Open System for Earthquake Engineering Simulation
Pacific Earthquake Engineering Research Center

NEES

Modeling SCB frames using beam-column elements

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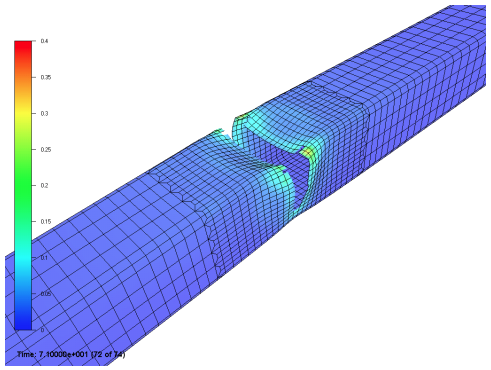
Agenda

- Different modeling approaches of SCBFs
- Line-element model of SCBF
  - 3 different models of gusset plate connections will be considered and demonstrated on an example
- Comparison of seismic responses of a SCBF considering different gusset plate connection models
- Sensitivity of the model to geometric imperfection of the brace and the number of elements used to model the brace
- Consideration of further simplifications of the model (demonstrated on an example)
- Conclusions and summary
- Q & A with web participants

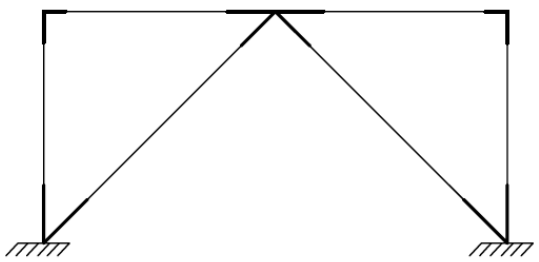
Introduction

- Special Concentrically Braced Frames (SCBF) are commonly used as the seismic resisting system in buildings.
- During large seismic events they may experience buckling of the braces.
- Inelastic deformation of the braces place inelastic deformation demands on beams, columns and connections.

Modeling approaches for SCBF



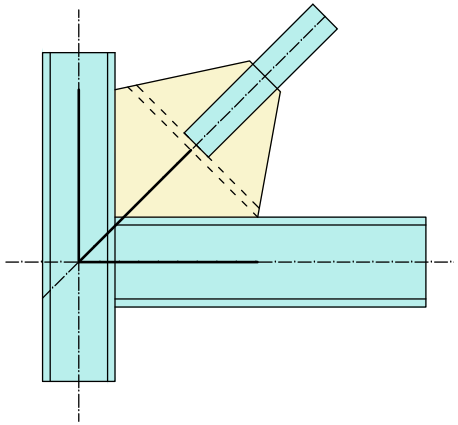
- Continuum models (shell or brick elements)
  - Accurate
  - Computationally expensive



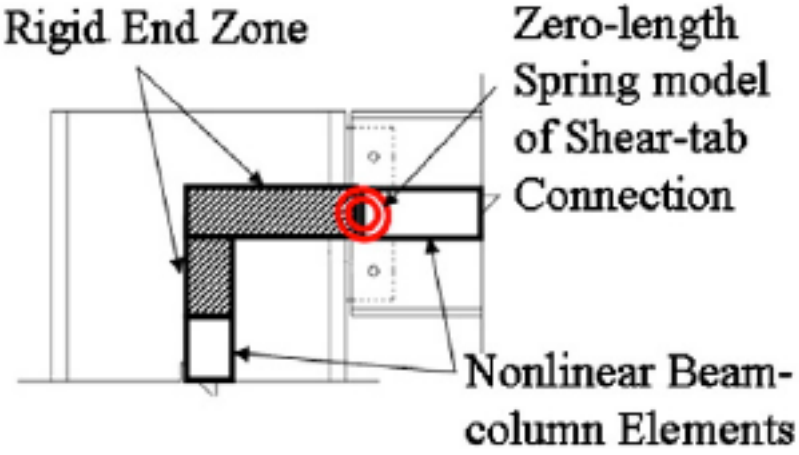
- Line-element models (beam-column elements and zero-length elements)
  - Simple = Computation time significantly reduced
  - Accurate simulation of global behavior
  - Reasonable predictions of many local behaviors

OpenSees elements used in Line-element models

- Braces, beams and columns can be modeled with force-based (FB) fiber beam-column elements.
- Rigidity of the gusset, gusset-to-beam, and gusset-to-column connections can be modeled with rigid elastic elements.



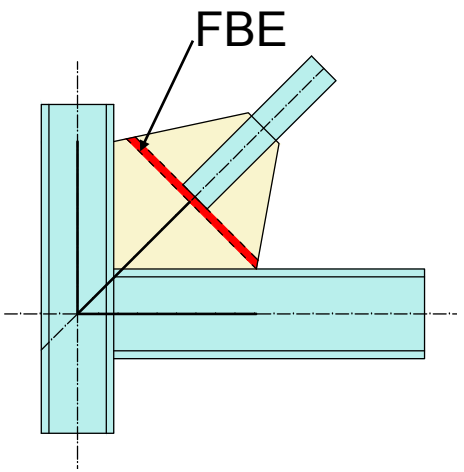
- Beam-column connections of shear tab type can be modeled with zero-length rotational spring model (Liu & Astaneh-Asl, 2004)

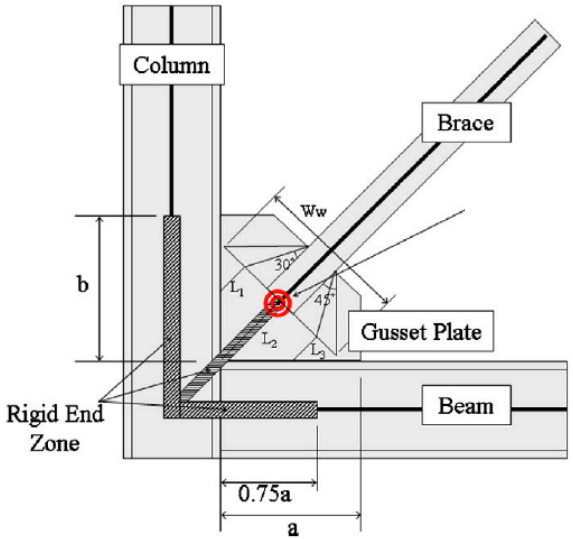


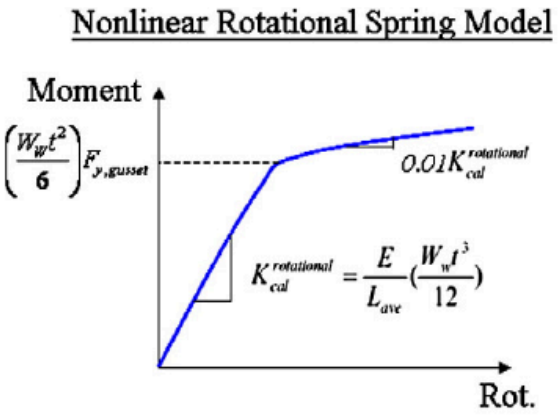
OpenSees elements used in Line-element models

Gusset plates (GP) connection can be modeled in two ways:

