# The Real ESSI Simulator System

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Introduction

Real-ESSI Simulator System

Summary



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# Motivation

Improve modeling and simulation for infrastructure objects

Expert numerical modeling and simulation tool

Reduction of modeling uncertainty

Choice of analysis level of sophistication

Goal: Predict and Inform rather than fit

Engineer needs to know!

System for modeling and simulation of Earthquakes and/or Soils and/or Structures and their Interaction: Real-ESSI Simulator http://real-essi.info/



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# Prediction under Uncertainty

► Modeling Uncertainty, Simplifying assumptions

Low, medium, high sophistication modeling and simulation Choice of sophistication level for confidence in results

• Parametric Uncertainty,  $M\ddot{u}_i + C\dot{u}_i + K^{ep}u_i = F(t)$ ,

Uncertain mass *M*, viscous damping *C* and stiffness  $K^{ep}$ Propagation of uncertainty in loads, F(t)Results are PDFs and CDFs for  $\sigma_{ij}$ ,  $\epsilon_{ij}$ ,  $u_i$ ,  $\dot{u}_i$ ,  $\ddot{u}_i$ 



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# ESSI: Energy Input and Dissipation

Energy input, dynamic forcing

Energy dissipation outside SSI domain: SSI system oscillation radiation Reflected wave radiation

Energy dissipation/conversion inside SSI domain: Inelasticity of soil, contact/interface zone, structure, foundation, dissipators Viscous coupling with pore fluids, and external fluids

Numerical, algorithmic energy dissipation/production



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# Real-ESSI Simulator System

The Real-ESSI, **<u>Real</u>**istic Modeling and Simulation of <u>Earthquakes</u>, <u>Soils</u>, <u>Structures and their</u> <u>Interaction</u>. Simulator is a software, hardware and documentation system for time domain, linear and nonlinear, elastic or inelastic, deterministic or probabilistic, 3D, finite element modeling and simulation of:

- statics and dynamics of soil,
- statics and dynamics of rock,
- statics and dynamics of structures,
- statics of soil-structure systems, and
- dynamics of earthquake-soil-structure system interaction

Used for:

- ► Design, linear elastic, load combinations, dimensioning
- Assessment, nonlinear/inelastic, safety margins

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# Real-ESSI Simulator System

- Real-ESSI System Components
  - Real-ESSI Pre-processor (gmsh/gmESSI, X2ESSI)
  - Real-ESSI Program (local, remote, cloud)
  - Real-ESSI Post-processor (Paraview/pvESSI, Python, ...)
- ► Real-ESSI System availability:
  - Universities: AWS, LinuxESSI image
  - Government, National Labs: AWS GovCloud, LinuxESSI image

Professional Practice: AWS, LinuxESSI image

- ► Real-ESSI Short Courses, online, worldwide
- Real ESSI Simulator system documentation at http://real-essi.info/



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## Real-ESSI Short Course, Fall 2019

- Online, live sessions, that are also recorded
- ► Weekly, 8 weeks, 3 hours per week, each Tuesdays
  - 3 hours lecture
  - Homework, practice problems
  - 3 hours discussion session
  - Message/discussion list
- October November 2019
- Documentation, examples available online



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## Real ESSI Quality Assurance

- Verification, mathematics issue
  - Solution verification for each component
    - Finite elements
    - Constitutive algorithms
    - Solution advancement, static and dynamic
    - Model verification
  - Error quantification for ranges of modeling parameters
  - Automatic verification, a 13 hour process on multiple CPUs
- ► Validation, physics issue, partially done, in progress
- Certification process in progress
  - ASME NQA-1
  - ► ISO-90003-2014

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# Real-ESSI Modeling Features

- Solid elements, dry, (un-)saturated, elastic, inelastic
- ► Structural elements, beams, shells, elastic, inelastic
- ► Contact/interface elements, dry, coupled/saturated,
- Super element, stiffness and mass matrices
- Material models, soil, concrete, steel...
- Seismic input, 1C and 3C, deterministic or probabilistic
- Solid/Structure Fluid interaction, full coupling
- Input programming language, requires units
- Energy dissipation calculations
- Intrusive probabilistic inelastic modeling



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# **Real-ESSI Simulation Features**

- Static loading stages
- Dynamic loading stages
- Restart, simulation tree
- Solution advancement methods/algorithms, on global and constitutive levels, with and without enforcing equilibrium
- High Performance Computing
  - . Fine grained, template mataprograms, small matrix library
  - . Coarse grained, distributed memory parallel



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## Real-ESSI Model Development

- Pre-Processing, model development gmsh/gmESSI
- ► Existing model translation, SASSI→Real-ESSI
- Choose level of sophistication
- Reduce modeling uncertainty
- Model developed in phases
- Verify model components
- Build confidence in inelastic modeling



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### Real-ESSI Results Post Processing

- ► All output is saved (stress, strain, displacements, energy...)
- ► Time histories, scripts to plot or extract in preferred format
- ► 3D visualization, Paraview with pvESSI plugin



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# Real-ESSI Core Functionality

- Introduction to inelastic, nonlinear analysis for practicing engineers
- Use of prescribed, required (low, medium, high) fidelity numerical models to analyze ESSI behavior
- Set of suggested modeling and simulation parameters
- Investigate sensitivity of response to model sophistication
- Investigate sensitivity of response to model parameters



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## Real-ESSI Core Functionality Components

- Structural elements: Truss, Beam, Shell, Super-Element
- ► Soil, solids: elastic, *G*/*G*<sub>max</sub>
- ► Contacts: Bonded, Frictional, Gap open/close
- ► Loads: Static, Dynamic (earthquake, 1C or 3×1C), restart1
- Simulation: Implicit equilibrium, Explicit no-equilibrium,
- Core Functionality Application programs: APPs



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- Numerical modeling to predict and inform, rather than fit
- Engineer needs to know!
- Education and Training is the key!
- Funding from and collaboration with the US-DOE, US-NRC, US-NSF, US-BR, US-FEMA, NASA, CNSC-CCSN, UN-IAEA, Shimizu Corp., and Basler&Hofmann is greatly appreciated,
- More info: http://real-essi.info/



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