Modeling and Simulations of Liquefied Soils

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Outline

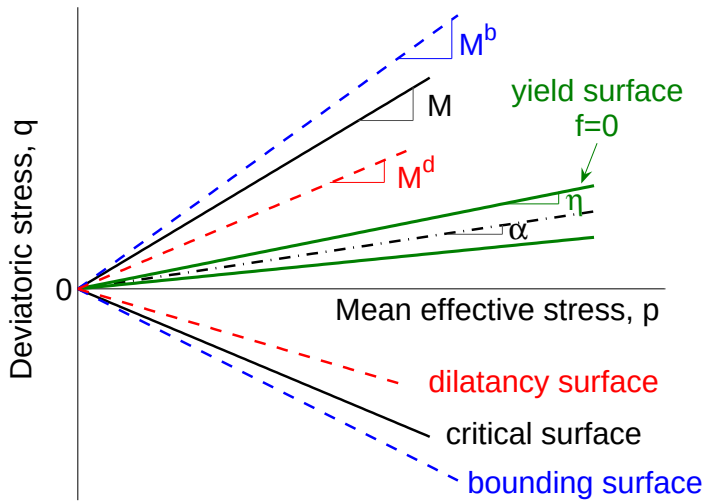
Fully Coupled $u - p - U$ Formulation

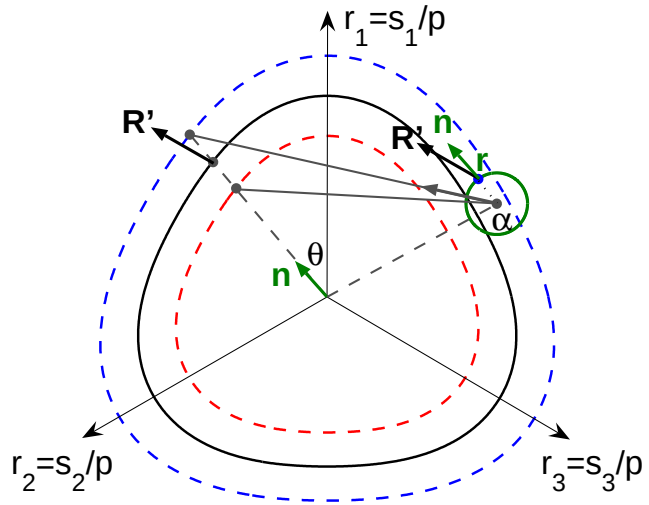
- Formulation: fully coupled by Zienkiewicz and Shiomi 1984), nonlinear dynamics by Argyris and Mlejnek (1991)
- Physical, velocity proportional damping from solid–fluid interaction (not using Raleigh damping)
- Accelerations of pore fluid not neglected
  - important for SFSI
  - inertial forces of fluid allow liquefaction modeling
- Stable formulation for near incompressible pore fluid

Dafalias Manzari Material Model

- Dafalias & Manzari (2004): critical state compatible elasto-plastic constitutive model for sands.
- Systematic and relatively simple calibration process.
- Capable of simulating different feature of sand response such as
  - hardening
  - softening
  - consolidation
  - dilation
- Single set of parameters for all stages of loading (self weight, cycling...)

Multiaxial Representation



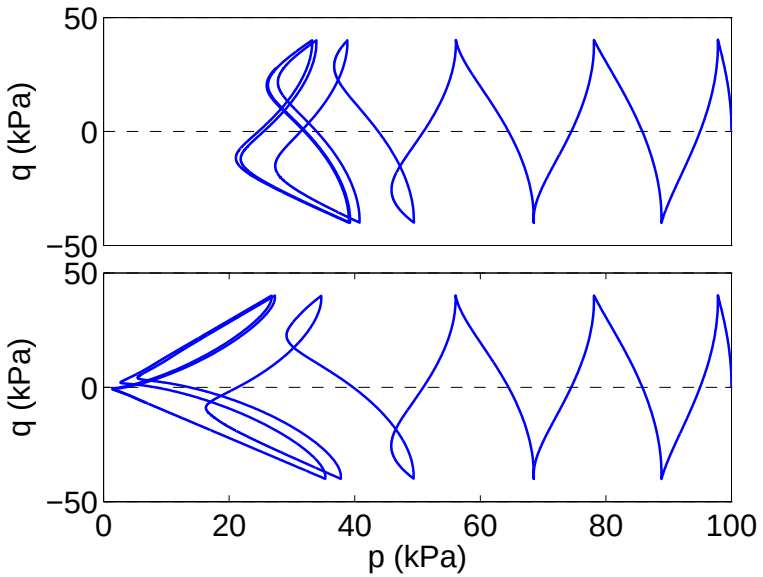


Dafalias Manzari Material Model

Fabric Dilatancy Tensor

$$\dot{\varepsilon}_v^p = A_d d \left| \dot{\varepsilon}_q^p \right|$$

$$A_d = A_0 \left(1 + \langle \mathbf{z}{:}\mathbf{n} \rangle\right) \quad ; \quad \mathbf{z} = -c_z \langle -\dot{\varepsilon}_v^p \rangle \left(z_{max}\mathbf{n} + \mathbf{z}\right)$$

