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 an assemblage 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

	Quasi-Static Test	Shaking Table Test	Hybrid Simulation
Dynamics	No	Yes	Yes
Strain rate	No	Yes	Maybe

- 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

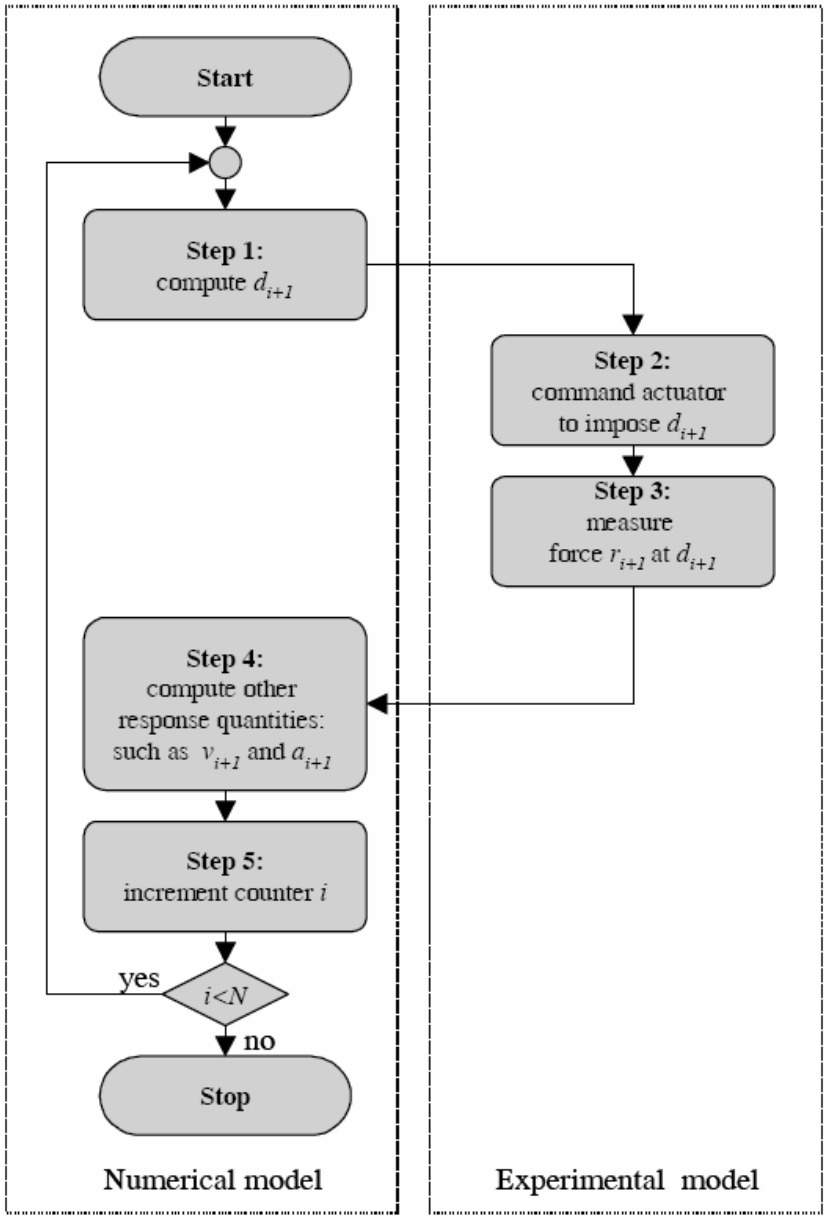
- At each time instance:

$$Ma_i + Cv_i + r_i = f_i$$

- 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

- EQM
- Central difference method for velocity and acceleration approximation
- Solution:

