Modeling of Seismic Energy Balance and Dissipation in Earthquake Soil Structure Interaction

Principal Investigator: Boris Jeremić, UC Davis
Postdoctoral Researcher: Han Yang, UC Davis
Jeremić Computational Mechanics Research Group, University of California Davis

Motivation

Energy balance and dissipation in Earthquake Soil Structure Interaction (ESSI) system is related to inelastic behavior of soil/rock, structural elements, soil-foundation interface, and energy dissipators.

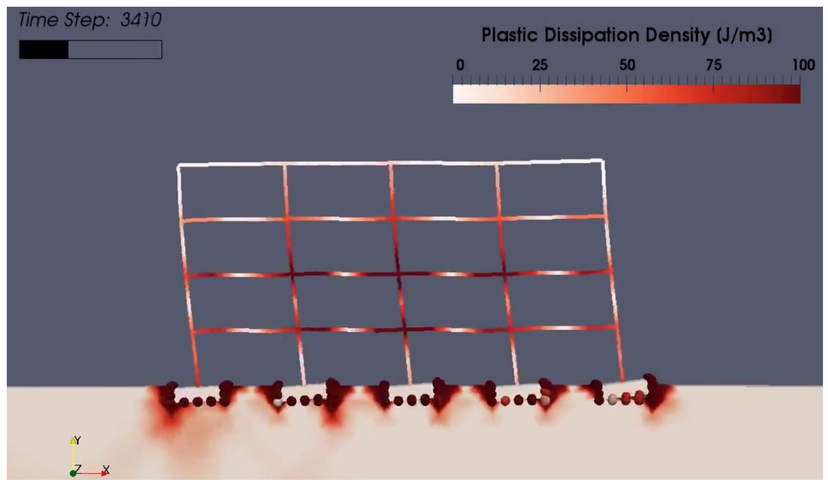

Fig 1: Distribution of energy dissipation in a four-story reinforced concrete frame structure under earthquake loading. Significant damage zones are observed around beam-column joints and soil-foundation interface.

ESSI system designs can be improved so that majority of seismic energy is dissipated within soil, soil-foundation interface, and energy dissipators, away from the structure.

Background

Energy-based design (EBD) of ESSI system is growing in popularity. Current practice of modeling energy storage and dissipation is often oversimplified or even incorrect. Taking advantage of state-of-the-art modeling and simulation techniques, modern EBD can be improved to a new level of accuracy.

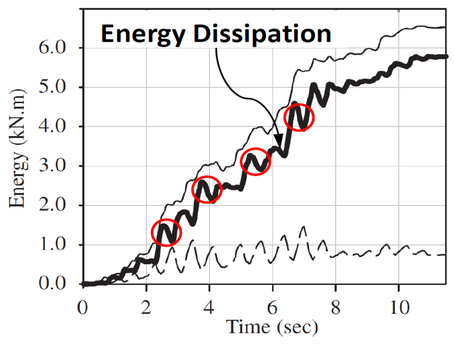

Fig 2: Many publications presented negative energy dissipation during certain time periods, which is a violation of the second law of thermodynamics.

Many current practices suffer from the misconception about the difference between plastic work and plastic energy dissipation. This difference is known as the latent energy of cold working or plastic free energy.

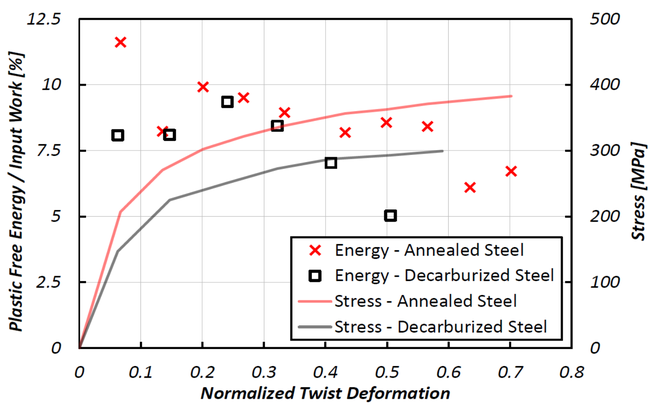

Fig 3: Percentage of input work which transforms into plastic free energy in steel specimen subjected to plastic twisting. (Data from Taylor and Quinney [1934])

