Application I: Small Component Hybrid Simulation

Selim Günay, Ph.D.
Project Scientist, PEER, University of California, Berkeley

Andreas Schellenberg, Ph.D., P.E.
Senior Structural Engineer, Maffei Structural Engineering

PEER-MTS Workshop on Hybrid Simulation
Technologies & Methods for Civil Engineering
Richmond Field Station

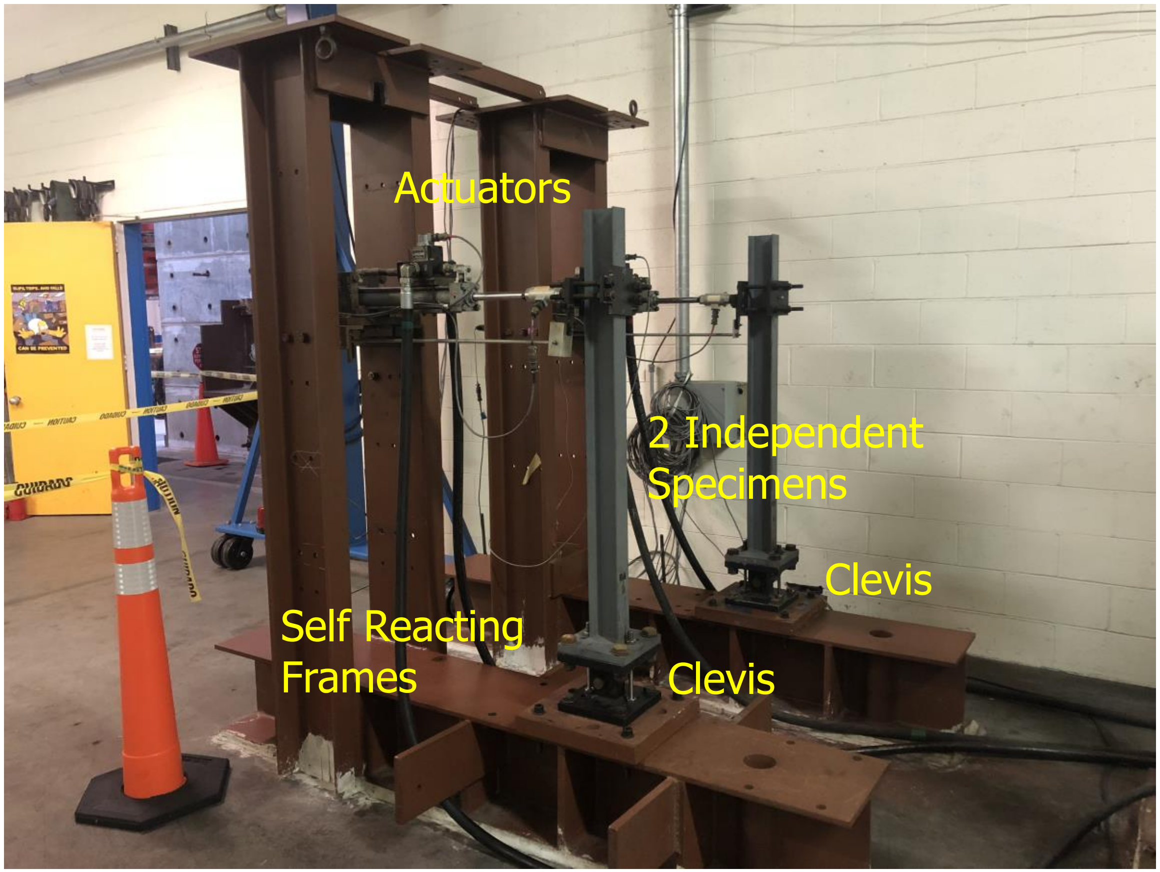
March 20-21, 2018

Outline

- Introduction
- Previous Studies
- Small Component Demo Details

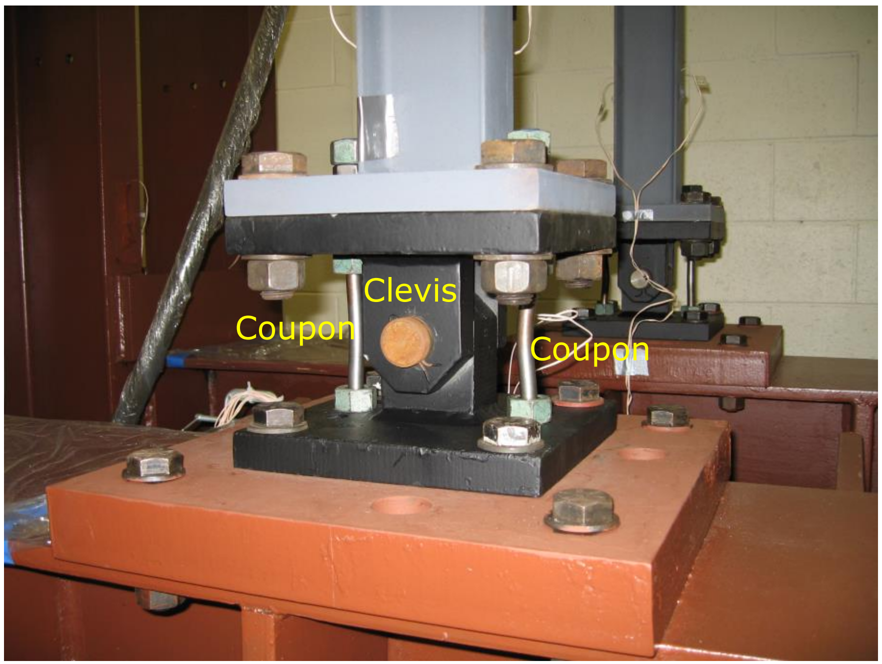
PEER

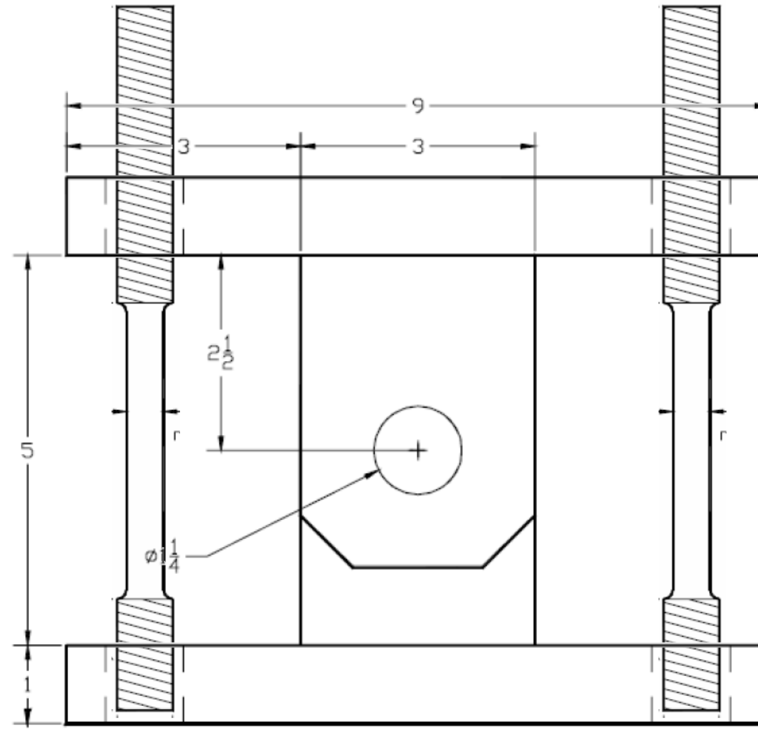
Introduction: Overview

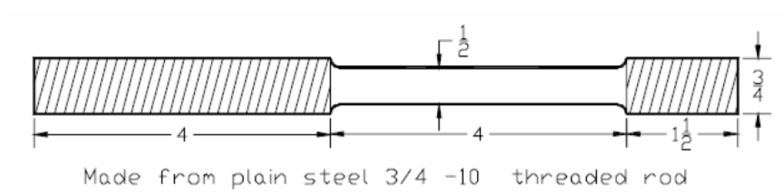


A small component setup exists at the PEER structural laboratories to assist with hybrid simulation developments and small scale applications