1. Force-based fiber elements (Uriz & Mahin, 2008)
2. Rotational hinge (Hsiao et al., 2012)



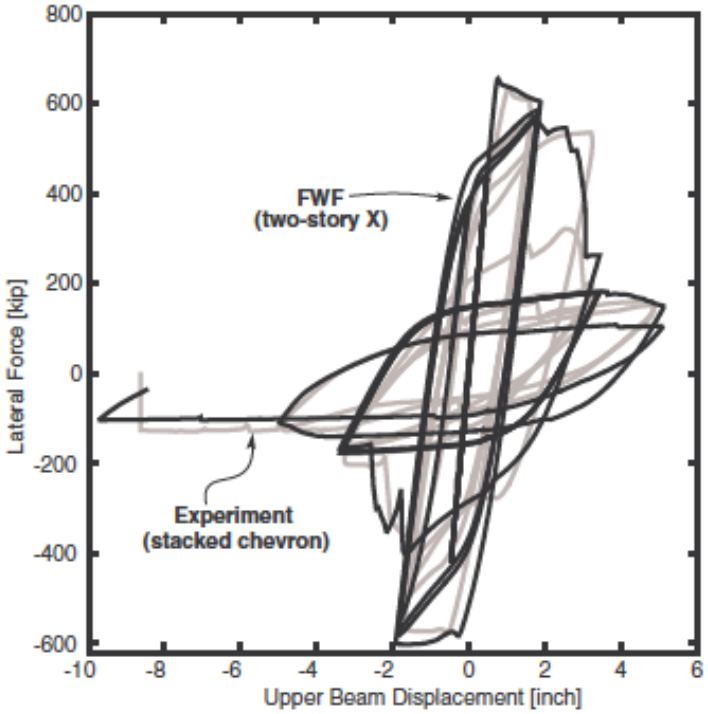




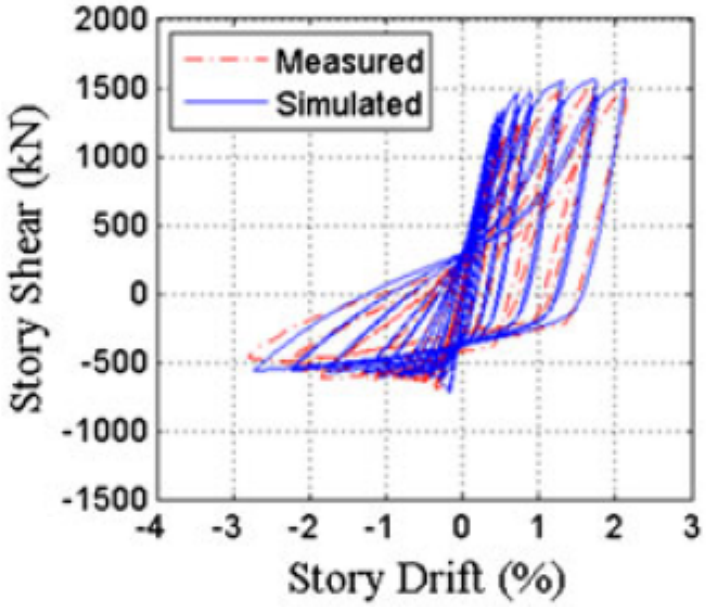
$L_{avg}=(L_1+L_2+L_3)/3$

Analytical Predictions

Uritz & Mahin, 2008

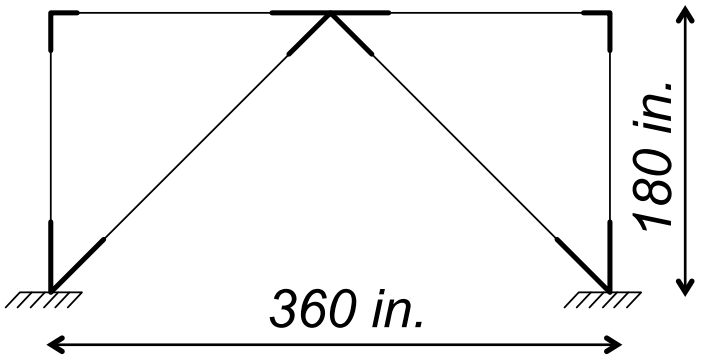


Hsiao et al., 2012



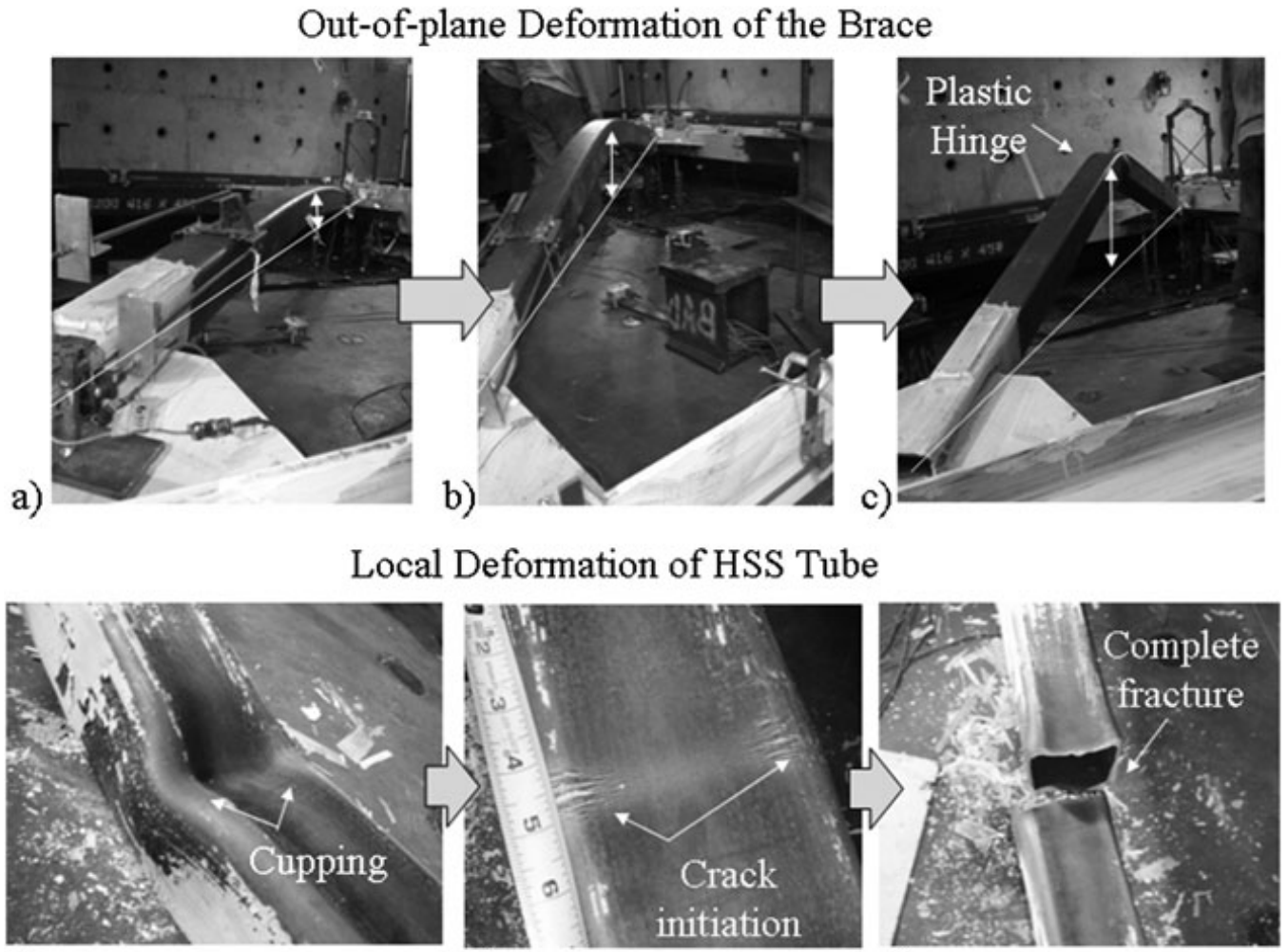
Example

- One story-one bay SCBF with chevron configuration of braces
- Beams: W27x84
- Columns: W14x176
- Braces:HSS10x10x0.625



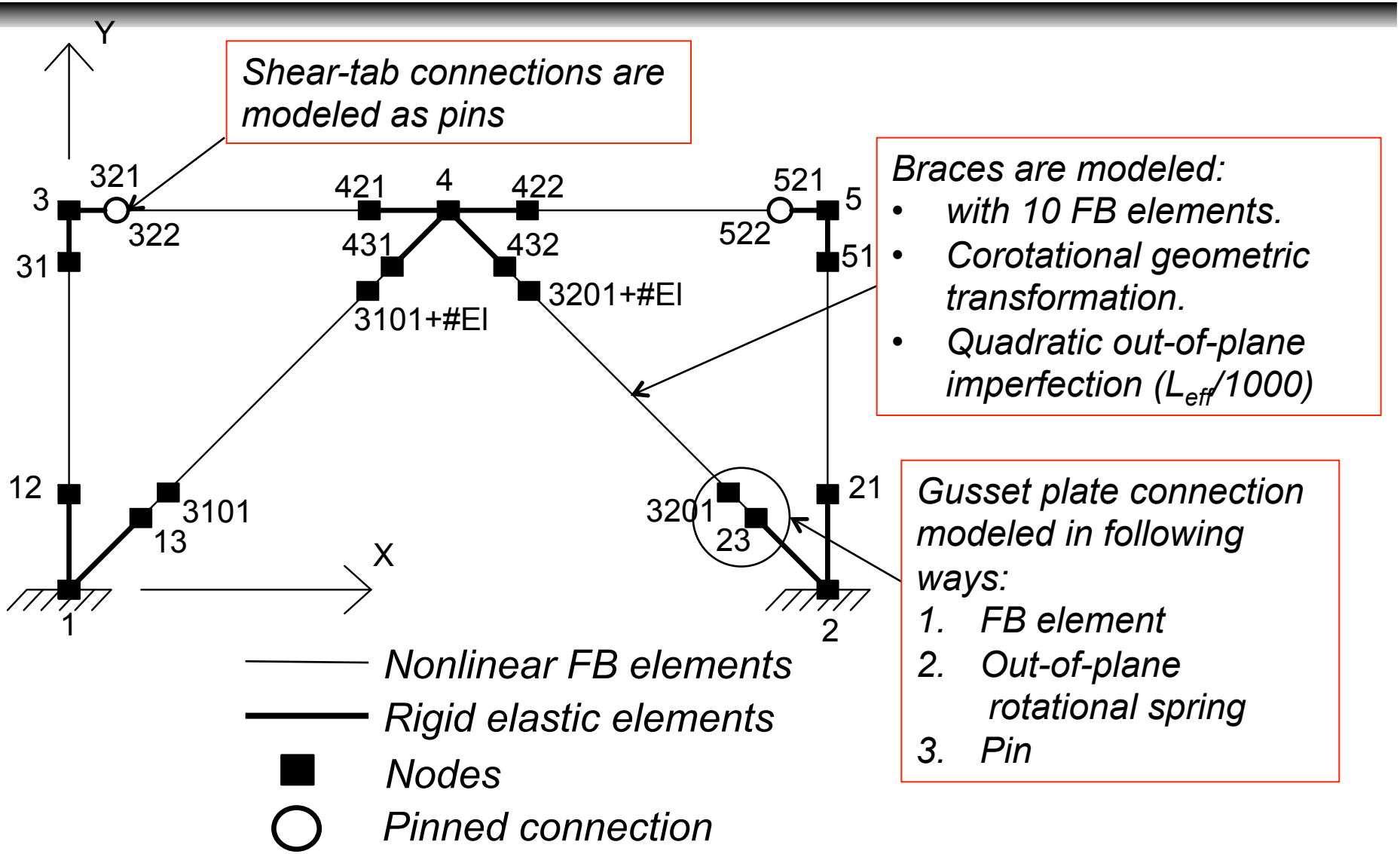
- Gusset plate: tapered plate with t=1.375 in
- Beam-column connections are shear tab connections (not designed for the purpose of this example)

