Benefits and Detriments of Soil Foundation Structure Interaction: Simulation Platform and Examples

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Outline

SFSI Hypothesis

- Flexibility (elastic) of foundations and soils modifies dynamic properties of the SFS system (Gazetas and Mylonakis)
- Reduction in stiffness (elasto–plasticity) of the SFS system modifies those dynamic properties even more so
- Earthquake period and SFS period might (will) coincide
- SFSI response a function of a tightly coupled triad of dynamic characteristic of
  - Earthquake
  - Soil
  - Structure
- Use detailed numerical models to study prototype models

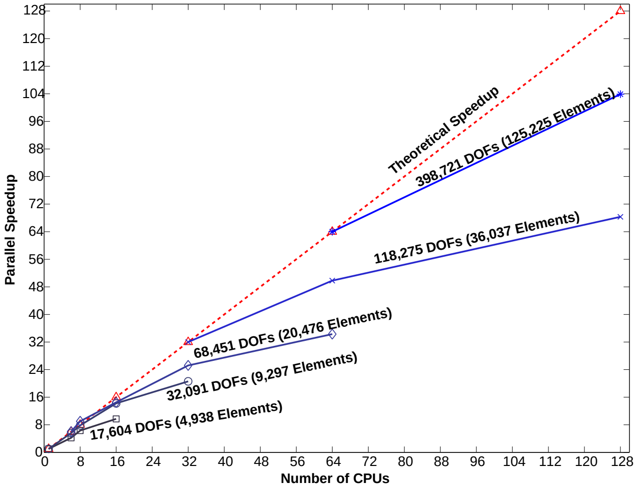
Parallel Elastic–Plastic Finite Element Computations

- Current Parallel FEM are
  - Well developed for elastic FEM
  - Undeveloped for elastic–plastic FEM
  - Well developed for homogeneous distributed memory parallel (DMP) computers,
  - Undeveloped for multiple performance (multi–generation) DMPs
- Need: dynamic computational load balancing for
  - multiple element types,
  - multiple material models
  - multiple compute node performances
  - multiple network performances

Plastic Domain Decomposition (PDD) Method

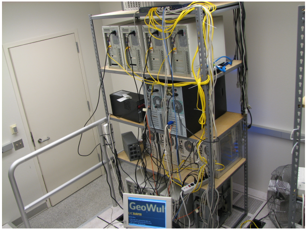
- Multi-objective optimization problem (minimize both the inter-processor communications, the data redistribution costs and create balanced partitions)
- Parallel program based on UCD CompGeoMech libraries (elements, mat. models, algorithms, PDD method), ParMETIS (graph repartitioning), PETSc (system solvers) and parts of OpenSees (upgraded analysis model)
- Adaptive domain repartitioning depending on compute node and network performance
- Scalable to a large number of CPUs (2–1024 or more)
- Performance tuning and production runs on my cluster GeoWulf (UCD), LongHorn (TACC) and DataStar (SDSC)

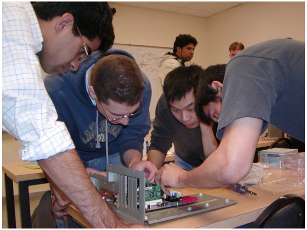
Speedup Overview



Parallel Computer GeoWulf

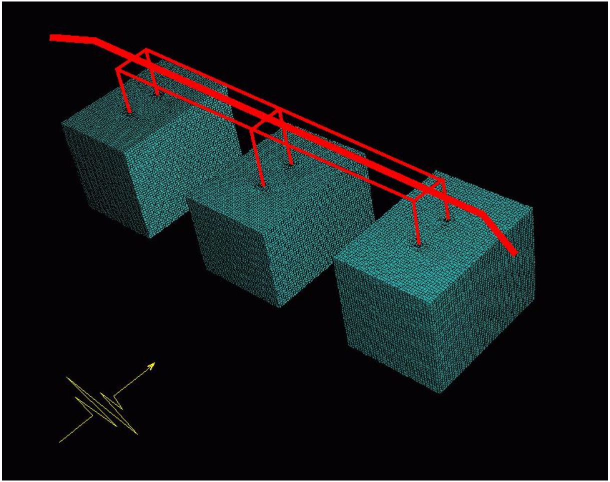
- Distributed memory parallel computer
- Multiple generation compute nodes and networks
- Very cost effective!
- Same architecture as large parallel supercomputers (SDSC, TACC, EarthSimulator...)
- Local design, construction, available at all times!





