

## Night School 28: Vertical Bracing Connections

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webinar. We will begin shortly.  
Please standby.

**AISC**  
Night School



### Vertical Bracing Connections, Session 6: The Corner Connection (seismic)

May 10, 2022 | Rafael Sabelli



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Stronger.  
Steel.**

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Night School

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## Course Description

### Vertical Bracing Connections

#### Session 6: The Corner Connection (seismic) May 10, 2022

The various steps and methodologies used for bracing connection design will be highlighted as the presenter works through a seismic design example. The session will discuss the requirements for Special Concentrically Braced Frame (SCBF) and Buckling Restrained Braced Frame (BRBF) connections. It review the several alternatives for the gusset plate design: linear hinge, elliptical hinge and rotated gusset. Finally, a design example will be presented to demonstrate applicability.





## Learning Objectives

1. Understand the role of AISC 341 in bracing-connection design
2. Learn the bracing-connection requirements for Special Concentrically Braced Frames
3. Learn the bracing-connection requirements for Buckling Restrained Braced Frames
4. Learn to determine design forces for bracing connections that include both collector forces from ASCE 7 and bracing force from AISC 341



# Night School 28: Bracing Connections and Related Topics

From the First Principles to Design  
Session 6: The Corner Connection (seismic)  
May 10, 2022



Rafael Sabelli, PE, SE  
Director of Seismic Design &  
Senior Principal  
Walter P Moore



Smarter.  
Stronger.  
Steel.

## Learning Objectives

- Understand the role of AISC 341 in bracing-connection design
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- Learn to determine design forces for bracing connections that include both collector forces from ASCE 7 and bracing force from AISC 341



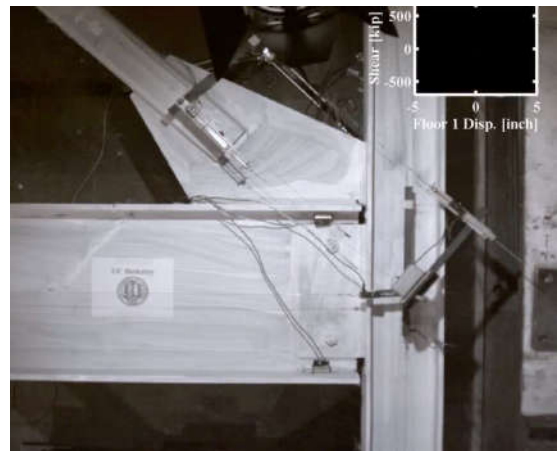
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## The Corner Connection—Seismic



BRBF

ALUME BRACING CO.





SCBF

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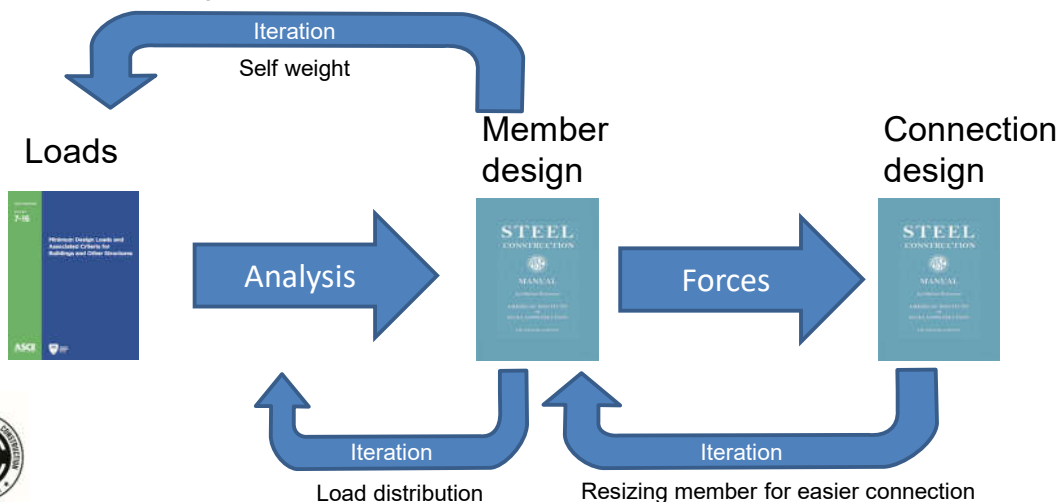
# The Corner Connection—Seismic

- The process
- System types
  - SCBF 
    - Buckling
    - Hinge types
    - Forces
  - BRBF 
    - Forces
    - Stability
- Beam-to-column connection
  - Pinned
  - Fixed
  - Design cases
- Design example
  - Limit states
  - Analysis



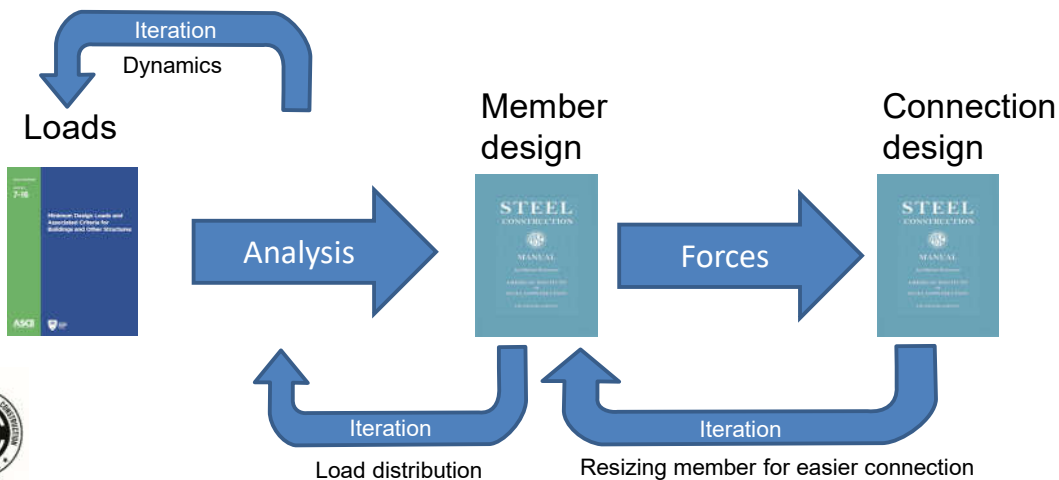
# ASCE 7, AISC 360, and AISC 341

- Gravity



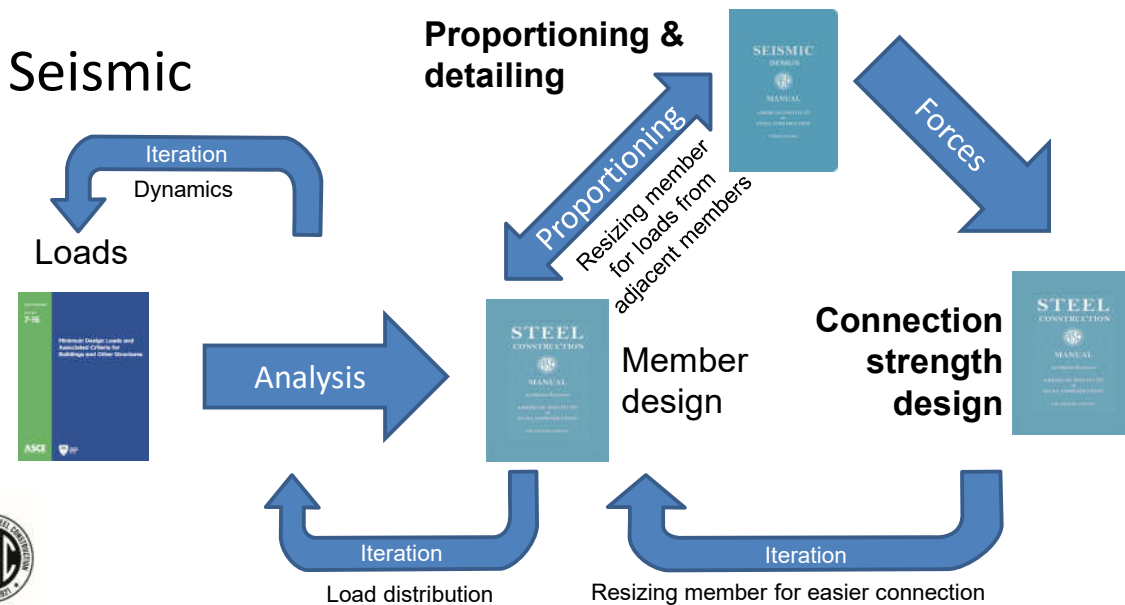
# ASCE 7, AISC 360, and AISC 341

- Wind



# ASCE 7, AISC 360, and AISC 341

Seismic



# AISC 341 Bracing Connections

- Capacity Design
  - Brace expected tension strength
  - Brace expected compression strength
  - Accommodation of brace deformation
- Concurrent actions
  - Gravity
    - Shear in beam
  - Beam moment capacity (if fixed-end)
  - Collector force



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## Special Concentrically Braced Frames (SCBF)



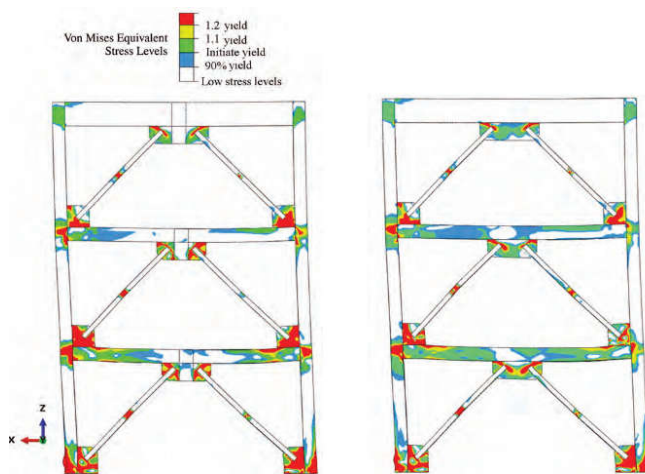
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## Special Concentrically Braced Frames (SCBF)

- System behavior
  - Member behavior
    - Brace buckling
      - Plane of buckling
      - End fixity
    - Brace tension yield
- Connection design
  - Fixed-end buckling
  - Gusset hinges
    - Linear hinge
    - Elliptical hinge
    - Knife-plate hinge



## Brace Buckling and Yielding

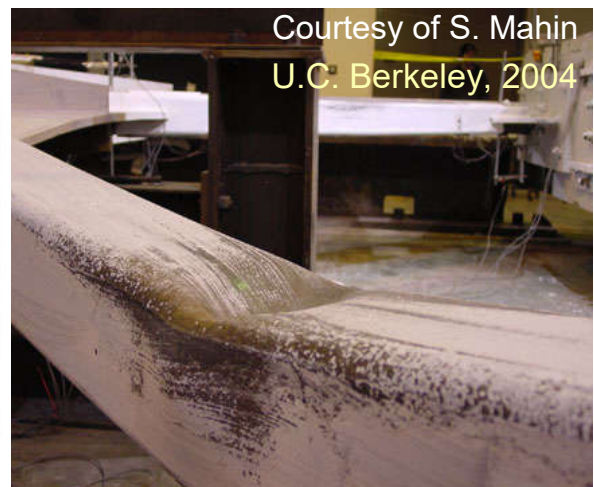


(a) Frame with chevron beam designed to current AISC Seismic Provisions with  $\lambda_w/\lambda_p$  of 0.8 and with stiffeners

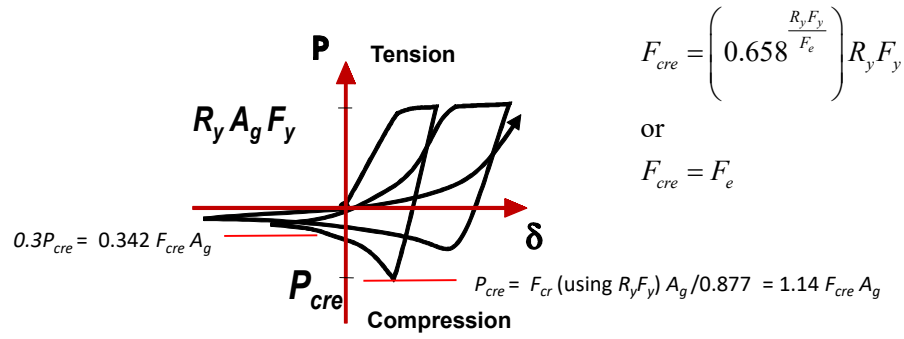
(b) Frame with chevron beam designed to current AISC Seismic Provisions with  $\lambda_w/\lambda_p$  of 0.8 and with no stiffeners

Fig. 4(a). Nonlinear analyses of chevron-braced frames.