Introduction: Clevis & Coupons

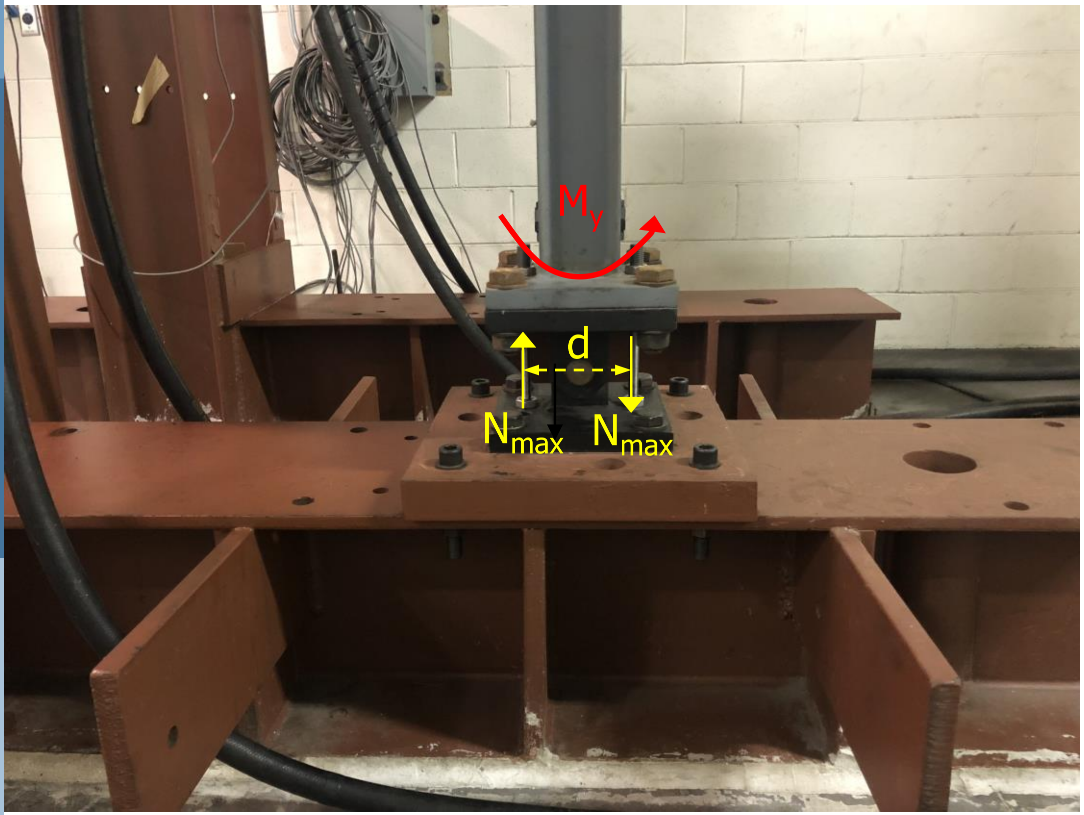






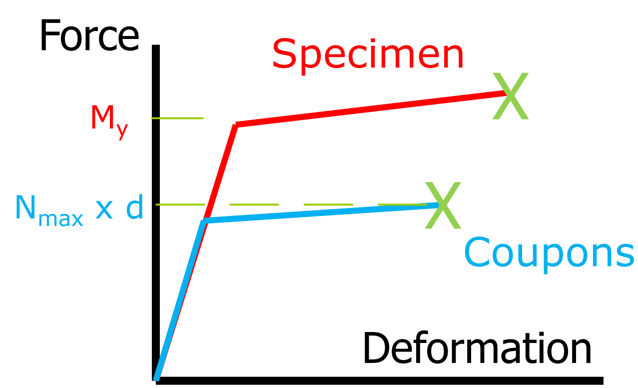
PEER

Introduction: Plastic Hinge



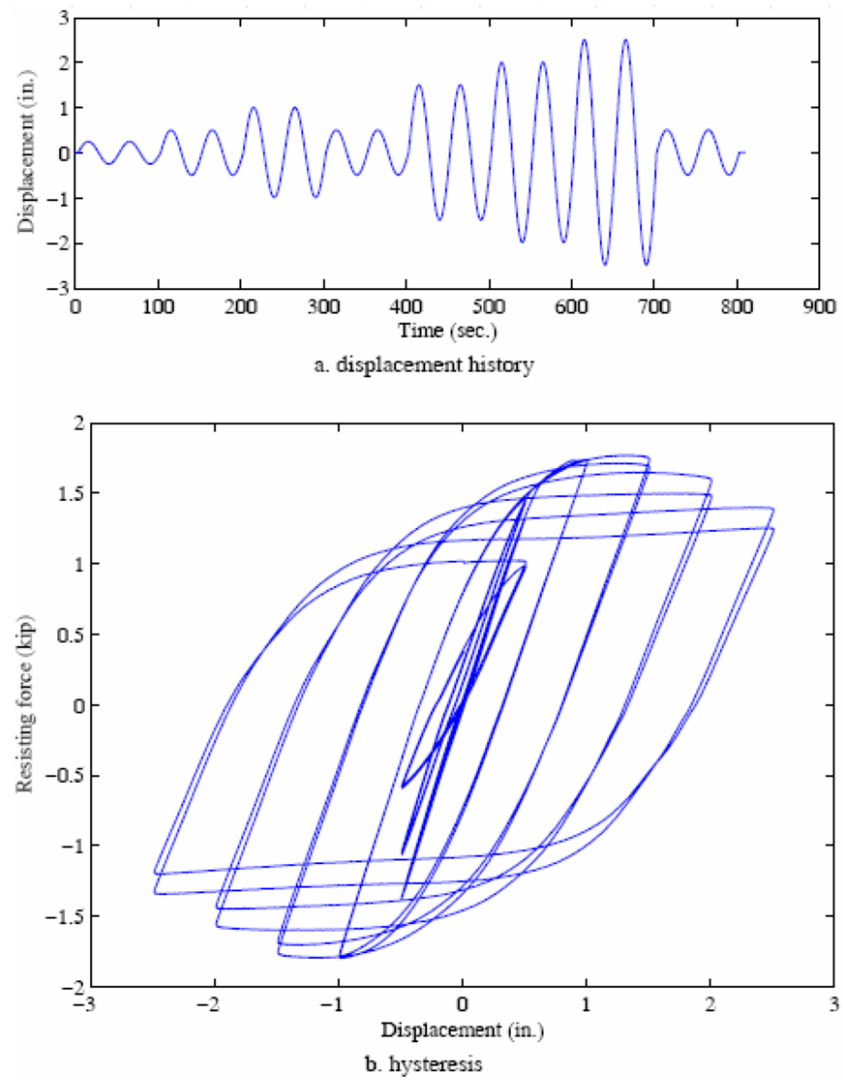
$M_y > N_{max} \times d$

- Yield moment of the I-beam section is larger than the ultimate moment developed by the two coupons, therefore the coupons fracture before any damage happens to the I-beam
- Coupons easily replaceable
- This allows repeated usage of the setup



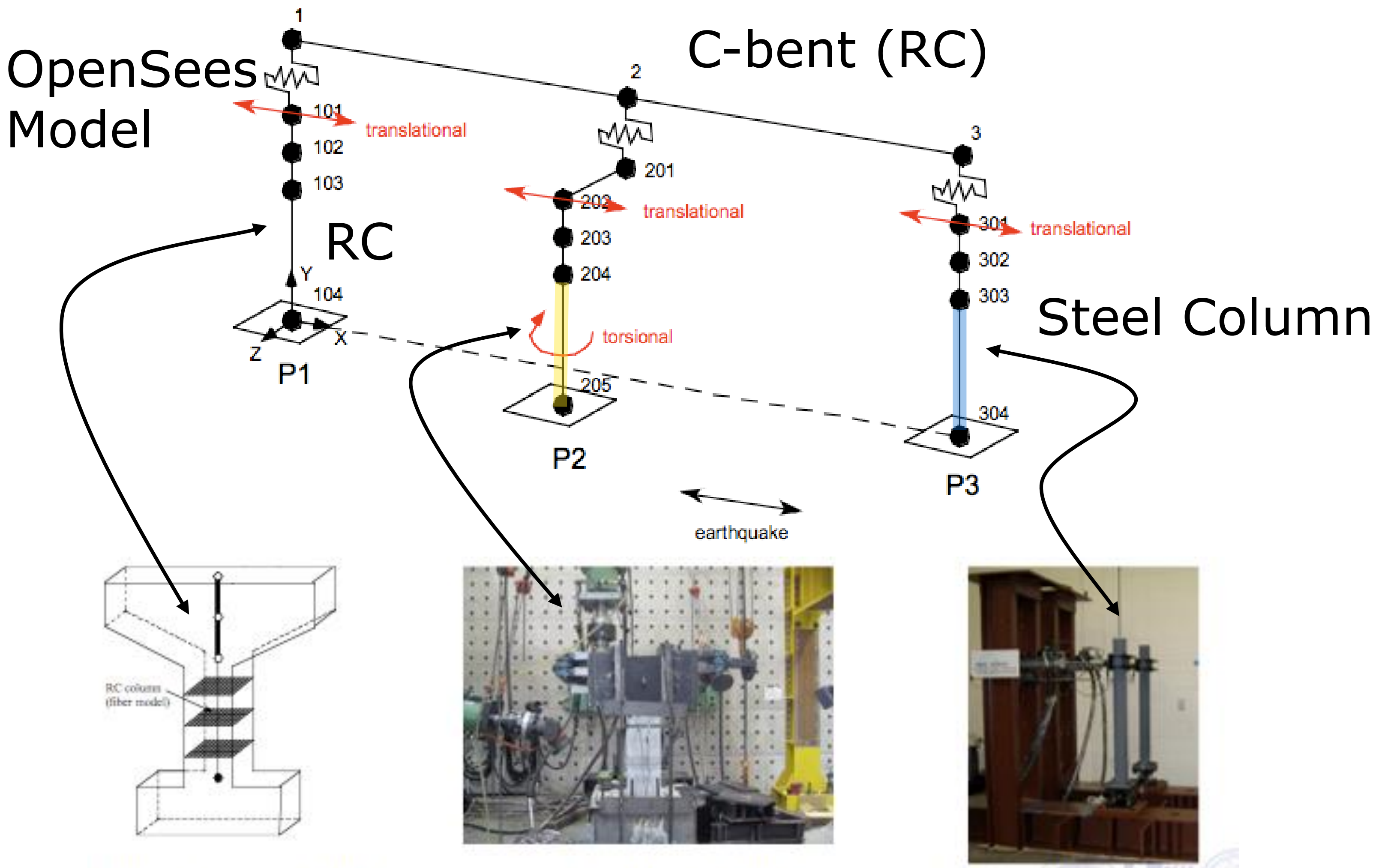
Column Response

- Stable and repeatable hysteretic response
- Different coupon designs result in very different response



PEER

Previous Studies: International Bridge Test



Numerical Component at Kyoto University

Experimental Component at Kyoto University

Experimental Component at nees@berkeley

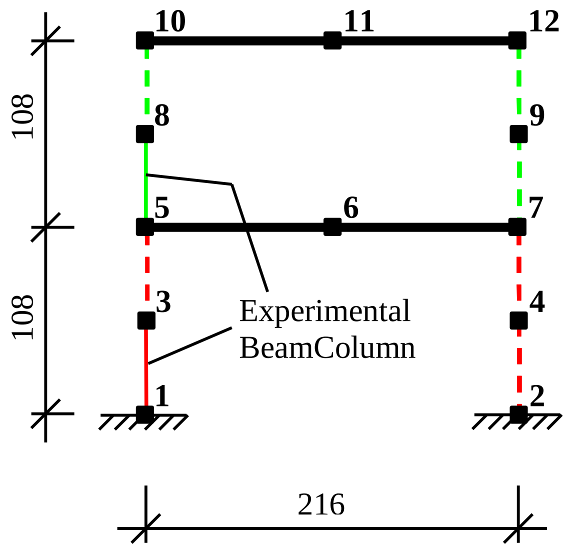
Previous Studies: International Bridge Test

Kyoto University

UC Berkeley

Tele-Conference Communication

Previous Studies: Two Story Shear Building

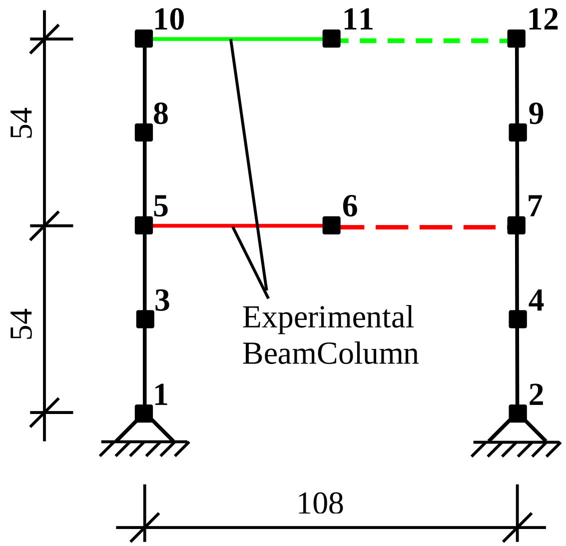


Properties of Model:

- num. DOF = 14 (6 with mass)
- Period: T_1 = 0.618sec
  T_2 = 0.236sec
- Damping: ζ_1 = 0.02
- ExpElements: EEBeamColumn2d
- ExpSetups: ESOneActuator
- ExpControl: ECxPCtarget