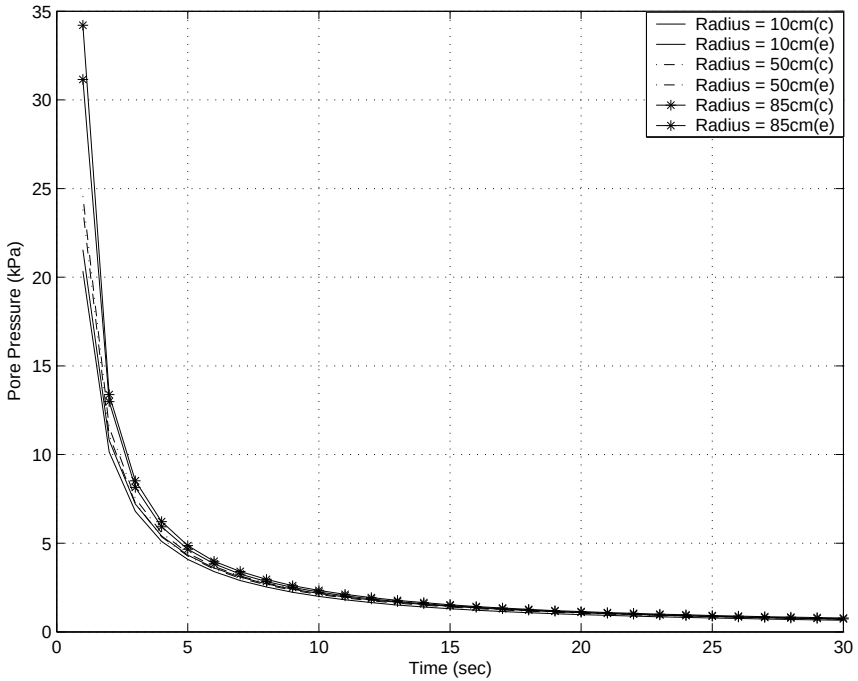


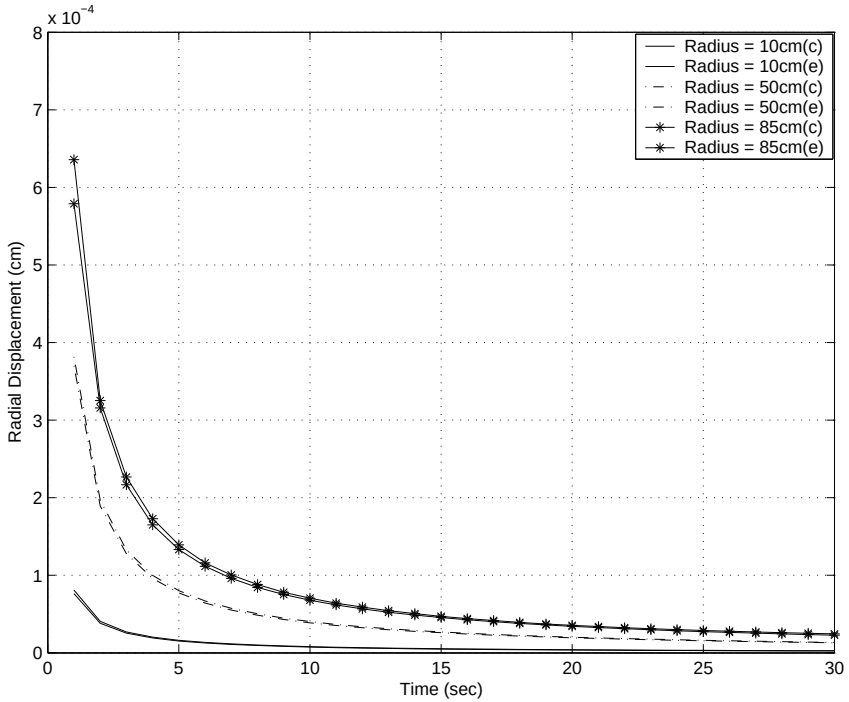
Verification, Validation and Prediction

- Verification: the process of determining that a model implementation accurately represents the developer's conceptual description and specification. Mathematics issue. *Verification provides evidence that the model is solved correctly.*
- Validation: The process of determining the degree to which a model is accurate representation of the real world from the perspective of the intended uses of the model. Physics issue. *Validation provides evidence that the correct model is solved.*
- Prediction: use of computational model to foretell the state of a physical system under consideration under conditions for which the computational model has not been validated

