Hands-on Exercise in Developing and Running a Hybrid Simulation

OpenFresco Workshop

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OpenFresco

Portal Frame Example

- Portal frame fully simulated local implementation including P-Delta effects

- PortalFrame Example Folder:
  - PortalFrame_Local.tcl
  - PlotOutput.m
  - SACNF01.txt

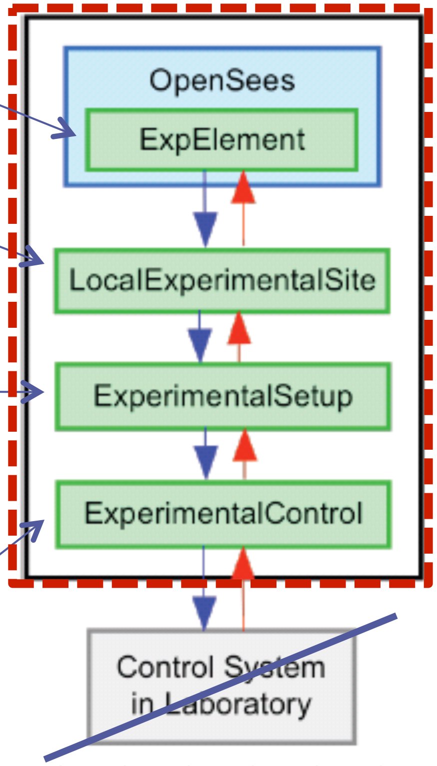
OpenFresco Local Architecture

beamColumn element defined in OpenSees

Communication methods for distributed testing.
In this case, we are using a local site.

Transforms between experimental element DOFs in OF and the actuator DOFs in the laboratory. Linear and non-linear transformations are available.

Interface with control and data acquisition systems. In this example, SimUniaxialMaterials will simulate the response of the experimental element using a material defined in OpenSees, Steel02



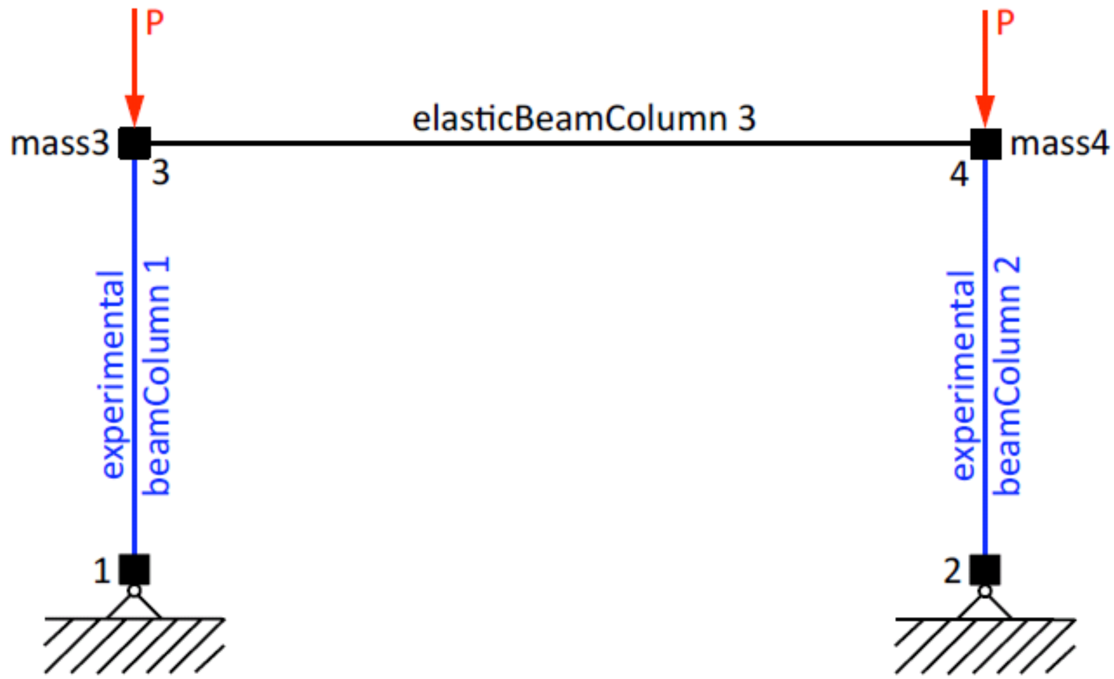
Fully simulated

Tcl File Components

Geometry
Materials
Experimental Control
Experimental Setup
Experimental Site
Geometric Transformation
Experimental Elements
Numerical Elements
Gravity Loads
Gravity Analysis
Dynamic Loads
Dynamic Analysis

