There's always a solution in steel.

AISC Live Webinars

Thank you for joining our live webinar today.
We will begin shortly. Please standby.

Thank you.

Need Help?
Call ReadyTalk Support: 800.843.9166

There's always a solution in Steel

AMERICAN INSTITUTE OF STEEL CONSTRUCTION
AISC
FOUNDED 1921

AISC Live Webinars

Today's audio will be broadcast through the internet.

Alternatively, to hear the audio through the phone, dial 855-697-4479.

Conference ID: 18891656

For additional support, please press *0 and you will be connected to a live operator.

AISC Live Webinars

Today's live webinar will begin shortly.
Please standby.
As a reminder, all lines have been muted. Please type any questions or comments through the Chat feature on the left portion of your screen.

Today's audio will be broadcast through the internet. Alternatively, to hear the audio through the phone, dial (855) 697-4479

Conference ID: 18891656

*For additional support, please press *0 and you will be connected to a live operator.*

AISC Live Webinars

AISC is a Registered Provider with The American Institute of Architects Continuing Education Systems (AIA/CES). Credit(s) earned on completion of this program will be reported to AIA/CES for AIA members. Certificates of Completion for both AIA members and non-AIA members are available upon request.

This program is registered with AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

AISC Live Webinars

Copyright Materials

Course Description

Analysis and Design of Chevron Brace Connections with Flat Bar Gussets – Part 2: Seismic Applications

April 16, 2015

Typically, chevron brace connections are detailed with one gusset plate used to connect all of the braces framing to a joint. When geometry permits, it may be more economical to provide a separate gusset for each brace. The analysis and design of chevron brace connections used in high seismic applications are presented. The force distribution through the connection and the frame beam, and detailing considerations are presented. Mechanistic load cases required by AISC 341-10 will be used in an example problem to support the discussion.

Learning Objectives

- Gain an understanding of analysis and design of chevron brace connections used in high seismic applications.
- Become familiar with force distribution through the connection and the frame beam.
- Become familiar with detailing considerations for chevron brace connections with separate flat bar gussets for each brace.
- Gain an understanding of mechanistic load cases required by AISC 341-10 through an example problem.

There's always a solution in steel.

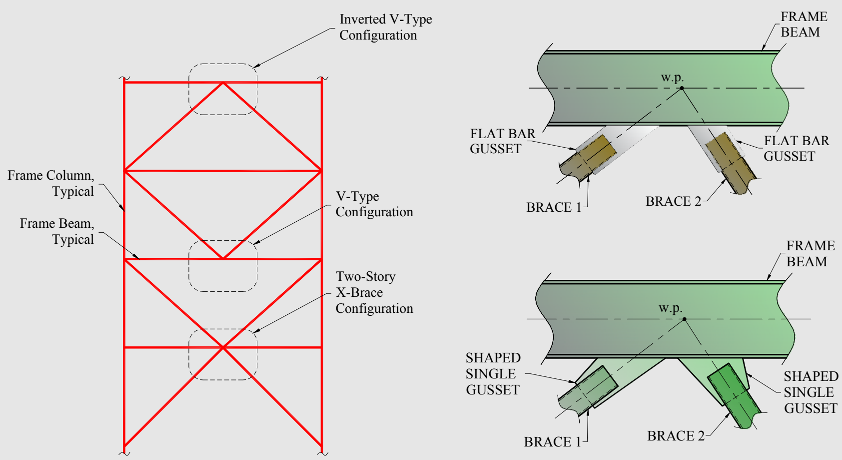
Analysis and Design of Chevron Brace Connections with Flat Bar Gussets

PART 2: Seismic Applications

written and presented by
Patrick J. Fortney, Ph.D., P.E., S.E., P.Eng
President: Cives Engineering Corporation
Chief Engineer: Cives Steel Company

CHEVRON BRACE CONNECTIONS

Use of Flat Bar and Shaped Single Gussets



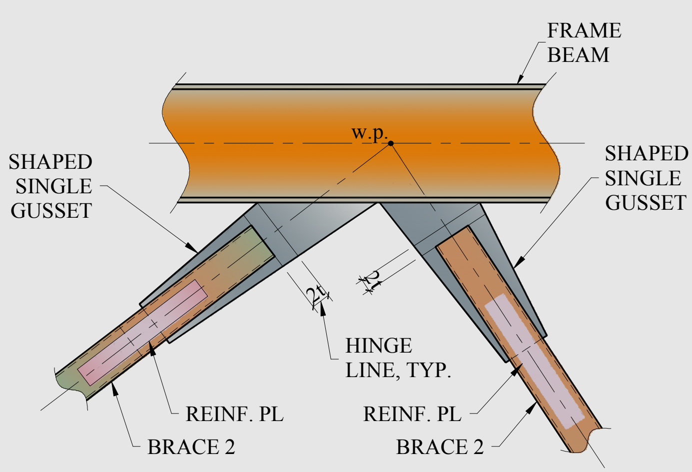
Presented by:
Patrick J. Fortney, Ph.D., P.E., S.E., P.Eng
President: Cives Engineering Corporation
Chief Engineer: Cives Steel Company

9

CHEVRON BRACE CONNECTIONS

Flat Bar and Individual Shaped Gussets

PART 2: Seismic Applications



10

AGENDA

PART 2: Seismic Applications

- ❖ Introduction
  - ➢ General Topics
    - Grade, Availability, etc
  - ➢ Seismic versus Non-Seismic
    - Brief Explanation of What's Different

11

AGENDA

PART 2: Seismic Applications

- ❖ AISC 341-10 Requirements for Braced Frame
  - ➢ Specific to Brace Connection Design relative to V-Type and Inverted V-Type configurations
    - Ordinary Concentric Braced Frames (OCBF)
      - o Strength Requirements
      - o Detailing Requirements
    - Special Concentric Braced Frames (SCBF)
      - o Strength Requirements
      - o Detailing Requirements

12

AGENDA

PART 2: Seismic Applications

- ❖ AISC 341-10 Requirements for Braced Frame
  - ➢ Some Frame Requirements
    - Gravity Loads and Braces
    - Beam Span
    - Mechanistic Analysis
- ❖ Example Problem

13

INTRODUCTION
General Topics

❖ The information provided in Part 1 relative to…

- ➢ Material grade,
- ➢ Available widths,
- ➢ Available thickness,
- ➢ Width increments, and
- ➢ Thickness increments…

…apply equally to this topic. Please refer to the information presented during Part 1 of this webinar.

14

INTRODUCTION

Seismic versus Non-Seismic

- Brace Force Distribution
  - Same as was discussed during Part 1 of this webinar
- Brace Forces
  - AISC 341 has specific connection strength requirements
    - More on this later, but specific to V-Type and Inverted V-Type configurations
    - Most required strengths are given as expected yield and tensile strengths

15

INTRODUCTION

Seismic versus Non-Seismic

- Brace Forces
  - Most required strengths are given as expected yield and tensile strengths
    - R_y is used as a correction factor to capture the expected material yield strength
    - R_t is used as a correction factor to capture the expected material tensile strength
  - Table A3.1 of AISC 341-10 tabulates R_y and R_t factors for various materials

16

INTRODUCTION

Seismic versus Non-Seismic

❖ Available Strength of Brace (when checking limit states)

A.3.2 Expected Material Strength

> When required to determine the nominal strength, R_n, for limit states within the same member from which the required strength is determined, the expected yield stress, R_yF_y, and the expected tensile strength, R_tF_u, are permitted to used in lieu of F_y and F_u, respectively.

17

AISC 341-10 Requirements for Braced Frames

❖ Specific to Brace Connection Design

- ➢ R_y is a correction factor to capture expected yield strength
- ➢ R_t is a correction factor to capture expected tensile strength

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 A1043/1043M Gr. 36 (250)	1.3	1.1
• ASTM A572/572M Gr. 50 (345) or 55 (380), ASTM A913/A913M Gr. 50 (345), 60 (415), or 65 (450), ASTM A588/A588M, ASTM A992/A992M	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 or C), ASTM A501	1.4	1.3
Pipe:		
• ASTM A53/A53M	1.6	1.2
Plates, Strips and Sheets:		
• ASTM A36/A36M	1.3	1.2
• ASTM A1043/1043M Gr. 36 (250)	1.3	1.1
• A1011/A1011M HSLAS Gr. 55 (380)	1.1	1.1
• ASTM A572/A572M Gr. 42 (290)	1.3	1.0
• ASTM A572/A572M Gr. 50 (345), Gr. 55 (380), ASTM A588/A588M	1.1	1.2
• ASTM 1043/1043M Gr. 50 (345)	1.2	1.1
Steel Reinforcement:		
• ASTM A615, ASTM A706	1.25	1.25

Hollow structural sections (HSS):		
• ASTM A500/A500M (Gr. B or C), ASTM A501	1.4	1.3
Pipe:		
• ASTM A53/A53M	1.6	1.2
• ASTM A572/A572M Gr. 50 (345), Gr. 55 (380), ASTM A588/A588M	1.1	1.2

18

INTRODUCTION

Seismic versus Non-Seismic

- Connection Geometry
  - Similar to what was discussed during Part 1 of this webinar; with the following exceptions
    - A hinge line (aka, fold line, *2t* line, etc.) must be detailed to accommodate brace buckling in an SCBF

19

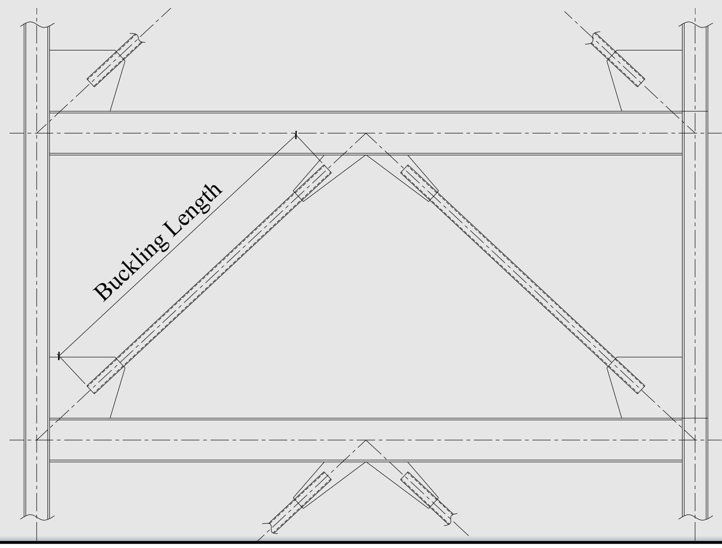
AISC 341-10 Requirements for Braced Frames

- Specific to Brace Connection Design
  - Special Concentric Braced Frames (SCBF)
    - Strength Requirements (F2.6c)
      - Brace in Tension: $R_y F_y A_g$
      - Brace in Compression (buckling strength): $(1.1)1.14F_{cre}A_g$
      - Brace in Compression (post-buckling strength): $(0.3)(1.1)1.14F_{cre}A_g$

20

AISC 341-10 Requirements for Braced Frames

When determining buckling and post-buckling brace strength for mechanism analysis and brace connection design, take brace length as:

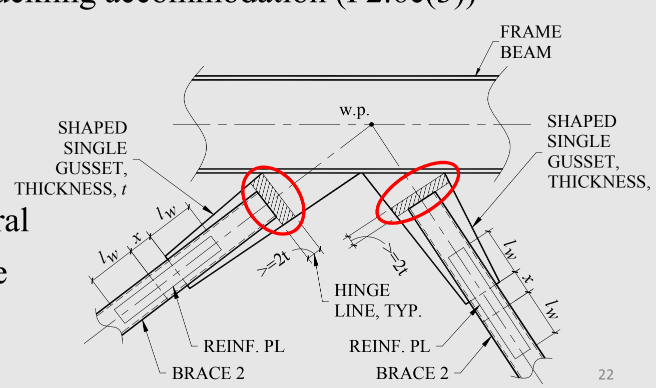


AISC 341-10 Requirements for Braced Frames

- Specific to Brace Connection Design
  - Special Concentric Braced Frames (SCBF)
    - Detailing Requirements
      - Brace buckling accommodation (F2.6c(3))

