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Course Description

The Uniform Force Method

September 29, 2014

A vertical brace connection is a highly indeterminate system. The Uniform Force Method is presented as one statically admissible force distribution in which no moments exist at the connection interfaces. This session will discuss the Uniform Force Method procedure as detailed in the 14th Edition of the AISC Steel Construction Manual.

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Learning Objectives

- Gain familiarity with the derivation of the Uniform Force Method.
- Develop an understanding of the Uniform Force Method procedures shown in the AISC Steel Construction Manual.
- Gain an understanding of the application of the Uniform Force Method through a design example.
- Learn practical tips for applying the Uniform Force Method.

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Bracing Connections and Related Topics

Session 2: The Uniform Force Method

Presented by
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Roswell, GA

structural STEEL

Bracing Connections and Related Topics

By: William Thornton

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Course Outline

1. Basic Principles
2. **Uniform Force Method**
3. Bracing Connection Details and Prying Action
4. Vertical Bracing Connections – Corner Part 1
5. Vertical Bracing Connections – Corner Part 2
6. Chevron Gussets for Wind or Low-Seismic
7. Chevron Gussets for High Seismic
8. Additional Connection Topics

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Session Outline

- The Uniform Force Method
  - Geometry
  - Control Points
  - Admissible Force Field
  - Example
  - Special Cases I, II, and III
  - Special Case IV
  - Research Basis for UFM
  - Non−Orthogonal UFM
  - Example
  - Summary

THE UNIFORM FORCE METHOD

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12

THE UNIFORM FORCE METHOD

What is it?

A geometric method to determine the statically indeterminate force distribution in a vertical bracing connection.

The method evolved from research sponsored by AISC performed by Ralph Richard at the University of Arizona

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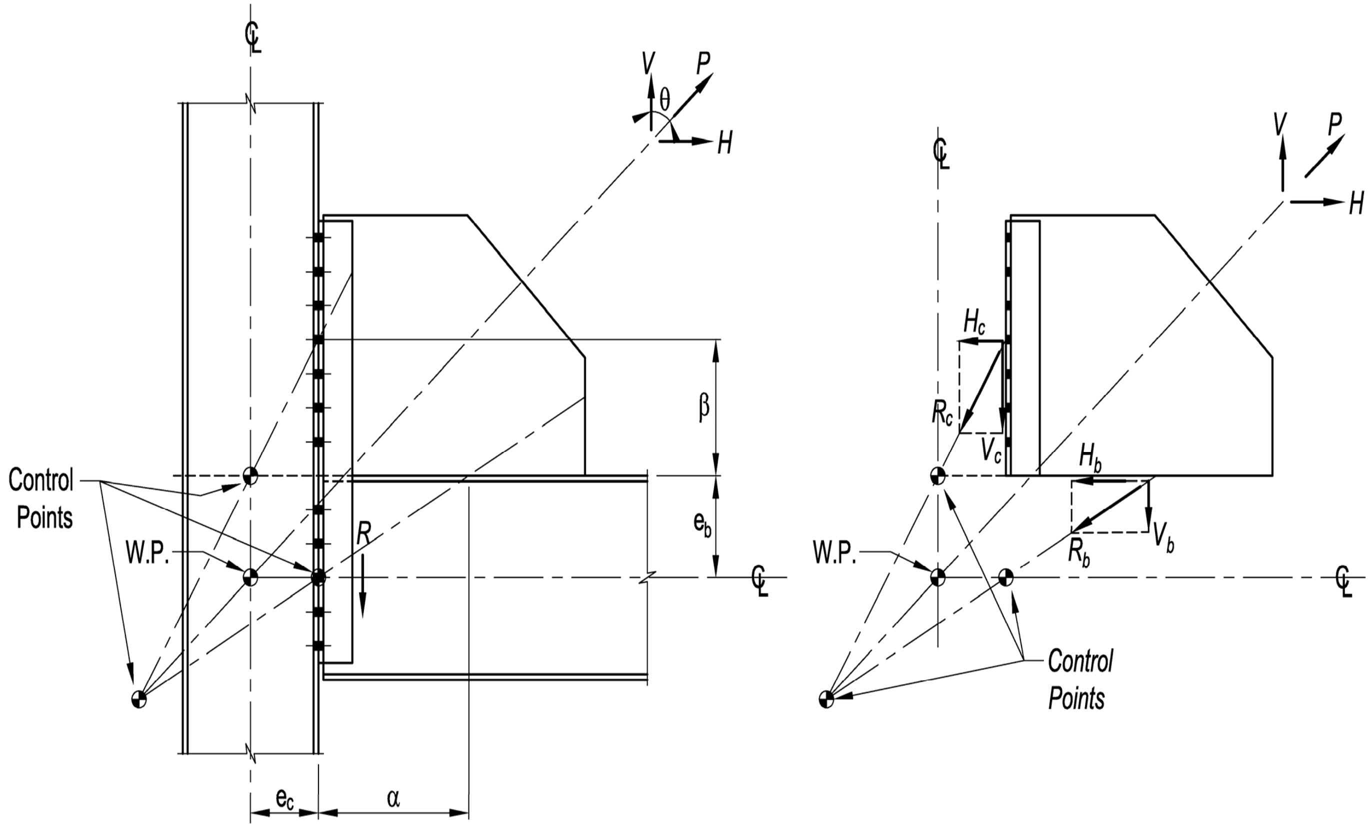
13

Uniform Force Method (UFM)

Geometry Control Points and Admissible Force Field



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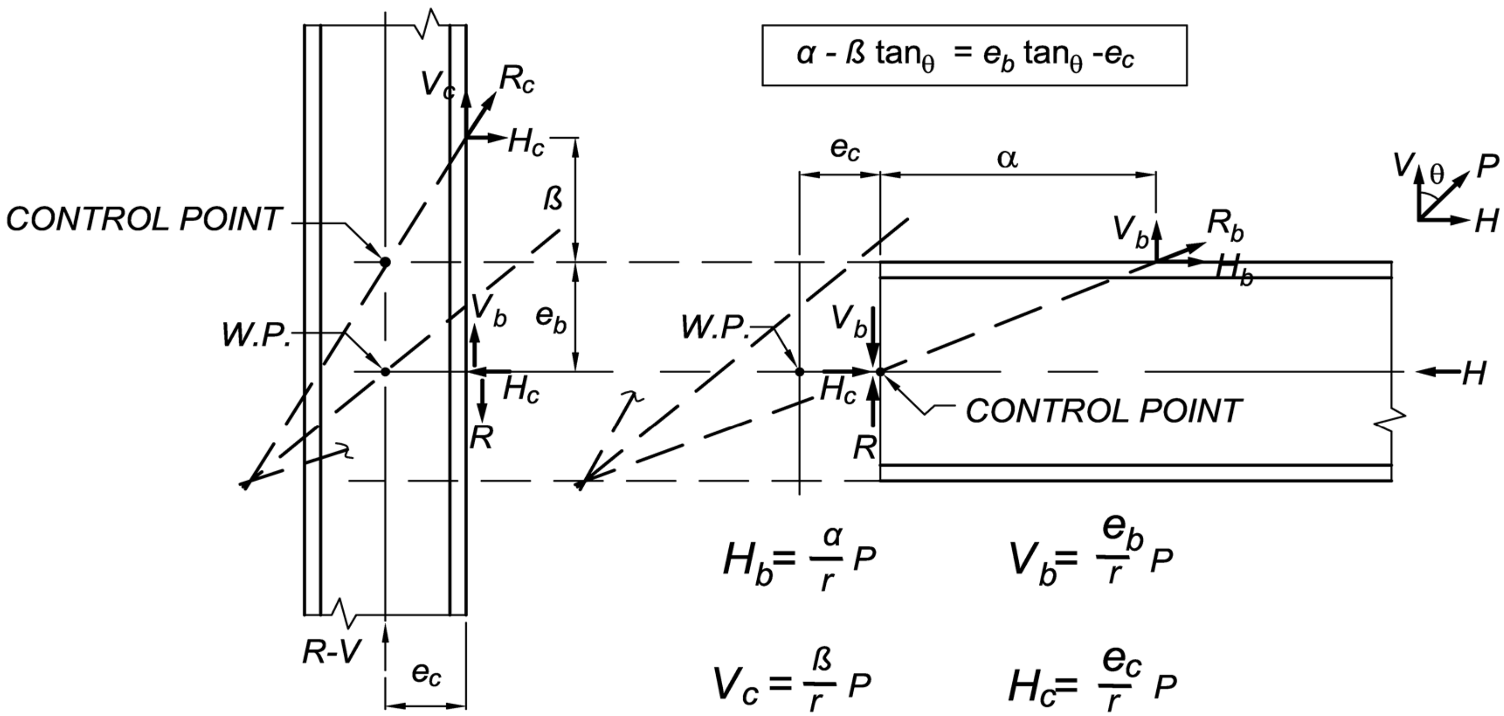
Geometry of UFM
All Parts are in Equilibrium



$$H_b = \frac{\alpha}{r} P \qquad V_b = \frac{e_b}{r} P$$

$$V_c = \frac{\beta}{r} P \qquad H_c = \frac{e_c}{r} P$$

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

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An admissible force field is an internal force distribution in equilibrium with the applied external forces

The load path is defined by the admissible force field

The control point geometry is dictated by the constraint

$$\alpha - \beta \tan \theta = e_b \tan \theta - e_c$$

α and β locate the gusset connection centroids

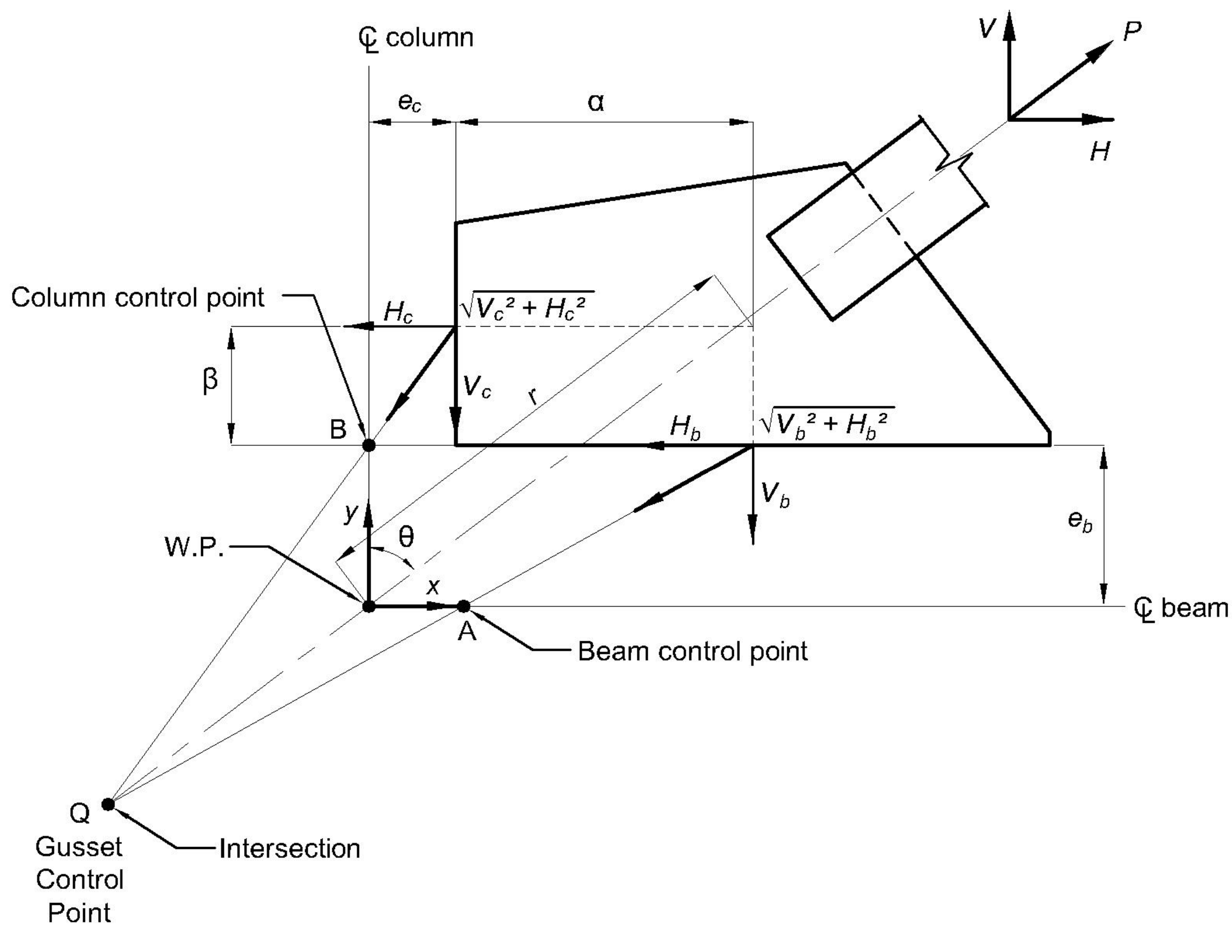
α and β vs $\bar{\alpha}$ and $\bar{\beta}$

When designing a connection, α and β can **always** be chosen to satisfy the geometric constraint.

When checking a connection designed by some other method the connection centroids may not satisfy the geometric constraint.

This is where $\bar{\alpha}$ and $\bar{\beta}$ appear. These locate the actual connections centroids and will not satisfy the constraint. Therefore, couples will exist on the gusset edges. Manual 14th Ed. Part 13 addresses this.

UFM Admissible Force Field for the Gusset



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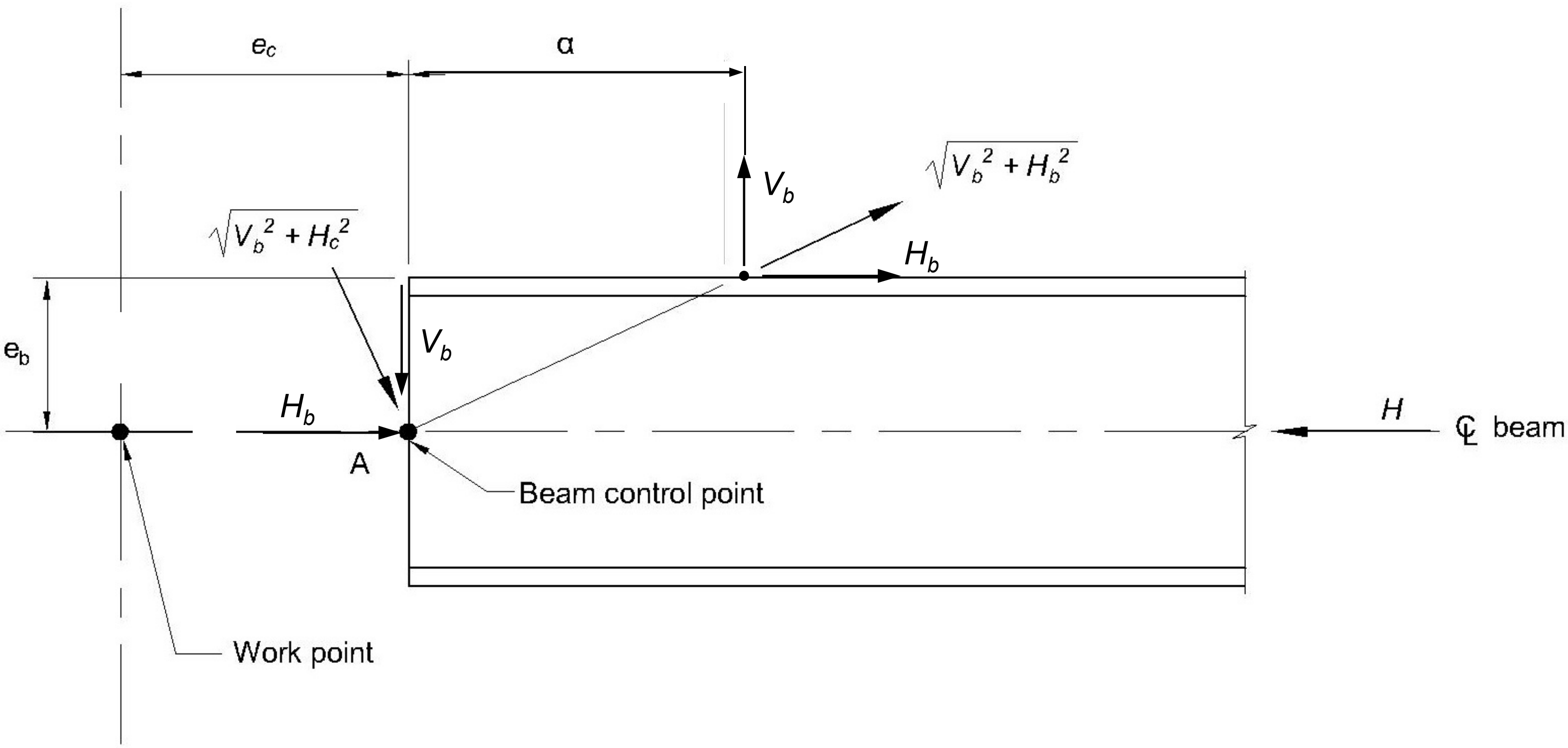
UFM Admissible Force Field for the Beam



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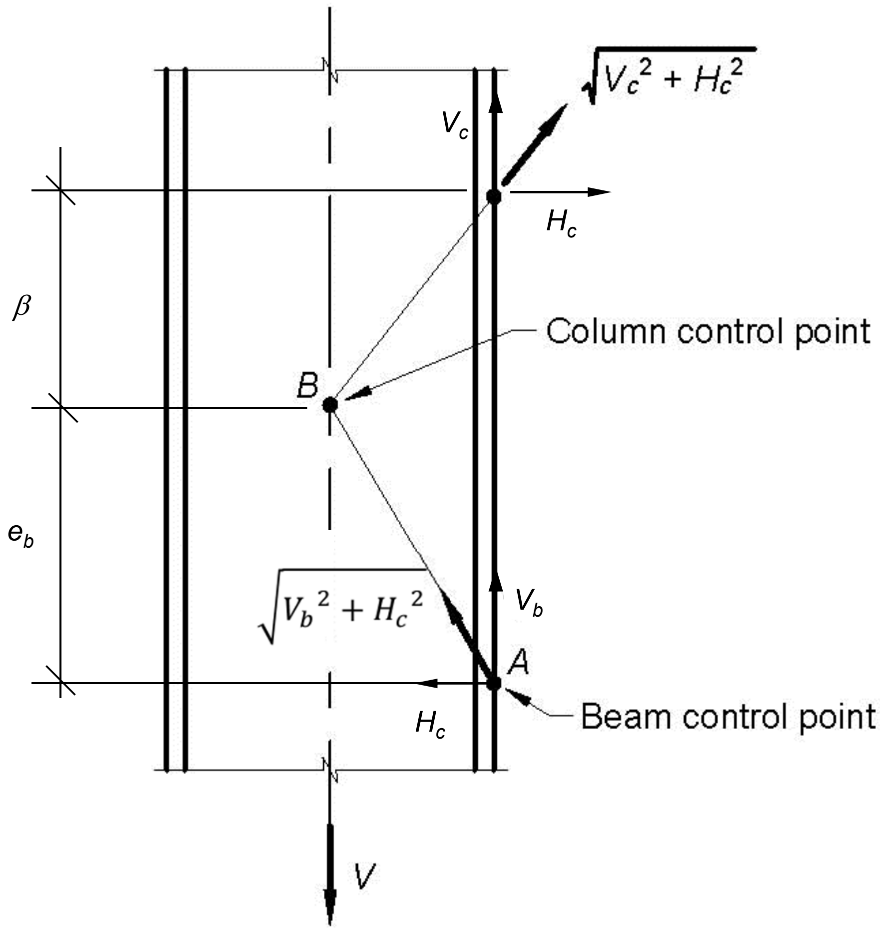
UFM Admissible Force Field for the Column



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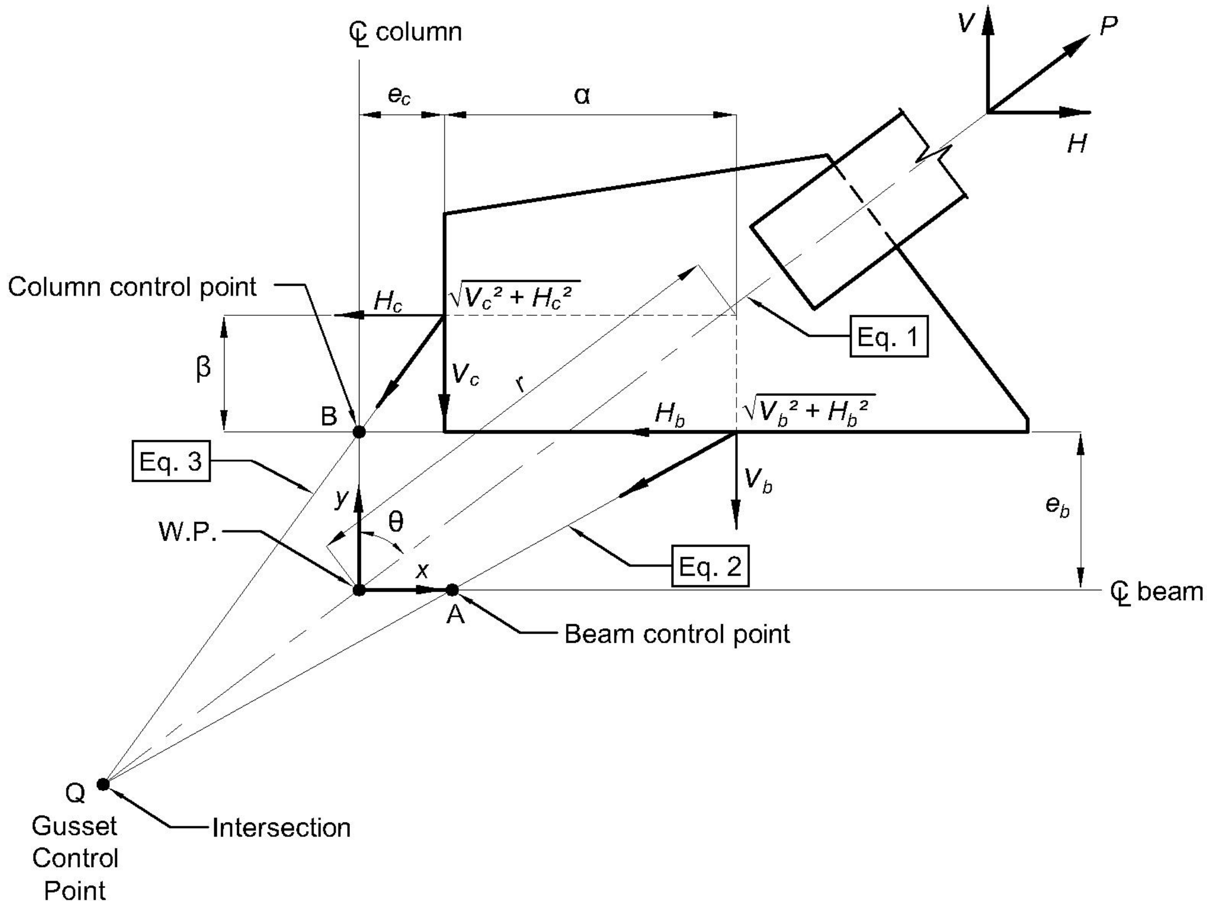
UFM Admissible Force Field for the Gusset



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Uniform Force Method Derivation

Equation of Brace Line of Action:

$$y = \frac{1}{tan\theta}x \qquad \text{Eq. 1}$$

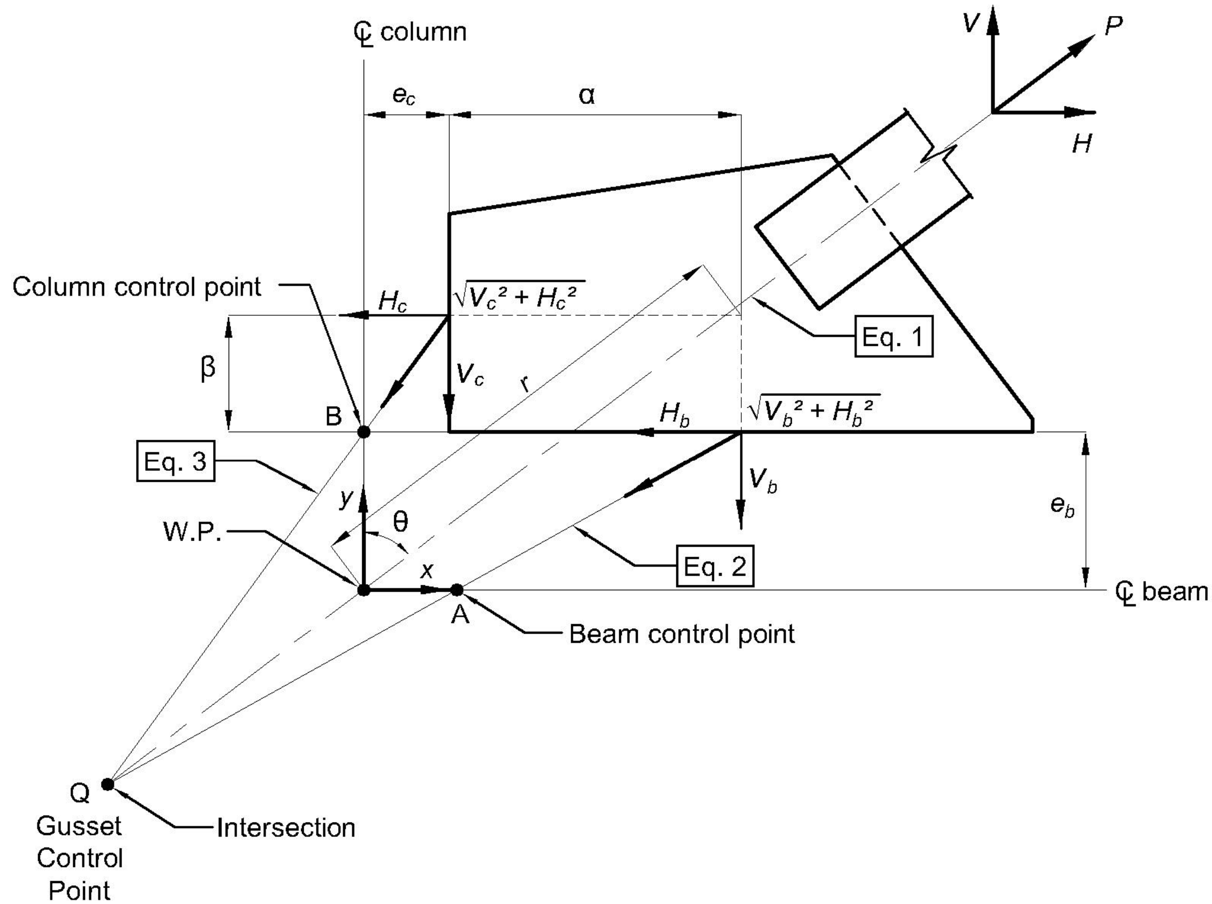
Equation of Gusset to Beam Force Line of Action:

$$y = \frac{e_b x}{\alpha} - \frac{e_b e_c}{\alpha} \qquad \text{Eq. 2}$$

Equation of Gusset to Column Force Line of Action:

$$y = \frac{\beta}{e_c}x + e_b \qquad \text{Eq. 3}$$

UFM Admissible Force Field for the Gusset



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24

Uniform Force Method Derivation

To find point *Q*:

Set Eq. 1 = Eq. 2, solve for x_Q:

$$x_Q = -\frac{e_b e_c}{\alpha} \frac{1}{\left(\frac{1}{tan\theta} - \frac{e_b}{\alpha}\right)} \qquad \text{Eq. 4}$$

Set Eq. 1 = Eq. 3, solve for x_Q:

$$x_Q = e_b \frac{1}{\left(\frac{1}{tan\theta} - \frac{\beta}{e_c}\right)} \qquad \text{Eq. 5}$$

x_Q given by 4 and 5 must be equal.