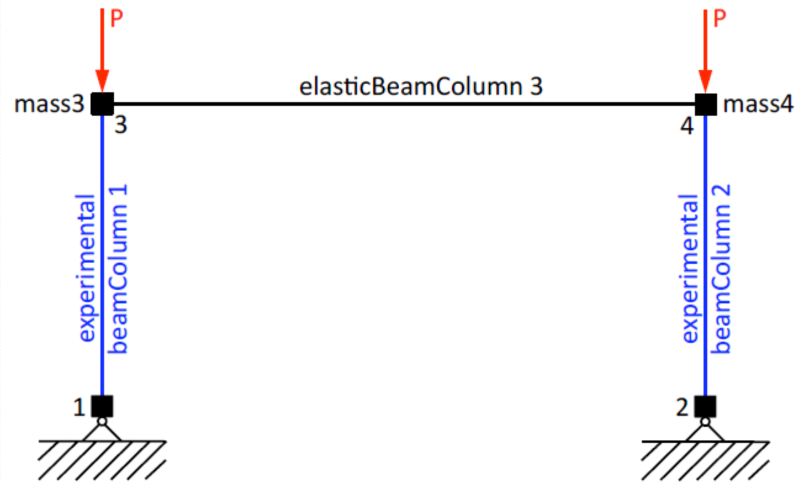
Portal Frame Model

```
# ------------------------------
# Start of model generation
# ------------------------------
# create ModelBuilder (with two-dimensions and 3 DOF/node)
model BasicBuilder -ndm 2 -ndf 3

# Load OpenFresco package
# -----------------------
# (make sure all dlls are in the same folder as openSees.exe)
loadPackage OpenFresco
```



Geometry

```
# Define geometry for model
# ------------------------
set withGravity 1;
set Pc 10.638;
set P [expr 0.5*$Pc];
set mass3 [expr $P/386.1];
set mass4 [expr $P/386.1];
# node $tag $xCrd $yCrd $mass
node  1     0.0   0.0
node  2   100.0   0.0
node  3     0.0  50.0  -mass $mass3 $mass3 0.0
node  4   100.0  50.0  -mass $mass4 $mass4 0.0

# set the boundary conditions
# fix $tag $DX $DY $RZ
fix 1   1  1  0
fix 2   1  1  0
```



withGravity 0: turns off gravity loads (no P-delta)

withGravity 1: turns on gravity loads (P-delta)

Assigned no rotational mass – must use implicit integration method

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Materials/Experimental Control

```
# Define materials
# ----------------
# uniaxialMaterial Steel02 $matTag $Fy $E $b $R0 $cR1 $cR2 $a1 $a2 $a3 $a4
uniaxialMaterial Steel02 1 1.5 2.8 0.01 18.5 0.925 0.15 0.0 1.0 0.0 1.0
#uniaxialMaterial Elastic 1 2.8

# Define experimental control
# ----------------------------
# expControl SimUniaxialMaterials $tag $matTags
expControl SimUniaxialMaterials 1 1
expControl SimUniaxialMaterials 2 1
```

Column 1

Column 2

- Want to control two columns
- SimUniaxialMaterials used to simulate a specimen
- Need to create a separate experimental control for each element so create experimental control with tags “1” and “2”
- Assign a material tag to each

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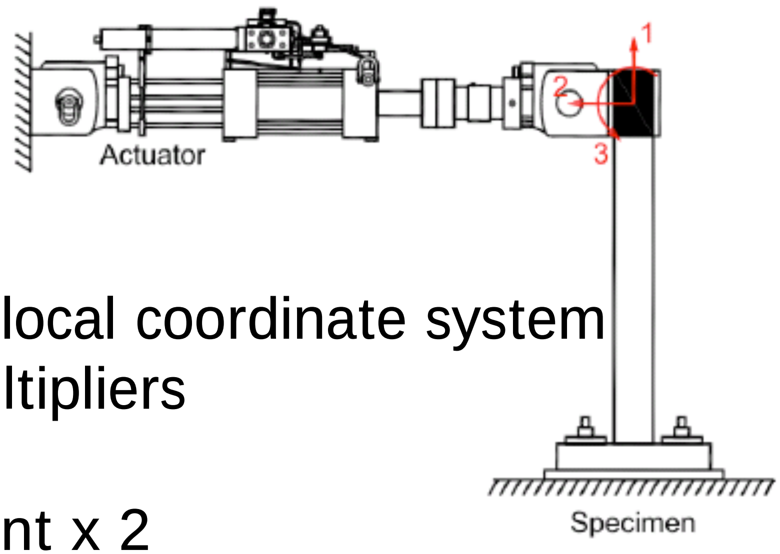
Experimental Setup and Site

Refers back to SimUniaxialMaterials Experimental Control
Left and right columns (tags 1 and 2)

```
# Define experimental setup
# ------------------------
# expSetup OneActuator $tag <-control $ctrlTag> $dir -sizeTrialOut $t $o <-trialDispFact $f> ...
expSetup OneActuator 1 -control 1 2 -sizeTrialOut 3 3
expSetup OneActuator 2 -control 2 2 -sizeTrialOut 3 3

# Define experimental site
# ------------------------
# expSite LocalSite $tag $setupTag
expSite LocalSite 1 1
expSite LocalSite 2 2
```



- OneActuator direction in element's local coordinate system
- Optional Factors: all factors are multipliers
- e.g.
- -crtlDispFact 2 = target displacement x 2
- -daqDispFact 2 = measured displacement x 2
- -daqForceFact 2 = measured force x 2
- This is the new convention for OF Version 2.5