Buckling of HSS braces



Hsiao et al. 2013

OpenSees model – 3D model

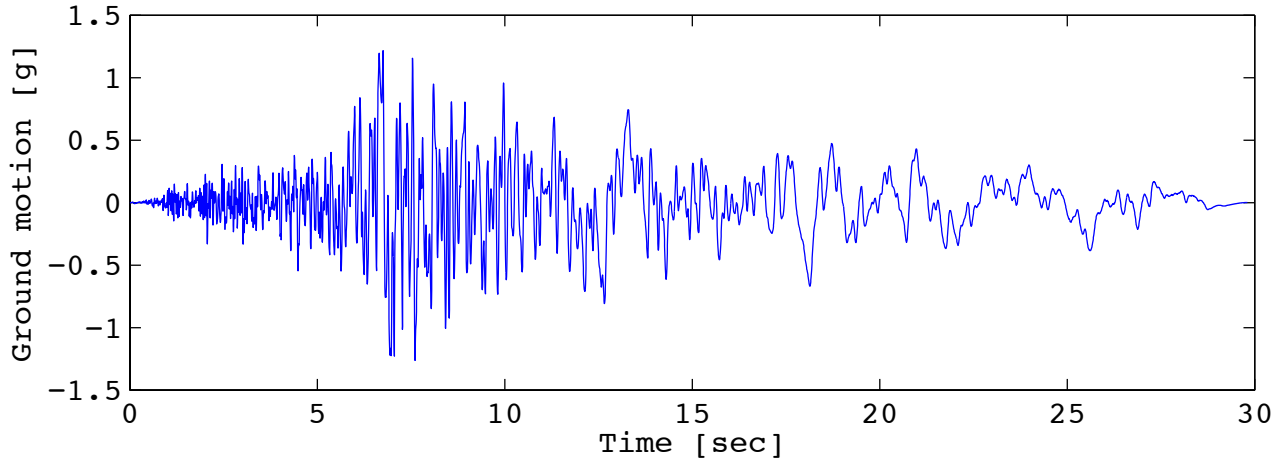


OpenSees model

- All nonlinear elements are modeled using Steel02 wrapped with Fatigue material
  - 3 integration points (IP) are used for braces and beams and 4 IPs are used for columns
- Nonlinear rotational spring is modeled using zero-length element and Steel02 material assigned to it.
- All rigid elements are modeled with elastic beam-column elements with 10 times bigger A and I than that of the corresponding element.

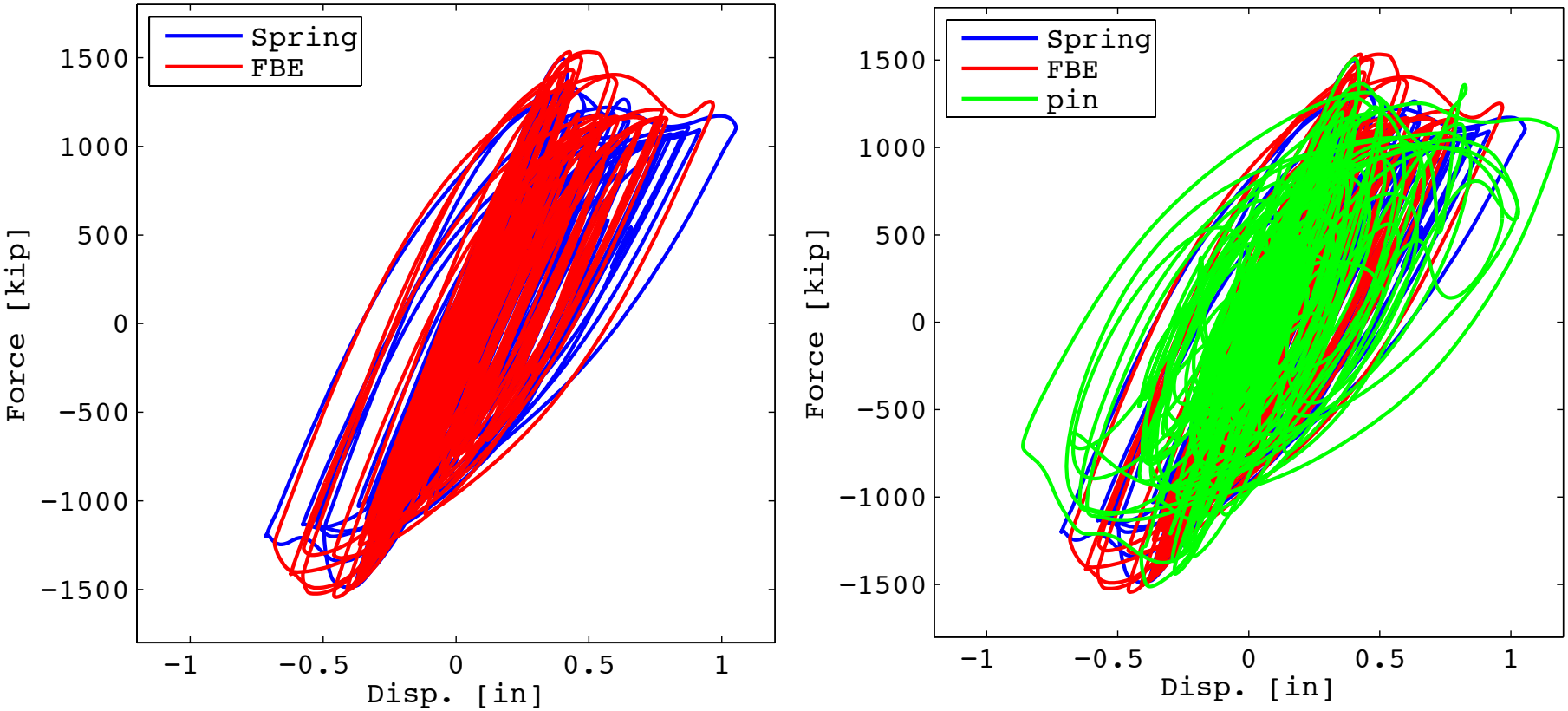
OpenSees model - loads

- Loads:
  - Gravity
  - Ground motion with its two components (horizontal and vertical)