Uniform Force Method Derivation

Set Eq. 4 = Eq. 5:

$$-\frac{e_b e_c}{\alpha}\frac{1}{\left(\frac{1}{tan\theta}-\frac{e_b}{\alpha}\right)} = e_b\frac{1}{\left(\frac{1}{tan\theta}-\frac{\beta}{e_c}\right)}$$

Simplifying,

$$\alpha - \beta\, tan\theta = e_b\, tan\theta - e_c \qquad \text{Eq. 6}$$

To satisfy the geometry of the Uniform Force Method, the equality given by Equation 6 must be satisfied.

Uniform Force Method Derivation

With the relationship given by Eq. 6 and introducing geometrical parameter

$$r = \sqrt{(\alpha + e_c)^2 + (\beta + e_c)^2}$$

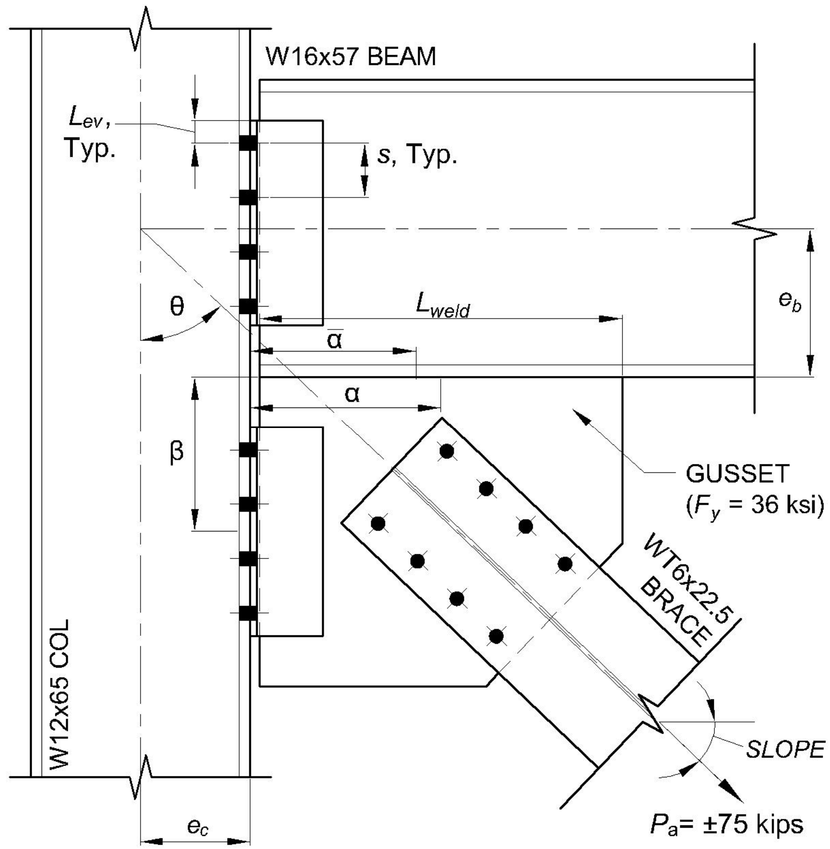
The component forces are

$$H_b = \alpha \frac{P}{r} \qquad V_b = e_b \frac{P}{r}$$

$$H_c = e_c \frac{P}{r} \qquad V_c = \beta \frac{P}{r}$$

Note: $H_b + H_c = H$ Note: $V_b + V_c = V$

Example of Brace-to-Beams/Column Connection



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Example of Brace-to-Beams/Column Connection (cont.)

Given:

1. AISC 14th Edition, ASD
2. Beam-to-Column and Gusset-to-Column: $n = 4$
3. L_{weld} = 20 in. min. with ¼" min. weld
4. ¾" dia. A325-N, STD holes, UNO
5. For double angles, horizontal SSLT with L_{ev} = 1.25 in. minimum and bolt spacing, s = 3 in.
6. Brace force, P_a = ±75 kips with slope = 43.6°, θ = 46.4°

Example of Brace-to-Beams/ Column Connection (cont.)

Solution:

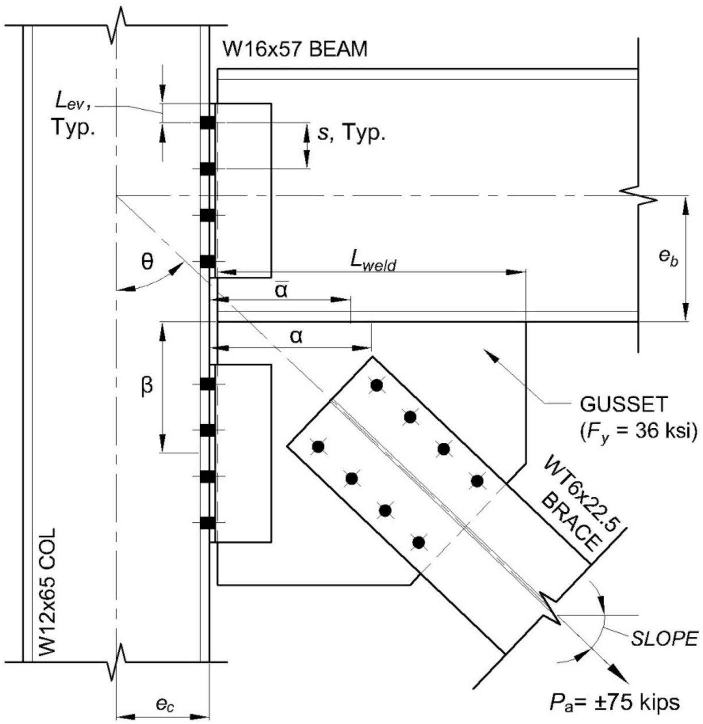
Determine Gusset Forces using UFM

$\tan\theta = 1.05$

$e_b = d_B/2 = 16.4 \text{ in.}/2 = 8.2 \text{ in.}$

$e_c = d_c/2 = 12.1 \text{ in.}/2 = 6.05 \text{ in.}$

(note: $e_c = 0.0$ in. for connections into column web, except Special Case IV)



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Example of Brace-to-Beams/ Column Connection (cont.)

$\bar{\beta}$ = distance to center of gusset-to-column connections

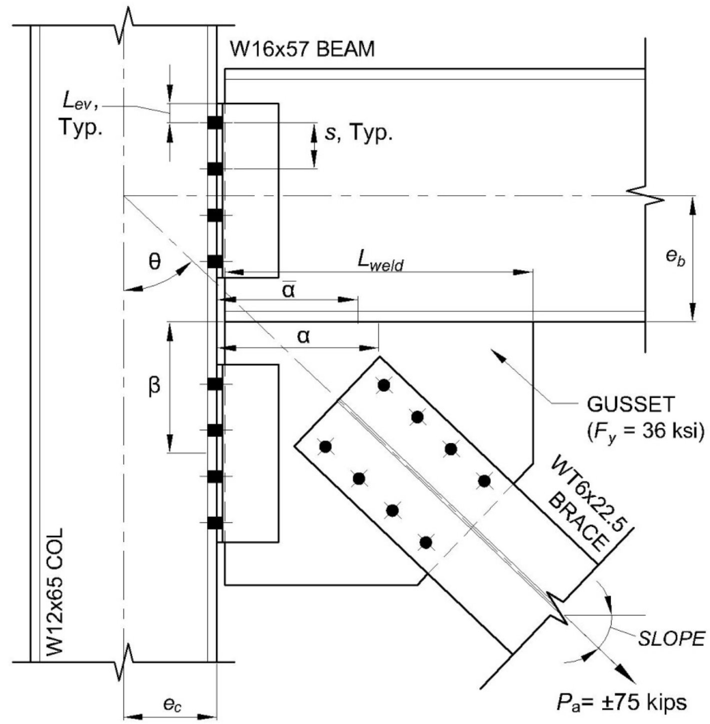
From geometric layout, H_{gusset} = 16.875 in.

Place bolts in approximate center of gusset,

$\bar{\beta} = 8.5$ in.

Let $\beta = \bar{\beta}$

$$\alpha = e_b \tan\theta - e_c + \beta \tan\theta$$
$$= (8.2 \text{ in.} \times 1.05) - 6.05 \text{ in.} + (8.5 \text{ in.} \times 1.05)$$
$$= 11.5 \text{ in.}$$



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Example of Brace-to-Beams/ Column Connection (cont.)

$\bar{\alpha} = L_{weld}/2 + 0.5$ in. (setback for angles)

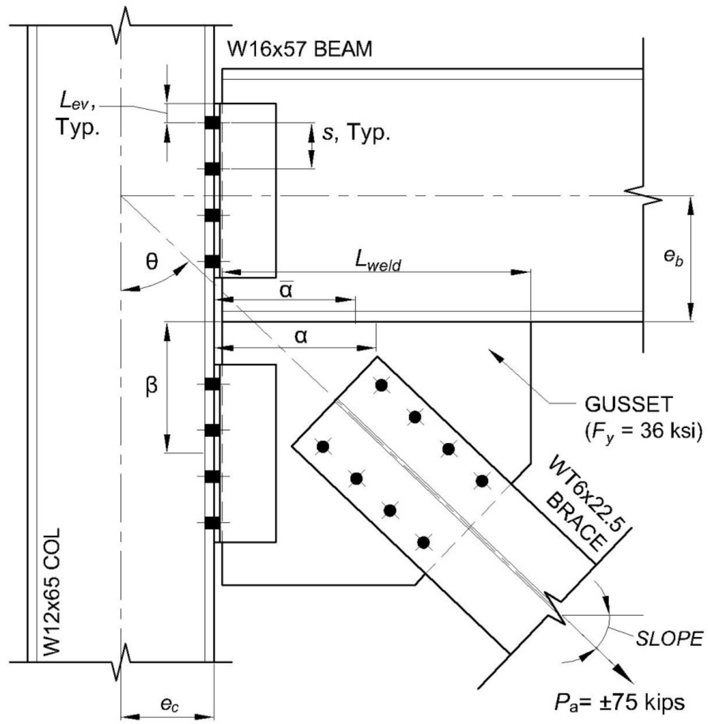
$= 20$ in./2 + 0.5 in.

$= 10.5$ in. min. → does not equal α

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

$= \sqrt{[(11.5 \text{ in.} + 6.05 \text{ in.})^2 + (8.5 \text{ in.} + 8.2 \text{ in.})^2}$

$= 24.2$ in.



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Example of Brace-to-Beams/ Column Connection (cont.)

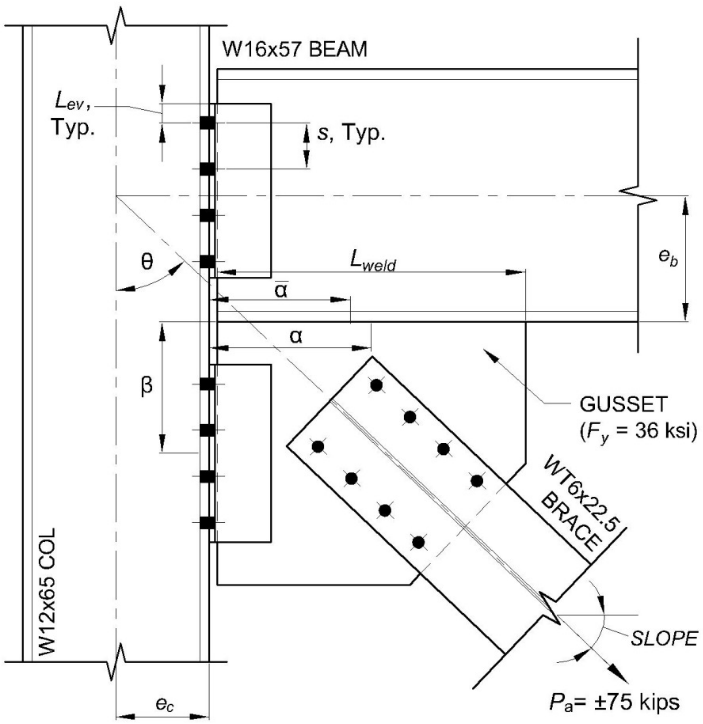
Note: If AISC Special Load Case 2 is selected, then:

V_B → transfer portion, ΔV_B, to V_C

$V_C = P_a(\beta/r) + \Delta V_B$

$M_B = V_B(\alpha - \overline{\alpha}) + (\Delta V_B)\overline{\alpha}$

For this example, Special Load Case 2 is not used. ($\Delta V_B = 0$)

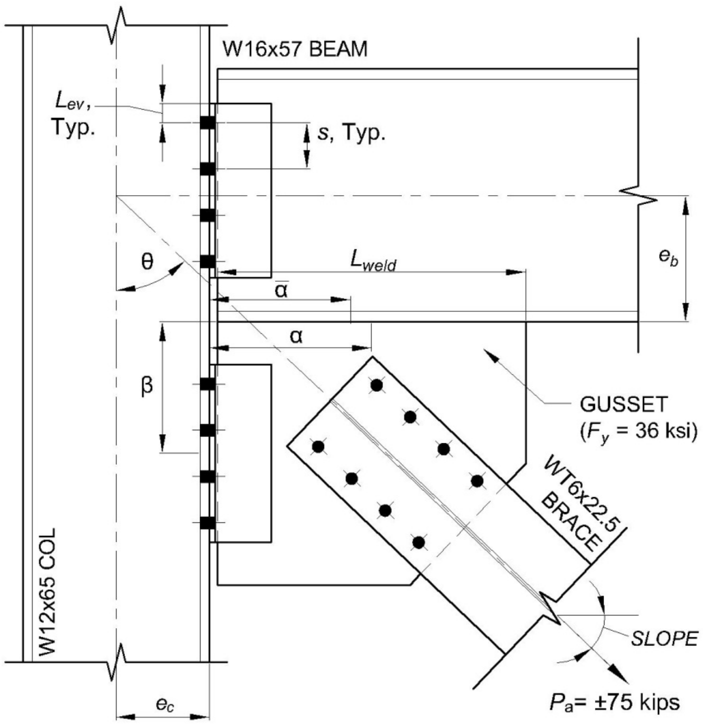


Example of Brace-to-Beams/ Column Connection (cont.)

For this example, Special Load Case 2 is not used. ($\Delta V_B = 0$):

$$V_B = P_a(e_b/r)$$
$$= 75 \text{ kips} \times (8.2 \text{ in.}/24.2 \text{ in.})$$
$$= 25.4 \text{ kips}$$

$$H_B = P_a(\alpha/r)$$
$$= 75 \text{ kips} \times (11.5 \text{ in.}/24.2 \text{ in.})$$
$$= 35.6 \text{ kips}$$



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Example of Brace-to-Beams/ Column Connection (cont.)

$M_B = V_B(\alpha - \overline{\alpha})$

$= 25.4\text{ kips}(11.5\text{ in.} - 10.5\text{ in.})$

$= 25.4\text{ kip-in.}$

$V_C = P_a(\beta/r)$

$= 75\text{ kips}(8.5\text{ in.}/24.2\text{ in.})$

$= 26.3\text{ kips}$

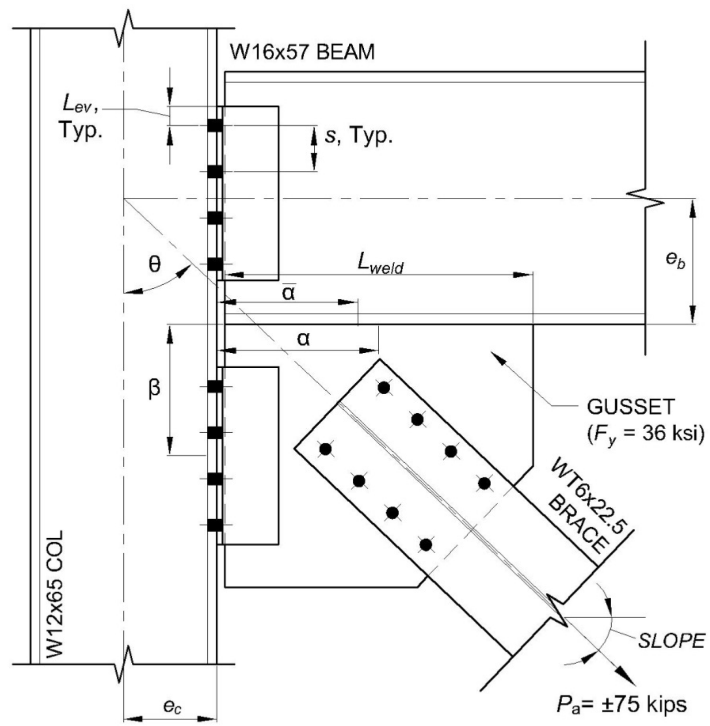
$H_C = P_a(e_c/r)$

$= 75\text{ kips}(6.05\text{ in.}/24.2\text{ in.})$

$= 18.8\text{ kips}$

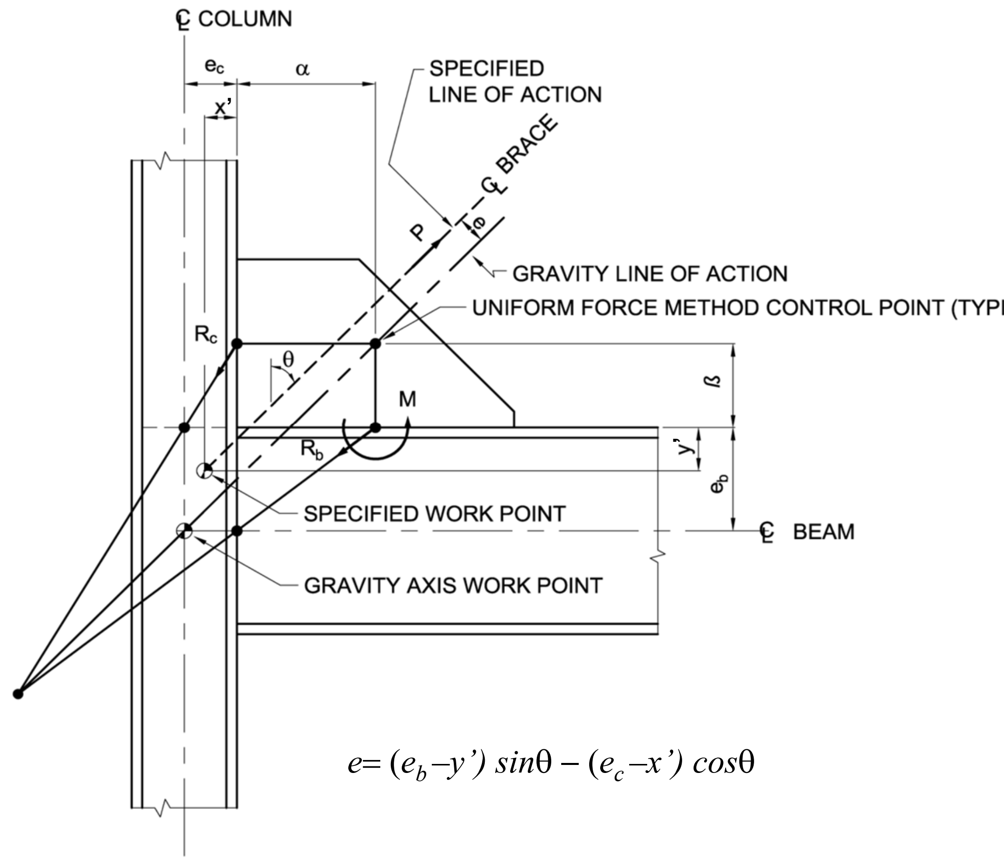
(Note: $H_C = 0$ kips for connections to column web, except Special Case IV)

$M_C = 0$ since $\beta = \overline{\beta}$



UFM Special Case I

Non Concentric Work Point



$$e = (e_b - y')\sin\theta - (e_c - x')\cos\theta$$

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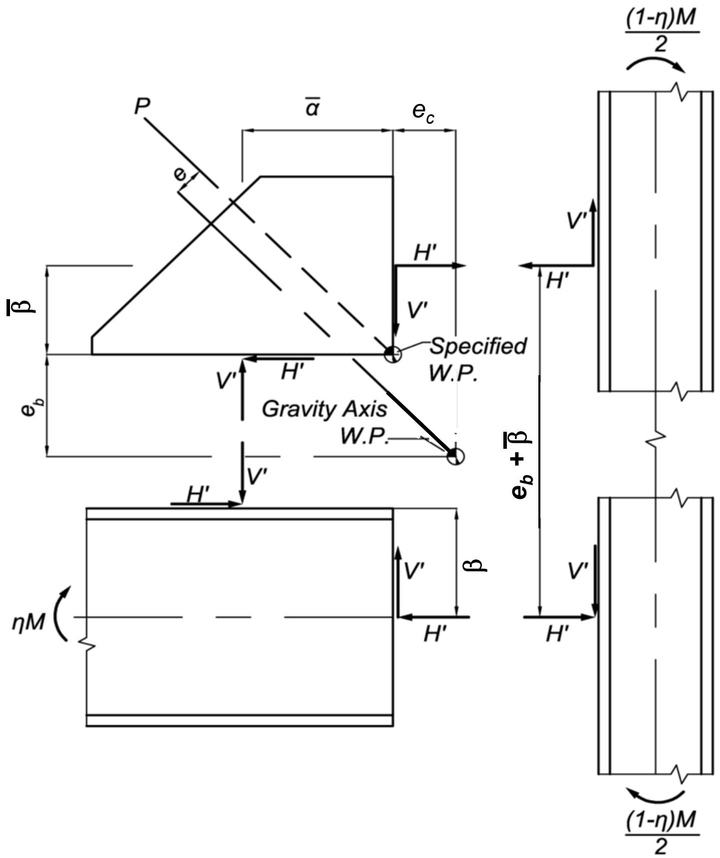
UFM Special Case I

Admissible Force Field



These forces are added algebraically to the UFM concentric forces
Note the extra moments in the beam and column

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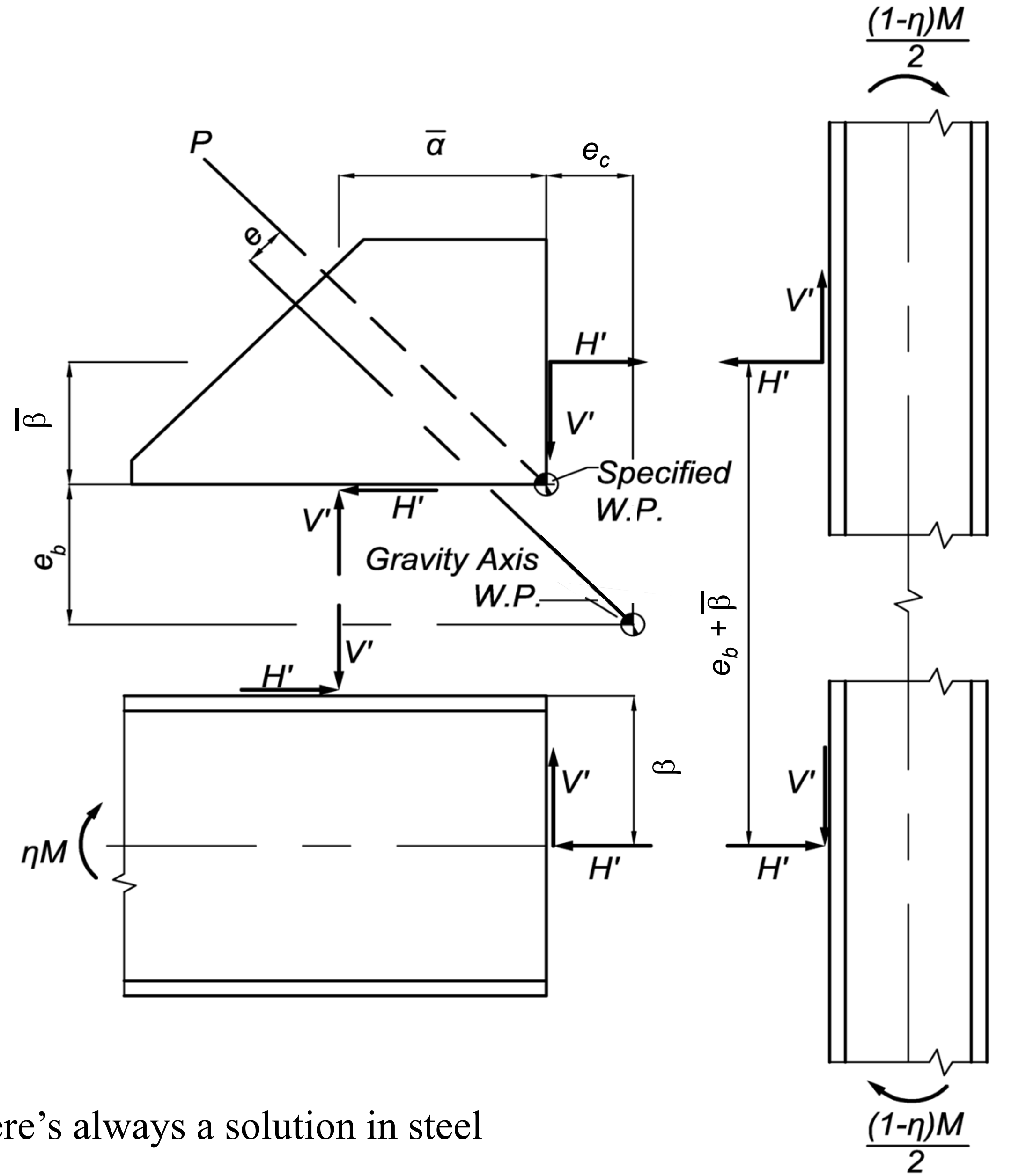