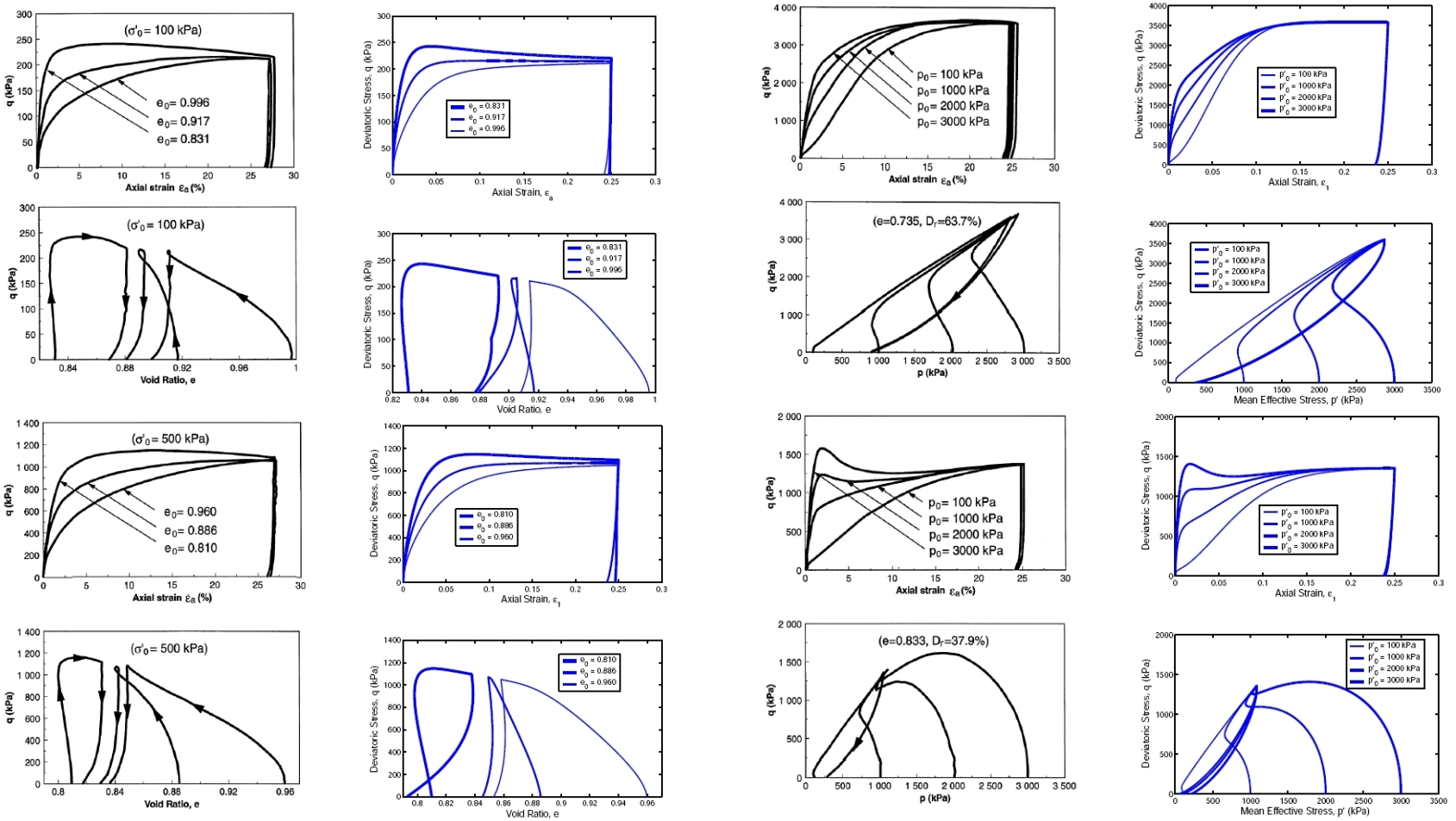
Formulation Verification

Using closed form solutions (consolidation, injection of fluid into reservoir, cylindrical cavity expansion, spherical cavity expansion.

