Night School 28: Vertical Bracing Connections

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Vertical Bracing Connections, Session 2: Uniform Force Method

April 12, 2022 | William A Thornton

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Stronger.
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AISC Night School

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Course Description

Vertical Bracing Connections

Uniform Force Method, Part 1
April 12, 2022

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 15th Edition of the AISC Steel Construction Manual.

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Learning Objectives

1. Describe the derivation of the Uniform Force Method.
2. List the Uniform Force Method procedures shown in the AISC Steel Construction Manual.
3. Apply the Uniform Force Method through a design example.
4. Explain outcomes from applying the Uniform Force Method.

Night School 28: Vertical Bracing Connections

Session 2: Uniform Force Method, Part 1
April 12, 2022

William A. Thornton, corporate consultant to Cives Steel

Smarter. Stronger. Steel.

Vertical Bracing Connections

By: William Thornton, Rafael Sabelli, and Carol Drucker

Course Outline

1. Basic Principles
2. **Uniform Force Method Part 1**
3. Bracing Connection Details and Prying Action
4. Vertical Bracing Corner Connection – Wind and Low-seismic
5. Uniform Force Method Part 2
6. Vertical Bracing Corner Connection – Seismic
7. Chevron Gussets Connection
8. Other Connection Topics and Case Study

10

Session Outline

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

11

The Uniform Force Method

12

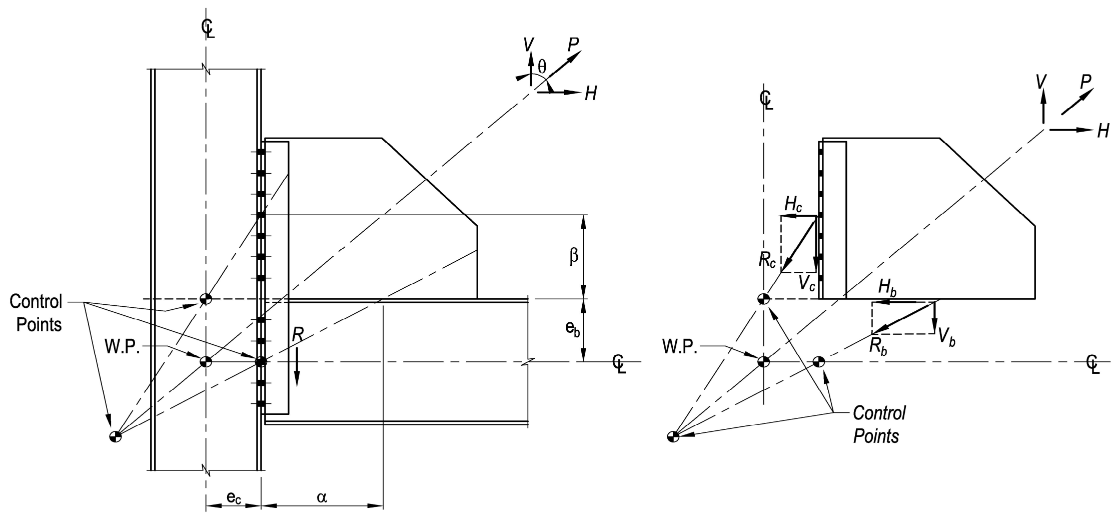
The Uniform Force Method

- 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

13

Uniform Force Method (UFM)

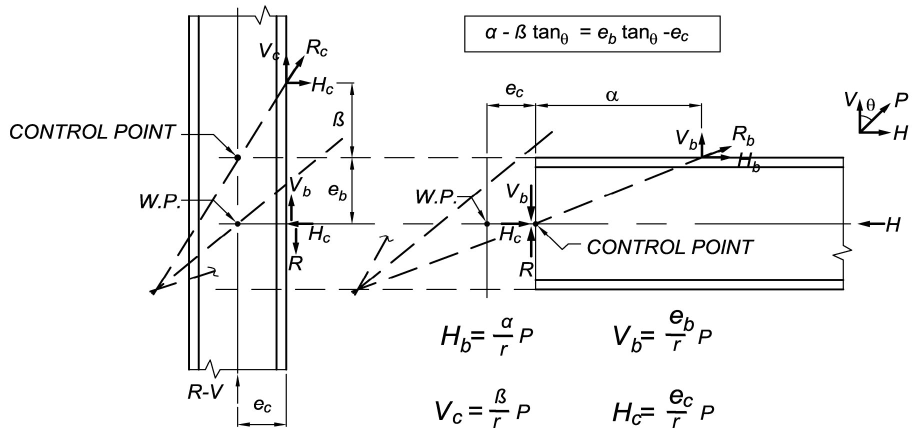
Geometry Control Points and Admissible Force Field



14

Geometry of UFM

All Parts are in Equilibrium



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

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

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

15

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.