9

Previous Studies: Two Story Frame Building

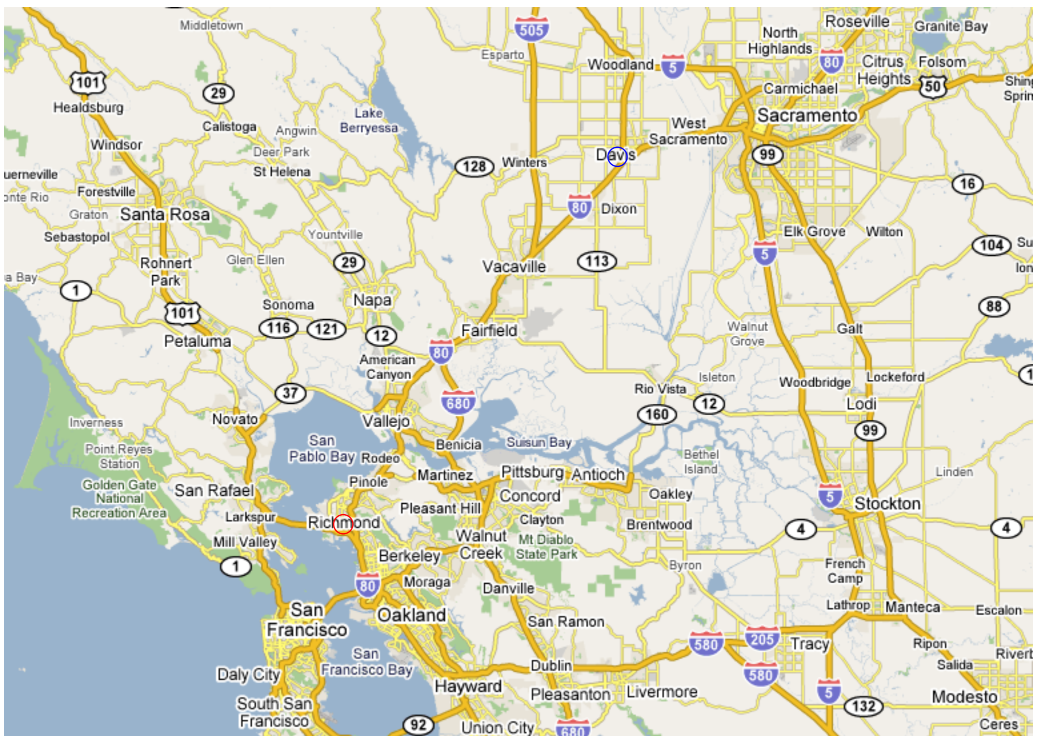


Properties of Model:

- num. DOF = 28 (4 with mass)
- Period: T_1 = 0.473sec
  T_2 = 0.071sec
- Damping: $\zeta_1 = 0.02$
- ExpElements: EEBeamColumn2d
- ExpSetups: ESOneActuator
- ExpControl: ECxPCtarget

Previous Studies: Rapid Geographically Distributed HS

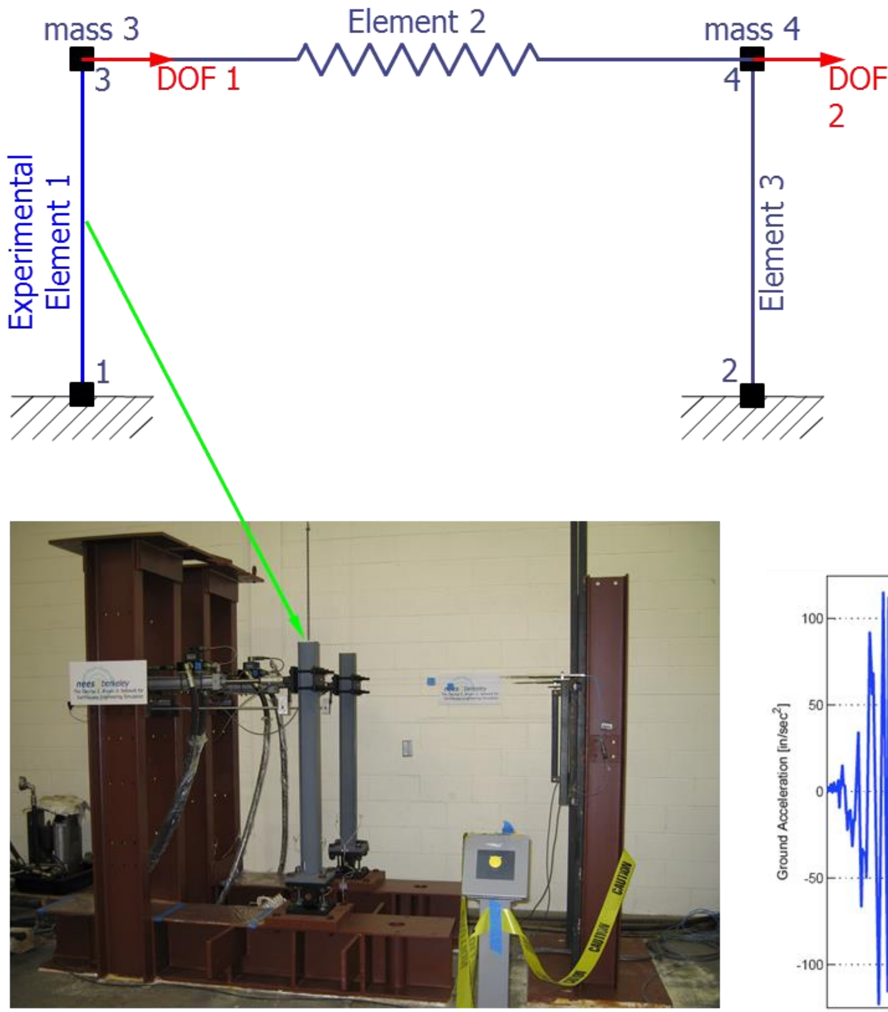
- Try to perform a geographically distributed hybrid simulation in real-time
- Soft real-time and not hard real-time, since deterministic execution is not guaranteed



- Client
  NEESinc, Davis
- Server
  RFS, UC Berkeley

PEER

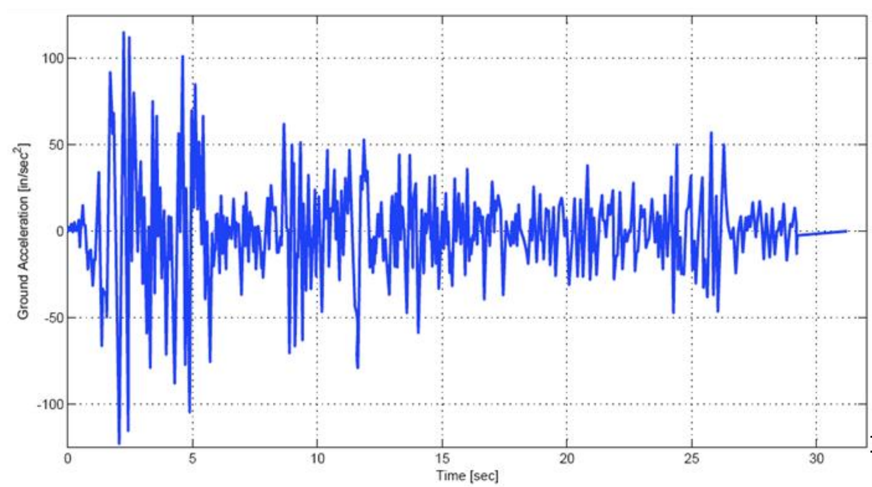
Previous Studies: Rapid Geographically Distributed HS



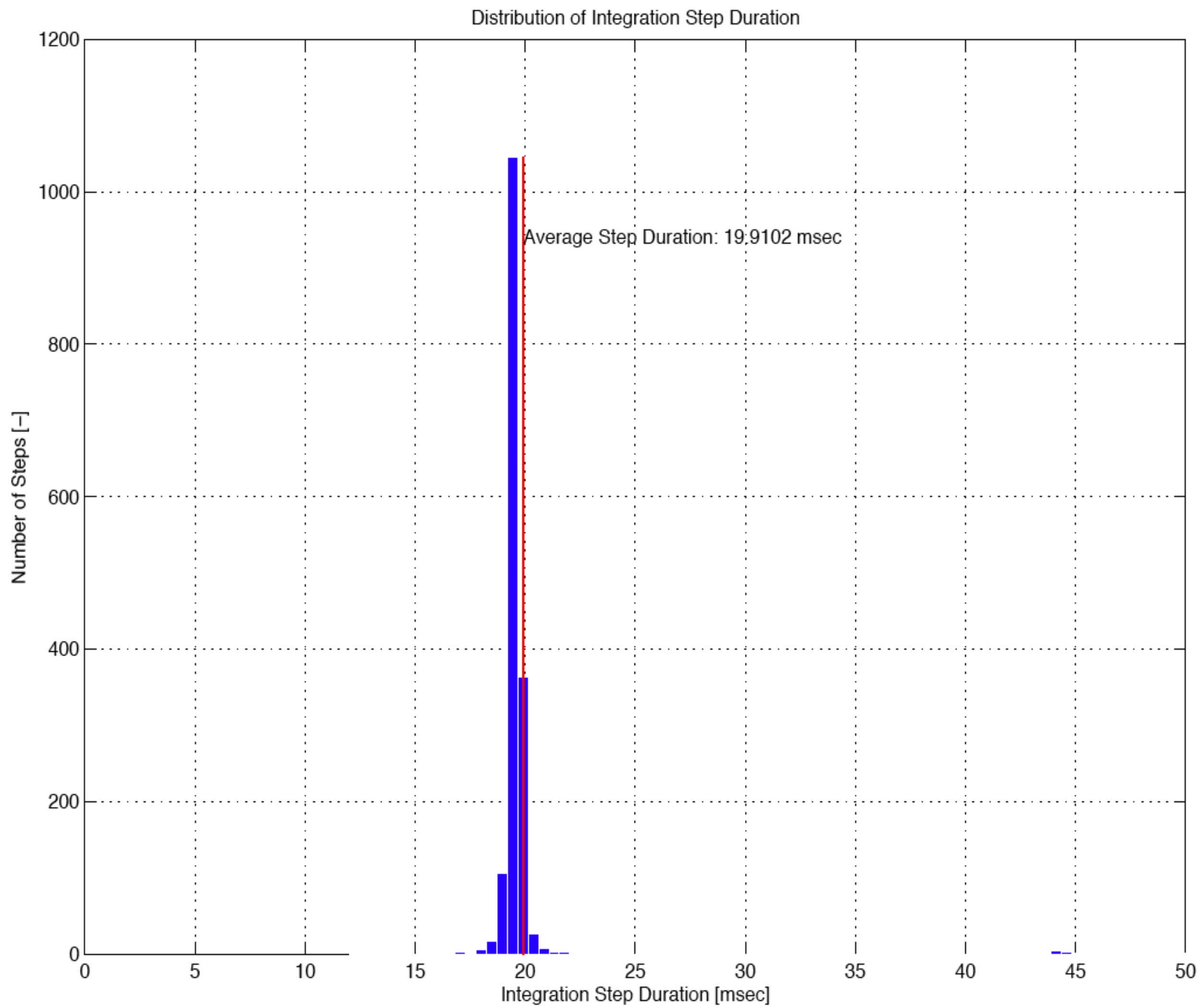
Properties of Model:

- NDOF = 2 (2 with mass)
- Period: T_1 = 0.622 sec
- Damping: ζ_1 = 0.05 (m-prop.)

