Design of Concentrically Braced Frames

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Example Configurations

- X-Braced
- Inverted V (Chevron)
- 2 Story X-Braced
Example Configurations

V (Inverted Chevron)  Zipper

Special Concentrically Braced Frames

- Primary location of energy dissipation are the braces
- Braces dissipate energy by tension yielding and compression buckling
Special Concentrically Braced Frames

Preferred Modes: Brace Tension Yielding

Consider maximum effects due to brace force ($R_f A_o$)

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Special Concentrically Braced Frames

Preferred Modes: Brace Buckling

Consider maximum effects due to brace force

(sometimes $P = R_f P_o$, sometimes $P = 0.3 P_o$)
Special Concentrically Braced Frames
Column Axial Load Distribution

Traditional Overturning Assumption
Interior column seismic axial load effect is zero

Special Concentrically Braced Frames
Column Axial Load Distribution

Overturning Distribution with Buckling

Yielding brace \( R_f A_p \)
Buckled brace \( 0.3P_n \)
Interior column seismic axial load effect is not zero
Special Concentrically Braced Frames
Beam Design – Axial Load

Yield Mechanism

$C < R_y P_n$

$C \geq 0.3 P_n$  (Maximum axial force in beam)

$C \geq 0.3 P_n$

Special Concentrically Braced Frames
Beam Design: Flexure

Yield Mechanism

$C < R_y P_n$

$C \geq 0.3 P_n$  (Maximum flexural force in beam)
Special Concentrically Braced Frames
Basic Design Procedure

- Calculate the demand based on ASCE 7
- Analyze the structure; find brace forces
- Size the fuses i.e. braces
- Capacity design other non yielding members

4. Capacity design other members
- Use expected brace capacity
- Eliminate conservative design assumptions
- Do not use $\phi$ factors for expected strength
Requirements for Member Design

Slenderness

- Bracing member slenderness \( KL/r \leq 4\sqrt{E/F_y} \)
- Braces with \( 4\sqrt{E/F_y} \leq KL/r \leq 200 \) is permitted in frames where columns are designed for \( R_y \) times nominal strength of the brace elements
- This load need not exceed the axial loads from inelastic analysis or the max load that can be developed by the system

Special Concentrically Braced Frames

Slenderness

\[
\Omega_0 E = \begin{align*}
1 & \ R_Y F A_s \sin \theta \\
+ & \ R_Y F c A_t \sin \theta 
\end{align*}
\]

Where columns can resist loads that include the expected brace strengths, \( k/l_r \) can be as high as 200.
Requirements for Member Design

Brace Effective Length

Brace effective length can be determined easily if pin-type connections are used.

Plane of Buckling

In-Plane
(Generally requires brace with weak in-plane axes and connections fixed out-of-plane)

Out-of-plane
(Generally governs if brace is round or square)
Requirements for Member Design

Brace Effective Length: End Fixity

Pin

Fixed

Requirements for Member Design

Brace Effective Length

Cross Bracing

Continuous connection

Hinged connection

Cross Bracing
(with flexural continuity at splice)

K = 1
(out-of-plane)
Requirements for Member Design

Required Strength

- If $UA_{nt} < Agross$
  - then $Fu(UA_{nt}) > RyFyAg$
  - Max load indicated by analysis that can be transferred to the brace by the system

Requirements for Member Design

Lateral Force Distribution

- Along any line of bracing at least 30% but not more than 70% of the force is to be resisted by brace in tension
- Exception allowed when compression braces are designed for Amplified ($\Omega$) load combinations of ASCE 7
Requirements for Member Design
Lateral Force Distribution

0.3V \leq \text{Tension} \leq 0.7V
0.3V \leq \text{Compression} \leq 0.7V

OK

Requirements for Member Design
Width-Thickness Limitations

- Members to be seismically compact. Follow requirements of Table I-8-1
Requirements for Member Design
Local Buckling

Connections to be designed for expected yield strength of member in tension $R_yF_{Ag}$

This force need not exceed the max load indicated by analysis that can be transferred to the brace by the system
Design of SCBF Connections

**Tension**

Member tension yielding OK

\[ \phi R_n \geq R_y F_y A_g \]

Connection fracture NOT PERMITTED

Design of SCBF Connections

**Flexure (Compression)**

Buckling: 3 hinges

OK (pinned end)

OK (fixed end)
Design of SCBF Connections

Pin ended

Fixed ended

Design of SCBF Connections

Flexure (Compression)

Gusset must fracture or weld must break to permit rotation

No Hinge Zone
Design of SCBF Connections

- Design flexural strength of the connection (if fixed)
  \[ \phi R_n \geq 1.1 R_y M_p \]

- Design compressive strength of the connection if pinned along with proper detailing
  \[ \phi R_n \geq 1.1 R_y P_n \]

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2t Offset

Provide accommodating detail (2t offset)

Recommendation: 2t + ¾" ± ¼"

Detail: 2t + ⅝" ± ¼"

Design: 2t + 1½"
Design of SCBF Connections

2t Offset @ Concrete Filled Deck

Design of SCBF Connections

Tearing of Gusset: No Hinge Zone

Crack formed by gusset plate folding

From Astanat-Aal, Seismic Behavior and Design of Gusset Plates, Steel Tins 1998
Design of SCBF Connections

Folding of Gusset: Hinge Zone

From Astaneh-Asl, Seismic Behavior and Design of Gusset Plates: Steel Tins 1998

Design of SCBF Connections
Gusset Compression

- Estimate the max. compression force from the brace:
  - Consider true brace length
  - Consider connection fixity
  - Consider material overstrength
  - Shortcut: Tension strength is always greater than compression strength
Design of SCBF Connections
Gusset Compression

Gussets: Effective Width

Whitmore limitation

Reality limitation

Design of SCBF Connections
Gusset Compression

Effective Length

\[ L_{\text{eff}} \]

K = 1.2

Astaneh-Asl,
Steel Tips # 42
“Seismic Behavior and Design of Gusset Plates”
Design of SCBF Connections
Gusset Compression

K = 1.2
(Astaneh, Steel Tips)

3 Options (all reasonably reliable)
L = Ave (L)?
L = Max (L)?
L = Q (L)?

Design of SCBF Connections
Gusset Compression

\[ \frac{L_e}{t} \leq \frac{3}{4} \sqrt{\frac{E}{F_y}} \]
(Astaneh-Asl, Steel Tips)
Design of SCBF Connections
Design of gussets

**Workpoint Location**
- Concentric
- Eccentric

An eccentric workpoint will induce flexural forces in the framing members.

Design of SCBF Connections
Design of gussets: Uniform Force Method
Design of SCBF Connections
Design of gussets: Uniform Force Method

\[ V_{uc} = \frac{\beta}{r} P_u \]
\[ H_{uc} = \frac{e_c}{r} P_u \]

\[ H_{ub} = \frac{\alpha}{r} P_u \]
\[ V_{ub} = \frac{e_b}{r} P_u \]

where

\[ r = \sqrt{(\alpha + e_c)^2 + (\beta + e_b)^2} \]

Design of SCBF: Specials for Chevron

Chevron

\[ T = R_yF_YA_g \]
\[ C = 0.3P_n \]
Design of SCBF: Specials for Chevron

**Chevron**

Forces apply to:
- Beams
- Connections
- Columns etc.

Beam must be continuous and strong enough for gravity

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Design of SCBF: Specials for Chevron

2-Story X

2 story X bracing resists unbalanced load caused by the buckled brace.

The beam does not need to be designed for this load.

- Braces on floor above support beam