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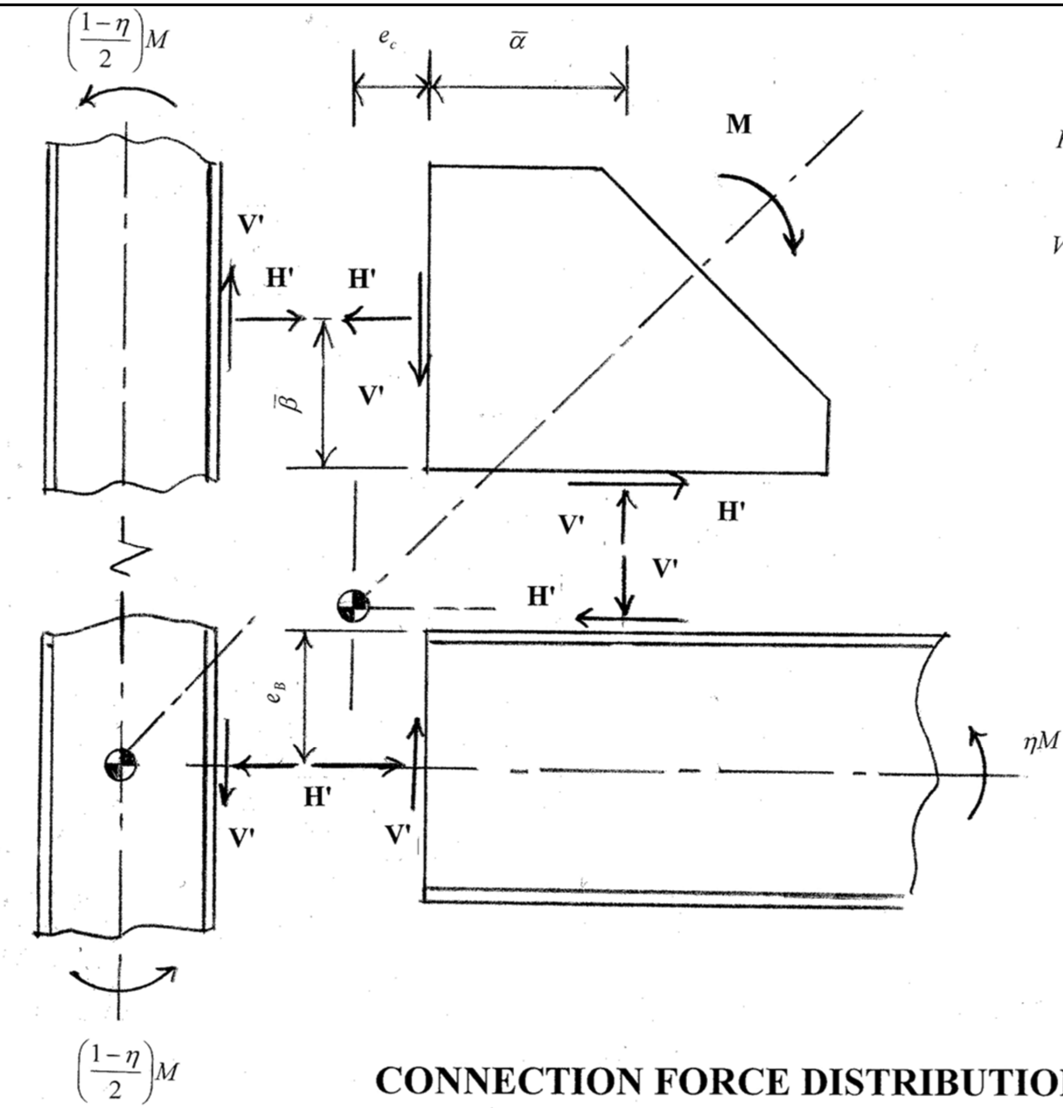
38



$$H' = \frac{(1-\eta)M}{e_B + \bar{\beta}}$$

$$V' = \frac{M - H'\bar{\alpha}}{\bar{\alpha}}$$

$$\eta = \frac{\left(\frac{I}{L}\right)Beam}{\Sigma\left(\frac{I}{L}\right)Beam + Columns}$$

or

$$\eta = \frac{M_p Beam}{\Sigma M_p Beam + Columns}$$

CONNECTION FORCE DISTRIBUTION DUE TO MOMENT M

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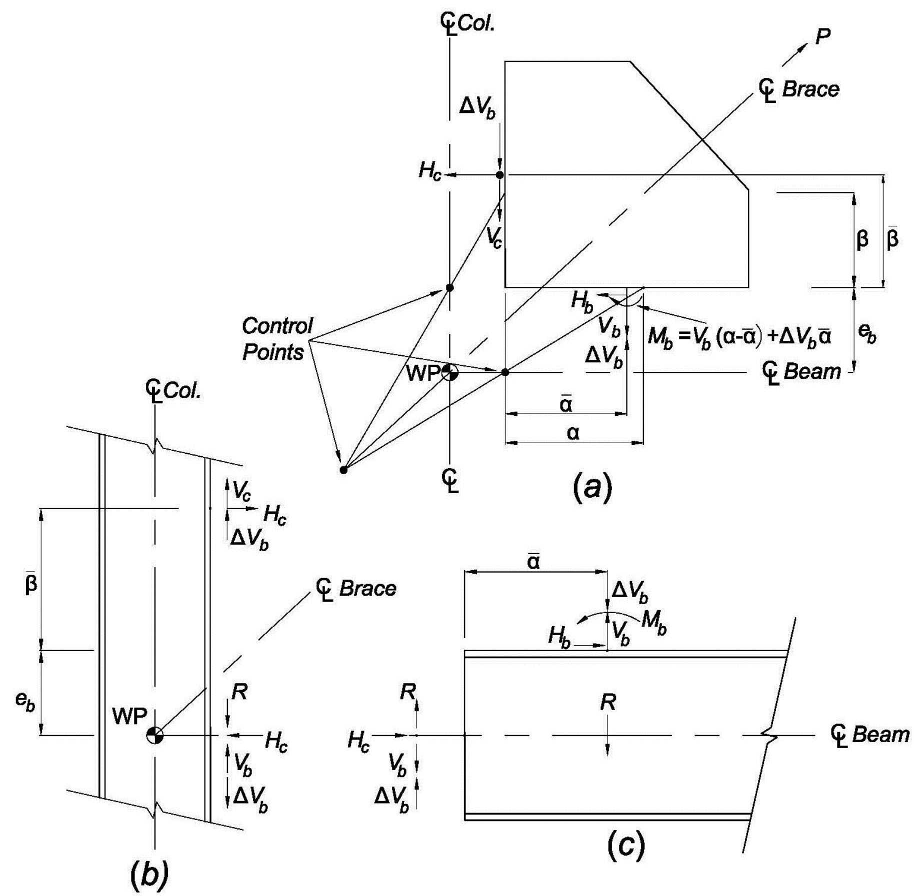
UFM Special Case II

Admissible Force Field

This reduces the beam to column shear

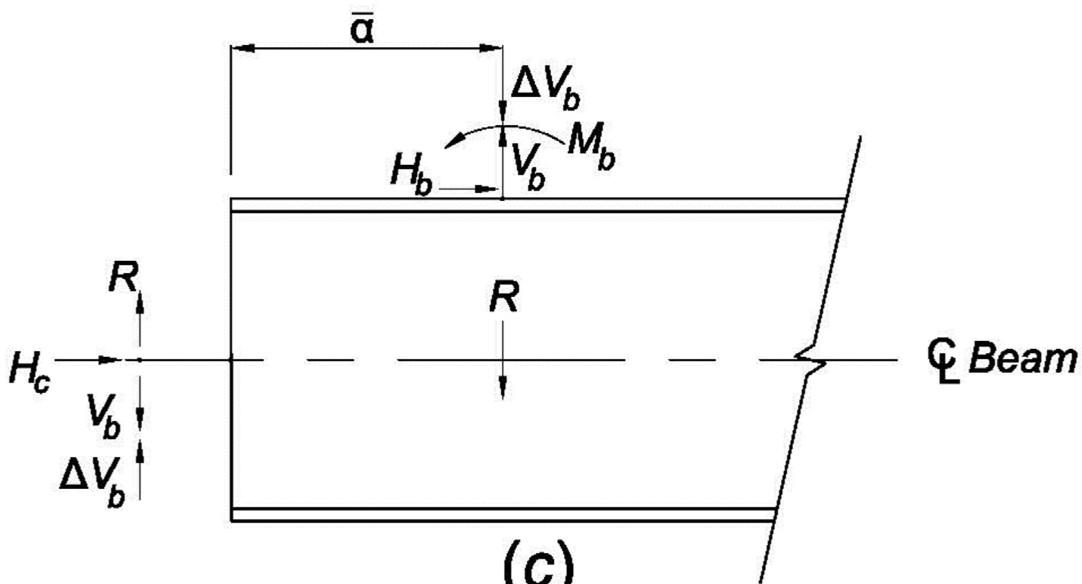


40

UFM Special Case II

Admissible Force Field

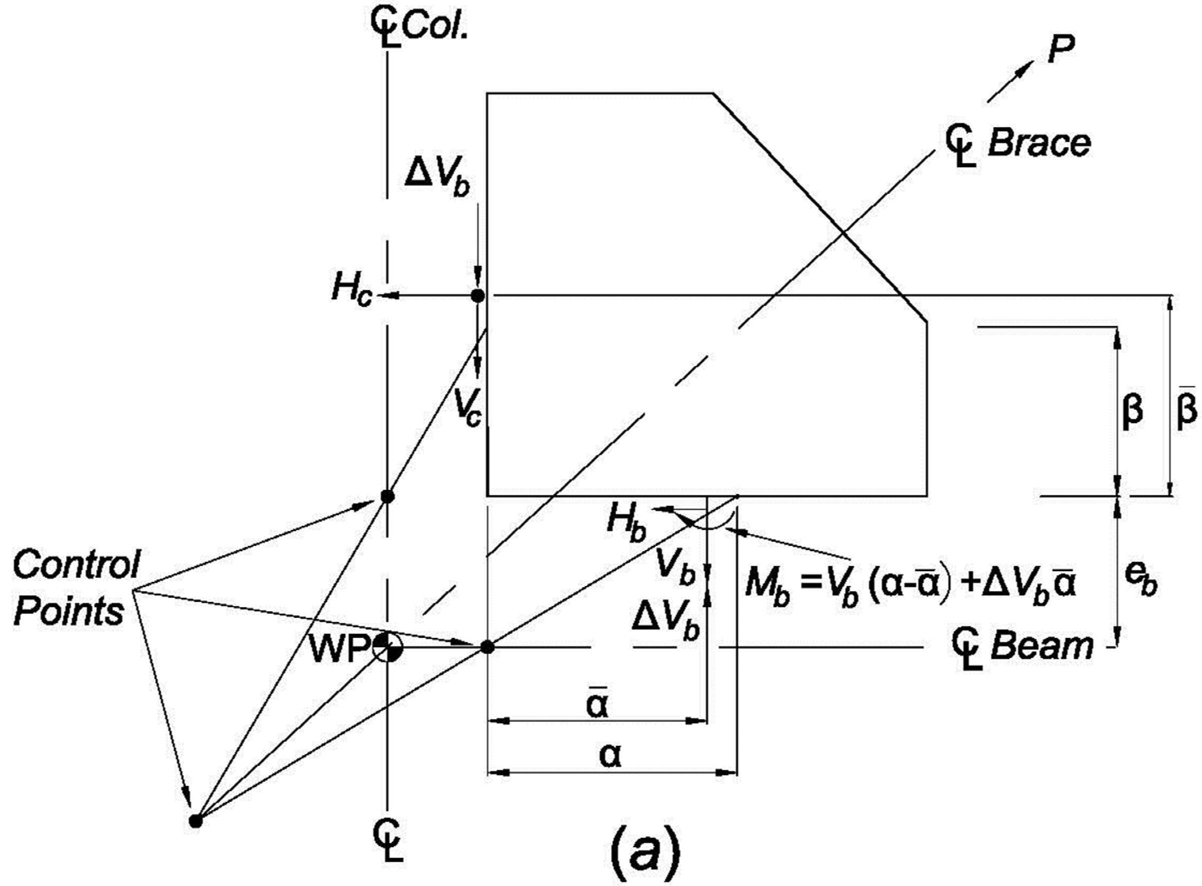
This reduces the beam to column shear



(c)

UFM Special Case II

Admissible Force Field



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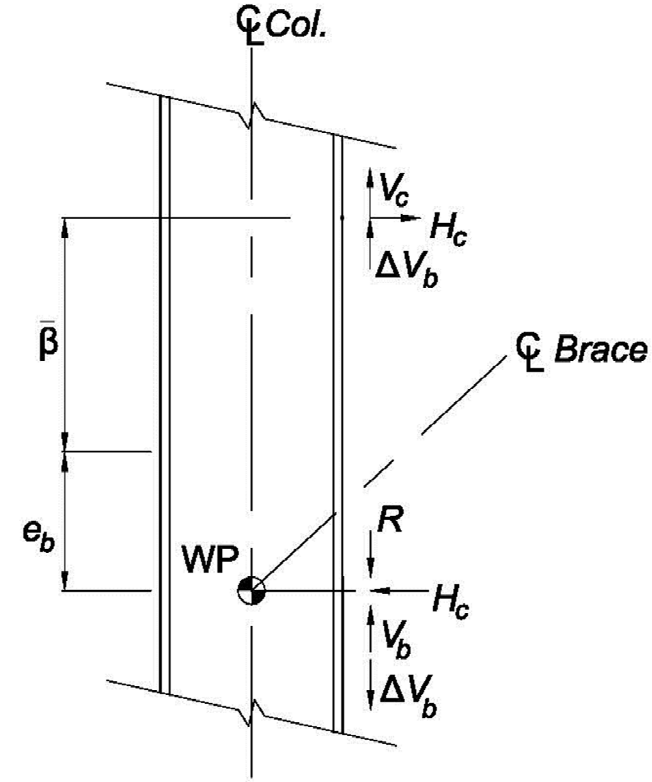
42

UFM Special Case II

Admissible Force Field

This reduces the beam to column shear



(b)

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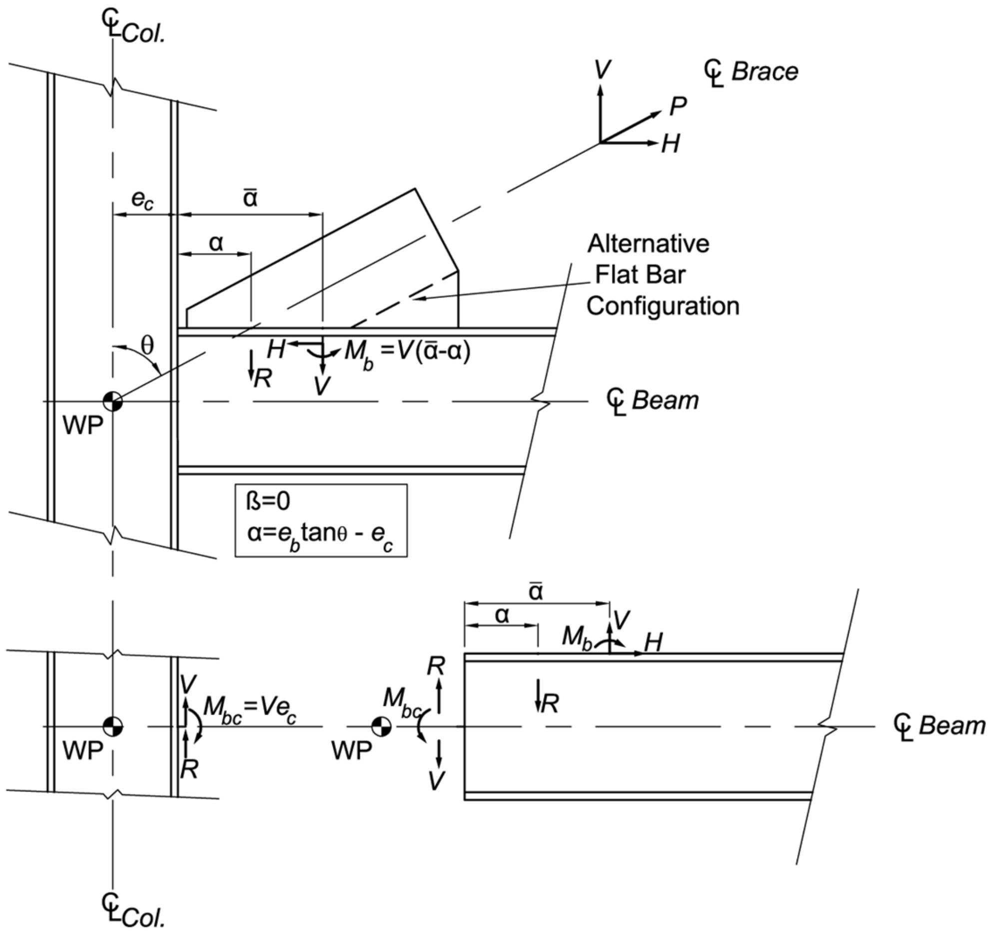
What causes the use of Special Case II

- Beam shear reactions based on beam strength rather than floor loads
- Most beams, especially those part of the lateral bracing system, are designed for stiffness, not strength
- This results in beams many times stronger than those required for strength, and larger shear reactions than those required for the floor loads

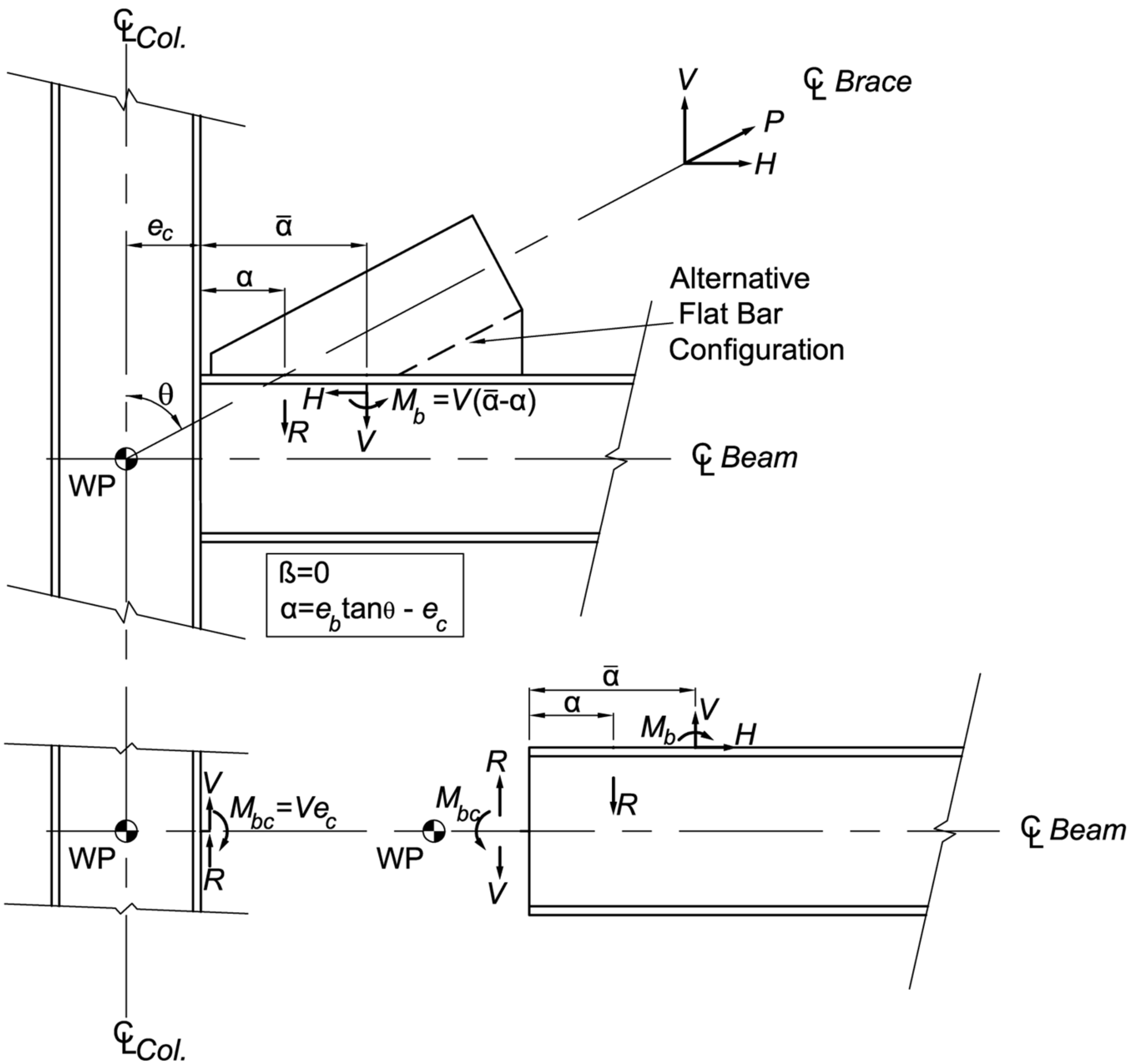
UFM Special Case III

Admissible Force Field

Connection to beam or column only

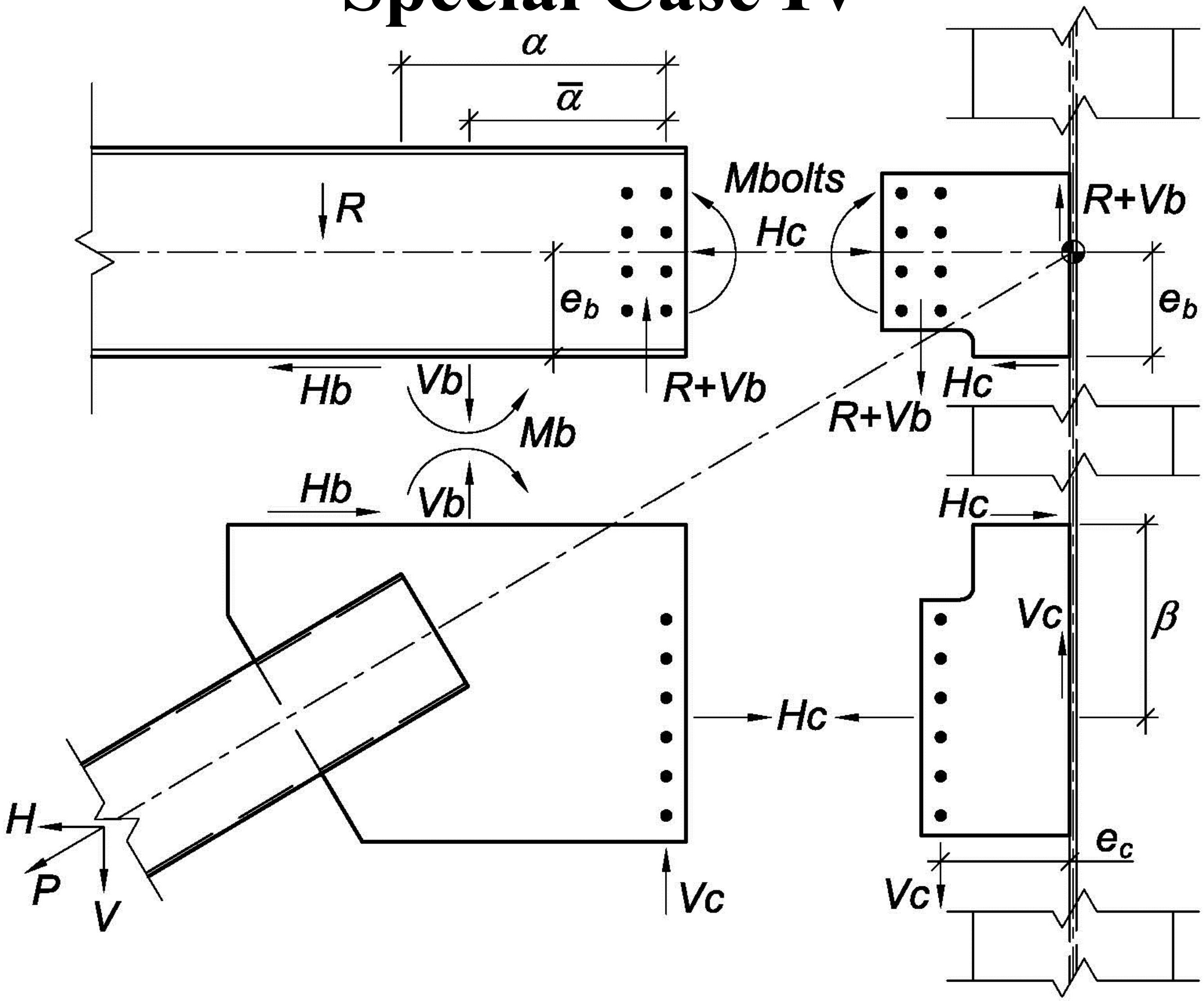


45


Col.
V
Brace
P
H
e_c
$\bar{\alpha}$
α
Alternative
Flat Bar
Configuration
θ
H
$M_b = V(\bar{\alpha}-\alpha)$
R
V
Beam
WP
ß=0
$\alpha = e_b \tan\theta - e_c$
$\bar{\alpha}$
α
V
M_b
H
R
V
$M_{bc} = Ve_c$
R
WP
M_{bc}
WP
V
R
Beam
Col.

46

Special Case IV



47

Special Case IV

A $2 Million dollar savings compared to the original estimate was attributed to the connection design on these two projects.

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48

Special Case IV

Conventional and Extended Tabs replaced the more traditional double clips at the jumbo columns reducing both fabrication and erection costs.

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Special Case IV

The Uniform Force Method was used extensively in novel ways to optimize the connections.

Special Case IV

X-bolts were also used wherever the threads excluded condition could be assured without additional inspection.

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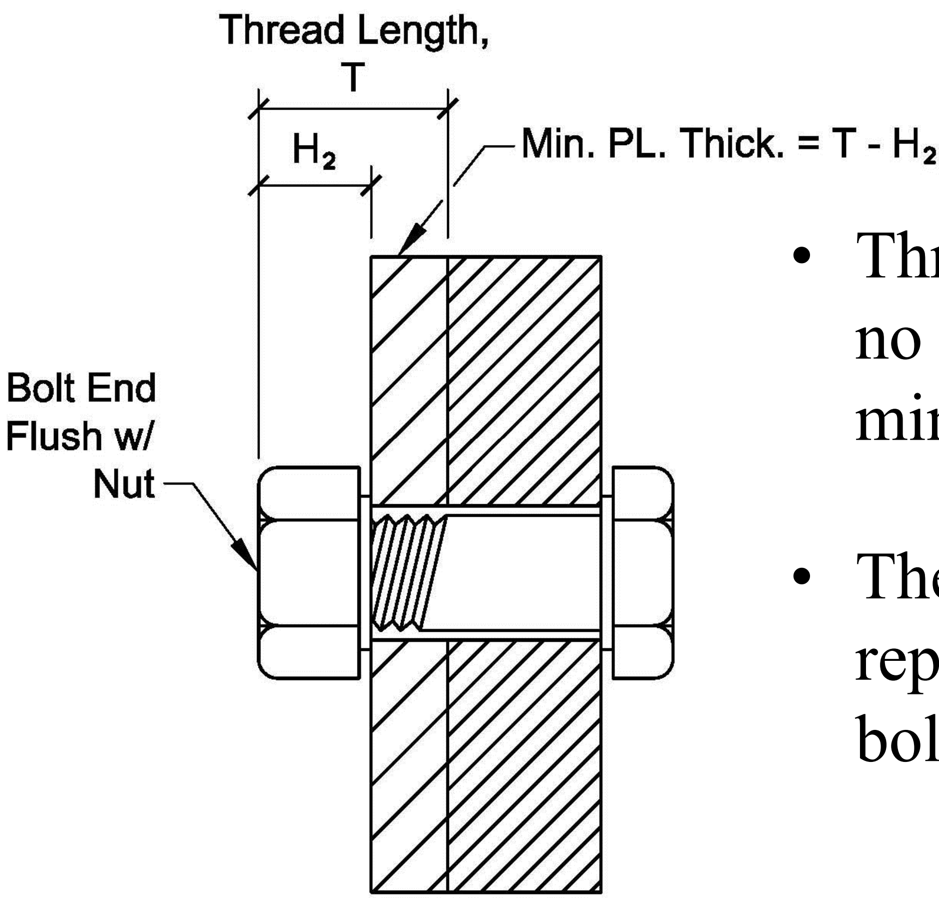
Allow X-Type Bolts Where Appropriate



- Threads can be excluded with no additional inspection given minimum plate thicknesses.
- The change from N to X represents a 25% increase in bolt capacity.

