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Modeling Instability of Beam-Column Elements

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Outline

- Background and motivation for brace modeling
- Modeling assumptions and limitations
- Two examples
  - Static Cyclic
  - Dynamic

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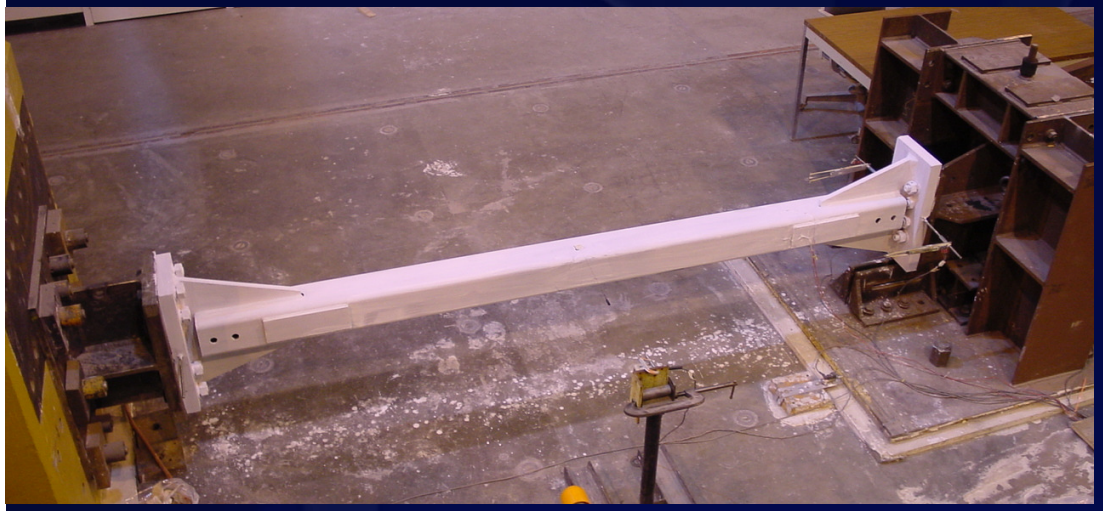
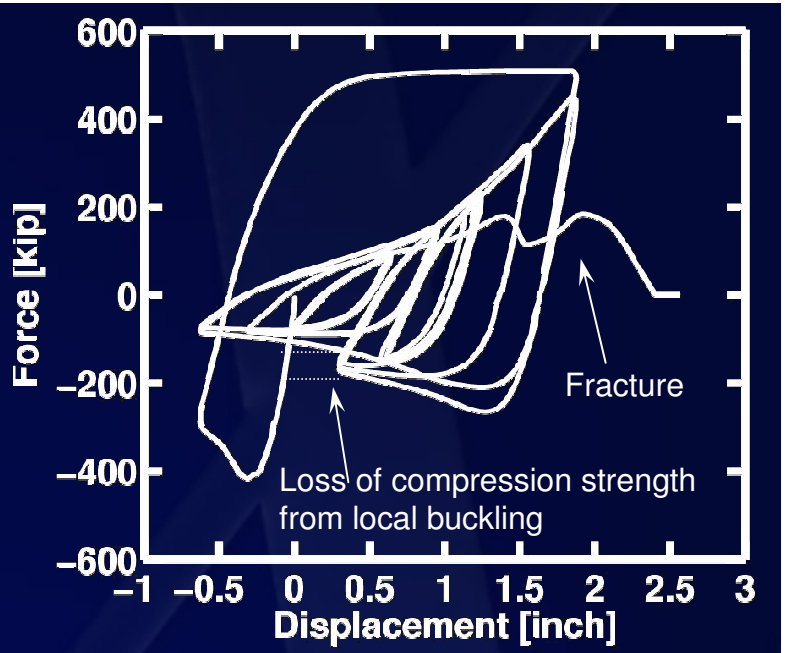
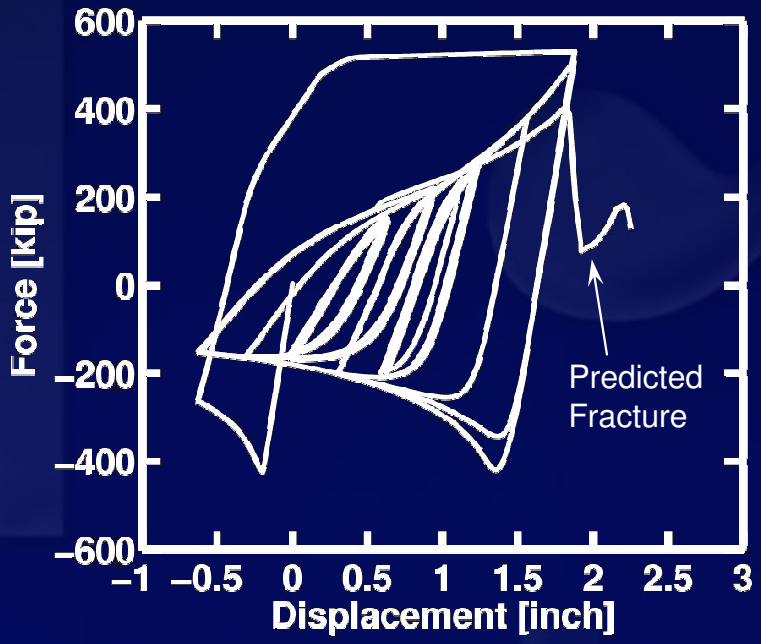
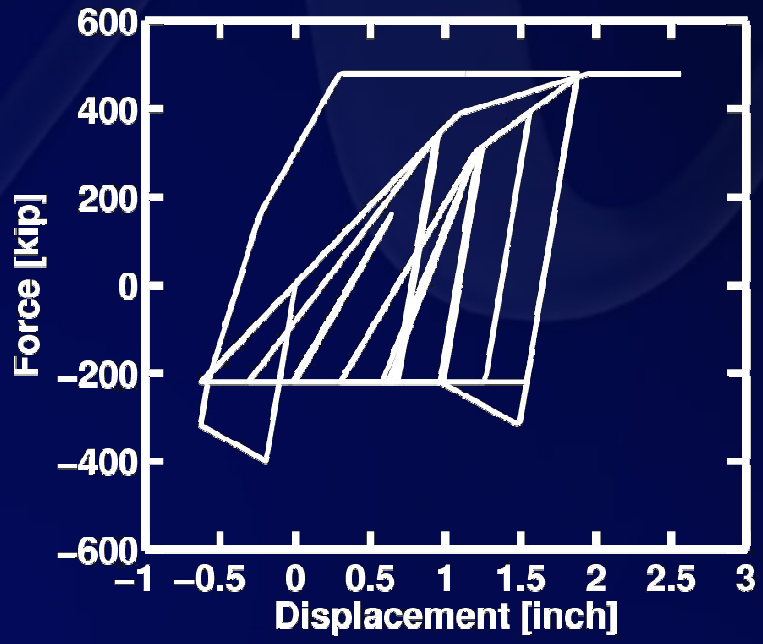