Fig. 4(b). Nonlinear analyses of chevron-braced frames.



# Brace cyclic behavior (SCBF)



$$F_{cre} = \left( 0.658 \frac{R_y F_y}{F_e} \right) R_y F_y$$

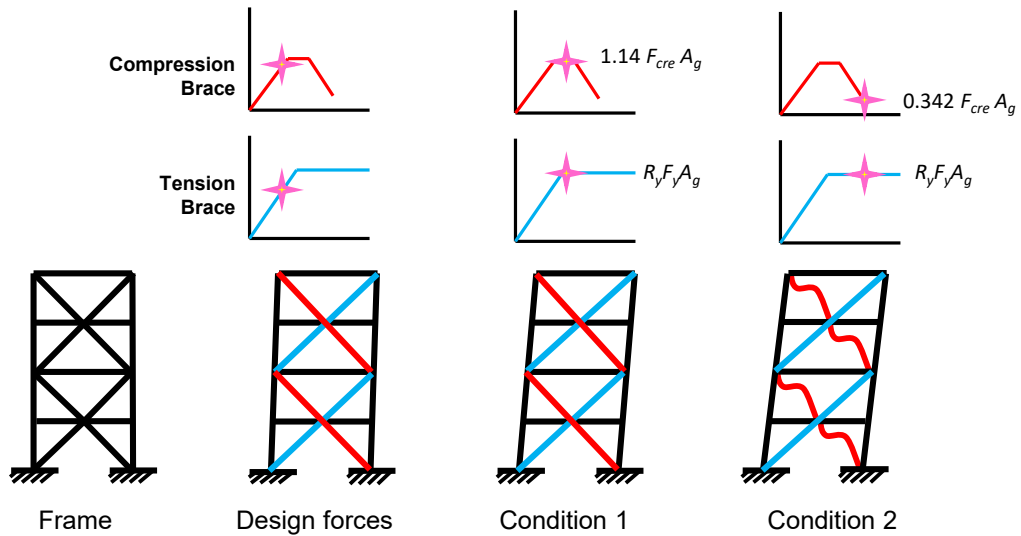
OR

$$F_{cre} = F_e$$

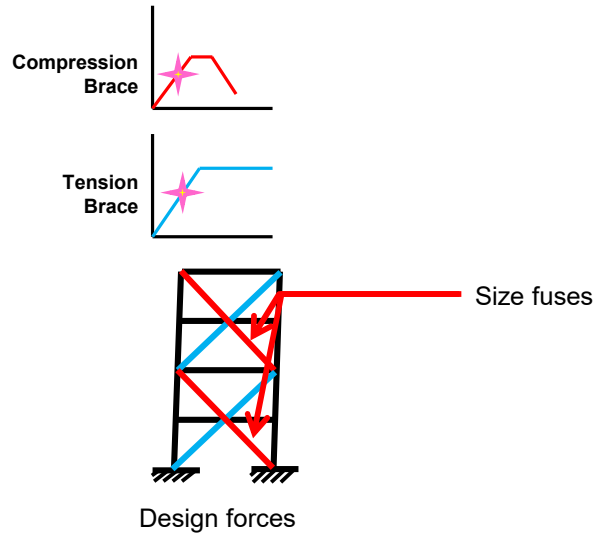
Brace behavior is asymmetric with respect to tension and compression and is subject to strength and stiffness degradation



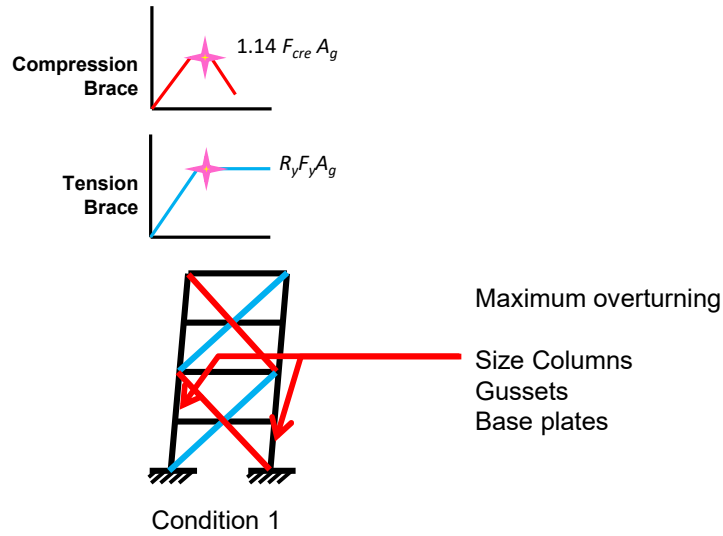
# Plastic mechanism analyses



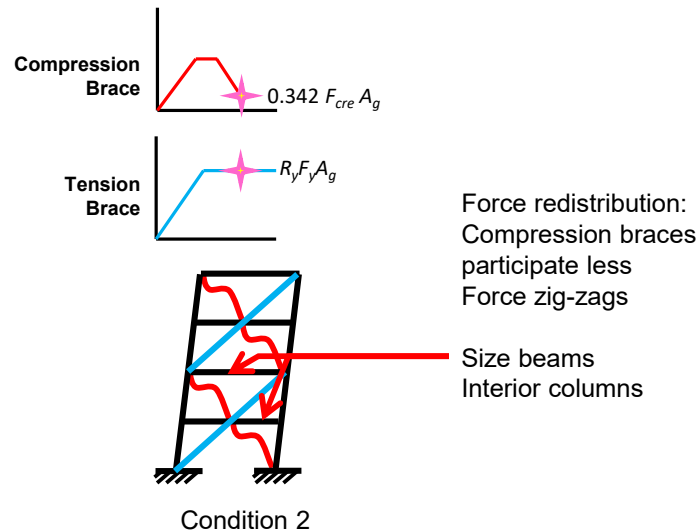
# Design forces



# Plastic mechanism analyses



## Plastic mechanism analyses



## Basic SCBF Connection Requirements (Tension)

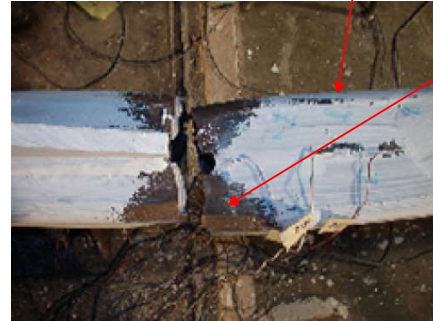
- Resist brace force (expected tension strength)
  - $R_y F_y A_g$
  - $R_y F_y$  is expected material yield stress
- Check all limit states discussed by Dr. Thornton
  - For limit states in gusset, etc.
    - $\phi F_y A_g$
    - $\phi F_u A_n$
  - For connection limit states in brace (net section rupture, block shear)
    - $\phi R_y F_y A_g$
    - $\phi R_t F_u A_n$



## Basic SCBF Connection Requirements (Tension)

**TABLE A3.1**  
 **$R_y$  and  $R_t$  Values for Steel and Steel Reinforcement Materials**

Application	$R_y$	$R_t$
Hot-rolled structural shapes and bars:		
• ASTM A36/A36M	1.5	1.2
• ASTM A1043/A1043M Gr. 36 (250)	1.3	1.1
• ASTM A992/A992M	1.1	1.1
• ASTM A572/A572M Gr. 50 (345) or 55 (380)	1.1	1.1
• ASTM A913/A913M Gr. 50 (345), 60 (415), 65 (450), or 70 (485)	1.1	1.1
• ASTM A588/A588M	1.1	1.1
• ASTM A1043/A1043M Gr. 50 (345)	1.2	1.1
• ASTM A529 Gr. 50 (345)	1.2	1.2
• ASTM A529 Gr. 55 (380)	1.1	1.2
Hollow structural sections (HSS):		
• ASTM A500/A500M Gr. B	1.4	1.3
• ASTM A500/A500M Gr. C	1.3	1.2
• ASTM A501/A501M	1.4	1.3
• ASTM A53/A53M	1.6	1.2
• ASTM A1085/A1085M	1.25	1.15



If the brace yields at 59 ksi here  
 $(R_y F_y = 1.4 * 42 \text{ksi} = 59 \text{ksi})$

It likely yields at 59 ksi here

And also likely has higher-than-specified rupture strength



## Failure at the Reduced Section



Hines and Fahnestock

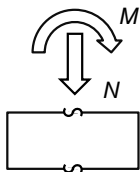


# Brace Reinforcement

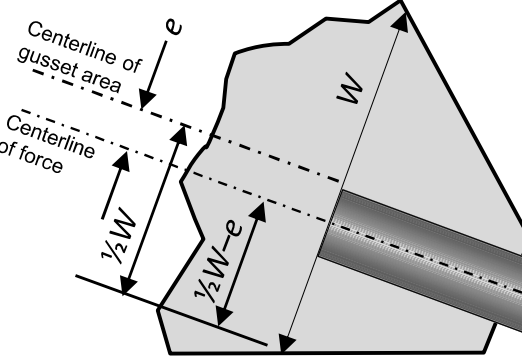
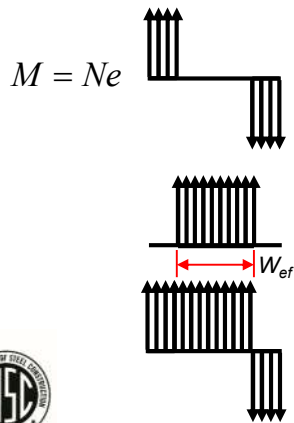
Courtesy of S. Mahin  
 U.C. Berkeley, 2004



# Tapered gussets



Tension may be applied eccentric to the critical section



$$W_{ef} = \frac{W}{\frac{2e}{W} + \sqrt{\left(\frac{2e}{W}\right)^2 + 1}}$$

$$\approx W - 2e$$

$$= 2 \left[ \frac{1}{2} W - e \right]$$



## Basic SCBF Connection Requirements (Compression)

- Resist expected compression strength
  - Use real brace length (for upper-bound force)
  - $F_{cre} A_g / 0.877 \leq R_y F_y A_g$
- Check all limit states discussed by Dr. Thornton
  - Gusset buckling
  - Web crippling
- Provide accommodation of brace buckling without loss of tension strength