Hinge line…

…in lieu of flexural strength of brace about critical buckling axis



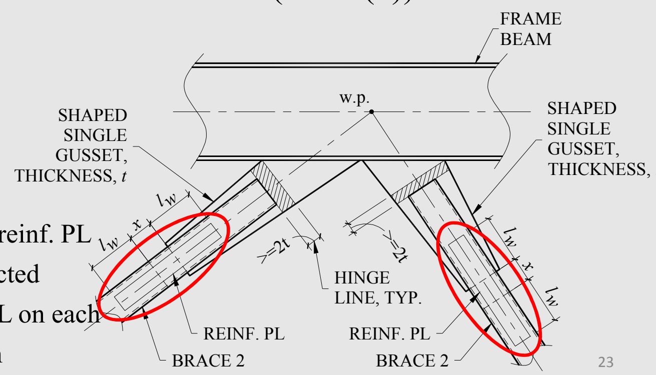
AISC 341-10 Requirements for Braced Frames

- Specific to Brace Connection Design
  - Special Concentric Braced Frames (SCBF)
    - Detailing Requirements
      - Net Section Reinforcement (F2.5b(3))

$A_e \ge A_g$

$F_{y,\mathrm{reinf}} \ge F_{y,brace}$

The connection of the reinf. PL shall develop the expected strength of the reinf. PL on each side of reduced section

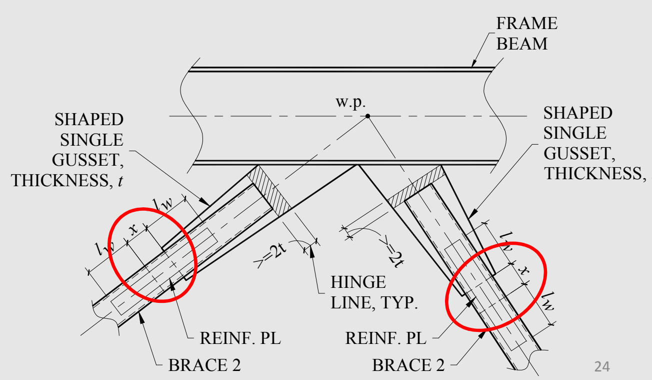


23

AISC 341-10 Requirements for Braced Frames

- Specific to Brace Connection Design
  - Special Concentric Braced Frames (SCBF)
    - Detailing Requirements

The dimension *x* in the figure represents the slot in the brace beyond the edge of the gusset. This dimension needs to be carefully considered in regard to erection.

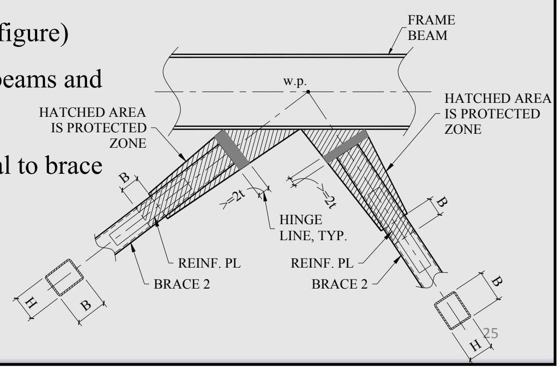


24

AISC 341-10 Requirements for Braced Frames

- ❖ Specific to Brace Connection Design
  - ➢ Special Concentric Braced Frames (SCBF)
    - ▪ Detailing Requirements
      - o Protected zones (F2.5c)

- Center ¼ of brace (not shown in figure)
- Elements that connect braces to beams and columns
- Zone adjacent to connection equal to brace depth in plane of buckling



25

AISC 341-10 Requirements for Braced Frames

- ❖ Some Frame Requirements (V-Type and Inverted V-Type)
  - ➢ Ordinary Concentric Braced Frames (OCBF)
    - ▪ Beam Analysis (F1.4a)

(1) The required strength shall be determined…assuming that the braces <u>provide no support of dead and live loads</u>…

…the seismic load effect, *E*, on the member shall be determined as follows:

26

AISC 341-10 Requirements for Braced Frames

- Some Frame Requirements (V-Type and Inverted V-Type)
  - Ordinary Concentric Braced Frames (OCBF)
    - Beam Analysis (F1.4a)

…the seismic load effect, *E*, on the member shall be determined as follows:

(i) The forces in braces in tension shall be assumed to be the least of the following:

(a) The expected tensile strength of the brace, $R_y F_y A_g$

(b) The load effect based upon the amplified seismic load (Ω_0)

(c) The maximum force that can be developed by the system

27

AISC 341-10 Requirements for Braced Frames

- Some Frame Requirements (V-Type and Inverted V-Type)
  - Ordinary Concentric Braced Frames (OCBF)
    - Beam Analysis (F1.4a)

…the seismic load effect, *E*, on the member shall be determined as follows:

(ii) The forces in braces in compression shall be assumed to be equal $0.3P_n$

28

AISC 341-10 Requirements for Braced Frames

❖ Some Frame Requirements (V-Type and Inverted V-Type)

- Special Concentric Braced Frames (SCBF)
  - Beam Analysis (F2.3)

The required strength of columns, beams…

…E_{mh}, shall be taken as the larger force determined from the following two analyses:

(i) 'Tension brace: $R_y F_y A_g$' ; compression brace: 1.14 $F_{cre} A_g$'

(ii) 'Tension brace: $R_y F_y A_g$' ; compression brace: (0.3)1.14 $F_{cre} A_g$'

29

AISC 341-10 Requirements for Braced Frames

❖ Some Frame Requirements (V-Type and Inverted V-Type)

- Special Concentric Braced Frames (SCBF)
  - Beam Analysis (F2.3)

The required strength of columns, beams…

…E_{mh}, shall be taken as the larger force determined from the following two analyses:

(i) 'Tension brace: $R_y F_y A_g$' ; compression brace: 1.14 $F_{cre} A_g$'

(ii) 'Tension brace: $R_y F_y A_g$' ; compression brace: (0.3)1.14 $F_{cre} A_g$'

<u>Note that for these analyses, the compression strengths are not multiplied by 1.1 (as they are for brace connection strength).</u>

30

AISC 341-10 Requirements for Braced Frames

- Some Frame Requirements (V-Type and Inverted V-Type)
  - Special Concentric Braced Frames (SCBF)
    - Beam Analysis (F2.3)

The required strength of columns, beams…

…E_{mh}, shall be taken as the larger force determined from the following two analyses:

(i) ‘Tension brace: $R_yF_yA_g$’ ; compression brace: 1.14 $F_{cre}A_g$’

(ii) ‘Tension brace: $R_yF_yA_g$’ ; compression brace: (0.3)1.14 $F_{cre}A_g$’

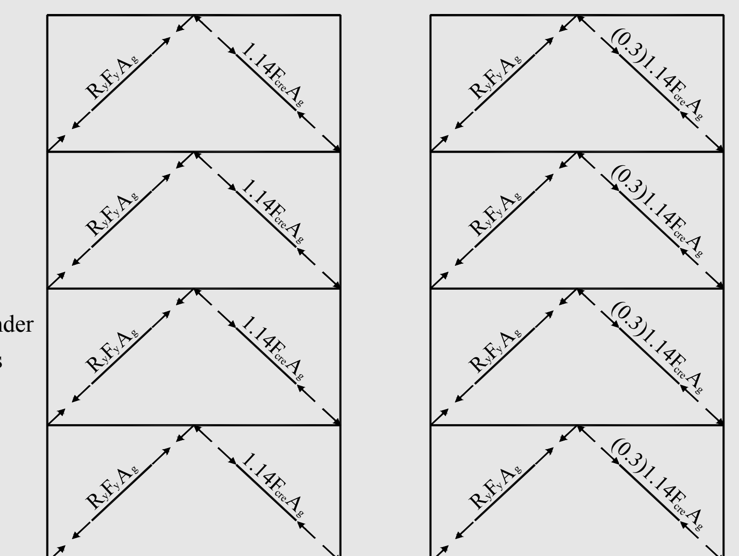
<u>This is the mechanistic analysis referred to in the Agenda!</u>

31

INTRODUCTION

Mechanistic Analyses

Columns,
Beams,
Column Splices,
Column Bases, etc.
must be evaluated under these load conditions



Buckling Strength   Post-Buckling Strength

32

AISC 341-10 Requirements for Braced Frames

- Some Frame Requirements (V-Type and Inverted V-Type)
  - Special Concentric Braced Frames (SCBF)
    - V- and Inverted V-Braced Frames (F2.4b)

Beams that are intersected by braces away from the beam-to-column connections shall satisfy the following requirements:

(1) Beams shall be continuous between columns.

33

AISC 341-10 Requirements for Braced Frames

- Some Frame Requirements (V-Type and Inverted V-Type)
  - Special Concentric Braced Frames (SCBF)
    - V- and Inverted V-Braced Frames (F2.4b)

Beams that are intersected by braces away from the beam-to-column connections shall satisfy the following requirements:

(1) Beams shall be continuous between columns.

i.e., they may not be discontinuous through the brace/beam work point

34

AISC 341-10 Requirements for Braced Frames

- Some Frame Requirements (V-Type and Inverted V-Type)
  - Special Concentric Braced Frames (SCBF)
    - V- and Inverted V-Braced Frames (F2.4b)

Beams that are intersected by braces away from the beam-to-column connections shall satisfy the following requirements:

(1) Beams shall be continuous between columns.

i.e., they may not be discontinuous through the brace/beam work point

See F4b for other requirements not specific to this webinar.

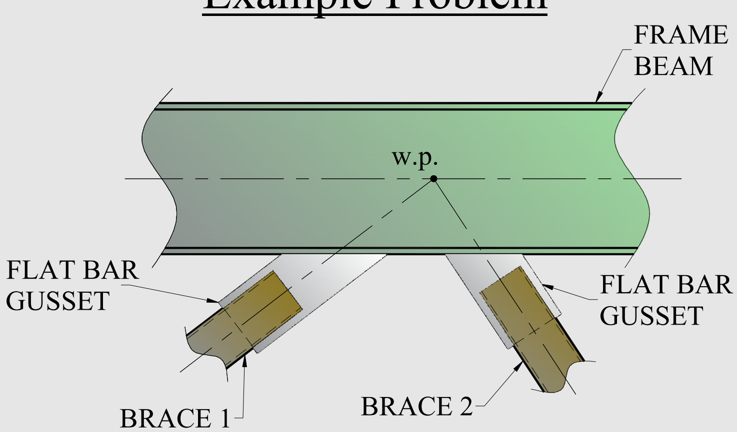
35

CHEVRON BRACE CONNECTIONS

Shaped Single Gussets

PART 2: Seismic Applications

Example Problem

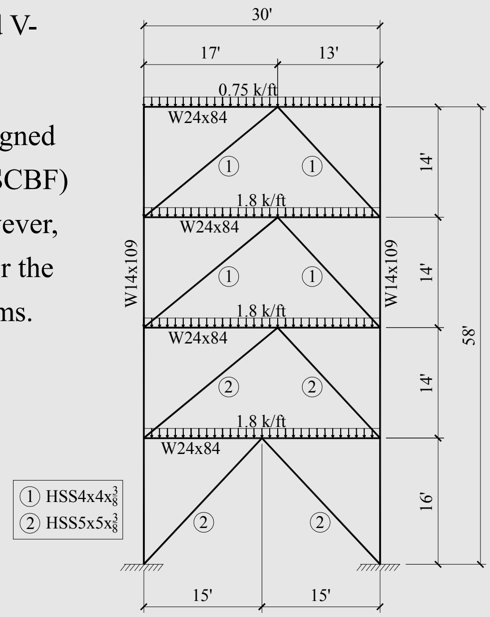


36

Example Problem

The frame elevation shows an Inverted V-type brace configuration.

This frame has been analyzed and designed as a special concentric braced frame (SCBF) in accordance with AISC 341-10. However, the beam has not yet been evaluated for the affects of the required brace mechanisms.