600
400
200
0
−200
−400
−600
Force [kip]
−1 −0.5 0 0.5 1 1.5 2 2.5 3
Displacement [inch]
Fracture
Loss of compression strength
from local buckling


600
400
200
0
−200
−400
−600
Force [kip]
−1 −0.5 0 0.5 1 1.5 2 2.5 3
Displacement [inch]
Predicted
Fracture


600
400
200
0
−200
−400
−600
Force [kip]
−1 −0.5 0 0.5 1 1.5 2 2.5 3
Displacement [inch]

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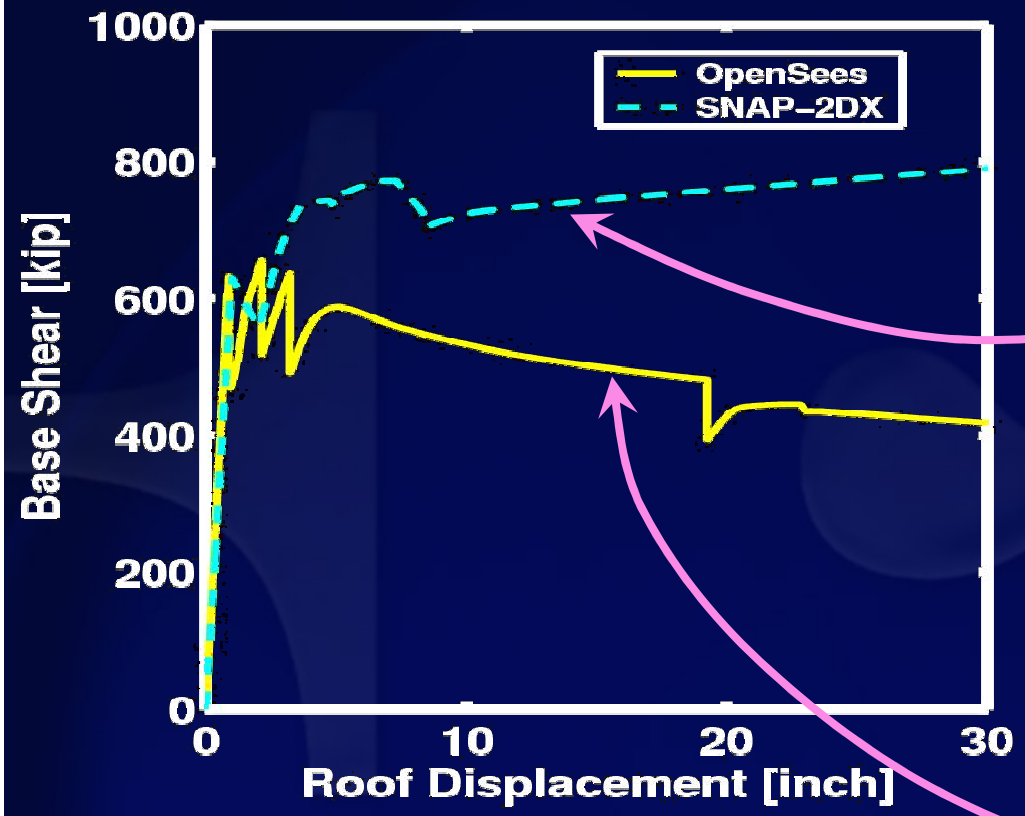
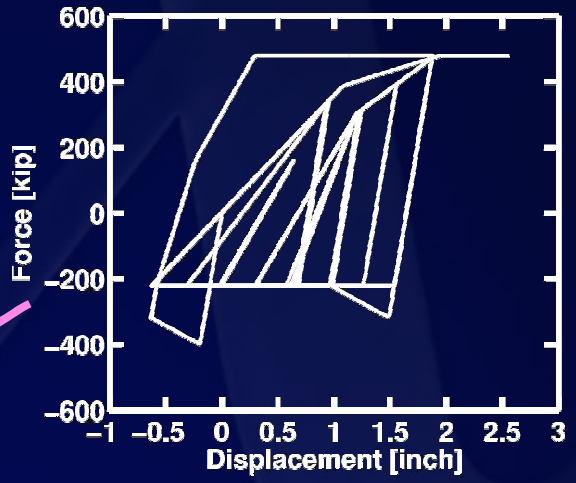
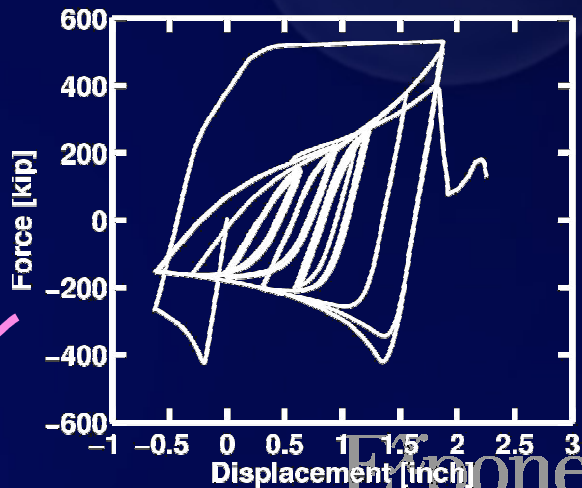
Brace Modeling