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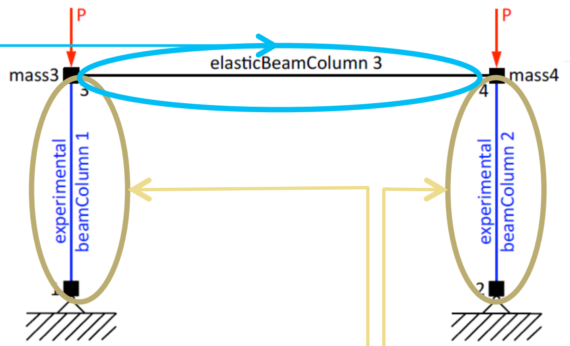
Geometric Transform/Experimental Elements




```
# Define geometric transformation
# --------------------------------
geomTransf PDelta 1
#geomTransf Corotational 1

# Define experimental elements
# -----------------------------
# left and right columns
# expElement beamColumn $eleTag $iNode $jNode $transTag -site $siteTag -initStif $Kij <-iMod> <-rho $rho>
expElement beamColumn 1 3 1 1 -site 1 -initStif 1310.8 0 0 0 11.2 -280.0 0 -280.0 9333.3333
expElement beamColumn 2 4 2 1 -site 2 -initStif 1310.8 0 0 0 11.2 -280.0 0 -280.0 9333.3333

# Define numerical elements
# --------------------------
# element elasticBeamColumn $eleTag $iNode $jNode $A $E $Iz $transfTag
element elasticBeamColumn 3 3 4 3.55 29000 22.1 1
```

$$K = \begin{bmatrix} 1310.8 & 0 & 0 \\ 0 & 11.2 & -280.0 \\ 0 & -280.0 & 9333.3333 \end{bmatrix}$$

- L=50”
- A=2.26 in^2
- I=4.02 in^4

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Gravity Loads

```
{$withGravity} {
 # Define gravity loads
 # ---------------------
 # Create a Plain load pattern with a Linear TimeSeries
 pattern Plain 1 "Linear" {
     # Create nodal loads at nodes 2
     #    nd    FX          FY   MZ
     load  3    0.0  [expr -$P] 0.0
     load  4    0.0  [expr -$P] 0.0
 }
 # ------------------------------
 # End of model generation
 # ------------------------------
```

Loads in the –y direction at notes 3 and 4

Gravity Analysis

```
# ------------------------------
# Start of analysis generation
# ------------------------------
# Create the system of equation
system BandGeneral
# Create the DOF numberer
numberer Plain
# Create the constraint handler
constraints Plain
# Create the convergence test
test EnergyIncr 1.0e-6 10
# Create the integration scheme
integrator LoadControl 0.1
# Create the solution algorithm
algorithm Newton
# Create the analysis object
analysis Static
# ------------------------------
# End of analysis generation
# ------------------------------
```

Banded General

DOFs assigned arbitrarily – good for small models

Only using single point constraints

Test EnergyIncr $tol $maxNumIter

Load Control with 10 steps

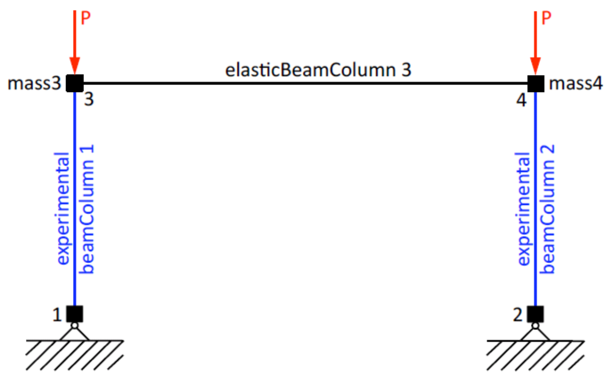
Newton-Raphson algorithm

Gravity Recorders and Analysis

```
# --------------------------------
# Start of recorder generation
# --------------------------------
# create a Recorder object for the nodal displacements at node 2
recorder Node -file Gravity_Dsp.out -time -node 3 4 -dof 1 2 3 disp
recorder Element -file Gravity_Frc.out -time -ele 1 2 3 force
# ----------------------------------
# End of recorder generation
# ----------------------------------


# --------------------------------
# Perform the gravity analysis
# --------------------------------
# perform the gravity load analysis, requires 10 steps to reach the load level
if {[analyze 10] == 0} {
    puts "\nGravity load analysis completed"
} else {
    puts "\nGravity load analysis failed"
    exit -1
}


# --------------------------------
# Start of model generation
# --------------------------------
# Set the gravity loads to be constant & reset the time in the domain
loadConst -time 0.0
remove recorders
```