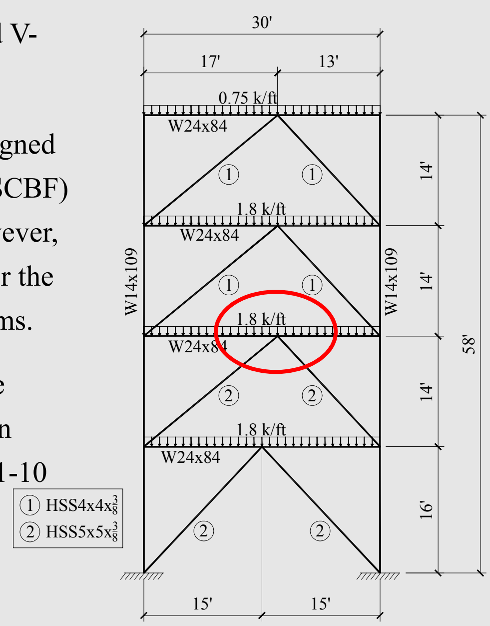
37

Example Problem

The frame elevation shows an Inverted V-type brace configuration.

This frame has been analyzed and designed as a special concentric braced frame (SCBF) in accordance with AISC 341-10. However, the beam has not yet been evaluated for the affects of the required brace mechanisms.

1. Make all the appropriate limit state checks to verify that the connection shown for Level 2 meets AISC 341-10 requirements.



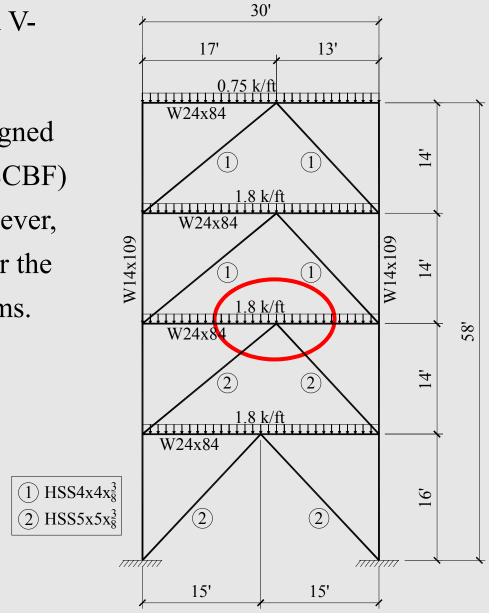
38

Example Problem

The frame elevation shows an Inverted V-type brace configuration.

This frame has been analyzed and designed as a special concentric braced frame (SCBF) in accordance with AISC 341-10. However, the beam has not yet been evaluated for the affects of the required brace mechanisms.

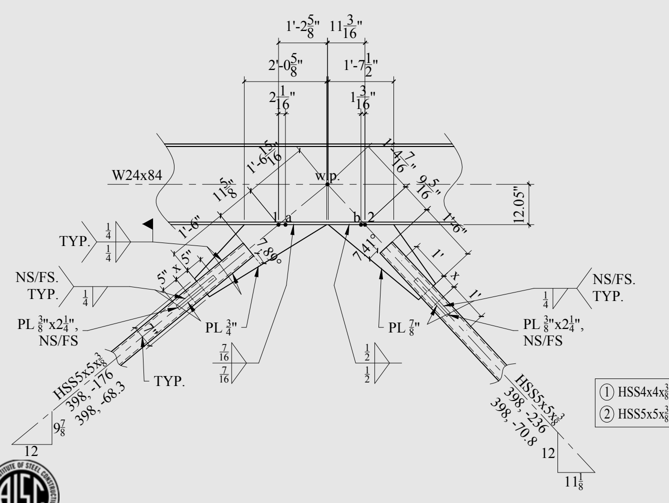
2. Evaluate the beam for the T-C load case shown

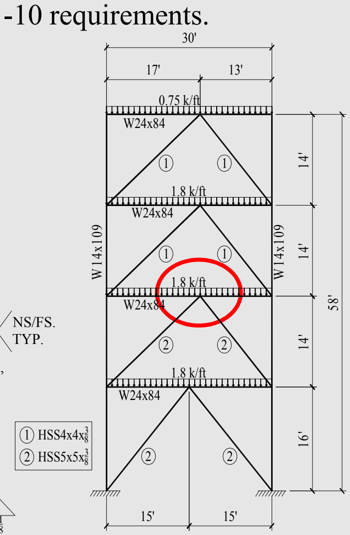


39

Example Problem

1. Make all the appropriate limit state and detailing checks to verify that the connection shown for Level 2 meets AISC 341-10 requirements.

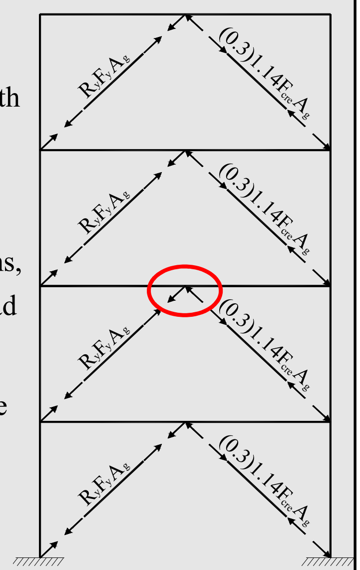




40

Example Problem

2. Evaluate the beam for the T-C load case shown
   - The T-C load case shown is:
     - Tension Brace: expected tensile strength
     - Compression Brace: expected post-buckling strength
   - Draw the beam shear and moment diagrams, for the T-C load case, including gravity load
     - Make a recommendation on beam size based on the result of the T-C load case considered.



41

Example Problem
Given

The following information is given:

<u>Material Grades</u>

- ❖ HSS shapes: A500-B
- ❖ Wide Flange shapes: A992-50
- ❖ Plate material: A572-50
- ❖ Flat bar material: A572-50

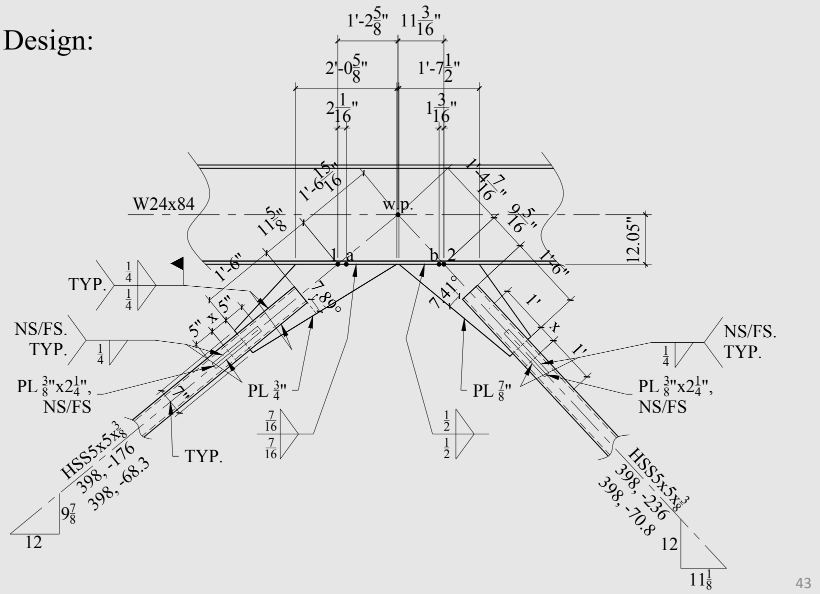
<u>Section and Material Properties</u>

W24x84	HSS5x5x3/8
$F_y = 50ksi$	$F_y = 46ksi, R_y = 1.4$
$F_u = 65ksi$	$F_u = 58ksi, R_t = 1.3$
$d = 24.1in$	$A = 6.18in^2$
$t_f = 0.770in$	$r = 1.87in$
$b_f = 9.02in$	$b/t = h/t = 11.3$
$k_{des} = 1.27in$	$t_{des} = 0.349in$
$k_1 = 1-1/16in$	workable flat = $3.3125in$

42

Example Problem
Given

Final Design:



43

Example Problem
SOLUTION

Connection Design Forces

- Brace 1 – HSS5x5x3/8

Expected Tension Strength

$$R_y F_y A_g = (1.4)(46)(6.18) = 398 kips$$

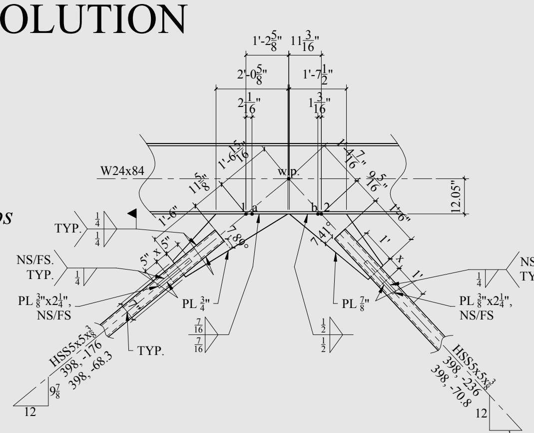
$$\theta_1 = \tan^{-1}\left(\frac{9.875}{12}\right) = 39.5^\circ$$

$$H_1 = \cos(39.5)(398) = 307 kips$$

$$V_1 = \sin(39.5)(398) = 253 kips$$

$$M_a = (307)(12.05) - (253)(14.625 - 2.0625)$$

$$M_a = 521 k - in$$



44

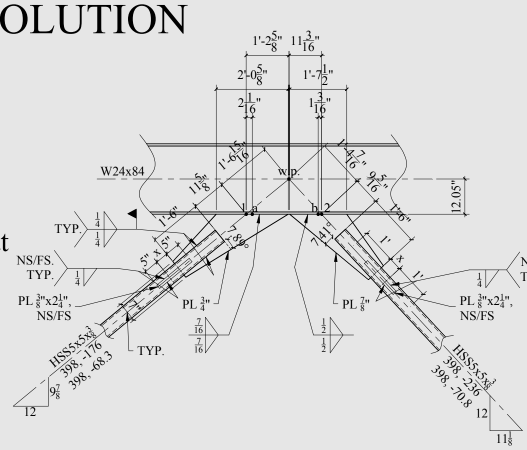
Example Problem
SOLUTION

Connection Design Forces

❖ Brace 1 – HSS5x5x3/8

Expected Buckling Strength

- Assume a 36" pull-off at opposite end of brace



$$L_{br1} = \sqrt{17^2 + 14^2} = 22.0\,ft$$

$$L_1 = (22.0)(12in/ft) - 18.9375 - 11.625 - 36.0 \Rightarrow$$

$$L_1 = 197in$$

$$\frac{KL_1}{r} = \frac{(1.0)(197)}{1.87} = 105$$

$$4.71\sqrt{\frac{29,000}{46}} = 118 > 105$$

45

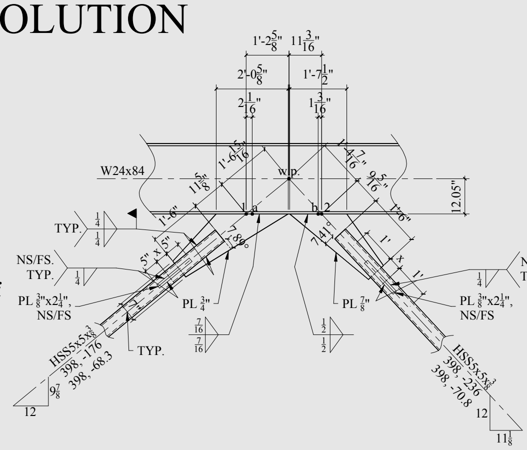
Example Problem
SOLUTION

Connection Design Forces

❖ Brace 1 – HSS5x5x3/8

$$F_e = \frac{\pi^2(29,000)}{(105)^2} = 25.9$$

$$F_{cre} = (0.658)^{\frac{(1.4)(46)}{25.9}}(1.4)(46) = 22.7ksi$$



$$1.1F_{buck} = (1.1)(1.14)F_{cre}A_g$$

$$1.1F_{buck} = (1.1)(1.14)(22.7)(6.18)$$

$$1.1F_{buck} = 176kips$$

$$H_1 = \cos(39.5)(176) = 136kips$$

$$V_1 = \sin(39.5)(176) = 112kips$$

$$M_a = (-136)(12.05) - (-112)(14.625 - 2.0625)$$

$$M_a = -232k - in$$

46

Example Problem
SOLUTION

<u>Connection Design Forces</u>

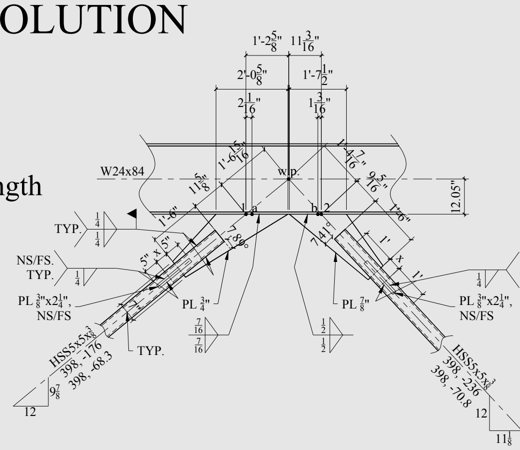
- Brace 1 – HSS5x5x3/8

Expected Post-Buckling Strength

$$1.1F_{post-buck} = (0.3)1.1F_{buck}$$
$$1.1F_{post-buck} = (0.3)(176)$$
$$1.1F_{post-buck} = 52.8kips$$