- Effect of modeling

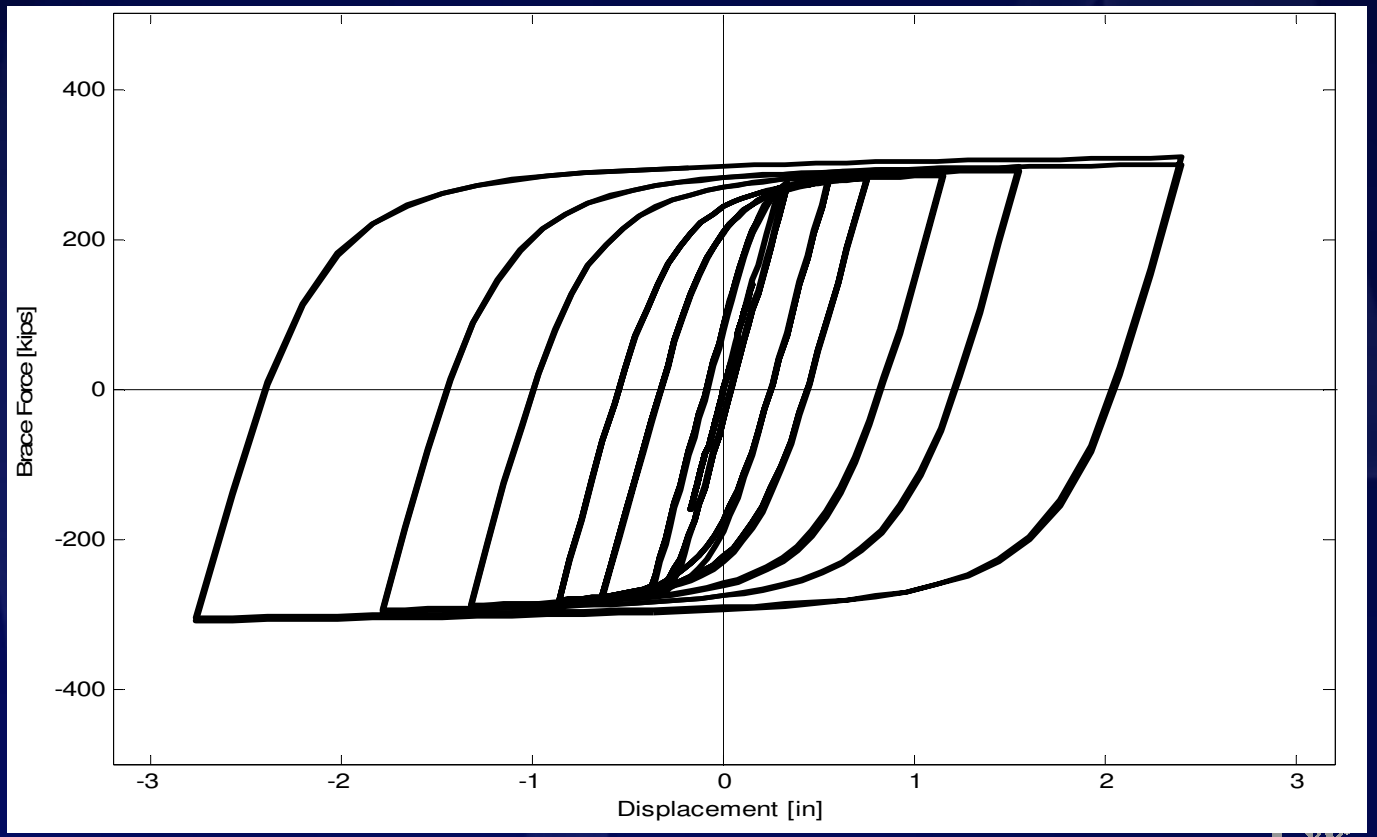






Brace Modeling

- Menegotto-Pinto Steel Material Model "Steel02"



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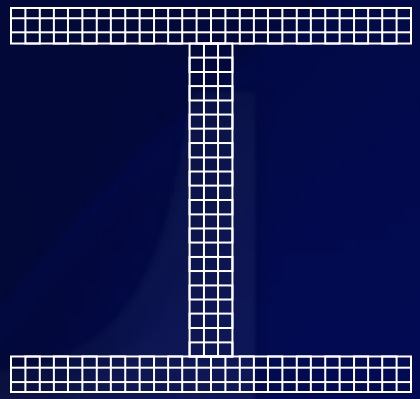
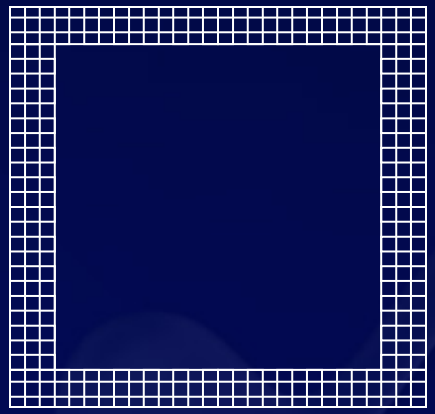
Brace Modeling

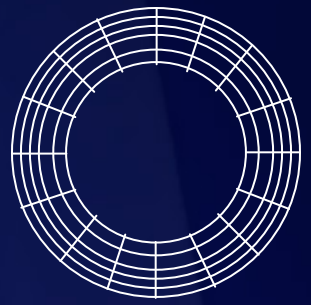
- W Section



- Box Section



- Pipe Section



- Gusset plate Section

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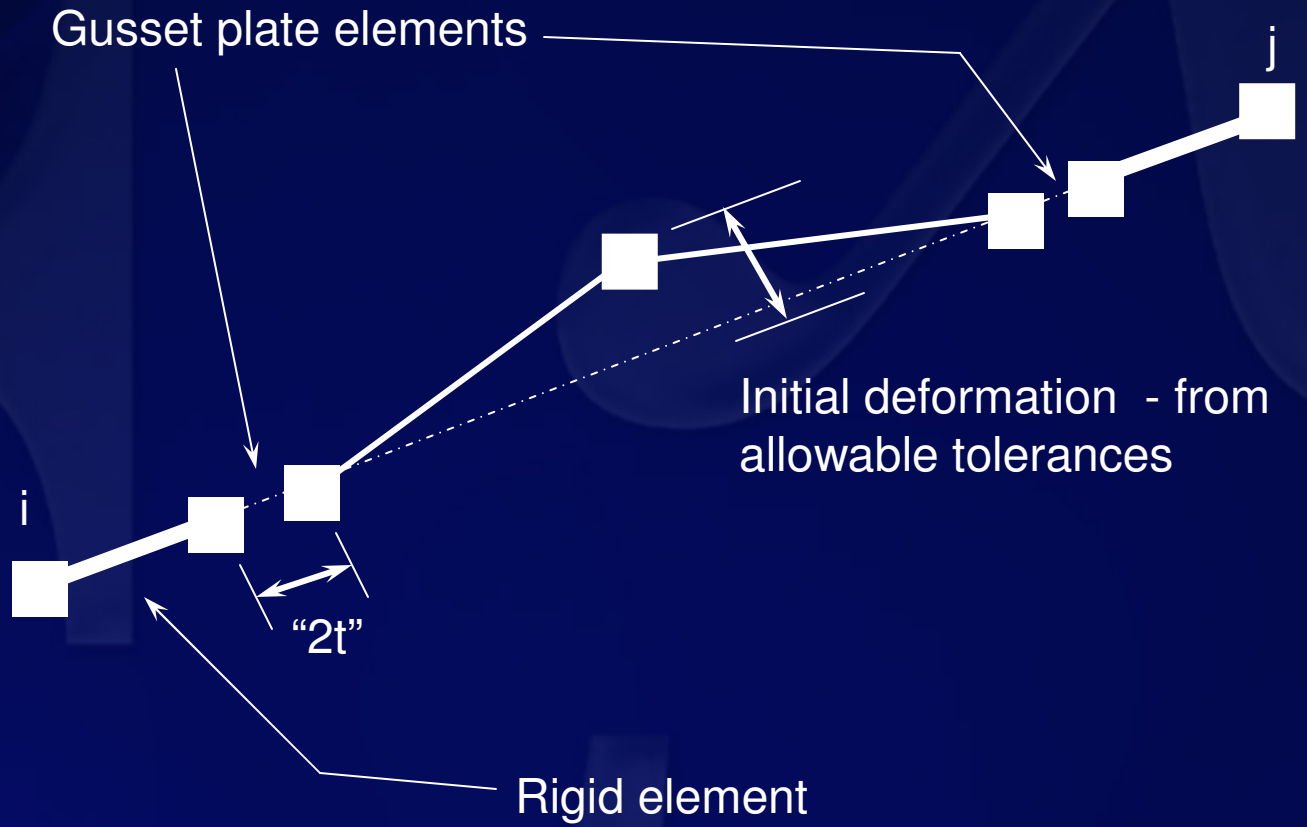
Brace Modeling

