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Collaborators: Professors Zhaohui Yang (UAA), Sashi Kunnath (UCD), Gregory Fenves (UCB), Jacobo Bielak (CMU), Drs. Francis McKenna (UCB), and research students Xiaoyan Wu (UW) Ritu Jain (UCD), Jinxiu Liao (UCD).
Leitmotiv

• Create high fidelity models of constructed facilities (bridges, buildings, port structures, dams...).

• Models will live concurrently with the physical system they represent.

• Models to provide owners and operators with the capabilities to assess operations and future performance.

• Use observed performance to update and validate models through simulations.
Presentation Overview

- The NEES MiniGrand Challenge Project
  - Validation experiments
  - Simulation challenge

- OpenSees NEESgrid simulation platform
  - Template Elasto–Plasticity
  - Full Coupling of Solid and Fluid
  - Seismic Motions (FEM input)
  - Distributed Memory Parallel Computing
  - General Large Deformations
Validation Experiments

• A validation experiment should be jointly designed and executed by experimentalist and computationalist
  – Need for close working relationship from inception to documentation
  – Elimination of typical competition between each
  – Complete honesty concerning strengths and weaknesses of both experimental and computational simulations

• A validation Experiment should be designed to capture the relevant physics
  – Measure all important modeling data in the experiment
  – Characteristics and imperfections of the experimental facility should be included in the model
Inference ⇒ Based on **physics** or **statistics**

Validation domain → non-convex aggregation of physical tests

Physical experiments (NEES) provide for non-overlapping validation domain
Participants: Wood (UT), Anagnos (SHSU), Arduino (UW), Eberhard (UW), Fenves (UCB), Finholt (UM), Futrelle (NCSA), Grant (UK), Jeremić (UCD), Kramer (UW), Kutter (UCD), Matamoros (UK), McMullin (SHSU), Ramirez (PU), Rathje (UT), Saidi (UNR), Sanders (UNR), Stokoe (UT), Wilson (UCD).
Validation SFSI Experiments

- UC Davis centrifuge, single piles, bents, frames, scale 1/50
- UT Austin, pile, pile-column, bent, scale 1/4
- UN Reno, frame (3 bents), scale 1/4
- Purdue U., pier components, scale 1/2 and 1/1
The OpenSees Platform
SFSI components

- Small deformation, single phase, linear and nonlinear elasticity and incremental template elasto–plasticity (PY springs, 2D/3D solids)
- General, large deformation hiperelasticity and hyperelasto–plasticity for solids
- Full coupling of solid and fluid \((u - p - U)\), (small deformations only at the moment)
- Elastic and inelastic beam–column elements, elastic plate and plane stress elements (shells), small and large deformations
- Seismic input through the Domain Reduction Method
Template Elasto–Plasticity

- Yield surfaces: von Mises, Drucker–Prager, Rounded Mohr–Coulomb, Cam–Clay, Parabolic Leon,

- Plastic flow directions (potential surfaces): von Mises, Drucker–Prager, Rounded Mohr–Coulomb, Cam–Clay, Manzari–Dafalias, Parabolic Leon,

- Isotropic or kinematic hardening/softening
  - linear and/or nonlinear isotropic hardening/softening
  - linear or nonlinear kinematic hardening/softening

- Hierarchical database of models (by materials)
Template Examples
Single Pile in Layered Soils
Pile Group Simulations

- Plastic zone
- Load distribution
- Pile interactions (P-Y)
Full Coupling of Solid and Fluid

\[
\begin{bmatrix}
(M_s)_{KijL} & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & (M_f)_{KijL}
\end{bmatrix}
\begin{bmatrix}
\ddot{u}_{Lj} \\
\ddot{p}_L \\
\ddot{U}_{Lj}
\end{bmatrix} + 
\begin{bmatrix}
(C_1)_{KijL} & 0 & -(C_2)_{KijL} \\
0 & 0 & 0 \\
-(C_2)_{LjiK} & 0 & (C_3)_{KijL}
\end{bmatrix}
\begin{bmatrix}
\dot{u}_{Lj} \\
\dot{p}_L \\
\dot{U}_{Lj}
\end{bmatrix} + 
\begin{bmatrix}
(K^{EP})_{KijL} & -(G_1)_{KiiL} & 0 \\
-(G_1)_{LjiK} & (P)_{KL} & -(G_2)_{LjiK} \\
0 & -(G_2)_{KiiL} & 0
\end{bmatrix}
\begin{bmatrix}
\ddot{u}_{Lj} \\
\ddot{p}_L \\
\ddot{U}_{Lj}
\end{bmatrix} = 
\begin{bmatrix}
\bar{f}_s \kappa_i \\
0 \\
\bar{f}_f \kappa_i
\end{bmatrix}
\int_{\Omega} N_{K}^{u,U} n^{2} k_{ij}^{-1} N_{L}^{u,U} d\Omega

(C_1)_{KijL} = (C_2)_{KijL} = (C_3)_{KijL} = \int_{\Omega} N_{K}^{u,U} n^{2} k_{ij}^{-1} N_{L}^{u,U} d\Omega

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Seismic Input

- Domain Reduction Method, (Bielak et al. at CMU)
- Seismic motions and accelerations input at the layer of elements that encompass an elastic–plastic zone (using SHAKE, Green’s functions, Quake, SCEC...), non-reflective boundaries
Verification SFSI Model

![Diagram of SFSI Model](image)

Graphs showing acceleration and displacement over time.
SFSI: Stiff Soil Model

Free Field

SFSI
SFSI: Soft Soil Model

Free Field

SFSI

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SFSI Model: Pile–Column Behavior

![Graph showing displacement vs. time for stiff soil and soft soil](image)

- Stiff soil
- Soft soil
SFSI Model: Seismic Results

Stiff soil

Soft soil
I–880 SFSI Example
SFSI Advantageous

Kobe–JMA
SFSI Disadvantageous

LP–Corralitos
Conclusions

- SFSI problem requires close cooperation of experimentalists, modelers and simulators,

- **Validation domain** and **Application domain** to be bridged using simulation tools,

- One such simulation tool is OpenSees, the NEESgrid simulation platform

- The main OpenSees web site [http://opensees.berkeley.edu/](http://opensees.berkeley.edu/) has links to documentation, examples, source code, executables, message board...