$$H_1 = \cos(39.5)(52.8) = 40.7kips$$
$$V_1 = \sin(39.5)(52.8) = 33.6kips$$

$$M_a = (-40.7)(12.05) - (-33.6)(14.625 - 2.0625)$$
$$M_a = -68.3k-in$$



47

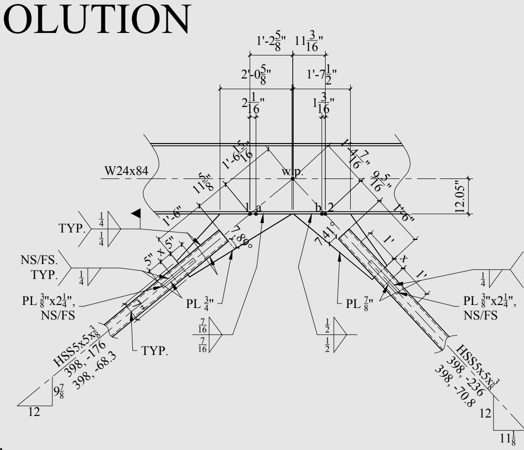
Example Problem
SOLUTION

<u>Connection Limit States</u>

- Brace 1 – HSS5x5x3/8

Brace-to-Gusset Weld

$$\phi R_w = 1.392DLn$$
$$\phi R_w = (1.392)(4)(18)(4)$$
$$\phi R_w = 401kips > 398kips \qquad \text{OK}$$



Shear Rupture of Brace Walls

$$\phi R_n = (0.75)(0.60)R_tF_u 4lt_{des}$$
$$\phi R_n = (0.75)(0.60)(1.3)(58)(4)(18)(0.349)$$
$$\phi R_n = 853kips > 398kips \qquad \text{OK}$$

48

Example Problem

SOLUTION

Connection Limit States

❖ Brace 1 – HSS5x5x3/8

Gusset Buckling

$$L_b = 11.625in$$

$$\frac{KL}{r} = \frac{(0.7)(11.625)}{0.75/\sqrt{12}} = 37.6$$

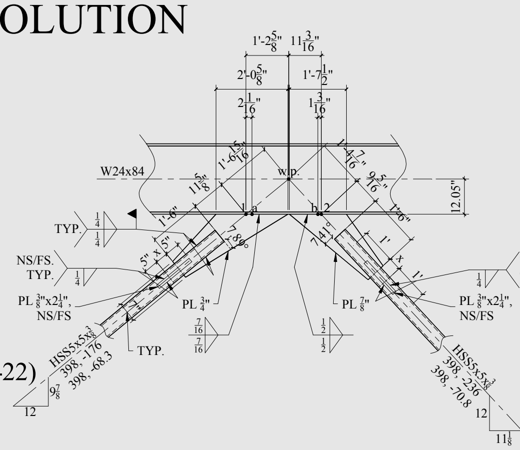
$$\phi F_{cr} = 40.5ksi \quad (\textit{Manual} \text{ Table 4-22})$$

$$W = 7 + 2\sin\theta_{s1} l_w$$

$$W = 7 + 2\sin(7.89)(18) = 11.9in$$

$$\phi P_c = (40.5)(11.9in)(0.75)$$

$$\phi P_c = 361kips > 176kips \quad \text{OK}$$



49

Example Problem

SOLUTION

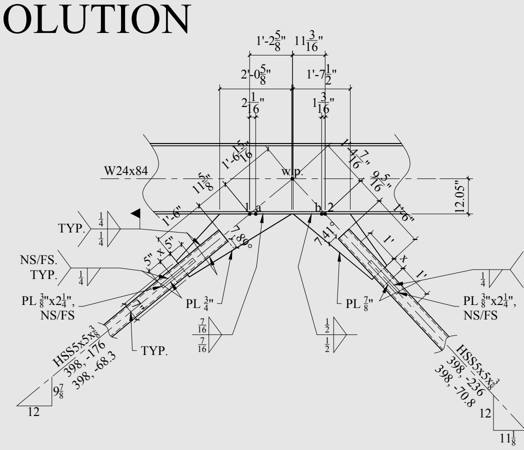
Connection Limit States

❖ Brace 1 – HSS5x5x3/8

Gusset Tension Yield

$$\phi R_n = (0.9)(50)(11.9)(0.75)$$

$$\phi R_n = 402kips > 398kips \quad \text{OK}$$



50

Example Problem

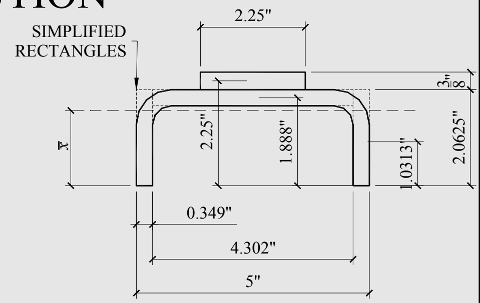
SOLUTION

Connection Limit States

❖ Brace 1 – HSS5x5x3/8

Brace Net Section Rupture

The net section is reinforced such that the net section area of the brace is equal to or greater than the brace gross area (11.6in²).



$$\therefore A_e = UA_n = U\left(A_{n,br} + 2A_r\right) \geq A_{g,br}$$

There are two reinforcing plates

51

Example Problem

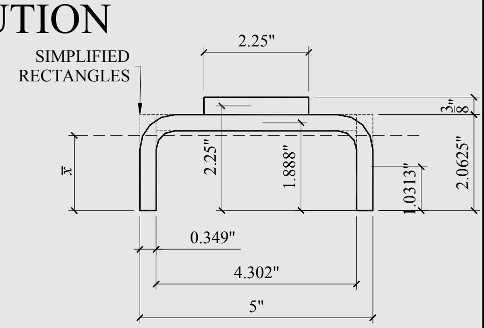
SOLUTION

Connection Limit States

❖ Brace 1 – HSS5x5x3/8

Brace Net Section Rupture

The figure shows the geometry used to calculate the shear lag factor.



$$\bar{x} = \frac{(2.25)(0.375)(2.25)+(4.302)(0.349)(1.888)+(2)(2.0625)(0.349)(1.0313)}{(2.25)(0.375)+(4.302)(0.349)+(2)(2.0625)(0.349)}$$

$$\bar{x} = 1.64in$$

$$U = 1 - \frac{\bar{x}}{l} = 1 - \frac{1.64}{18.0} = 0.909$$

52

Example Problem

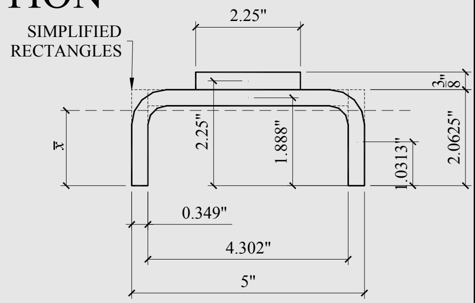
SOLUTION

Connection Limit States

- Brace 1 – HSS5x5x3/8

Brace Net Section Rupture

The figure shows the geometry used to calculate the shear lag factor.



$$A_{n,br} = 6.18 - (2)(0.375)(0.75 + 0.125) = 5.52 in^2$$

$$A_r = (2.25)(0.375) = 0.844 in^2$$

$$A_e = (0.909)\left[5.52 + (2)(0.844)\right]$$

$$A_e = 6.55 in^2 > 6.18 in^2 \qquad \text{OK}$$

53

Example Problem

SOLUTION

Connection Limit States

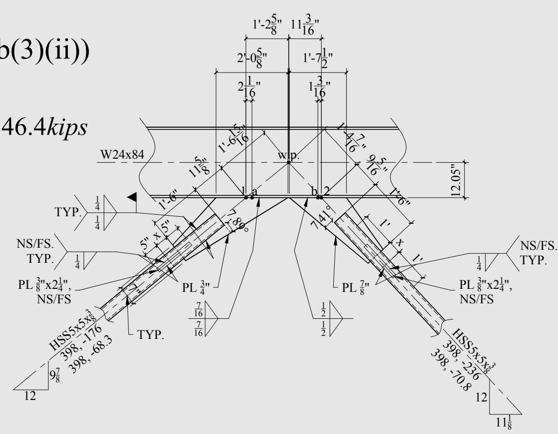
- Brace 1 – HSS5x5x3/8

Reinforcing Plate Weld (F2.5b(3)(ii))

$$R_y F_y A_r = (1.1)(50)(2.25)(0.375) = 46.4 kips$$

$$\phi R_w = (1.392)(2)(4)(5)$$

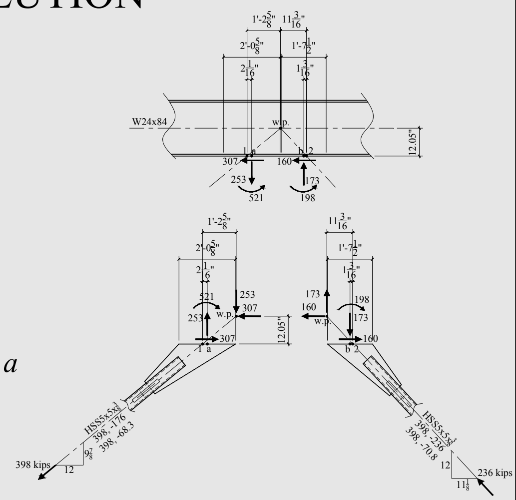
$$\phi R_w = 55.6 kips > 46.4 kips \qquad \text{OK}$$



54

Example Problem

SOLUTION



Connection Limit States

❖ Brace 1 – HSS5x5x3/8

Gusset Shear Yield on Section *a*

$$\phi R_n = (1.0)0.6F_y x_1 t_g$$
$$\phi R_n = (1.0)(0.6)(50)(24.625)(0.75)$$
$$\phi R_n = 554 kips > 307 kips \quad \text{OK}$$

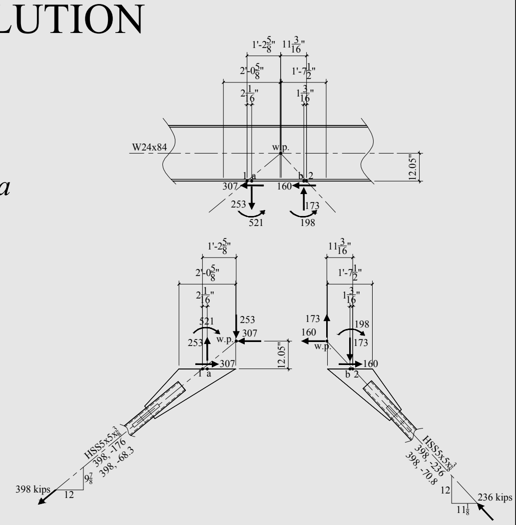
Gusset Shear Rupture on Section *a*

$$\phi R_n = (0.75)0.6F_u x_1 t_g$$
$$\phi R_n = (0.75)(0.6)(65)(24.625)(0.75)$$
$$\phi R_n = 540 kips > 307 kips \quad \text{OK}$$

