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Course Description

Session L4: Design of the Braced Frames

October 1, 2018

This live webinar presents the design of the buckling restrained braced frames including: sizing braces, beam and column design, gusset plate design and connection analysis. The session will also cover plastic mechanism analysis, base plate design and concludes with a course summary.

Learning Objectives

- Describe the steps for the sizing of braces.
- Describe the steps of a plastic mechanism analysis.
- Describe the steps for the design of the beams and columns.
- Describe the steps for the design of the gusset plates.

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Seismic Design in Steel: Concepts and Examples

Session L4: Design of the Braced Frames

October 1, 2018

Rafael Sabelli, SE

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Course objectives

- Understand the principles of seismic design of steel structures.
- Understand the application of those principles to two common systems:
  - Special Moment Frames
  - Buckling-Restrained Braced Frames.
- Understand the application of design requirements for those systems.

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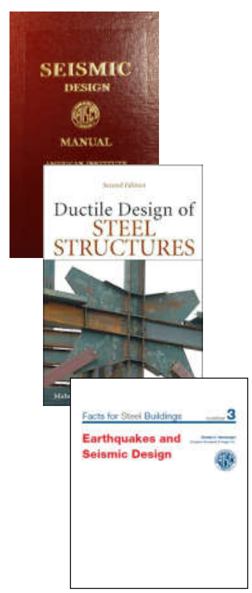
Resources

- AISC *Seismic Design Manual*
- *Ductile Design of Steel Structures*, Bruneau, Uang, and Sabelli, McGraw Hill.
- *Earthquakes and Seismic Design,* Facts for Steel Buildings #3. Ronald O. Hamburger, AISC.
- Other publications suggested in each session



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Other resources

- AISC Solutions Center
  - 866.ASK.*AISC* (866-275-2472)
  - Solutions@AISC.org
- AISC Webinars
  - Webinars@AISC.org

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Course outline

Part I: Concepts

R1. Introduction to effective seismic design

R2. Seismic design of moment frames

R3. Seismic design of braced frames

R4. Seismic design of buildings

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Course outline

Part II: Application

L1. Planning the seismic design

L2. Building analysis and diaphragm design

L3. Design of the moment frames

L4. <u>Design of the braced frames</u>

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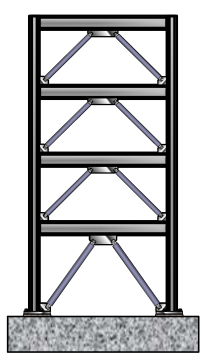
Session L4: Design of the braced frames



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Session topics

- Buckling-restrained brace sizing
- Plastic mechanism analysis
- Column and beam design
- Final analysis
- Gusset connections
- Base plate design
- Improved performance
- Course summary

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BRBF design overview

- Compute demands using design base shear
- Size braces (fuses)
- Compute maximum brace forces
- Perform plastic mechanism analysis
- Size beams and columns for PMA forces
- Final analysis
  - Confirm period
  - Determine drift
- Design connections

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Brace sizing

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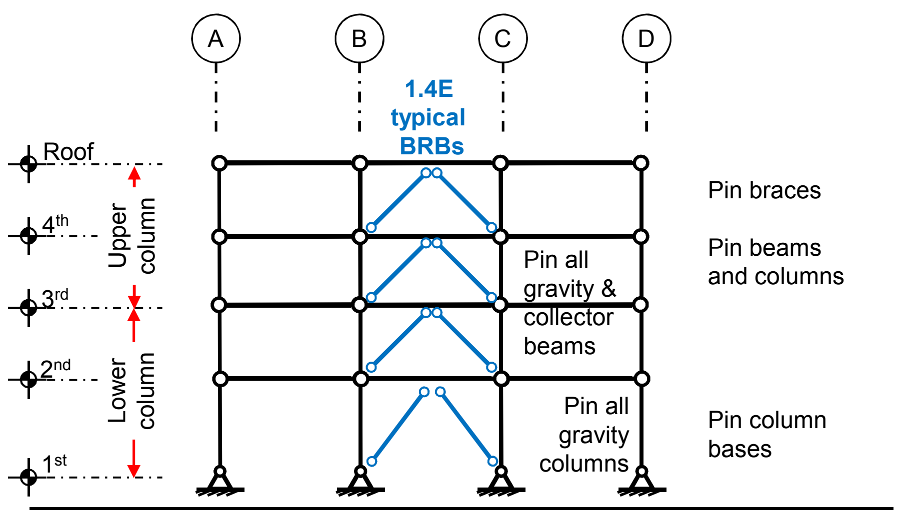
Braced-frame model



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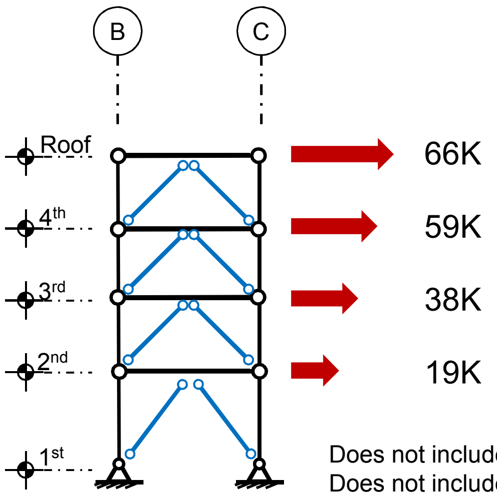
Braced-frame forces



Does not include ρ=1.3
Does not include B_2

Forces derived in sessions L1 & L2

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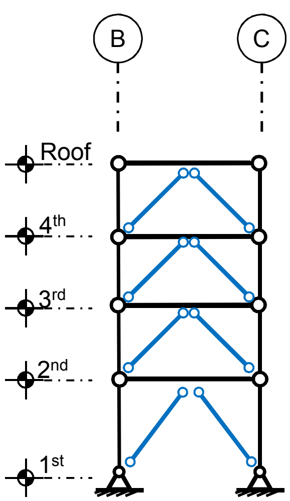
Braced-frame forces



As an alternative to introducing pins in the model, the analysis results can be examined to confirm that the braces resist close to 100% of the required base shear. Brace forces can be adjusted upwards if necessary

Level	Frame F_x, (kips)	B_2	ρ	Frame $\rho B_2 F_x$, (kips)	Frame $\rho B_2 V_x$, (kips)
Roof	66.0	1.02	1.30	87.6	88
4th	59.2	1.03	1.30	79.3	167
3rd	38.3	1.03	1.30	51.3	218
2nd	18.7	1.04	1.30	25.3	243

Forces, ρ, B_2 derived in sessions L1 & L2

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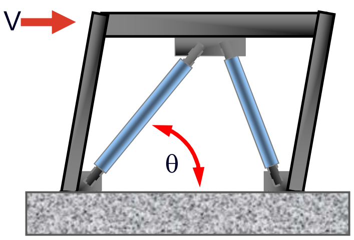
Force-based design

$$P_u = \frac{V}{2\cos\theta}$$

- Assume braces resist 100% of story shear V



$$A_{sc} = \frac{P_u}{\emptyset F_y}$$

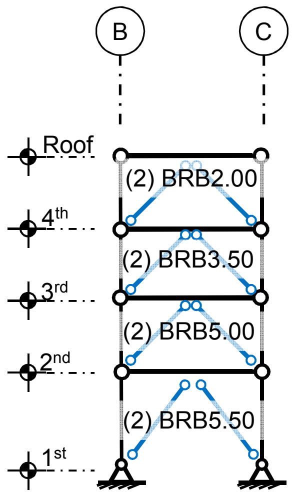
Design braces precisely to calculated capacity ($P_u = \phi P_n = \phi F_y A_{sc}$)

Do not include gravity load

Brace design

- Specifying area
  - "A_{sc} = 5.00 in^2"
  - Allow
    - 38ksi ≤ F_y ≤ 46ksi
  - Determine area
    - Based on F_y ≥ 38ksi
  - Determine expected brace strength
    - Based on $R_y F_y$ = 42ksi
- Specifying strength
  - "ϕP_{sc} = 200K"
  - Allow
    - 38ksi ≤ F_y ≤ 46ksi
  - Determine area for model
    - Based on $R_y F_y$ = 42ksi
  - Determine expected brace strength
    - Based on $R_y F_y A_{sc} = P_{sc}$
    - i.e., R_y = 1.0
    - Use R_y = 1.05 for tolerance

Brace sizes



From brace manufacturer:
38ksi ≤ F_y ≤ 46ksi
Use F_y = 38ksi

Level	Brace Force $\rho B_2 P_x$, (kips)	Required core area A_{sc}, (in^2)	Design core area A_{sc}, (in^2)
4th	62	1.81	2.00
3rd	118	3.45	3.50
2nd	154	4.51	5.00
1st	183	5.34	5.50

Typically rounded up ≤10%
For example, ¼in^2 typically used up to 5in^2, ½in^2 up to 10in^2, etc.