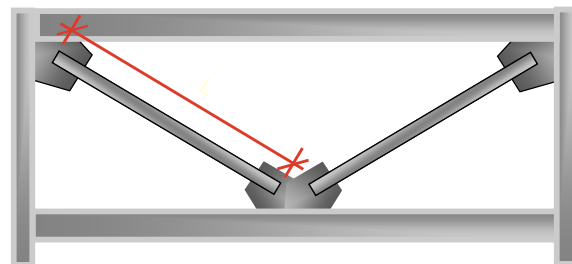
## Check Detail for Compression

- Use realistic effective length
- Eliminate “conservative” assumptions that would reduce demand

$$F_{cre} = \left( 0.658 \frac{R_y F_y}{F_e} \right) R_y F_y$$

or

$$F_{cre} = F_e$$



$$P_{cre} = F_{cre} A_g / 0.877$$

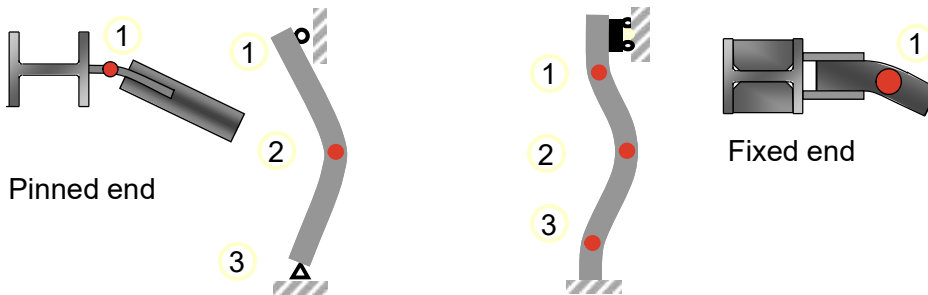
$$= 1.14 F_{cre} A_g$$



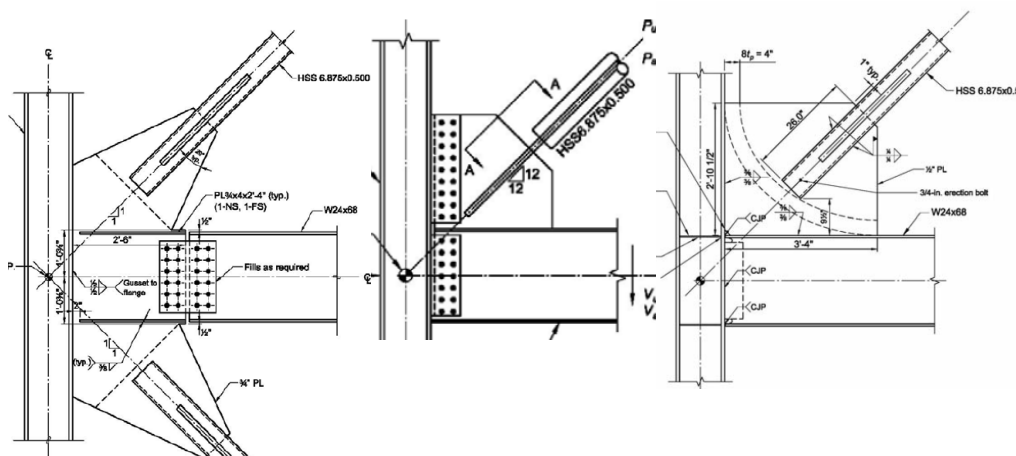
# Brace Buckling

Flexural buckling (Compression)

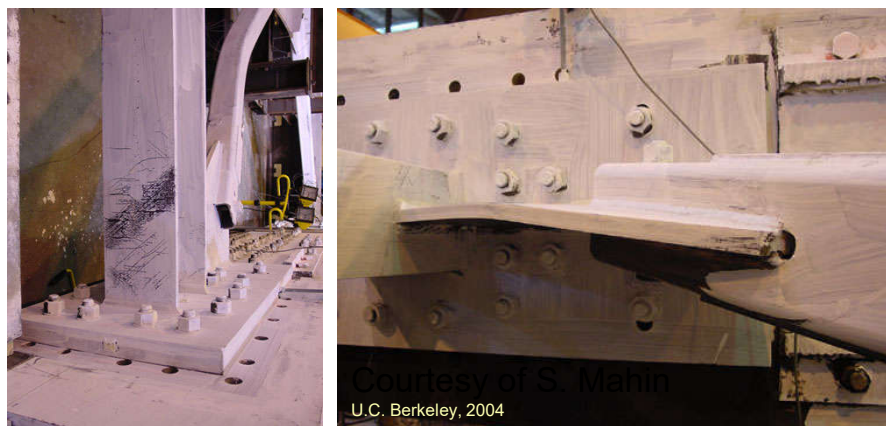
Buckling: 3 hinges



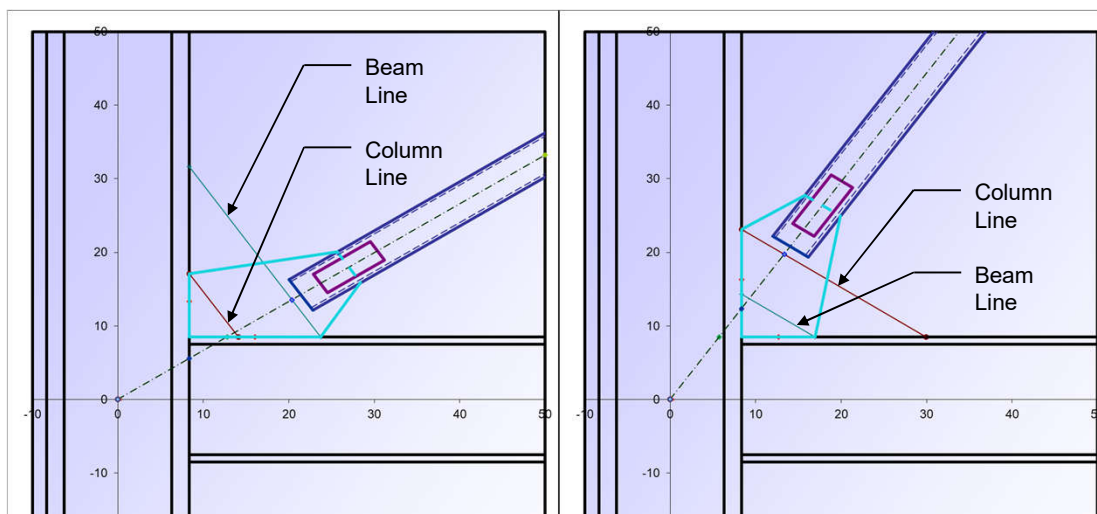
# Accommodating buckling



# Pinned-End Gusset Hinging

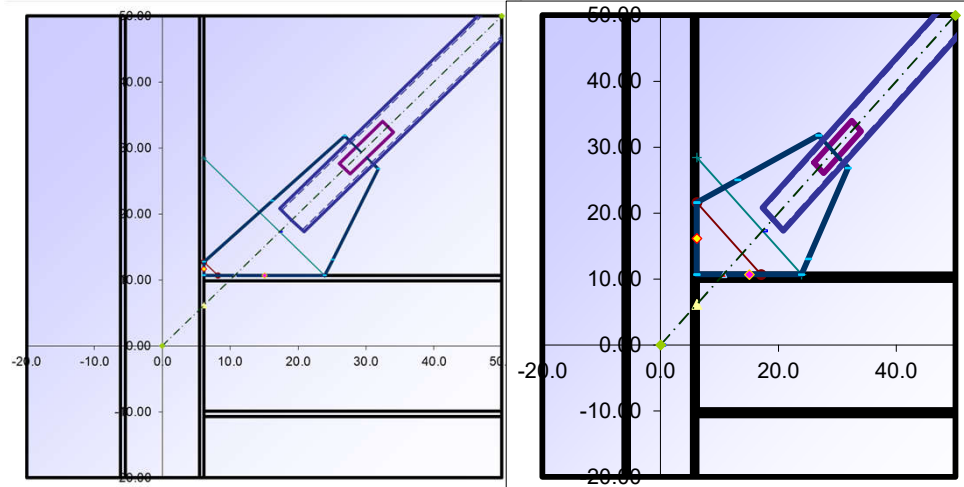


# Folding of Gusset (Hinge Zone)



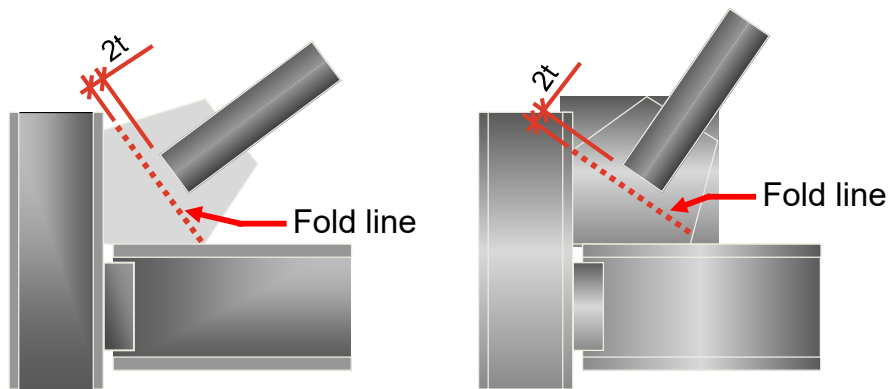
# Folding of Gusset (Hinge Zone)

- Graph your design!
- Don't wait for shop drawings



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# 2t Offset



Provide accommodating detail (2t offset)

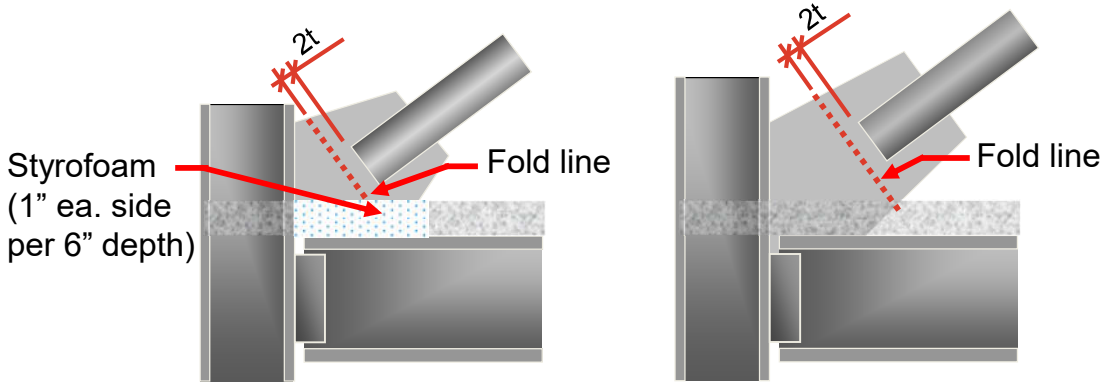
Recommendation: Detail:  $2t + \frac{3}{4}'' \pm \frac{3}{4}''$

Check gusset buckling:  $2t + 1\frac{1}{2}''$



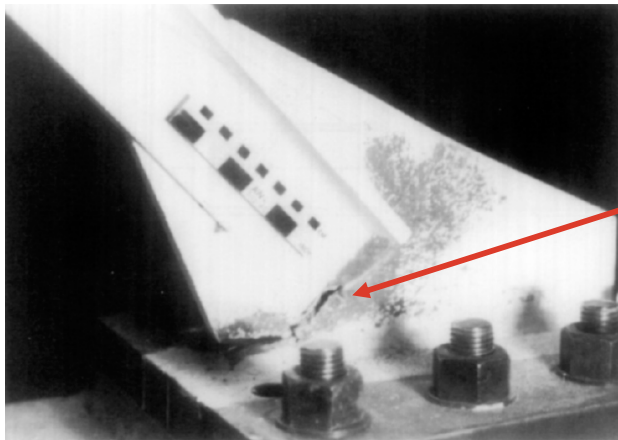
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## 2t Offset at Concrete Fill



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## Tearing of Gusset (No Hinge Zone)



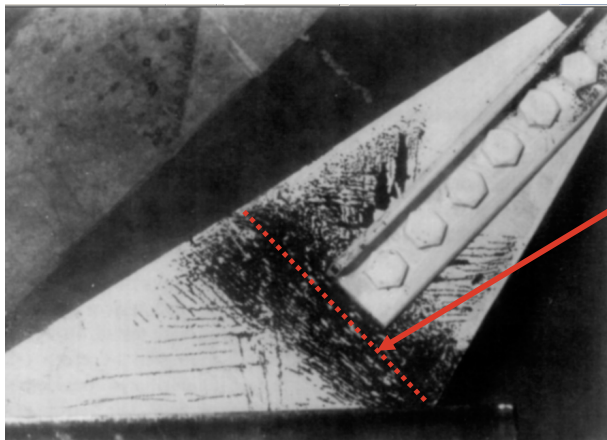
Crack formed by  
gusset plate folding



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

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# Folding of Gusset (Hinge Zone)