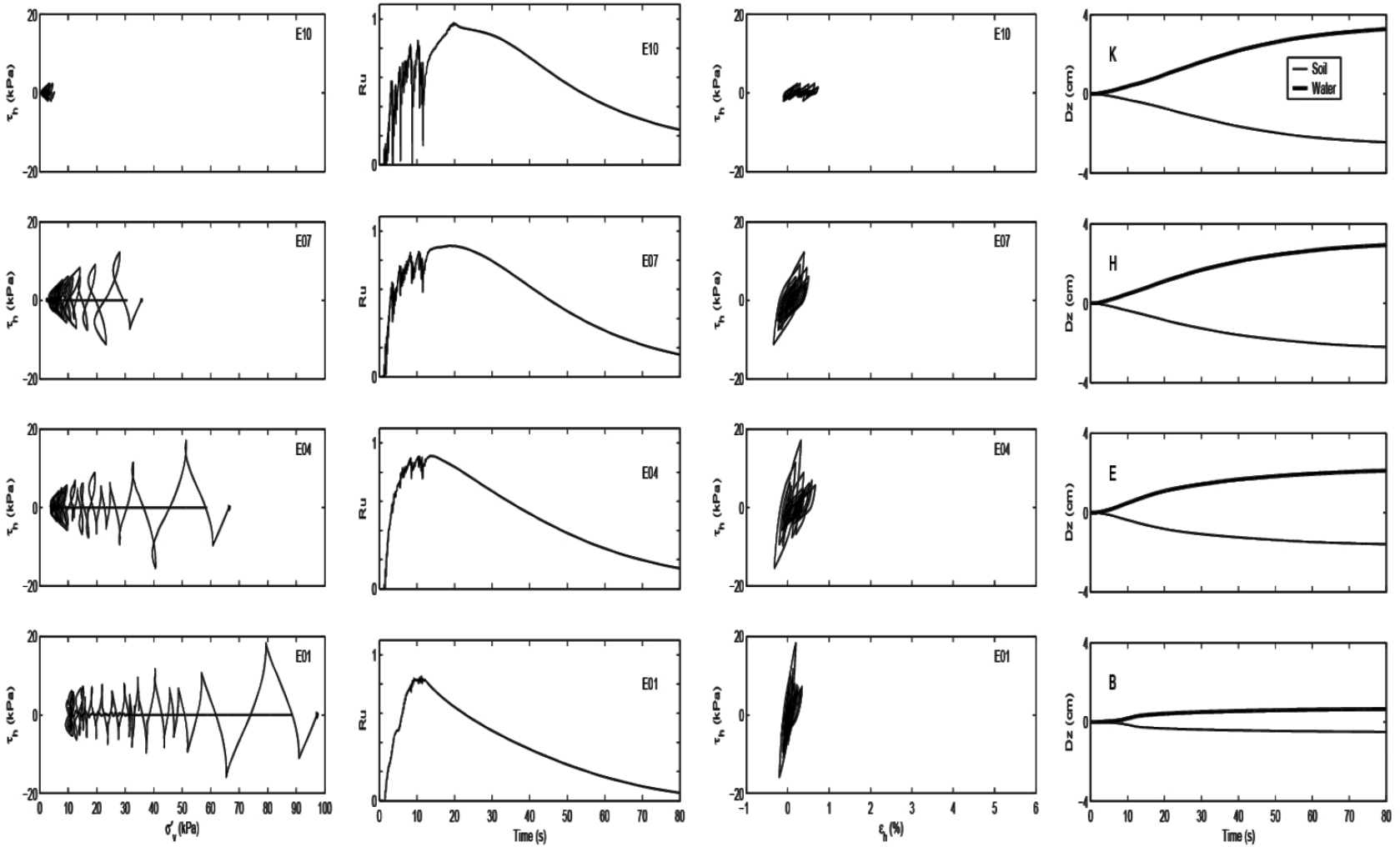




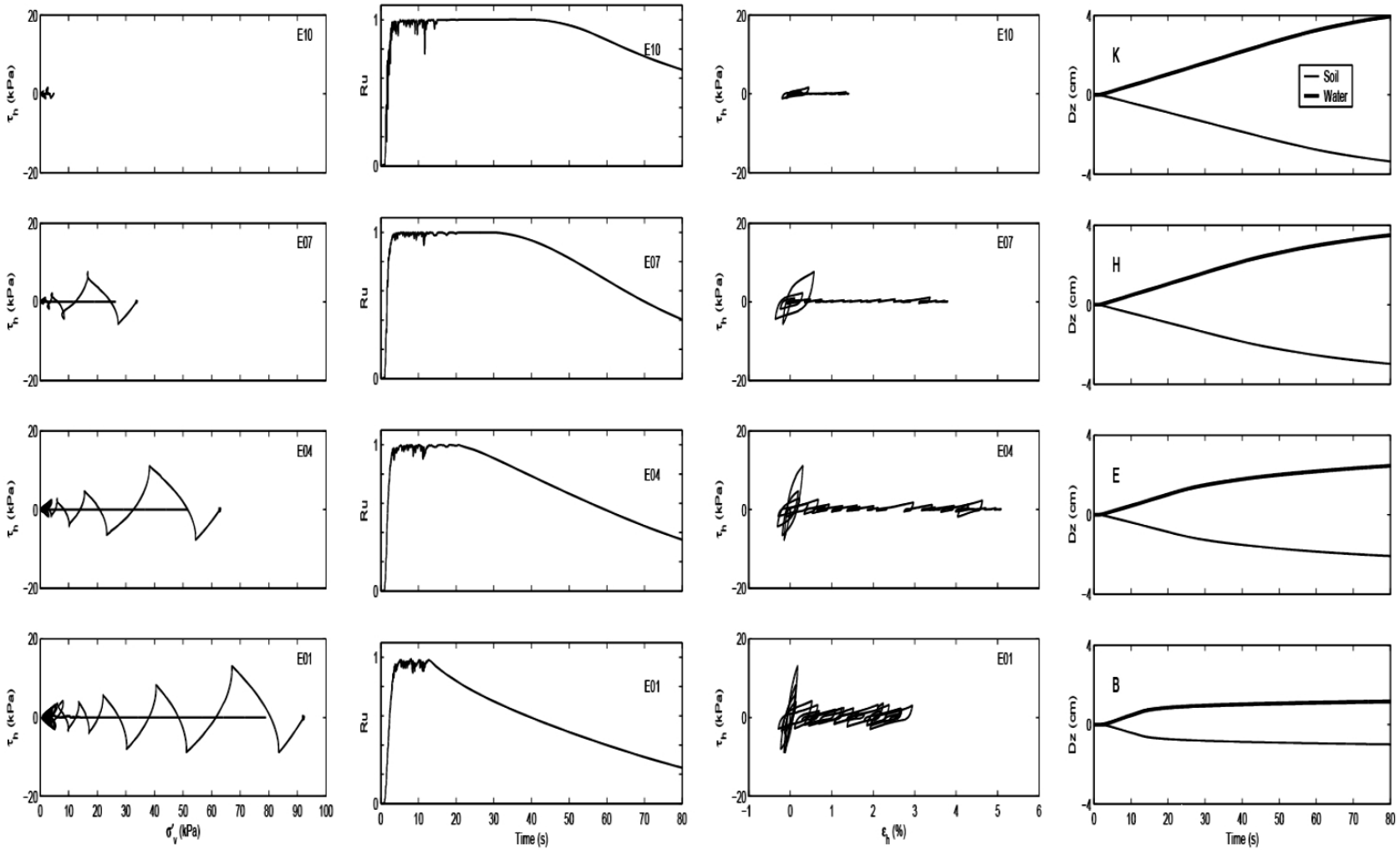
Material Model Validation



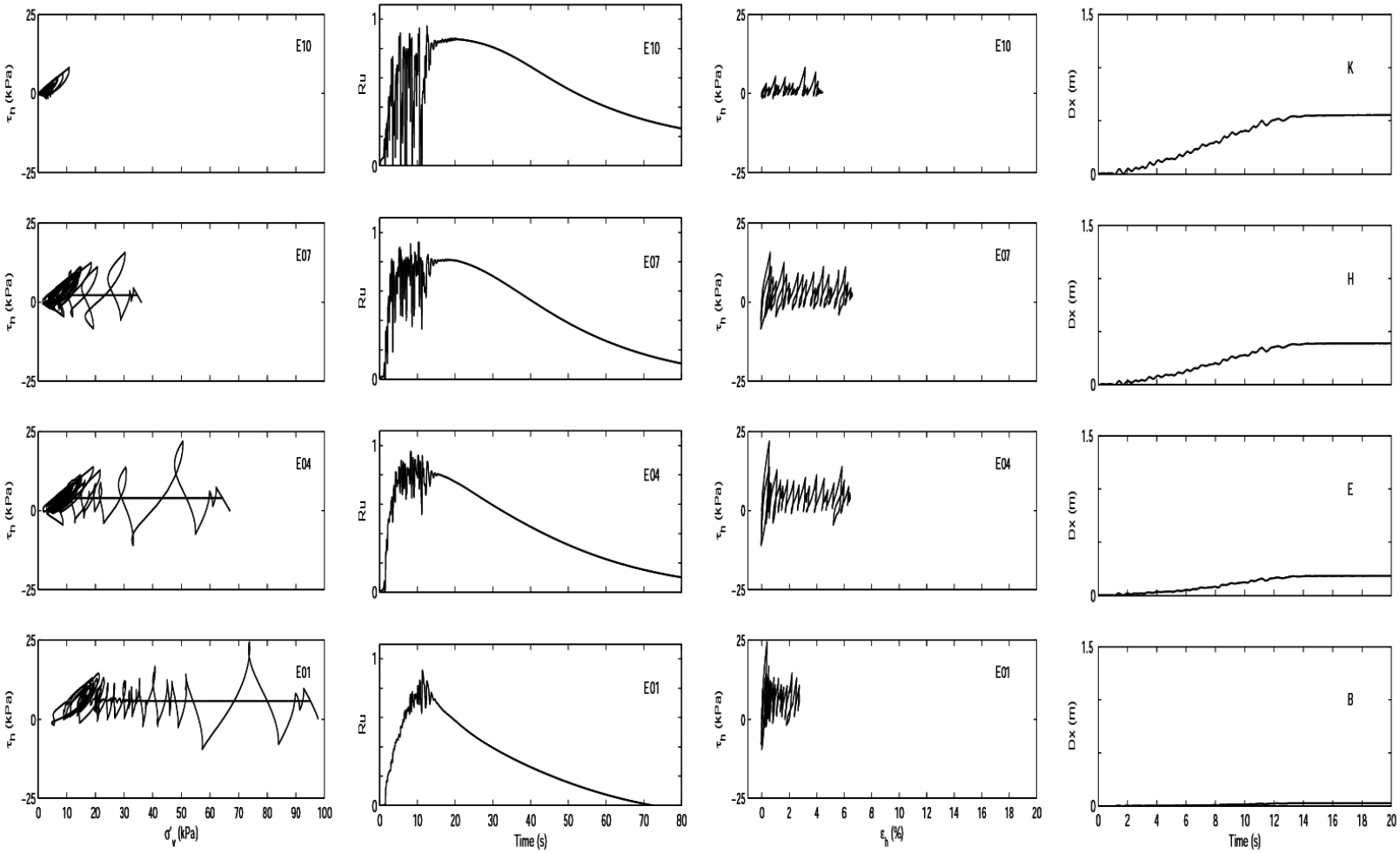
Level Ground, Dense Sand



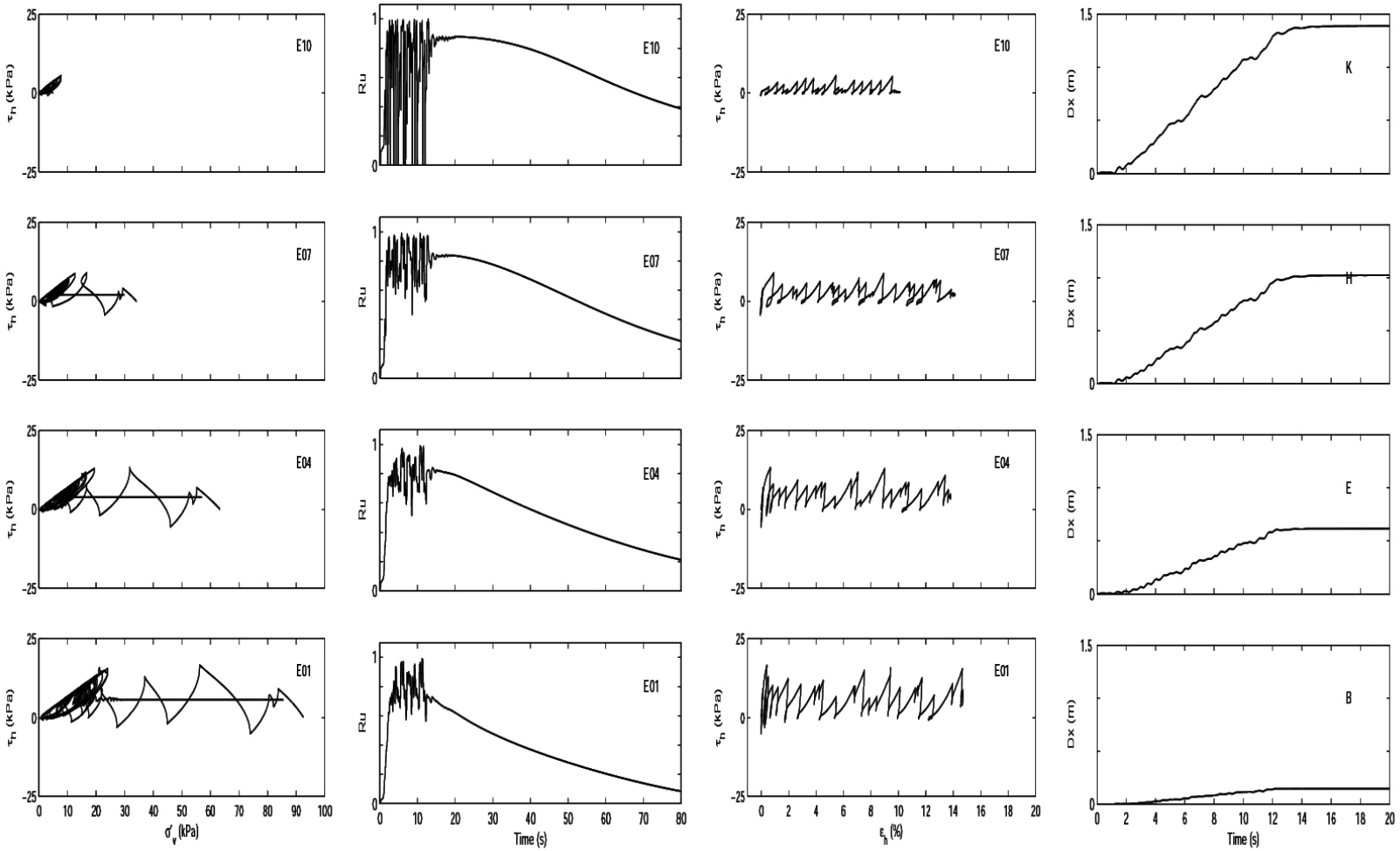