Allow X-Type Bolts Where Appropriate

Minimum Ply Thickness for Threads Excluded Condition			
Bolt Dia. (in.)	Min. Ply Thick (in.)	Min. Ply Thick w/ $^5/_{32}$" washer (in.)	Min. Ply Thick w/ $^5/_{32}$" washer & $^1/_4$" stick-thru (in.)
$^3/_4$	0.641	0.485	0.235
$^7/_8$	0.641	0.485	0.235
1	0.766	0.610	0.360
$1^1/_8$	0.891	0.735	0.485
$1^1/_4$	0.781	0.625	0.375

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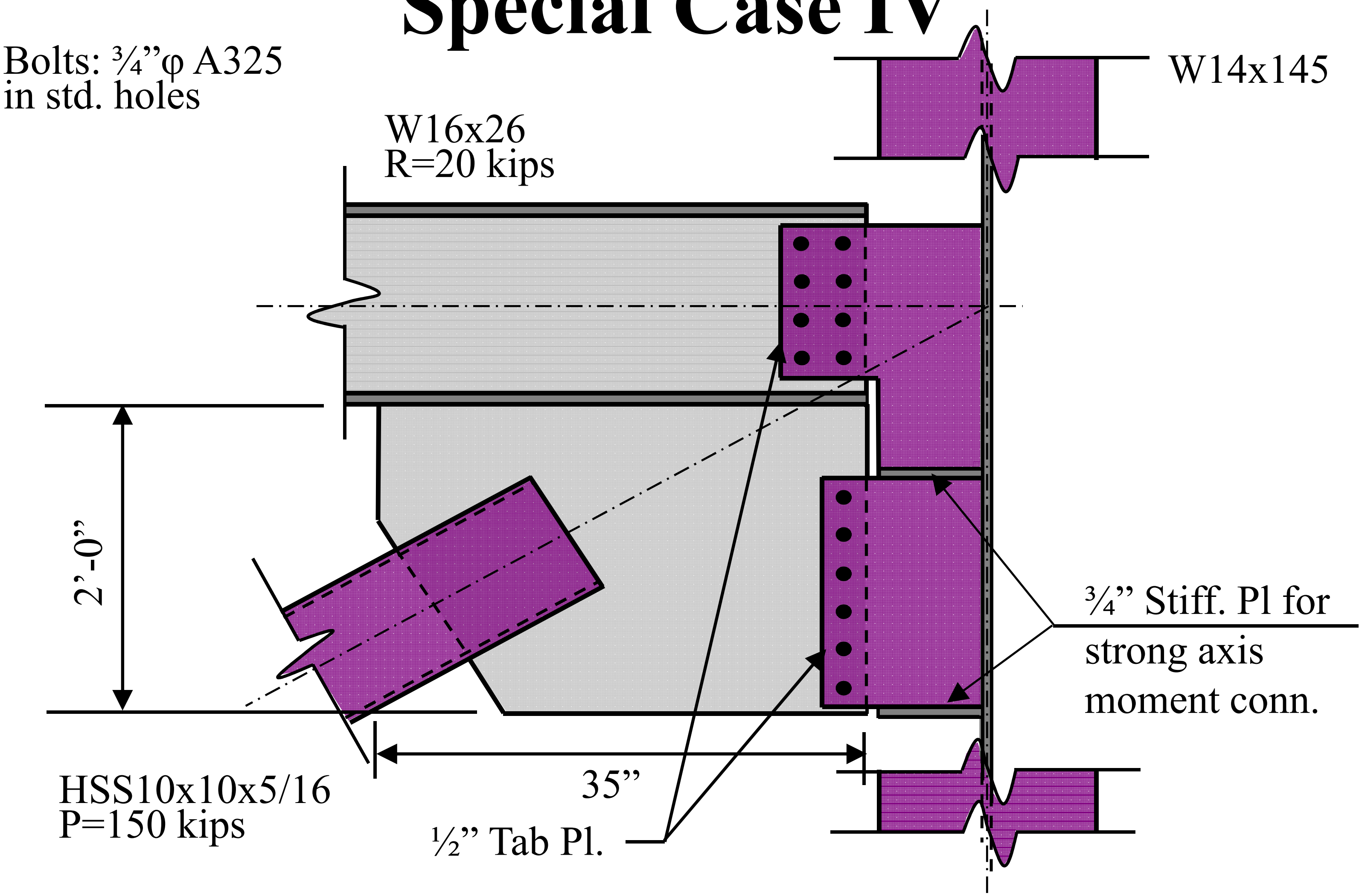
Special Case IV



Vertical Bracing w/ Ext. Tab

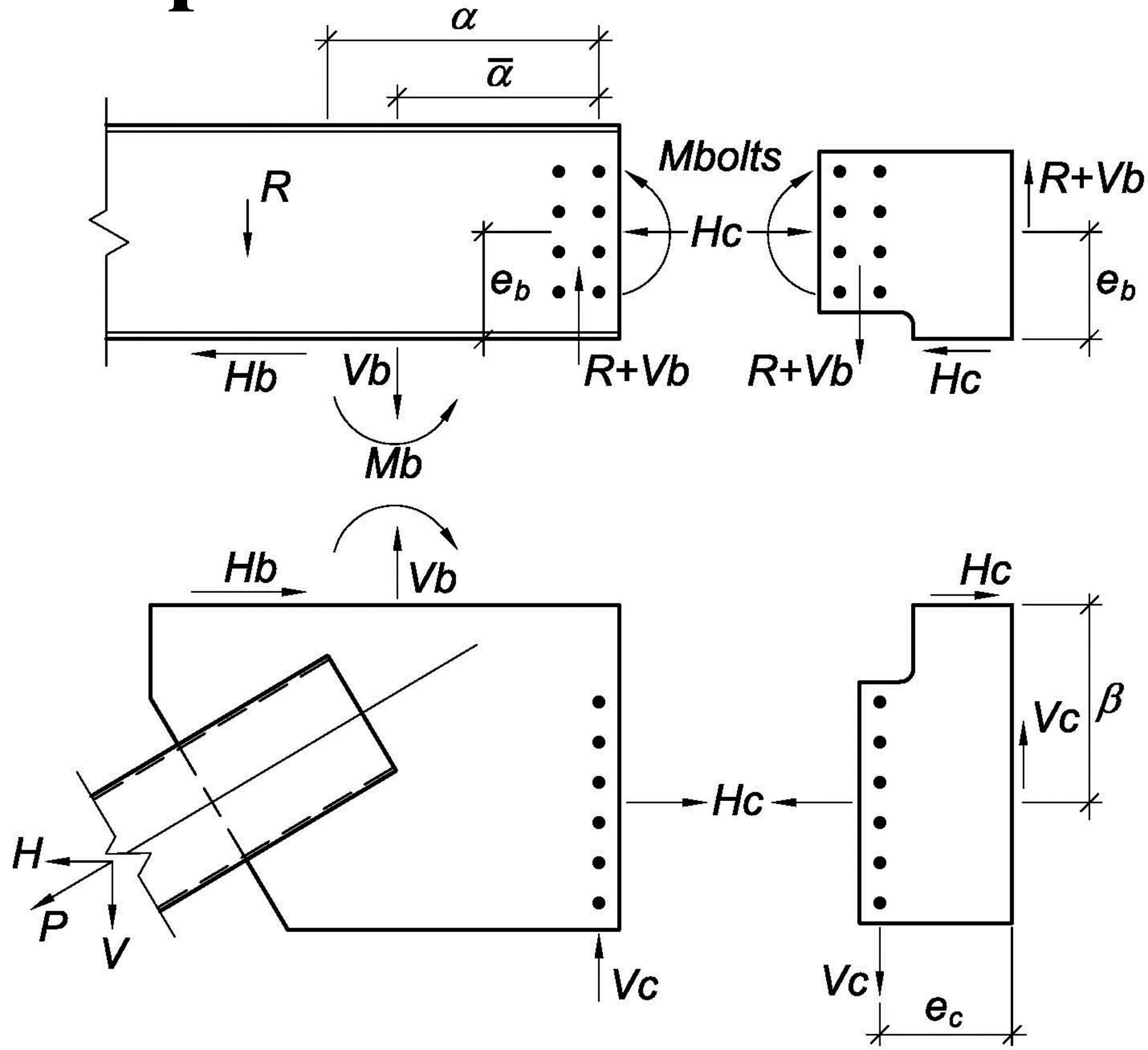
Optimum Load Path e_c = 10.25

54

Special Case IV

FBD of Optimum Solution

Special Case IV



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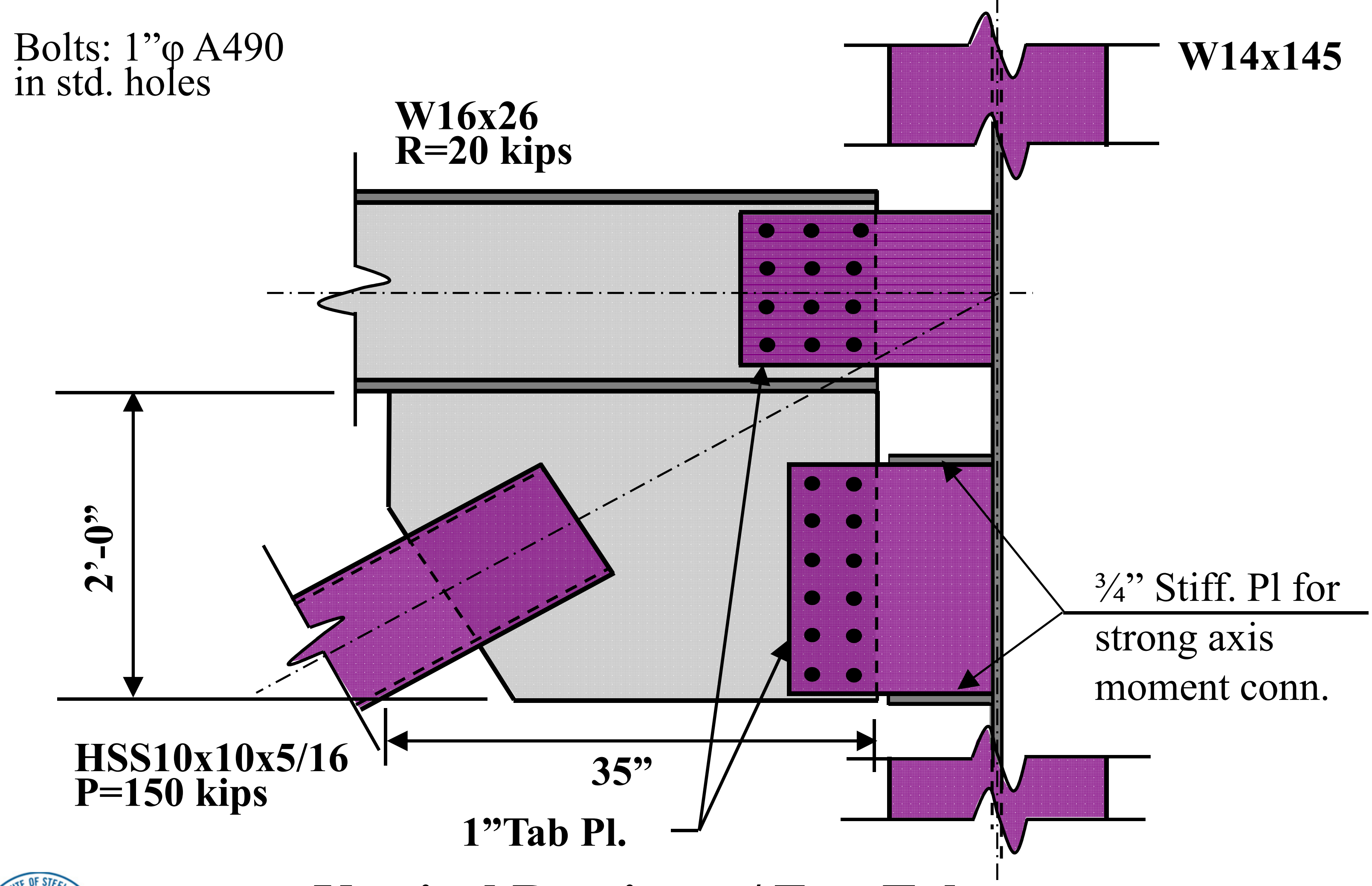
55

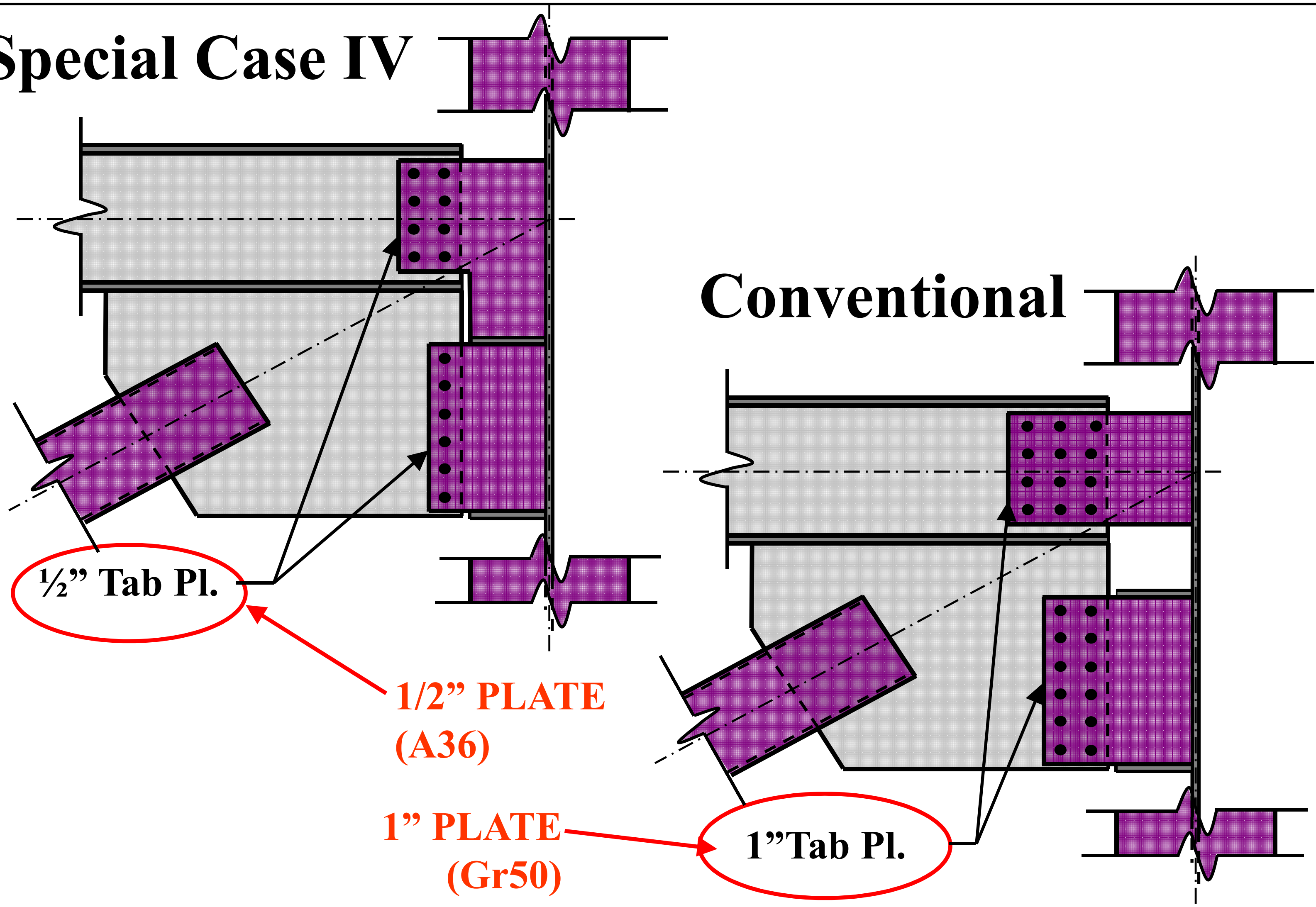
Conventional UFM



Vertical Bracing w/ Ext. Tab
Standard Load Path $e_c = 0$

56

Special Case IV



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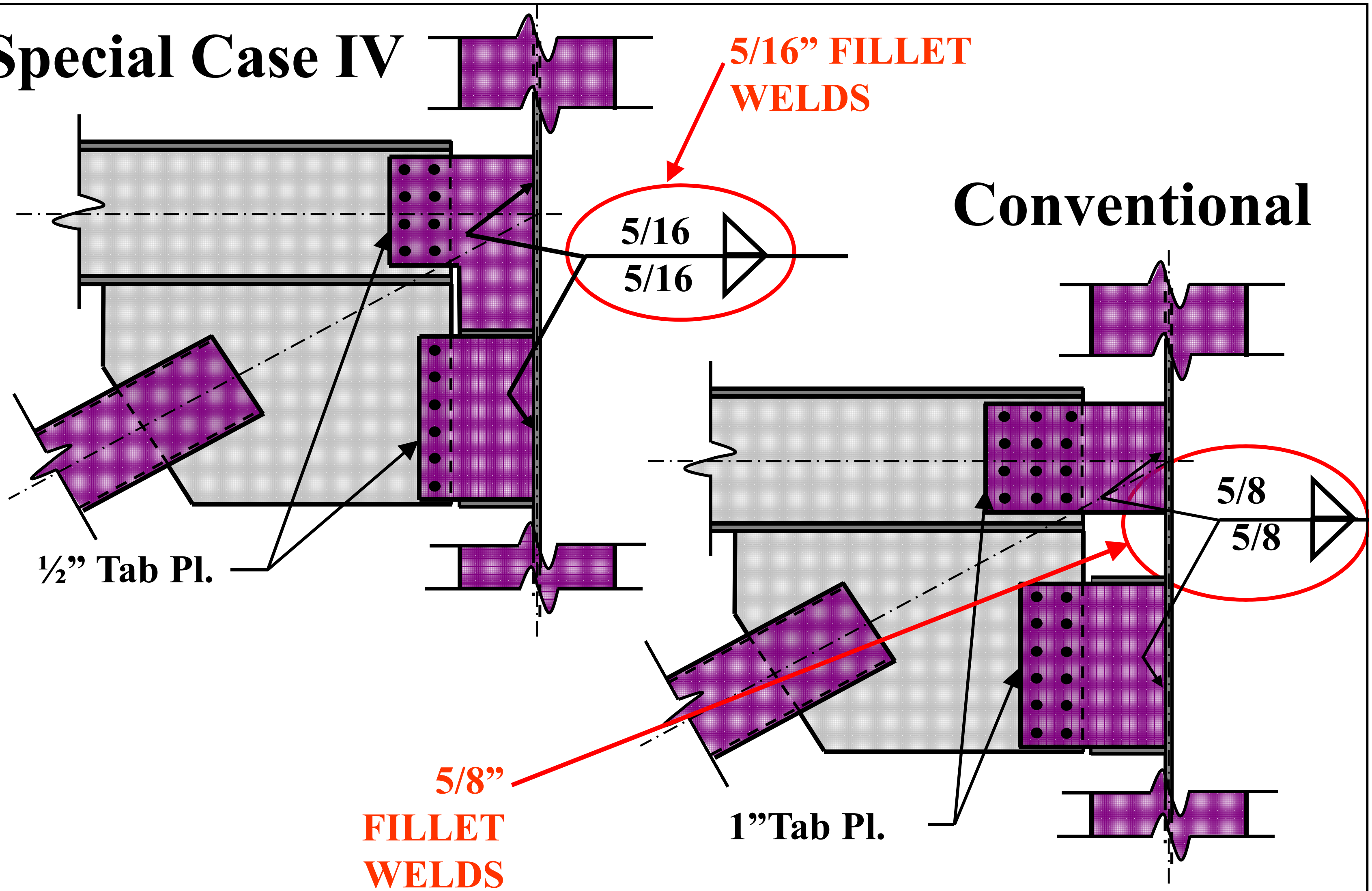
Special Case IV



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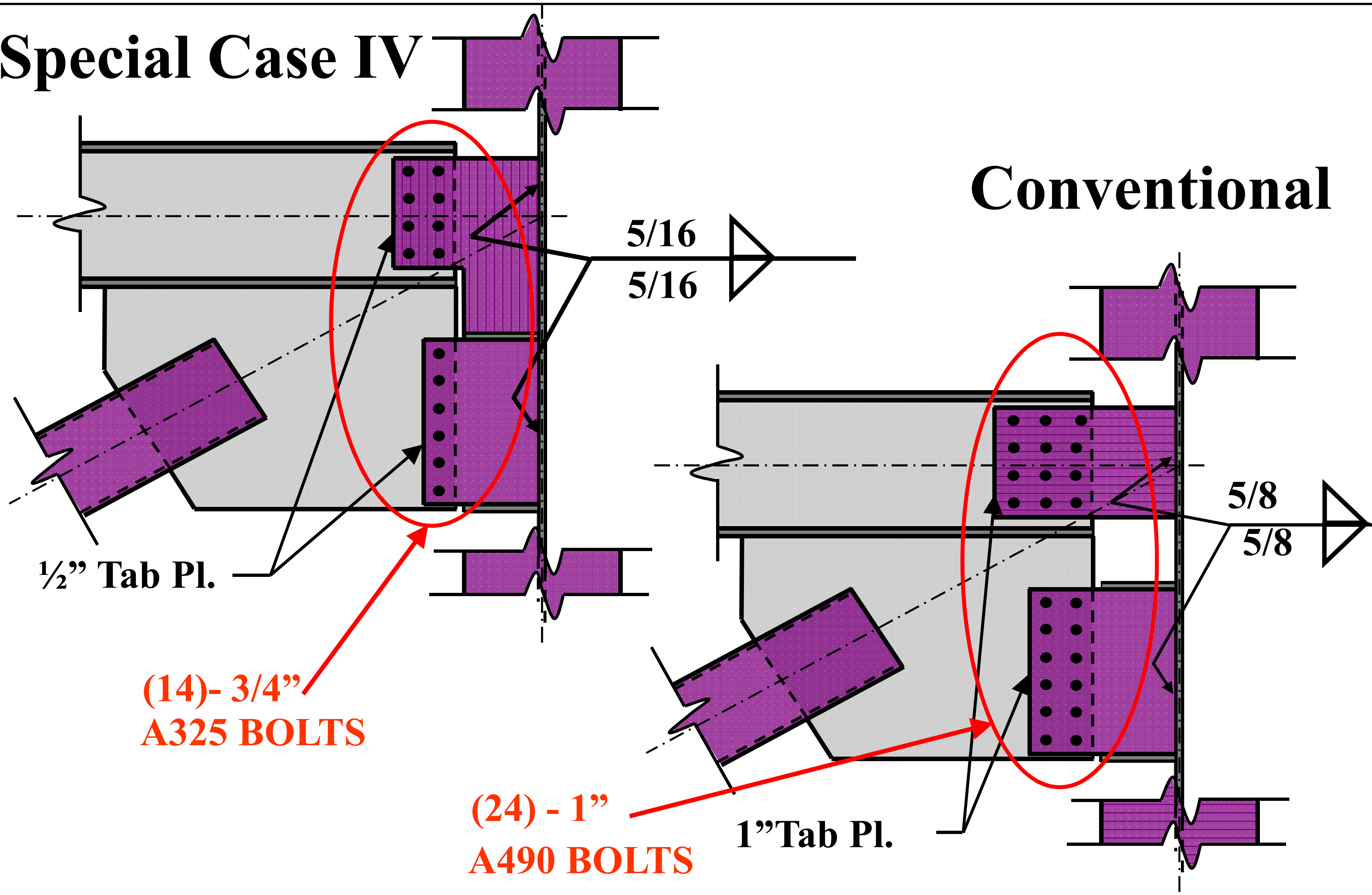
58

Special Case IV



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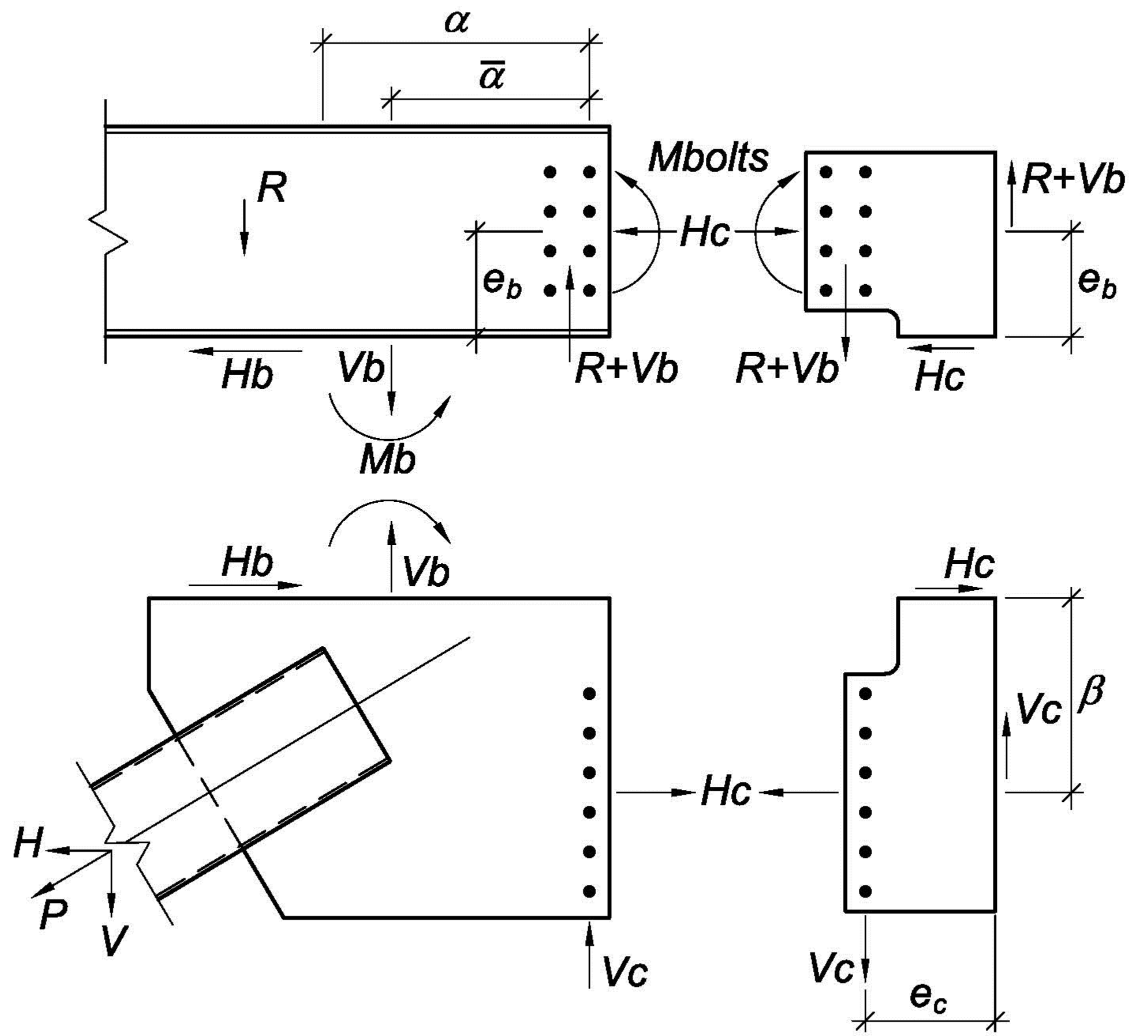
Special Case IV