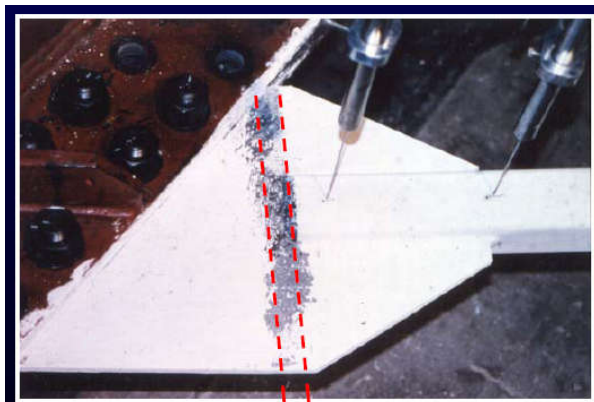


Gusset plate fold line

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



# Folding of Gusset (Hinge Zone)



Courtesy of  
R. Tremblay

$2 t_g$



# Welding in the vicinity of gusset hinging

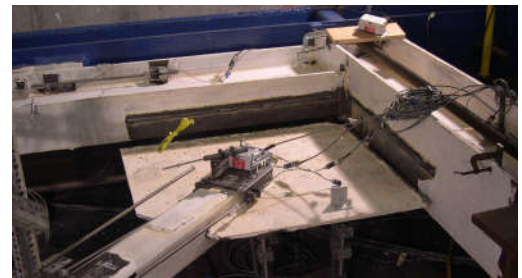
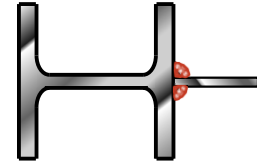
Weld from gusset to beam and column:

Minimum double fillet ~0.75 times gusset thickness

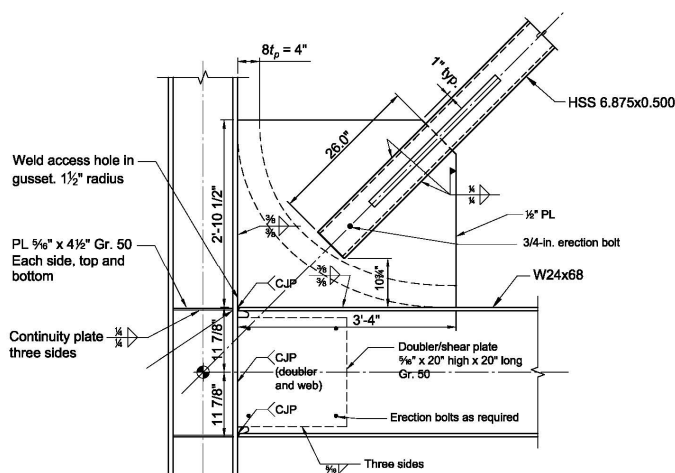
$$2\phi(0.6)F_{EXX} (0.707)(D/16) \geq 0.6R_y F_y t_{gusset}$$

$$D/16 \geq 0.75t_{gusset}$$

Weld is stronger than plate; inelastic action occurs in plate



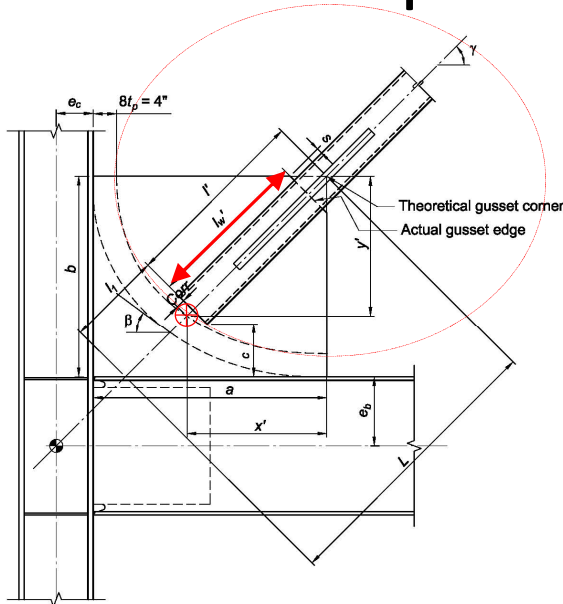
# Elliptical Hinge



1. Size gusset using UFM
  - a. Gusset limit states
  - b. Web limit states
2. Determine brace-gusset lap length
  - a. Weld
  - b. Block shear
3. Check if brace intrudes into elliptical-hinge zone; resize gusset if necessary



# Elliptical Hinge



Define ellipse

$$a' = a - 8t_p \quad b' = b - 8t_p \quad \rho = \frac{a'}{b'}$$

Determine intersection with brace axis

$$y' = a' \sqrt{\frac{1}{\cot^2 \gamma + \rho^2}} \quad x' = a' \sqrt{1 - \left(\frac{y'}{b'}\right)^2}$$

Correct for brace width

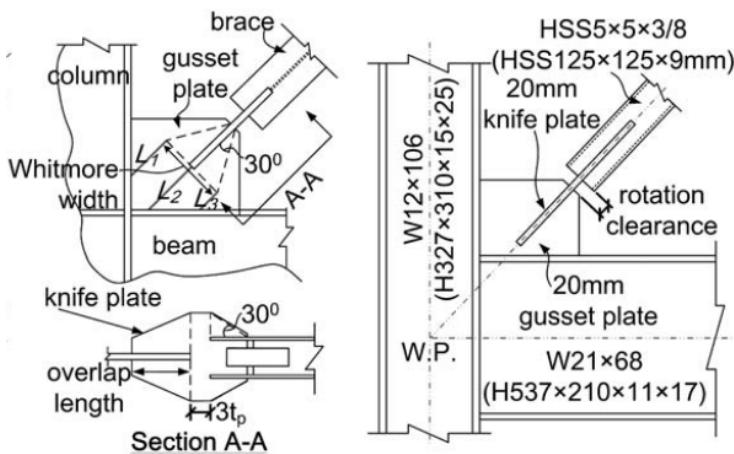
$$\beta = \tan^{-1} \left( \frac{x'}{y' \rho^2} \right) \quad Corr = \frac{D_{brace}}{2} \tan(90^\circ - \beta - \gamma)$$

Check lap length

$$l' = \sqrt{(x')^2 + (y')^2} - Corr \quad l'_w = l' - \left( \frac{D_{brace}}{2} + s \right) \cot \gamma \quad 43$$



# In-plane buckling detail

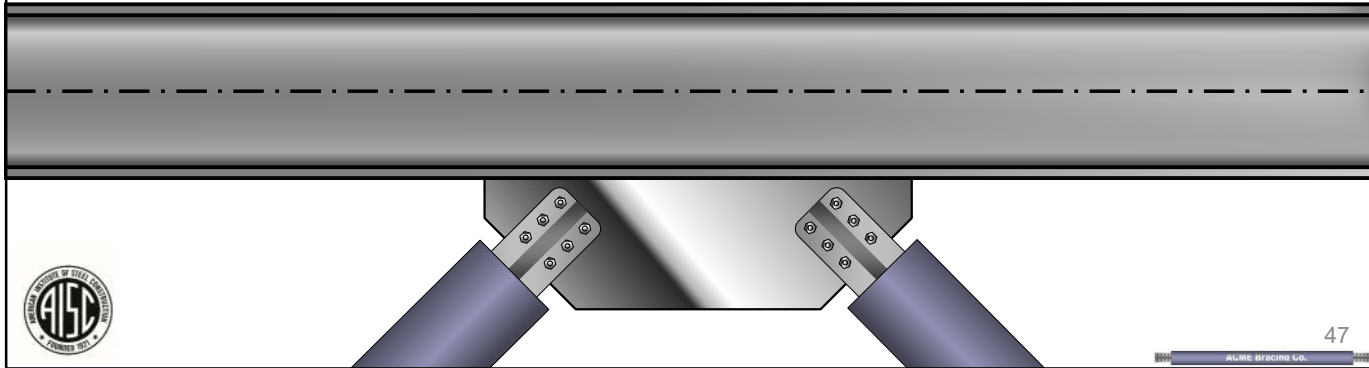


Seismic Design and Hybrid Tests of a Full-Scale Three-Story Concentrically Braced Frame Using In-Plane Buckling Braces  
 Ching-Yi Tsai, Keh-Chyuan Tsai, Pao-Chun Lin, Wai-Hang Ao, Charles W. Roeder, Stephen A. Mahin, Chih-Han Lin, Yi-Jer Yu, Kung-Juin Wang, An-Chien Wu, Jia-Chian Chen, and Te-Hung Lin

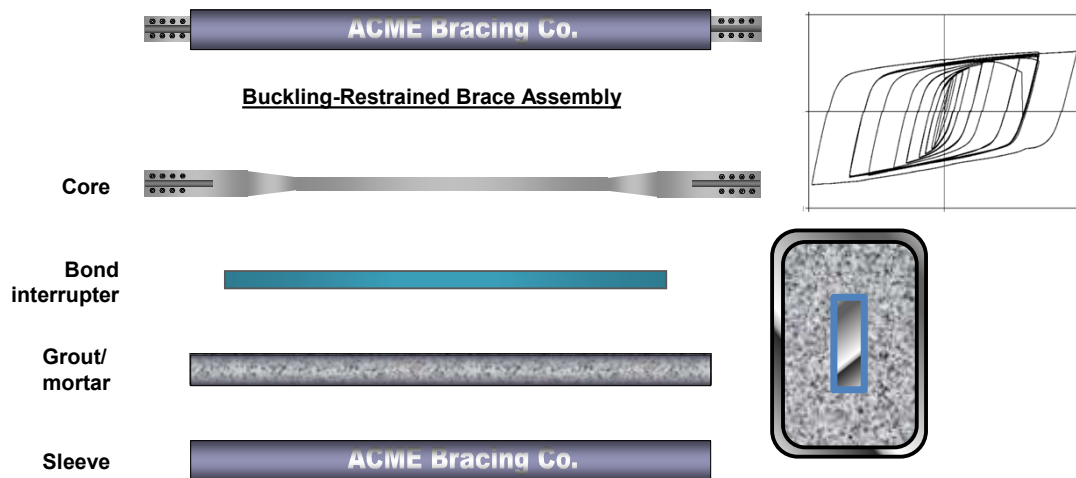


# BRBF

- System behavior
- Gusset design
  - Forces
  - Stability



# Buckling Restrained Braces



# Buckling-Restrained Brace Types



# Buckling-Restrained Brace Types



Direct bolting of core

Courtesy of CoreBrace



Bolted Connection

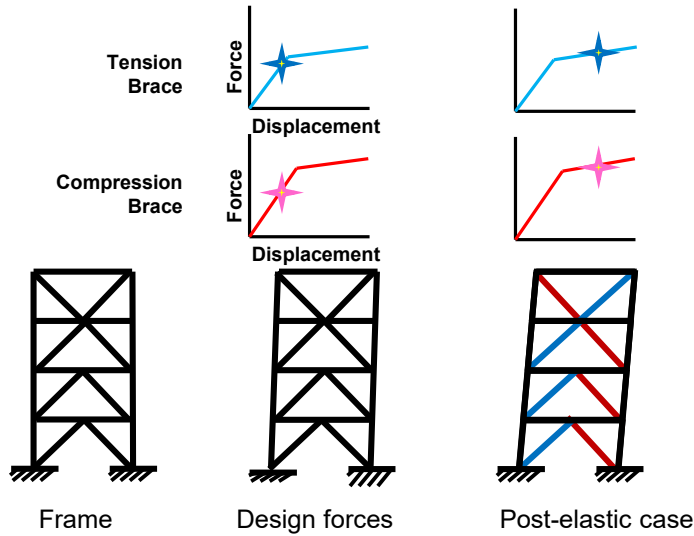


Welded Connection

Courtesy of STAR Seismic

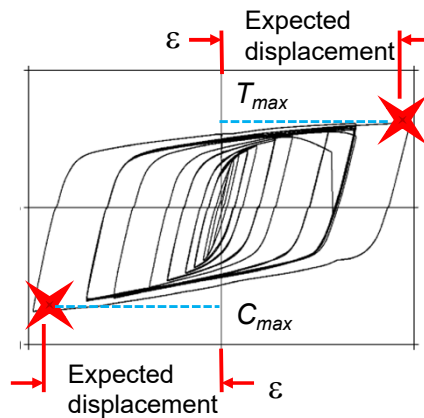


# Plastic mechanism analyses (BRBF)



# Brace demands on frame

- Estimate fuse capacity
  - Expected material strength
  - Strain hardening
- Based on testing  
 Calculate deformation