Theoretical Highlights

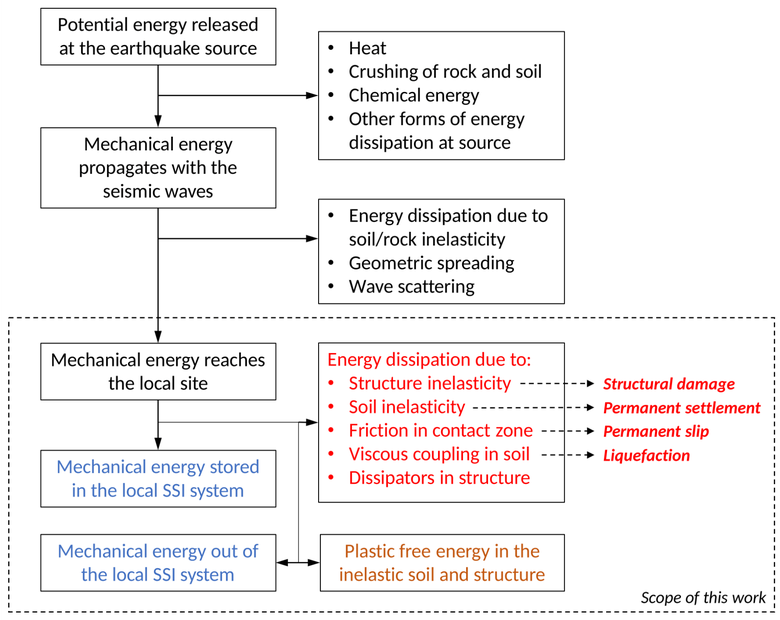

Fig 4: Seismic energy propagation and dissipation.

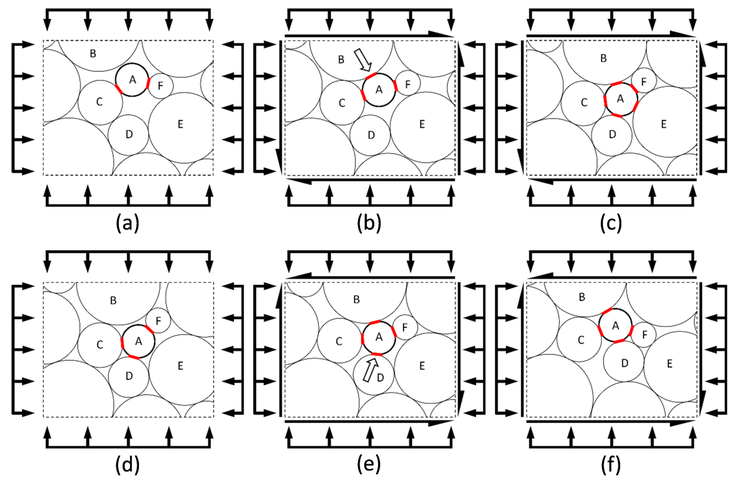

Fig 5: Particle rearrangement of a 2D granular assembly under cyclic shearing: (a) Initial state; (b) Loading (accumulating plastic free energy); (c) End of loading (Maximum plastic free energy); (d) Unloading (plastic free energy unchanged); (e) Reverse loading (releasing plastic free energy); (f) End of reverse loading (plastic free energy released).

Illustrative Examples

All modeling and simulations are done using the Real-ESSI Simulator system (http://real-essi.info/).

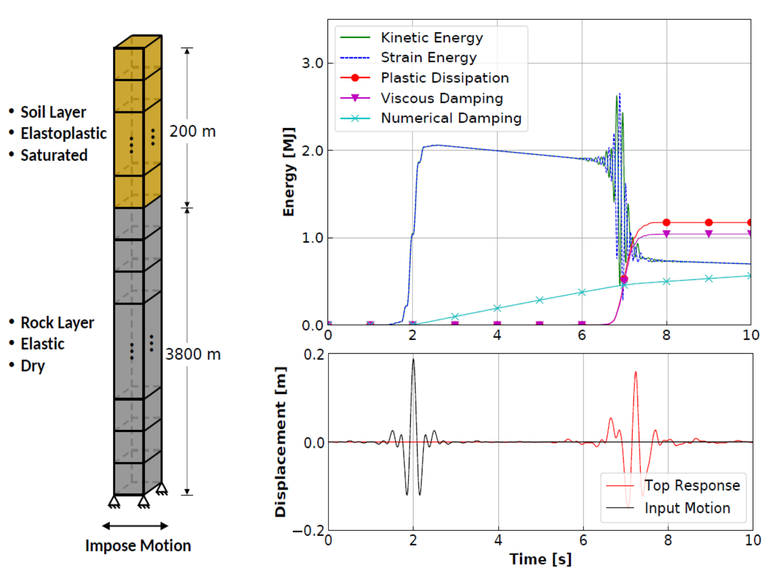

Fig 6: Energy dissipation analysis of wave propagating through a soil and rock column