Detailed 3D FEM Model (one of)

- Soils: elastic–plastic solids (Drucker-Prager, Armstrong-Frederick)
- Structure and piles: non–linear beam–column elements (fiber element)

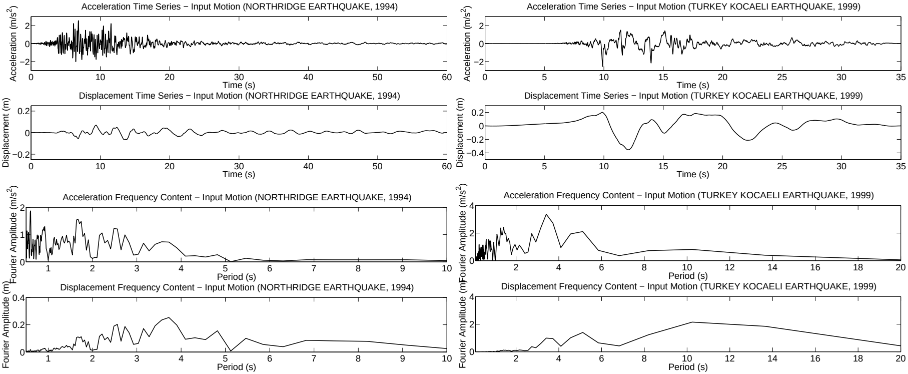


Detailed 3D FEM Model

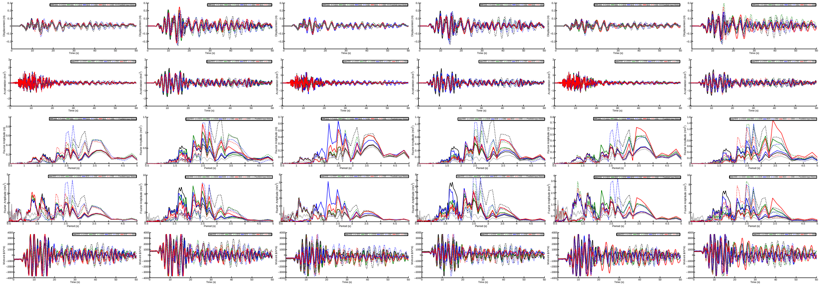
- Construction process
- Two types of soil: stiff soil (UT, UCD), soft soil (Bay Mud)
- Deconvolution of given surface ground motions
- Use of the DRM (Prof. Bielak et al.) for seismic input
- Piles $\rightarrow$ beam-column elements in soil holes
- No artificial damping (only mat. dissipation, radiation)
- Structural model: UCB (Fenves), UW (Eberhardt)
- Element size issues (filtering of frequencies)

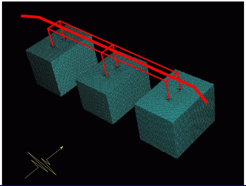
elem. #	elem. size	f_{cutoff}	min. $G^{ep}/Gmax$	γ
12K	1.00 m	10 Hz	1.0	<0.5 %
15K	0.90 m	>3 Hz	0.08	<1.0 %
150K	0.30 m	10 Hz	0.08	<1.0 %
500K	0.15 m	10 Hz	0.02	<5.0 %