# Brace demands on frame

- Based on testing

$$\omega = T_{max} / A_g F_y$$

Typical  $1.3 \leq \omega \leq 1.5$

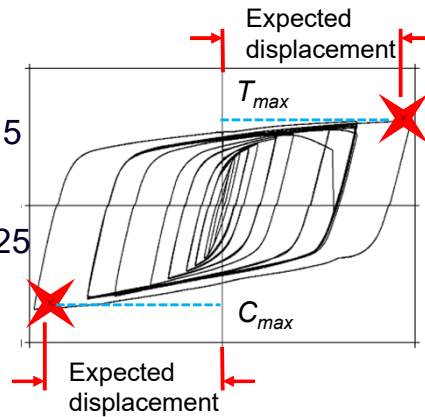
$$\beta\omega = C_{max} / A_g F_y$$

Typical  $1.1 \leq \beta \leq 1.25$

- For design

$$R_{u(\text{tension})} = \omega A_g R_y F_y$$

$$R_{u(\text{compression})} = \beta\omega A_g R_y F_y$$

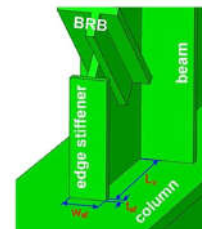
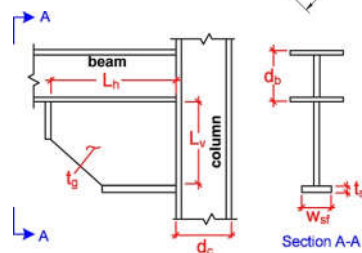
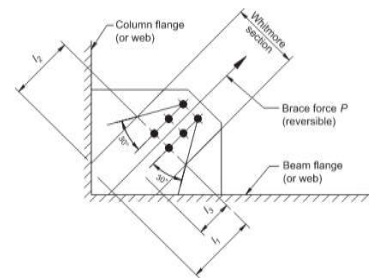


AISC 341 F4.2

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# BRB Gusset stability

- Easy (conservative) path
  - Design gusset with  $K=2$
  - or
  - Design gusset with edge stiffeners with  $K=0.65$ 
    - Difficult to erect
    - Add stiffeners after brace



(K.C. Tsai)

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Development and Implementation of Buckling  
Restrained Braces in Taiwan

S.L. Lin & G.A. MacRae  
University of Canterbury, Christchurch, New Zealand  
A.C. Wu, P.C. Lin & K.C. Tsai  
National Taiwan University, Taipei, Taiwan



2012 NZSEE  
Conference



# BRB Gusset stability

- Explicit path
  - Typically done by BRB manufacturers

Out-of-plane stability of gusset plates using a simplified notional load yield line method

B. Zaboli & G.C. Clifton  
Department of Civil and Environmental Engineering, University of Auckland, Auckland.  
K. Cowie  
Steel Construction New Zealand, Auckland.  
SESOJ Journal

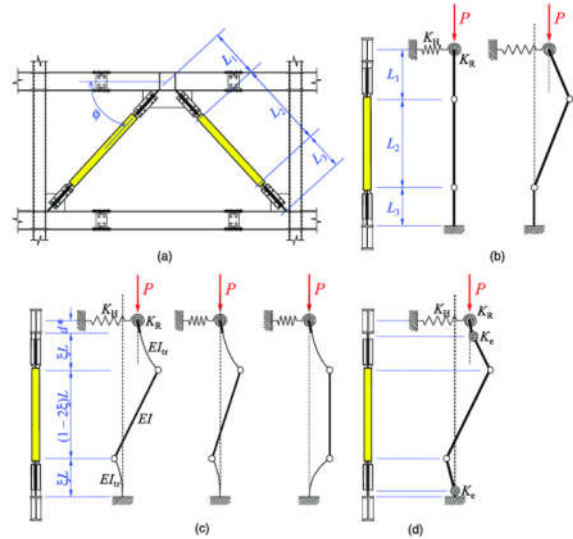


## BRBF AND CBF GUSSET PLATES: OUT-OF-PLANE STABILITY DESIGN USING A SIMPLIFIED NOTIONAL LOAD YIELD LINE (NILYL) METHOD

B. Zaboli & G.C. Clifton<sup>1</sup>, K. Cowie<sup>2</sup>  
ACKNOWLEDGEMENTS  
This study is based upon work supported by the Natural Sciences Research Platform (NSRP) under Grant No. 3710091. This work was also supported in part by Steel Construction New Zealand (SCNZ). However, any opinions, findings, conclusions and recommendations presented in this paper are those of the writers alone and do not necessarily reflect the views of those acknowledged here.

Work by:

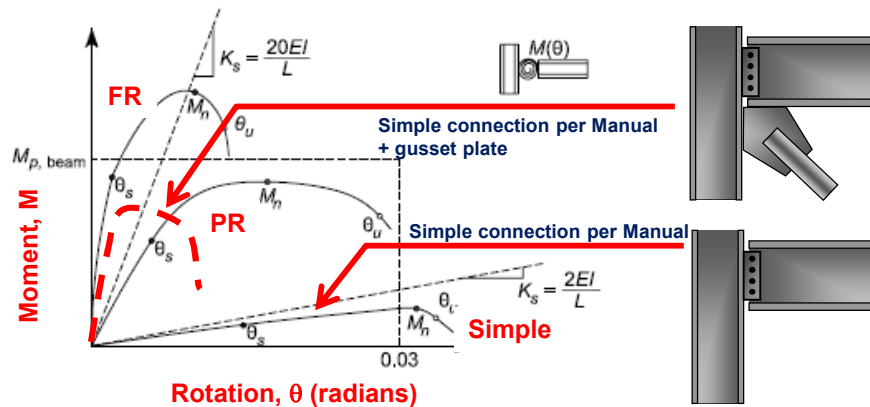
- Takeuchi, et al (Tokyo Inst of Technology)
- Zaboli, Clifton (Univ of Canterbury)
- 2020 SEAC Paper (Saxey et al.)



Out-of-plane stability model: (a) chevron brace; (b) model for standard connections; (c) model proposed by Kinoshita et al. (2007); (d) model for alternative conditions

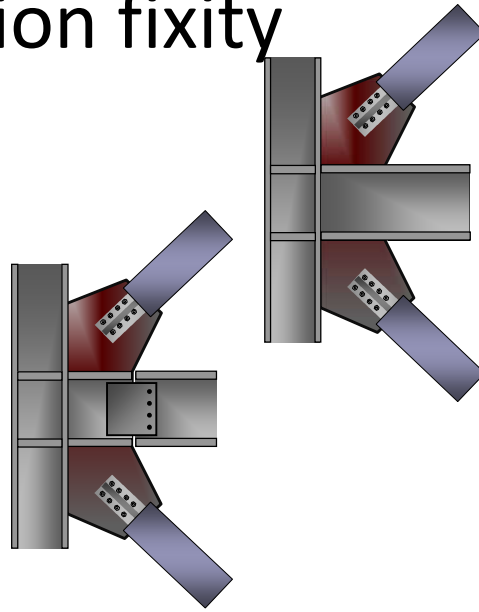


# Rotation in gusseted beam-column connections (BRBF and SCBF)



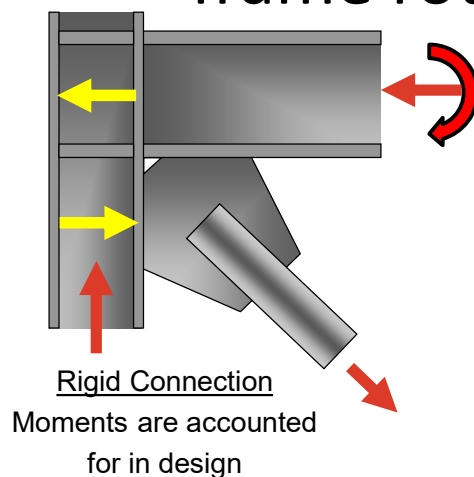
## Connection fixity

- Ductile moment frames provide extra resistance
  - Lateral strength and stiffness
  - Resistance to story mechanisms
- Ductile moment connections require careful detailing



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## Method of accommodating frame rotations



Connection strength exceeds beam strength

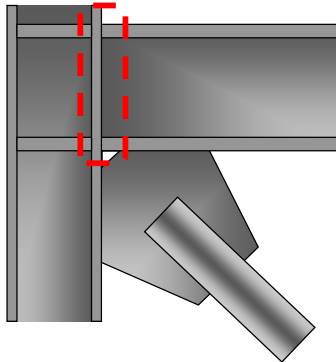
Consider brace and beam forces together

Consider brace and beam forces independently, too



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## Method of accommodating frame rotations



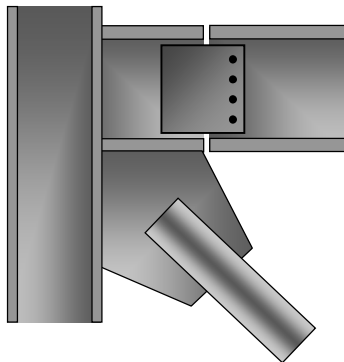
Connection consists of Ordinary Moment Frame (OMF) connection, plus gusset

Rigid Connection  
Moments are implicitly accounted for



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## Method of accommodating frame rotations



Connection typically provides rotation by means similar to shear connections in AISC manual

2.5% rotation (0.025 radians) required

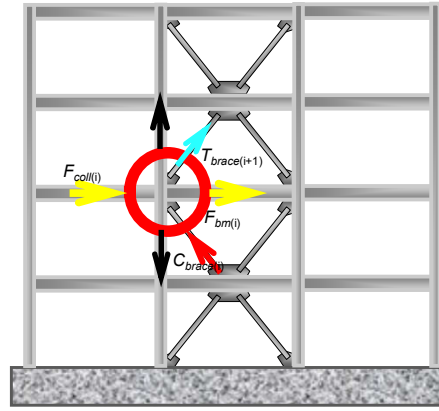
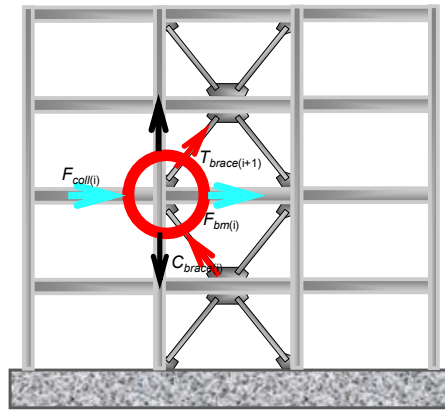
Flexible Connection  
Rotations are accommodated



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# Capacity Design Collector Forces

Make two cases:



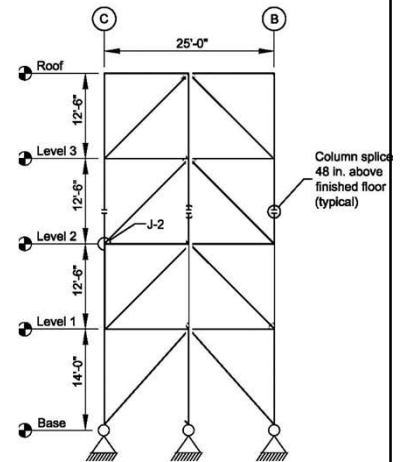
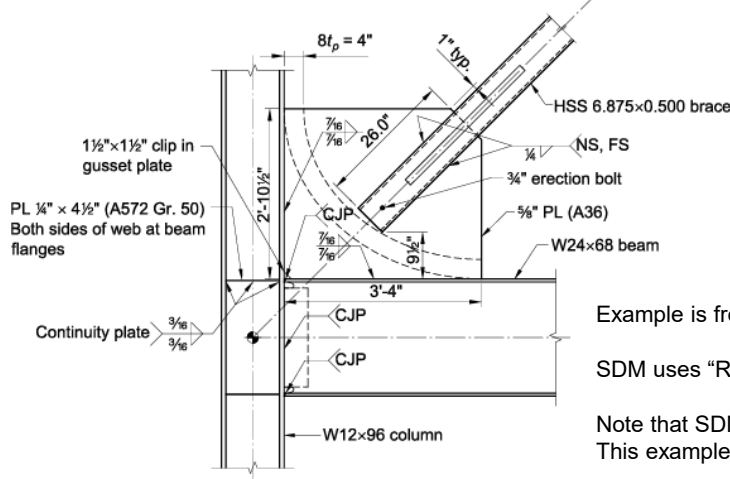
Forces
Capacity Design
Diaphragm ( $\Omega_0$ )
Statics

1. Maximum brace forces; statically consistent collector force

2. Maximum collector force and maximum brace force below; statically consistent brace force above



# Design Example (SCBF)



Example is from Seismic Design Manual

SDM uses "Ricker Method;" this example uses UFM

Note that SDM gusset is slightly oversized: 1/2" plate suffices. This example uses 5/8" plate, consistent with SDM.



