Seismic Energy Flow Calculations for Earthquake Soil Structure Interaction Systems

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Outline

Introduction

Energy Flow Simulations

Conclusion
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Conclusion
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 Realistic modeling and simulation of Earthquakes, Soils, Structures and their Interaction:

Real-ESSI Simulator  http://real-essi.info/
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
Energy Dissipation Control Mechanisms

Plasticity  Viscous  Numerical
Real-ESSI Simulator System

The Real-ESSI, Realistic Modeling and Simulation of Earthquakes, Soils, Structures and their Interaction. Simulator is a software, hardware and documentation system for time domain, linear and nonlinear, 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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Plastic Energy Dissipation

Single elastic-plastic element under cyclic shear loading

Difference between plastic work and plastic dissipation
Plastic work can decrease
Plastic dissipation always increases
Energy Dissipation Control

![Graph showing energy flow simulations over time with various energy components: Kinetic Energy, Strain Energy, Plastic Free Energy, Plastic Dissipation, Viscous Damping, Numerical Damping, and Input Work.](image)

- Kinetic Energy
- Strain Energy
- Plastic Free Energy
- Plastic Dissipation
- Viscous Damping
- Numerical Damping
- Input Work
Inelastic Modeling of Soil Structure Systems

- Soil, inelastic, elastic-plastic
  - Dry, single phase
  - Unsaturated, partially saturated
  - Fully saturated

- Contact, inelastic, soil/rock – foundation
  - Dry, single phase,
  - Normal, hard and soft, gap open/close
  - Friction, nonlinear
  - Fully saturated, suction, excess pressure, buoyant force

- Structure, inelastic, damage, cracks
  - Nonlinear/inelastic 1D reinforced concrete fiber beam
  - Nonlinear/inelastic 3D reinforced concrete solid element
  - Alcali Silica Reaction concrete modeling
Energy Dissipation in a NPP and SMR Models

(MP4)
Energy Dissipation for Design

Section A-A

Cover Concrete
Core Concrete
Steel Rebar

Reinforced Concrete Frame

Contact

Soil

DRM Layer
Damping Layers

140 m
51 m
32 m
16 m
40 m
12 m
2 m

Jeremić et al.
Real-ESSI
Design Alternatives, Individual Footing

Time Step: 3880

Plastic Dissipation Density (J/m3)

0 1.25 2.5 3.75 5
Design Alternatives, Slab Foundation
Design Alternatives
Wall, Regular and ASR Concrete

\[ u_y = 1.4 \text{ mm} \quad u_y = 1.8 \text{ mm} \quad u_y = 3.0 \text{ mm} \]
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Summary

▶ Numerical modeling to predict and inform, rather than fit
▶ Accurate energy dissipation calculations
▶ Education and Training is the key!
▶ Real-ESSI short course this Fall!
▶ http://real-essi.info/