Hybrid Simulation:
Sub-structures

Bozidar Stojadinovic, Associate Professor

University of California, Berkeley
Hybrid Model

- Physical model of structural resistance
- Computer models of structural damping and inertia

By definition, a hybrid model is sub-structured

\[ ma + cv + r = -\mu g \]
\[ ma + m\ddot{u}g + cv = -r \]
Multiple Substructures

There are no limits:

- Many physical substructures: *hard models*
- Many analytical substructures: *soft models*

Testing infrastructure must enable:

- Simulation of individual substructures
- Integration of the equations of motion
Advantages and Disadvantages

Advantages:
- Physically model resistance of sub-structures whose computer models are not good enough
- Model the inertia forces (and damping, and second order effects) in the computer

Disadvantages:
- Sub-structures are connected and interact at their boundaries
- Specimens have inertia and damping, too
Equation of Motion

\[
\begin{bmatrix}
  m_{pp} & m_{pc} \\
  m_{cp} & m_{cc}
\end{bmatrix}
\begin{bmatrix}
  \ddot{u}_p \\
  \ddot{u}_c
\end{bmatrix} +
\begin{bmatrix}
  c_{pp} & c_{pc} \\
  c_{cp} & c_{cc}
\end{bmatrix}
\begin{bmatrix}
  \dot{u}_p \\
  \dot{u}_c
\end{bmatrix} +
\begin{bmatrix}
  R_p \\
  R_c
\end{bmatrix} =
\begin{bmatrix}
  m_{pp} & m_{pc} \\
  m_{cp} & m_{cc}
\end{bmatrix}
\begin{bmatrix}
  \ddot{u}_{pg} \\
  \ddot{u}_{cg}
\end{bmatrix}
\]

Restoring forces can be assembled

However, so can:

- Damping forces from physical dampers
- Inertia forces from the mass of the physical specimens
Interfaces

- Equilibrium and compatibility must be satisfied
- Deformations and forces
  - Displacement (relatively easy)
  - Rotation (very difficult)
- Opportunity to do:
  - DOF condensation
- Coordinate transformations
  - Physical to numerical DOF’s
- Geometry corrections
  - Actuator movements

\[ d = T \bar{d} \]
Interfaces

Damping and inertia:

- Explicit consideration of physical dampers and physical masses, based on measured velocities and accelerations
- DOF condensation must be done carefully
- Coordinate transformations must be propagated to velocities and accelerations

Second order effects:

- Geometric stiffness may be assembled into the resistance: $\overline{r} = r - K_g d$
Thank you!

Development and operation of the nees@berkeley equipment site is sponsored by NSF.

http://nees.berkeley.edu

Contributions to this presentation from Prof. Andrei Reinhorn and Prof. Gilberto Mosqueda are gratefully acknowledged.