- **Bracing Elements**

Corotational Transformation
{ geomTransf Corotational $mtag }



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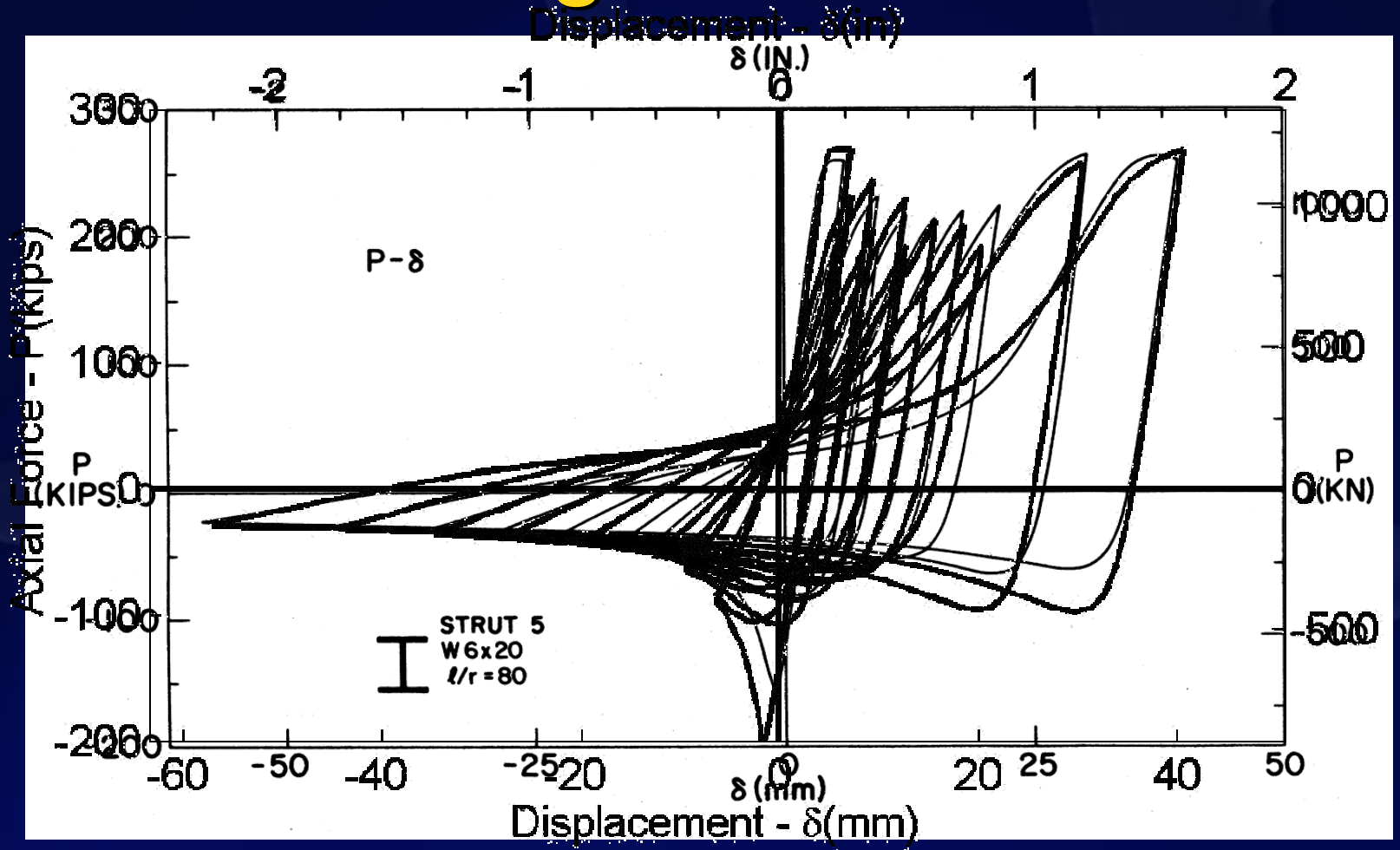
Brace Modeling



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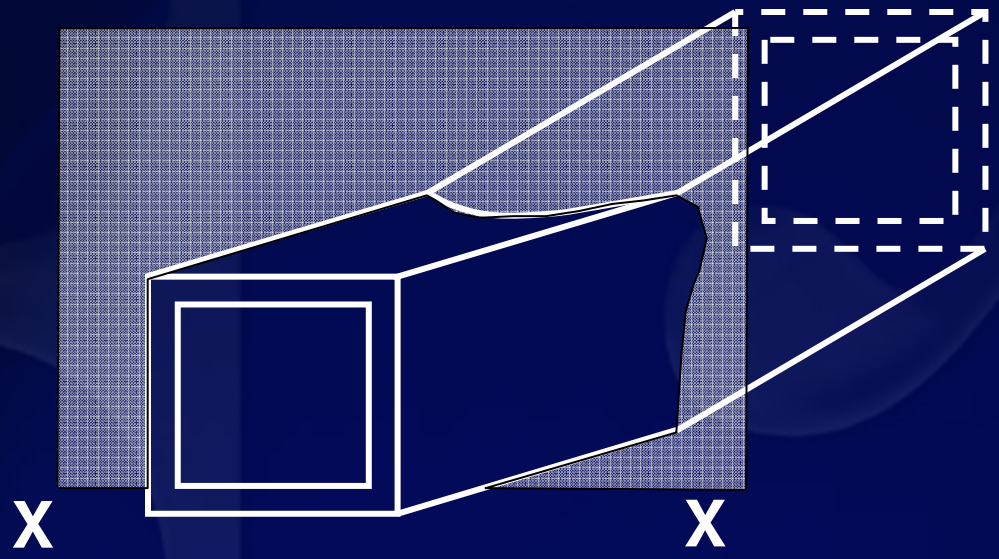
Brace Modeling

