Modeling SCB frames using beam-column elements

Vesna Terzic
UC Berkeley

January 2013
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)
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)
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

Out-of-plane Deformation of the Brace

a) b) c)

Plastic Hinge

Local Deformation of HSS Tube

Cupping Crack initiation Complete fracture

Hsiao et al. 2013
Braces are modeled:
1. with 10 FB elements.
2. Corotational geometric transformation.
3. Quadratic out-of-plane imperfection ($L_{eff}/1000$)

Gusset plate connection modeled in following ways:
1. FB element
2. Out-of-plane rotational spring
3. Pin

Shear-tab connections are modeled as pins

Nonlinear FB elements
Rigid elastic elements
Nodes
Pinned connection
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
Seismic performance of SCBF with different gusset plate connections

Floor acceleration

![Chart showing floor acceleration over time for different connections (FBE, Spring, pin)]
Seismic performance of SCBF with different gusset plate connections

Axial force – deformation at the middle of the left brace

- Axial Force [kip] vs. Axial Strain [in/in] for different connections (Spring, FBE, pin)
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

<table>
<thead>
<tr>
<th>Geometric imperfection</th>
<th>Max. Drift [%]</th>
<th>Max. Acc. [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1%Leff</td>
<td>0.62</td>
<td>1.33</td>
</tr>
<tr>
<td>0.2%Leff</td>
<td>0.59</td>
<td>1.56</td>
</tr>
<tr>
<td>0.1%Leff</td>
<td>0.54</td>
<td>1.59</td>
</tr>
<tr>
<td>0.05%Leff</td>
<td>0.52</td>
<td>1.61</td>
</tr>
</tbody>
</table>

*Note: compression elements usually have constriction tolerance of 0.1%Leff*
Effect of initial imperfection on the results – GPC = FBE

Local responses

![Graphs showing local responses](image)
Effect of number of FBE used to model the brace – GPC = FBE

Global responses

<table>
<thead>
<tr>
<th>Number of elements</th>
<th>Max. Drift [%]</th>
<th>Max. Acc. [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.55</td>
<td>1.59</td>
</tr>
<tr>
<td>4</td>
<td>0.54</td>
<td>1.59</td>
</tr>
<tr>
<td>8</td>
<td>0.54</td>
<td>1.59</td>
</tr>
<tr>
<td>16</td>
<td>0.54</td>
<td>1.59</td>
</tr>
</tbody>
</table>
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**

![Graph showing local responses for 2D and 3D frames with axial strain vs. axial force plots for left and right braces.](image-url)
3D vs. 2D frame – GP connection modeled with FBE

Global responses

<table>
<thead>
<tr>
<th>Spatial dimension</th>
<th>Max. Drift [%]</th>
<th>Max. Acc. [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D</td>
<td>0.58</td>
<td>1.60</td>
</tr>
<tr>
<td>3D</td>
<td>0.54</td>
<td>1.60</td>
</tr>
</tbody>
</table>
3D vs. 2D frame – GP connection modeled with rotational spring

Local responses

- Left brace
- Right brace

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 $L_{\text{eff}}/1000$ (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