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Plastic mechanism analysis

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Plastic mechanism analysis

- Determine maximum brace forces
- Determine vertical and horizontal components
- Apply components to frame
  - Use spreadsheet, or
  - Use temperature (or stress) based analysis

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Maximum brace forces

- Based on testing

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

  Typical $1.3 \leq \omega \leq 1.5$

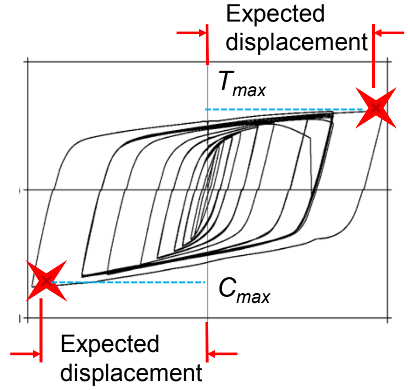
  $\beta\omega = C_{max}/A_g F_y$

  Typical $1.1 \leq \beta \leq 1.2$

- For design

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

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



AISC 341 F4.2a

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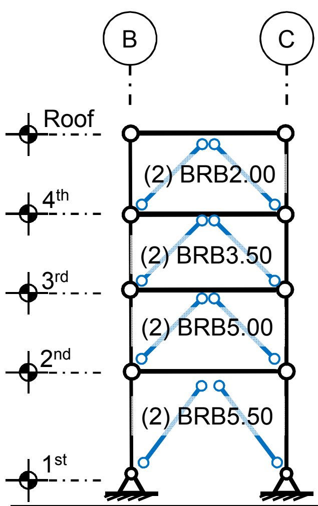
Maximum brace forces

- Based on testing
  - May vary with manufacturer
- Based on deformation demands
  - Drift not known at this stage
  - Drift subject to change during design
    - Don't be overly precise
- Use reasonably liberal values for frame design
  - $\beta = 1.15$
    - Tends to be more than this for longer & larger braces
  - $\omega = 1.4$
  - $R_y F_y = 42$ksi
  - $\beta\omega R_y F_y = 67.6$ksi
  - $\omega R_y F_y = 58.8$ksi

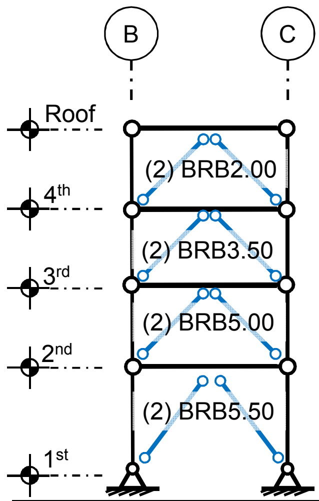
Maximum brace forces



From brace manufacturer:
$\beta\omega R_y F_y = 67.6$ksi
$\omega R_y F_y = 58.8$ksi

Level	Design core area A_{sc}, (in^2)	Tension Brace Force $\omega R_y F_y A_{sc}$, (kips)	Compression Brace Force $\beta\omega R_y F_y A_{sc}$, (kips)
4th	2.00	118	135
3rd	3.50	206	237
2nd	5.00	294	338
1st	5.50	323	372

Maximum brace forces



From brace manufacturer:
$\beta\omega R_y F_y = 67.6$ksi
$\omega R_y F_y = 58.8$ksi

Level	Required Brace Strength P_u, (kips)	Tension overstrength $\omega R_y F_y A_{sc}/P_u$	Compression overstrength $\beta\omega R_y F_y A_{sc}/P_u$
4th	62	1.90	2.18
3rd	118	1.74	2.01
2nd	154	1.91	**2.19**
1st	183	1.77	2.03

Use of 2.19*E* OK for seismic axial forces,
but will not capture beam flexure due to β.

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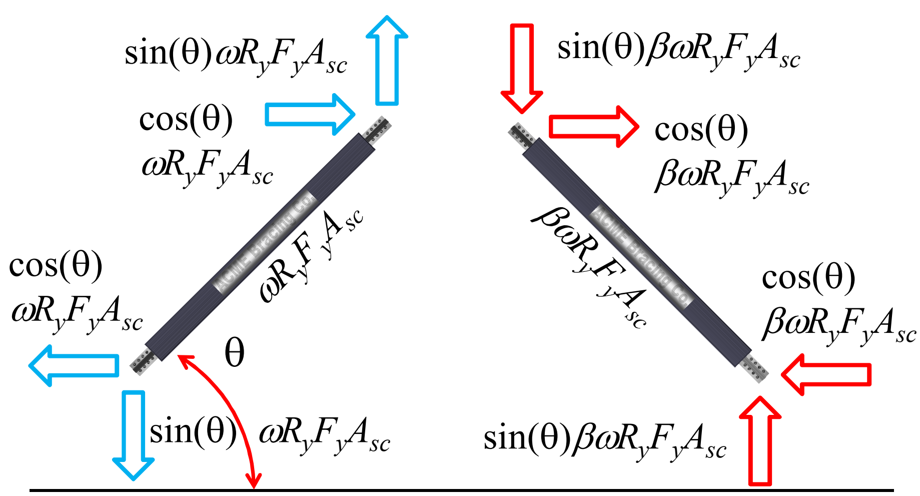
A little trigonometry



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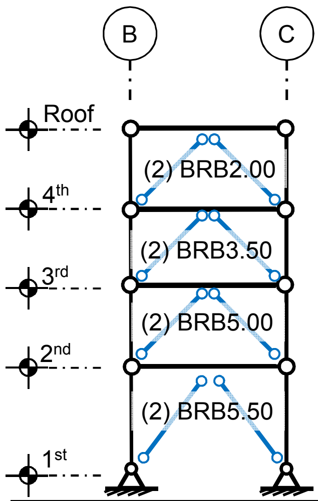
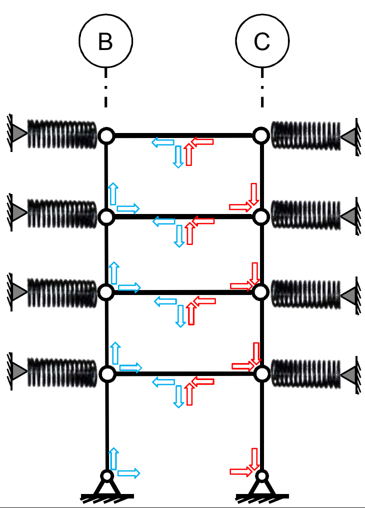
Maximum brace forces



Level	Tension Brace Force $\omega R_y F_y A_{sc}$, (kips)	Tension Brace x component (kips)	Tension Brace y component (kips)
4th	118	83	83
3rd	206	146	146
2nd	294	208	208
1st	323	215	241

Level	Compression Brace Force $\beta\omega R_y F_y A_{sc}$, (kips)	Compression Brace x component (kips)	Compression Brace y component (kips)
4th	135	96	96
3rd	237	167	167
2nd	338	239	239
1st	372	248	277

Plastic mechanism analysis



Level	Tension Brace x component (kips)	Tension Brace y component (kips)
4th	83	83
3rd	146	146
2nd	208	208
1st	215	241

Level	Compression Brace x component (kips)	Compression Brace y component (kips)
4th	96	96
3rd	167	167
2nd	239	239
1st	248	277

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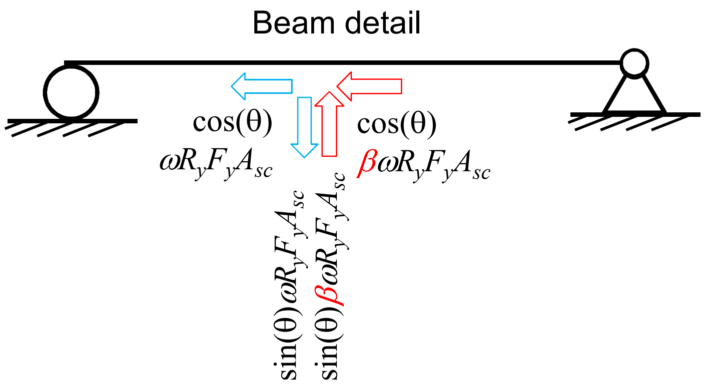
Plastic mechanism analysis



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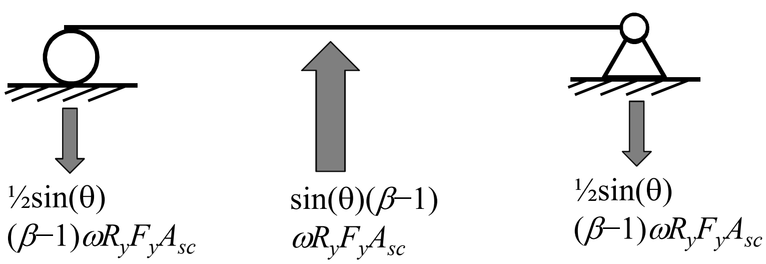
Plastic mechanism analysis



V_{Ecl}=½sin(θ)$(\beta-1)\omega R_y F_y A_{sc}$

M_{Ecl}=½ $V_{Ecl} L$

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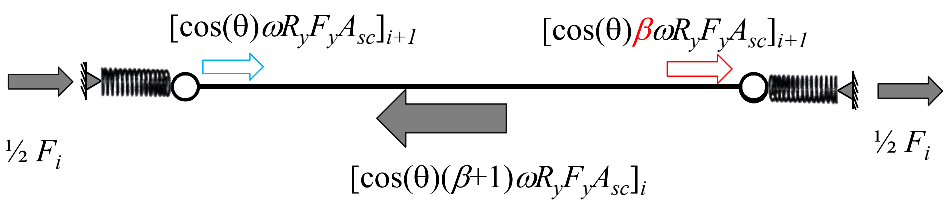
Plastic mechanism analysis



$$P_{Ecl} = \tfrac{1}{2}\,[\cos(\theta)(\beta+1)\omega R_y F_y A_{sc}]_i \pm \tfrac{1}{2}\,[\cos(\theta)(\beta-1)\omega R_y F_y A_{sc}]_{i+1}$$

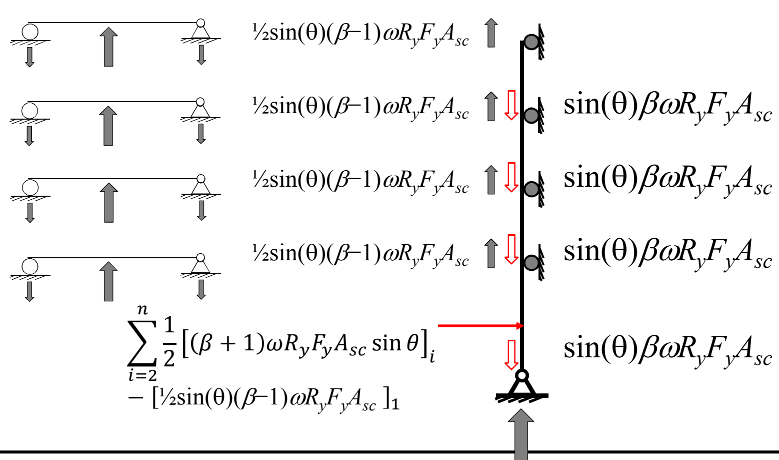
Plus for tension
(Minus for compression, but it's unconservative to reduce compression based on β)

Take as: $P_{Ecl} = [\cos(\theta)\beta\omega R_y F_y A_{sc}]_i$ ~8% conservative in this example

$$F_i = \left[[\cos(\theta)(\beta+1)\omega R_y F_y A_{sc}]_i - [\cos(\theta)(\beta+1)\omega R_y F_y A_{sc}]_{i+1}\right]$$