55

Example Problem

SOLUTION



Connection Limit States

❖ Brace 1 – HSS5x5x3/8

Gusset Tension Yield on Section *a*

$$\phi R_n = (0.9)F_y x_1 t_g$$
$$\phi R_n = (0.9)(50)(24.625)(0.75)$$
$$\phi R_n = 831 kips > 253 kips \quad \text{OK}$$

56

Example Problem

SOLUTION

Connection Limit States

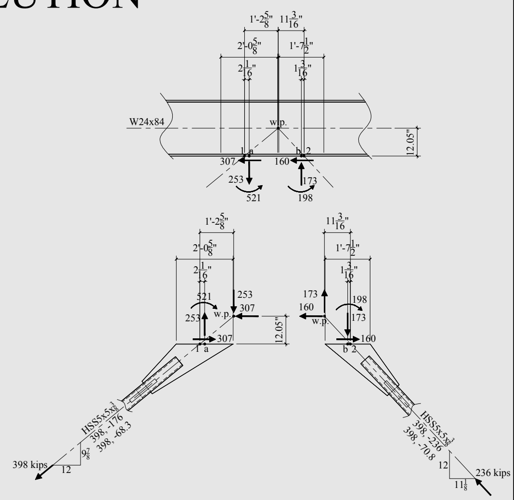
❖ Brace 1 – HSS5x5x3/8

Gusset Bending on Section *a*

$$\phi M_n = (0.9)F_y Z_a$$

$$\phi M_n = \frac{(0.9)(50)(0.75)(24.625)^2}{4}$$

$$\phi M_n = 5{,}116k-in > 521k-in \quad \text{OK}$$



57

Example Problem

SOLUTION

Connection Limit States

❖ Brace 1 – HSS5x5x3/8

Gusset-to-Beam Weld at Section *a*

$$V_a = 307kips$$

$$N_a = 253kips$$

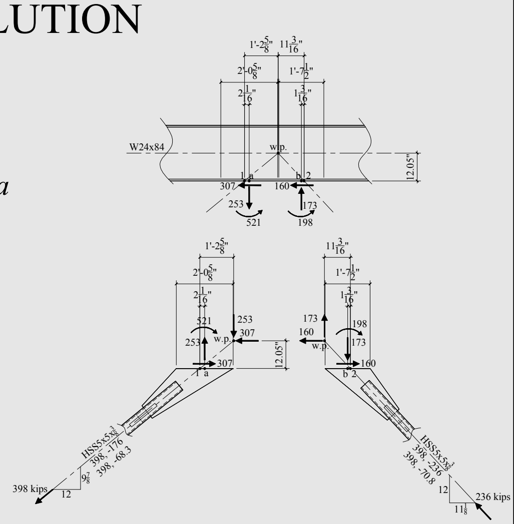
$$M_a = 521k-in$$

$$N_{eq} = 253 + \frac{(4)(521)}{24.625} = 338kips$$

$$R = \sqrt{338^2 + 307^2} = 457kips$$

$$\theta = \tan^{-1}\left(\frac{338}{307}\right) = 47.8^\circ$$

$$\mu = 1 + .05\sin^{1.5}(47.8) = 1.32$$



58

Example Problem

SOLUTION

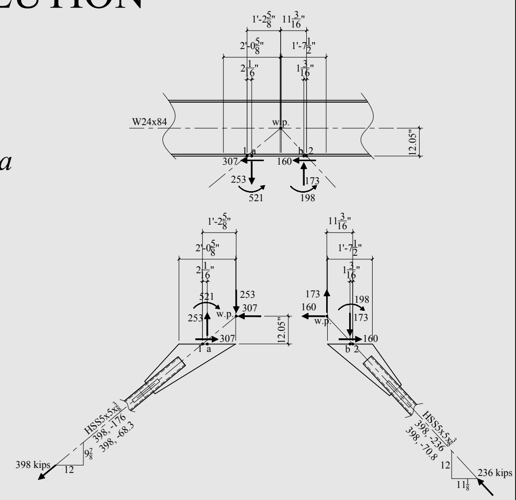
Connection Limit States

❖ Brace 1 – HSS5x5x3/8

Gusset-to-Beam Weld at Section *a*

$$\phi R_w = \frac{(1.392)(2)(7)(24.625)(1.32)}{1.25}$$

$$\phi R_w = 507kips > 457kips \qquad \text{OK}$$



59

Example Problem

SOLUTION

Connection Design Forces

❖ Brace 2 – HSS5x5x3/8

Expected Tension Strength

$$R_y F_y A_g = (1.4)(46)(6.18) = 398kips$$

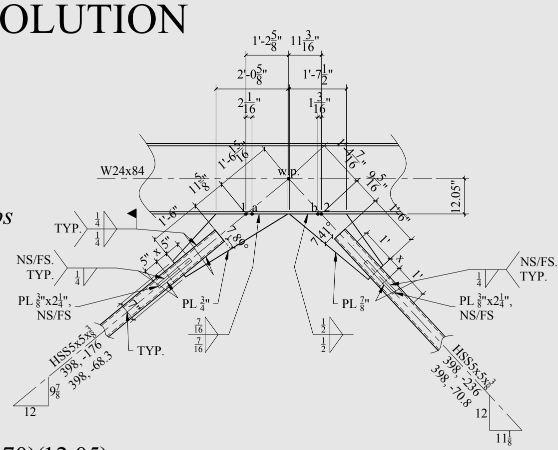
$$\theta_2 = \tan^{-1}\left(\frac{12}{11.125}\right) = 47.2^{\circ}$$

$$H_2 = \cos(47.2)(398) = 270kips$$

$$V_2 = \sin(47.2)(398) = 292kips$$

$$M_b = (292)(11.1875 - 1.1875) - (270)(12.05)$$

$$M_b = -334k - in$$



60

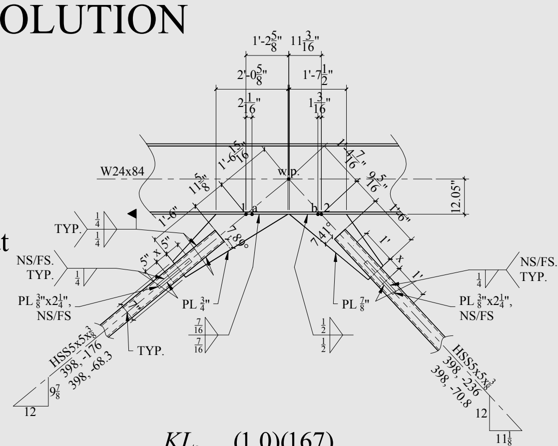
Example Problem
SOLUTION

Connection Design Forces

❖ Brace 2 – HSS5x5x3/8

Expected Buckling Strength

- Assume a 36" pull-off at opposite end of brace



$$L_{br2} = \sqrt{13^2 + 14^2} = 19.1 ft$$

$$L_2 = (19.1.0)(12 in/ft) - 16.4375 - 9.3125 - 36.0 \Rightarrow$$

$$L_2 = 167 in$$

$$\frac{KL_2}{r} = \frac{(1.0)(167)}{1.87} = 89.3$$

$$4.71\sqrt{\frac{29,000}{46}} = 118 > 89.3$$

61

Example Problem
SOLUTION

Connection Design Forces

❖ Brace 2 – HSS5x5x3/8

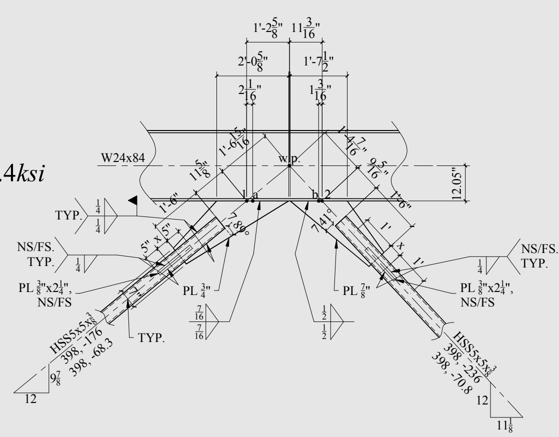
$$F_e = \frac{\pi^2 (29,000)}{(89.3)^2} = 35.9$$

$$F_{cre} = (0.658)^{\frac{(1.4)(46)}{35.9}} (1.4)(46) = 30.4 ksi$$

$$1.1F_{buck} = (1.1)(1.14) F_{cre} A_g$$

$$1.1F_{buck} = (1.1)(1.14)(30.4)(6.18)$$

$$1.1F_{buck} = 236 kips$$



$$H_2 = \cos(47.2)(236) = 160 kips$$

$$V_2 = \sin(47.2)(236) = 173 kips$$

$$M_b = (-173)(11.1875 - 1.1875) - (-160)(12.05)$$

$$M_b = 198 k-in$$

62

Example Problem
SOLUTION

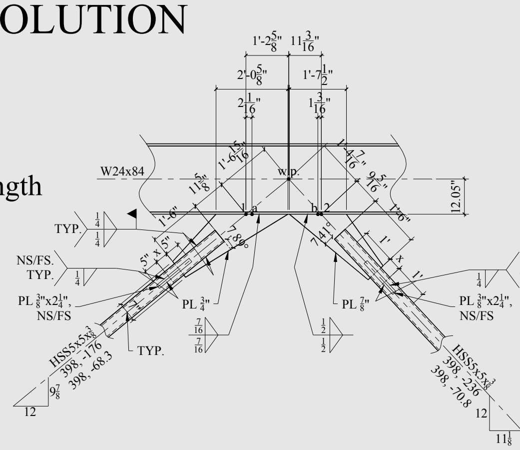
Connection Design Forces

❖ Brace 2 – HSS5x5x3/8

Expected Post-Buckling Strength

$$1.1F_{post-buck} = 0.3\left(1.1F_{buck}\right)$$
$$1.1F_{post-buck} = (0.3)(236)$$
$$1.1F_{post-buck} = 70.8kips$$

$$H_2 = \cos(47.2)(70.8) = 48.1kips$$
$$V_2 = \sin(47.2)(70.8) = 51.9kips$$



$$M_b = (-51.9)(11.1875 - 1.1875) - (-48.1)(12.05)$$
$$M_b = 60.6k - in$$

63

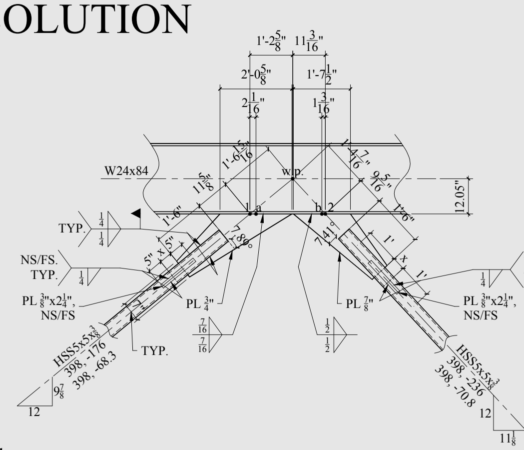
Example Problem
SOLUTION

Connection Limit States

❖ Brace 2 – HSS5x5x3/8

Brace-to-Gusset Weld

$$\phi R_w = 1.392DLn$$
$$\phi R_w = (1.392)(4)(18)(4)$$
$$\phi R_w = 401kips > 398kips \qquad \text{OK}$$



Shear Rupture of Brace Walls

$$\phi R_n = (0.75)(0.60)R_t F_u 4lt_{des}$$
$$\phi R_n = (0.75)(0.60)(1.3)(58)(4)(18)(0.349)$$
$$\phi R_n = 853kips > 398kips \qquad \text{OK}$$

