



The NRC ESSI Simulator

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Outline

Introduction

NRC ESSI Simulator System

- NRC ESSI Simulator Program

- NRC ESSI Simulator Computer

- NRC ESSI Simulator Notes

Verification and Validation

- V&V Intro

- Model/Mesh Verification

Summary



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Introduction

- ▶ U.S.-NRC need: high fidelity (Hi-Fi) modeling and simulation of seismic response of NPPs
 - ▶ 3 dimensional, inclined, body and surface, uncorrelated, realistic seismic waves
 - ▶ Material nonlinear behavior of the rock, soil, interfaces/contacts, isolators, concrete, steel
 - ▶ High performance computing (parallel)
 - ▶ Verification and Validation for high confidence in predictions
 - ▶ Documentation, user friendly,
 - ▶ Education (U.S.-NRC staff capacity building)

- ▶ Project: Development of the NRC ESSI Simulator System



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Project Goals

- ▶ Development of the NRC ESSI Simulator System for Hi-Fi modeling and simulation of earthquake soil/rock structure interaction problems:
 - ▶ **NRC-ESSI-Program**
 - ▶ **NRC-ESSI-Computer**
 - ▶ **NRC-ESSI-Notes**
- ▶ Education: NRC Staff Capacity Building (seminars, short courses, NRC ESSI Notes, advising)
- ▶ Development of ESSI case studies: 3D, inclined seismic motions, soil/rock; foundation interface slip, seismic energy propagation dissipation



NRC ESSI Simulator System

- ▶ **The NRC-ESSI-Program** is a 3D nonlinear parallel finite element program specifically developed for Hi-Fi modeling and simulation of Earthquake Soil/Rock Structure Interaction problems for NPPs on NRC-ESSI-Computer.
- ▶ **The NRC-ESSI-Computer** is a distributed memory parallel computer, a cluster of clusters with multiple performance processors and multiple performance networks.
- ▶ **The NRC-ESSI-Notes** represent a hypertext documentation system detailing modeling and simulation of NPP ESSI problems.



NRC ESSI Simulator Program

- ▶ Based on a Collection of Useful Libraries (modular, portable)
- ▶ Library centric software design
- ▶ Various public domain licenses (GPL, LGPL, BSD)
- ▶ Verification and Validation
- ▶ Program documentation (part of NRC ESSI Notes)
- ▶ Target users: U.S.-NRC staff, UCD, UB students, external users
- ▶ Sources will be available through
`http://nrc-essi-simulator.info`



Collection of Useful Libraries (Modeling Part)

- ▶ Template3D-EP libraries for elastic and elastic-plastic computations (UCD, LGPL)
- ▶ FEMTools finite element libraries provide finite elements (solids, beams, shells, contacts/isolators, seismic input) (UCD, UCB, CU, LGPL)
- ▶ Domain Specific Language for input (C-binding) (UCD, LGPL)



Collection of Useful Libraries (Simulation Part)

- ▶ Plastic Domain Decomposition (PDD) for parallel computing (UCD, LGPL)
- ▶ PETSc (ANL, GPL-like) and UMFPACK (UF, GPL) solvers
- ▶ Modified OpenSees Services (MOSS) for managing the finite element domain (UCD, LGPL; UCB, GPL?)
- ▶ nDarray (UCD, LGPL), LTensor (CIMEC, GPL), BLAS (UTK, GPL) for lower level computational tasks,
- ▶ Message Passing Interface (MPI, openMPI, new BSD license)



NRC ESSI Simulator Computer

- ▶ Cluster of multiple performance processors interconnected with multiple performance networks
- ▶ Multiple generation processors and networks, modular, expandable, the most cost effective solution
- ▶ Secure access for the U.S.-NRC, located at UCD
- ▶ 15 current users (U.S.-NRC and UCD)
- ▶ Source compatibility with large supercomputers
- ▶ Design/components documentation will be posted at <http://nrc-essi-simulator.info>