16

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

17

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

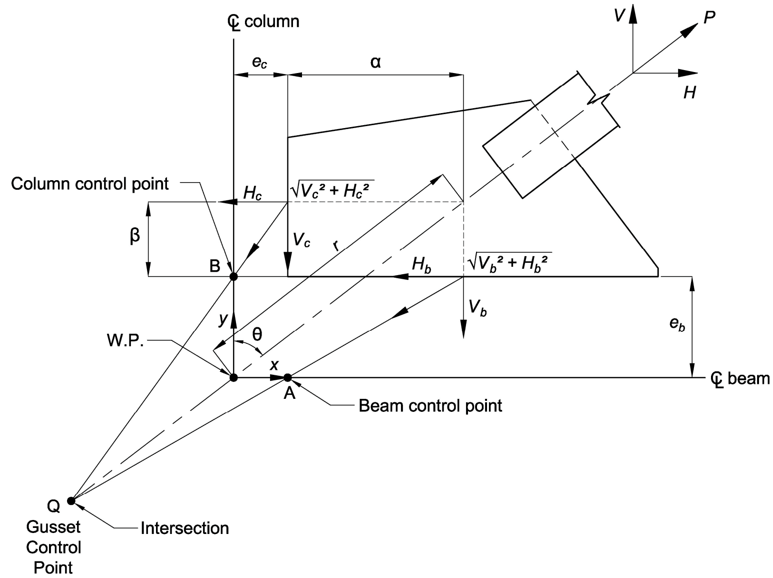
When designing a connection, α and β can **always** be chosen to satisfy the geometric constraint.

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 15th Ed. Part 13 addresses this.

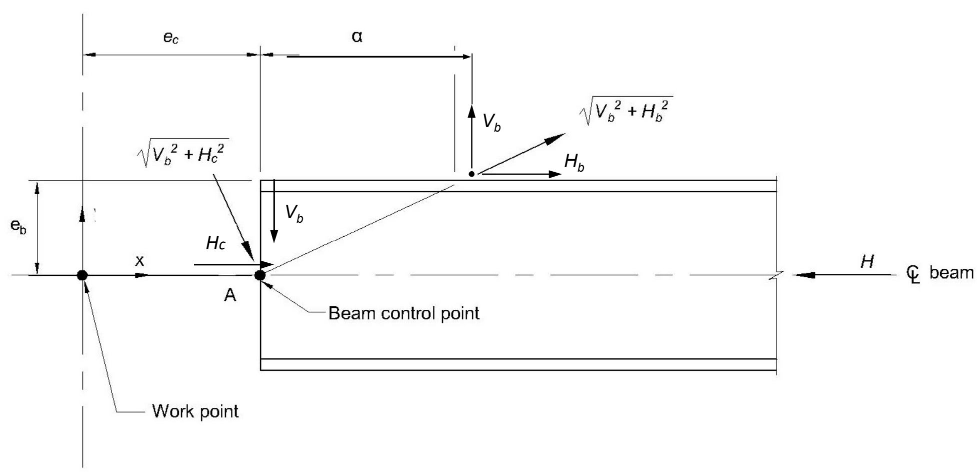
18

UFM Admissible Force Field for the Gusset



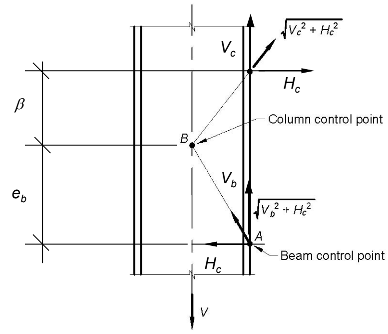
19

UFM Admissible Force Field for the Beam



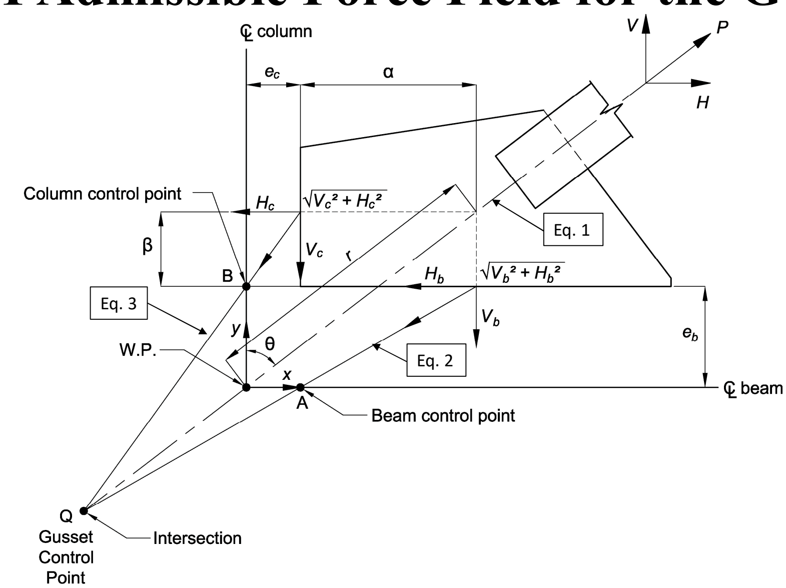
20

UFM Admissible Force Field for the Column



21

UFM Admissible Force Field for the Gusset



22

Uniform Force Method Derivation

$$y = \frac{1}{tan\theta}x$$

Equation of Brace Line of Action (Eq. 1)