64

Example Problem

SOLUTION

Connection Limit States

❖ Brace 2 – HSS5x5x3/8

Gusset Buckling

$L_b = 9.3125in$

$$\frac{KL}{r} = \frac{(0.7)(9.3125)}{0.875/\sqrt{12}} = 25.8$$

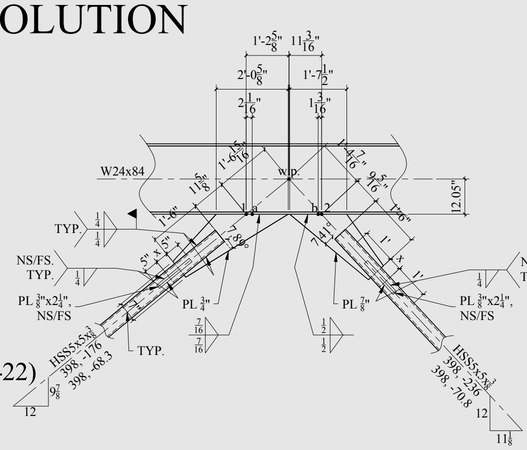
$\phi F_{cr} = 42.8ksi$ (*Manual* Table 4-22)

$W = 7 + 2\sin\theta_{s1} l_w$

$W = 7 + 2\sin(7.41)(18) = 11.6in$

$\phi P_c = (42.8)(11.6in)(0.875)$

$\phi P_c = 434kips > 236kips$ OK



65

Example Problem

SOLUTION

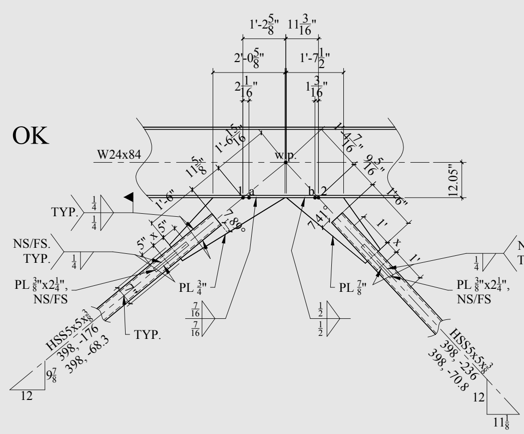
Connection Limit States

❖ Brace 2 – HSS5x5x3/8

Gusset Tension Yield

$\phi R_n = (0.9)(50)(11.6)(0.875)$

$\phi R_n = 456kips > 398kips$ OK



66

Example Problem

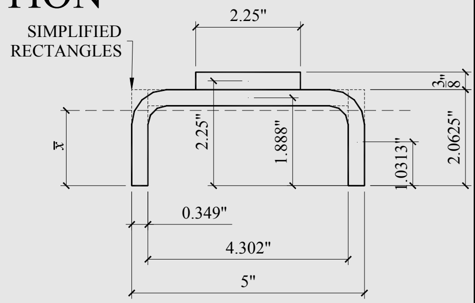
SOLUTION

Connection Limit States

❖ Brace 2 – HSS5x5x3/8

Brace Net Section Rupture

The net section is reinforced such that the net section area of the brace is equal to or greater than the brace gross area ($11.6in^2$).



$$\therefore A_e = UA_n = U\left(A_{n,br} + 2A_r\right) \geq A_{g,br}$$

There are two reinforcing plates

Example Problem

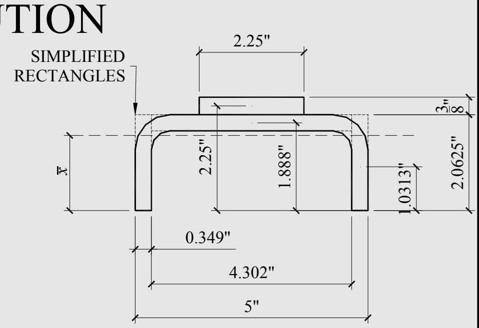
SOLUTION

Connection Limit States

❖ Brace 2 – HSS5x5x3/8

Brace Net Section Rupture

The figure shows the geometry used to calculate the shear lag factor.



$$\bar{x} = \frac{(2.25)(0.375)(2.25)+(4.302)(0.349)(1.888)+(2)(2.0625)(0.349)(1.0313)}{(2.25)(0.375)+(4.302)(0.349)+(2)(2.0625)(0.349)}$$

$$\bar{x} = 1.64in$$

$$U = 1-\frac{\bar{x}}{l} = 1-\frac{1.64}{18.0} = 0.909$$

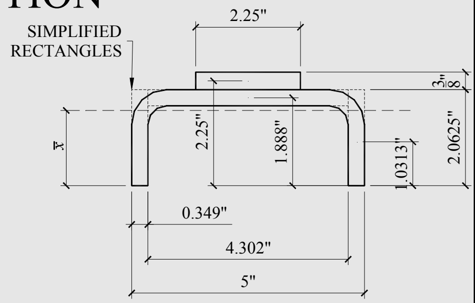
Example Problem
SOLUTION

Connection Limit States

❖ Brace 2 – HSS5x5x3/8

Brace Net Section Rupture

The figure shows the geometry used to calculate the shear lag factor.



$$A_{n,br} = 6.18 - (2)(0.375)(0.75 + 0.125) = 5.52 in^2$$
$$A_r = (2.25)(0.375) = 0.844 in^2$$
$$A_e = (0.909)\left[5.52 + (2)(0.844)\right]$$
$$A_e = 6.55 in^2 > 6.18 in^2 \quad \text{OK}$$

69

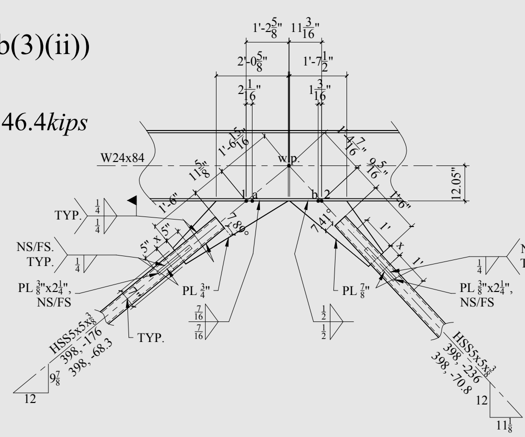
Example Problem
SOLUTION

Connection Limit States

❖ Brace 2 – HSS5x5x3/8

Reinforcing Plate Weld (F2.5b(3)(ii))

$$R_y F_y A_r = (1.1)(50)(2.25)(0.375) = 46.4 kips$$
$$\phi R_w = (1.392)(2)(4)(5)$$
$$\phi R_w = 55.6 kips > 46.4 kips \quad \text{OK}$$



70

Example Problem
SOLUTION

Connection Limit States

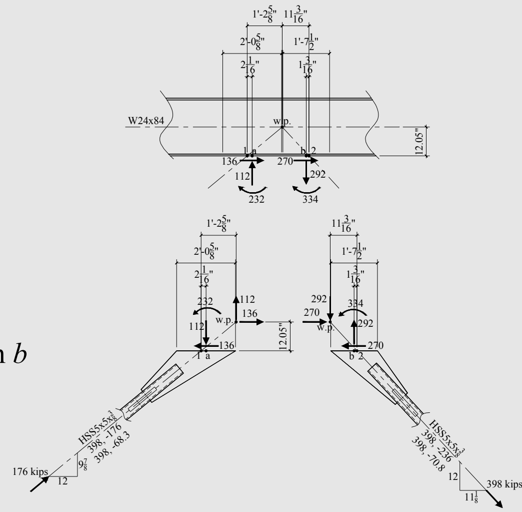
❖ Brace 2 – HSS5x5x3/8

Gusset Shear Yield on Section *b*

$$\phi R_n = (1.0)0.6F_y x_2 t_g$$
$$\phi R_n = (1.0)(0.6)(50)(19.5)(0.875)$$
$$\phi R_n = 512kips > 270kips \quad \text{OK}$$

Gusset Shear Rupture on Section *b*

$$\phi R_n = (0.75)0.6F_u x_1 t_g$$
$$\phi R_n = (0.75)(0.6)(65)(19.5)(0.875)$$
$$\phi R_n = 499kips > 270kips \quad \text{OK}$$



71

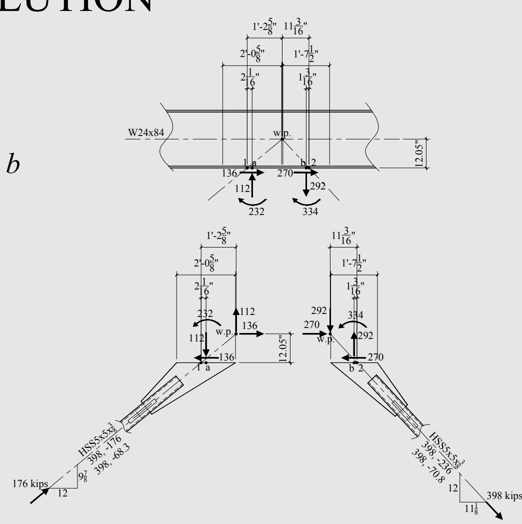
Example Problem
SOLUTION

Connection Limit States

❖ Brace 2 – HSS5x5x3/8

Gusset Tension Yield on Section *b*

$$\phi R_n = (0.9)F_y x_2 t_g$$
$$\phi R_n = (0.9)(50)(19.5)(0.875)$$
$$\phi R_n = 768kips > 292kips \quad \text{OK}$$