Plastic mechanism analysis

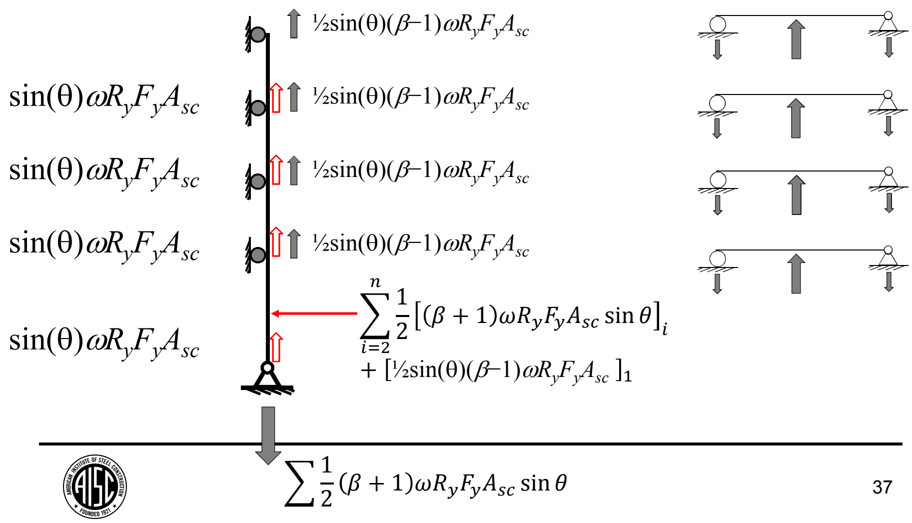
Column detail



$$\sum \frac{1}{2}(\beta+1)\omega R_y F_y A_{sc}\sin\theta$$

Plastic mechanism analysis

Column detail



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Column design

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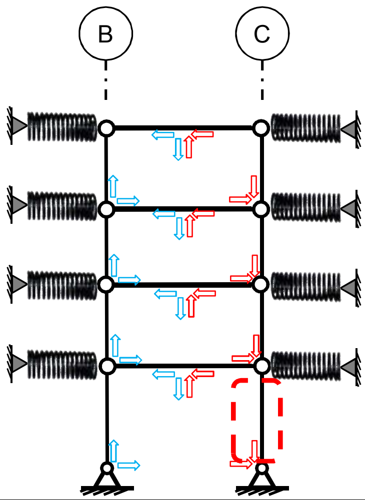
Plastic mechanism analysis



Level	Tension Brace *y* component (kips)	Compression Brace *y* component (kips)
4th	83	96
3rd	146	167
2nd	208	239
1st	241	277

Level	Column tension force E_{cl} (kips)	Column compression force E_{cl} (kips)
4th	6	-6
3rd	100	78
2nd	261	230
1st	487	451
Base	729	729

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Column design

- Axial loads
  - P_D = 147K
  - P_L = 60.0K
  - P_{Ecl} = 451K
    - (compression)
  - P_{Ecl} = 487K
    - (tension)
- Compression
  - $R_u = 1.4D + 0.5L + E_{cl}$
  - R_u = 687K
- Tension
  - $R_u = 0.7D + E_{cl}$
  - R_u = 384K

Use W10x77
ϕP_n = 753K (Manual Table 4-1)
Seismically compact (SDM Table 1-3)

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Member Selection

- Compactness
  - Use SDM table
  - AISC 341-16 permits moderately ductile members for BRBF beams and columns
    - Use IMF column

Table 1-3 (continued)
Sections That Satisfy Seismic Width-to-Thickness Requirements
W-Shapes
F_y = 50 ksi

Shape	EBF			BRBF	SPSW	P_a max, kips ASD		P_u max, kips LRFD		Web Access Holes
	Diagonal Braces	Columns	Links	Beams and Columns	HBE and VBE	λ_{hd}	λ_{md}	λ_{hd}	λ_{md}	
W10×112	•	•	•	•	•	—	—	—	—	D
×100	•	•	•	•	•	—	—	—	—	D
×88	•	•	•	•	•	—	—	—	—	C
×77	•	•	•	•	•	—	—	—	—	C
×68	•	•	•	•	•	—	—	—	—	C
×60	•		1			—	—	—	—	C
×54	•		1			—	—	—	—	B
×49	•		1			—	—	—	—	A or B

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Beam design

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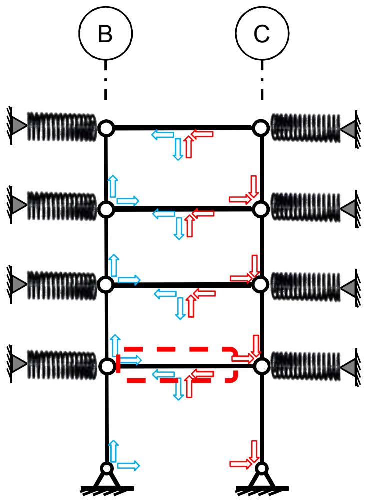
Plastic mechanism analysis



Level	Beam axial force E_{cl} (kips)	Beam shear force E_{cl} (kips)	Beam moment E_{cl} (ft-kips)
Roof	96	6.2	78
4th	167	10.9	136
3rd	239	15.6	195
2nd	248	18.1	226

$P_{Ecl}=\cos(\theta)\beta\omega R_y F_y A_{sc}$

$V_{Ecl}=½\sin(\theta)(\beta-1)\omega R_y F_y A_{sc}$

$M_{Ecl}=½\, V_{Ecl} L$

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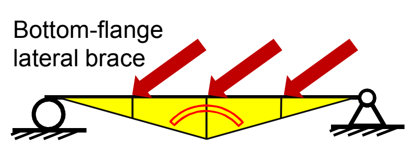
Beam design

- Shear
  - V_D = 11.2K
  - V_L = 8.5K
  - V_E = − 18.1K
  - V_u = 0.7D + E_{cl} = − 10.3K
- Moment
  - M_D = 120'K
  - M_L = 100'K
  - M_E = −226'K
  - M_u = 0.7D + E_{cl} = − 142'K
- Axial
  - P_D = 0K
  - P_L = 0K
  - P_E = 248K
  - P_u = 248K



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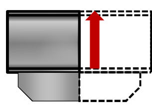
Beam design

- W18x55
  - Shear
    - ϕV_n = 212K > V_u OK
    - Check chevron connection

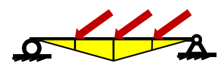
$$L_g \geq \frac{2(P_1 + P_2)\cos\theta e_b}{\phi V_n}$$

- $L_g \geq$ 40" < $^L/_6$=48" OK (rule of thumb)



$$V_u = \frac{2(P_1 + P_2)\cos\theta e_b}{L_g}$$

- Moment
  - ϕM_n = 417'K
    - Table 3-10
      - L_b =6'
      - C_b =1
    - C_b = 1.25 (for M_2=2M_1)
      - (1.25) 417'K = 521'K
  - ϕM_p = 420'K
  - ϕM_n = ϕM_p = 420'K



Chevron check illustrated in connection design. However, it should be considered in member selection.

Member Selection

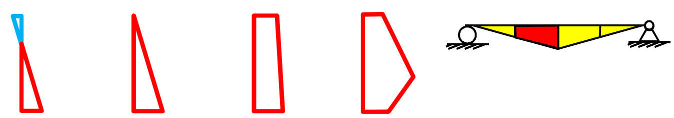
- Compactness
  - Use SDM Table
  - AISC 341-16 permits moderately ductile members for BRBF beams and columns
    - Use IMF column

Table 1-3 (continued)
Sections That Satisfy Seismic Width-to-Thickness Requirements
F_y = 50 ksi
W-Shapes

Shape	EBF			BRBF	SPSW	P_a max, kips ASD		P_u max, kips LRFD		Web Access Holes
	Diagonal Braces	Columns	Links	Beams and Columns	HBE and VBE	λ_{hd}	λ_{md}	λ_{hd}	λ_{md}	
W21×57		•	•	•	•	217	307	326	461	B
×50		•	•	•	•	117	219	176	330	A or B
×44		•	•	•	•	38.3	133	57.6	201	A or B
W18×311	•	•	•	•	•	—	—	—	—	I
×283	•	•	•	•	•	—	—	—	—	H
×258	•	•	•	•	•	—	—	—	—	G
×234	•	•	•	•	•	—	—	—	—	G
×211	•	•	•	•	•	—	—	—	—	F
×192	•	•	•	•	•	—	—	—	—	F
×175	•	•	•	•	•	—	—	—	—	E
×158	•	•	•	•	•	—	—	—	—	E
×143	•	•	•	•	•	—	—	—	—	D
×130	•	•	•	•	•	—	—	—	—	D
×119	•	•	•	•	•	—	—	—	—	D
×106	•	•	•	•	•	—	—	—	—	C
×97	•	•	•	•	•	—	—	—	—	C
×86	•	•	•	•	•	—	—	—	—	C
×76			1			595	620	895	932	C
W18×71	•	•	•	•	•	—	—	—	—	C
×65	•	•	•	•	•	—	—	—	—	C
×60		•	•	•	•	444	472	668	709	C
×55		•	•	•	•	346	391	520	588	B
×50		•	•	•	•	217	288	326	433	A or B
W18×46		•	•	•	•	212	273	319	411	B
×40		•	•	•	•	65.4	156	98.3	[illegible]	A or B
×35		•	•	•	•	30.9	107	46.5	161	A or B

Beam design

- $B_1 = \frac{C_m}{1 - {P_u}/{P_{E1}}} \geq 1$
  - Assume C_m=0.8 (M_1/ M_2 =−2)



  - $P_{E1} = \frac{\pi^2 EI}{L^2} = 45{,}300K$
  - $B_1 = 1$

If C_m=0.8
$B_1 = 1\ for P_u \leq 0.2 P_{E1}$

AISC 360 Appendix 8

Beam design

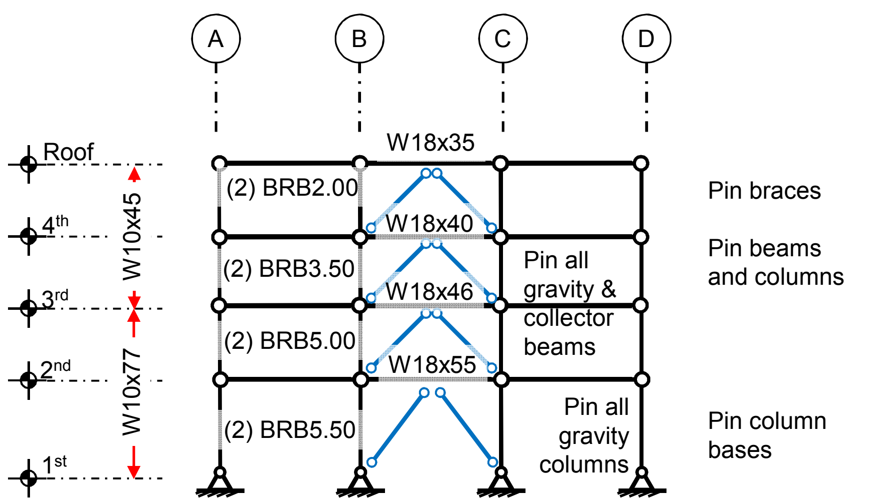
- Axial
  - KL/r_y = 75”/1.67”
    = 44.9
  - ϕF_{cr} = 38.8ksi
    - Table 4-22
  - $\phi F_{cr} A$ = 629K
- Chapter H Interaction
  - P_u/ $\phi F_{cr} A$ =0.39
  - P_u/ $\phi F_{cr} A$ + 8/9 M_u/ϕM_n
    = 0.39+ 8/9(142’K/420’K)
    = 0.69 OK

There's always a solution in steel.