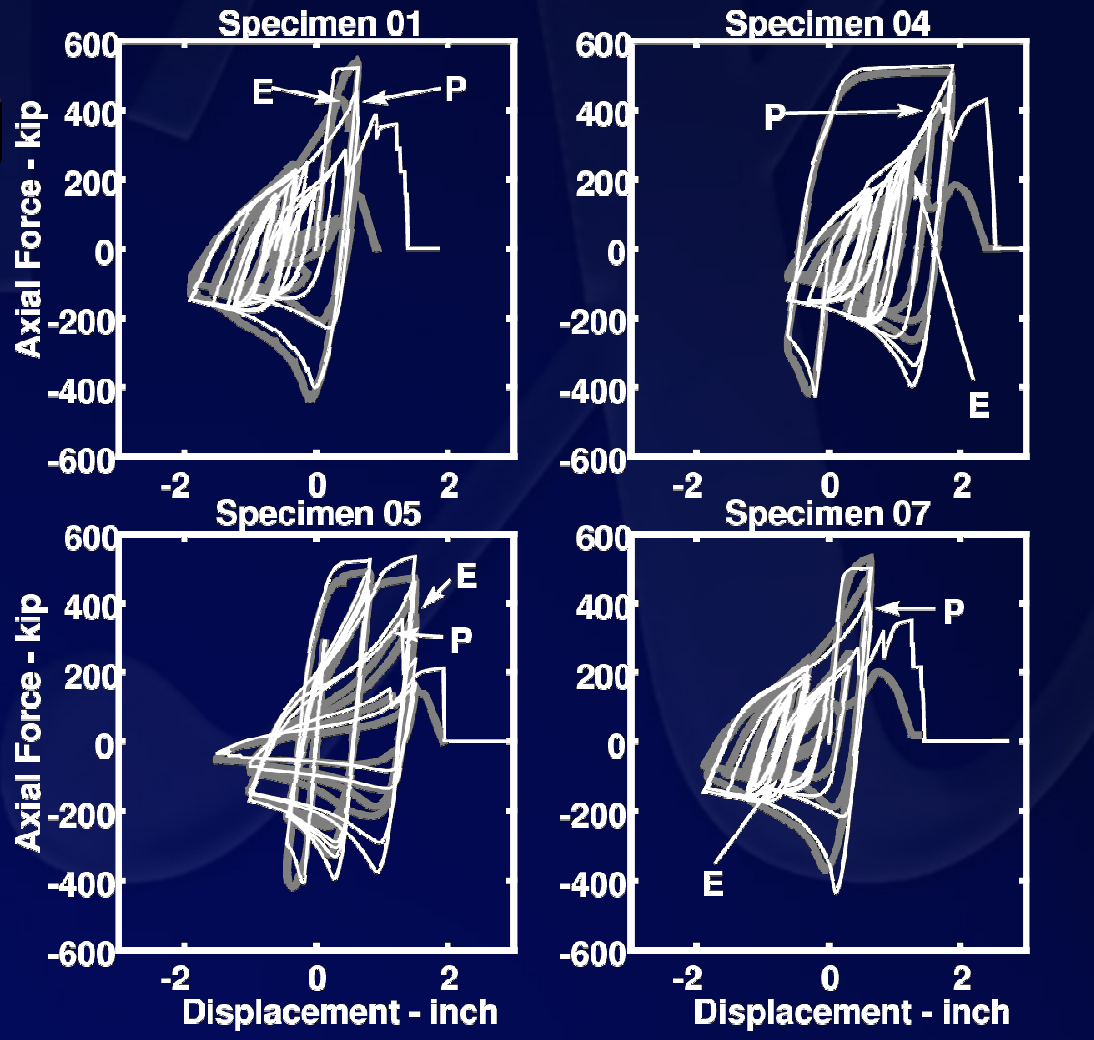
- Modeling with limited local buckling



Section X-X

Brace Modeling

- Limited local buckling and fatigue fracture



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OpenSees Examples

- Static Cyclic
- Dynamic

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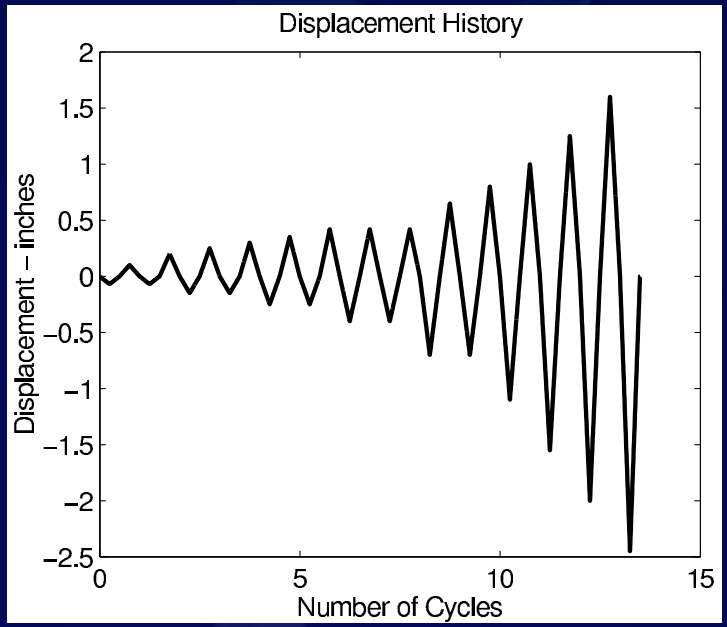
Static Cyclic