- ExpElements: EETwoNodeLink
- ExpSetups: ESOneActuator
- ExpControl: ECxPCtarget
- ELC: pga = 0.319g



Previous Studies: Rapid Geographically Distributed HS



$dt_{int} = 0.0200$

$dt_{sim} = 0.0195$

$dt_{avg} = 0.0199$

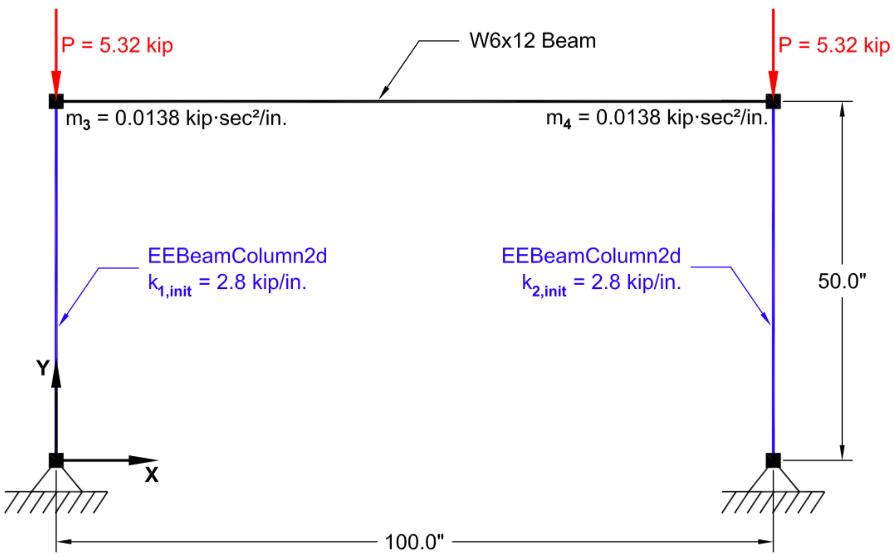
$t_{eq} = 31.98$

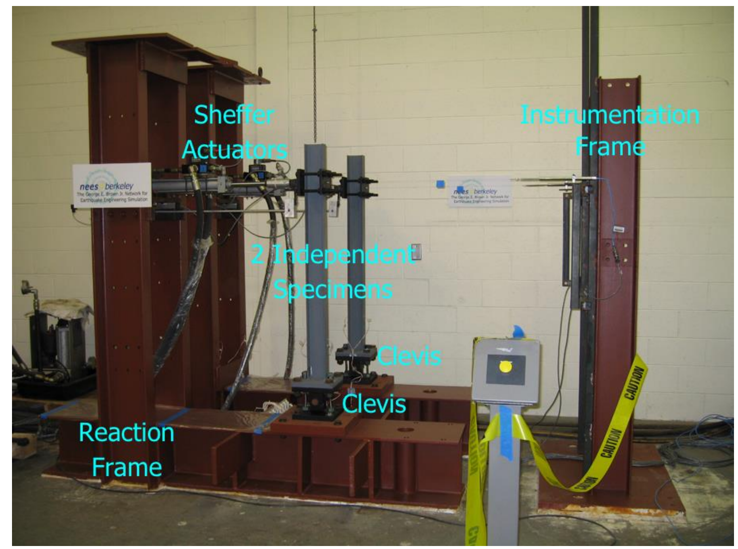
$t_{sim} = 31.23$

$t_{avg} = 31.84$

PEER

Previous Studies: Structural Collapse of Portal Frame





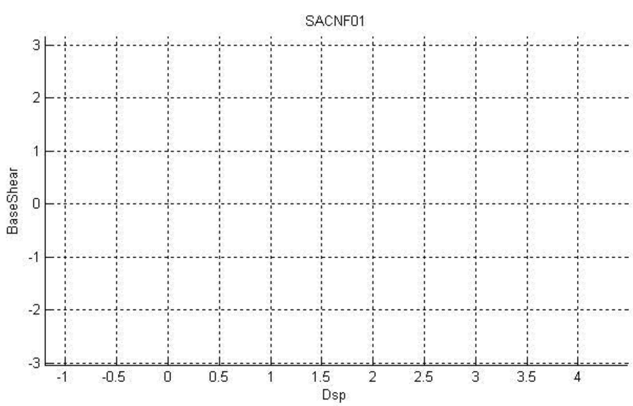
Properties of Model:

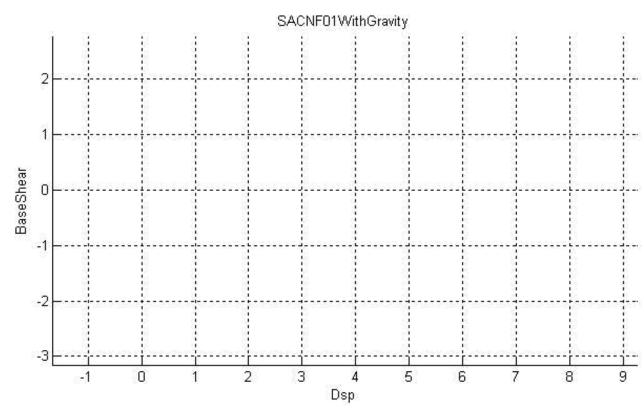
- NDOF = 8 (2 with mass)
- Period: T_1 = 0.49 sec
- Damping: ζ_1 = 0.05
- P = 50% of φPn

- Crd-Trans: P-Delta, Corotational
- ExpElements: EEBeamColumn2d
- ExpSetups: ESOneActuator
- ExpControl: ECxPCtarget
- SACNF01: pga = 0.906g