Final analysis

structural STEEL

Braced-frame model

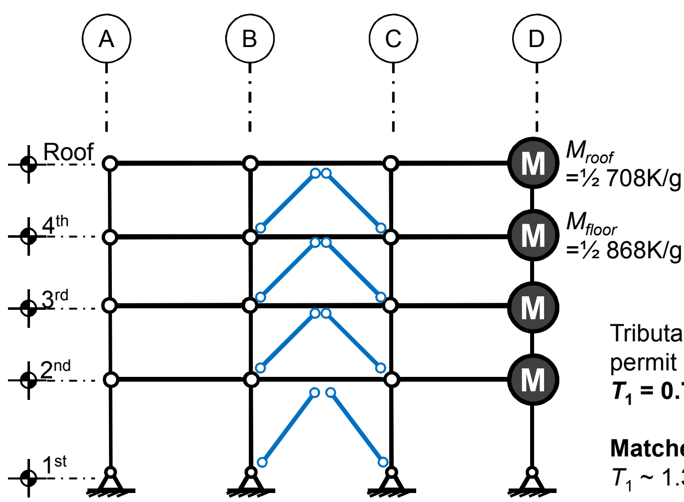


Brace stiffness

- Consult manufacturer
  - Direct communication
  - Brochure

Level	Design core area A_{sc}, (in^2)	Workpoint length (ft)	Stiffening factor
4th	2.00	17.7	1.39
3rd	3.50	17.7	1.39
2nd	5.00	17.7	1.43
1st	5.50	18.8	1.46

Braced-frame model



Tributary mass included to permit period calculation
***T_1* = 0.75 sec**

Matches assumption!!
$T_1 \sim 1.3T_a$ from Session L1

Drift

- Obtain from model
- Recalculate B_2
- Amplify drift for second-order effects
  - Only necessary per ASCE 7 if θ>0.1 (B_2>1.1)
  - Preferable not to modify process for B_2<1.1

Level	Model drift (%)	B_2	Drift*B_2
4th	1.76%	1.02	1.80%
3rd	1.68%	1.02	1.71%
2nd	1.60%	1.03	1.65%
1st	1.36%	1.03	1.40%

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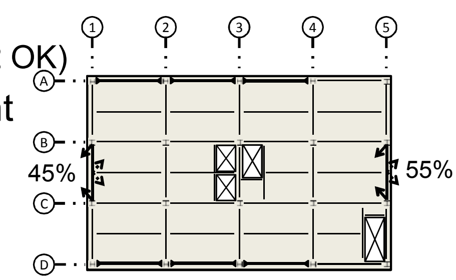
Check irregularities

- Horizontal torsional irregularity
  - Same check as initial
    - Lines A & D identical
    - Lines 1 & 5 identical
    - $\Delta_5 \leq 1.1\Delta_{ave}$ (up to 1.2 OK)
  - Irregularity not present



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Check irregularities

- Vertical soft story
  - Results from model

Level	**Displacement** (in.)	**Shear** (kips)	**Stiffness** (kips/in)
4^{th}	0.528	66.0	125
3^{rd}	0.504	125.2	248
2^{nd}	0.480	163.6	341
1^{st}	0.457	182.3	399

  - Story stiffness increases with story shear
  - Irregularity not present

(at least 70% of the stiffness above)

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Check irregularities

- Vertical weak story
  - Brace strength

Level	Design core area A_{sc}, (in^2)	Tension Brace Force $\omega R_y F_y A_{sc}$, (kips)	Compression Brace Force $\beta\omega R_y F_y A_{sc}$, (kips)	Story shear strength (kips)
4^{th}	2.00	118	135	358
3^{rd}	3.50	206	237	626
2^{nd}	5.00	294	338	894
1^{st}	5.50	323	372	926

  - Story strength increases with story shear
  - Irregularity not present

(at least 80% of the stiffness above)

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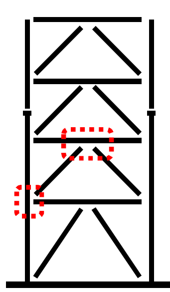
There's always a solution in steel.

Gusset connections

structural STEEL

Gusset connection

- Beam-column-brace connection
  - Rotation approach
  - Configuration
  - Gusset design
  - Beam-to-gusset connection
- Chevron connection
  - Minimum length
  - Local forces
  - Gusset design



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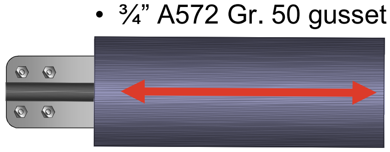
Gusset connection

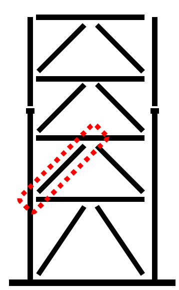
- Manufactured braces
  - Manufacturer-designed brace to gusset connection
  - Gusset thickness relates to BRB core plate thickness
  - Manufacturer can assist with gusset connection to beam & column
- EOR
  - Remains responsible for structure
  - Must communicate
    - Non-brace forces at connection
      - Beam shear
      - Column shear?
    - Load path restrictions
      - Especially at base plates

Gusset connection

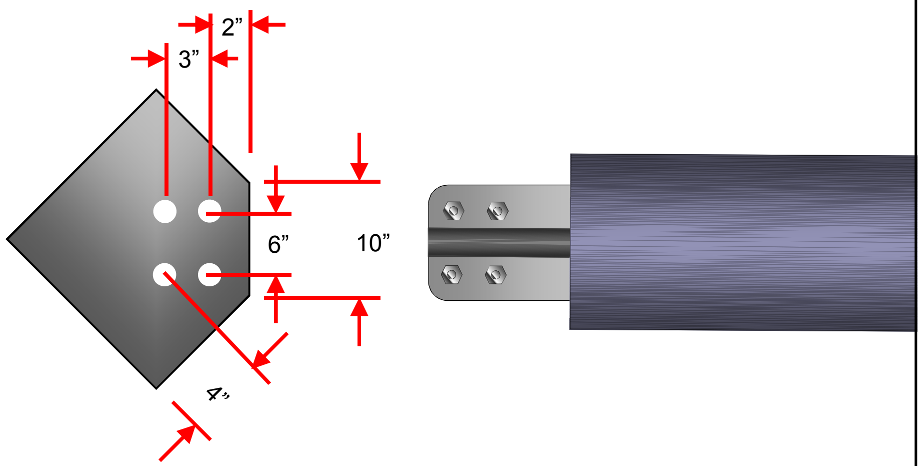
- Brace-to-gusset connections
  - Check manufacturer's design
    - (4)1"Ø A490X bolts
    - Double shear
    - ¾" A572 Gr. 50 gusset



P_u =338K (compression)
P_u =294K (tension)



Gusset connection



Gusset connection

- Compression
  - R_u = 338K
  - Bolt shear
    - (Table 7-1)
    - ϕR_n = 4*98.9K =396K
  - Bearing (spacing)
    - (Table 7-4)
    - ϕR_n = 4*¾*113K =339K
- Tension
  - R_u = 294K
  - Bearing (edge distance)
    - (Tables 7-4 & 7-5)
    - ϕR_n = 2*¾*113K +2*¾*85.9K = 298K

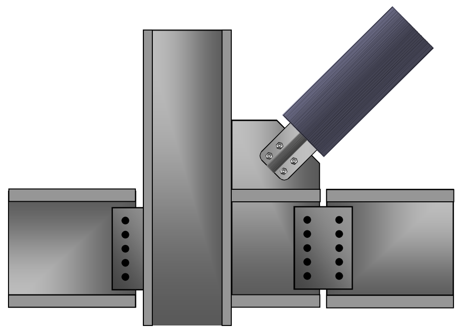
Gusset connection

- Block shear
  - $R_n = 0.6F_uA_{nv} + U_{bs}F_uA_{nt} \leq 0.6F_yA_{gv} + U_{bs}F_uA_{nt}$
    - 0.6(65ksi)(5.53in^2)+(1.0)(65ksi)(3.84in^2) = 466K
    - 0.6(50ksi)(7.5in^2)+(1.0)(65ksi)(3.94in^2) = 475K
  - ϕR_n = 0.75(466K) = 349K

Beam-column-brace connection

Beam-column-brace connection

- Mega-gusset
  - Beam connection outside gusset
    - Follow "simple connection" limits to allow for rotation
  - Flange plates
    - Stability
    - Deck support
  - Eccentric moment on column



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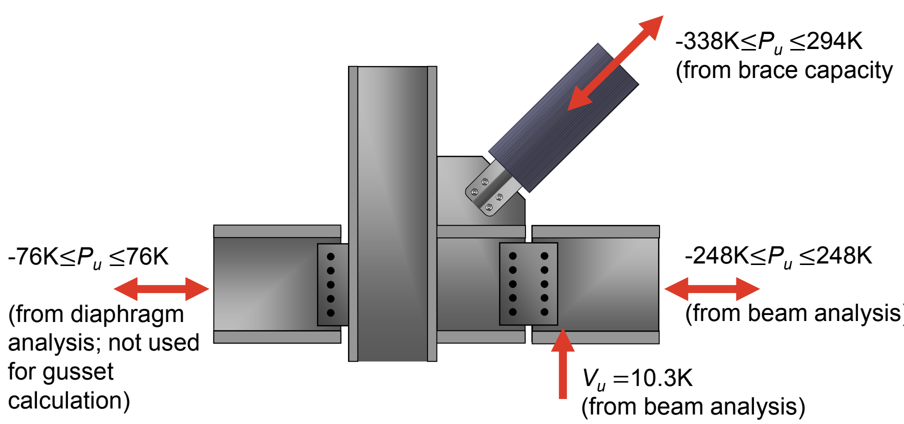
Beam-column-brace connection