$$y = \frac{e_b x}{\alpha} - \frac{e_b e_c}{\alpha}$$

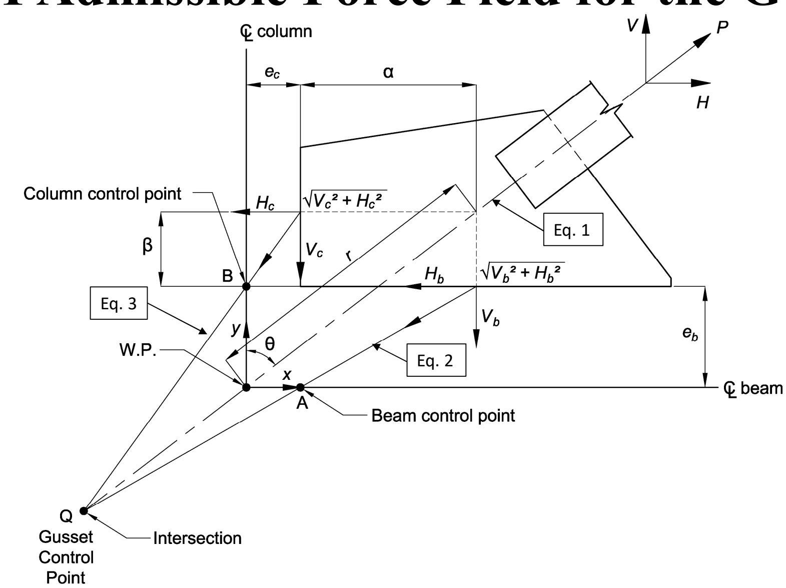
Equation of Gusset to Beam Force Line of Action (Eq. 2)

$$y = \frac{\beta}{e_c}x + e_b$$

Equation of Gusset to Column Force Line of Action (Eq. 3)

23

UFM Admissible Force Field for the Gusset



24

Uniform Force Method Derivation

To find point Q:

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

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

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

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

x_Q given by 4 and 5 must be equal.

25

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.

26

Uniform Force Method Derivation

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

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

The component forces are

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

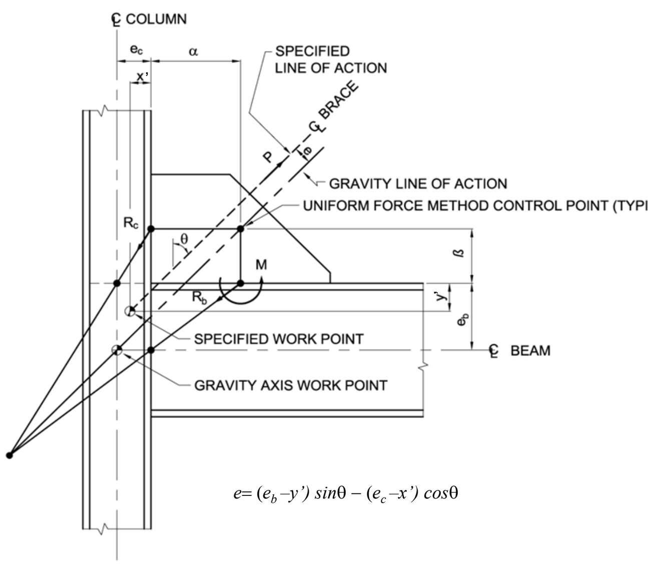
$$H_c = e_c \frac{P}{r} \qquad V_c = \beta \frac{P}{r}$$