Level Ground, Loose Sand



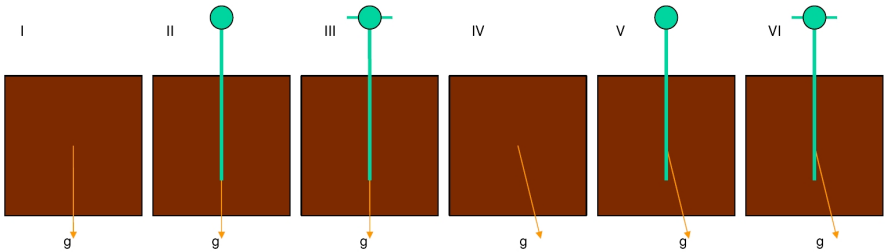
Sloping Ground, Dense Sand

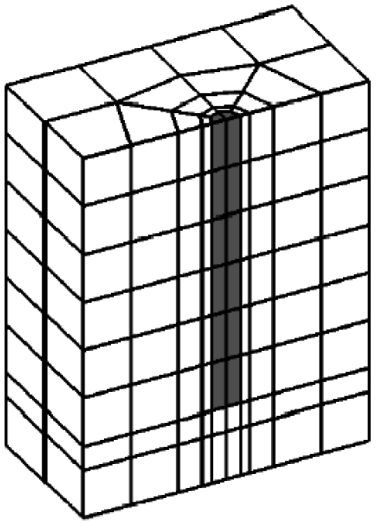


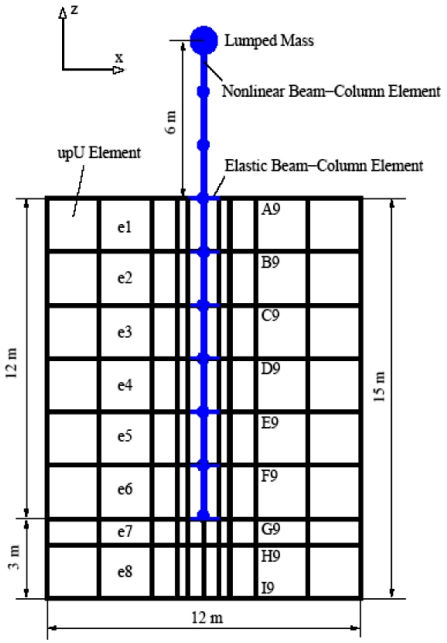
Sloping Ground, Loose Sand