Seismic performance of SCBF with different gusset plate connections

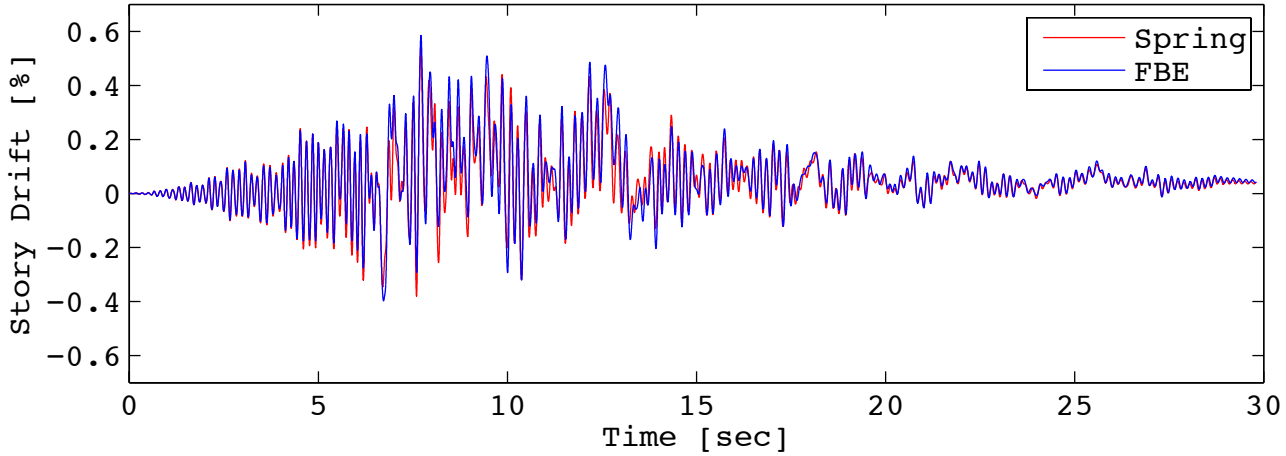
Base shear vs. displacement

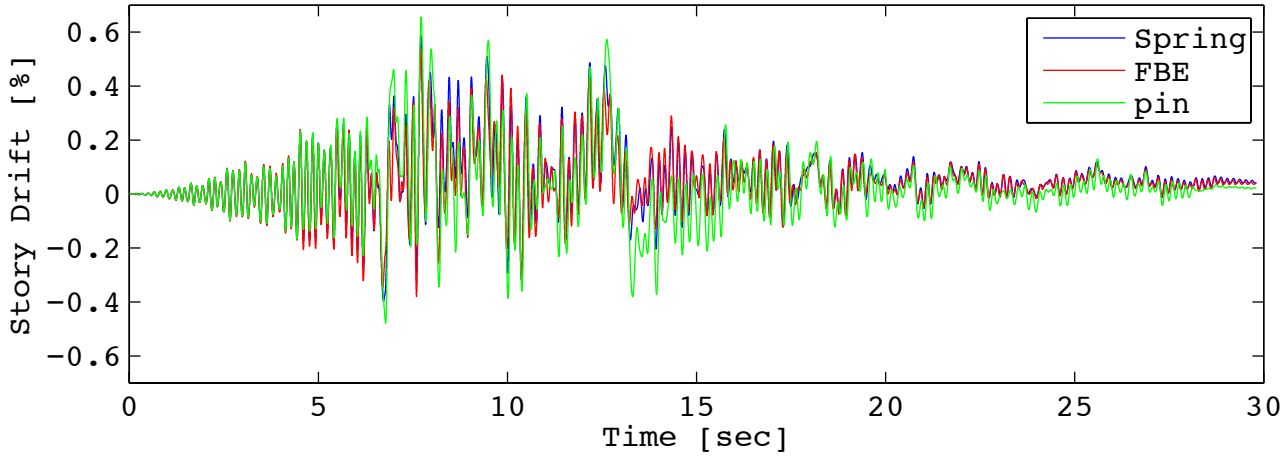


Note: period is ~ the same for all three types of models: T=0.156 sec

Seismic performance of SCBF with different gusset plate connections

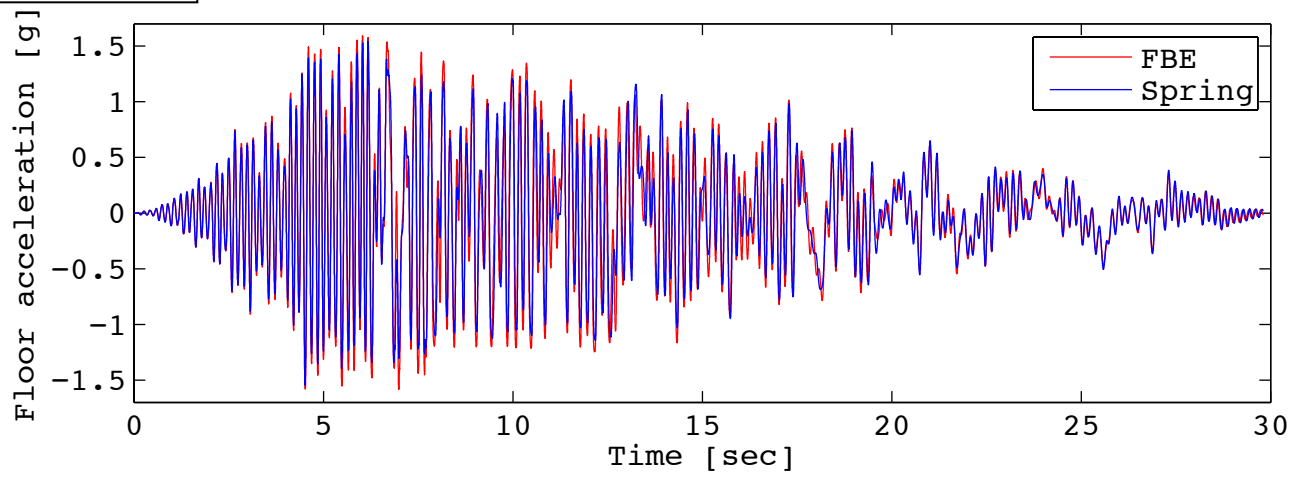
Story drift

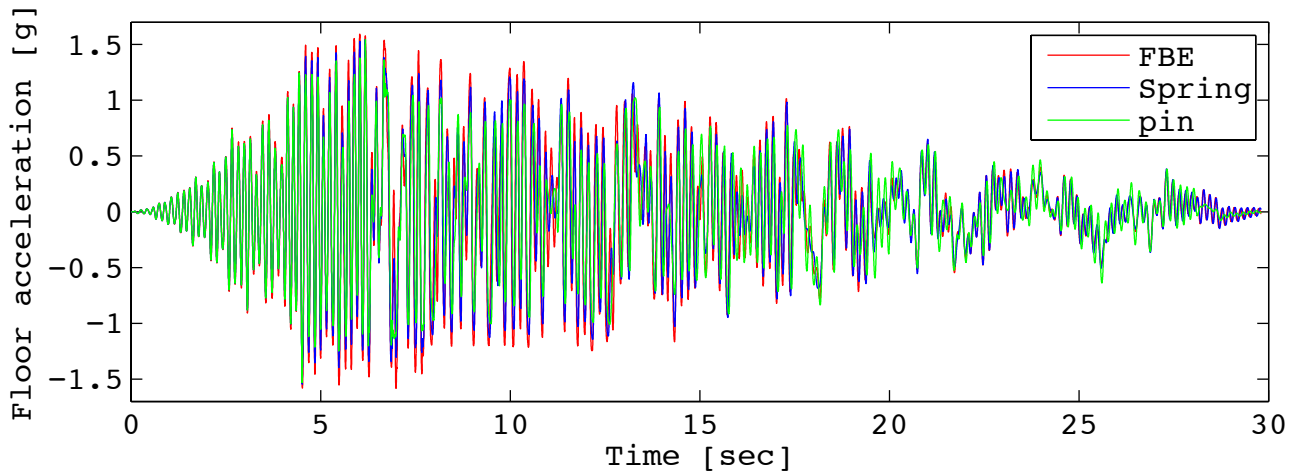




Seismic performance of SCBF with different gusset plate connections

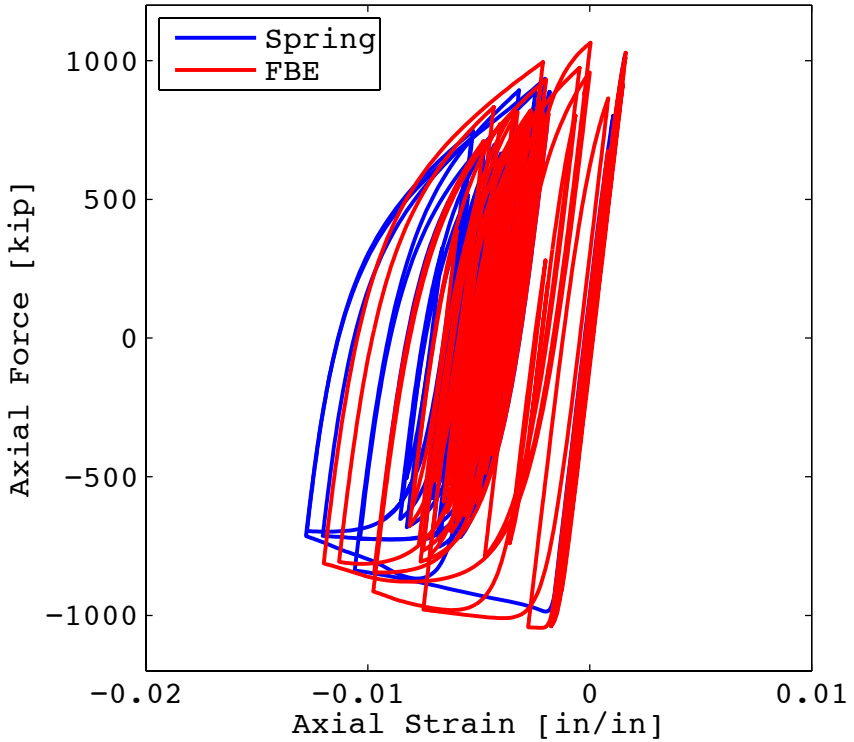
Floor acceleration

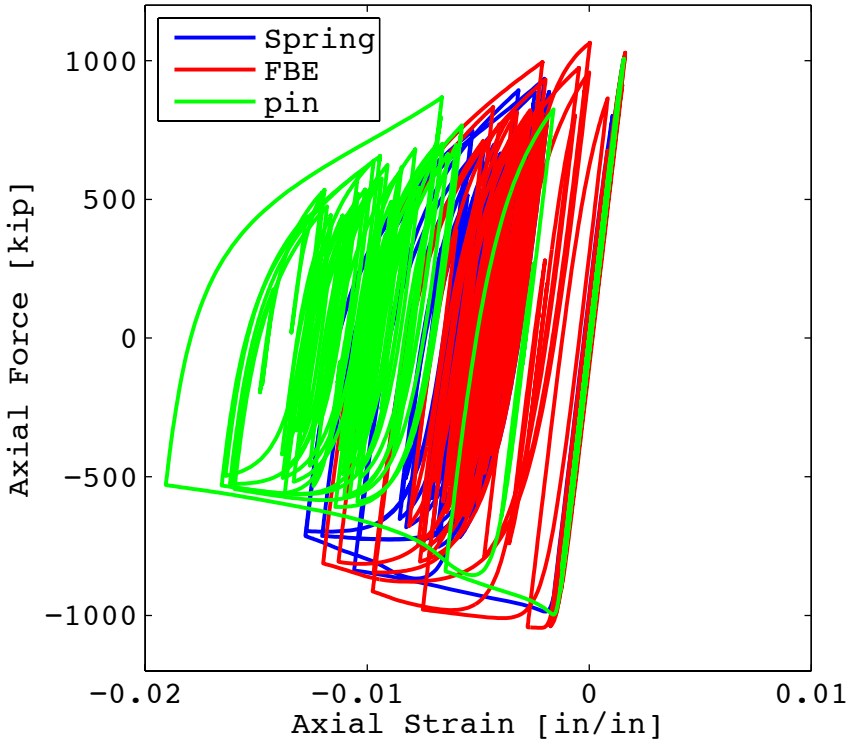




Seismic performance of SCBF with different gusset plate connections

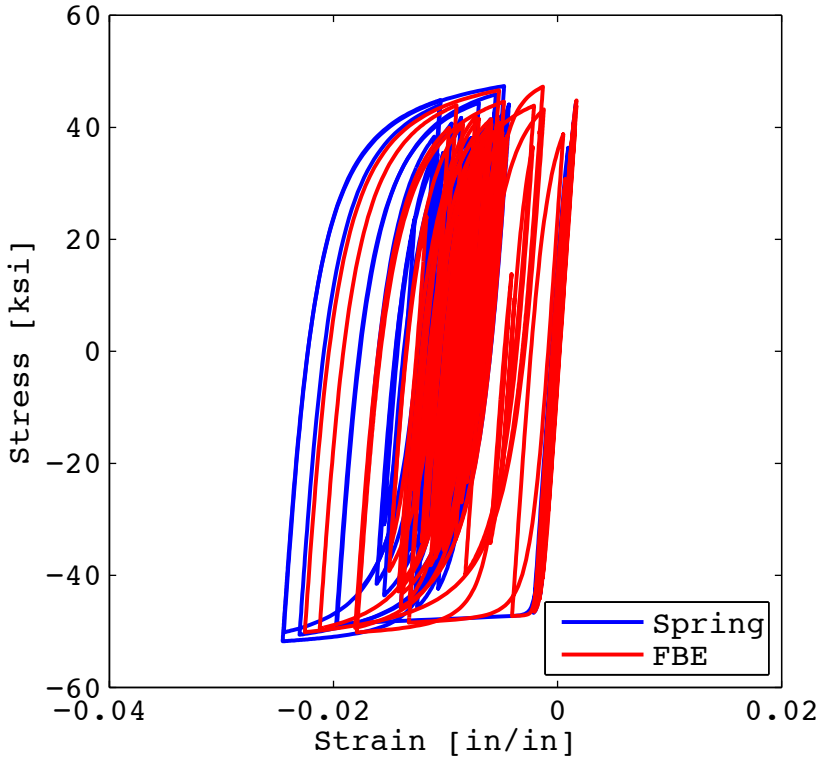
Axial force – deformation at the middle of the left brace