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Example (Model.tcl)

```
model      BasicBuilder   -ndm 2       -ndf 3
## Nodes
node 1 0.0   0.0
…
## Mass
mass 7 1.0 0.0 0.0
#Boundary Conditions
fix 1 1 1 1
…
## Materials
uniaxialMaterial Steel02 1 40.0 29800.0 0.003 20 \
    0.925 0.15 0.0005 0.01 0.0005 0.01
## Pipe Section (4" diameter, 1/2" wall thickness)
section fiberSec  1  {
    patch circ 1 20 4 0.0 0.0 2.0 1.5 360.0 0.0
}
## Gusset Plate Section (1" thick, 20" wide)
…
```

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Example (Model.tcl – Continued)

```
## Transformation
geomTransf Corotational 1
## Define Model
element elasticBeamColumn   1  1 2   1e3
1e8 1e6   1 ;# 'Rigid' offset
element nonlinearBeamColumn 2  2 3   3
2         1 ;# Gusset plate
element nonlinearBeamColumn 3  3 4   3
1         1 ;# Brace
element nonlinearBeamColumn 4  4 5   3
1         1 ;# Brace
element nonlinearBeamColumn 5  5 6   3
2         1 ;# Gusset plate
element elasticBeamColumn   6  6 7   1e3
1e8 1e6   1 ;# 'Rigid' offset
```

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Example (Example1.tcl)

```
## Source in the model
source Model.tcl
## Apply the nodal Load
pattern Plain 1 Linear { load 7 1.0 0.0 0.0 }
## Recorder
recorder Node -file LoadDisp.dat -time -node 7 -dof 1 disp
## Static Analysis parameters
test EnergyIncr 1.0e-8   30    0
algorithm Newton
system UmfPack
numberer RCM
constraints Plain
analysis Static
set peaks [ list 0.25 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 ]
for {set i 1 } { $i <= 9 } {incr i } {
    set dU [expr -1.0*pow((-1.0),$i)*[lindex $peaks [expr $i-1] ]/100.0 ]
    integrator DisplacementControl 7 1 $dU 1 $dU $dU
    analyze 100
}
```

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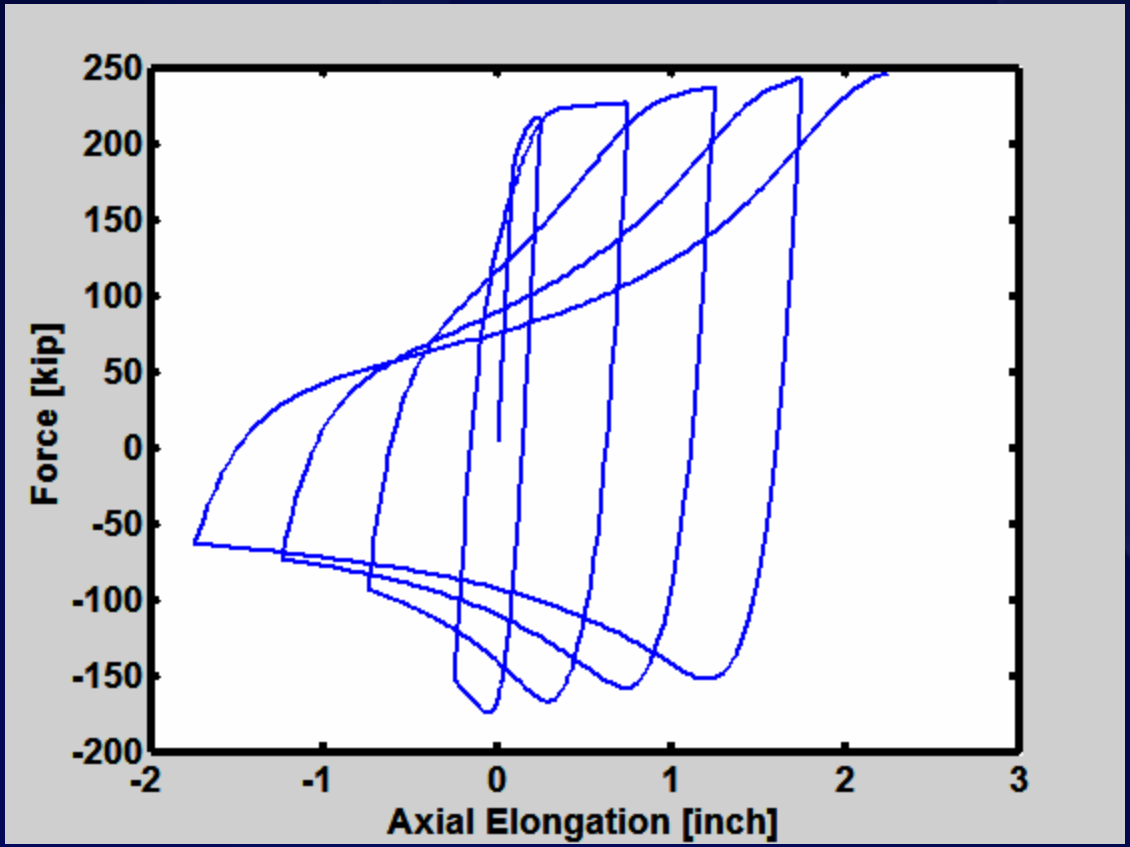
Example 1