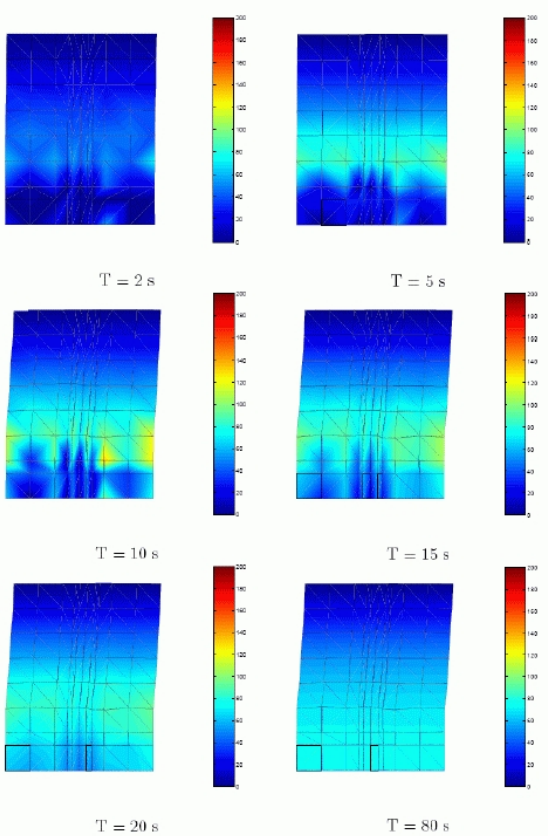
Bridge Pier–Pile Model



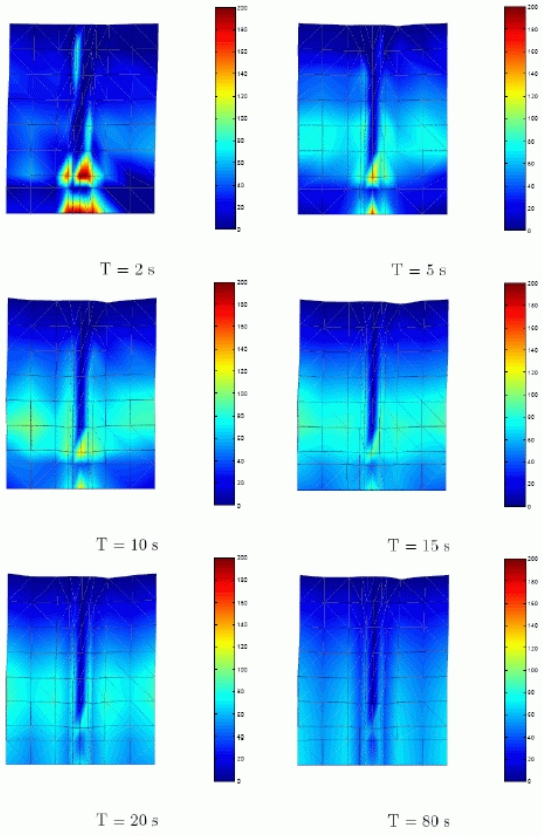




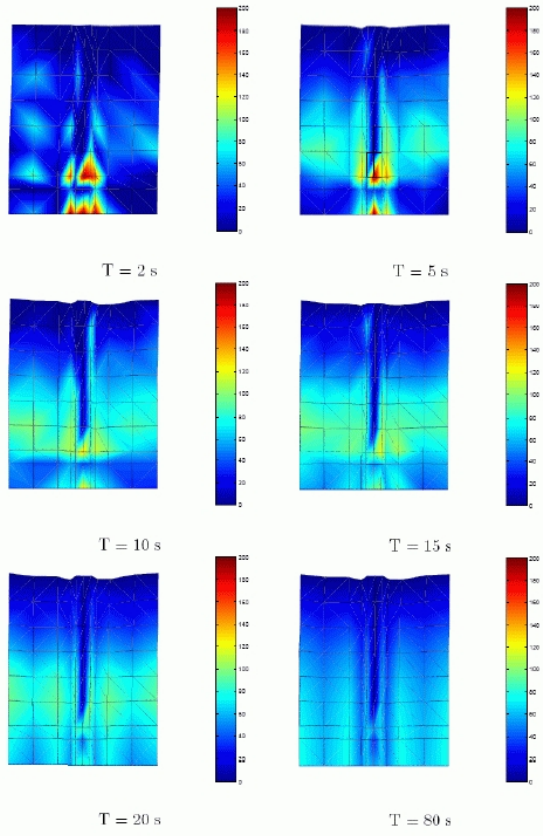
Bridge Pier in Level Ground



Case I