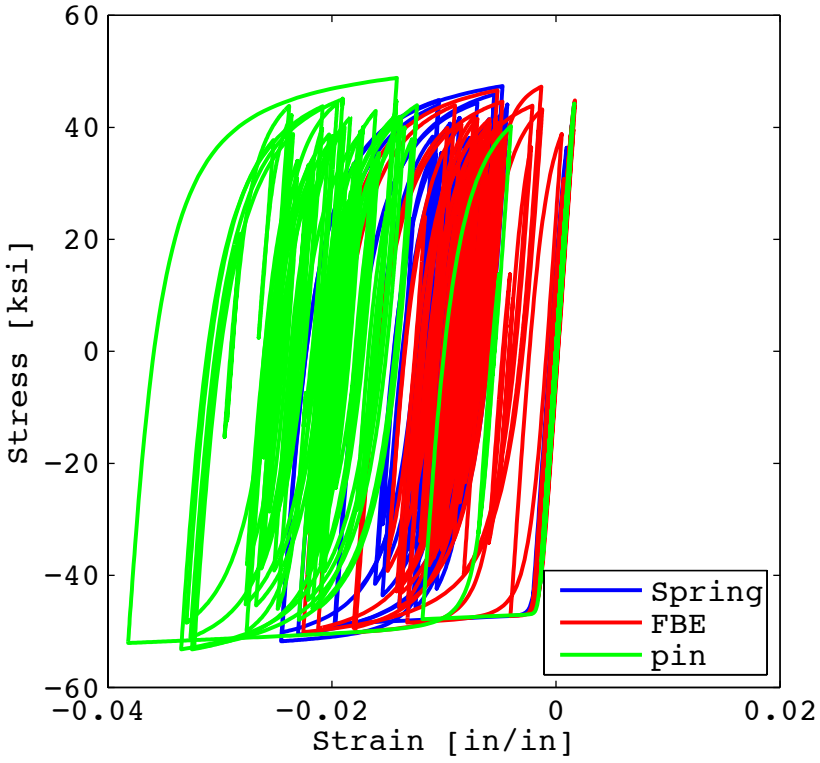




Seismic performance of SCBF with different gusset plate connections

Stress-strain of a fiber at the midd cross-section of the left brace



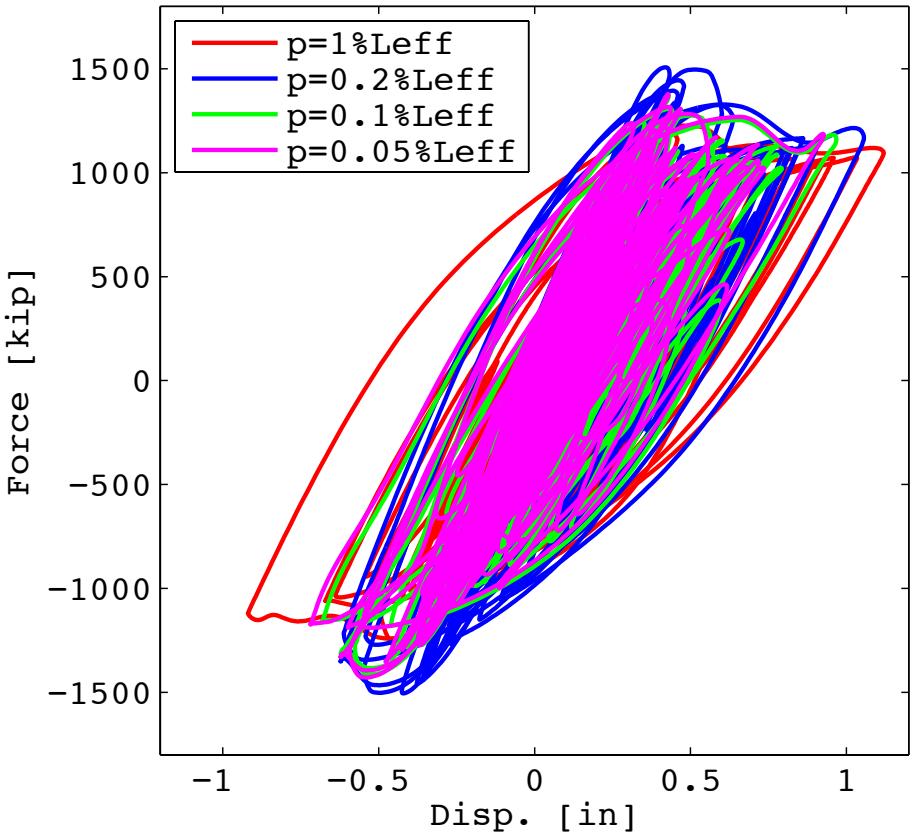


Summary

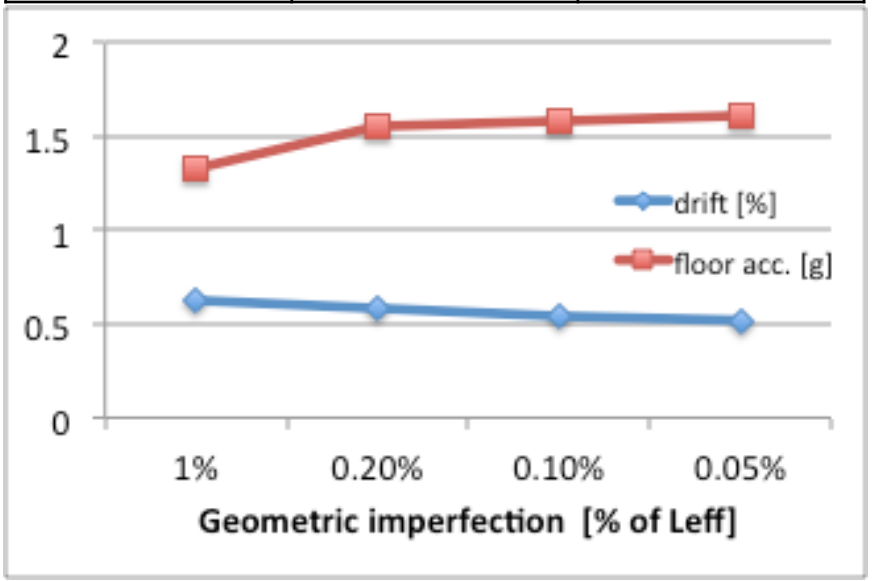
- GP connections modeled with either FBE or rotational spring provide similar global and local responses of the system.
- FBE element is simpler to model (input information are t, W_w) than rotational spring (input information are t, W_w and L_{avg})
- Pinned GP connection results in great loss of accuracy and is not recommended for estimating a seismic performance of SCBF under large earthquakes that can induce the buckling of the braces.