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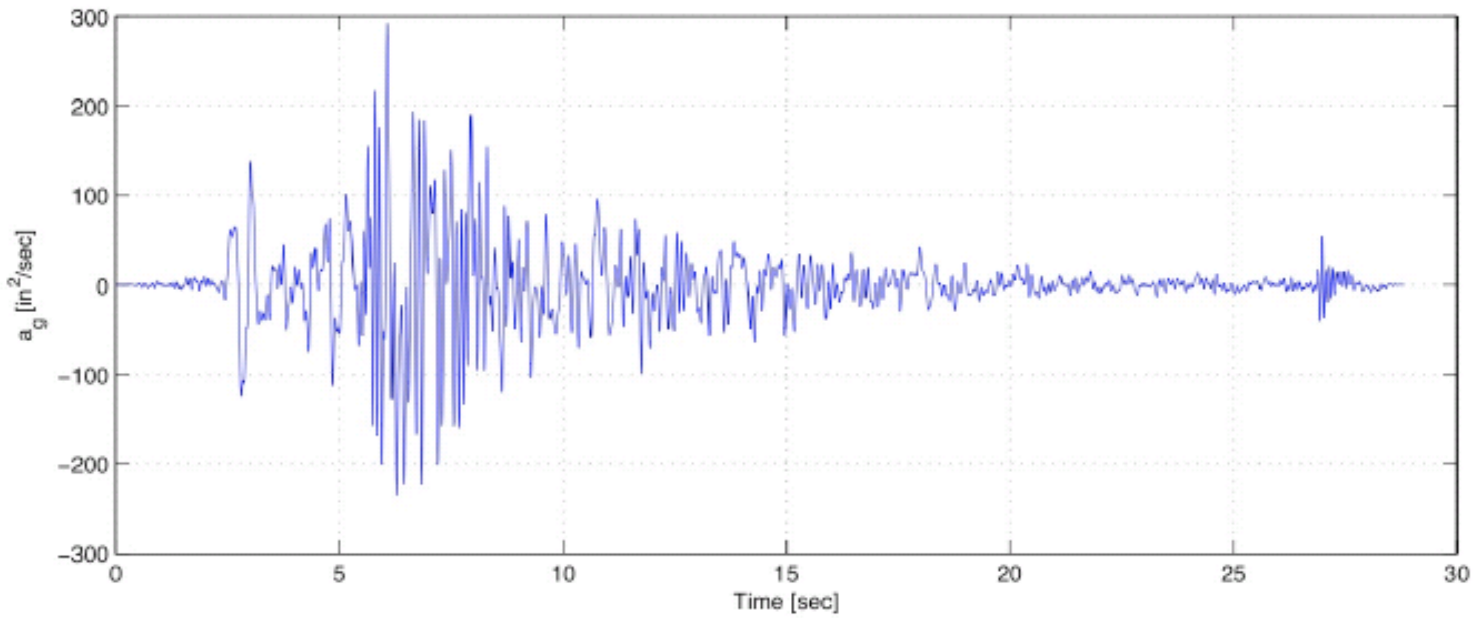
1978 Tabas Earthquake

- SACNF01.txt
- PGA=0.755g
- dt=0.01 s.



Dynamic Loads

```
# Define dynamic loads
# --------------------
# set time series to be passed to uniform excitation
set dt 0.01
set scale 1
set accelSeries "Path -filePath SACNF01.txt -dt $dt -factor [expr 386.1*$scale]"

# create UniformExcitation load pattern
# pattern UniformExcitation $tag $dir
pattern UniformExcitation  2 1 -accel $accelSeries

# calculate the rayleigh damping factors for nodes & elements
set alphaM     1.2797;    # D = alphaM*M
set betaK      0.0;       # D = betaK*Kcurrent
set betaKinit  0.0;       # D = beatKinit*Kinit
set betaKcomm  0.0;       # D = betaKcomm*KlastCommit

# set the rayleigh damping
rayleigh $alphaM $betaK $betaKinit $betaKcomm;
# ------------------------------
# End of model generation
# ------------------------------
```

Place ground motion file in the same folder as the PortalFrame_Local.tcl file

Dynamic Analysis

```
# ------------------------------
# Start of analysis generation
# ------------------------------
# create the system of equations
system BandGeneral

# create the DOF numberer
numberer Plain

# create the constraint handler
constraints Plain

# create the convergence test
test FixedNumIter 5

# create the integration scheme
integrator NewmarkHSFixedNumIter 0.5 0.25

# create the solution algorithm
algorithm Newton

# create the analysis object
analysis Transient
# ------------------------------
# End of analysis generation
# ------------------------------
```

Same as gravity analysis

5 iterations/time step

NewmarkHSFixedNumIter: implicit Newmark method with 5 iterations/step

γ =0.5: second order accuracy, no numerical damping
β =0.25: average acceleration, unconditional stability