NRC ESSI Simulator Notes

- ▶ A hypertext documentation system for modeling and simulations of NPP ESSI problems (Theory and Formulation, Software and Hardware, Verification and Validation, and Case Studies and Practical Examples)
- ▶ NRC-ESSI-Program code API (Application Programming Interface).
- ▶ NRC-ESSI-Program DSL (Domain Specific Language)
- ▶ Documentation for verification and validation examples
- ▶ Practical NPP ESSI examples and case studies
- ▶ Will be available to general public through **`http://nrc-essi-simulator.info`**



NRC ESSI Simulator Education

- ▶ U.S.-NRC staff capacity building, seminars, short courses, consultations, advising,
- ▶ NRC ESSI Program Verification and Validation
- ▶ NRC ESSI Model Development and Verification
- ▶ NRC ESSI Simulator short courses, seminars in preparation for outside users



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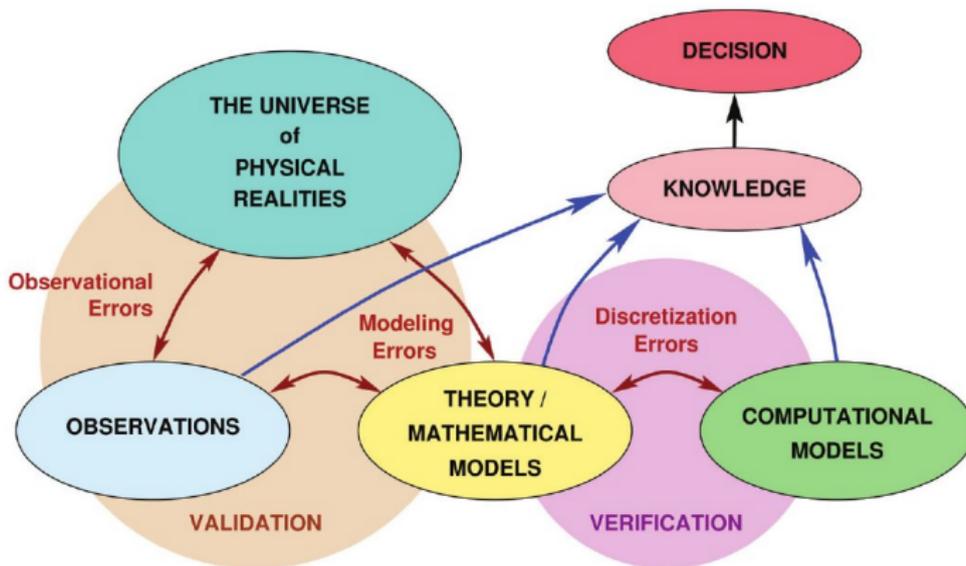


Verification, Validation, Prediction

- ▶ Verification: provides evidence that the model is solved correctly. Mathematics issue.
- ▶ Validation: provides evidence that the correct model is solved. Physics issue.
- ▶ V&V increases confidence in numerical prediction
- ▶ V&V increases confidence in decision making



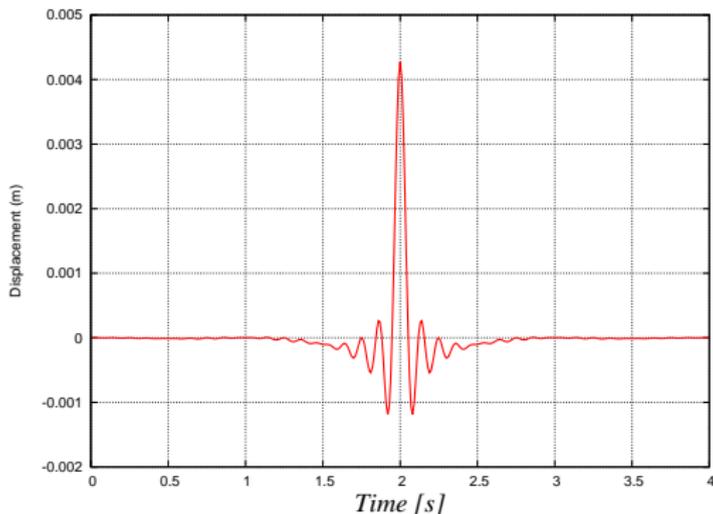
Role of Verification and Validation (Oden et al.)





