

# 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:

$$Ma_i + Cv_i + r_i = f_i$$

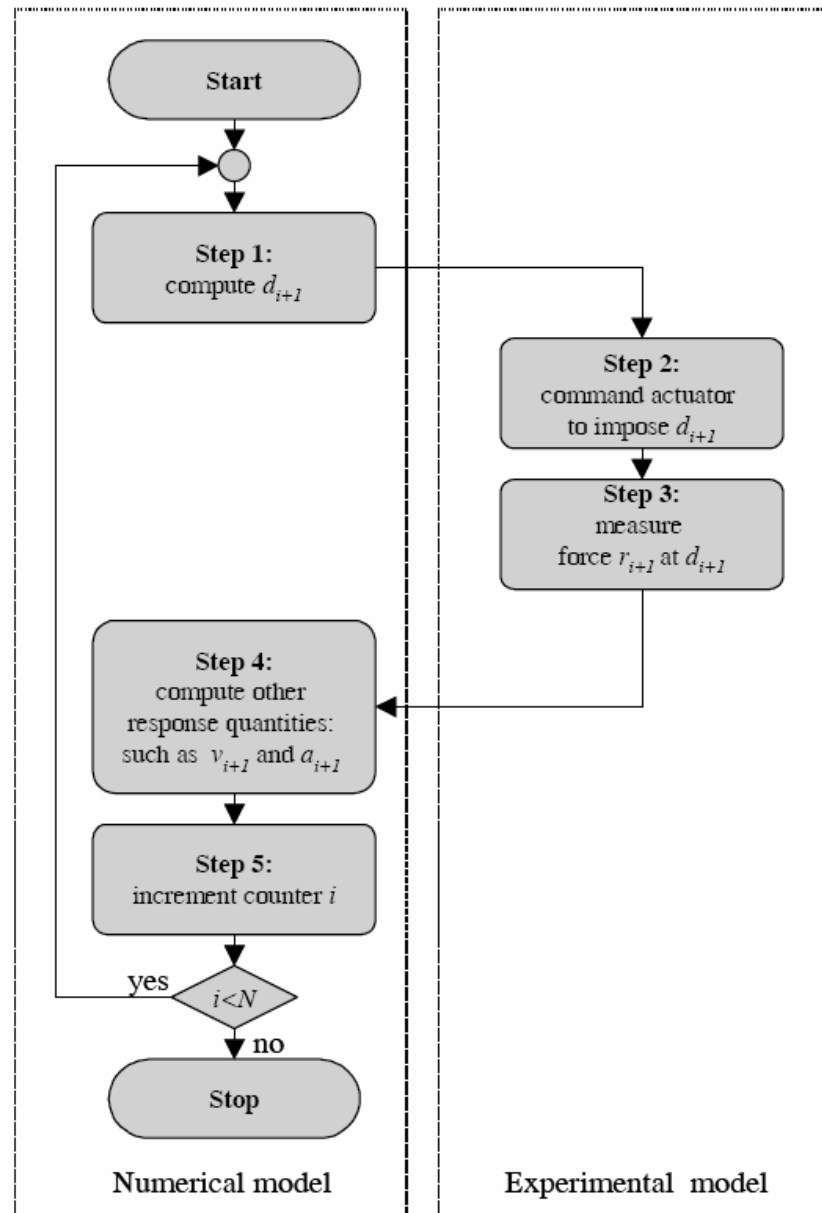
◆ Use measured restoring force

◆ 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

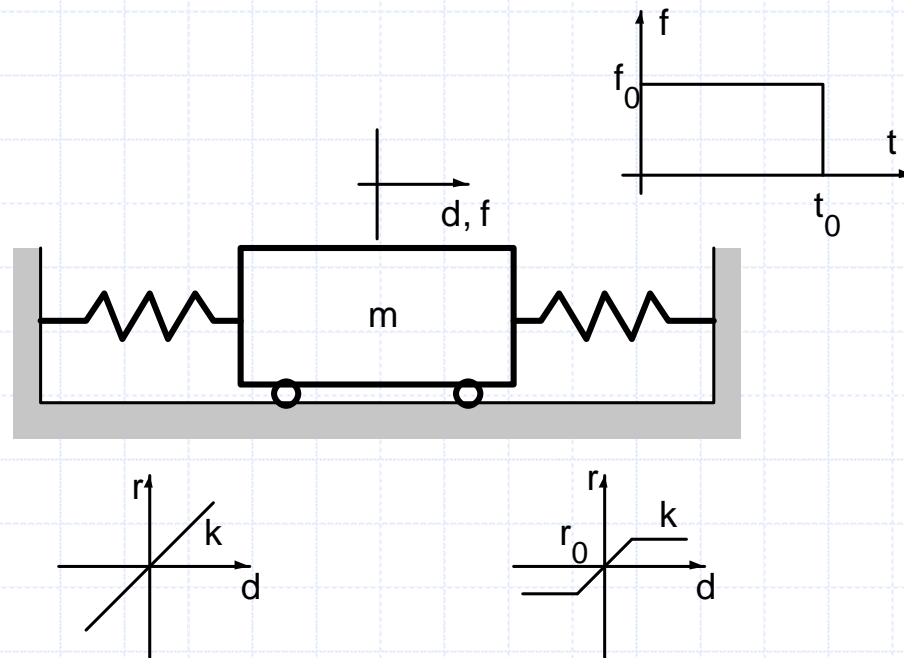
- ◆ Not self-starting
- ◆ Given state at time zero:
  - Compute acceleration to satisfy equilibrium
  - Compute fictitious displacement to start the procedure