Dynamic Recorders

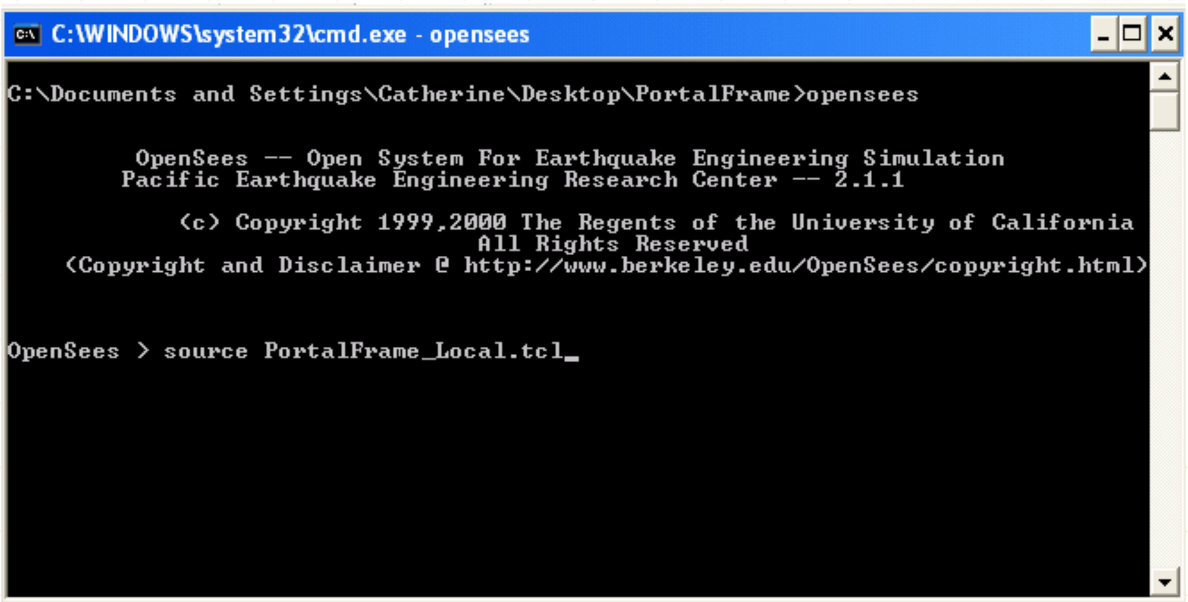
```
# ------------------------------
# Start of recorder generation
# ------------------------------
# create the recorder objects
recorder Node -file Node_Dsp.out -time -node     3 4 -dof 1 2 3 disp
recorder Node -file Node_Vel.out -time -node     3 4 -dof 1 2 3 vel
recorder Node -file Node_Acc.out -time -node     3 4 -dof 1 2 3 accel
recorder Node -file Node_Rxn.out -time -node 1 2 3 4 -dof 1 2 3 reactionIncludingInertia

recorder Element -file Elmt_glbFrc.out  -time -ele 1 2 3 forces
expRecorder Control -file Control_ctrlDsp.out -time -control 1 2 ctrlDisp
expRecorder Control -file Control_daqDsp.out  -time -control 1 2 daqDisp
expRecorder Control -file Control_daqFrc.out  -time -control 1 2 daqForce
# --------------------------------
# End of recorder generation
# --------------------------------
```

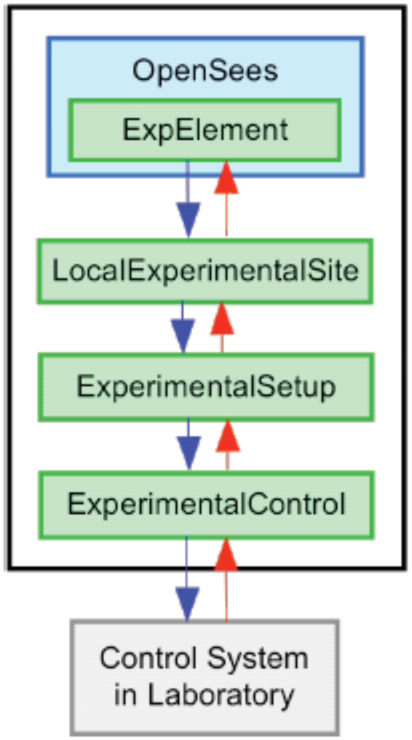
Dynamic Analysis

```
# ------------------------------
# Finally perform the analysis
# ------------------------------
# perform an eigenvalue analysis
set pi 3.14159265358979
set lambda [eigen -fullGenLapack 4]
puts "\nEigenvalues at start of transient:"
puts "lambda         omega          period"
foreach lambda $lambda {
    if {$lambda > 0.0} {
        set omega [expr pow($lambda,0.5)]
        set period [expr 2*$pi/pow($lambda,0.5)]
        puts "$lambda  $omega  $period"
    }
}

# open output file for writing
set outFileID [open elapsedTime.txt w]
# perform the transient analysis
set tTot [time {
    for {set i 1} {$i < 2500} {incr i} {
        set t [time {analyze  1  [expr $dt/1.0]}]
        puts $outFileID $t
            #puts "step $i"
    }
}]
puts "\nElapsed Time = $tTot \n"
# close the output file
close $outFileID

wipe
# --------------------------------
# End of analysis
# --------------------------------
```