PEER

Previous Studies: Structural Collapse of Portal Frame



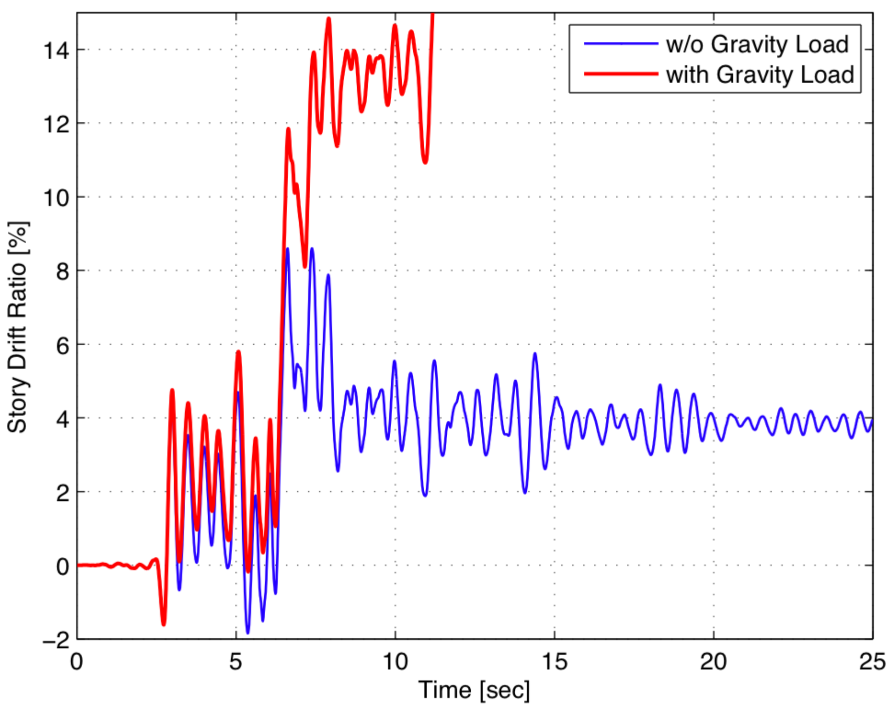


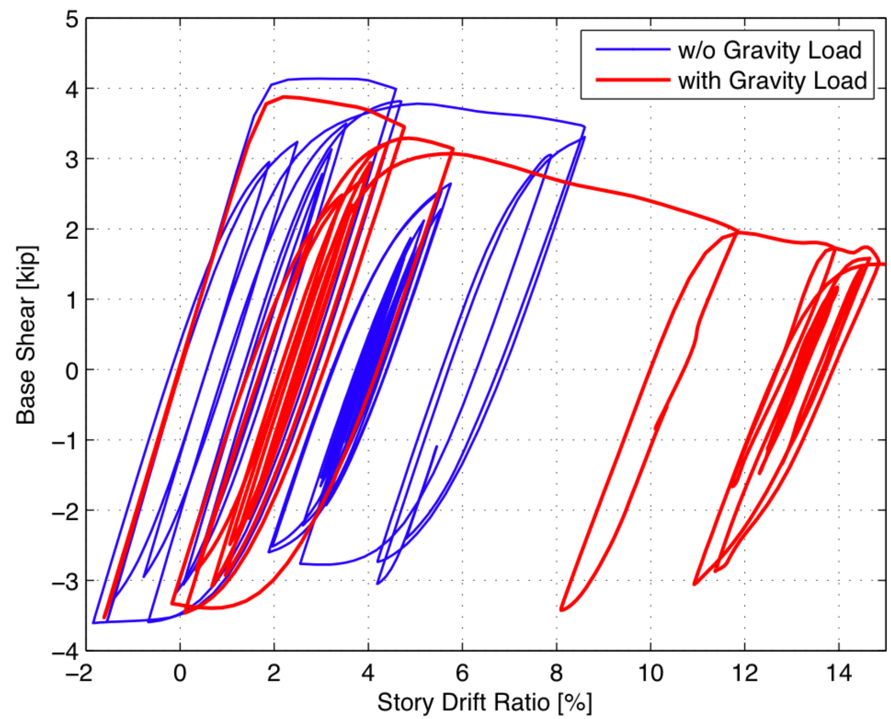
Without Gravity Load

With Gravity Load

Previous Studies: Structural Collapse of Portal Frame

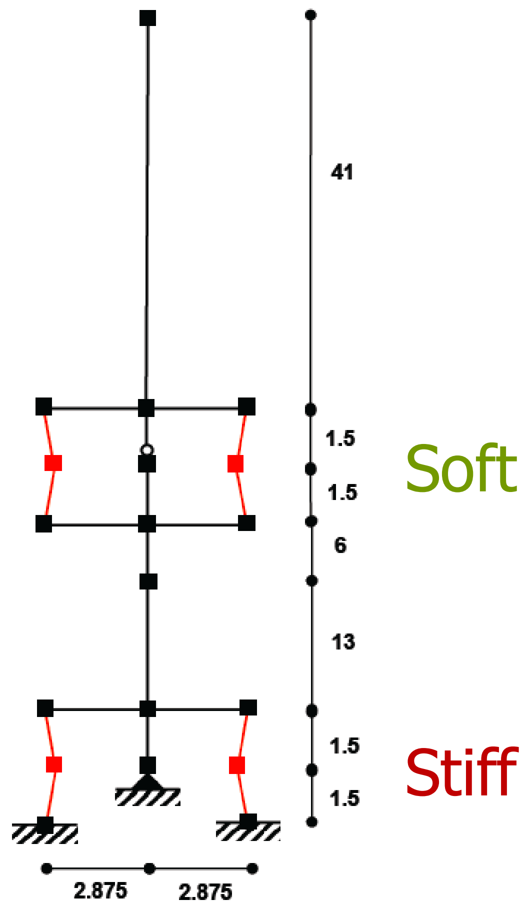
Global Response Comparison





Previous Studies: Force Control Validation & Verification

2 DOF Specimen



$$T_1 = 0.55\text{sec}$$

$$T_2 = 0.20\text{sec}$$

$$m = \begin{bmatrix} 0.01 & 0 \\ 0 & 0.1 \end{bmatrix}$$

$$k = \begin{bmatrix} 3.4 & -12 \\ -12 & 84 \end{bmatrix}$$

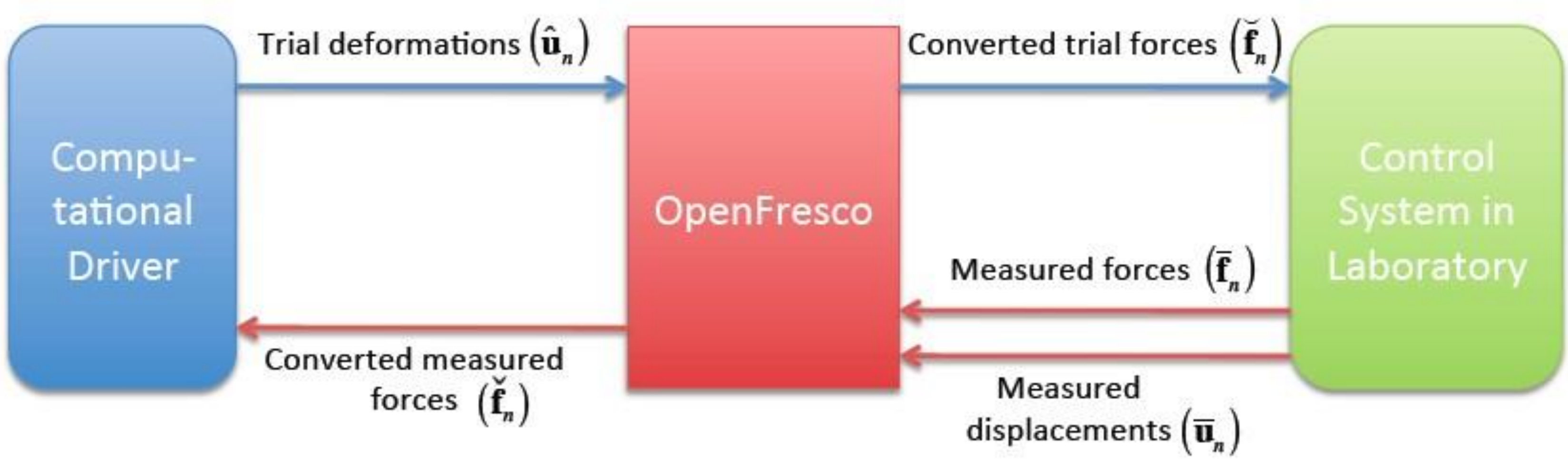
By Hong K. Kim

Previous Studies: Force Control Validation & Verification

- Compatibility (of displ.) methods:
  - Tangent-based:
    - Broyden, BFGS, Intrinsic, Transpose
  - Krylov sub-space
  - Compatible with numerical model implementation methods
- Equilibrium (of forces) methods:
  - Derived from flexibility FEM formulation
  - Require compatible numerical models

Previous Studies: Force Control Validation & Verification

- Compatibility methods



- Conversion implemented in the `ExperimentalSignalFilter` class

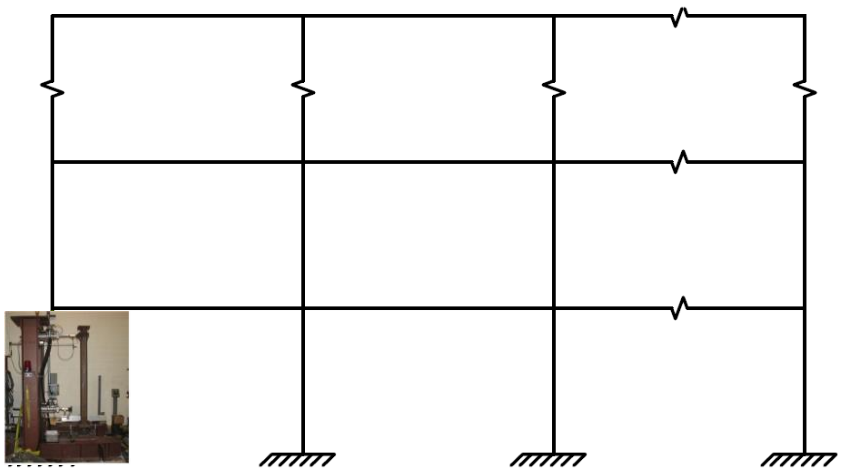
By Hong K. Kim

PEER

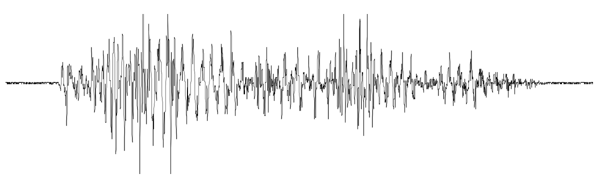
Previous Studies: Force Control Validation & Verification

- Equilibrium methods
- Implemented in:
  - Flexibility (force) based FEA package in Matlab (based on OpenSees structure)
  - OpenFresco force-based predictor and corrector in Simulink/Stateflow
  - OpenFresco force experimental control sub-class

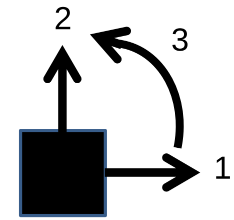
Previous Studies: Large Analytical Substructures



M-Story X N-Bay
(**OpenSees**)

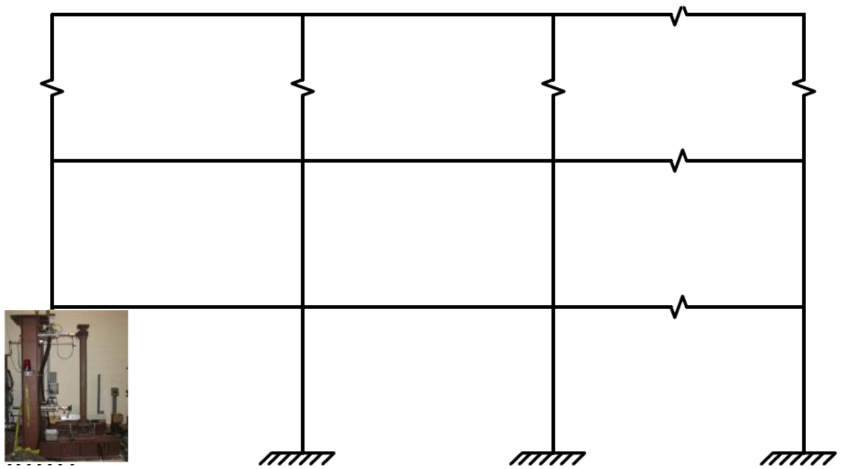


Investigation of the maximum number of degrees of freedom (DOF) that can be run in real-time hybrid simulation



# of DOF = 3*(M+1)*N

Previous Studies: Large Analytical Substructures

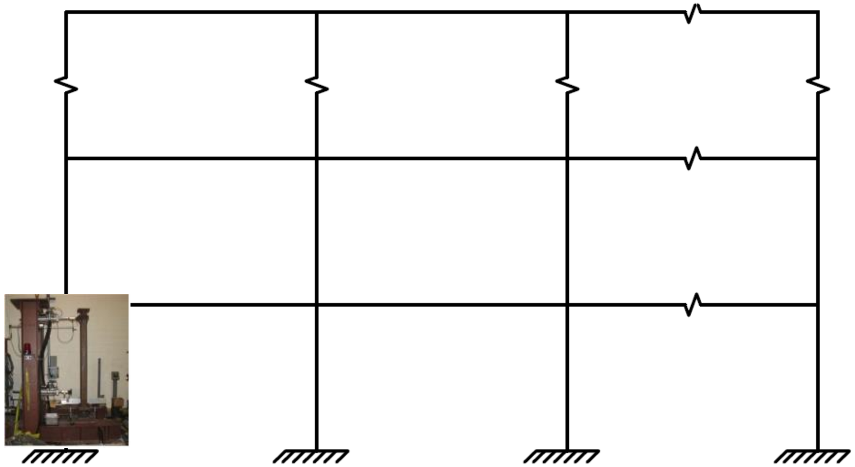


M-Story X N-Bay

- ❑ Analytical beams and columns
  - ➢ Linear elastic
  - ➢ Nonlinearity defined with moment-curvature
  - ➢ Nonlinearity defined with fiber sections

PEER

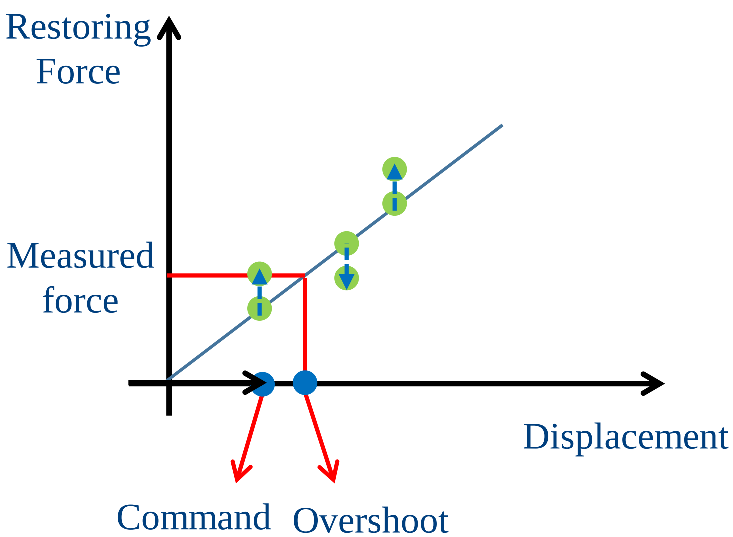
Previous Studies: Large Analytical Substructures

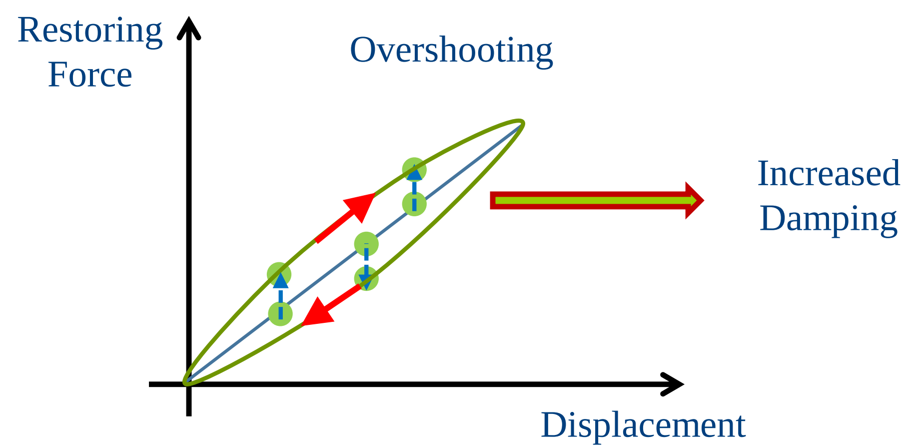


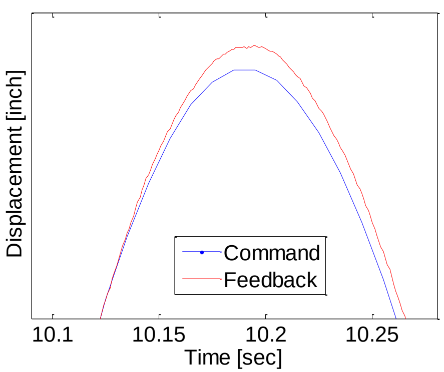
M-Story X N-Bay

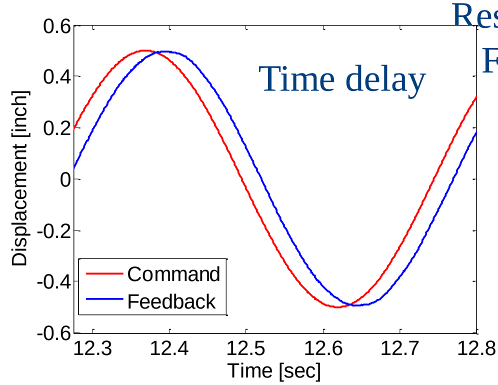
- The study was conducted in 2012 and the maximum DOF were 720, 480 and 120 for the linear elastic, moment-curvature nonlinearity and fiber section nonlinearity cases respectively
- Computation power increased exponentially over the past 5 years (check out the recently assembled computers in the control room!)
- We will repeat the study soon to update these numbers