FBD of Optimum Solution

Special Case IV



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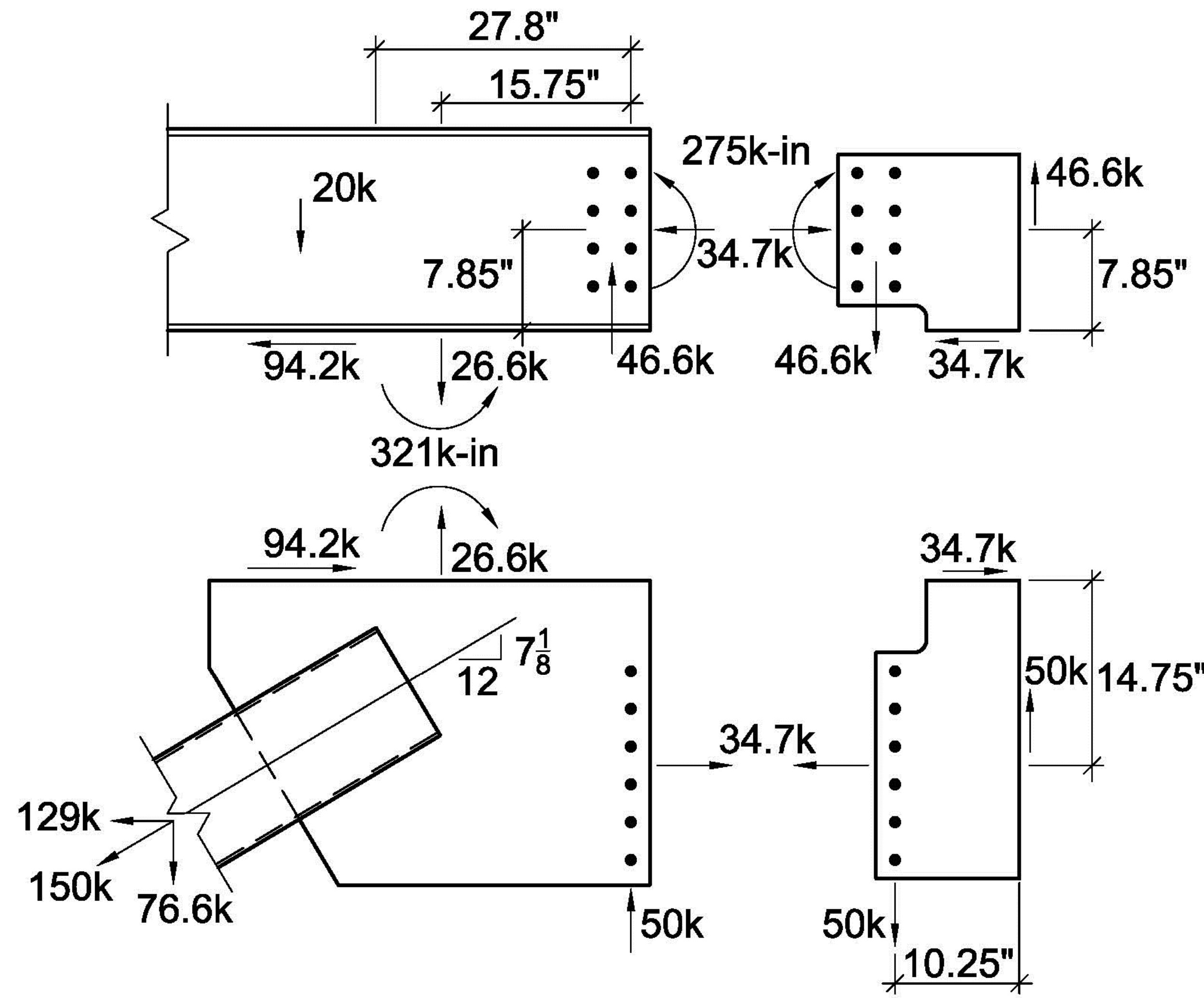
Special Case IV

FBD of Optimum Solution

Special Case IV



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61

Comparison of Design Results

COMPARISON OF DESIGNS RESULTING FROM DIFFERENT LOAD PATHS																
	DRILLING				WELDING				MATERIAL							
	# of Holes	Plate Thick. (in.)	Area Holes (in.^{2})	Vol. of Holes (in.^{3})	Weld Size (in.)	Length (in.)	Volume (in.^{3})	Length Single Pass Weld (in.)	Area of Tabs (ft^2)	Thick. Tabs (ft)	Volume Tabs (ft^3)	Area of Gusset (ft^2)	Thick. Gusset (ft)	Volume Gusset (ft^3)	Weight Connection Plates (lbs)
Standard Load Path	24	1	0.6	14.4	5/8	30.0	5.86	180	3.25	0.083	0.27	5.41	0.0417	0.226	243
Optimum Load Path	14	0.5	0.44	3.09	5/16	52.3	2.55	52.3	3.00	0.042	0.12	5.41	0.0417	0.226	172
Optimum / Standard				21%			44%	29%							71%

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62

Comparison of Design Results

COMPARISON OF DESIGNS RESULTING FROM DIFFERENT LOAD PATHS															
	DRILLING				WELDING				MATERIAL						
	# of Holes	Plate Thick. (in.)	Area Holes (in.^{2})	Vol. of Holes (in.^{3})	Weld Size (in.)	Length (in.)	Volume (in.^{3})	Length Single Pass Weld (in.)	Area of Tabs (ft^2)	Thick. Tabs (ft)	Volume Tabs (ft^3)	Area of Gusset (ft^2)	Thick. Gusset (ft)	Volume Gusset (ft^3)	Weight Connection Plates (lbs)
Standard Load Path	24	1	0.6	14.4	5/8	30.0	5.86	180	3.25	0.083	0.27	5.41	0.0417	0.226	243
Optimum Load Path	14	0.5	0.44	3.09	5/16	52.3	2.55	52.3	3.00	0.042	0.12	5.41	0.0417	0.226	172
Optimum / Standard				21%			44%	29%							71%

± 80% SAVINGS IN DRILLING TIME

Comparison of Design Results

COMPARISON OF DESIGNS RESULTING FROM DIFFERENT LOAD PATHS																
	DRILLING				WELDING				MATERIAL							
	# of Holes	Plate Thick. (in.)	Area Holes ($in.^2$)	Vol. of Holes ($in.^3$)	Weld Size (in.)	Length (in.)	Volume ($in.^3$)	Length Single Pass Weld (in.)	Area of Tabs (ft^2)	Thick. Tabs (ft)	Volume Tabs (ft^3)	Area of Gusset (ft^2)	Thick. Gusset (ft)	Volume Gusset (ft^3)	Weight Connection Plates (lbs)
Standard Load Path	24	1	0.6	14.4	5/8	30.0	5.86	180	3.25	0.083	0.27	5.41	0.0417	0.226	243
Optimum Load Path	14	0.5	0.44	3.09	5/16	52.3	2.55	52.3	3.00	0.042	0.12	5.41	0.0417	0.226	172
Optimum / Standard				21%			44%	29%							71%

± 50% SAVINGS IN WELD CONSUMABLES

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Comparison of Design Results

COMPARISON OF DESIGNS RESULTING FROM DIFFERENT LOAD PATHS															
	DRILLING				WELDING				MATERIAL						
	# of Holes	Plate Thick. (in.)	Area Holes (in.^{2})	Vol. of Holes (in.^{3})	Weld Size (in.)	Length (in.)	Volume (in.^{3})	Length Single Pass Weld (in.)	Area of Tabs (ft^2)	Thick. Tabs (ft)	Volume Tabs (ft^3)	Area of Gusset (ft^2)	Thick. Gusset (ft)	Volume Gusset (ft^3)	Weight Connection Plates (lbs)
Standard Load Path	24	1	0.6	14.4	5/8	30.0	5.86	180	3.25	0.083	0.27	5.41	0.0417	0.226	243
Optimum Load Path	14	0.5	0.44	3.09	5/16	52.3	2.55	52.3	3.00	0.042	0.12	5.41	0.0417	0.226	172
Optimum / Standard				21%			44%	29%							71%

± 60% SAVINGS IN WELDING LABOR

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Comparison of Design Results

COMPARISON OF DESIGNS RESULTING FROM DIFFERENT LOAD PATHS																
	DRILLING				WELDING				MATERIAL							
	# of Holes	Plate Thick. (in.)	Area Holes (in.^{2})	Vol. of Holes (in.^{3})	Weld Size (in.)	Length (in.)	Volume (in.^{3})	Length Single Pass Weld (in.)	Area of Tabs (ft^2)	Thick. Tabs (ft)	Volume Tabs (ft^3)	Area of Gusset (ft^2)	Thick. Gusset (ft)	Volume Gusset (ft^3)	Weight Connection Plates (lbs)
Standard Load Path	24	1	0.6	14.4	5/8	30.0	5.86	180	3.25	0.083	0.27	5.41	0.0417	0.226	243
Optimum Load Path	14	0.5	0.44	3.09	5/16	52.3	2.55	52.3	3.00	0.042	0.12	5.41	0.0417	0.226	172
Optimum / Standard				21%			44%	29%							71%

± 30% SAVINGS IN MATERIAL

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The Uniform Force Method

The Uniform Force Method is not based on theory alone.

The concept of concentrically loaded interfaces developed from observations of the tests run by Richard.

ANALYTICAL AND PHYSICAL TESTING

ORIGINS OF UNIFORM FORCE METHOD

STEEL CONNECTION DESIGN

BASED ON

INELASTIC FINITE ELEMENT ANALYSIS

A DESIGN REPORT PREPARED FOR

AMERICAN INSTITUTE OF STEEL CONSTRUCTION

GEORGE C. WILLIAMS, Ph.D.

RALPH M. RICHARD, Ph.D.,P.E.

UNIVERSITY OF ARIZONA

ALSO PROCEEDINGS, AISC NATIONAL STEEL CONSTRUCTION CONFERENCE, NASHVILLE, TN, 1986

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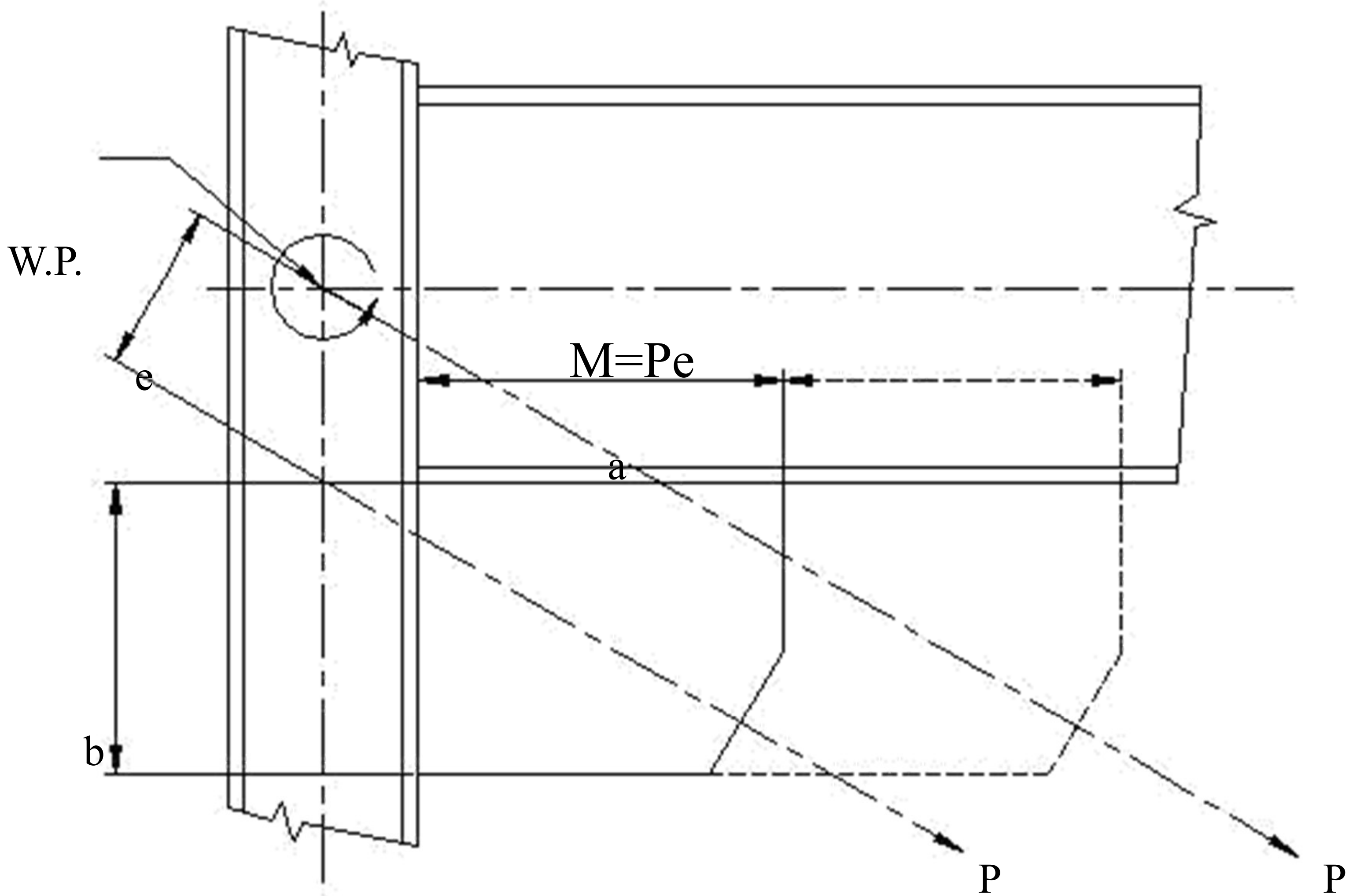
69



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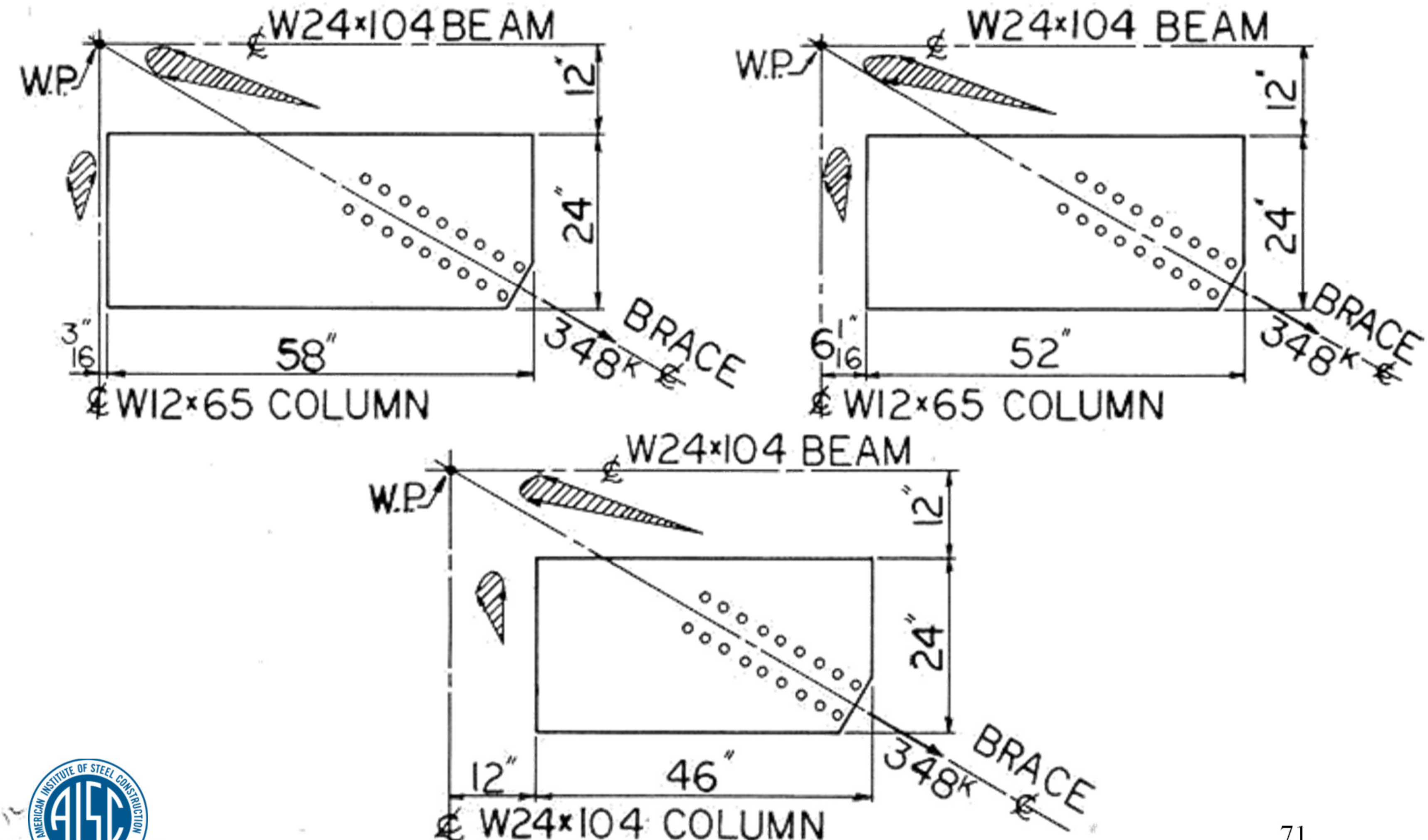
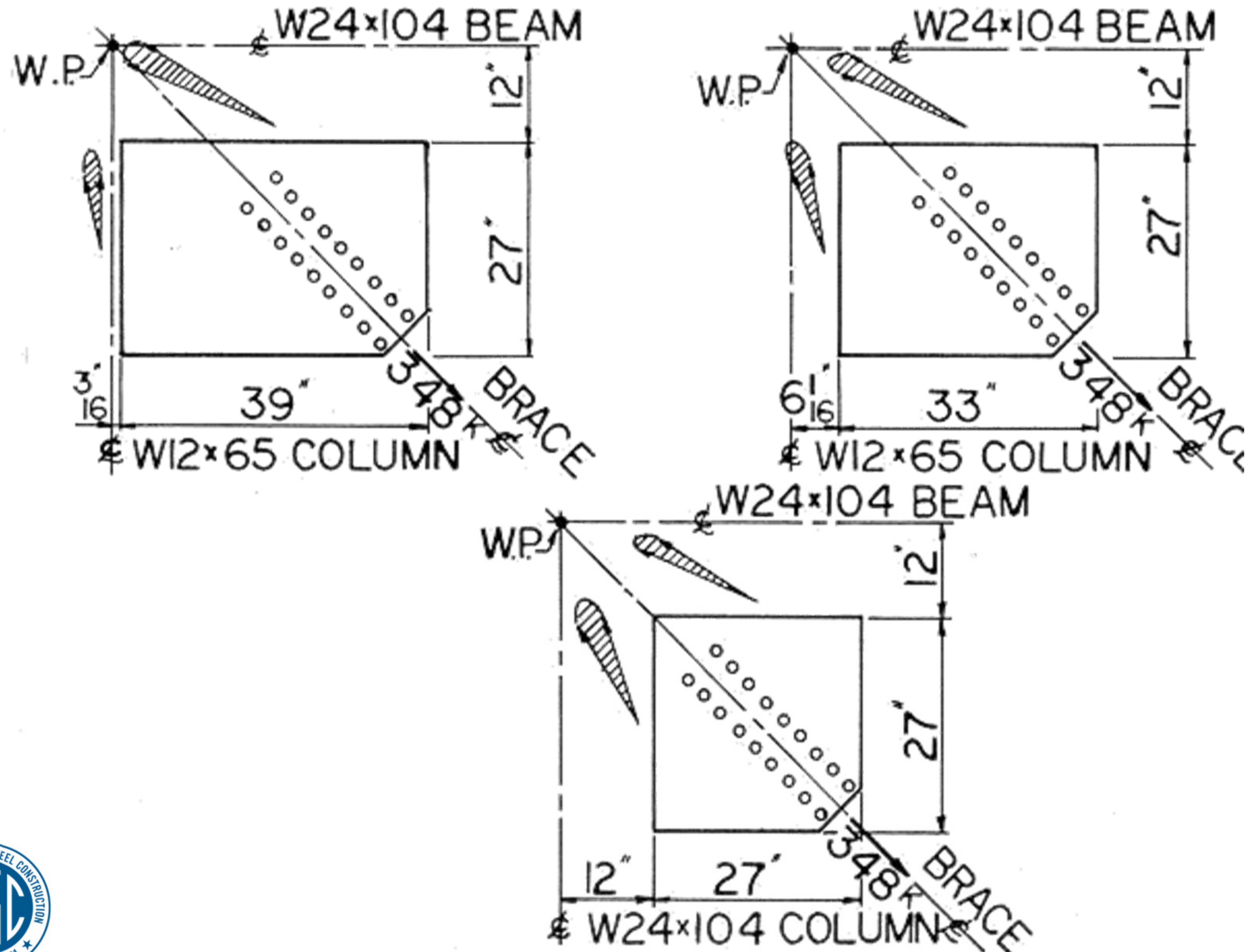
GUSSET EDGE FORCE RESULTANT ENVELOPES
30º WORKING POINT MODELS