Running the Local Hybrid Simulation

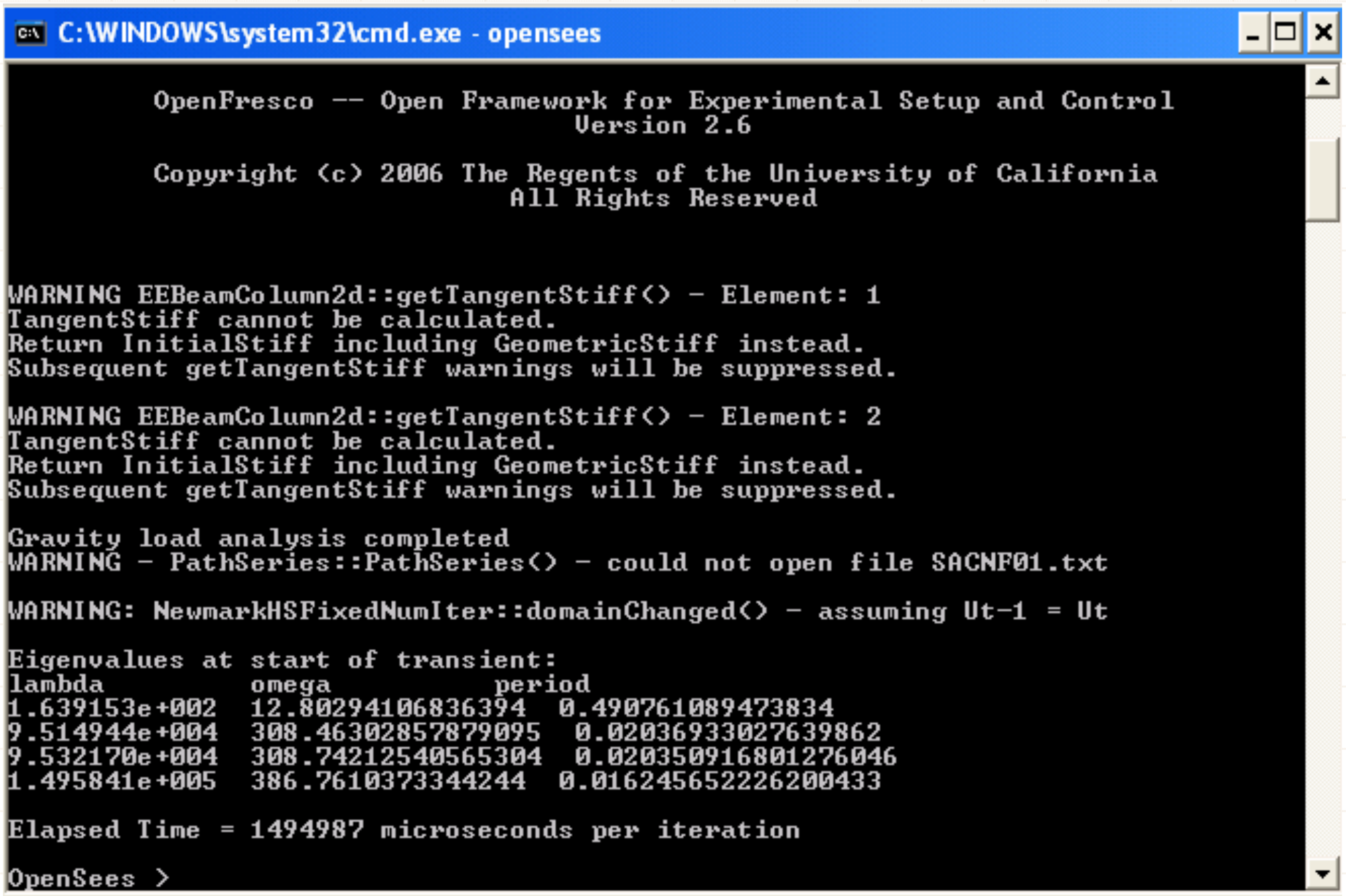
- Start the OpenSees executable file from the directory where you saved PortalFrame_Local.tcl
- At the prompt, type source PortalFrame_Local.tcl and press enter





Run Simulation

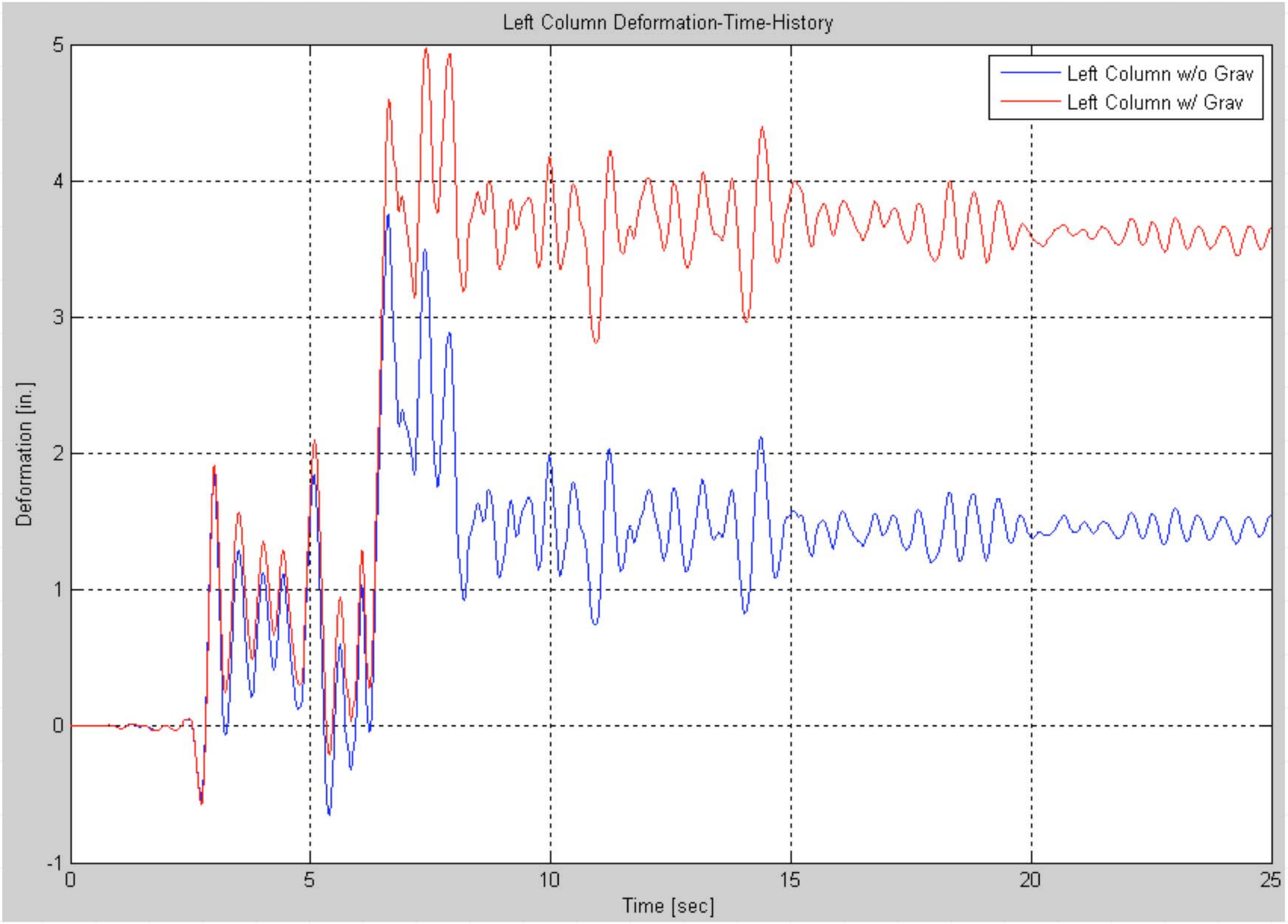
- Warnings since SimUniaxialMaterials is simulating an experimental element which cannot return the tangent stiffness