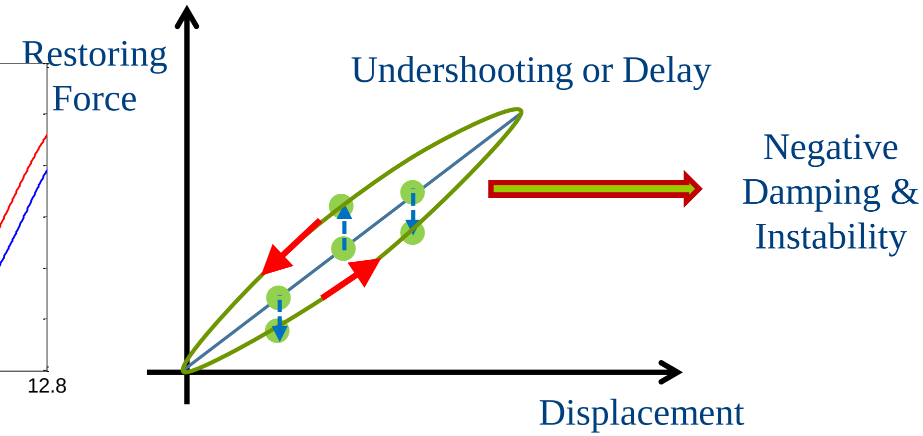
Previous Studies: Effect of Time Delay on Real-time Hybrid Simulation





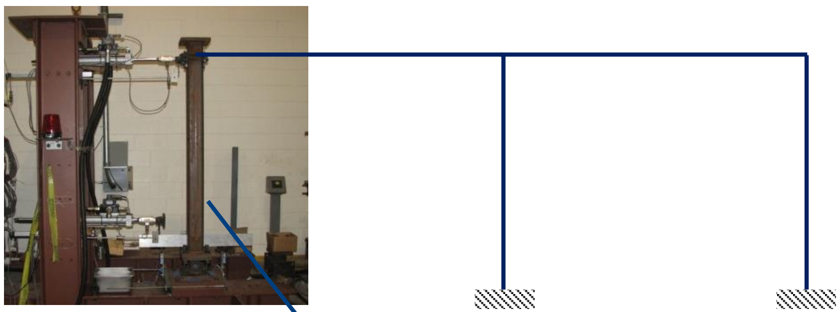




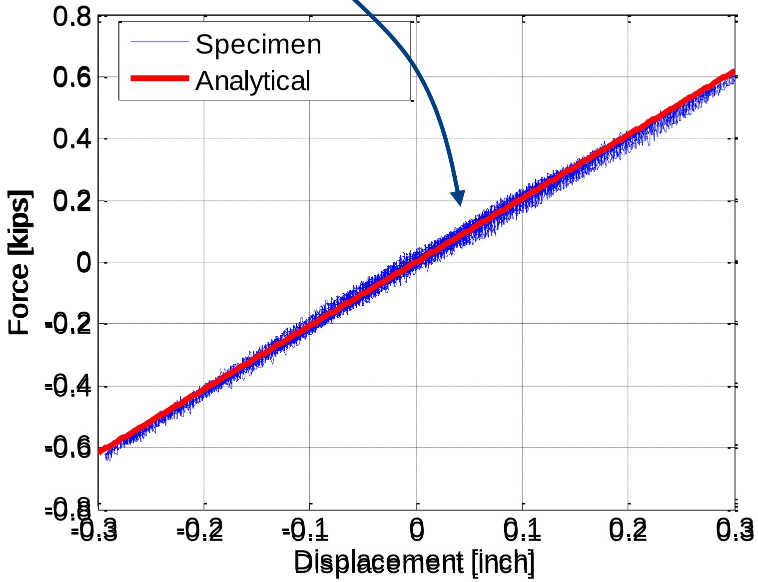


Simulation Errors Lecture in the Morning Session

Previous Studies: Effect of Time Delay on Real-time Hybrid Simulation

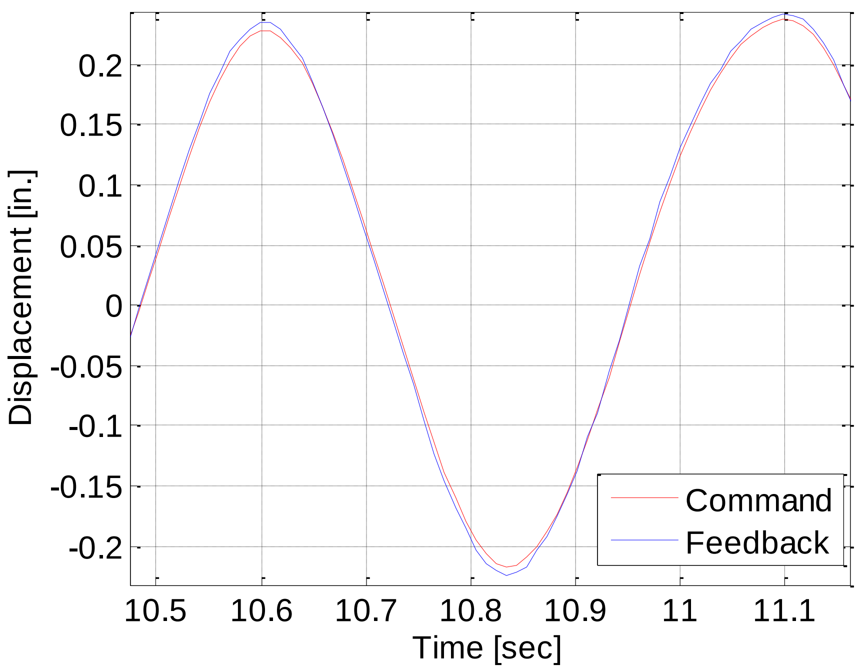


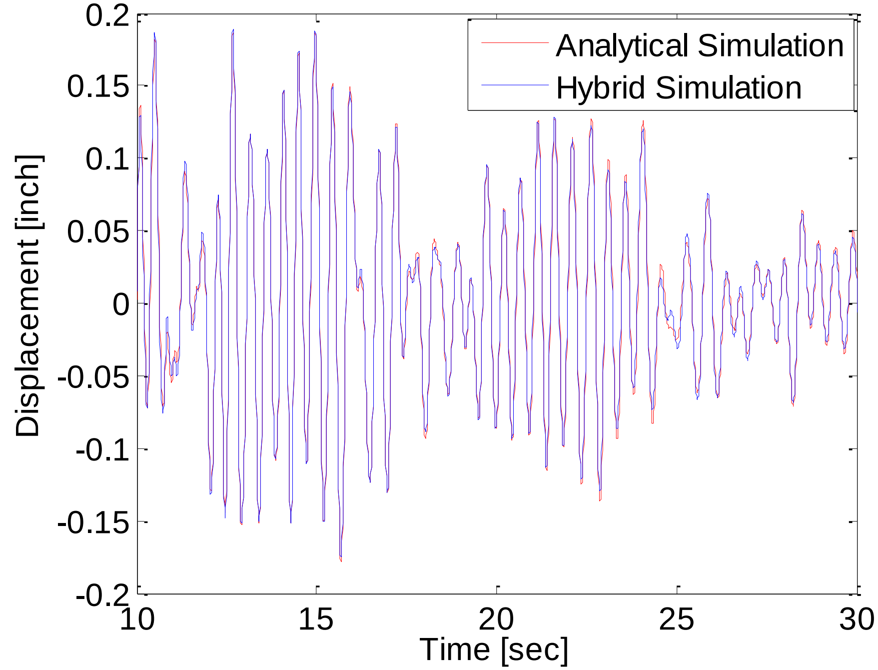
T =0.5 sec
ζ=5%



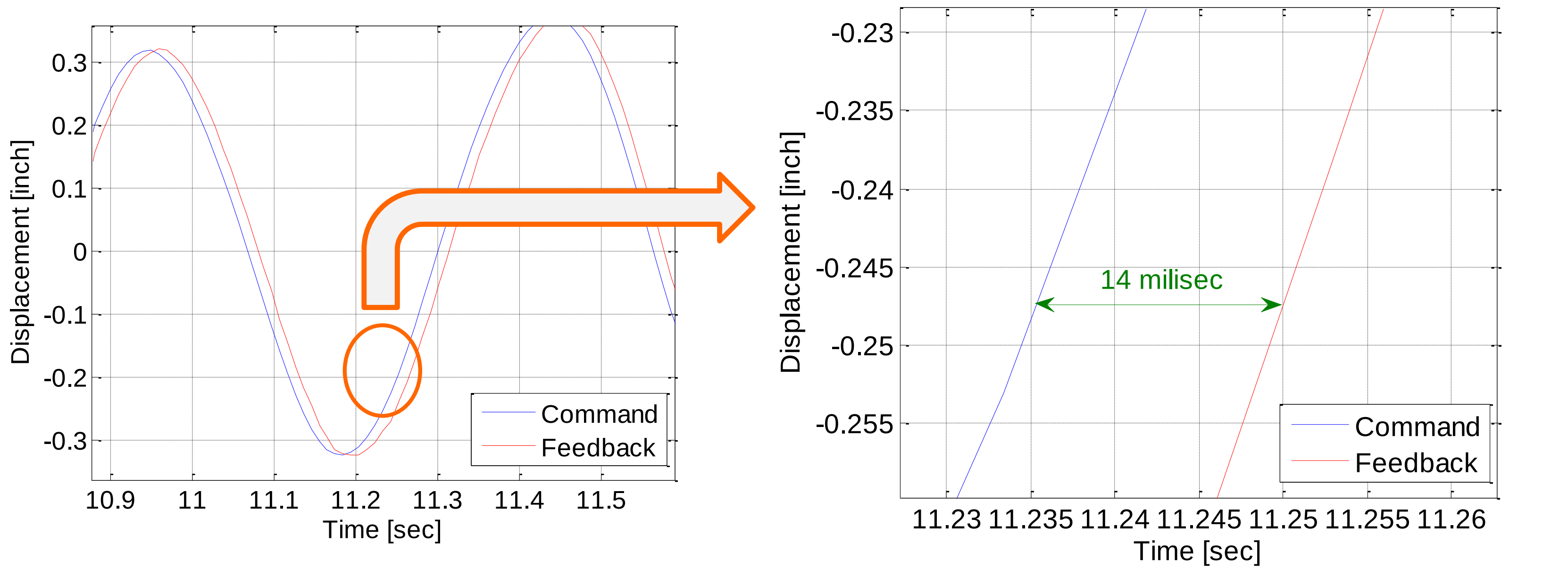
Previous Studies: Effect of Time Delay on Real-time Hybrid Simulation