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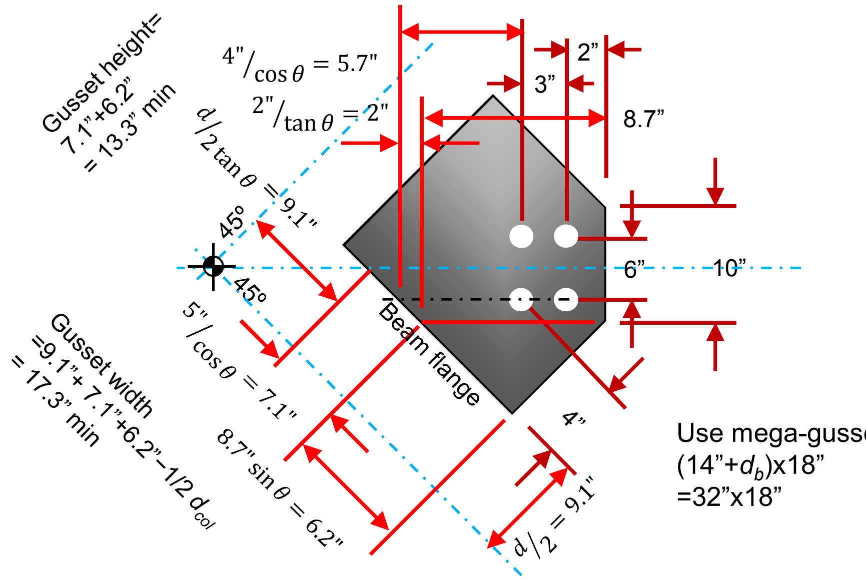
Gusset connection trigonometry



Use mega-gusset
(14"+d_b)x18"
=32"x18"

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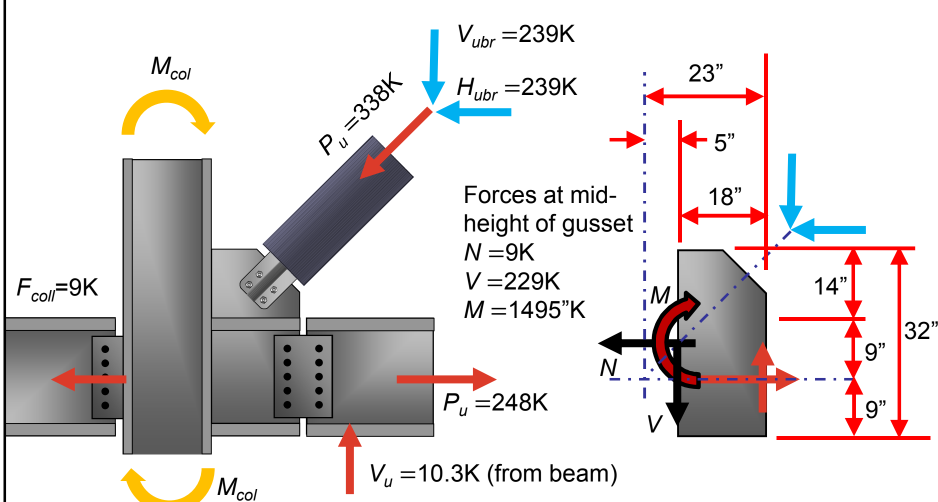
Beam-column-brace connection



F_{col}=248K−239K
F_{col}=9K

M_{col}= V_u(23") = 234"K
(higher for gravity combinations)

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Beam-column-brace connection

$V = 229K$

$$f_v = \frac{229k}{(0.75in)(32in)} = 9.5ksi$$

$N = 9K$

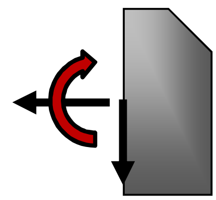
$$f_a = \frac{9k}{(0.75in)(32in)} = 0.4ksi$$

$M = 1495"K$

$$f_b = \frac{4 * 1495"K}{(0.75in)(32in)^2} = 7.8ksi$$

Plate:

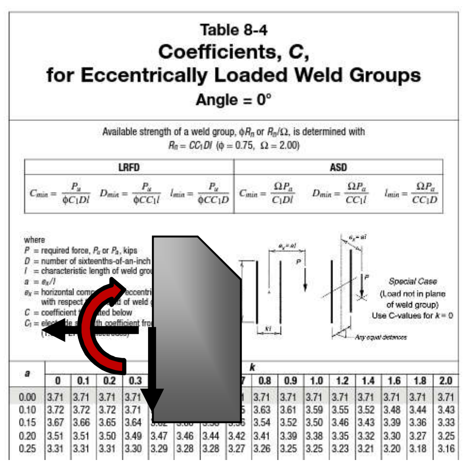
$$f_e = \sqrt{(f_a + f_b)^2 + 3f_v^2} = 22.7ksi < \emptyset F_y$$



AISC Manual EQ 9-1 69

Beam-column-brace connection

- Weld:
  - $e=M/V$ = 6.5”
    - (ignore small N)
  - $a=e/L$ =6.5”/32” =0.20
  - Table 8-4
    - Angle = 0°
    - k=0 for out-of-plane
    - C=3.51K/in/($^1/_{16}$in)
    - D ≥229/(0.75*3.51*32)
    - D ≥2.7, x1.25=3.4
    - Use (2) $^5/_{16}$” fillet welds



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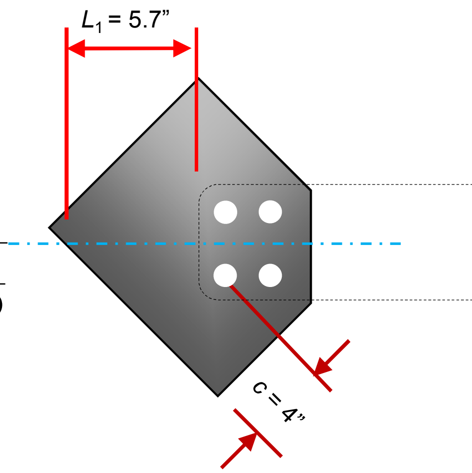
Beam-column-brace connection

- Check gusset compactness
  - Per Dowswell (2006 AISC Engineering Journal)

$$t_\beta = 1.5\sqrt{\frac{F_y c^3}{EL_1}} = 1.5\sqrt{\frac{(50\text{ ksi})(4\text{ in})^3}{(29{,}000\text{ ksi})(5.7\text{ in})}}$$

$$= 0.14\text{ in} \le 0.75\text{ in}$$

- Gusset is compact
- No further stability evaluation required



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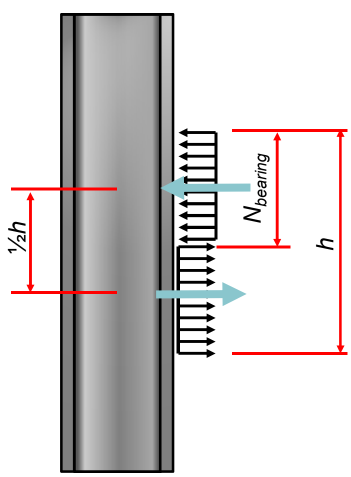
Beam-column-brace connection

- Check column
  - WLY, WC
  - Forces
    - R_u = $M/(½h)+½N$ = 98K
    - $N_{bearing}$= $½h$ = 16”
    - (evaluation not presented)



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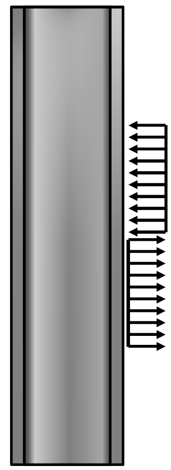
Beam-column-brace connection

- Panel Zone
  - R_u = $M/(½h)$
    = 93K
  - $\frac{P_u}{P_y} = \frac{687K}{(50ksi)(22.7in^2)} = 0.6$
  - $\emptyset R_n = 0.9 * 0.6 F_y t_w d \left(1.4 - \frac{P_u}{P_y}\right)$
    =121K OK



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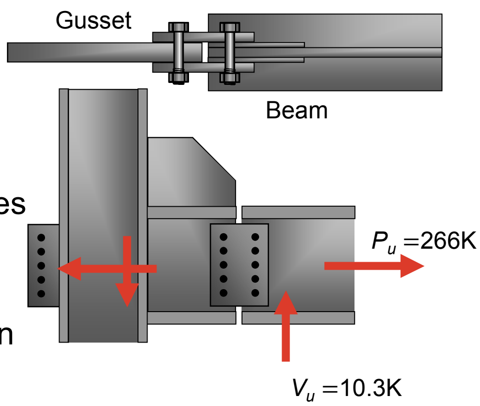
Beam-column-brace connection

- Double plate connection
  - (5)⅞"Ø A325X bolts
    - At beam
    - At gusset
  - Double shear
  - (2) ⅜" A572 Gr. 50 plates
    - 15"x12"
  - Tack welds for erection
  - See collector connection calculations
  - Reinforce beam web



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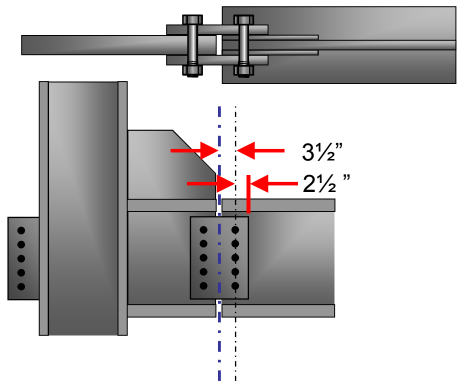
Beam-column-brace connection

- Double plate connection
  - Meets limits for single plate connection
    - #bolts =5 ≤12
    - Bolt-to-weld distance≤3½”
      - Bolt-line-to-bolt-line distance≤7”
    - STD holes
    - Horizontal edge distance
      - L_{eh}≥2d
    - Maximum plate thickness
      - $d/2+{}^{1}/_{16}$” = ½“



Extended configuration procedure available beyond these limits

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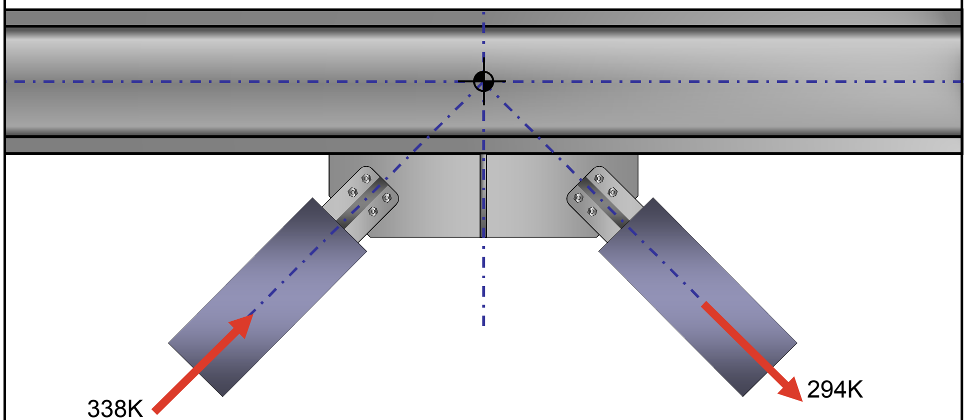
There's always a solution in steel.