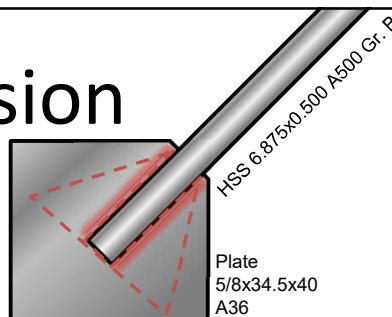
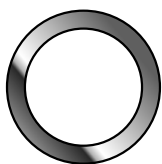
# Brace Forces: Tension

HSS 6.875x0.500 A500 Gr. B

$$\begin{aligned} t_{nom} &= 0.500 \text{ in.} \\ t_{des} &= 0.465 \text{ in.} \\ A &= 9.36 \text{ in.}^2 \\ r &= 2.27 \text{ in.} \end{aligned}$$

Tension demand

$$\begin{aligned} R_y &= 1.4 \\ P_{tension} &= R_y F_y A_g \\ &= 1.4(42 \text{ ksi})(9.36 \text{ in.}^2) \\ &= 550 \text{ kips} \end{aligned}$$



Design brace-to-gusset weld

$$\frac{550 \text{ kips}}{\phi 0.6 F_{EXX} \frac{\sqrt{2}}{2} 4 \left(\frac{1}{4} \text{ in.}\right)} = 24.6 \text{ in.}$$

Check block shear (conservatively neglecting tension area)

$$\frac{550 \text{ kips}}{\phi 0.6 F_y 2 \left(\frac{5}{8} \text{ in.}\right)} = \frac{550 \text{ kips}}{(0.9) 0.6 (36 \text{ ksi}) 2 \left(\frac{5}{8} \text{ in.}\right)} = 22.6 \text{ in.}$$

Note that block shear addresses tension on the "Whitmore area"

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# Brace Forces: Tension

Net-section rupture

$$\begin{aligned} A_n &= A_g - 2[t_{pl} + 2(\text{gap})]t_{des} & U &= 1.0 \\ & & A_e &= A_n \\ A_n &= 9.36 \text{ in.}^2 - 2 \left[ \frac{5}{8} \text{ in.} + 2 \left( \frac{1}{16} \text{ in.} \right) \right] (0.465 \text{ in.}) \\ &= 8.66 \text{ in.}^2 < A_g & \text{Must reinforce!} \end{aligned}$$

Assume  $U = 0.9$  (check after design)

$$\begin{aligned} A_r &= \frac{A_g}{U} - A_n \\ A_r &= 1.74 \text{ in.}^2 \end{aligned}$$



Use (4) 0.75x0.75 Grade 50 rods

Part	$\bar{x}$	$A$	$\bar{x}A$
	in.	in. <sup>2</sup>	in. <sup>3</sup>
Half-brace	2.19	4.33	9.48
2 bars	2.70	1.125	3.03
$\Sigma$		5.46	12.51

$$\begin{aligned} \bar{x} &= \frac{\Sigma \bar{x} A}{\Sigma A} & U &= 1 - \frac{\bar{x}}{L} \\ &= 2.29 \text{ in.} & &= 1 - \frac{2.29}{24.6} \\ & & &= 0.91 \end{aligned}$$

Half-brace (conservative simplifications)

$$\bar{x} = r \frac{\sin \theta}{\theta} \approx 2r / \pi \approx OD / \pi$$

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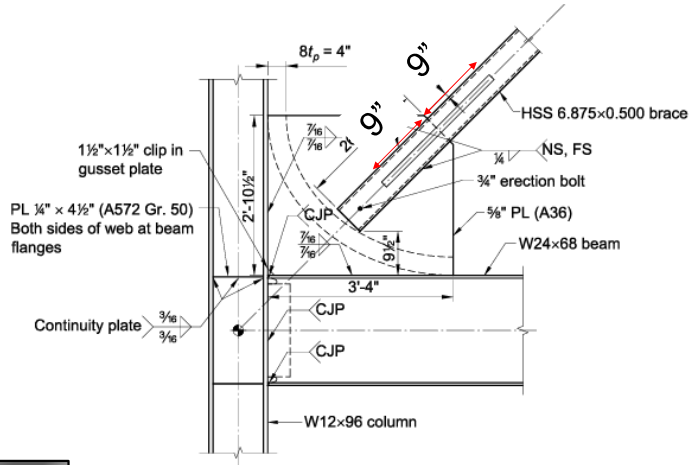


# Brace Forces: Tension

$$R_y F_y A = 1.1(50 \text{ ksi}) \left(\frac{3}{4} \text{ in.}\right)^2 = 30.9 \text{ kips}$$

$$\frac{30.9 \text{ kips}}{\phi 0.6 F_{EXX} \frac{\sqrt{2}}{2} 2 \left(\frac{1}{8} \text{ in.}\right)} = 5.5 \text{ in.}$$

Use 18" long bars, centered on critical section



# Corner gussets: UFM

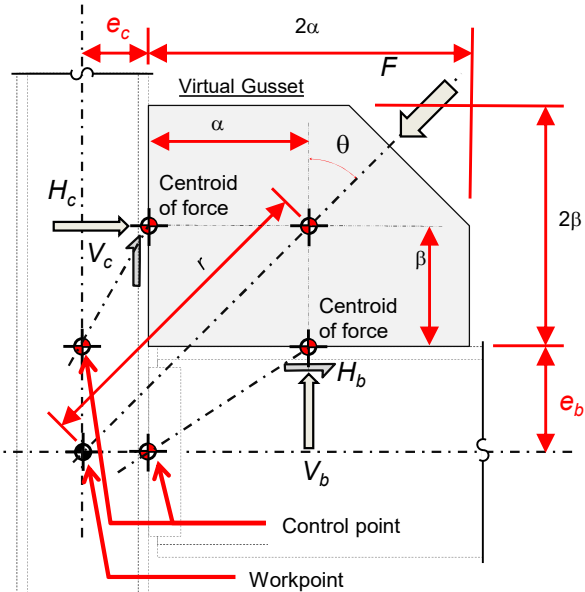
Optimal proportioning:

$$\alpha - \beta \tan \theta = e_b \tan \theta - e_c \quad r = \sqrt{(e_c + \alpha)^2 + (e_b + \beta)^2}$$

$$\alpha = r \sin \theta - e_c \quad \beta = r \cos \theta - e_b$$

$$H_c = \frac{e_c}{r} F \quad H_b = \left(\sin \theta - \frac{e_c}{r}\right) F$$

$$V_b = \frac{e_b}{r} F \quad V_c = \left(\cos \theta - \frac{e_b}{r}\right) F$$



Design for Local Web Shear at Brace Connections:  
 An Adaptation of the Uniform Force Method

RAFAEL SABELLI, BRANDT SAXEY, CHAO-HSIEN LI, and WILLIAM A. THORNTON

**ABSTRACT**  
 Recent literature has examined local shear forces in beams in chevron brace methods based on optimal stress distributions to address these shears were. This paper extends those design methods to gusset connections at columns, with design to reduce required member shear strength. The design model presented is compared to the conventional application of the Uniform Force Method. The force to the column interface using a "bypass method," as well as utilizing the g method. Finite element analyses are used to confirm the adequacy of a design.

**Keywords:** gusset plates, braced frames, truss connections.

Engineering  
 Journal



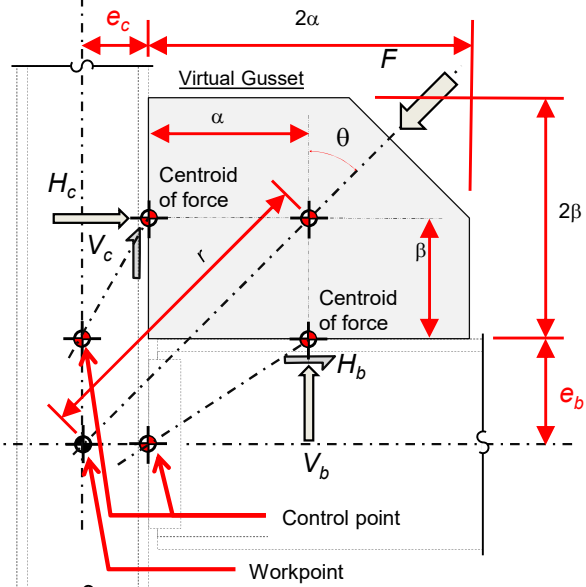
# Minimum virtual gusset dimension

- Minimum dimension  $r$  necessary to limit column shear to its capacity

$$r \geq r_{minCol} = \frac{e_c P}{V_{efC}} = 16.7 \text{ in.}$$

- Minimum dimension  $r$  necessary to limit beam shear to its capacity

$$r \geq r_{minBm} = \frac{e_b P}{V_{efB}} = 24.9 \text{ in.}$$



## Design for Local Web Shear at Brace Connections: An Adaptation of the Uniform Force Method

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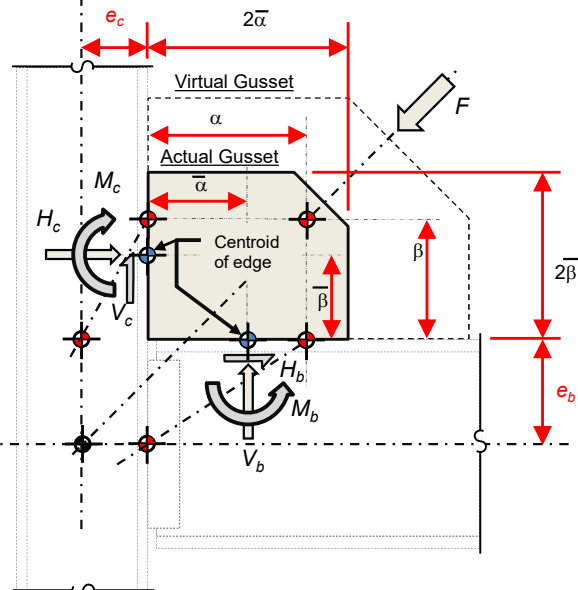
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# Minimum virtual gusset dimension

- Eccentricity between centroid of force (=centroid of virtual gusset) and centroid of actual gusset causes moment

$$M_b = V_b (\alpha - \bar{\alpha})$$

$$M_c = H_c (\beta - \bar{\beta})$$



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# Gusset design: UFM

Select  $\bar{\beta} = \beta \quad \beta = \frac{1}{2}(2'-10.5") = 17.3 \text{ in.}$

$$r = \frac{e_b + \bar{\beta}}{\cos \theta} = \frac{11.85 \text{ in.} + 17.3 \text{ in.}}{0.707} = 41.2 \text{ in.}$$