72

Example Problem

SOLUTION

Connection Limit States

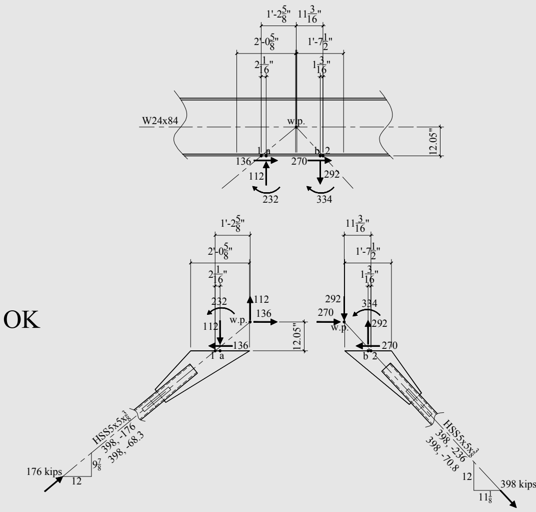
- Brace 2 – HSS5x5x3/8

  Gusset Bending on Section *b*

$$\phi M_n = (0.9)F_y Z_a$$

$$\phi M_n = \frac{(0.9)(50)(0.875)(19.5)^2}{4}$$

$$\phi M_n = 3,743k-in > 334k-in \quad \text{OK}$$



73

Example Problem

SOLUTION

Connection Limit States

- Brace 2 – HSS5x5x3/8

  Gusset-to-Beam Weld at Section *b*

$$V_b = 270kips$$

$$N_b = 292kips$$

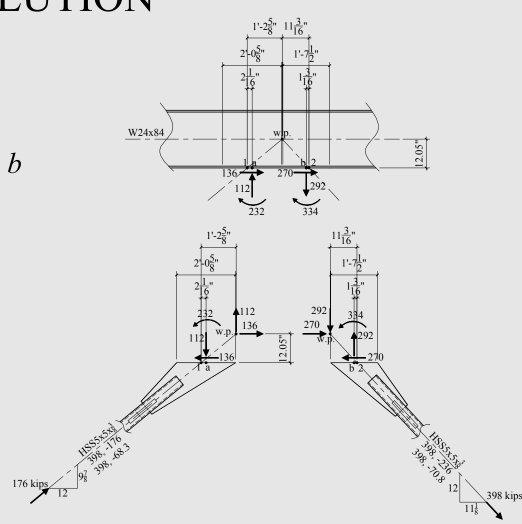
$$M_a = 334k-in$$

$$N_{eq} = 292 + \frac{(4)(334)}{19.5} = 361kips$$

$$R = \sqrt{361^2 + 270^2} = 451kips$$

$$\theta = \tan^{-1}\left(\frac{361}{270}\right) = 53.2^\circ$$

$$\mu = 1 + .05\sin^{1.5}(53.2) = 1.36$$



74

Example Problem
SOLUTION

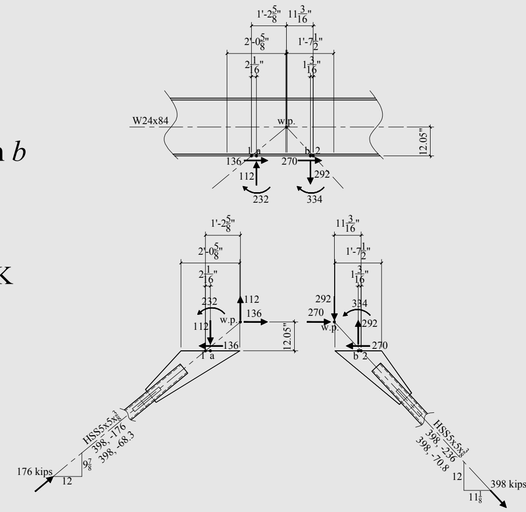
<u>Connection Limit States</u>

❖ Brace 2 – HSS5x5x3/8

Gusset-to-Beam Weld at Section *b*

$$\phi R_w = \frac{(1.392)(2)(8)(19.5)(1.36)}{1.25}$$

$$\phi R_w = 472kips > 451kips \quad \text{OK}$$

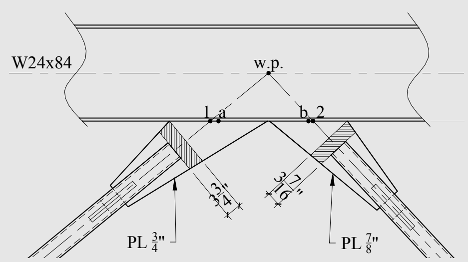


75

Example Problem
SOLUTION

<u>Brace Buckling Accommodation</u>

❖ The "2*t* Hinge Line"



➢ Brace 1 Gusset

Clearance Required $\geq (2)(0.75) = 1.5in$

Clearance Provided $3.75in >= 1.5in$ OK

➢ Brace 2 Gusset

Clearance Required $\geq (2)(0.875) = 1.75in$

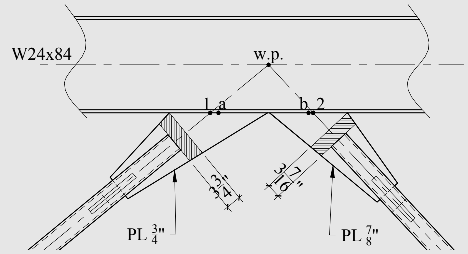
Clearance Provided $3.44in >= 1.75in$ OK

76

Example Problem
SOLUTION

Brace Buckling Accommodation

- ❖ The "2*t* Hinge Line"

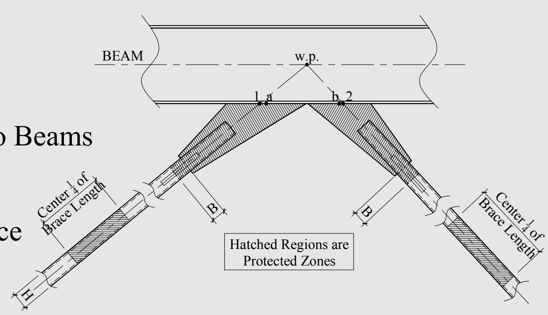


- ➢ 2 times the plate thickness (2*t*) really should be thought of as the minimum clearance. To allow for fabrication and erection tolerances, it's a good idea to provide a pull-off that will allow for these tolerances.

77

Example Problem
SOLUTION

Protected Zones

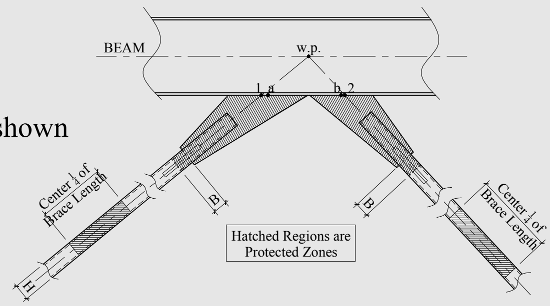


- ❖ Elements Connecting Braces to Beams and Columns
- ❖ Center One-Quarter of the Brace Length
- ❖ Zones Adjacent to Each Connection Equal to the Brace Depth in the Plane of Buckling

78

Example Problem
SOLUTION

Protected Zones



- These areas should be clearly shown on:
  - Structural Drawings
  - Engineering Sketches
  - Shop Drawings
  - Erection Drawings

79

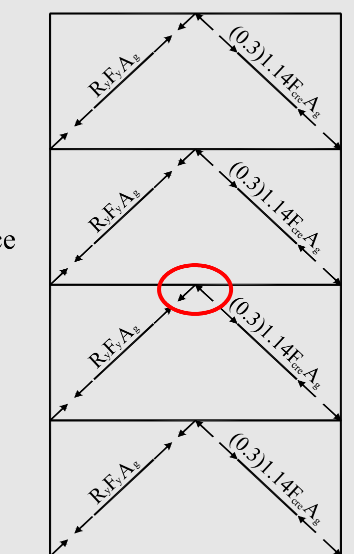
Example Problem
SOLUTION

- Beam Loading
  - Recall that we are asked to evaluate appropriate beam limit states for the load case shown to the right
  - To do this, we need to calculate the interface forces, as follows
    - Tension Brace (Brace 1)

      $P_T = R_y F_y A_g$

    - Compression Brace (Brace 2)

      $P_c = P_{post-buck} = 1.14 F_{cre} A_g$



80

Example Problem
SOLUTION

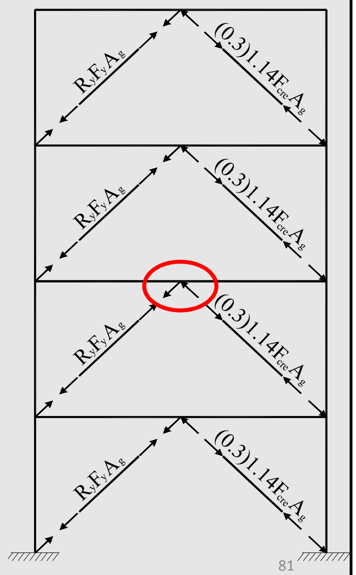
- Beam Loading
  - To do this, we need to calculate the interface forces, as follows
    - Tension Brace (Brace 1)

      $P_T = R_y F_y A_g$
    - Compression Brace (Brace 2)

      $P_c = P_{post-buck} = 1.14 F_{cre} A_g$

We'll use the component forces are calculated for the connection design…

…Note that for the compression forces, we will divide by 1.1 (no 1.1 increase for beam analysis)



81

Example Problem
SOLUTION

- Beam Loading
  - Tension Brace Force Components
    - Brace 1 – HSS5x5x3/8

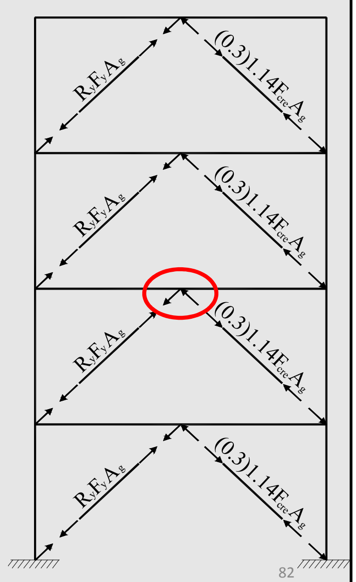
      Expected Tension Strength

      $R_y F_y A_g = (1.4)(46)(6.18) = 398 kips$

      $\theta_1 = \tan^{-1}\left(\frac{9.875}{12}\right) = 39.5^\circ$

      $H_1 = \cos(39.5)(398) = 307 kips$

      $V_1 = \sin(39.5)(398) = 253 kips$



82

Example Problem
SOLUTION

- ❖ Beam Loading
  - ➢ Tension Brace Force Components
    - • Brace 1 – HSS5x5x3/8

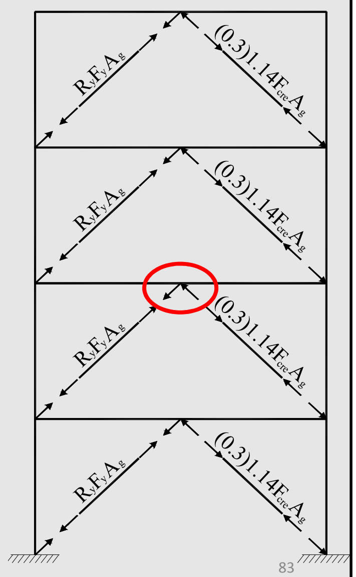
Expected Tension Strength

$$R_y F_y A_g = (1.4)(46)(6.18) = 398 kips$$

$$M_a = H_1 e_b - V_1 \left(L_1 - \Delta_1 \right)$$

$$M_a = (307)(12.05) - (253)(14.625 - 2.0625)$$

$$M_a = 521 k - in$$



83

Example Problem
SOLUTION

- ❖ Beam Loading
  - ➢ Compression Brace Force Components
    - • Brace 2 – HSS5x5x3/8

Expected Post-Buckling Strength

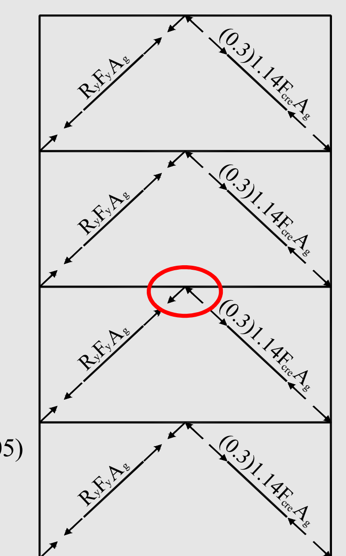
$$H_2 = {}^{48.1kips}\!/_{1.1} = 43.7kips$$

$$V_2 = {}^{51.9kips}\!/_{1.1} = 47.2kips$$

$$M_b = V_2 \left(L_2 - \Delta_2 \right) - H_2 e_b$$

$$M_b = (-47.2)(11.1875 - 1.1875) - (-43.7)(12.05)$$

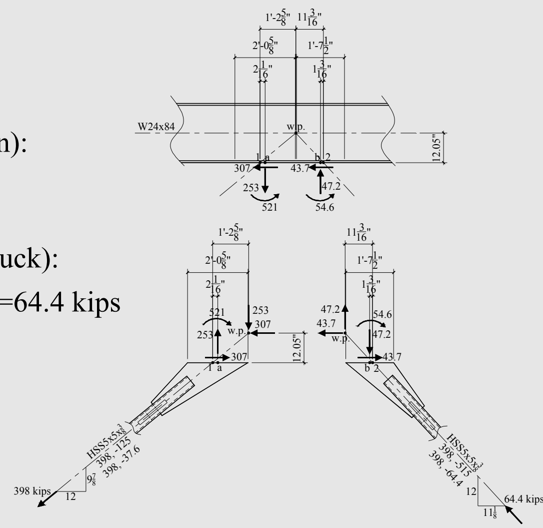
$$M_b = 54.6k - in$$



84

Example Problem
SOLUTION

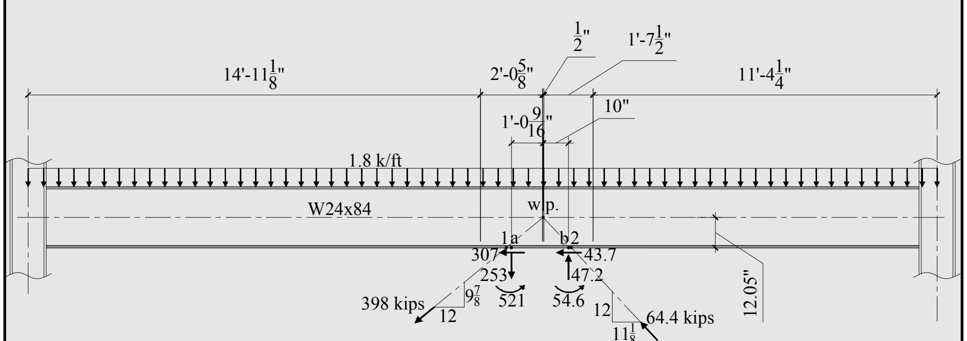
- Beam Loading
  - T-C Load Case
    - Brace 1 (expected tension): $R_y F_y A_g$=398 kips
    - Brace 2 (expected post-buck): $(0.3)1.14F_{cre}A_g$=70.8/1.1=64.4 kips



