Hybrid Simulation: Basics

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Hybrid Simulation

- Hybrid simulation is an experimentally based method for investigating the response of structure to dynamic excitation using a hybrid model.

- A hybrid model is a combination of one or more physical and one or more numerical, consistently scaled, substructures.

- The equation of motion of a hybrid model under dynamic excitation is solved during a hybrid simulation test.
Response of Structures to Dynamic Loads

- Dynamic loading excites a structure:
  - Resistance
  - Energy dissipation (damping)
  - Inertia

\[ Ma(t) + Cv(t) + R(d(t)) = f(t) \]

- Important dynamic excitations:
  - Seismic
  - Wind
  - Blast
A Comparison of Test Methods

<table>
<thead>
<tr>
<th></th>
<th>Quasi-Static Test</th>
<th>Shaking Table Test</th>
<th>Hybrid Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamics</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Strain rate</td>
<td>No</td>
<td>Yes</td>
<td>Maybe</td>
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- Pseudo-dynamic test method
- For a short historic review of PDTM, see Mosqueda, Stojadinovic and Mahin EERC report EERC-2005-02
Hybrid Simulation Concept

- Discretize the structure:
  \[ Ma(t) + Cv(t) + R(d(t)) = f(t) \]
- Discretize time:
  \[ t_i = i\Delta t; \quad i = 1, N \]
- Assign:
  - an actuator
  - an excitation component
  to each degree of freedom
Impose Dynamic Equilibrium

At each time instance:

\[ Ma_i + Cv_i + r_i = f_i \]

Use measured restoring force

Use computer models for:

- Excitation
- Inertia
- Energy dissipation, commonly known as damping
Stepwise Solution

- Start from a known state at instance $i$
- Use a numerical technique to compute a target displacement at instance $(i+1)$
- Using actuators, impose target displacement and measure force
- Compute state at instance $(i+1)$
SDOF Example

- **EJM**
- **Central difference method for velocity and acceleration approximation**
- **Solution:**

\[
ma_i + cv_i + r_i = f_i
\]

\[
v_i = \frac{d_{i+1} - d_{i-1}}{2\Delta t}
\]

\[
a_i = \frac{d_{i+1} - 2d_i + d_{i-1}}{\Delta t^2}
\]

\[
d_{i+1} = \frac{1}{m\Delta t^2 + \frac{c}{2\Delta t}} \left[ \frac{2m}{\Delta t^2} d_i - \left( \frac{m}{\Delta t^2} - \frac{c}{2\Delta t} \right) d_{i-1} - r_i + f_i \right]
\]
Initial Conditions

- Not self-starting
- Given state at time zero:
  - Compute acceleration to satisfy equilibrium
  - Compute fictitious displacement to start the procedure

\[
a_0 = \frac{1}{m} (f_0 - cv_0 - r_0)
\]

\[
d_{-1} = d_0 - \Delta tv_0 - \frac{\Delta t^2}{2} a_0
\]
Example

- A SDOF system with two springs
- Work in 4-member teams
Observe

- **Tasks:**
  - Complexity
  - Required time to complete
- **Data flow**
- **Sources of error**
- **Opportunities for doing work in parallel**
- **Limitations of the iteration process:**
  - Physical specimens cannot revert to a previous state and restart
Solution: SDOF Response
Issues

- Substructures
- Similitude
- Errors
- Integration methods
- Implementation in the lab
Thank you!

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