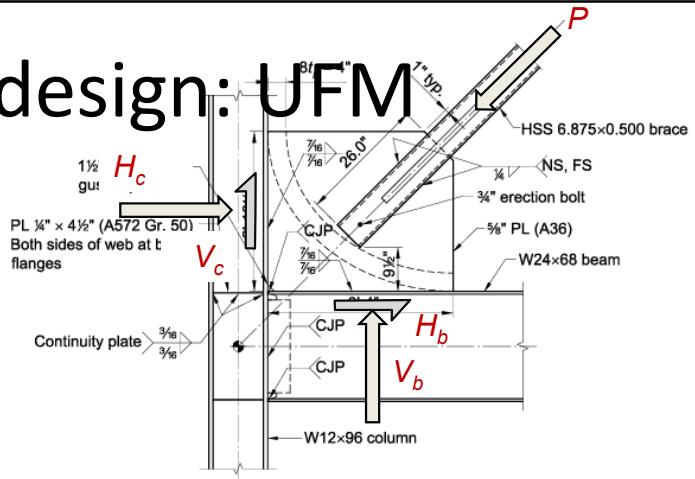
$$\alpha = r \sin \theta - e_c = (41.2 \text{ in.})(0.707) - 6.35 \text{ in.} = 22.8 \text{ in.}$$

$$V_c = \frac{\bar{\beta}}{r} P = \frac{17.3 \text{ in.}}{41.2 \text{ in.}} (550 \text{ kips}) = 231 \text{ kips}$$

$$H_c = \frac{e_c}{r} P = \frac{6.35 \text{ in.}}{41.2 \text{ in.}} (550 \text{ kips}) = 85 \text{ kips}$$

$$V_b = \frac{e_b}{r} P = \frac{11.85 \text{ in.}}{41.2 \text{ in.}} (550 \text{ kips}) = 158 \text{ kips}$$

$$H_b = \frac{\alpha}{r} P = \frac{22.8 \text{ in.}}{41.2 \text{ in.}} (550 \text{ kips}) = 304 \text{ kips}$$

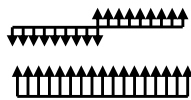


# Gusset design: UFM

$\bar{\beta} = \beta$   
 $M_c = 0$

$\bar{\alpha} = \frac{1}{2}(3'-4") = 20 \text{ in.}$   
 $M_b = V_b(\alpha - \bar{\alpha}) = 158 \text{ kips}(22.8 \text{ in.} - 20 \text{ in.}) = 442 \text{ in.-kips}$

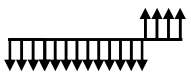
In reality, we would likely make  $\bar{\alpha} = \alpha$



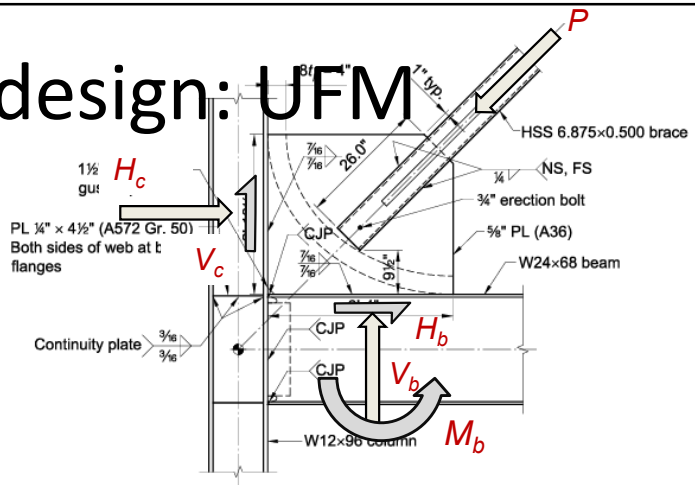
$$\frac{4M_b}{(3'-4")^2} = 1.11 \text{ kip/in.}$$

$$\frac{V_b}{(3'-4")^2} = 3.95 \text{ kip/in.}$$

$$e = \frac{M_b}{V_b} = 2.80 \text{ in.}$$

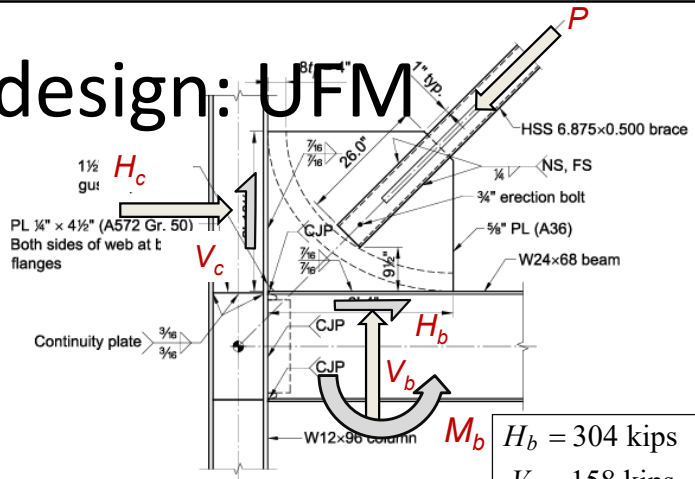


$$W_{of} = \frac{W}{\frac{2e}{W} + \sqrt{\left(\frac{2e}{W}\right)^2 + 1}} = \frac{40 \text{ in.}}{\frac{2(2.80 \text{ in.})}{40 \text{ in.}} + \sqrt{\left(\frac{2(2.80 \text{ in.})}{40 \text{ in.}}\right)^2 + 1}} = 34.8 \text{ in.}$$



# Gusset design: UFM

$$\begin{aligned} H_c &= 85 \text{ kips} \\ V_c &= 231 \text{ kips} \\ M_c &= 0 \end{aligned}$$



$$\begin{aligned} H_b &= 304 \text{ kips} \\ V_b &= 158 \text{ kips} \\ M_b &= 442 \text{ in.-kips} \end{aligned}$$

Same as low-seismic/wind:

- Check gusset interfaces
- Check beam shear, column shear
- Check beam WLY, column WLY
- Check beam WC, column WC
- Design beam-to-column connection (include  $V_b$ )

Weld from gusset to beam and column:  
 Minimum double fillet ~0.75 times gusset thickness

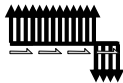


## Plane stresses; rectangular plates

- Von Mises interaction

$$\sqrt{\left(\frac{f_n}{\phi F_y}\right)^2 + 3\left(\frac{f_v}{\phi F_y}\right)^2} \leq 1$$

- Optimal plastic (with VM)



$$\sqrt{\frac{M_u}{2\phi M_n} + \sqrt{\left(\frac{M_u}{2\phi M_n}\right)^2 + \left(\frac{P_u}{\phi P_n}\right)^2}} + \left(\frac{V_u}{\phi V_n}\right)^2 \leq 1$$

- Neal (approximation of OPM)

$$\frac{M_u}{\phi M_n} + \left(\frac{P_u}{\phi P_n}\right)^2 + \frac{\left(\frac{V_u}{\phi V_n}\right)^4}{1 - \left(\frac{P_u}{\phi P_n}\right)^2} \leq 1$$

- Simplified by Astanek

$$\frac{M_u}{\phi M_n} + \left(\frac{P_u}{\phi P_n}\right)^2 + \left(\frac{V_u}{\phi V_n}\right)^4 \leq 1$$



# Gusset design: Elliptical Hinge

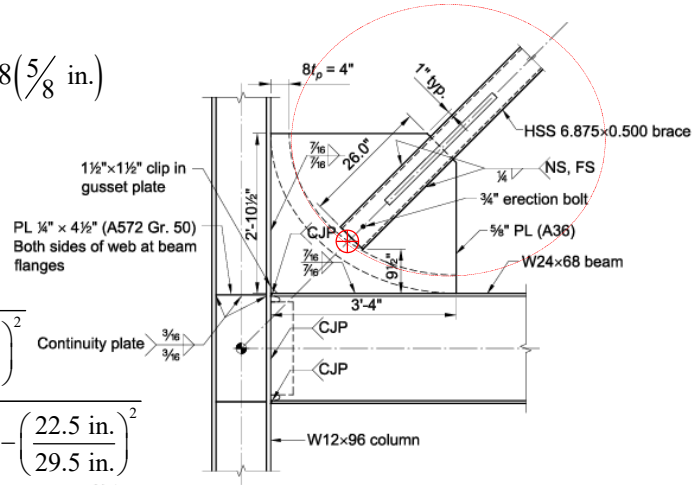
$$a' = a - 8t_p = 40.0 \text{ in.} - 8\left(\frac{5}{8} \text{ in.}\right) = 35.0 \text{ in.}$$

$$b' = b - 8t_p = 34.5 \text{ in.} - 8\left(\frac{5}{8} \text{ in.}\right) = 29.5 \text{ in.}$$

$$\rho = \frac{a'}{b'} = \frac{35.0 \text{ in.}}{29.5 \text{ in.}} = 1.19$$

$$y' = a' \sqrt{\frac{1}{\cot^2 \gamma + \rho^2}} = 35.0 \text{ in.} \sqrt{\frac{1}{\cot^2 45^\circ + (1.19)^2}} = 22.5 \text{ in.}$$

$$x' = a' \sqrt{1 - \left(\frac{y'}{b'}\right)^2} = 35.0 \text{ in.} \sqrt{1 - \left(\frac{22.5 \text{ in.}}{29.5 \text{ in.}}\right)^2} = 22.5 \text{ in.}$$



# Gusset design: Elliptical Hinge

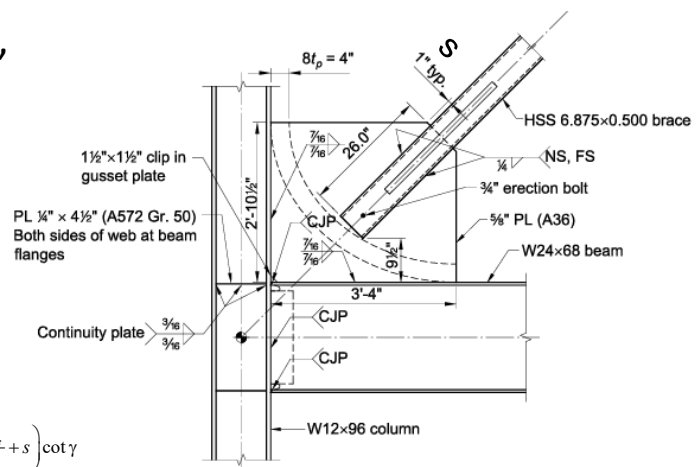
- Hold brace back “slightly”
- Or do explicit calculation:

$$\beta = \tan^{-1}\left(\frac{x'}{y'\rho^2}\right) = \tan^{-1}\left(\frac{(22.5 \text{ in.})}{(22.5 \text{ in.})(1.19)^2}\right) = 35.2^\circ$$

$$Corr = \frac{D_{brace}}{2} \tan(90^\circ - \beta - \gamma) = \frac{6.875 \text{ in.}}{2} \tan(90^\circ - 35.2^\circ - 45.0^\circ) = 0.59 \text{ in.}$$

$$l'_w = \sqrt{(x')^2 + (y')^2} - Corr = \sqrt{(22.5 \text{ in.})^2 + (22.5 \text{ in.})^2} - 0.59 \text{ in.} = 31.2 \text{ in.}$$

$$l'_w = l' - \left(\frac{D_{brace}}{2} + s\right) \cot \gamma = 31.2 \text{ in.} - \left(\frac{6.875 \text{ in.}}{2} + 1.0 \text{ in.}\right) \cot 45^\circ = 26.8 \text{ in.}$$



Allows for full 25" brace-to-gusset weld previously calculated



# Brace Forces: Compression

$$\frac{KL}{r} = \frac{1(12.0 \text{ ft.})(12 \text{ in./ft.})}{2.27 \text{ in.}}$$

$$= 63.4$$

$$4.71 \sqrt{\frac{E}{R_y F_y}} = 4.71 \sqrt{\frac{29,000 \text{ ksi}}{1.4(42 \text{ ksi})}}$$

$$= 105$$

$$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}$$

$$= \frac{\pi^2 (29,000 \text{ ksi})}{(63.4)^2}$$

$$= 71.2 \text{ ksi}$$

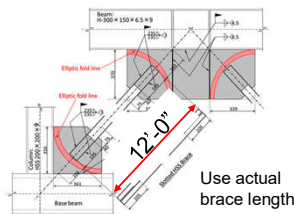
$$P_{\text{compression}} = 1.14 F_{cre} A_g$$

$$= 1.14 (41.6 \text{ ksi})(9.36 \text{ in.}^2)$$

$$= 444 \text{ kips}$$

$$F_{cre} = \left[ 0.658 \frac{R_y F_y}{F_e} \right] R_y F_y$$

$$= 41.6 \text{ ksi}$$



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# Gusset Design: Compression

$$W_{Whitmore} = 2(\text{length of weld})\tan(30^\circ) + D_{\text{brace}}$$

$$= 2(25 \text{ in.})(\tan(30^\circ)) + 6.875 \text{ in.}$$

$$= 35.7 \text{ in.}$$

Check Dowsell criterion for compact gusset

$$c = l_1 \sin \gamma - \frac{1}{2} D_{\text{brace}} \cos \gamma$$

$$= 16.9 \text{ in.}(\sin 45^\circ) - \frac{1}{2}(6.875 \text{ in.})(\cos 45^\circ)$$