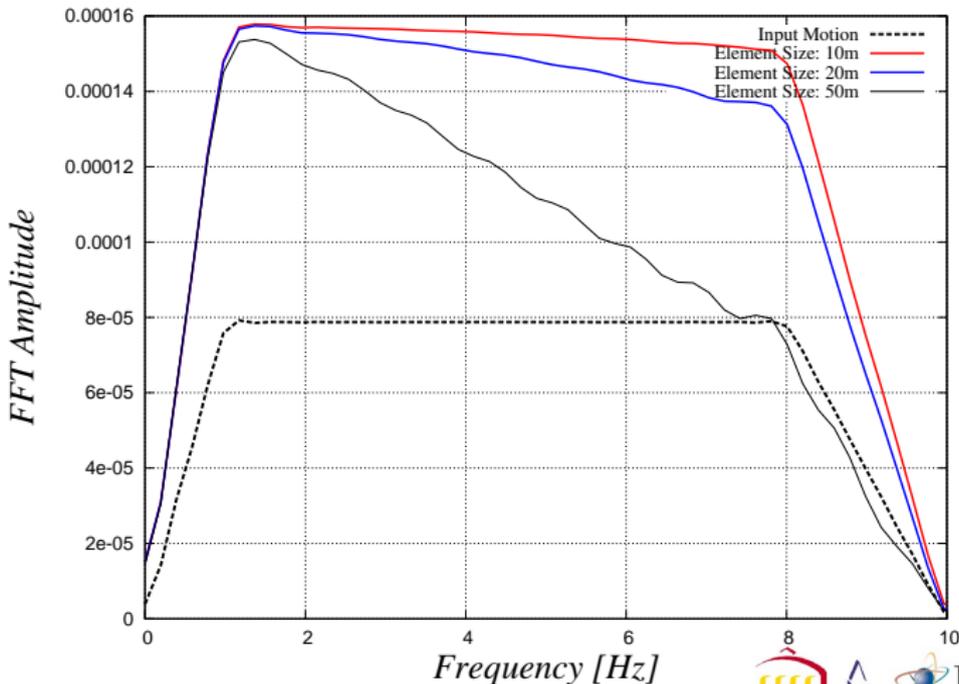
Mesh Size Effects on Wave Propagation Modeling

- ▶ Insufficient finite element size "filters out" high frequencies
- ▶ Rule of thumb: 10-12 elements per wave length
- ▶ Models, 1000m, $V_s = 1000\text{m/s}$ and $V_s = 100\text{m/s}$, element sizes $h = 10, 20, 50\text{m}$
- ▶ With and without physical and/or numerical damping,
- ▶ Ormsby wavelet