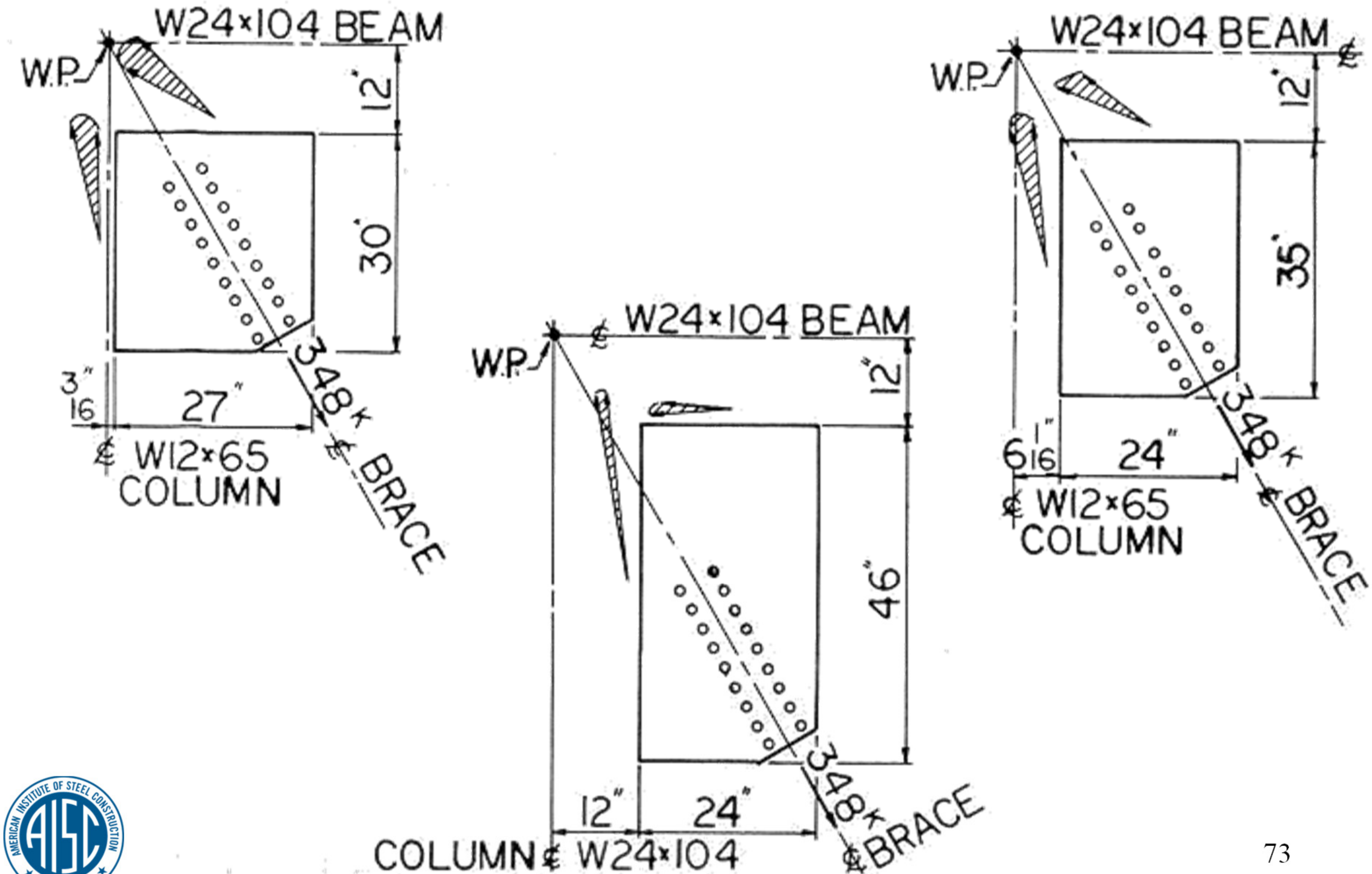
71

GUSSET EDGE FORCE RESULTANT ENVELOPE
45º WORKING POINT MODELS



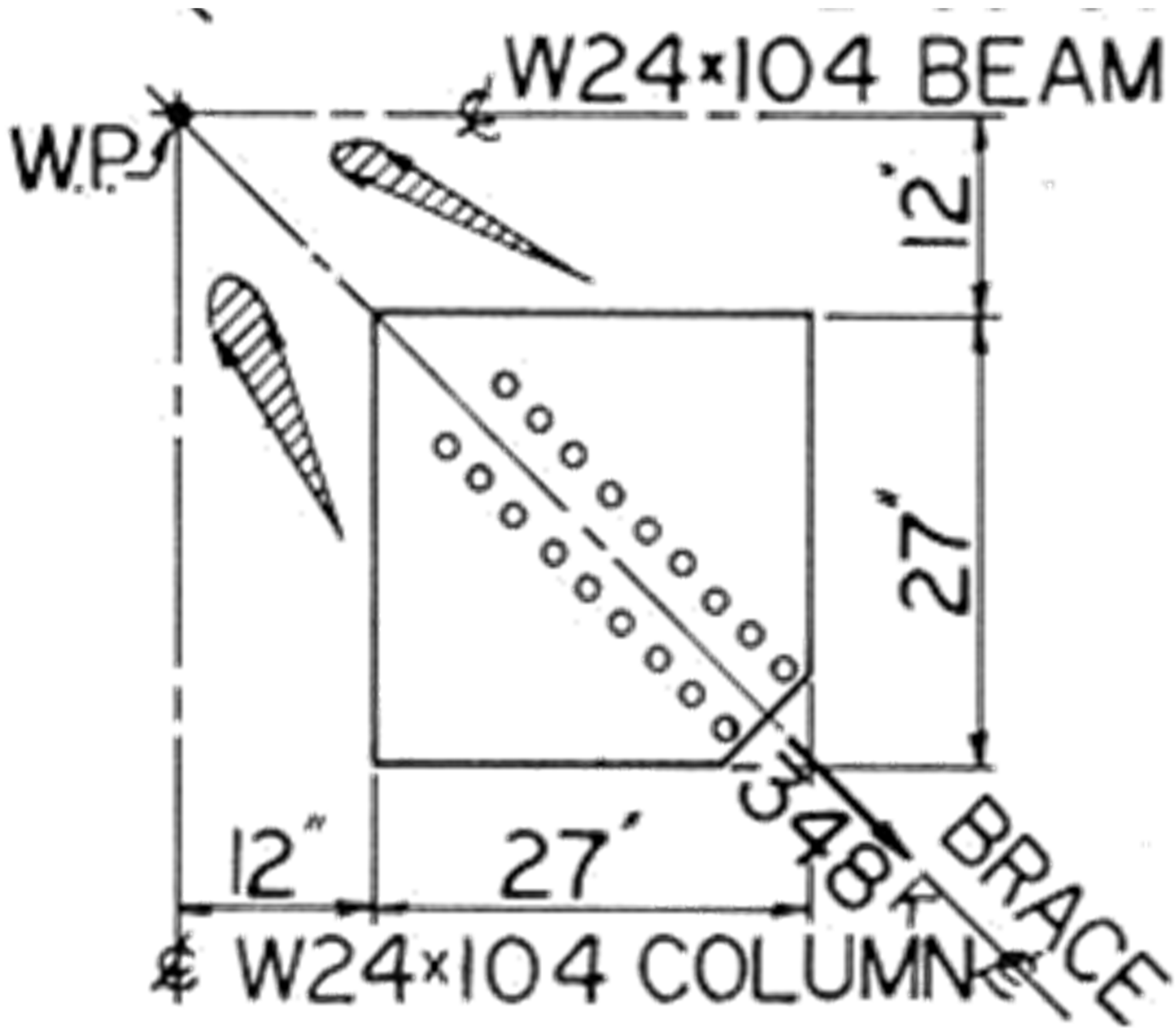
72

GUSSET EDGE FORCE RESULTANT ENVELOPES
60º WORKING POINT MODELS

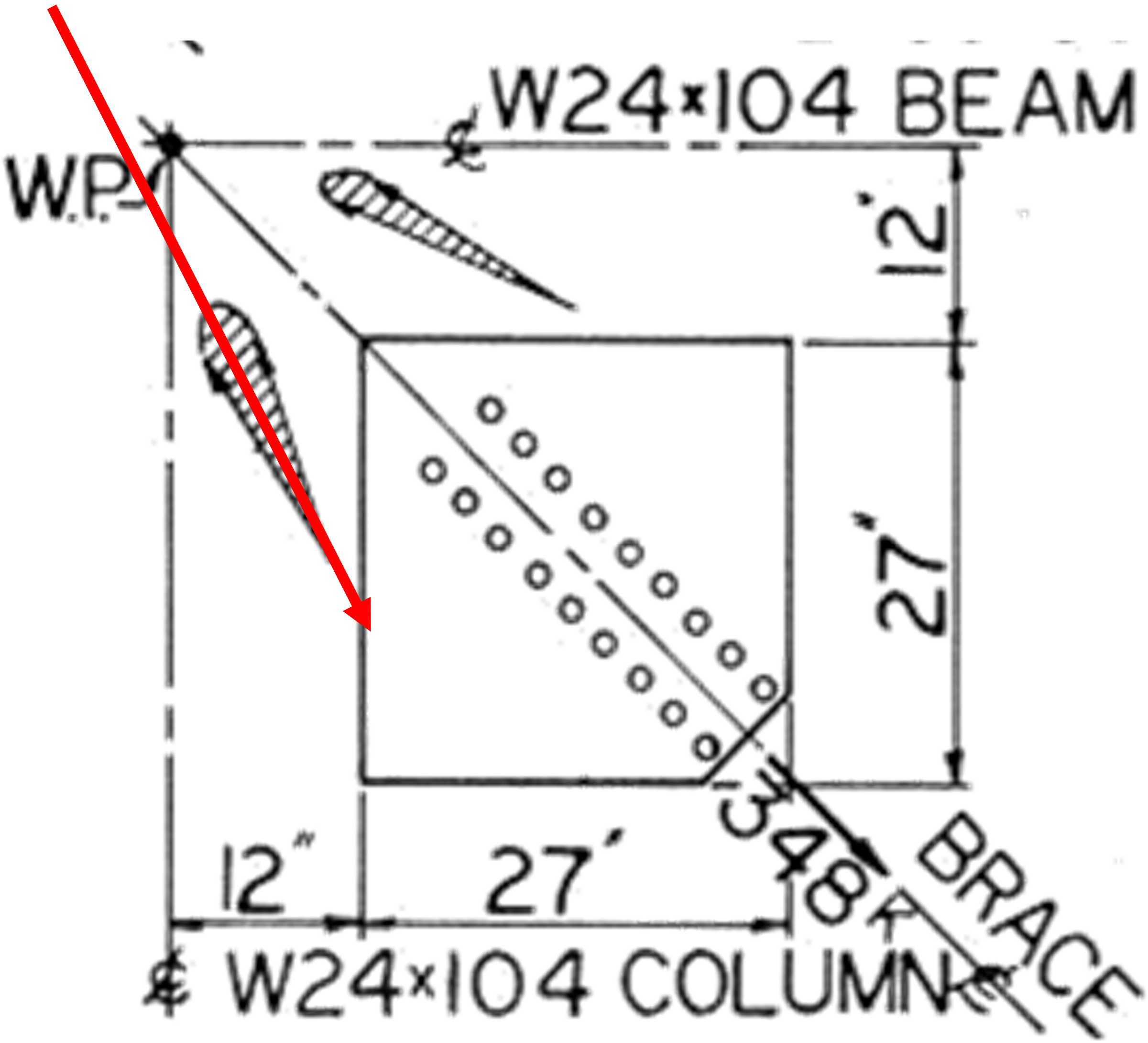


73

GUSSET EDGE FORCE RESULTANT ENVELOPE
45º WORKING POINT MODELS

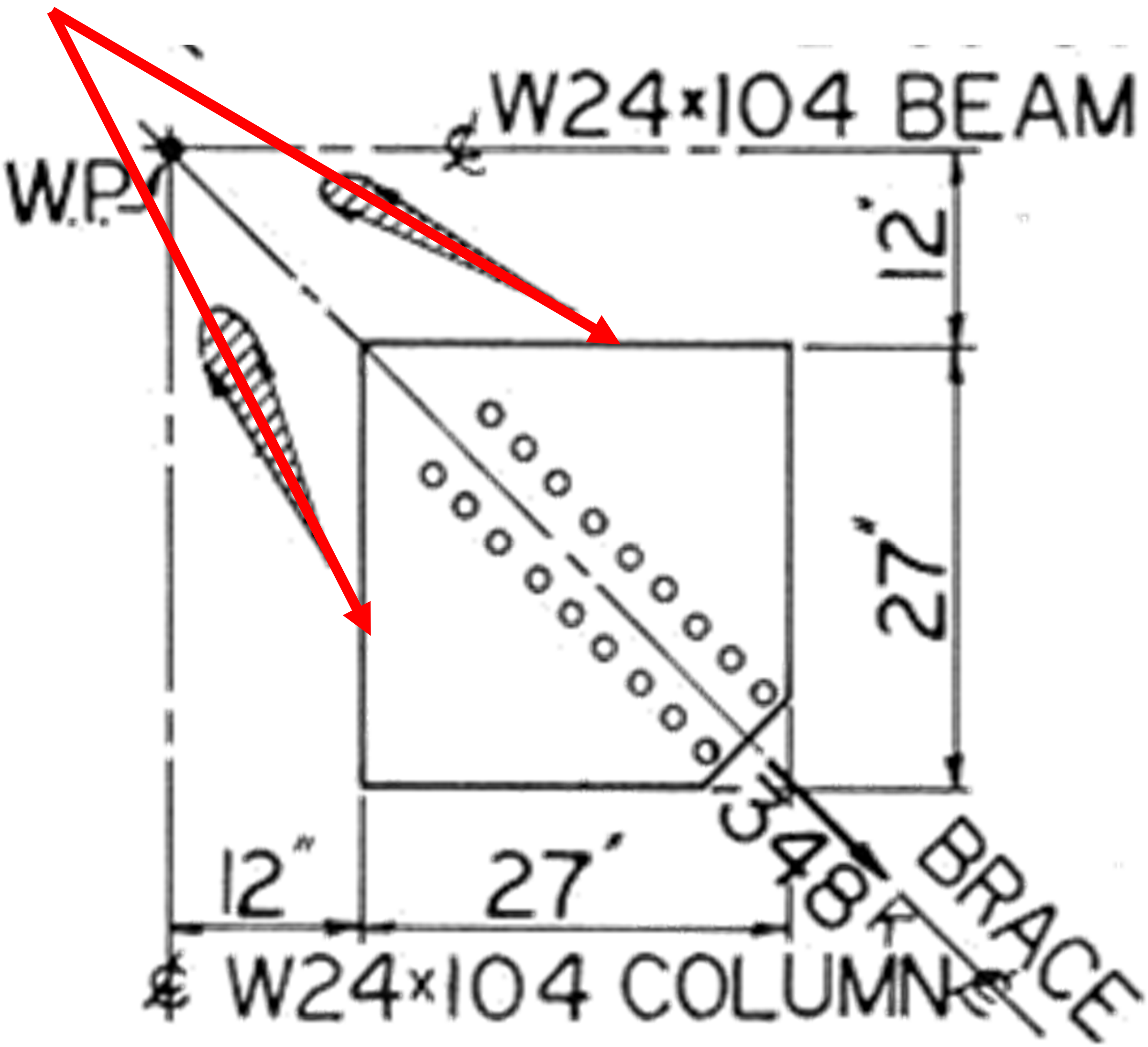


GUSSET EDGE FORCE RESULTANT ENVELOPE
45º WORKING POINT MODELS



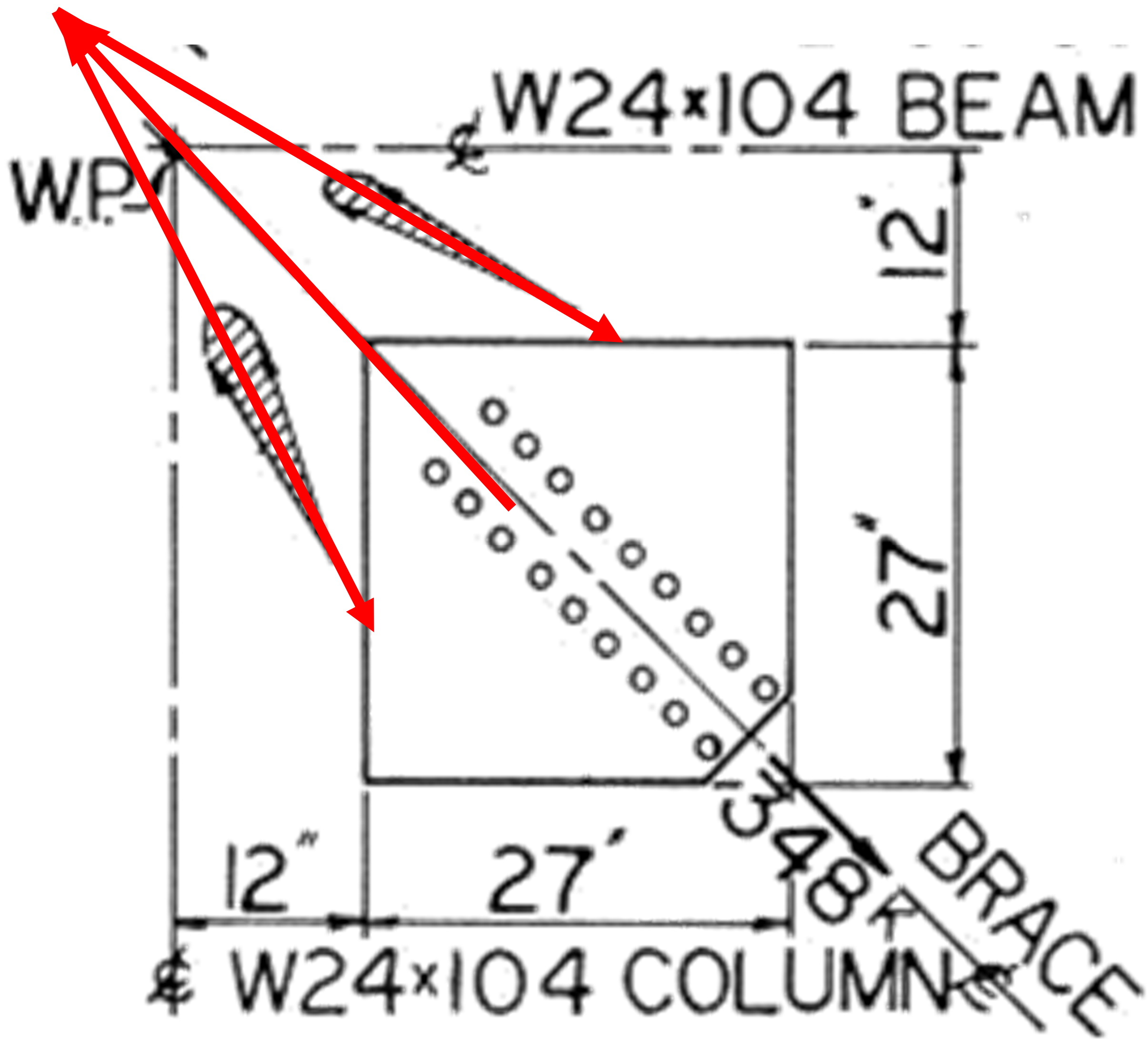
75

GUSSET EDGE FORCE RESULTANT ENVELOPE 45° WORKING POINT MODELS



76

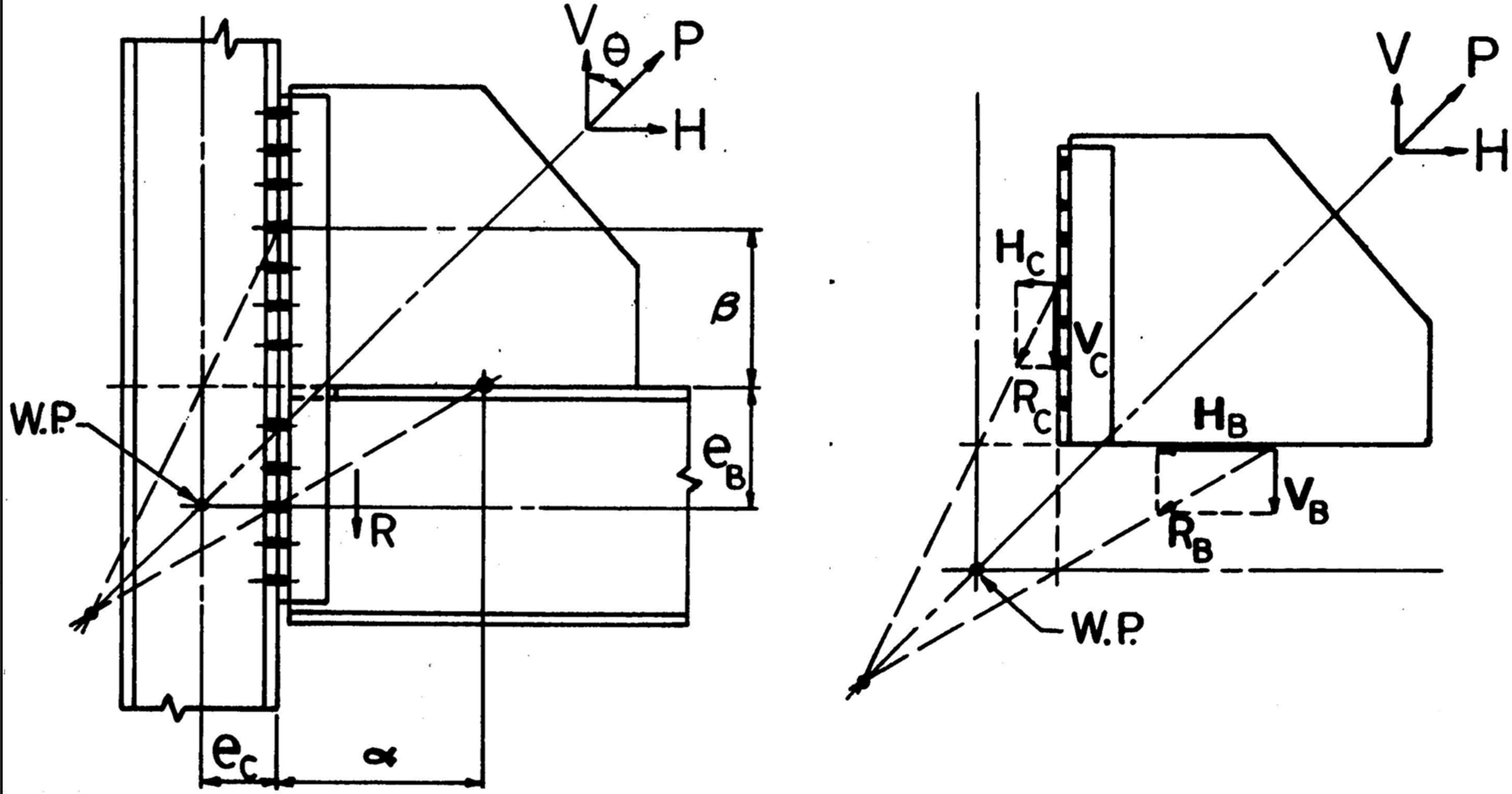
GUSSET EDGE FORCE RESULTANT ENVELOPE
45º WORKING POINT MODELS



77

The force distributions shown on the previous four slides, based on the work of Ralph Richard, gave rise to the UFM force distribution shown on the next slide

UNIFORM FORCE METHOD (UFM) ADMISSIBLE FORCE FIELD



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The UFM was first introduced in 1991

"On the Analysis and Design of Bracing Connections", William A. Thornton, Proceedings of the 1991 AISC National Steel Construction Conference, Washington, DC, June

A version of this paper is available on the Cives Steel Company website at

www.cives.com

Comparison of the Uniform Force Method with Physical Test Results

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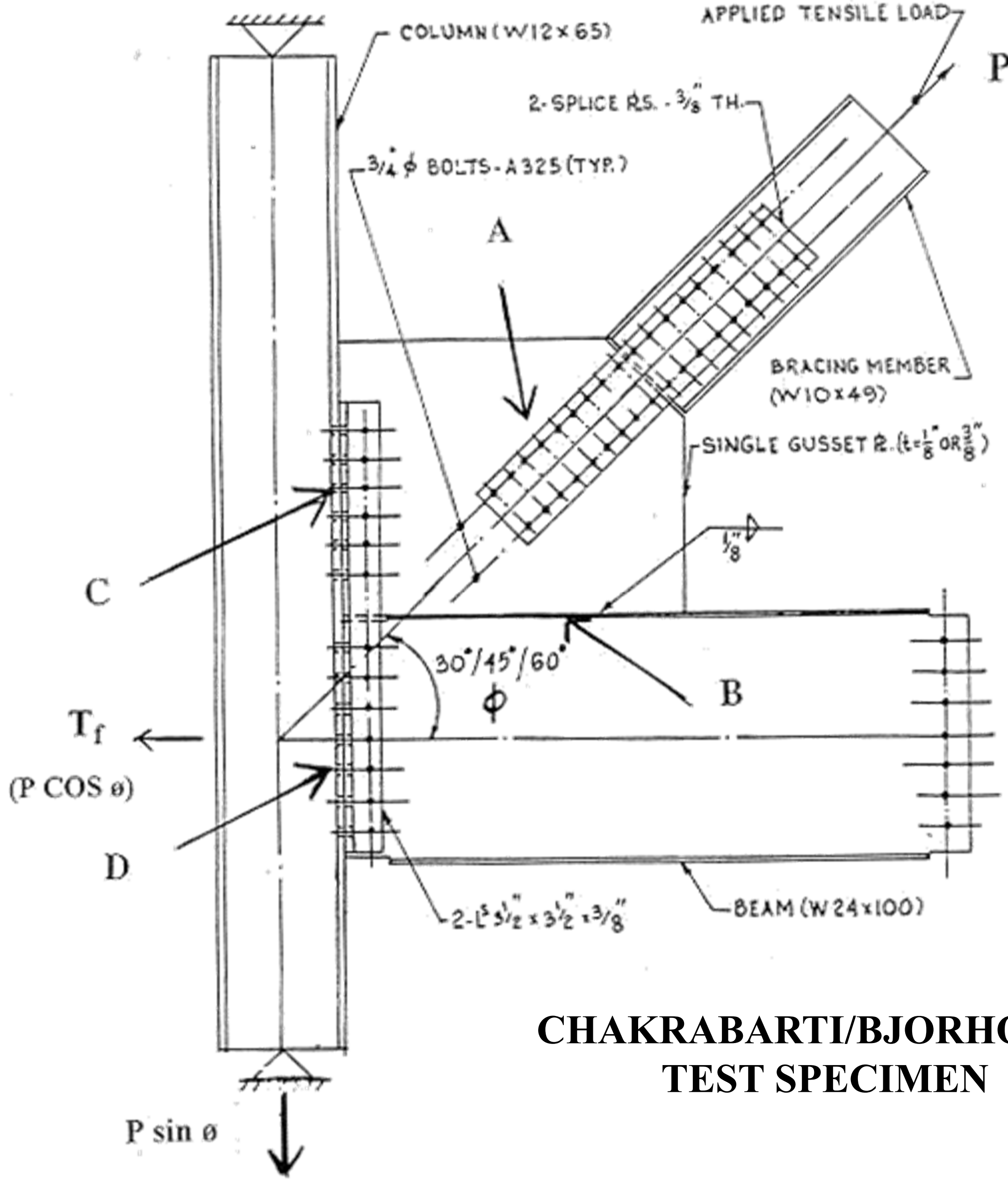
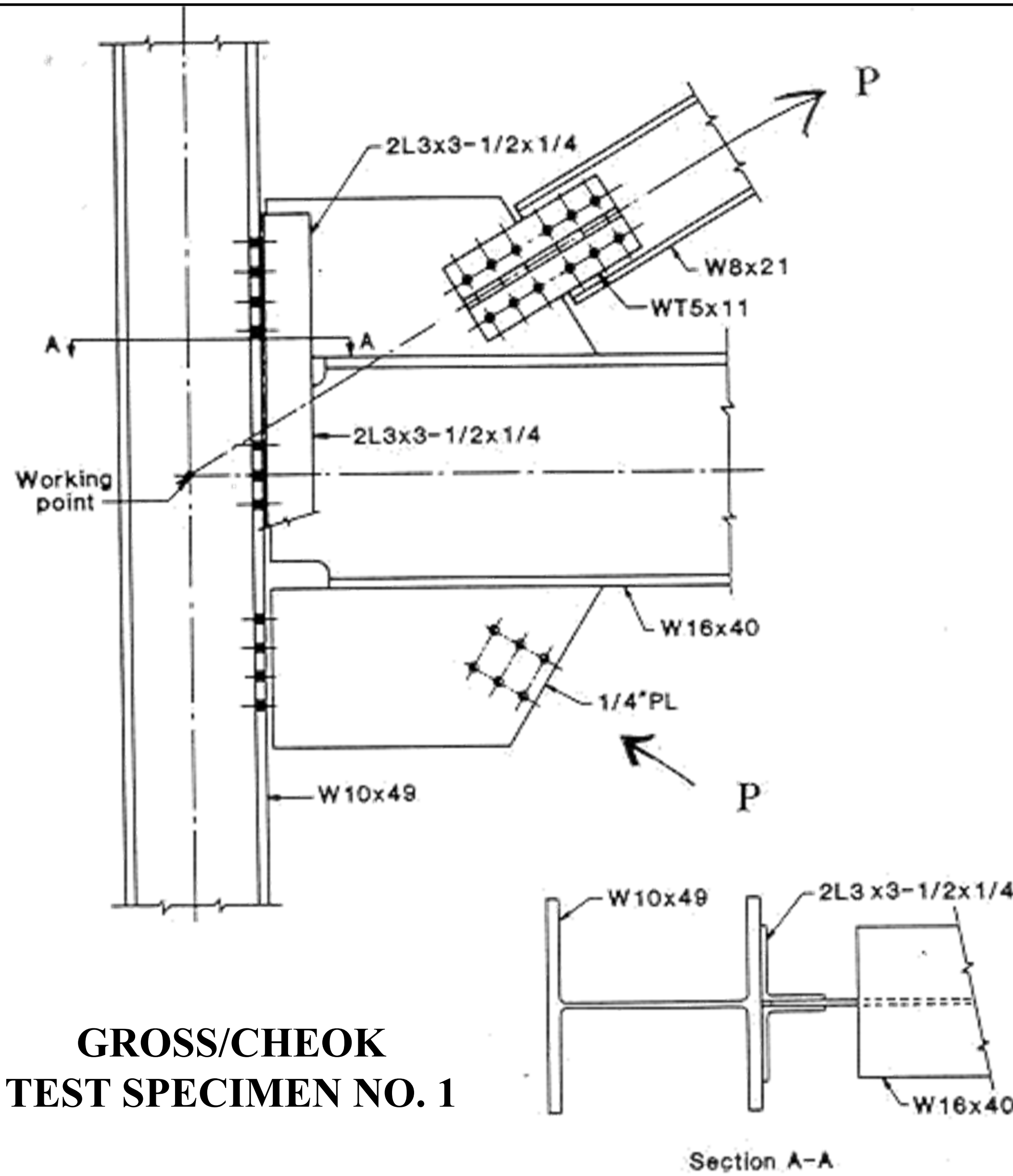
81



CHAKRABARTI/BJORHOVDE TEST SPECIMEN

82



GROSS/CHEOK
TEST SPECIMEN NO. 1

83

Limit State Identification for Bracing Connections

Limit State Type	Limit State Number
Bolt Shear Fracture	1
Bolt Shear/Tension Fracture	2
Whitmore Yield	3
Whitmore Buckling	4
Tearout Fracture	5
Bearing	6
Gross Section Yield	7
Net Section Fracture	8
Fillet Weld Fracture	9
Beam Web Yield (beyond *k* distance)	10
Bending (including Prying Action) Yield	11
Bending (including Prying Action) Fracture	12

Limit States Considered for Each Interface of the Bracing Connection

Connection Interface	Connection Element	Limit States
Brace to Gusset (A)	Bolts to Gusset	1
	Gusset	3,4,5,6
	Bolts to Brace	1
	Brace	5,6,7,8
	Splice plates or WTs	5,6,7,8
Gusset to Beam (B)	Gusset	7
	Fillet Weld	9
	Beam Web	10
Gusset to Column (C)	Bolts to Gusset	1
	Fillet Weld to Gusset	9
	Gusset	6,7,8
	Bolts to Column	2
	Clip Angles	6,7,8,11,12
	Column	6,11,12
Beam to Column (D)	Bolts to Beam Web	1
	Fillet Weld to Beam Web	9
	Beam Web	6,7,8
	Bolts to Column	2
	Clip Angles	6,7,8,11,12
	Column	6,11,12

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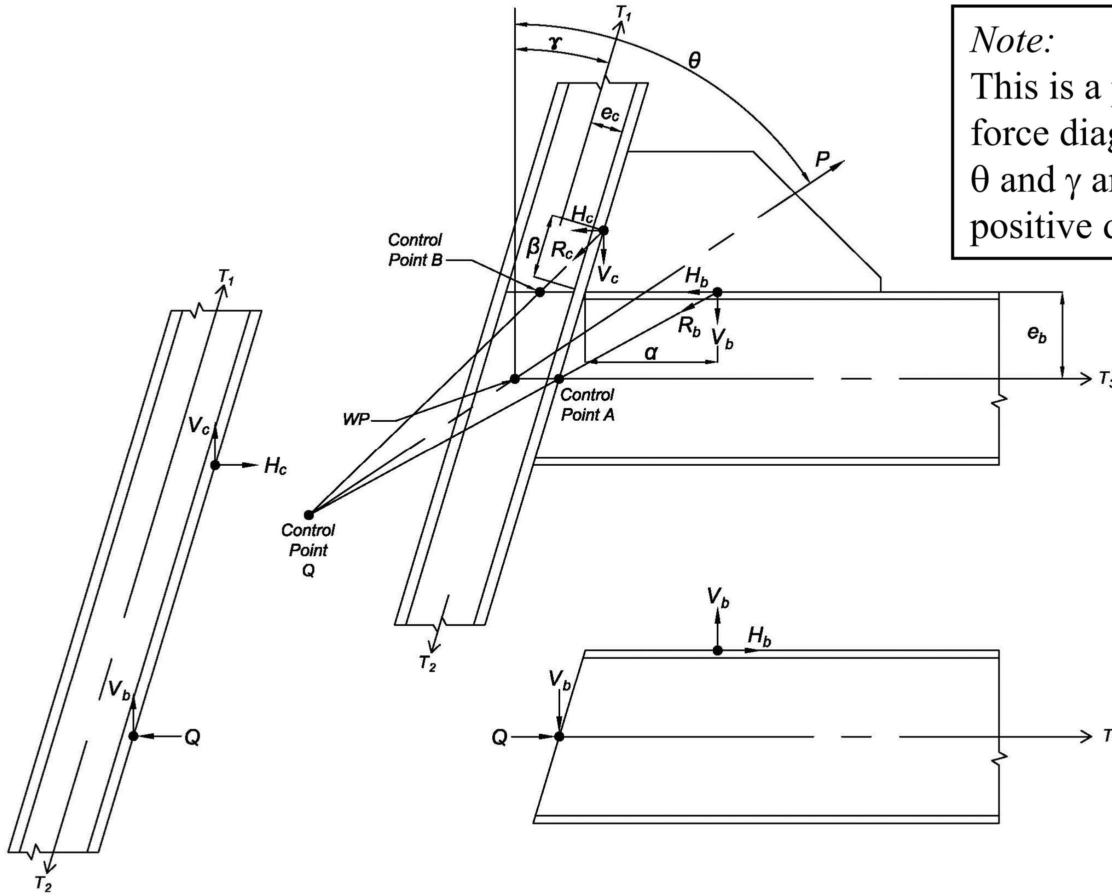
Comparison of Uniform Force Method Predicted Results with Test Results

Test Specimen	Predicted Results						Test Results		
	Brace To Gusset A (kips)	Gusset to Beam B (kips)	Gusset to Column C (kips)	Beam to Column D (kips)	Predicted Capacity (kips)	Predicted Failure Interface	Test Capacity (kips)	Test Failure Interface	Test Capacity / Predicted Capacity
Chakrabarti/ Bjorkovde 30°	142 (3,5)[(1)]	184 (7)	216 (5)	152 (3,5)	142 (3,5)	A (3,5)	143	A (5)	1.01
Charkrabarti/ Bjorhobde 45 °	142 (3,5)	182 (7)	164 (5)	210 (12)	142 (3,5)	A (3,5)	148	A (5)	1.04
Chakrabarti/ Bjorhovde 60 °	142 (3,5)	169 (7)	155 (5)	342 (12)	142 (3,5)	A (3,5)	158	C (5)	1.11
Gross/ Cheok No. 1	73 (4)	212 (7)	67 (12)	149 (9)	67 (12)	C (12)	116	A (4)	1.73
Gross/ Cheok No. 2	78 (4)	77 (7)	143 (7)	NL[(2)]	77 (7)	B (7)	138	A (4)	1.79
Gross/ Cheok No. 3	84 (4)	94 (7)	171 (7)	NL[(2)]	84 (4)	A (4)	125	A (5)	1.49

(1) Limit state number from Table , typical
(2) NL = No Limit: this part of connection does not carry any of brace load P

86

Non-Orthogonal UFM



Note:
This is a positive force diagram where θ and γ are in the positive direction.

