Effects

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

ESSI Modeling Phases

Summary

- Numerical analysis to predict and inform

- V&V most important for providing confidence in results

- Analysis of quality of numerical results

- Numerical analysis should not be used without V&V

- Engineer needs to know!

- Analysis governance

- Education and Training is the key!