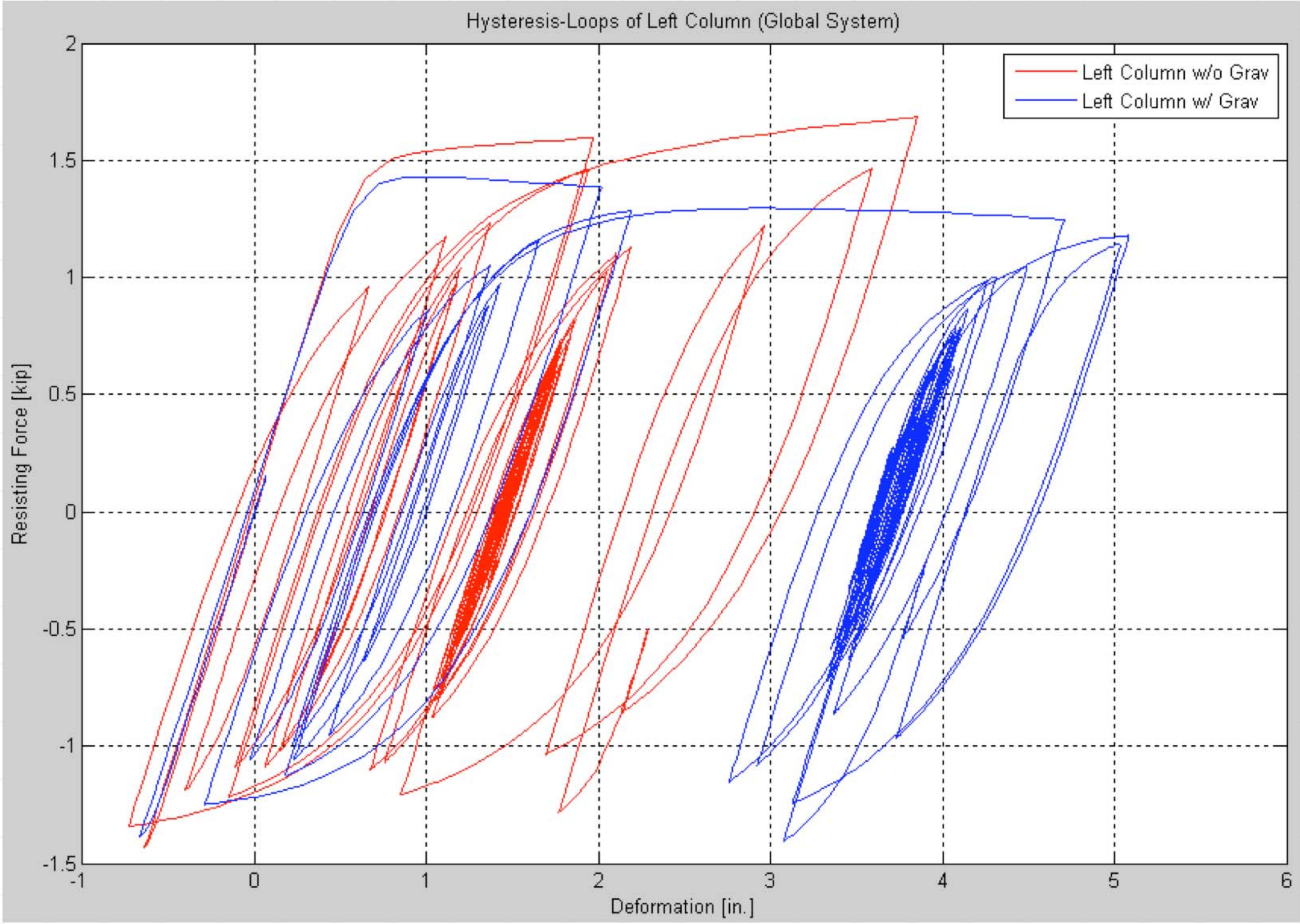
Recorders Save Output Files

elapsedTime	79 KB	Text Document	8/20/2009 10:15 PM
PlotOutput	9 KB	MATLAB M-file	8/20/2009 10:12 PM
PortalFrame_Local	8 KB	ActiveTcl Script	8/20/2009 10:09 PM
SACNF01	78 KB	Text Document	1/1/2008 5:22 PM
Control_ctrlDsp.out	61 KB	OUT File	8/20/2009 10:15 PM
Control_daqDsp.out	61 KB	OUT File	8/20/2009 10:15 PM
Control_daqFrc.out	64 KB	OUT File	8/20/2009 10:15 PM
Elmt_glbFrc.out	384 KB	OUT File	8/20/2009 10:15 PM
Gravity_Dsp.out	1 KB	OUT File	8/20/2009 10:15 PM
Gravity_Frc.out	2 KB	OUT File	8/20/2009 10:15 PM