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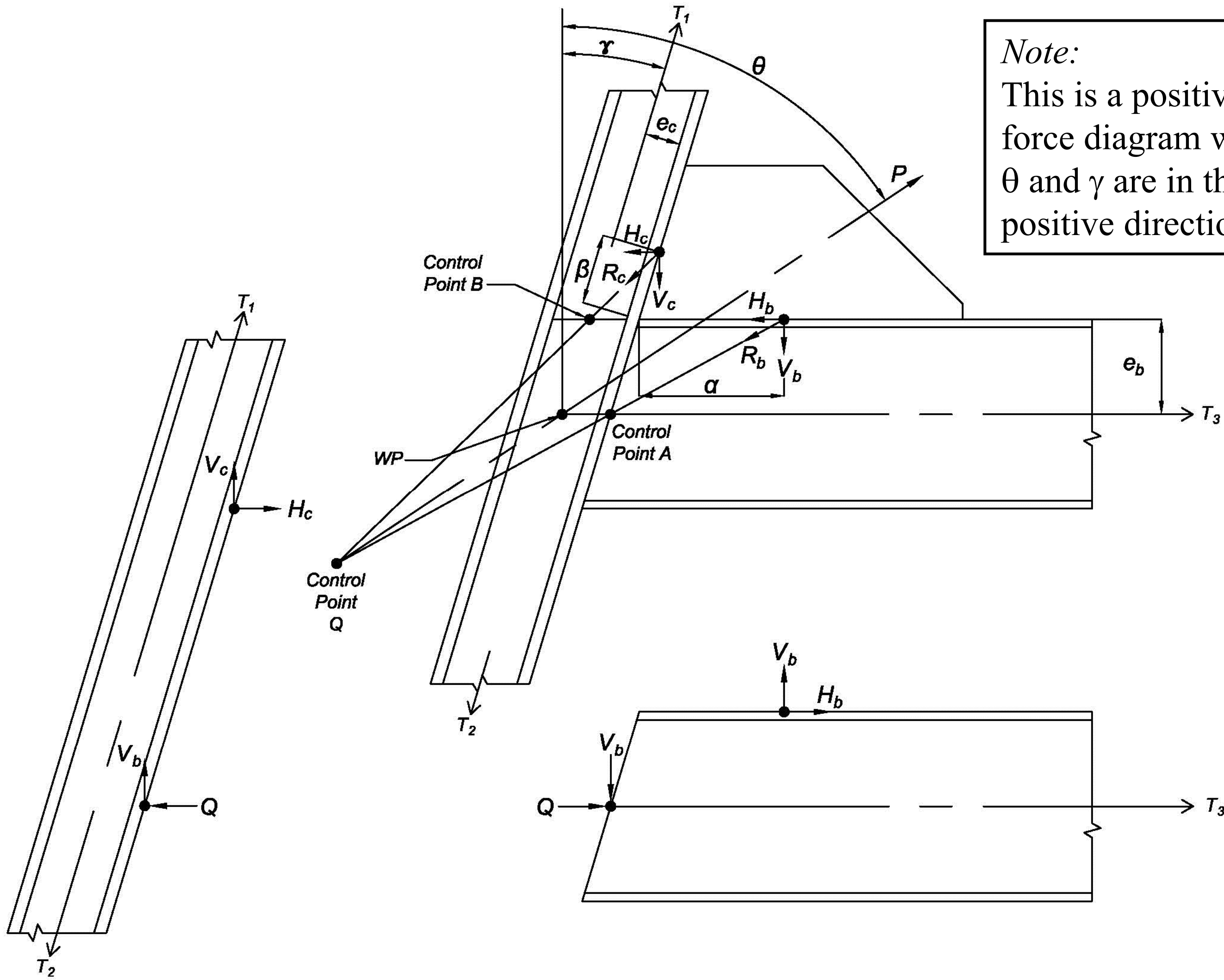

Note:
This is a positive force diagram where θ and γ are in the positive direction.

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Non-Orthogonal UFM

$$\alpha - \beta(\cos\gamma \tan\theta - \sin\gamma) = e_b(\tan\theta - \tan\gamma) - \frac{e_c}{\cos\gamma}$$

$$V_b = \frac{(e_b)}{(r)} P$$

$$H_b = \frac{\alpha + e_b \tan\gamma}{r} P$$

$$V_c = \frac{\beta \cos\gamma}{r} P$$

$$H_c = (\beta \sin\gamma + e_c / \cos\gamma)\, P / r$$

$$Q = H_c - P\cos\theta \tan\gamma$$

$$r = \sqrt{\left(\alpha + e_c \tan\gamma + \beta\sin\gamma + \frac{e_c}{\cos\gamma}\right)^2 + (e_b + \beta\cos\gamma)^2}$$

89

Another Example

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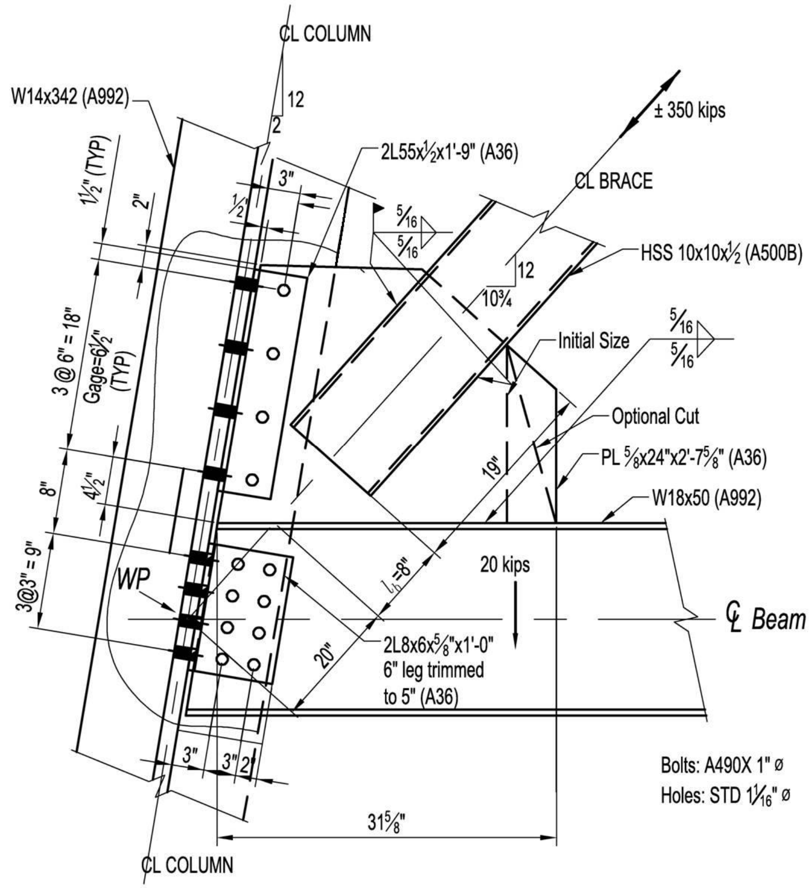
Bracing Connection with Sloping Column

From AISC Bracing Design Guide 29 (To appear)



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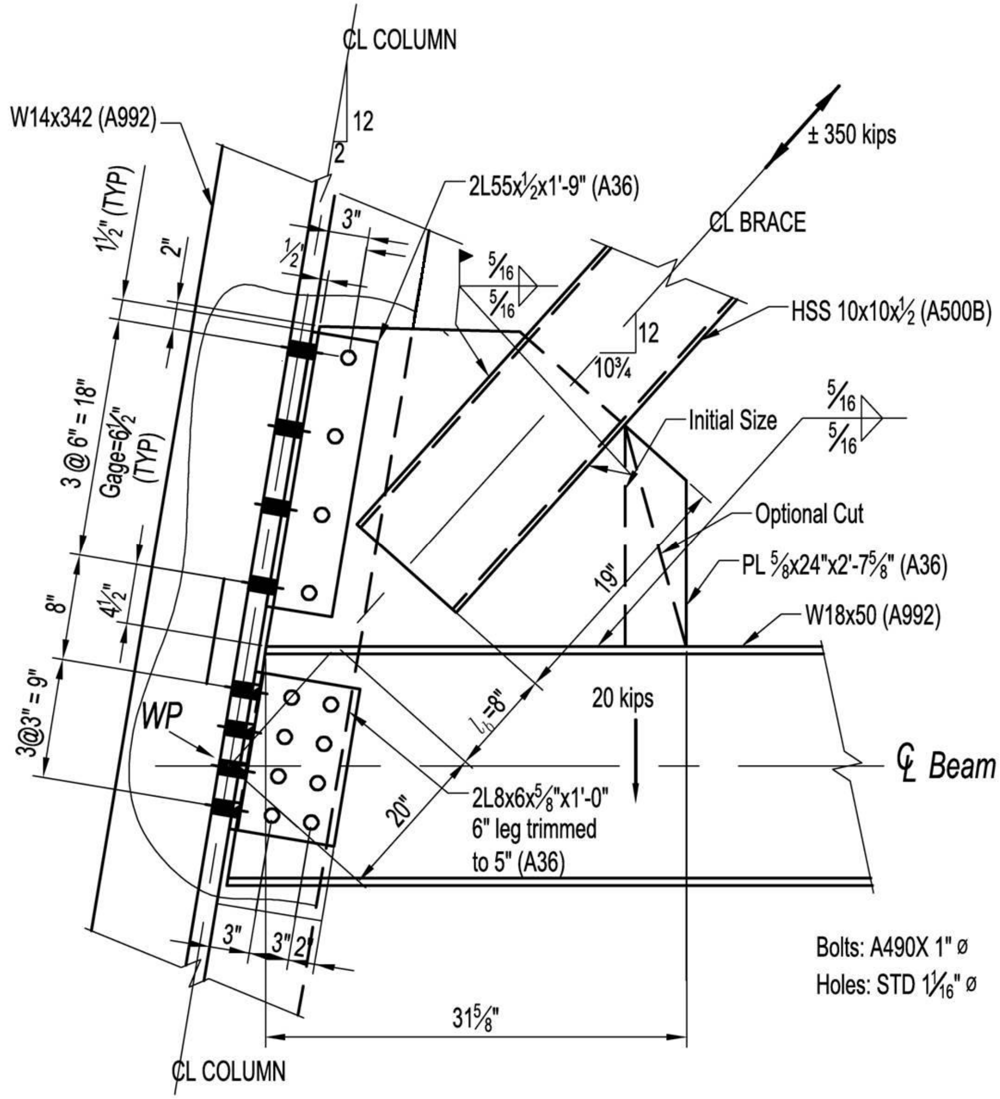

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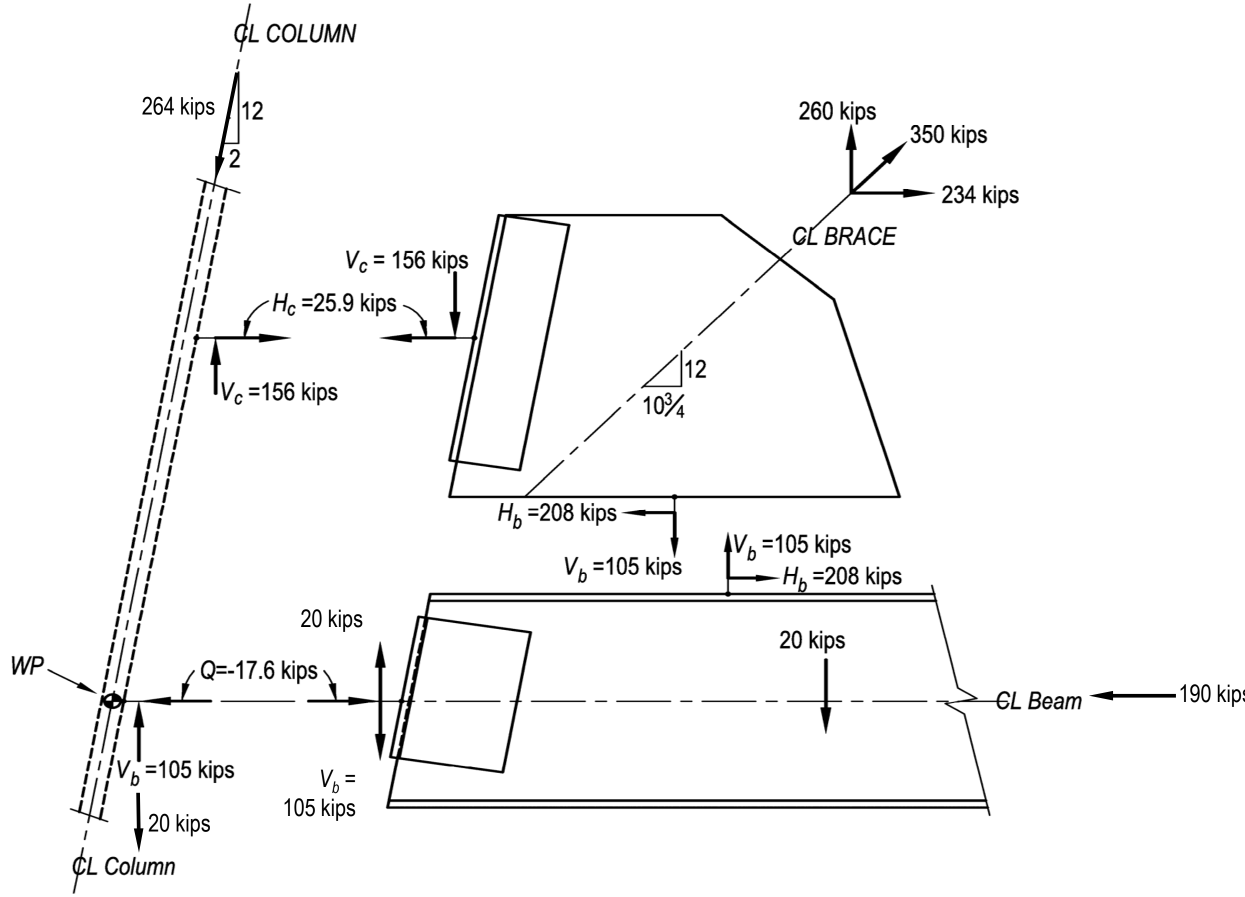
Design for a sloping building column

Admissible Force Field



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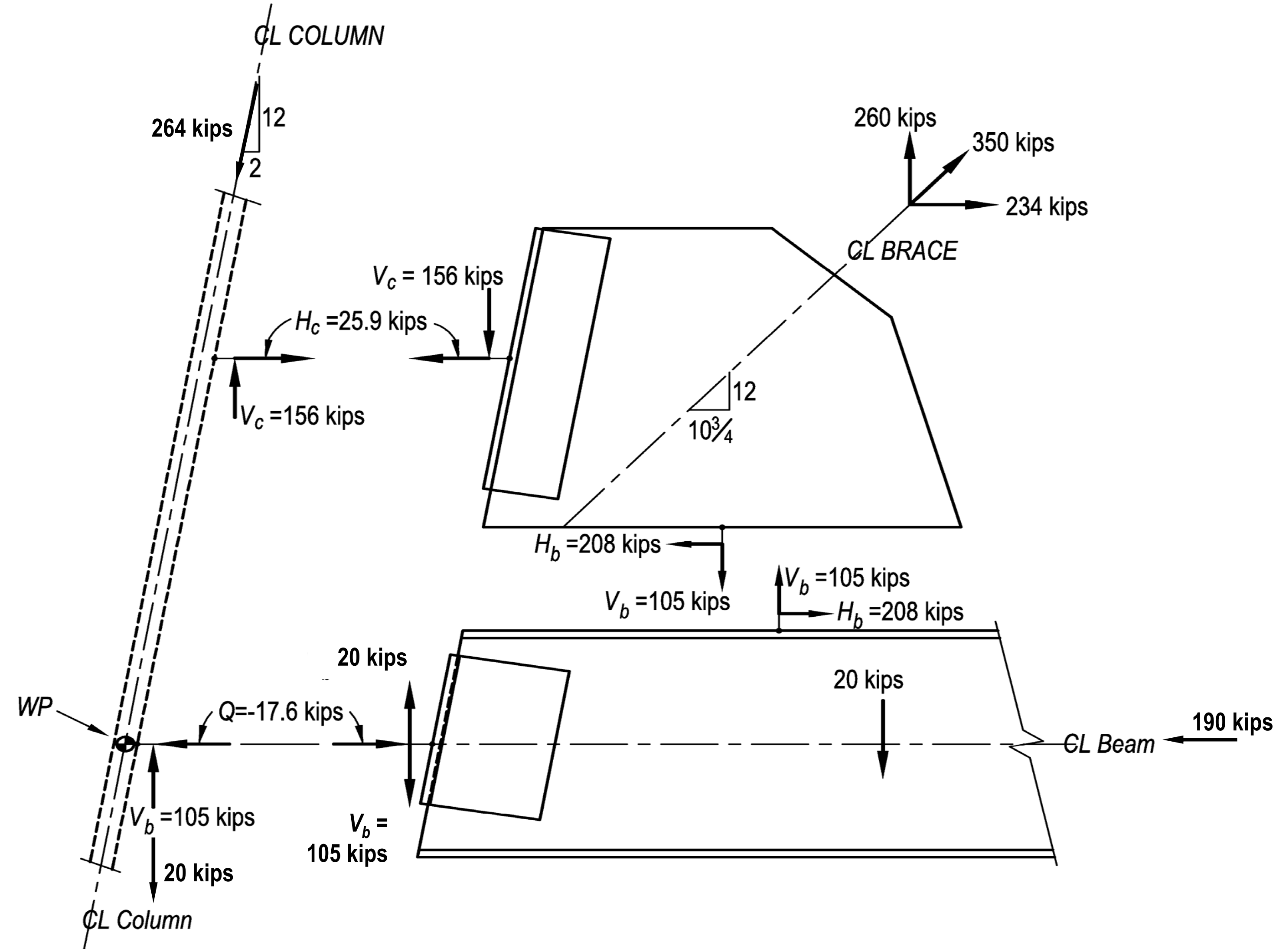
93



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Calculations

$e_c = 0.0$, $e_b = 9.0$ in.

$\tan \gamma = 2/12$, $\gamma = 9.46$ deg.

$\sin \gamma = 0.164$, $\cos \gamma = 0.986$

$\tan \theta = 10.75/12$

Set $\beta = 13.5$ in., centroid of gusset to column connection

Calculations

From the constraint,

$$\alpha = e_b(\tan\theta - \tan\gamma) - e_c/\cos\gamma + \beta(\cos\gamma\tan\theta - \sin\gamma)$$

$$\alpha = 9.0(0.896 - 0.167) - 0 + 13.5(0.986 \times 0.896 - 0.164)$$

$$= 16.3 \text{ in.}$$

Calculations (continued)

$$r = [(\alpha + e_b \tan\gamma + \beta \sin\gamma + e_c/\cos\gamma)^2 + (e_b + \beta \cos\gamma)^2]^{1/2}$$

$$r = [(16.3+9.0\times0.167+13.5\times0.164+0)^2+(9.0+13.5\times0.986)^2]^{1/2}$$
$$= 30.0 \text{ in.}$$

$$P/r = 350 \text{ kips}/30.0 \text{ in.} = 11.7 \text{ kips/in.}$$

Calculations (continued)

$V_b = e_b(P/r) = 9.0 \times 11.7 = 105$ kips

$V_c = \beta \cos\gamma (P/r) = 13.5 \times 0.986 \times 11.7 = 156$ kips

$\Sigma(V_b + V_c) = 261$ kips

Brace vertical component = 350 cosθ = 261 kips OK

Calculations (continued)

$H_b = (\alpha + e_b \tan\gamma)(P/r) = (16.3 + 9.0 \times 0.167)(11.7) = 208$ kips

$H_c = (\beta \sin\gamma + e_c/\cos\gamma)(P/r) = (13.5 \times 0.164 + 0)(11.7) = 25.9$ kips

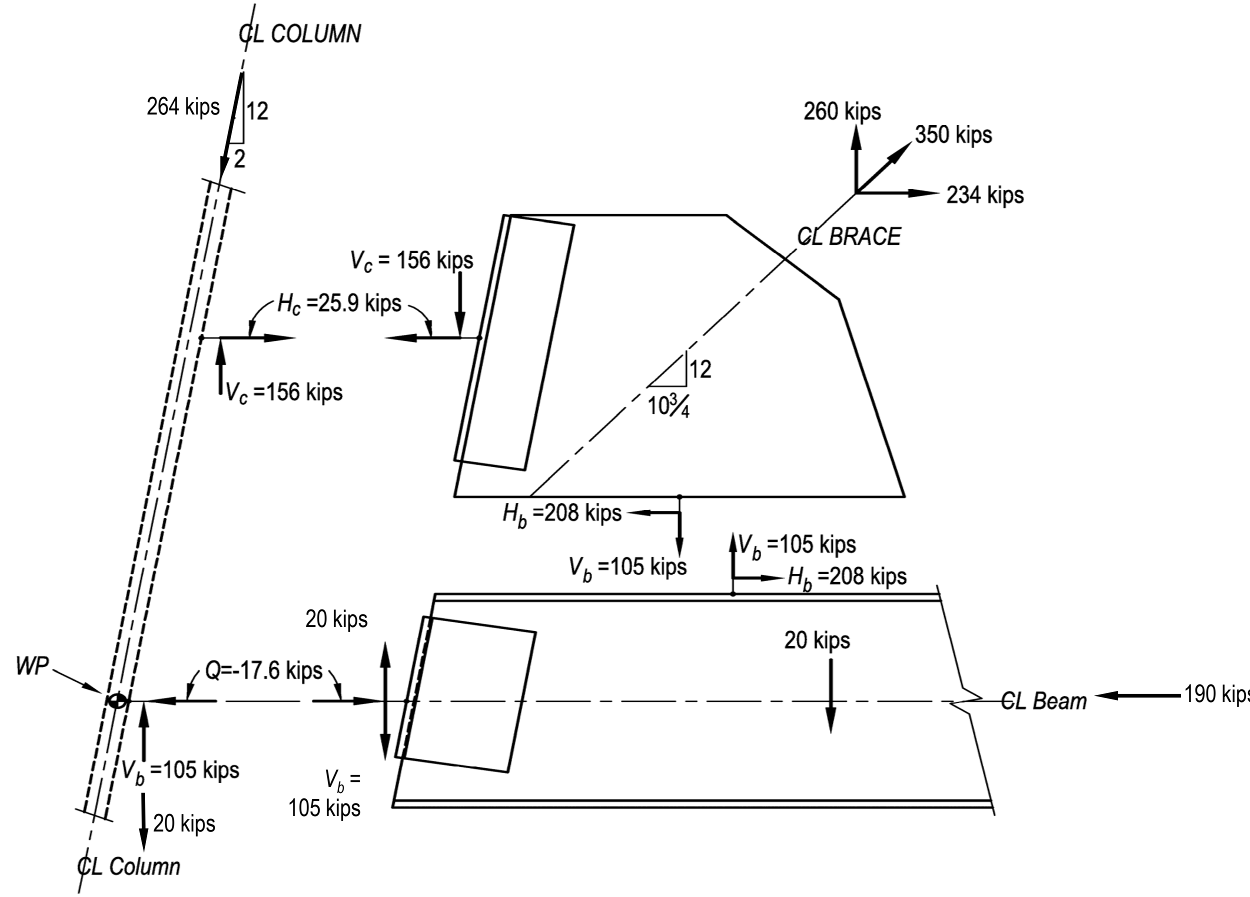
$\Sigma(H_c + H_b) = 234$ kips

Brace horizontal component = 350 sinθ = 234 kips OK

$Q = \mathrm{H_c} - P\cos\theta\tan\gamma = 25.9 - 350(0.744)(0.167) = -17.6$ kips