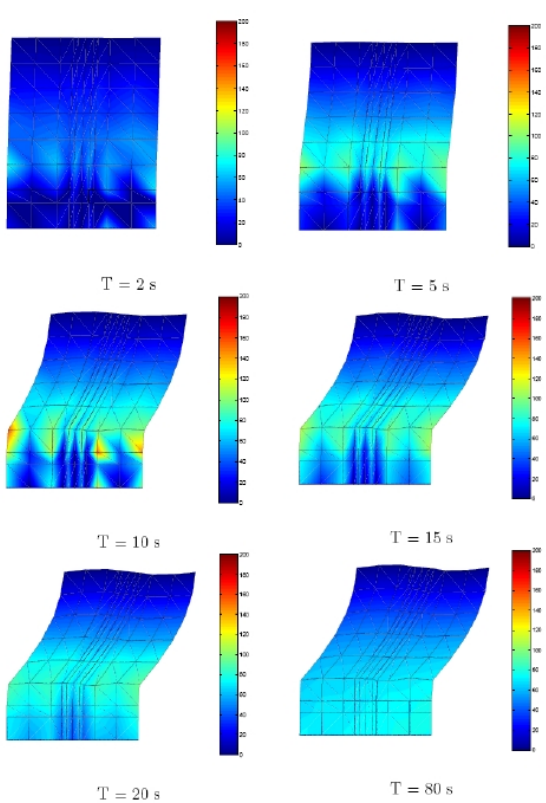


Case II

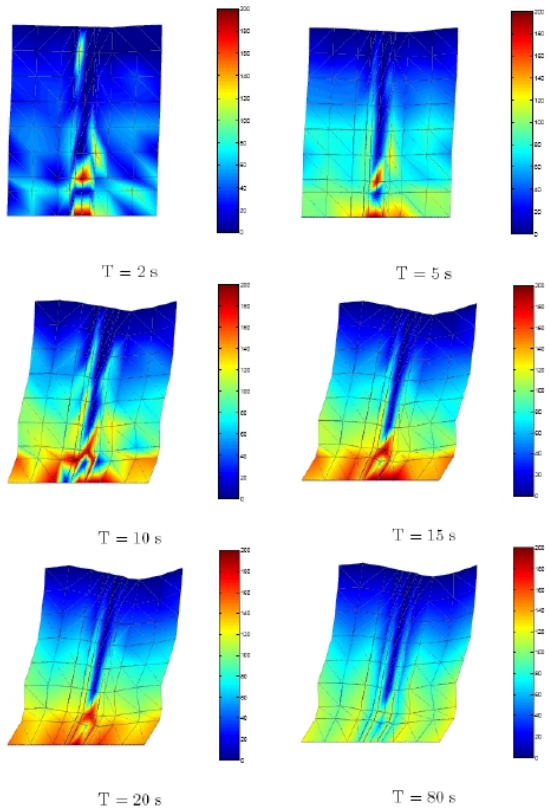


Case III

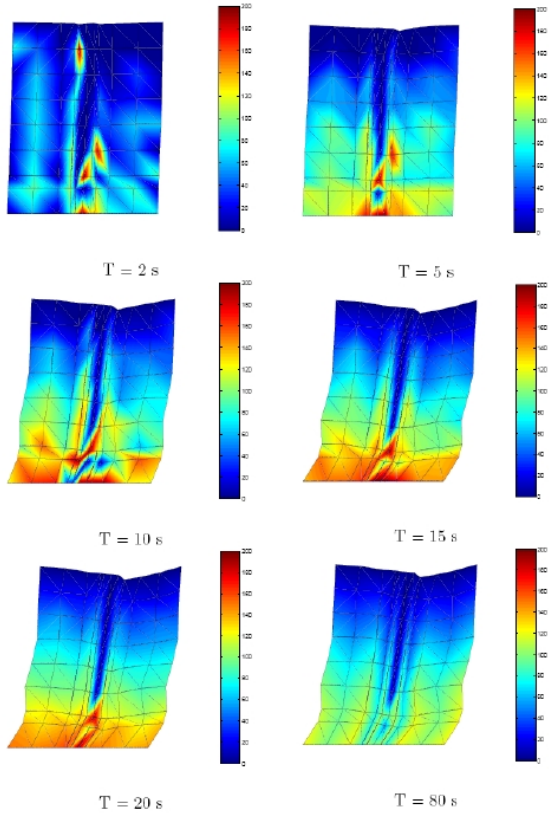
Bridge Pier in Sloping Ground



Case IV



Case V



Case VI

Summary

- Importance of consistent formulation, material modeling and implementation
- Verified, validate models and simulations tools used for prediction of behavior
- Program and examples available in public domain (Author's web site)