Node_Acc.out	147 KB	OUT File	8/20/2009 10:15 PM
Node_Dsp.out	176 KB	OUT File	8/20/2009 10:15 PM
Node_Rxn.out	290 KB	OUT File	8/20/2009 10:15 PM
Node_Vel.out	172 KB	OUT File	8/20/2009 10:15 PM

Compare Deformations

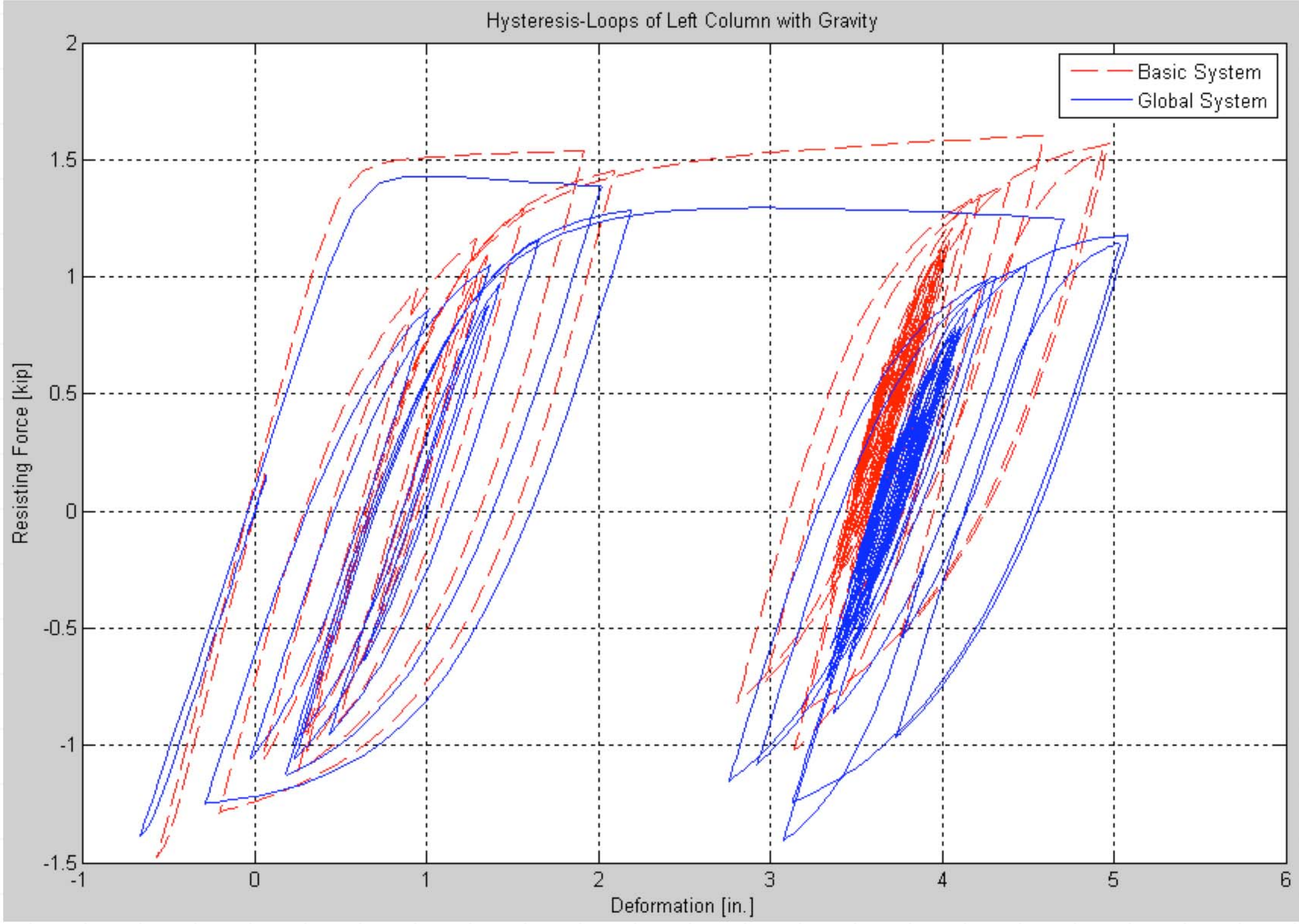


Hysteresis Left Column Global System



Negative stiffness is apparent in global system with gravity loads

Hysteresis Left Column w/ Gravity Basic vs. Global System



Questions?
Thank you!

http://openfresco.neesforge.nees.org

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