No time delay



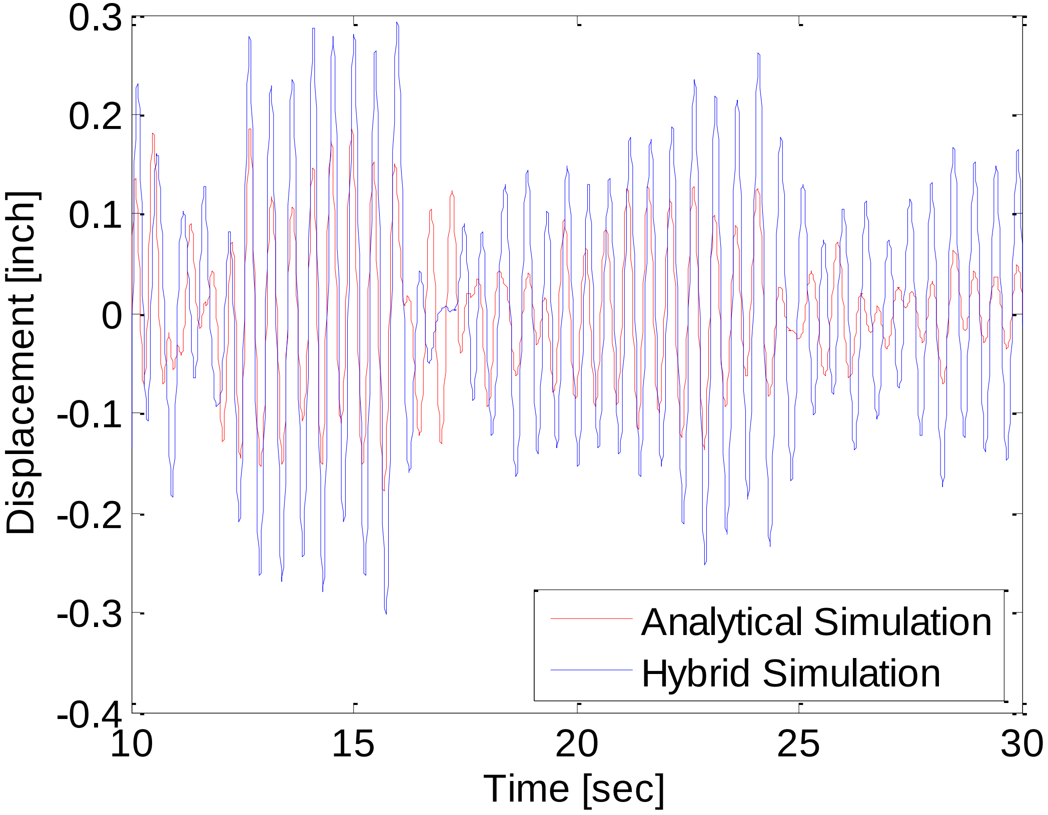


Previous Studies: Effect of Time Delay on Real-time Hybrid Simulation



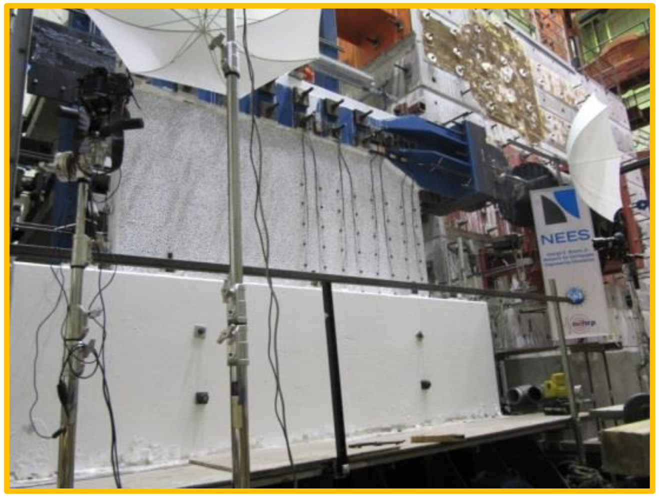
14 millisecond time delay introduced artificially by adjusting the feed-forward gain

Previous Studies: Effect of Time Delay on Real-time Hybrid Simulation



PEER

Previous Studies: Rehearsals for Large-Scale HS Tests



Hybrid Simulation of Squat Walls (Whyte and Stojadinovic)

Feasibility of using Explicit Newmark integration

Hybrid Simulation of Tomorrow's Braced Frames (Lai and Mahin)

Validation of OpenSees / OpenFresco files, HS communications

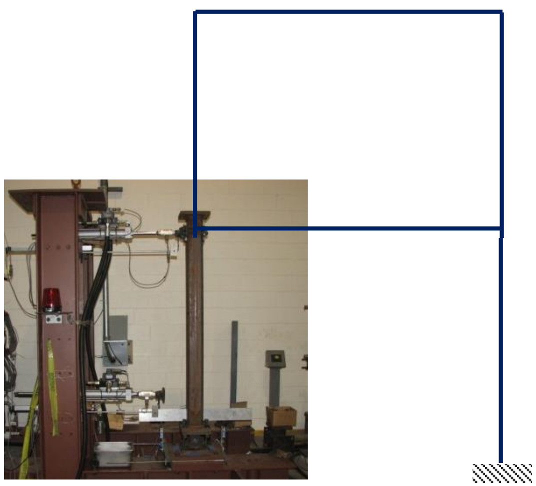
Demonstrations

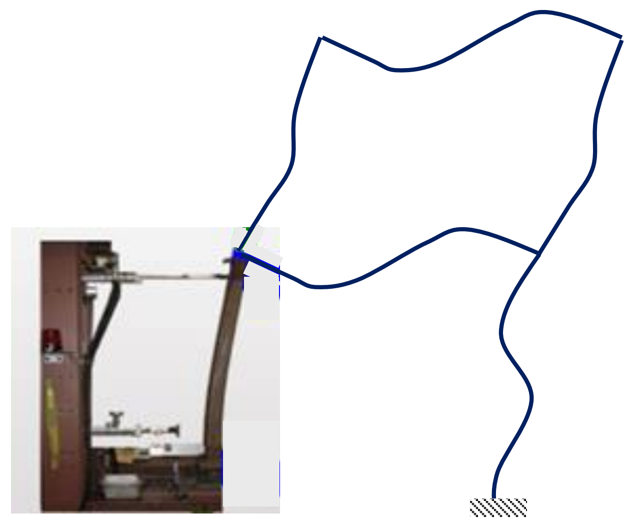
- ✓ Free vibration HS
- ✓ Geographically Distributed HS with Davis Hall
- ✓ Local HS

Free Vibration HS

Error identification using free vibration

Step 1: Push the hybrid structure, generally in the first mode, to a displacement within the linear range

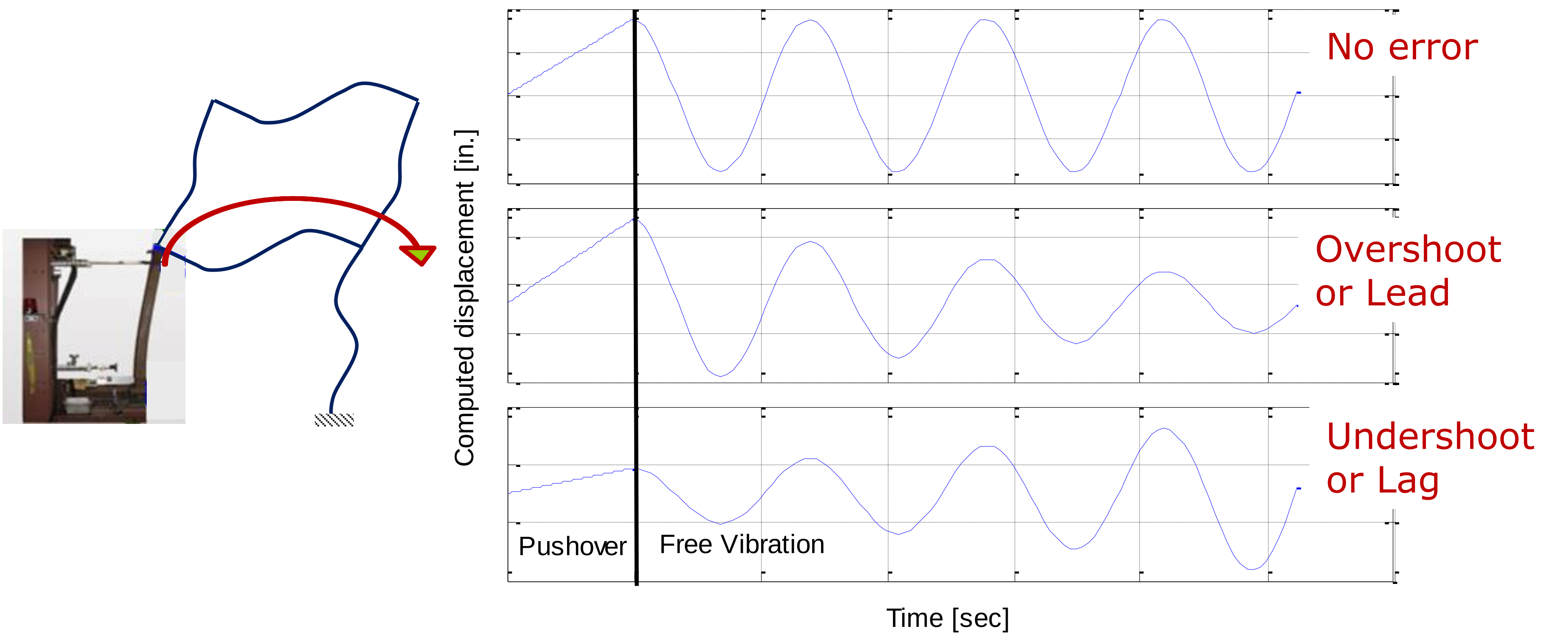




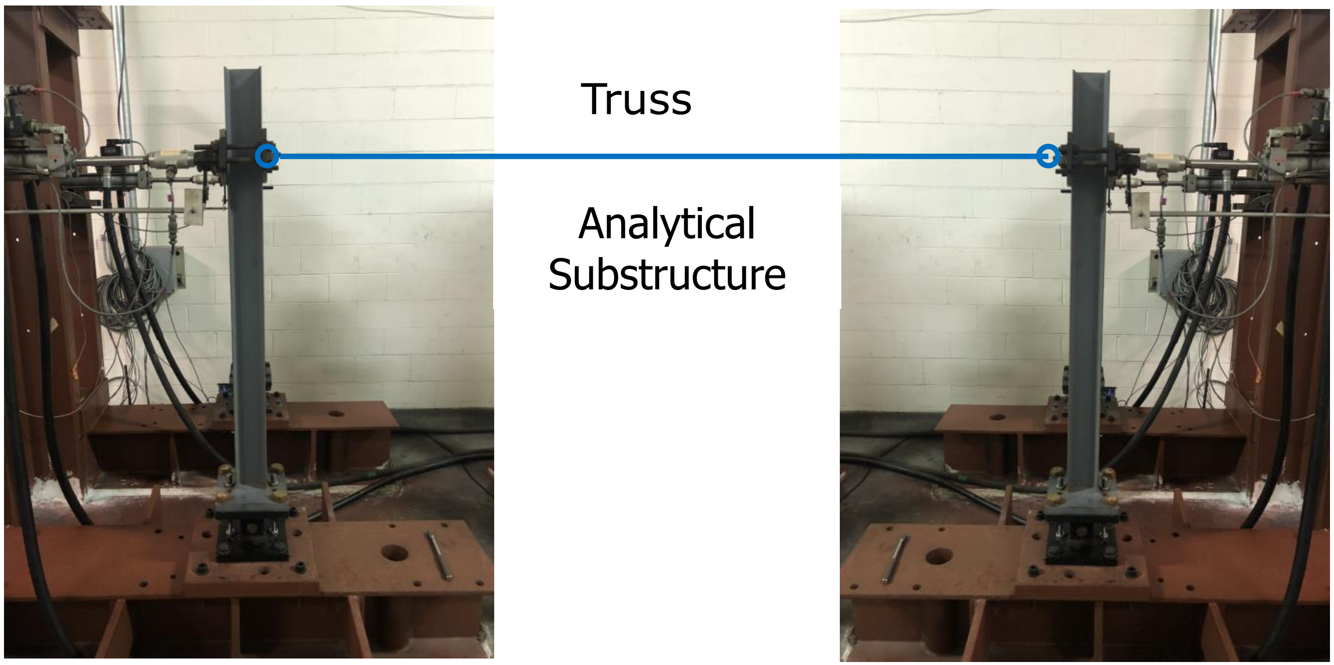
Step 2: Run the free vibration hybrid simulation test from this displaced configuration