Chevron connection

Chevron connection



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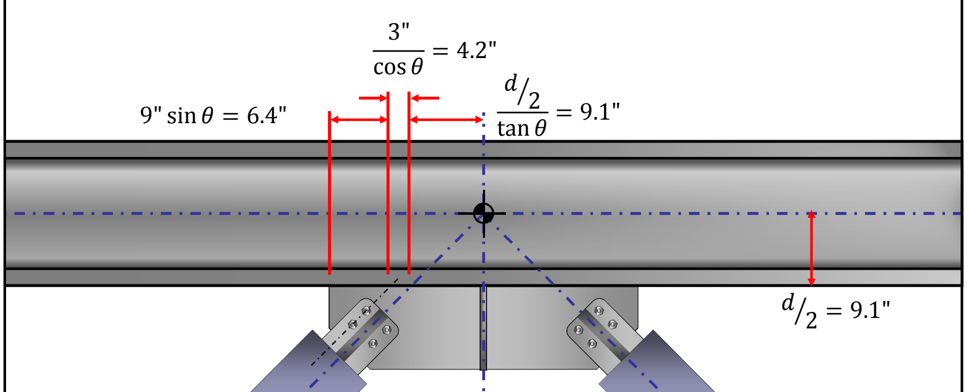
Chevron connection



Minimum gusset length =2(6.4”+4.2”+9.1”)=39.3”, try 40”

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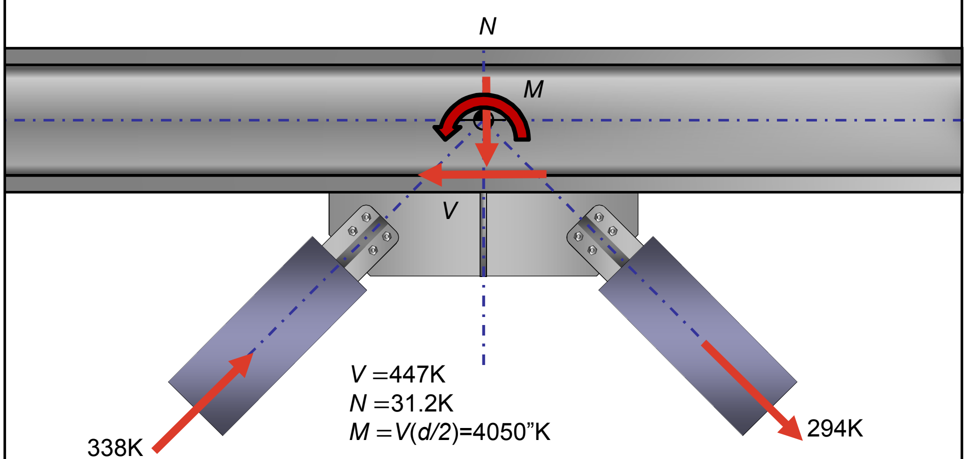
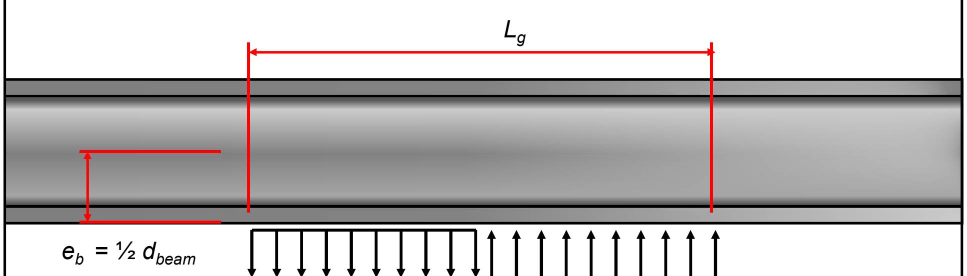
Chevron connection



Check local web shear



$$\emptyset V_n = 1(0.6)(50ksi)dt_w = 195K$$

$$L_g \geq \frac{2(P_1 + P_2)\cos\theta e_b}{\phi V_n} = \frac{2(294K + 338K)\cos(45\,\text{deg})(9.05")}{195K} = 41.4"$$

Use L_g = 42"

"Design of Chevron Gusset Plates"
2017 SEAOC proceedings

Chevron connection

$V = 447K$

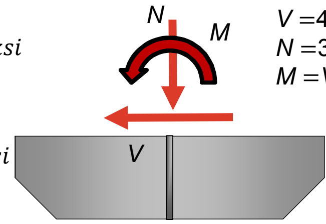
$$f_v = \frac{447k}{(0.75in)(42in)} = 14.2ksi$$

$N = 31K$

$$f_a = \frac{31k}{(0.75in)(42in)} = 1.0ksi$$

$M = 4050"K$

$$f_b = \frac{4 * 4050"K}{(0.75in)(42in)^2} = 12.2ksi$$



V =447K
N =31.2K
M =*V*(*d*/2)=4050"K

$$f_e = \sqrt{(f_a + f_b)^2 + 3f_v^2} = 28ksi < \emptyset F_y$$

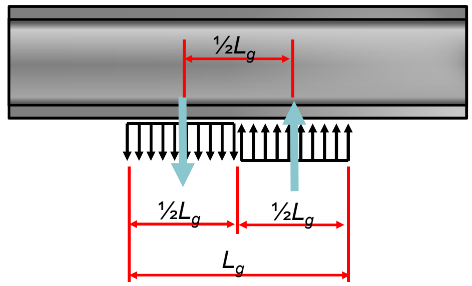
von Mises effective stress

Chevron connection

- Weld:
  - *e*=*M*/*V* = 9.1"
    - (ignore small *N*)
  - *e*/*L* =9.1"/42" =0.23 Table 8-4
    - Angle = 0°
    - *k*=0
    - *C*=3.31K/in/($^1/_{16}$in)
    - *D* ≥447/(0.75*3.51*42)
    - *D* ≥4.3, x1.25=5.4
    - Use (2) $^3/_8$" fillet welds

Chevron connection

- Check beam
  - WLY
  - WC
  - Forces
    - R_u = $M/(½L_g)+½N$ = 208K
    - $N_{bearing}$= $½L_g$ = 21"
  - (evaluation not presented)



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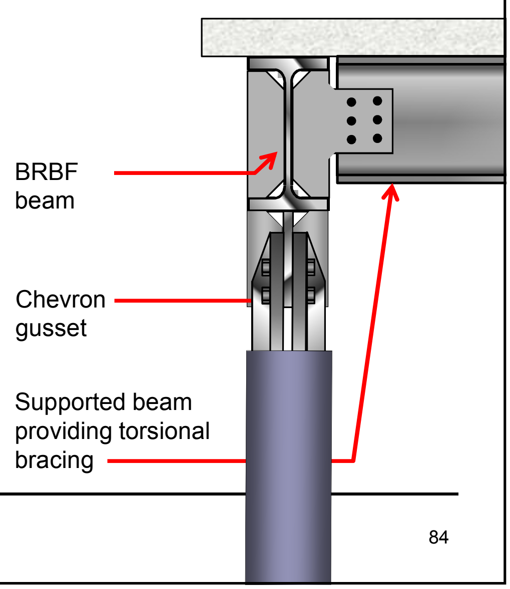
Chevron connection

- Provide torsional bracing at chevron connection
  - AISC 341 F4.4a(2)



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There's always a solution in steel.

Base plate

structural STEEL

Base-plate design

- Maximum forces from plastic mechanism analysis
- Use anchor rods for tension
- Do not use anchor rods for shear
- Provide rotational ductility
- Is the manufacturer assisting with gusset design?
    - Specify if base plate is designed to resist vertical gusset force