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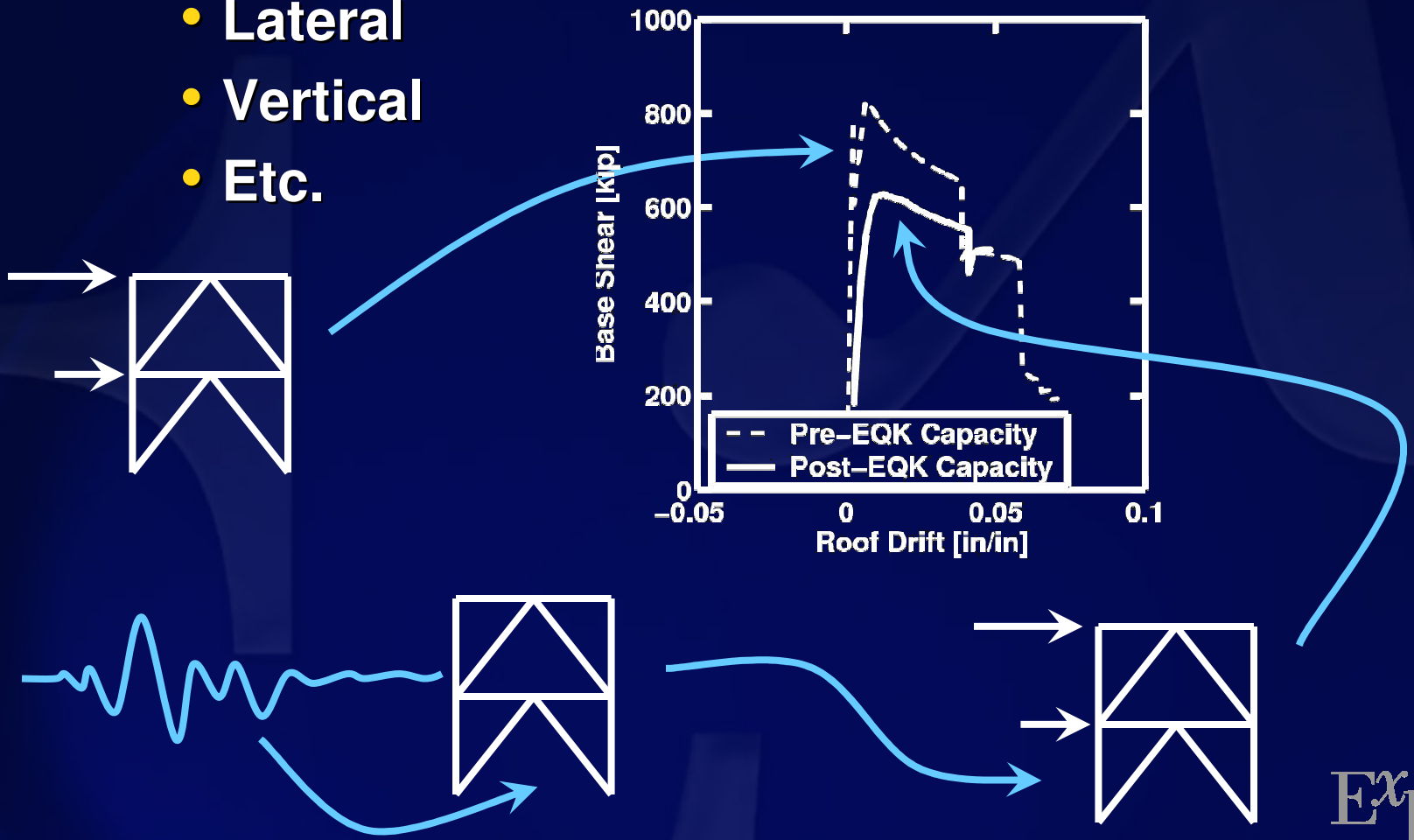
Dynamic

- Goal: Determine post-EQK capacity
  - Lateral
  - Vertical
  - Etc.



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Example (Example2.tcl)

```
## Source in the model
source Model.tcl
## Load profile
pattern Plain 1 Linear { load 7 1.0 0.0 0.0 }
## Recorder
recorder Node -file StaticPush.dat -time -node 7 -dof 1 disp
## Static Analysis parameters
test EnergyIncr 1.0e-8   30    0
algorithm Newton
system UmfPack
numberer RCM
constraints Plain
analysis Static
## Push past buckling
set dU -0.01
integrator DisplacementControl 7 1 $dU 1 $dU $dU
analyze 300
## close out model and recorders
wipe
```

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Example (Example2.tcl - Continued)

```
## Find peak compressive capacity
set Capacity 0.0
set fid [open StaticPush.dat r]
foreach ln [split [read $fid] \n] {
    set tmpMin [lindex $ln 0]
    if {[llength $ln] == 0} {
            continue
    } elseif { $tmpMin < $Capacity } {
            set Capacity $tmpMin
    }
}
close $fid
```

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Example (Example2.tcl - Continued)

```
## Run dynamic analysis
source Model.tcl
recorder Node -file Dynamic.dat -time -node 7 -dof 1 disp
## Transient Analysis parameters
set SineSeries "Sine 0.0 2.0 0.80 -factor 200 "
pattern UniformExcitation 1 1 -accel $SineSeries
integrator Newmark  0.5  0.25 0.05 0.05 0.0 0.0
test EnergyIncr 1.0e-8   300    0
algorithm KrylovNewton
system UmfPack
numberer RCM
constraints Plain
analysis Transient
analyze 40000 0.0001
## Keep structure data and rename the file
wipeAnalysis
remove loadPattern 1
```

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Example (Example2.tcl - Continued)

```
## Load profile
pattern Plain 1 Linear { load 7 1.0 0.0 0.0 }
## Recorder
recorder Node -file StaticPushPost.dat -time -node 7 -dof 1 disp
## Static Analysis parameters
test EnergyIncr 1.0e-8   30    0
algorithm Newton
system UmfPack
numberer RCM
constraints Plain
analysis Static
## Push past buckling
set dU -0.01
integrator DisplacementControl 7 1 $dU 1 $dU $dU
analyze 700
## close out model and recorders
wipe
```

Example (Example2.tcl - Continued)

```
## Find peak compressive capacity
set PostEQKCap 0.0
set fid [open StaticPushPost.dat r]
foreach ln [split [read $fid] \n] {
    set tmpMin [lindex $ln 0]
    if {[llength $ln] == 0} {
            continue
    } elseif { $tmpMin < $PostEQKCap} {
            set PostEQKCap $tmpMin
    }
}
close $fid
puts [ format " \n\n\n\n \
 Prior to loading the buckling capacity was: %3.4f kips \n \
 After dynamic time-history analysis, \n \
   the buckling capacity is now : %3.4f kips \n " $Capacity $PostEQKCap ]
```