No damping in the analytical substructure and the specimen response is linear elastic, therefore any negative or positive damping is due to errors

Free Vibration HS

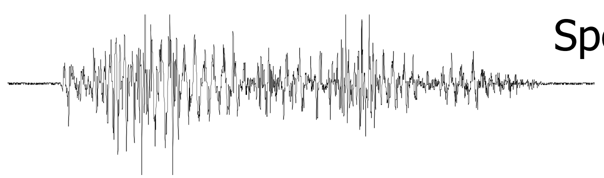


Local HS

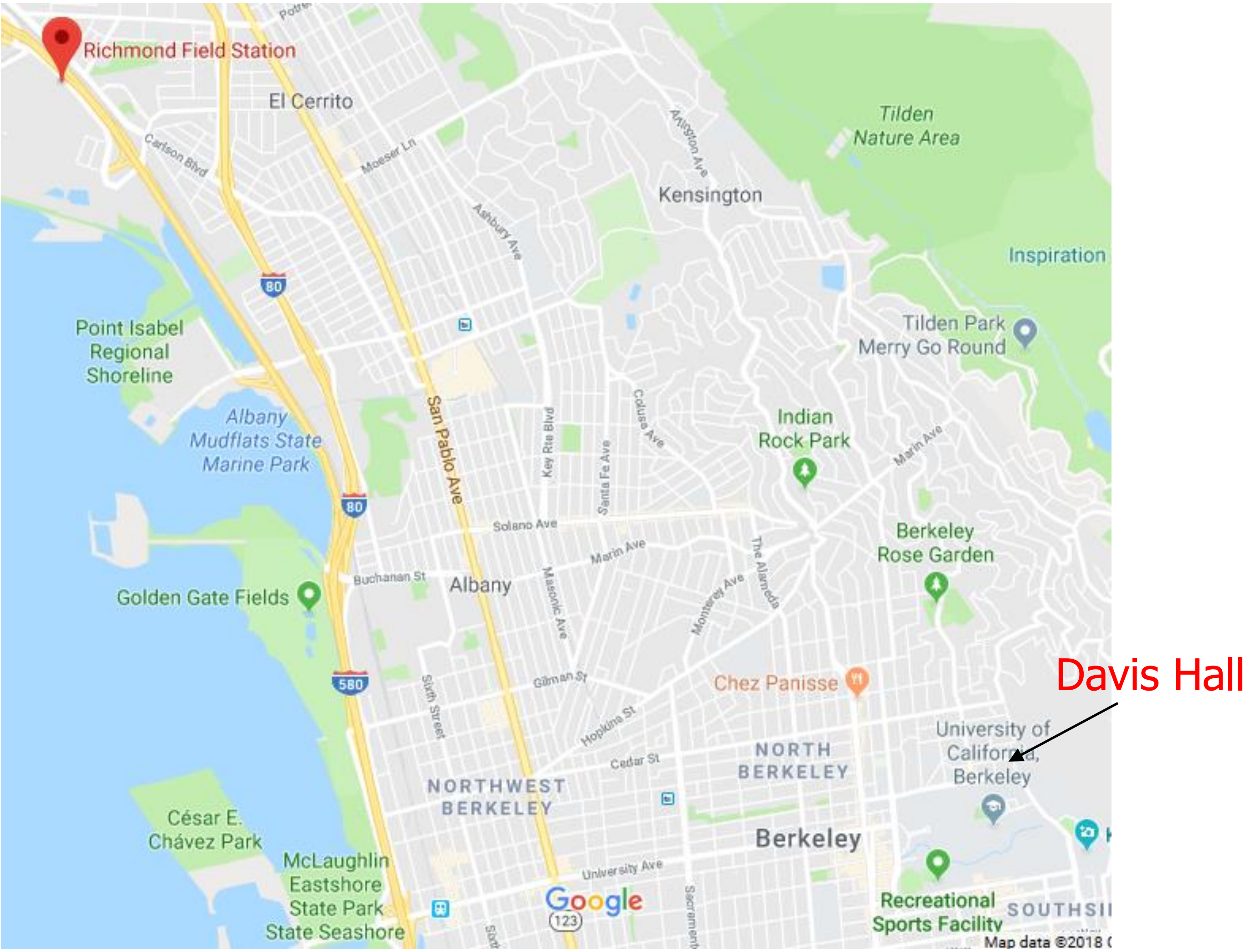


Specimen 1

Specimen 2



Geographically Distributed HS

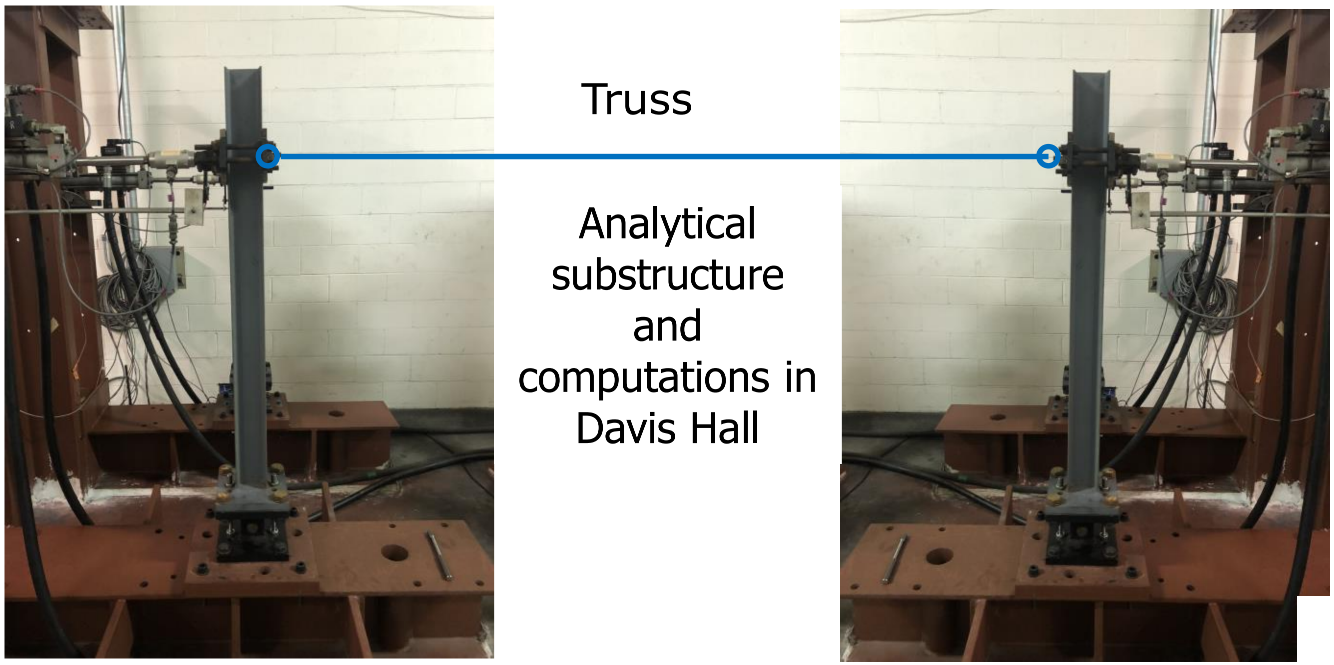


PEER

Geographically Distributed HS

PC in Davis Hall for running the computations

Geographically Distributed HS



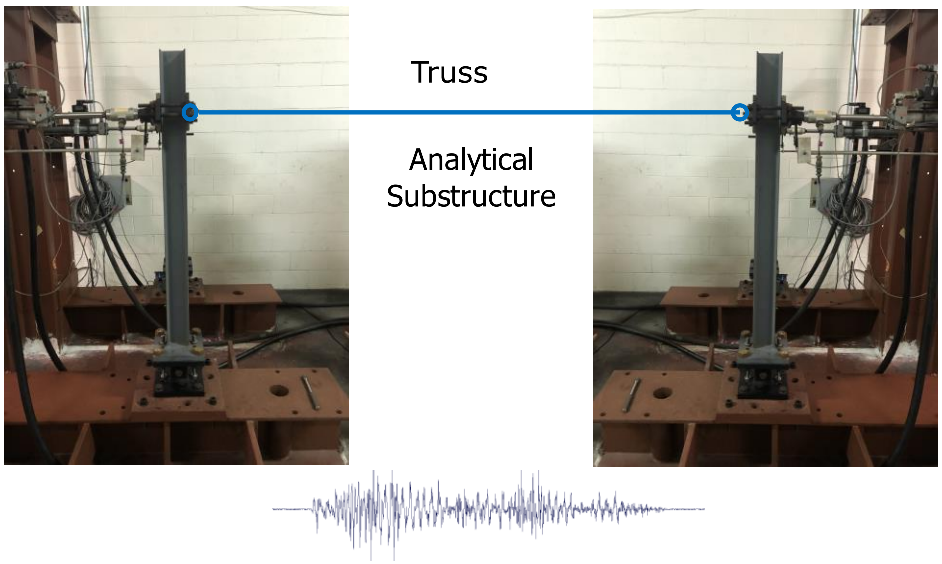
Specimen 1 | Specimen 2 | Experimental substructures in Davis Hall

In geographically distributed HS, the finite element model needs to know that:

1. The displacement to be imposed &
2. The corresponding force

will be sent and received over the internet

Geographically Distributed HS



In the OpenFresco file in RFS:

expSite ActorSite 1 –setup 1 8091

- 1 → Exp. Site Tag
- 1 (after –setup) → Exp. Setup Tag
- 8091 → IP port

In the OpenFresco file in Davis Hall:

expSite ShadowSite 1 169.229... 8091

- 1 → Exp. Site Tag
- 169.229... → IP address of the actor site
- 8091 → IP port of the actor site

Thank You