Effect of initial imperfection on the results – GPC = FBE

Global responses



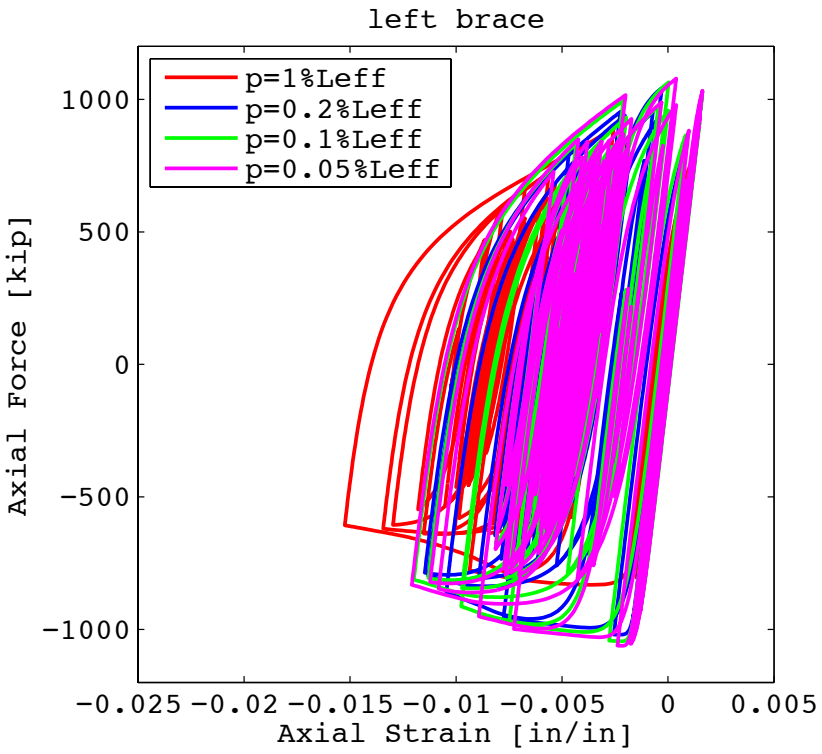
Geometric imperfection	Max. Drift [%]	Max. Acc. [g]
1%Leff	0.62	1.33
0.2%Leff	0.59	1.56
0.1%Leff	0.54	1.59
0.05%Leff	0.52	1.61