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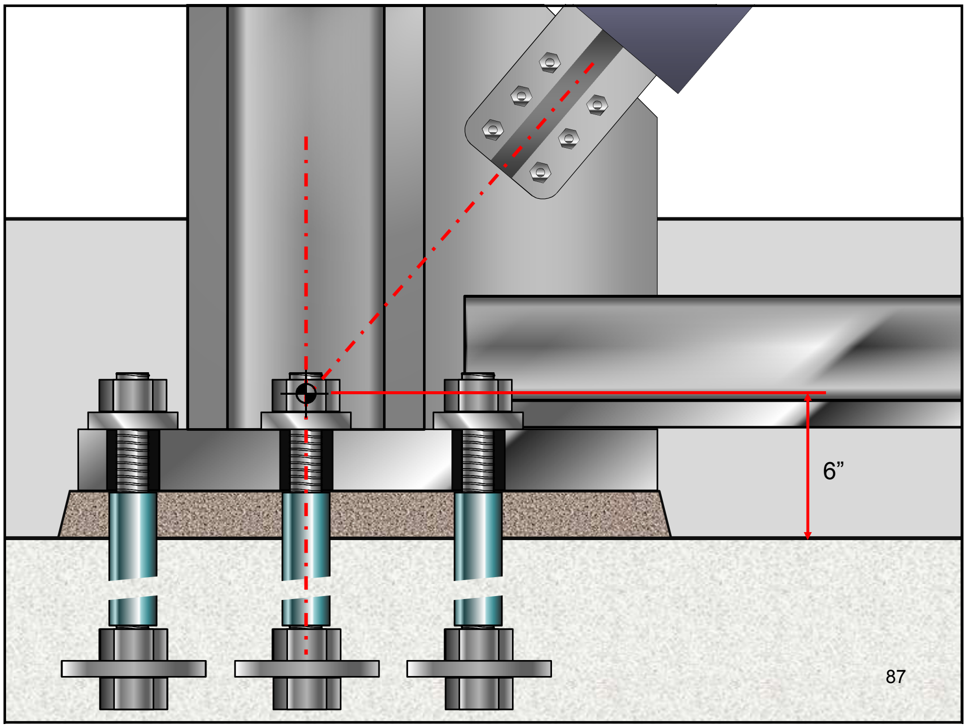
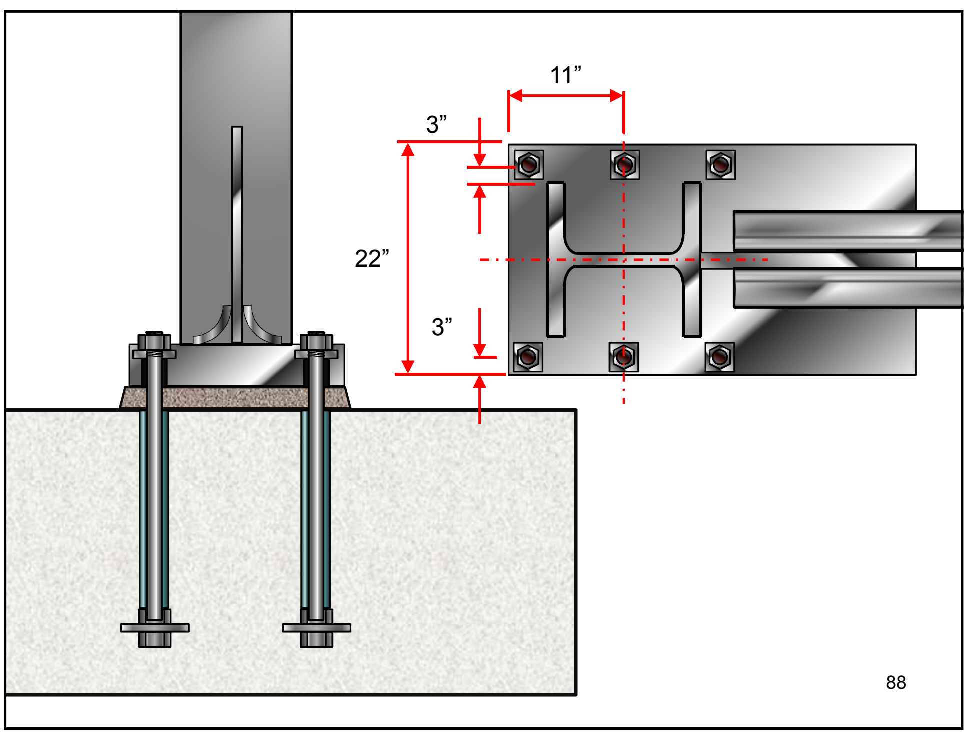

6”
87


11”
3”
22”
3”
88

Base-plate design

- Tension
  - Size rods
  - Check plate bending
  - Rotational ductility
    - Anchor rods
    - Base plates
    - Column rotation
    - Foundation rotation
- Compression
  - Check bearing
  - Check plate bending
  - Rotational ductility
    - Column rotation
    - Foundation rotation
    - Base plates and anchor rods will not provide rotation

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Base-plate design

- Axial loads
  - P_D = 147K
  - P_L = 60.0K
  - P_{Ecl} = 729K

Level	Column tension force E_{cl} (kips)	Column compression force E_{cl} (kips)
4th	6	-6
3rd	100	78
2nd	261	230
1st	487	451
Base	729	729

- Compression
  - $R_u = 1.4D + 0.5L + E_{cl}$
  - R_u = 965K
- Tension
  - $R_u = 0.7D + E_{cl}$
  - R_u = 626K

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Base-plate design

- Shear loads
  - Brace in tension
    - V_{Ecl} = 215K
  - Brace in compression
    - V_{Ecl} = 248K

Level	Tension Brace Force $\omega R_y F_y A_{sc}$, (kips)	Tension Brace x component (kips)	Tension Brace y component (kips)
4th	118	83	83
3rd	206	146	146
2nd	294	208	208
1st	323	215	241

Level	Compression Brace Force $\beta\omega R_y F_y A_{sc}$, (kips)	Compression Brace x component (kips)	Compression Brace y component (kips)
4th	135	96	96
3rd	237	167	167
2nd	338	239	239
1st	372	248	277

Anchor-rod design

- $F_{nt} = \emptyset 0.75 F_u = 44.7\text{ksi}$
- $A_{required}$ =626K/44.7ksi = 14.0in^2
- Use (6) 1¾” Ø F1554 Gr 55 anchor rods
  - A_{net} = 1.90in^2
  - $\phi F_u A_{net}$ = 0.75(75ksi)1.90in^2 = 107K/rod
  - 6 rods: 6*107K=641K OK

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Anchor-rod design

Table 14-2
Recommended Maximum Sizes for Anchor-Rod Holes in Base Plates

Increase for grade 55

- Use (6) 1¾"Grade 55 anchor rod F1554, S1

Anchor Rod Diameter, in.	Hole Diameter, in.	Min. Washer Size, in.	Min. Washer Thickness
1 1/2	2 5/16	3 1/2	1/2
1 3/4	2 3/4	4	¾
2	3 1/4	5	3/4
2 1/2	3 3/4	5 1/2	7/8

Notes: 1. Circular or square washers meeting the washer size are acceptible.
2. Clearance must be considered when choosing an appropriate anchor rod hole location, noting effects such as the position of the rod in the hole with respect to the column, weld size and other interferences.
3. When base plates are less than 1 1/4 in. thick, punching of holes may be an economical option. In this case, 3/4-in. anchor rods and 1 1/16-in.-diameter punched holes may be used with ASTM F844 (USS Standard) washers in place of fabricated plate washers.

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Base-plate design

- Flexure under tension
  - x = 3"+ 0.1b_f= 3.10"
  - Use B=22"
  - T=626K/2=313K
    - M=313K(3.10")=970"K
  - $t_p \geq 2.11\sqrt{\frac{Tx}{BF_y}}$= 1.98" Use 2" plate

AISC Design Guide 1 §3.2

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Base-plate design

- Compression: assume 18"x18" bearing area
  - 965K/(18inx18in)=2.98ksi
  - L = ½ [18"-0.8b_f]= ½ [18"-0.8(10.2")]=4.92"

$$\lambda n' = \lambda \cdot \frac{\sqrt{db_f}}{4} = 1\frac{\sqrt{(10.6)(10.2)}}{4} = 2.6"$$

  - M=WL^2/2=2.98ksi(18in)(4.92in)^2/2=649"K
  - $t_p \geq 2.11\sqrt{\frac{M}{BF_y}}$=1.79in. Use 2" plate

AISC Design Guide 1 §3.1

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Shear design

- $V_u = 248\text{K}$
- Provide direct transfer to concrete slab
  - Embedded structural steel angles (or other shapes)
  - A706 bar
  - etc.
  - Provide load path into foundation
- Combined tension shear and bending:
  - 3"Ø anchor rods

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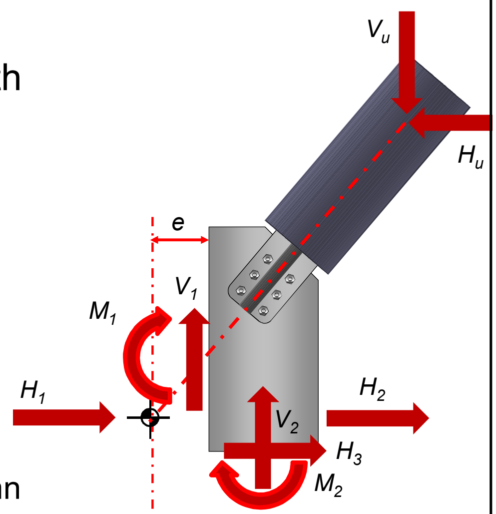
Gusset design coordination

- Communicate load path to gusset designer:
  - Tension
    - $H_2 = H_3 = 50\%\ H_u$
    - $V_1 = 100\%\ V_u$
    - $M_1 = 100\%\ eV_u$
  - Compression
    - $H_2 = H_3 = 50\%\ H_u$
    - No tension on gusset bottom edge
  - EOR must check column



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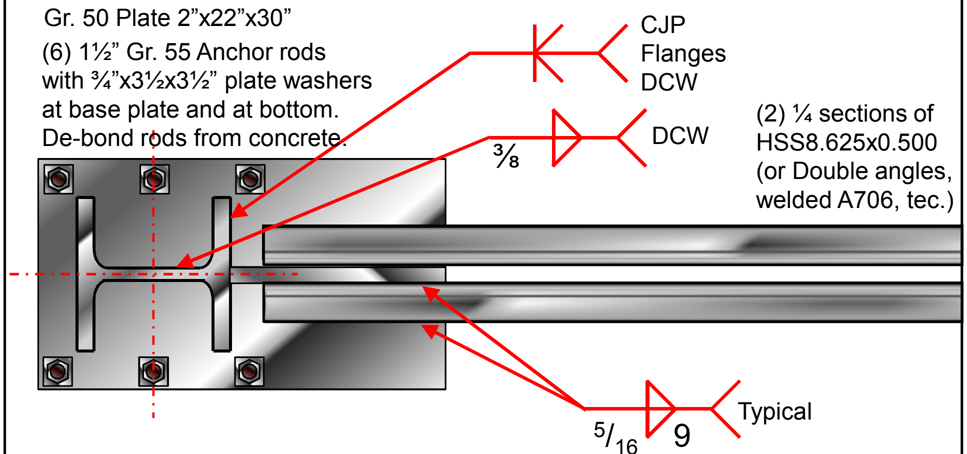
Base Plate

Gr. 50 Plate 2”x22”x30”
(6) 1½” Gr. 55 Anchor rods with ¾”x3½x3½” plate washers at base plate and at bottom.
De-bond rods from concrete.



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There's always a solution in steel.