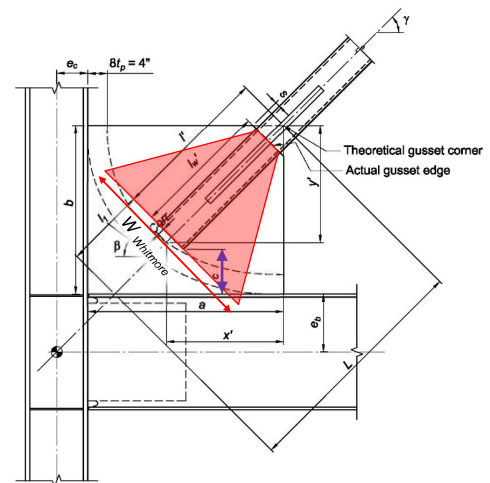
$$= 9.52 \text{ in.}$$

$$t_\beta = 1.5 \sqrt{\frac{F_y c^3}{E l_1}}$$

$$= 1.5 \sqrt{\frac{(36 \text{ ksi})(9.52 \text{ in.})^3}{(29,000 \text{ ksi})(16.9 \text{ in.})}}$$

$$= 0.378 \text{ in.}$$

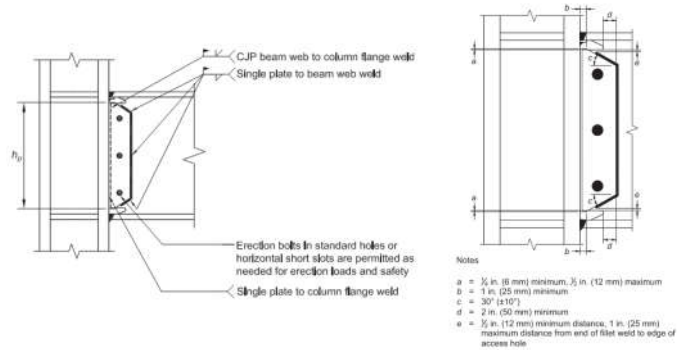
Gusset is sufficiently compact  
to preclude buckling



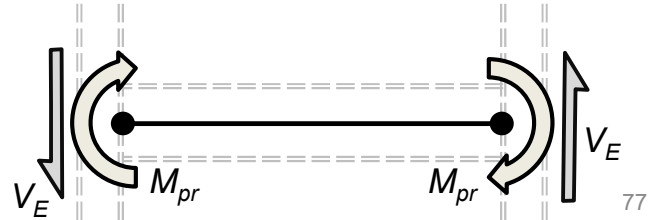
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# Beam-to-column connection

- Design as OMF
  - WUF-W
  - Prescriptive detailing
  - Check shear for  $\Sigma$



- $V_b$
- $V_{gravity}$
- $V_E = 2M_{pr}/L_{cf}$   
 $= 2(1.1R_y M_p)/L_{cf}$

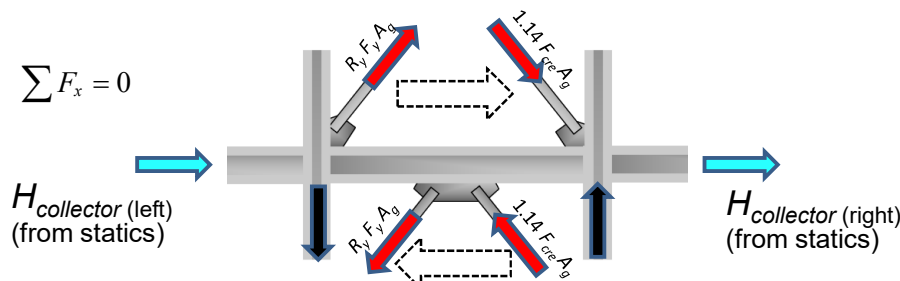


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# Beam-to-column connection

- Check adequacy for horizontal force (2 cases):

- $\Sigma$ 
  - $H_c$  (from tension-capacity design)
  - $H_{collector} = \frac{1}{2} \{ [R_y F_y A_g + 1.14 F_{cre} A_g]_2 \cos(\theta_2) - [R_y F_y A_g + 1.14 F_{cre} A_g]_3 \cos(\theta_3) \}$



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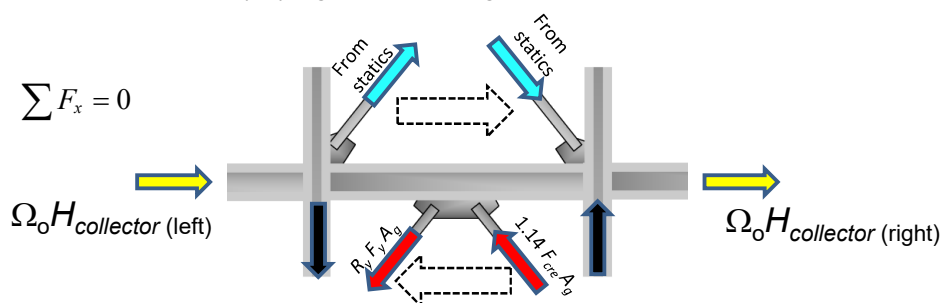
# Beam-to-column connection

– Check adequacy for horizontal force (2 cases):

•  $\Sigma$

–  $\Omega_o H_{collector}$  (from analysis)

–  $H_c = \frac{1}{2} \{ [R_y F_y A_g + 1.14 F_{cre} A_g]_2 \cos(\theta_2) - \Omega_o H_{collector} \}$



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## Summary

- AISC 341 requires capacity design for bracing connections
- SCBF require connections to accommodate brace buckling
- BRBF require connections to stabilize the brace and prevent brace buckling
- Combining collector and bracing forces requires creation of additional load cases



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**AISC** | Questions?



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- All WFH individuals associated with a group registration will be issued a certificate.
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  - Be on the lookout: Check your spam filter! Check your junk folder!
  - Completely fill out online form. Don't forget to check the boxes next to each attendee's name!



## 8-Session Registrants

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### PDH Certificates

One certificate will be issued at the conclusion of all 8 sessions.



## 8-Session Registrants

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### Access to the quiz

Information for accessing the quiz will be emailed to you by Wednesday. It will contain a link to access the quiz. EMAIL COMES FROM [NIGHTSCHOOL@AISC.ORG](mailto:NIGHTSCHOOL@AISC.ORG).

### Quiz and attendance records

Posted Friday mornings. [www.aisc.org/nightschool](http://www.aisc.org/nightschool) -- Click on Current Course Details.

### Reasons for quiz

- EEU – You must take all quizzes and the final exam to receive EEU.
- PDHs – If you watch a recorded session, you must pass quiz for PDHs.
- REINFORCEMENT – Reinforce what you learn tonight. Get more out of the course.

*Note: If you attend the live presentation, you do not have to take the quizzes to receive PDHs*



## 8-Session Registrants

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### Access to the recording

Information for accessing the recording will be emailed to you by Wednesday. The recording will be available for four weeks. (For 8-session registrants only.) EMAIL COMES FROM [NIGHTSCHOOL@AISC.ORG](mailto:NIGHTSCHOOL@AISC.ORG).

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If you watch a recorded session, you must take *and pass* the quiz for PDHs.



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<a href="#">NS 13 8-Session Package-Night School 13 - Design of Industrial Buildings</a>	1/30/2017 7:00:00 PM
<a href="#">NS 14 8-Session Package-Night School 14 - Fundamentals of Stability</a>	6/5/2017 7:00:00 PM

# 8-Session Registrants

## Night School Resources



### Night School 13: Design of Industrial Buildings

#### 8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
NS13 - Design Criteria	1/30/2017 7:00:00 PM	<a href="#">Handouts</a>	<a href="#">View</a> Passcode: NS13DSN	Pass Score: 80	Pending
NS13 - Economic Considerations	2/6/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 02/08/2017 5pm EST	Available 02/08/2017 5pm EST	Pending
NS13 - Lateral Load Systems and Details	2/13/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 02/15/2017 5pm EST	Available 02/15/2017 5pm EST	Pending
NS13 - Preliminary Design Procedures	2/27/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 03/01/2017 5pm EST	Available 03/01/2017 5pm EST	Pending
NS13 - Crane Girder Design and Frame Analysis	3/6/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 03/08/2017 5pm EST	Available 03/08/2017 5pm EST	Pending
NS13 - Frame Member and Connection Design	3/13/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 03/15/2017 5pm EST	Available 03/15/2017 5pm EST	Pending
NS13 - Transfer Crane Girder & Longitudinal Bldg Bracing Dsn	3/27/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 03/29/2017 5pm EST	Available 03/29/2017 5pm EST	Pending
NS13 - Building Envelope and Bracing Design	4/3/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 04/05/2017 5pm EST	Available 04/05/2017 5pm EST	Pending

## 8-Session Registrants

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### Night School Resources

- Weekly “quiz and recording” email.
- Weekly updates of the master quiz and attendance record, found at [www.aisc.org/nightschool28](http://www.aisc.org/nightschool28). Scroll down to Quiz and Attendance records.
  - Updated on Friday mornings.



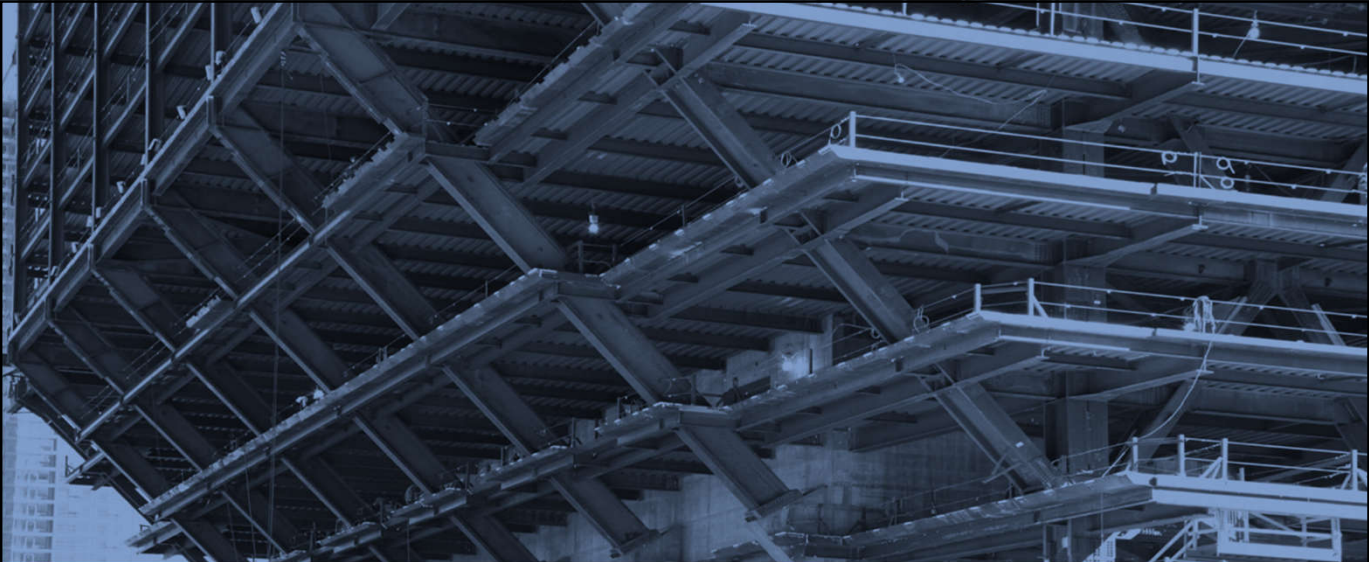
## 8-Session Registrants

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### Night School Resources

- Webinar connection information
  - Reminder email sent out Monday mornings
- Links to handouts also found here





**AISC** | Thank you