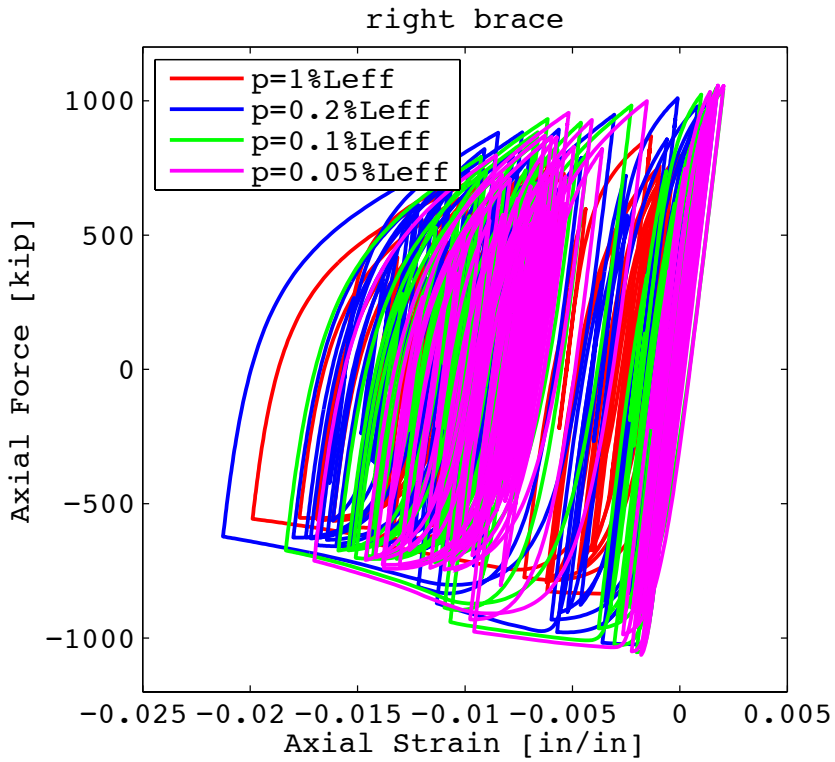


Note: compression elements usually have constriction tolerance of 0.1%L_{eff}

Effect of initial imperfection on the results – GPC = FBE

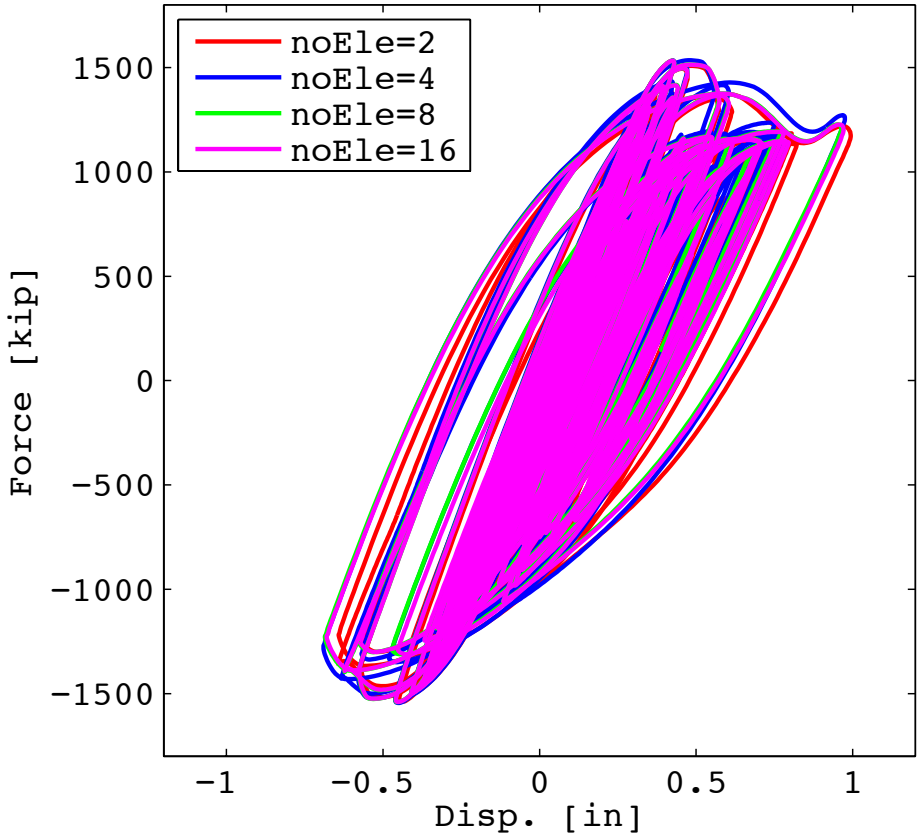
Local responses





Effect of number of FBE used to model the brace – GPC = FBE

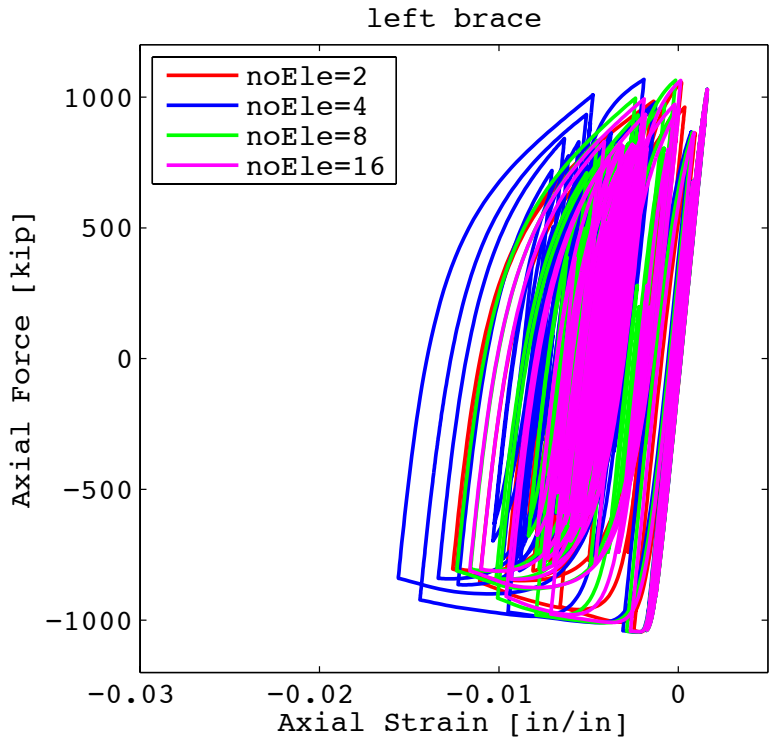
Global responses

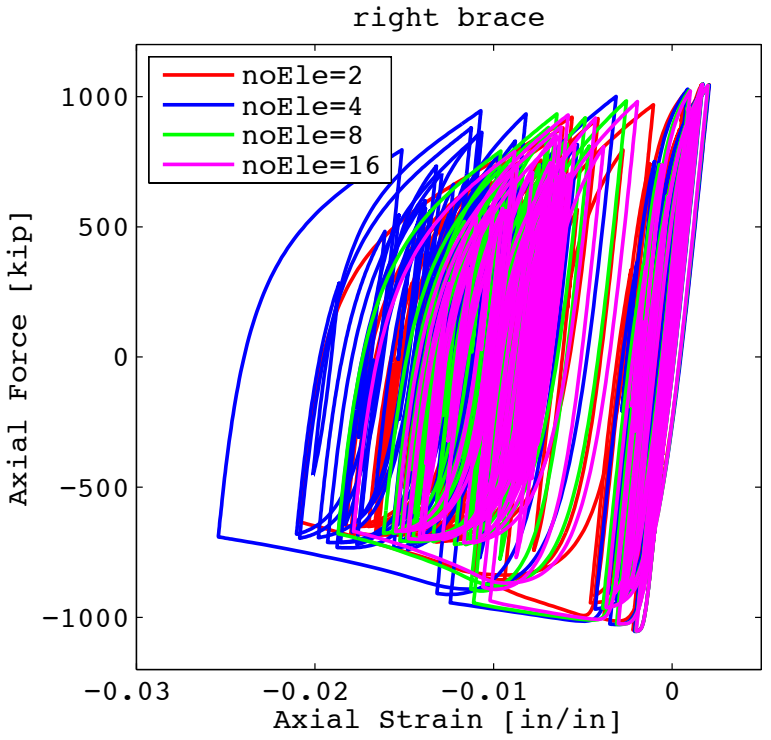


Number of elements	Max. Drift [%]	Max. Acc. [g]
2	0.55	1.59
4	0.54	1.59
8	0.54	1.59
16	0.54	1.59

Effect of number of FBE used to model the brace – GPC = FBE

Local responses

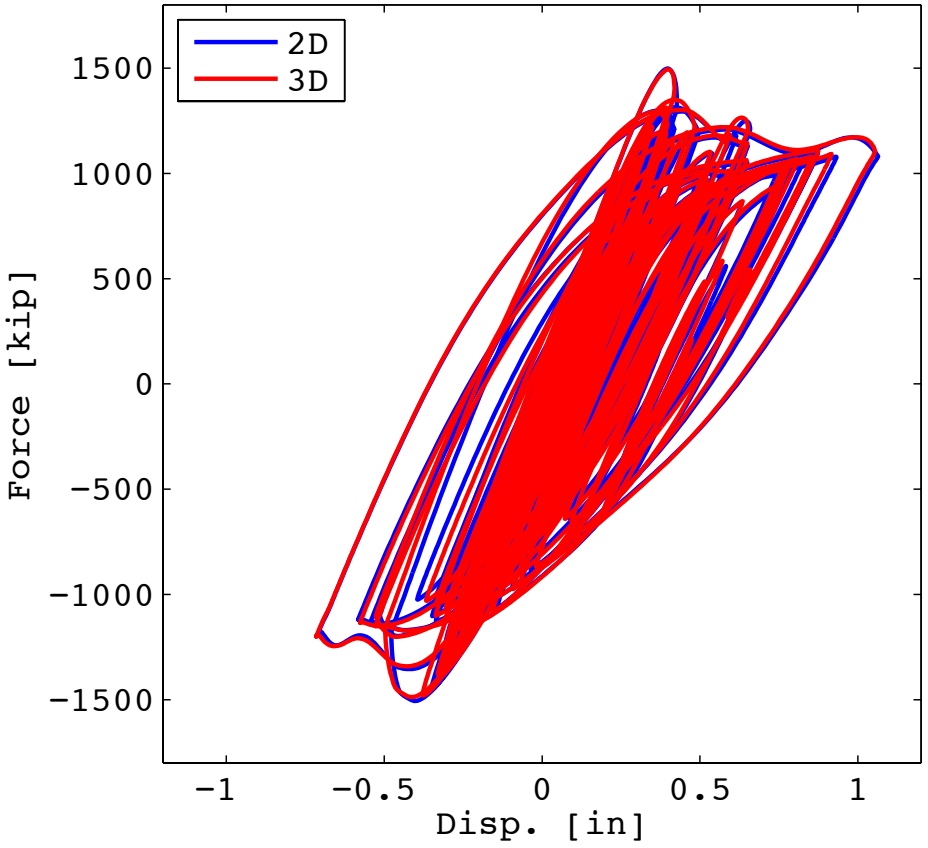




To capture failure of the brace it is suggested to use 10-20 elements (Uriz & Mahin 2008)