Improved performance

structural STEEL

Improved performance

- BRBF provide very good reliability against collapse
- Residual drift is not addressed in AISC 341
  - Residual drift can be reduced through the introduction of a modest restoring force
  - Add moment frames adjacent to braced frames
    - Act as robust collectors
    - Reduce overturning on braced-frame columns

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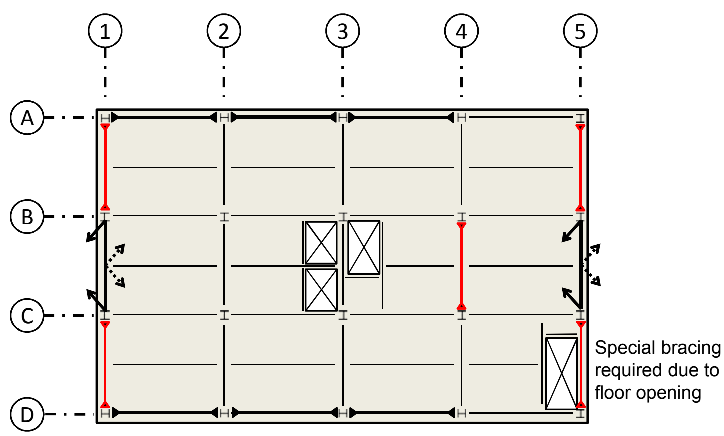
Improved performance

- Supplemental moment frames
  - Design as OMF
    - Follow OMF connection detailing requirements
  - Do not utilize OMF in the analysis
    - Design BRBF for 100% of the force

Improved performance



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Completion of design

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Completion of design

- Braces
  - Indicate protected zone
  - Review manufacturer's design
  - Review testing information
- Connections
  - Indicate DCW
- Beam
  - Design lateral bracing
- Column
  - Design column splice

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Completion of design

- Base plate
  - Provide load path for shear
  - Design concrete anchorage/force transfer to foundation
  - Design grade beam for ductile rotation
- Specifications
  - Specify weld toughness requirements
  - Specify Quality Assurance Plan

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Summary

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Summary

- BRBF have a rigorous capacity design procedure
  - Design braces first
  - Compute maximum brace forces
    - Requires data from manufacturers
  - Design
    - Beams
    - Columns
    - Connections

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Summary

- BRBF require coordination and partnership with manufacturers
  - Review assumptions
    - Load path
    - Design responsibilities
  - Review factors
    - β, ω
  - Review testing
    - Factors
    - Cover all project braces

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Course wrap-up

structural STEEL

Course wrap-up

- Mild structural steel provides excellent ductility
- Proper proportioning and detailing of steel systems provides controlled inelastic behavior
- Ductile design permits economical buildings
  - Required strength is reduced
  - Large inelastic drifts can be accommodated

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Course wrap-up

- Design example
  - Efficient design can result from
    - Early identification of governing design loads
    - Simplifying as appropriate so that analysis supports design decisions
  - Economical design can result from
    - Selecting the appropriate systems
    - Reducing the need for member reinforcement

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End of session L4

And the end of the webinar series

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Additional resources

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Question time

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Individual Webinar Registrants
CEU/PDH Certificates

Within 2 business days…

- You will receive an email on how to report attendance from: registration@aisc.org.
- 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!

Individual Webinar Registrants
CEU/PDH Certificates

Within 2 business days…

- New reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
- Password: Same as AISC website password.

8-Session Package Registrants
CEU/PDH Certificates

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

8-Session Package Registrants
CEU/PDH Certificates

<u>Videos and Quizzes</u>

- For Sessions R1 – R4, access has been available since July 16.
- For Sessions L1 – L4, find access within two days after the live air date. (An email will be sent from webinars@aisc.org.)
- All video recordings are available through October 22.
- All quizzes are due October 22.
- A final exam will also be given. It will be available October 5 and due October 22.
- Quiz scores are displayed in the Course Resources table.

8-Session Package Registrants
CEU/PDH Certificates

Attendance and PDH Certificates

- For Sessions R1 – R4, you must pass the quiz to receive credit for the session.
- For Sessions L1 – L4, you have two options to receive credit for the session.
  - Option 1: Watch the session live. Credit for live attendance will be displayed in the Course Resources table within two days of the session.
  - Option 2: Watch the recording and pass the quiz.

EEU Certificates – Certificate of Completion

- In addition to PDH certificates earned for each individual session, an EEU (Equivalent Education Unit) certificate of completion will be issued for participants who complete the full course. Participants must pass at least 7 of 8 quizzes and the final exam to earn the EEU.

Distribution of Certificates

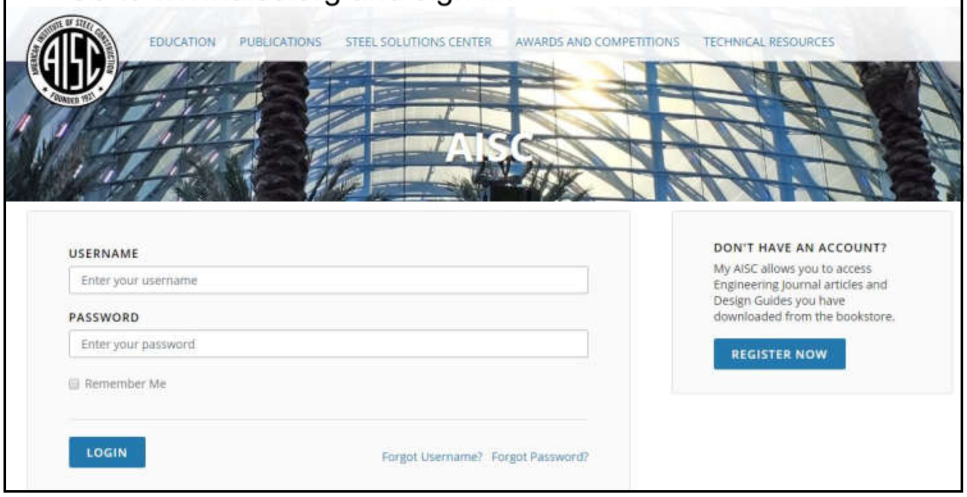
- All certificates (PDH and EEU) will be issued after the course is completed (the week of October 22). Only the registrant will receive certificates for the course.

8-Session Package Registrants
Course Resources

Find all your handouts, quizzes and quiz scores, recording access, and attendance information all in one place!

8-Session Package Registrants
Course Resources

Go to www.aisc.org and sign in.



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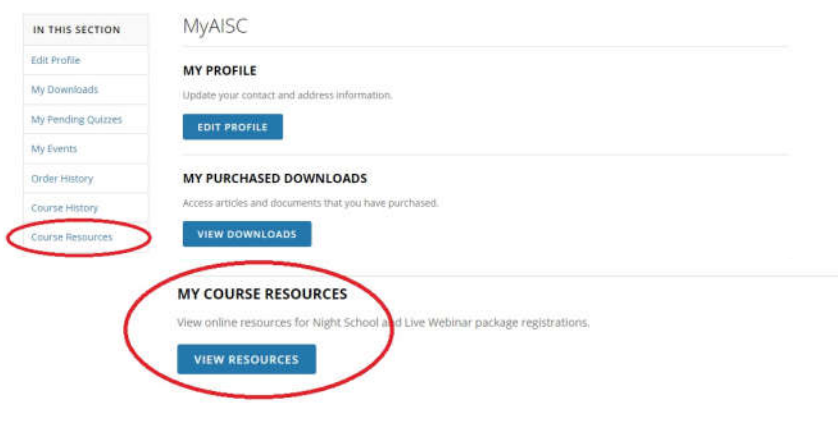
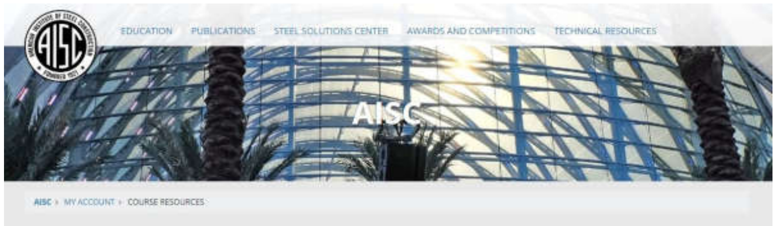


8-Session Package Registrants
Course Resources



Course Resources

Event	Start Date
Test Course	1/1/1900 12:00:00 AM
NS 15 8-Session Package-Night School 15 - Fundamentals of Connection Design	10/3/2017 7:00:00 PM
NS 16 8-Session Package-Night School 16 - Seismic Design in Steel	2/5/2018 7:00:00 PM
NS 17 4-Session Package-Night School 17: Design of Facade Attachments	7/16/2018 7:00:00 PM
8-Session Package-Seismic Design in Steel - Concepts & Examples	7/16/2018 1:30:00 PM

8-Session Package Registrants
Course Resources

Seismic Design in Steel

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
R1: Introduction To Effective Seismic Design	N/A	Handouts	View Passcode: 18NSRS1	Pass Score: 100	N/A
R2: Seismic Design Concepts - Moment Frames	N/A	Handouts	View Passcode: 18221218	Pass Score: 100	N/A
R3: Seismic Design Concepts - Braced Frames	N/A	Handouts	View Passcode: 3610305	Pass Score: 100	N/A
R4: Seismic Design Concepts - Design	N/A	Handouts	View Passcode: N/A	Pass Score: 100	N/A
L1: Application - Planning the Seismic Design	Sep 10 2018 1:30PM EDT	Handouts	Available 09/12/2018 5:00PM EDT	Available 09/12/2018 5:00PM EDT	Pending
L2: Application - Building Analysis/Diaphragms	Sep 17 2018 1:30PM EDT	Handouts	Available 09/19/2018 5:00PM EDT	Available 09/19/2018 5:00PM EDT	Pending
L3: Application - Moment Frames	Sep 24 2018 1:30PM EDT	Handouts	Available 09/26/2018 5:00PM EDT	Available 09/26/2018 5:00PM EDT	Pending
L4: Design of the Braced Frames	Oct 1 2018 1:30PM EDT	Handouts	Available 10/03/2018 5:00PM EDT	Available 10/03/2018 5:00PM EDT	Pending
Seismice Design in Steel - Final Exam	Oct 3 2018 12:00AM EDT			Available 10/05/2018 5:00PM EDT	


Thank You
Please give us your feedback!
Survey at conclusion of webinar.
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