Design for a sloping building column

Admissible Force Field



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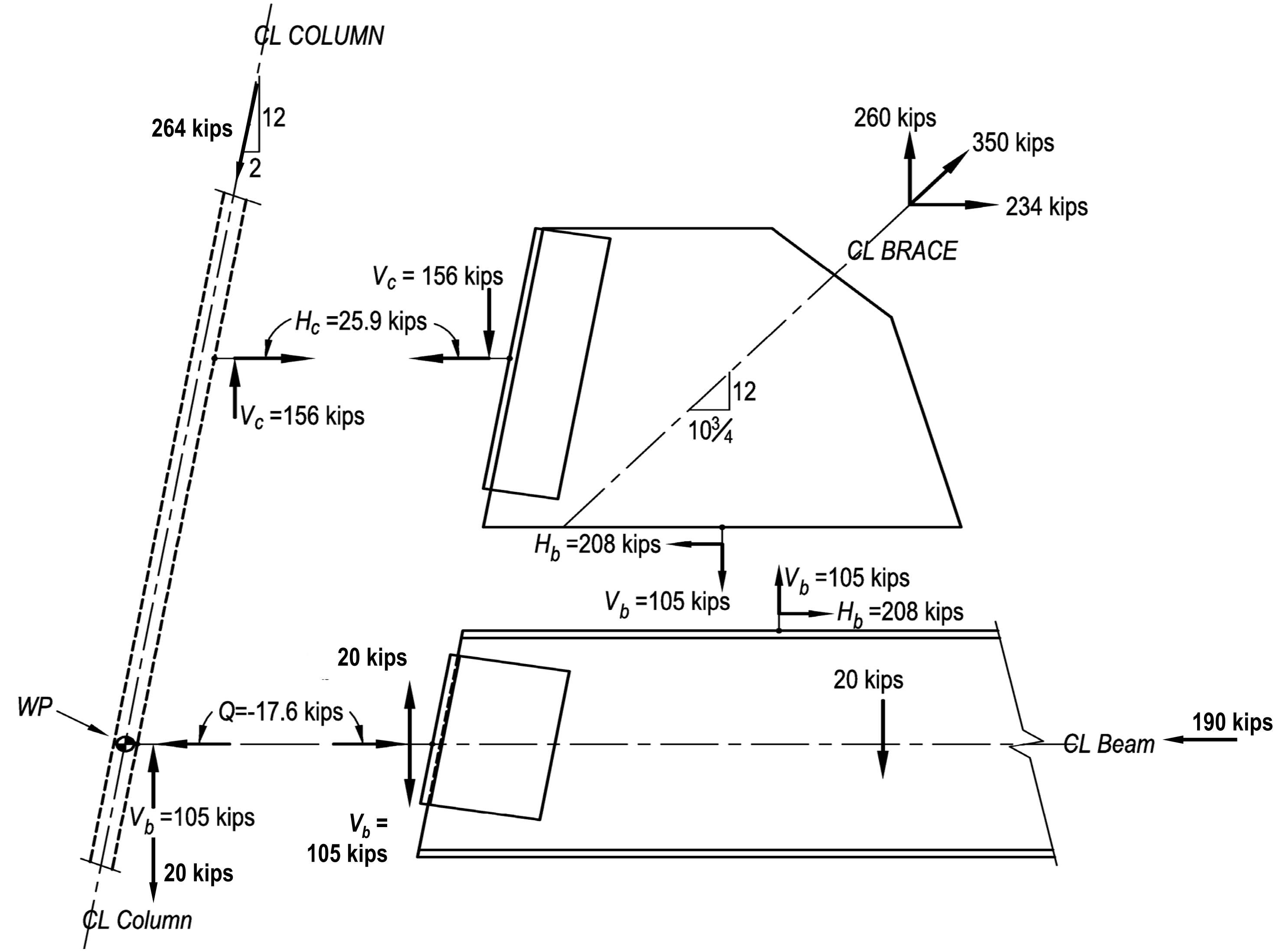
100



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Jack Truss to Main Truss

The UFM applied to a truss to truss connection

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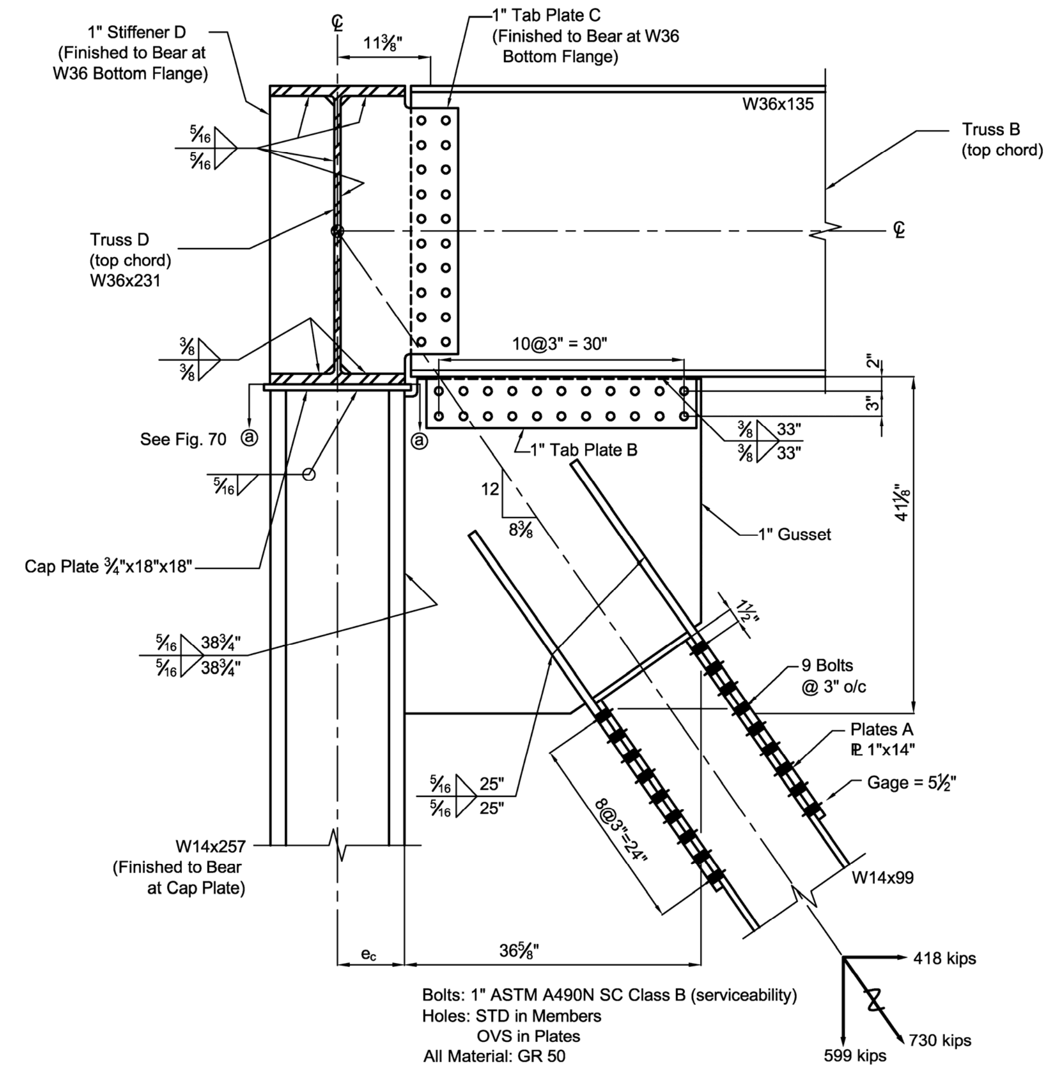
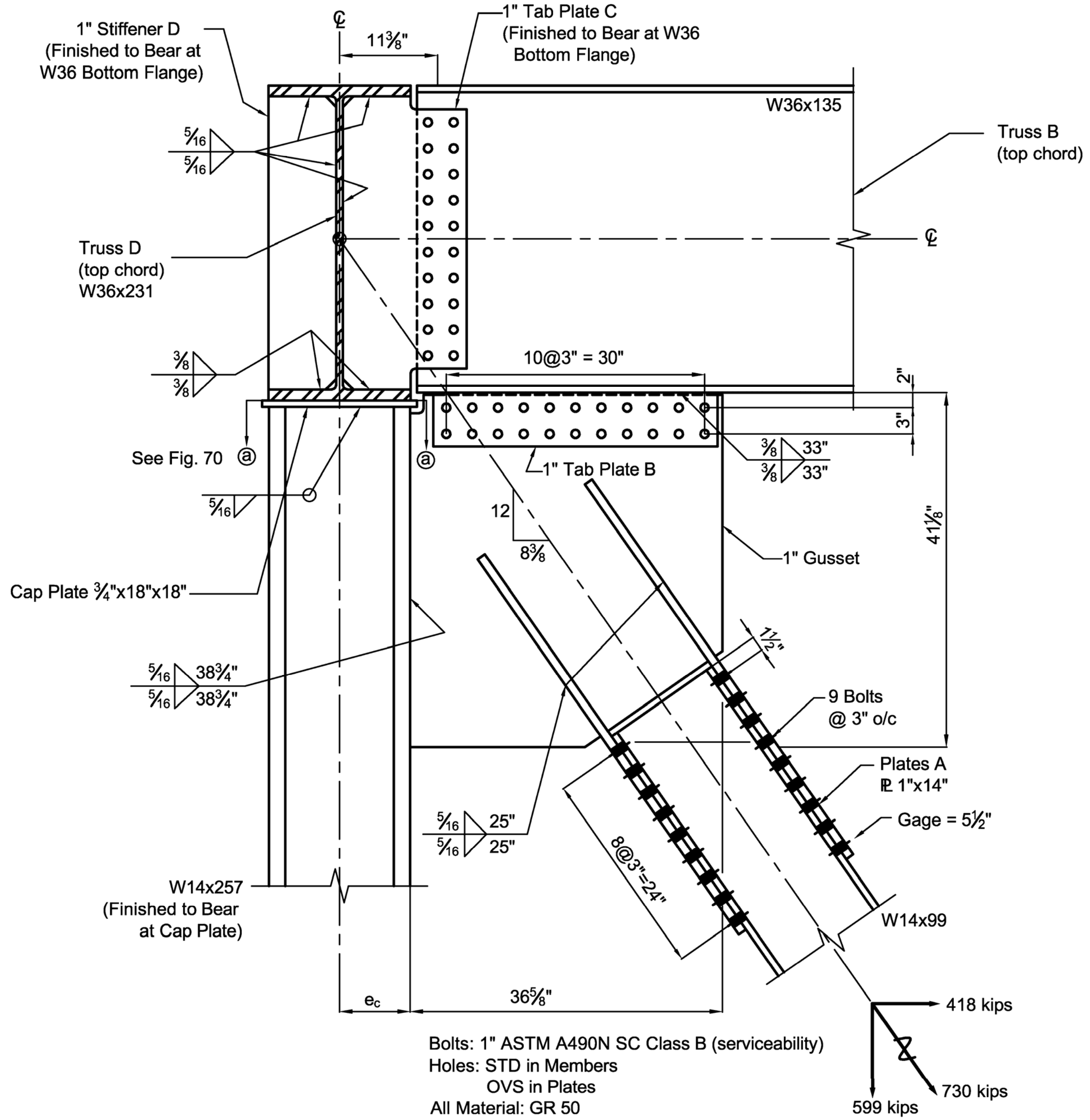
104

A Jack Truss to Main Truss Connection

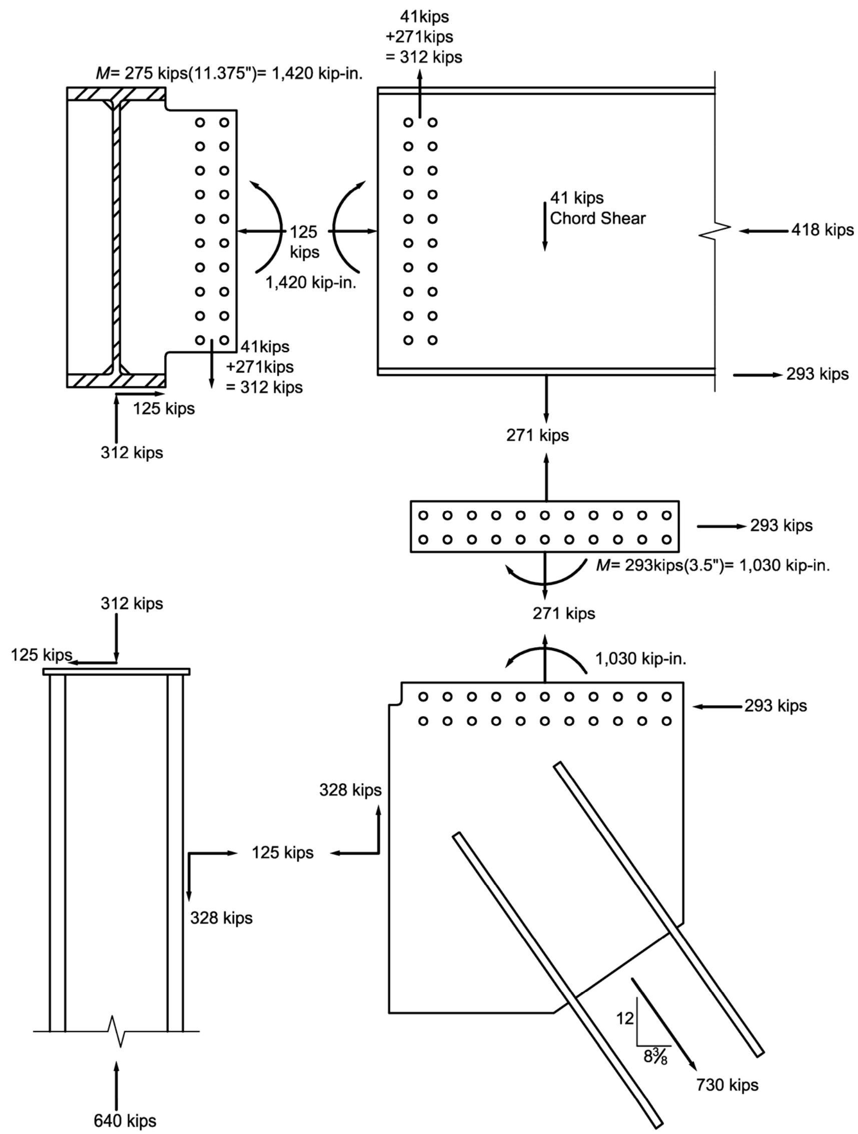


105


1" Stiffener D
(Finished to Bear at
W36 Bottom Flange)
11⅜"
1" Tab Plate C
(Finished to Bear at W36
Bottom Flange)
W36x135
Truss B
(top chord)
Truss D
(top chord)
W36x231
10@3" = 30"
2"
3"
See Fig. 70
1" Tab Plate B
⅜ 33"
⅜ 33"
12
8⅜
41⅛"
1" Gusset
Cap Plate ¾"x18"x18"
1½"
5⁄16 38¾"
5⁄16 38¾"
9 Bolts
@ 3" o/c
Plates A
PL 1"x14"
Gage = 5½"
5⁄16 25"
5⁄16 25"
8@3"=24"
W14x257
(Finished to Bear
at Cap Plate)
W14x99
e_c
36⅝"
418 kips
730 kips
599 kips
Bolts: 1" ASTM A490N SC Class B (serviceability)
Holes: STD in Members
OVS in Plates
All Material: GR 50

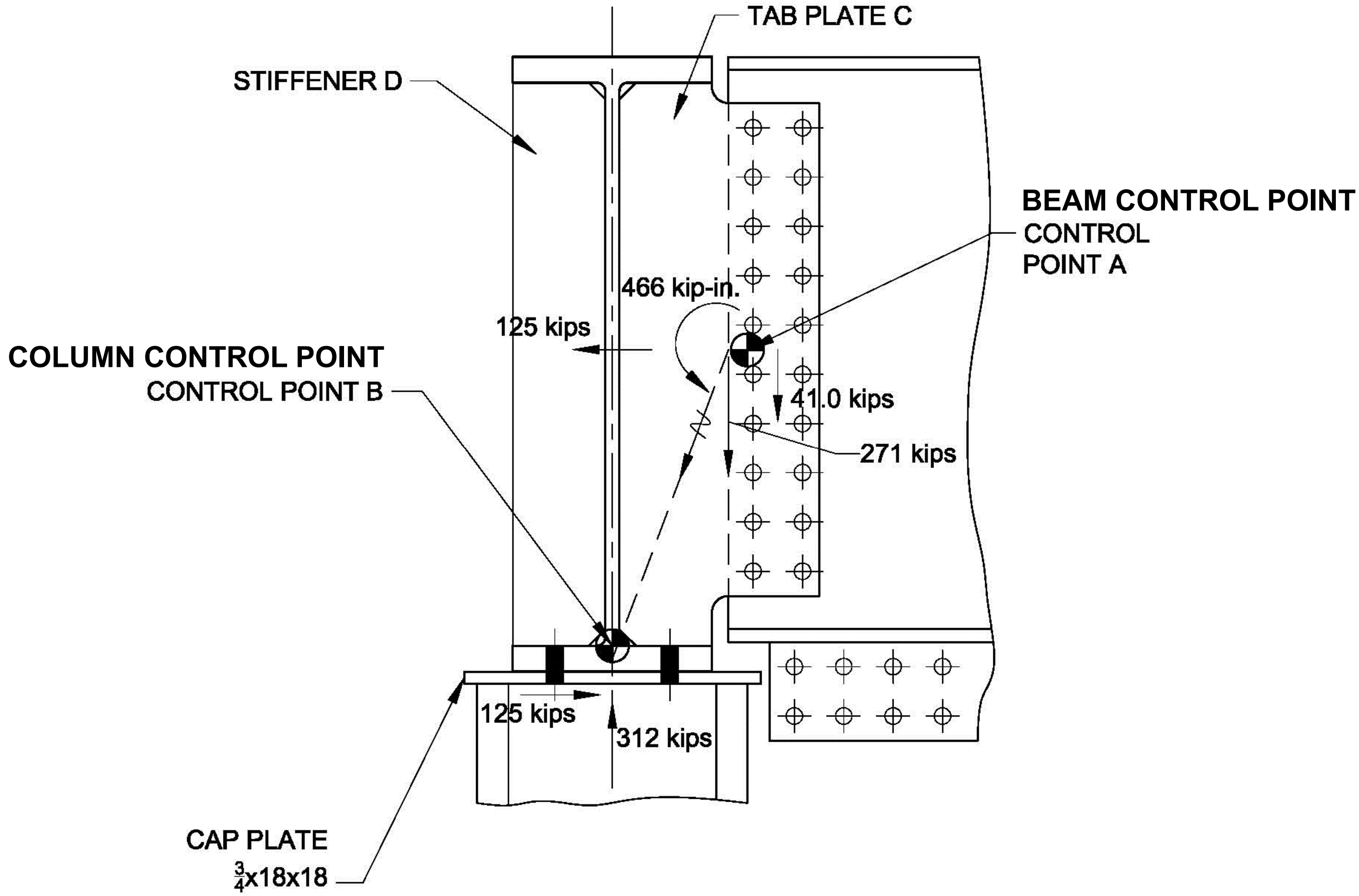
106

Admissible Force Field



107

Use of Control Points



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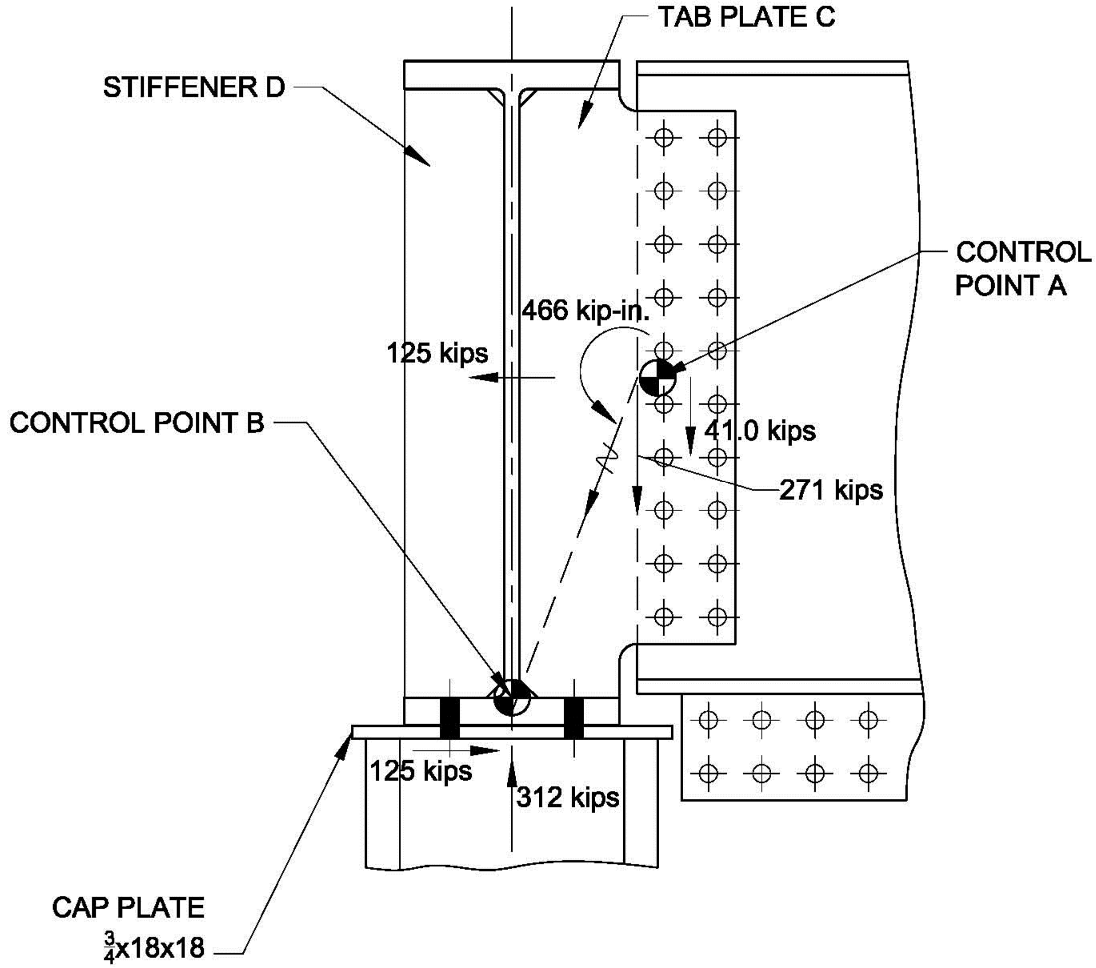
Column Control Point (B)

simplifies interface force calculation



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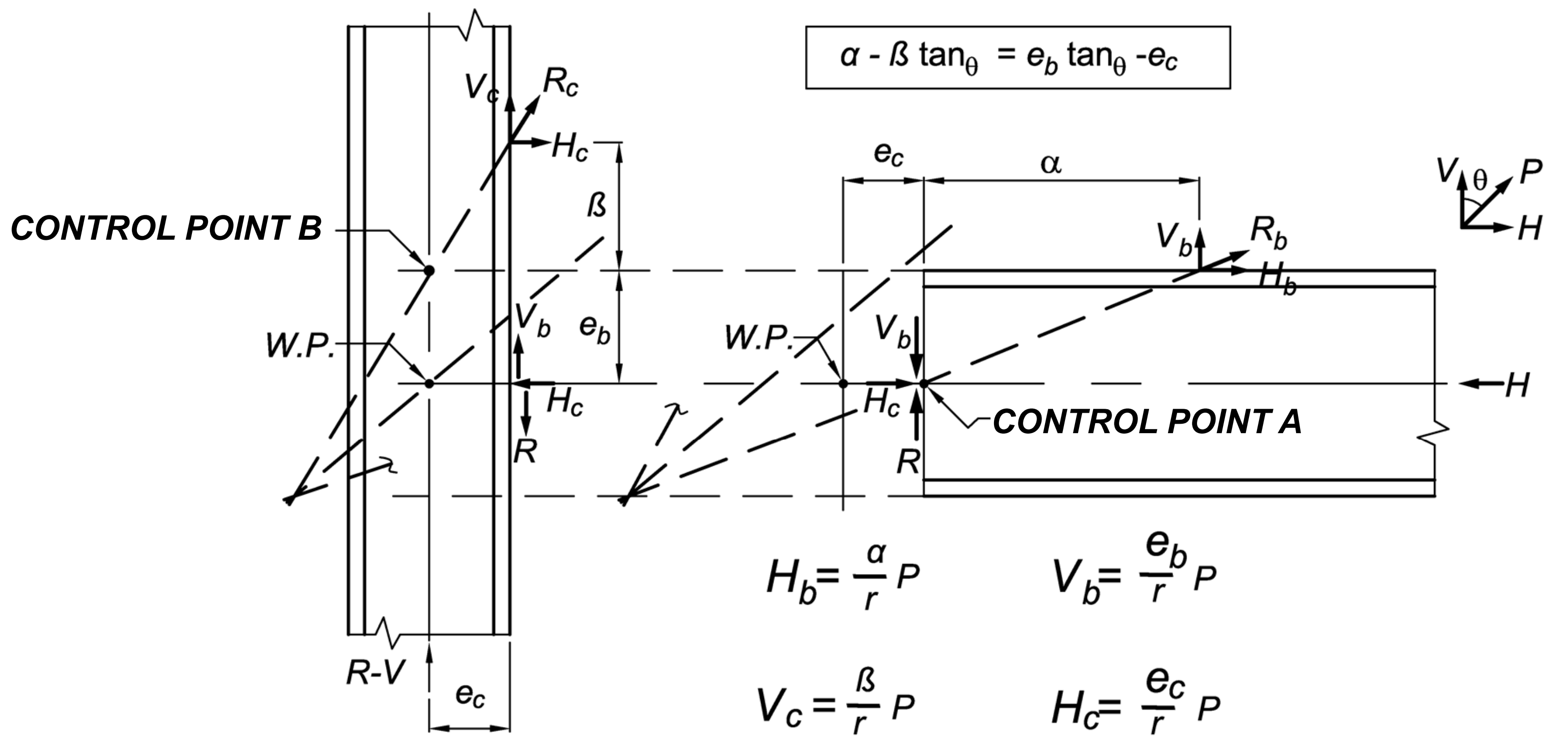
109

Geometry of UFM



$$H_b = \frac{\alpha}{r} P \qquad V_b = \frac{e_b}{r} P$$

$$V_c = \frac{\beta}{r} P \qquad H_c = \frac{e_c}{r} P$$

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

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General Summary

Connections can account for 50% of the cost of erected steel

Rational design of connections requires engineering knowledge

General Summary

- The Uniform Force Method is a rational method.
- In the context of the Corollary to the Lower Bound Theorem, it provides a design closer to the actual unknown admissible internal force distribution than any other known method.
- It provides economical connections when properly used.
- The geometry and loads determine whether to use the general UFM or special cases I, II, III, or IV.

References

Additional UFM discussion will be found in the following:

1. Tamboli, A.K., 2010, Handbook of Structural Steel Connection Design and Details, 2nd Ed., McGraw-Hill, Chapter 2

2. Brockenbrough, R.L., and Merritt, F.S., 2010, Structural Steel Designer's Handbook, 4th Ed., McGraw-Hill, Chapter 3

Questions?

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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!

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.

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Quiz and Attendance records: Posted Tuesday mornings. www.aisc.org/nightschool - click on Current Course Details.

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Thank You

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

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