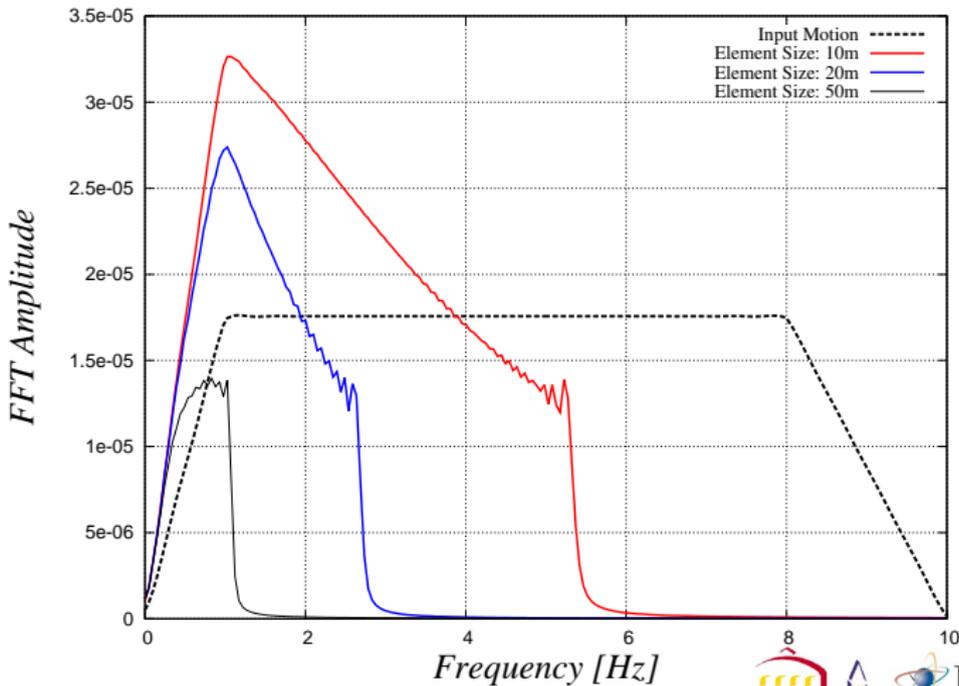


Base and Surface Dynamic Motions



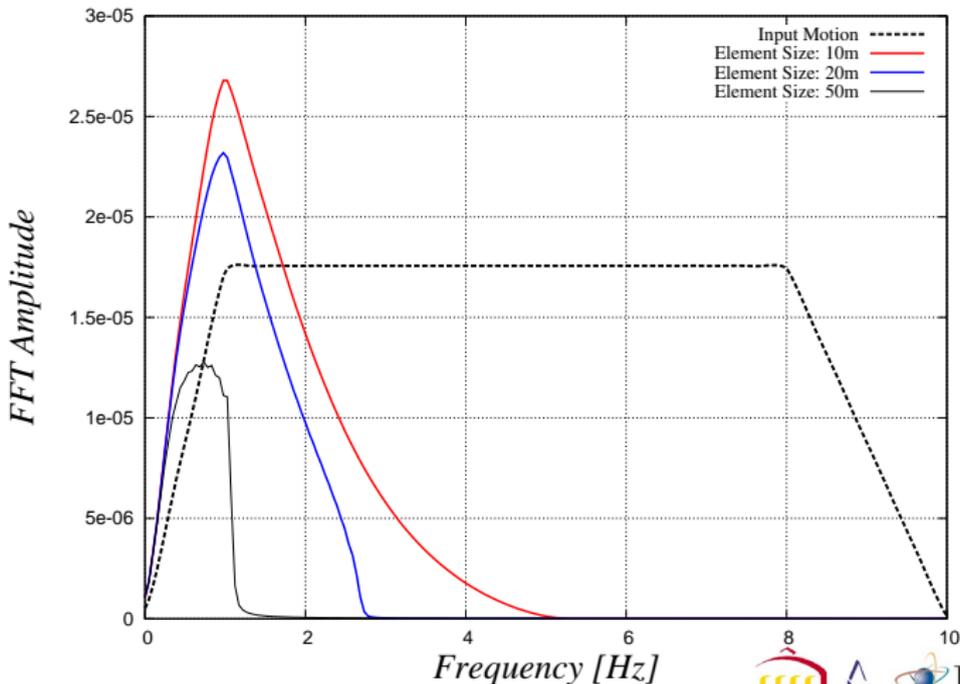


Dynamic Motions for 10× Softer Soil





Dynamic Motions 10, \times Softer, + Num. Damping





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- ▶ High fidelity, time domain, nonlinear, earthquake soil structure interaction (ESSI) modeling and simulations
- ▶ The NRC ESSI Simulator System (Program, Computer, Notes)
- ▶ Educational component (U.S.-NRC, UCD, others), seminars, short courses
- ▶ Information Portal:
`http://nrc-essi-simulator.info`
- ▶ Funding by and Collaboration with the U.S.-NRC is gratefully acknowledged