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

$$d_{-1} = d_0 - \Delta tv_0 - \frac{\Delta t^2}{2} a_0$$

# Example

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



# Observe

## ◆ Tasks:

- Complexity
- Required time to complete

## ◆ Data flow

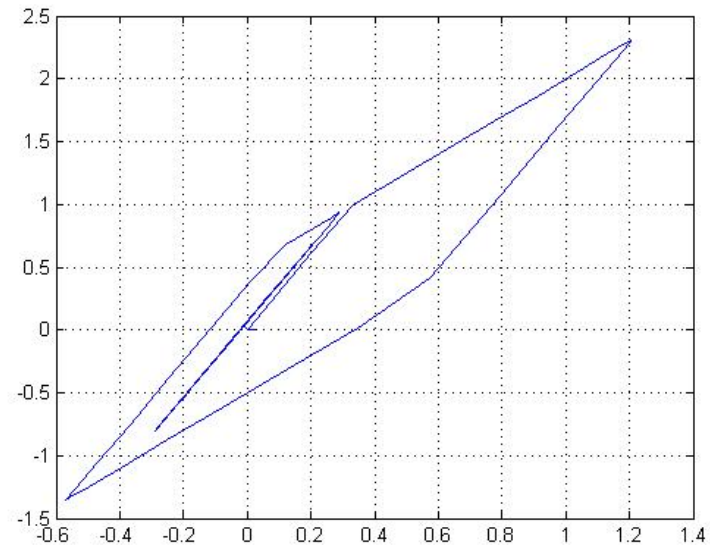
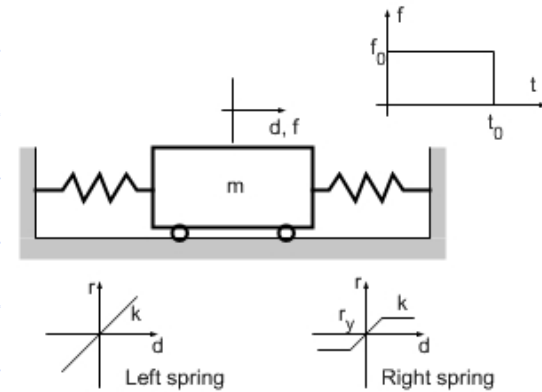
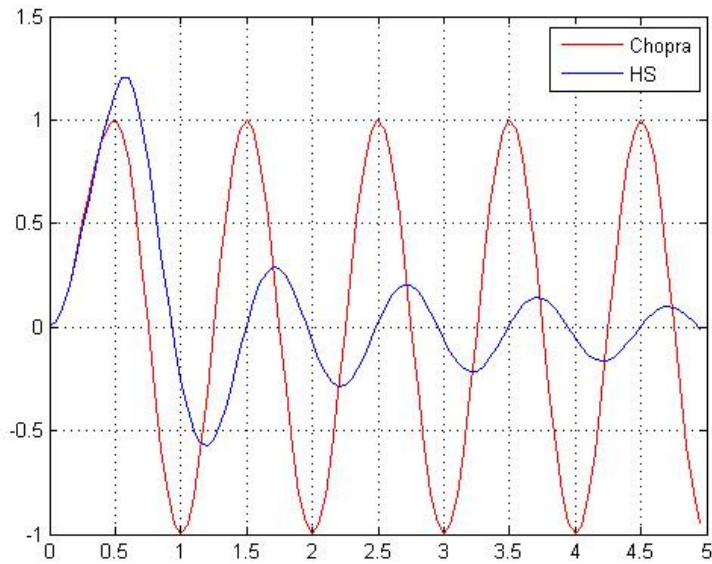
## ◆ Sources of error

## ◆ 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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<http://nees.berkeley.edu>

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