3D vs. 2D frame – GP connection modeled with rotational spring

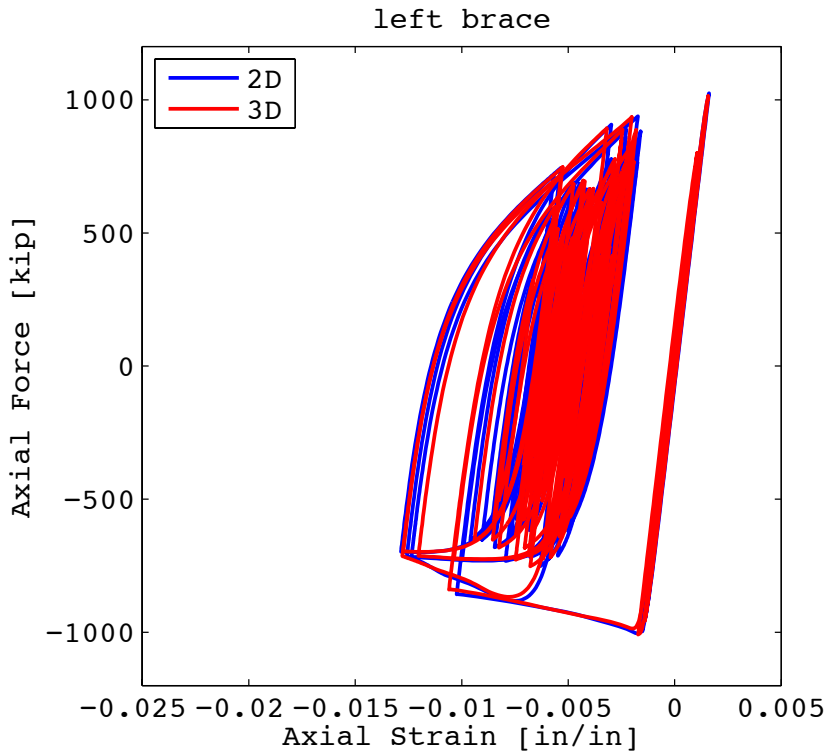
Global responses

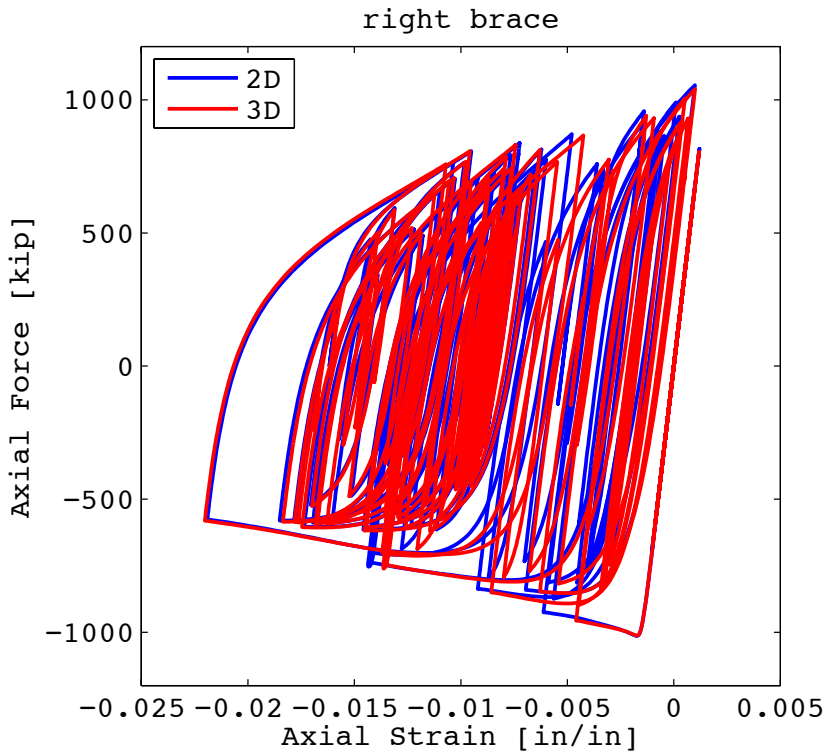


Spatial dimension	Max. Drift [%]	Max. Acc. [g]
2D	0.591	1.569
3D	0.586	1.554

3D vs. 2D frame – GP connection modeled with rotational spring

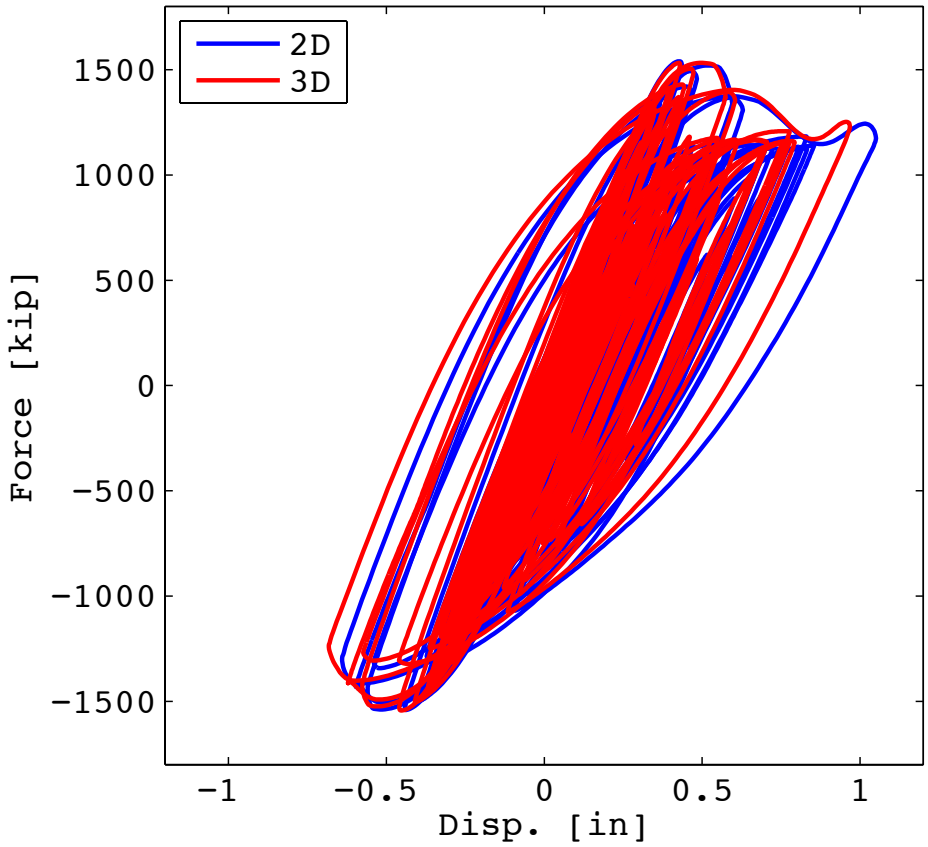
Local responses





3D vs. 2D frame – GP connection modeled with FBE

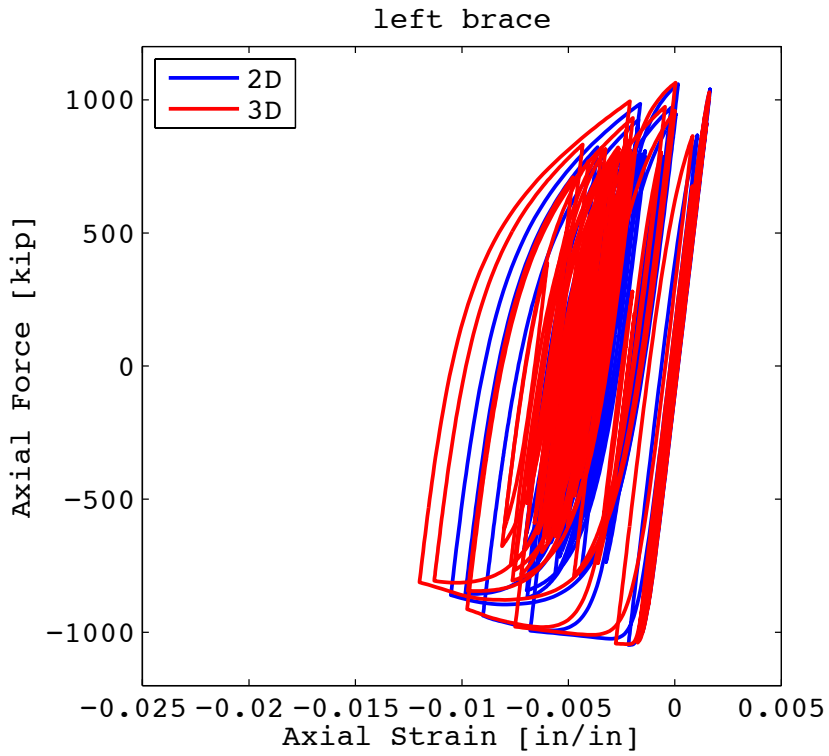
Global responses

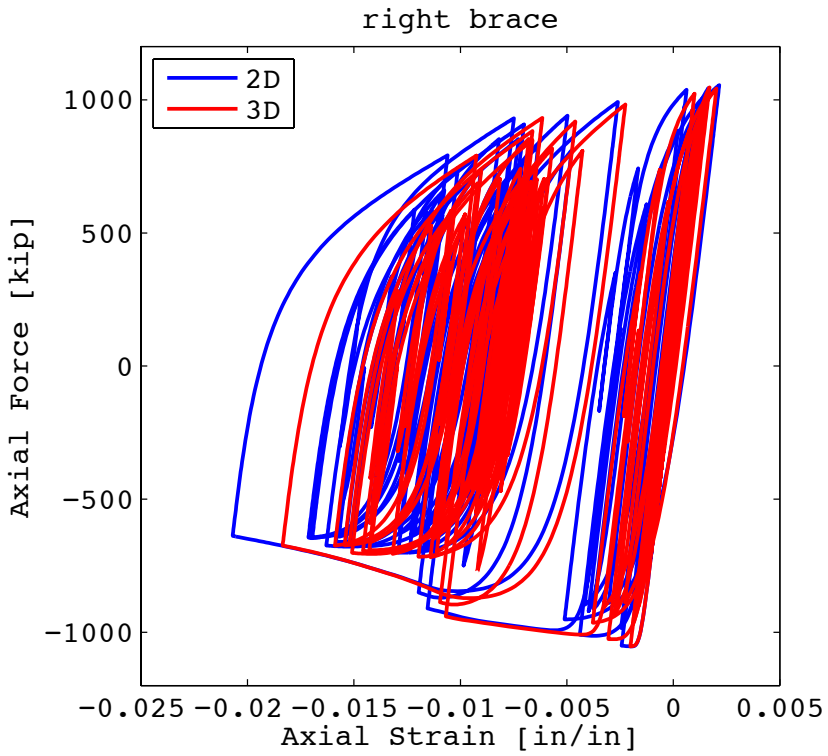


Spatial dimension	Max. Drift [%]	Max. Acc. [g]
2D	0.58	1.60
3D	0.54	1.60

3D vs. 2D frame – GP connection modeled with rotational spring

Local responses





Summary and conclusions

- GP connections modeled with either FBE or rotational spring provide similar both global and local responses of the system.
- GP connections should not be modeled as pinned if buckling of the braces is expected.
- Global and local responses are sensitive to the value of the geometric imperfection at the middle of the brace
  - AISC specifies construction tolerance of steel elements under compression to $L_{eff}/1000$ (design documents)
- Local response of the system is sensitive to the number of FB elements used to model the brace.
  - To capture the fracture of the brace it is recommended to use 10-20 elements
- 3D frame models can be replaced with 2D models without compromising the accuracy of the results (especially in the case of GP connections modeled with rotational springs)

References

1. Patxi Uriz, and Stephen A. Mahin, (2008), “Toward Earthquake-Resistant Design of Concentrically Braced Steel-Frame Structures”, PEER report 2008/08.
2. Po-Chien Hsiao, Dawn E. Lehman, and Charles W. Roeder, (2012), "Improved analytical model for special concentrically braced frames", *Journal of Constructional Steel Research* 73 (21012) 80-94.
3. Liu J, and Astaneh-Asl A, (2004), “Moment-Rotation Parameters for Composite Shear Tab Connections,” *Journal of structural engineering*, ASCE 2004;130(9).
4. Po-Chien Hsiao, Dawn E. Lehman, and Charles W. Roeder, (2013), “A model to simulate special concentrically braced frames beyond brace fracture,” *Earthquake Engng Struct. Dyn*. 2013; 42:183–200