85

Example Problem
SOLUTION

Thus, the resultant and uniformly distributed loads acting on the beam are shown in the figures below



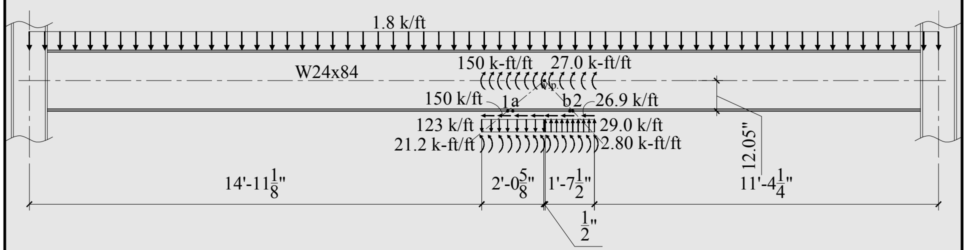
Resultant Loads Acting on Beam

86

Example Problem

SOLUTION

Thus, the resultant and uniformly distributed loads acting on the beam are shown in the figures below

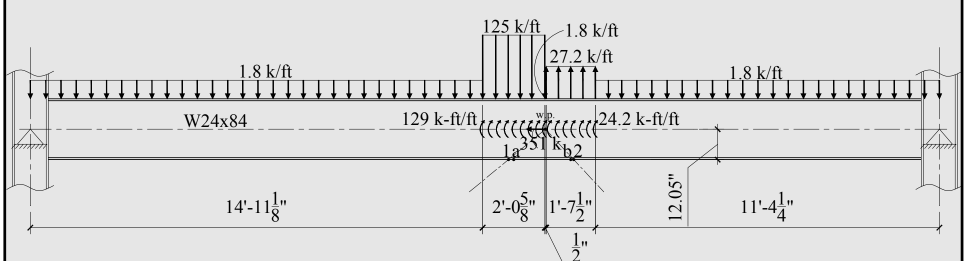


Uniformly Distributed Loads Acting on Beam

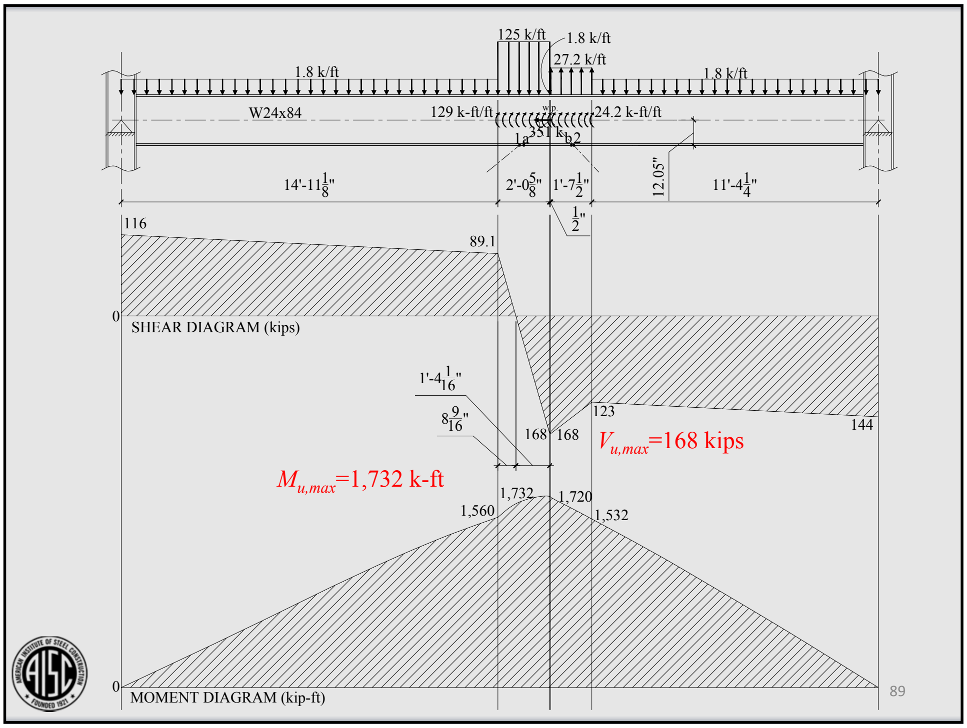
Example Problem

SOLUTION

Thus, the resultant and uniformly distributed loads acting on the beam are shown in the figures below



Equivalent Uniformly Distributed Loads Acting on Beam



Example Problem

SOLUTION

Beam Limit States

❖ Bending

$\phi M_n = 840k - ft$ (*Manual* Table 3-6)

$M_u = 1,732k - ft < \phi M_n = 840k - ft$ N.G.

❖ Shear

$\phi V_n = 340k$ (*Manual* Table 3-6)

$V_u = 168k < \phi V_n = 340k$ OK

90

Example Problem

SOLUTION

Beam Limit States

❖ Bending

$\phi M_n = 840k - ft$ (*Manual* Table 3-6)

$M_u = 1,732k - ft < \phi M_n = 840k - ft$ N.G.

❖ Shear

$\phi V_n = 340k$ (*Manual* Table 3-6)

$V_u = 168k < \phi V_n = 340k$ OK

- Beam size needs to be increased to satisfy required moment.
- We'll go ahead and check local limit states first, then make a recommendation for the final beam size.

91

Example Problem

SOLUTION

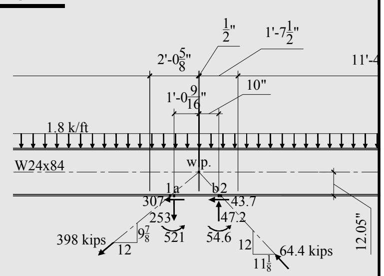
Beam Limit States

❖ Web Local Yielding

$\phi R_n = \phi F_{yw} t_w \left(5k + l_b\right)$

$\phi R_n = (1.00)(50)(0.470)\left[(5)(1.27) + 11.625\right]$

$\phi R_n = 422k > 253k$ OK

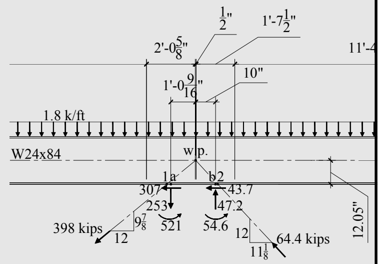


92

Example Problem

SOLUTION

Beam Limit States



❖ Web Local Crippling

$$\phi R_n = \phi 0.80 t_w^2 \left[1 + 3\left(\frac{l_b}{d}\right)\left(\frac{t_w}{t_f}\right)^{1.5}\right]\sqrt{\frac{EF_{yw}t_f}{t_w}}$$

$$\phi R_n = (0.75)(0.80)(0.47)^2 \left[1 + 3\left(\frac{11.625}{24.1}\right)\left(\frac{0.47}{0.77}\right)^{1.5}\right]\sqrt{\frac{(29,000)(50)(0.77)}{0.47}}$$

$\phi R_n = 314k > 47.2k$ OK

93

Example Problem

SOLUTION

Beam Limit States

❖ Back to Bending

$\phi M_n = 840k - ft$ (*Manual* Table 3-6)

$M_u = 1,732k - ft < \phi M_n = 840k - ft$ N.G.

- A plastic section modulus greater than or equal to $462 in^3$ is required to resist the design maximum moment of 1,732*k-ft*.

94

Example Problem

SOLUTION

Beam Limit States

❖ Back to Bending

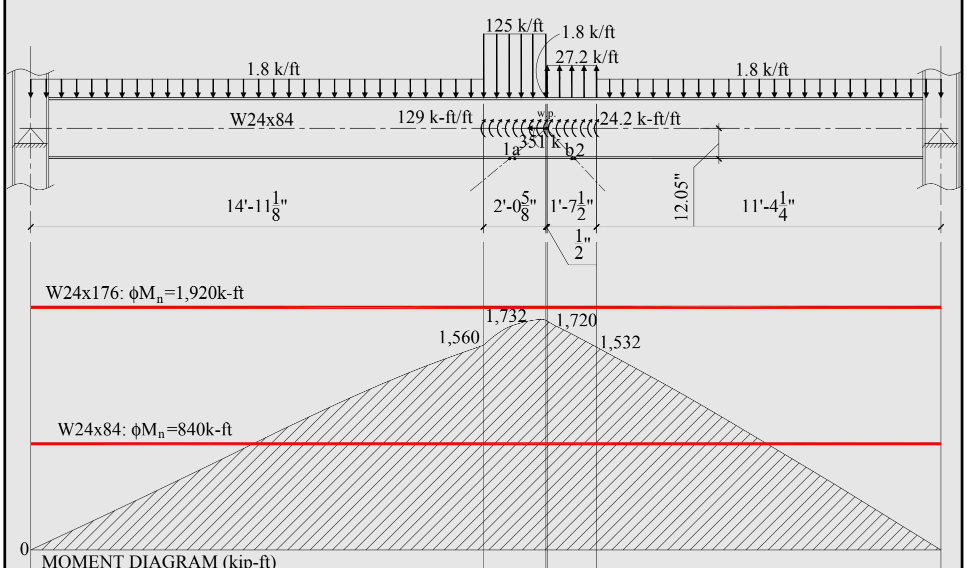
$\phi M_n = 840k - ft$ (*Manual* Table 3-6)

$M_u = 1{,}732k - ft < \phi M_n = 840k - ft$ N.G.

- A W24x176 has a plastic section modulus equal 511*in³* which is greater the required 462*in³*.
  - The W24x176 is 25.2*in* deep; 1.1*in* deeper than the W24x84 (d=24.1*in*), giving an increase in e_b equal to 0.55*in*. This would create modest changes in force distributions, pull-offs, and beam shear and moment.

95

Example Problem

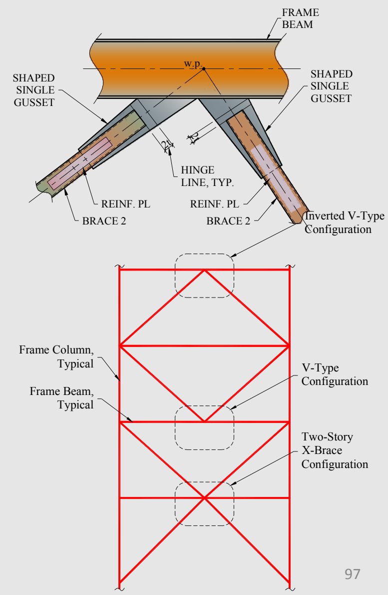


96

CHEVRON BRACE CONNECTIONS

Flat Bar and Individual Shaped Gussets

PART 2: Seismic Applications



This Concludes Part 2

Questions?
Comments

97

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!

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.

www.aisc.org/nightschool

Class begins April 27, 2015

AISC Night School

Design of Composite Floor Systems in Steel Framed Buildings

Presented by W. Samuel Easterling, PhD, P.E., William P. Jacobs V, P.E., S.E., and Thomas M. Murray, PhD, P.E.

Monday nights 7:00 p.m. Eastern Time
(90 minutes each)

4/27, 5/4, 5/11, 5/18, 6/1, 6/8, 6/22 & 6/29

- Fundamentals of economical steel-framed floor systems
- Behavior and design of composite slabs, beams, and girders
- Composite beam stiffness for drift control, composite drag struts, and much more…

There's always a solution in steel.

Thank You

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