Northridge and Kocaeli Input Motions

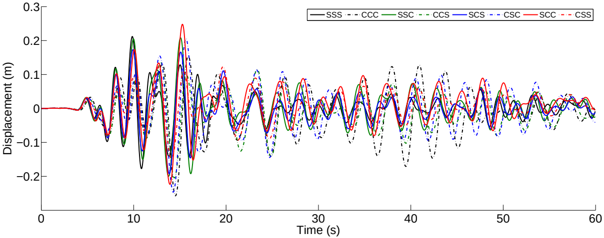


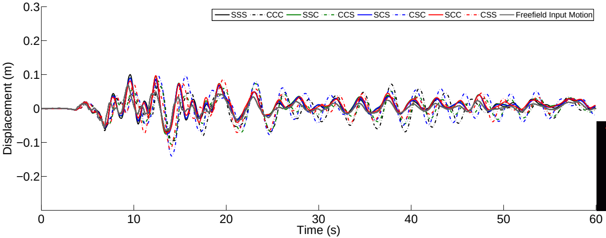
Simulation Results

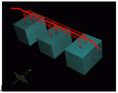




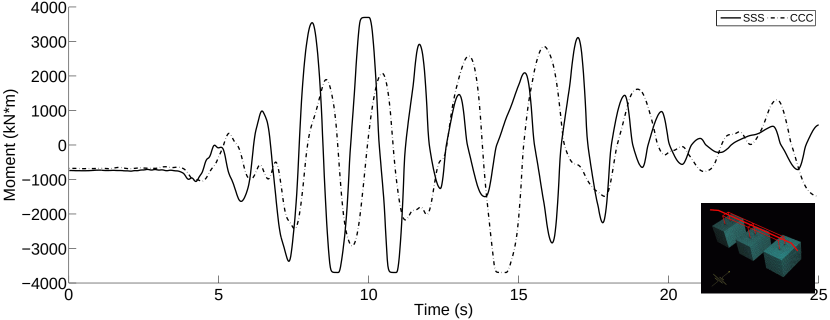
Short Period E.: Left Bent, Structure and Soil, Disp.



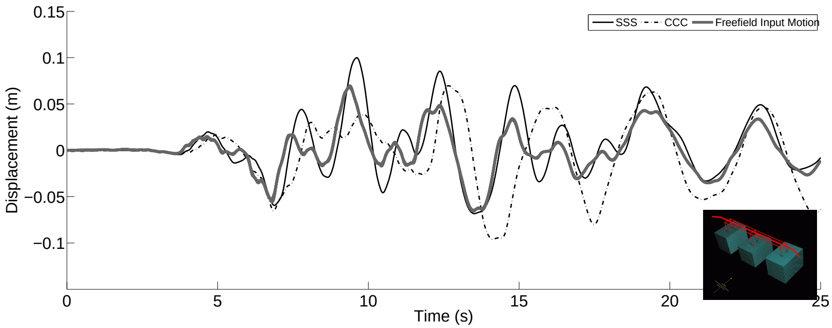




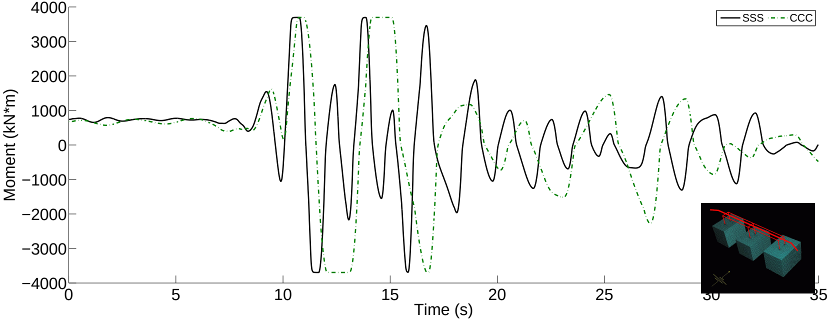
Short Period E.: Left Bent, Bending Moments



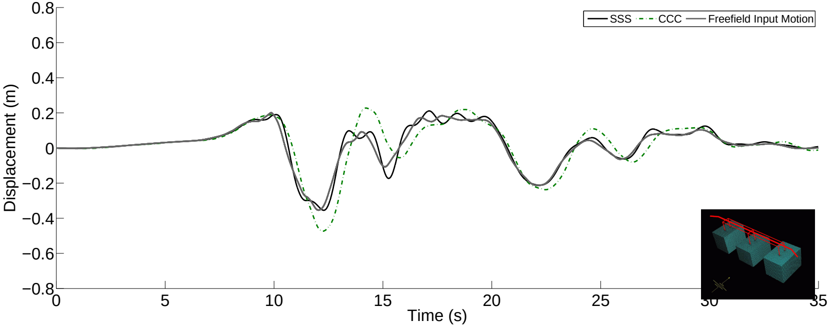
Short Period E.: Left Bent, Free Field vs Real Disp.



Long Period E.: Left Bent, Bending Moments.



Long Period E.: Left Bent, Structure and Soil, Disp.



Summary

- High fidelity numerical models of ESS systems
- High performance computational tools (software and hardware) developed and available
- **Matching Triad**: Earthquake, Soil and Structure (**ESS**) interaction determines possible benefits or detriments of SFSI
- Program sources and tools available in public domain (GPL) at Author's web site