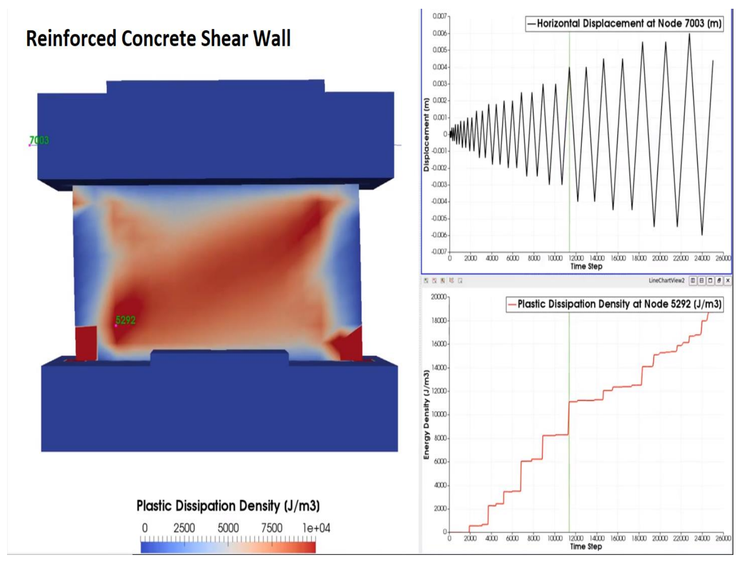

Fig 7: Energy dissipation analysis of a reinforced concrete shear wall under cyclic pushover loading.

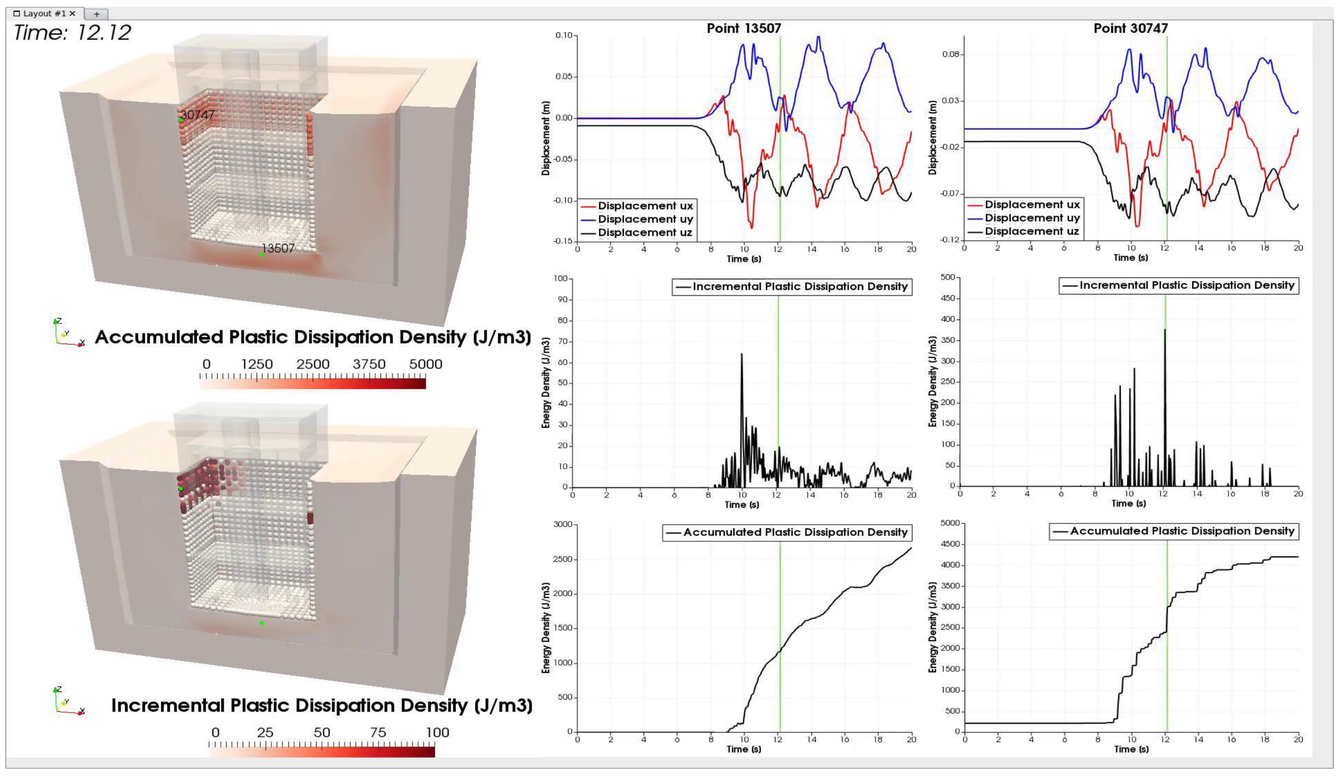

Fig 8: Energy analysis of a small modular reactor under earthquake loading.

Conclusions

- Proper modeling of energy can improve safety and economy of ESSI system design.
- Calculation of energy dissipation must follow the principles of thermodynamics.
- ESSI energy computation is available in Real-ESSI Simulator (http://real-essi.info/).

Acknowledgements

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