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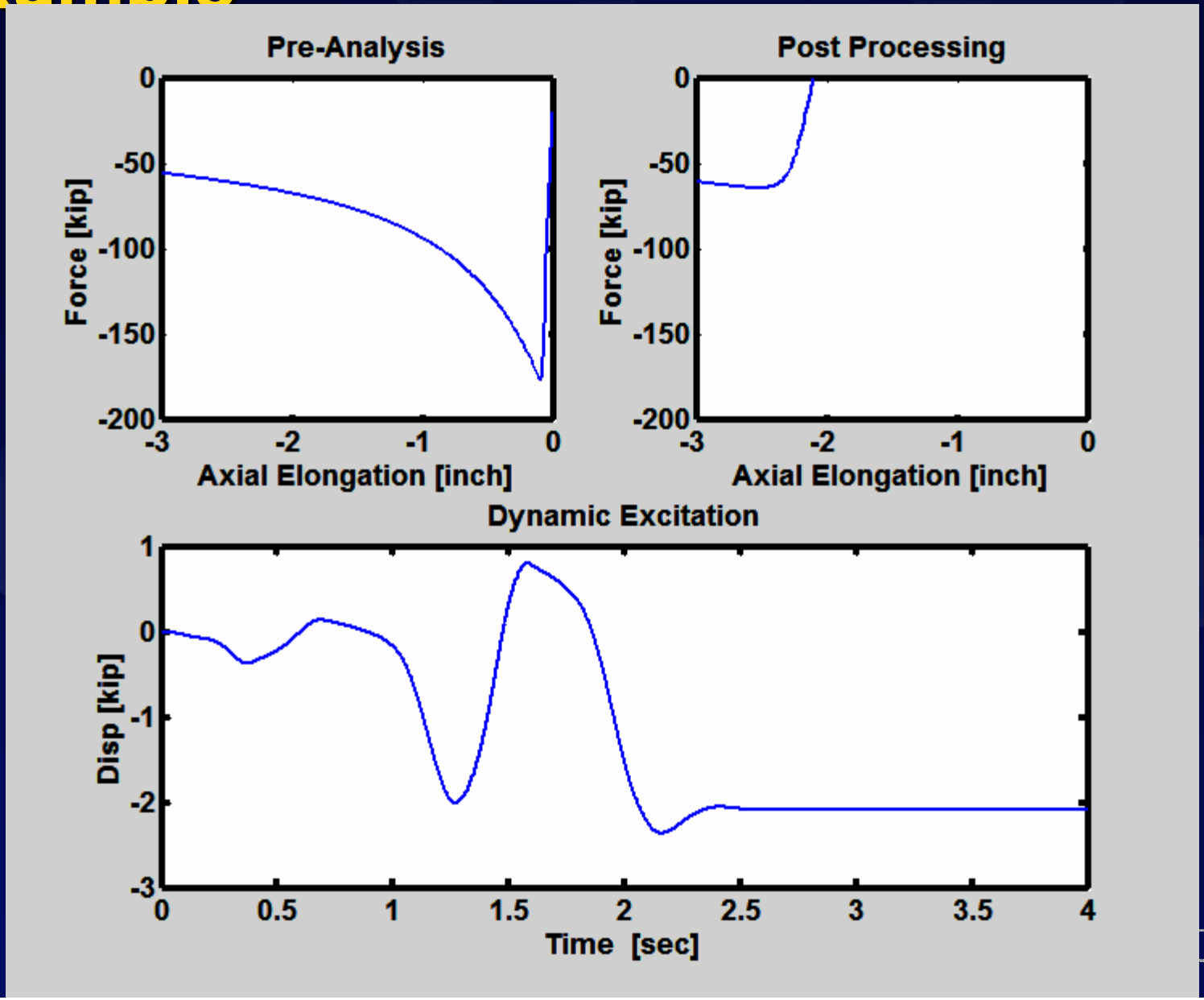
Example


Pre-Analysis
Force [kip]
0
-50
-100
-150
-200
-3
-2
-1
0
Axial Elongation [inch]
Post Processing
Force [kip]
0
-50
-100
-150
-200
-3
-2
-1
0
Axial Elongation [inch]
Dynamic Excitation
Disp [kip]
1
0
-1
-2
-3
0
0.5
1
1.5
2
2.5
3
3.5
4
Time [sec]

Reference

- Uriz, P., and Mahin, S. A. (2004). "Seismic Vulnerability Assessment of Concentrically Braced Steel Frames." *International Journal of Steel Structures*, 4(4), 239-248.
- Uriz, P. “Towards Earthquake Resistant Design of Concentrically Braced Steel Frames,” Doctoral Dissertation, University of California, Berkeley, December, 2005

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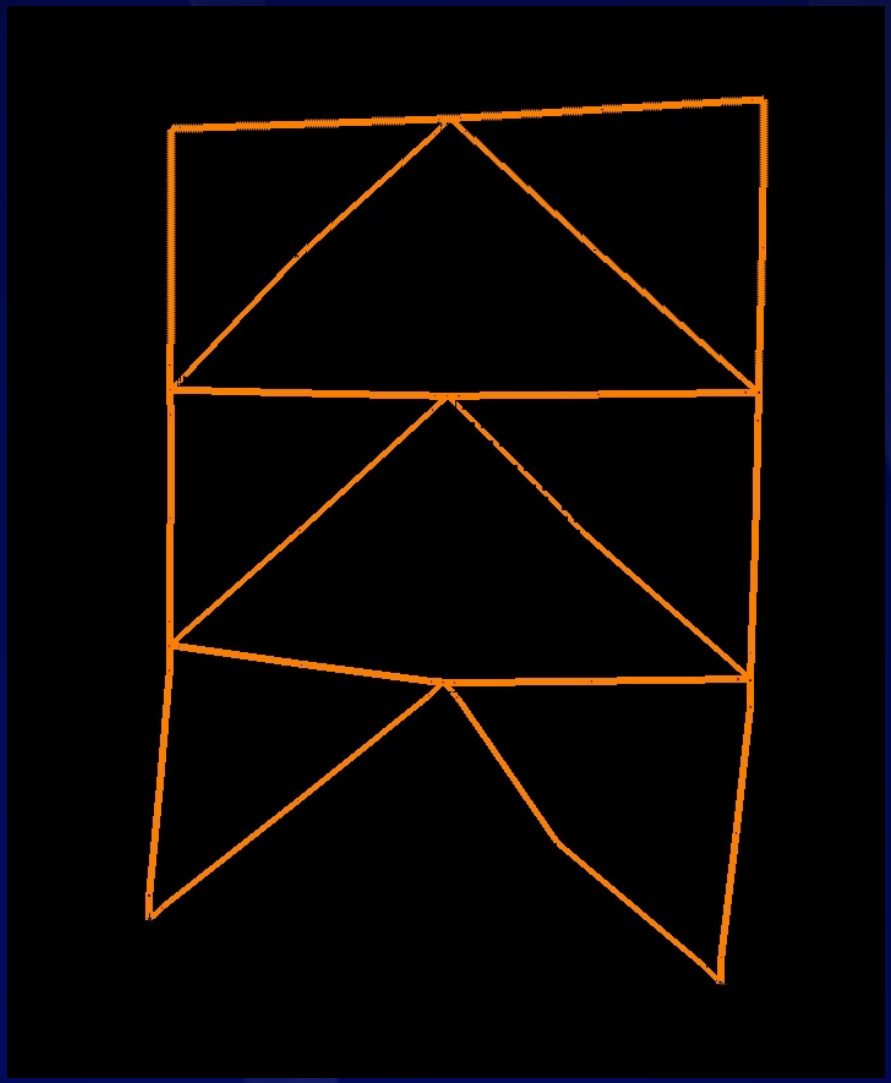
OpenSees Examples



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