$$ma_i + cv_i + r_i = f_i$$

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

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

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

Initial Conditions

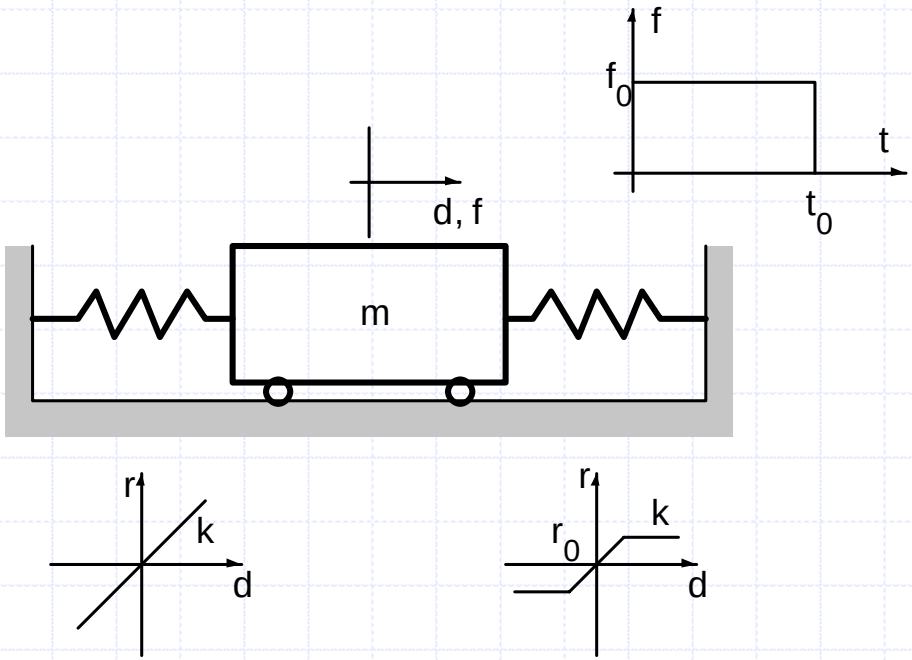
- Not self-starting
- Given state at time zero:
  - Compute acceleration to satisfy equilibrium
  - Compute fictitious displacement to start the procedure

$$a_0 = \frac{1}{m}\left(f_0 - cv_0 - r_0 \right)$$

$$d_{-1} = d_0 - \Delta t v_0 - \frac{\Delta t^2}{2} a_0$$

Example

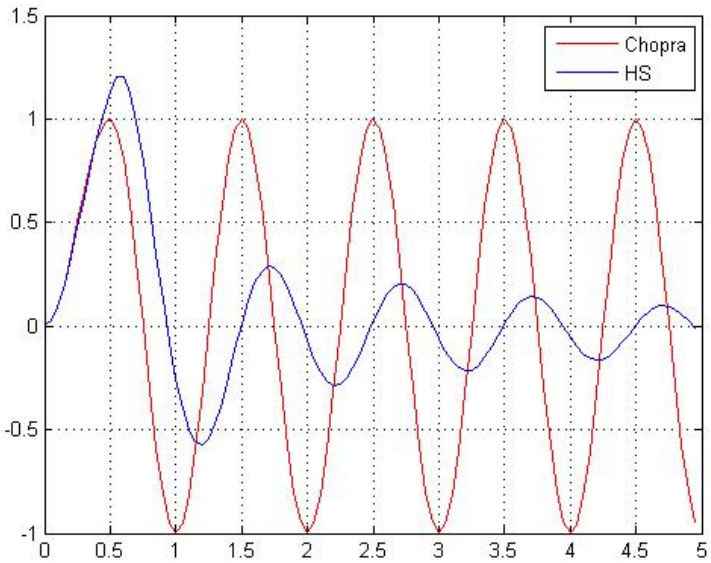
- A SDOF system with two springs
- Work in 4-member teams

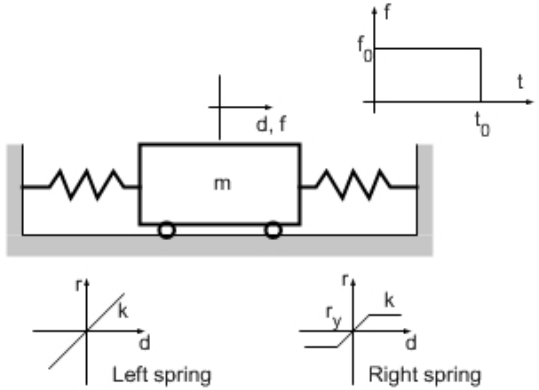


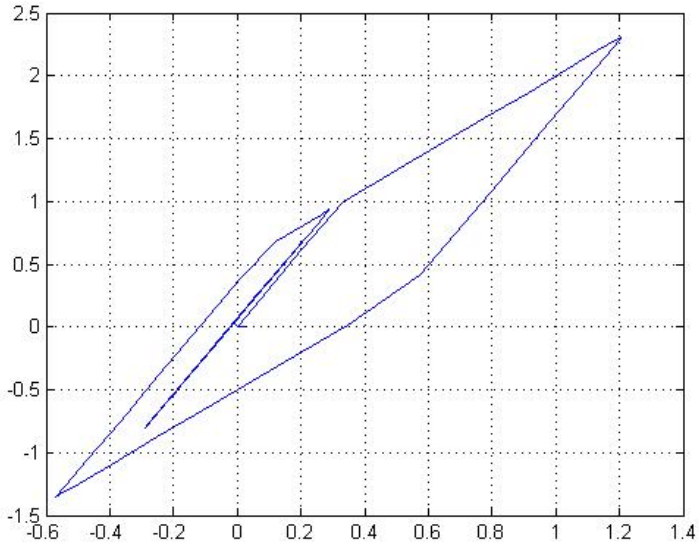
Observe

- 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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