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

27

UFM Special Case I

Non-Concentric Work Point

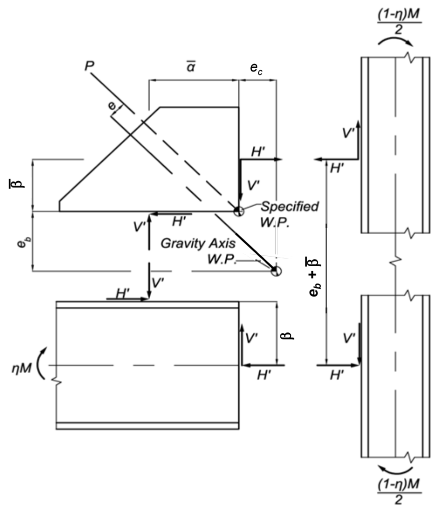


$e = (e_b - y')\sin\theta - (e_c - x')\cos\theta$

28

UFM Special Case I

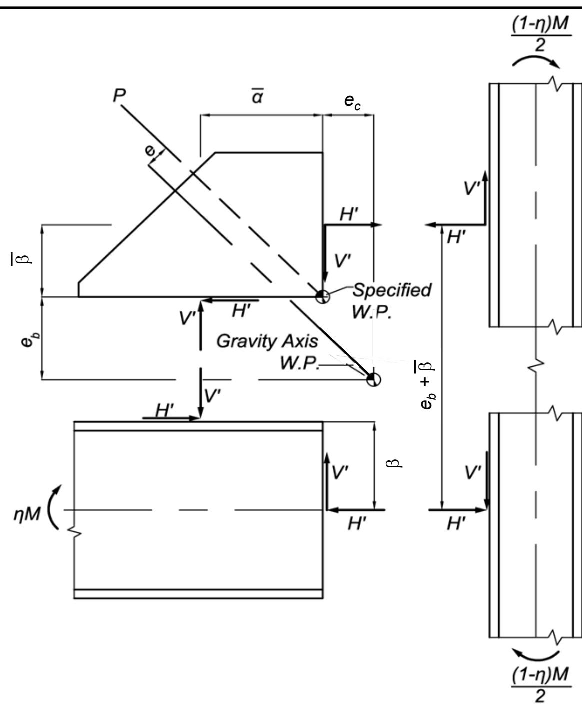
Admissible Force Field



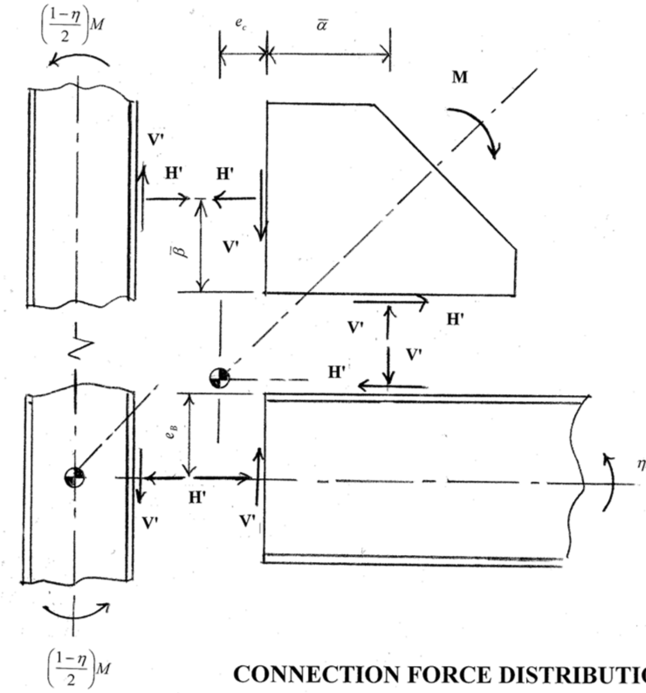
These forces are added algebraically to the UFM concentric forces

Note the extra moments in the beam and column

29



30



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

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

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

or

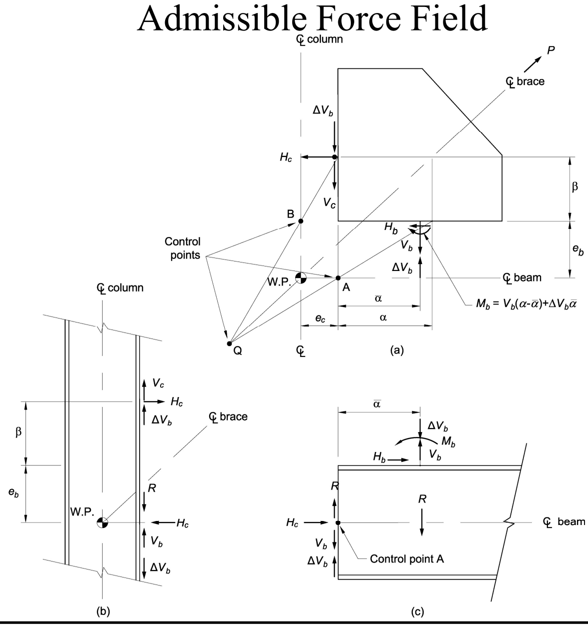
$$\eta = \frac{M_p Beam}{\Sigma M_p Beam + Columns}$$

CONNECTION FORCE DISTRIBUTION DUE TO MOMENT M

31

UFM Special Case II

Admissible Force Field

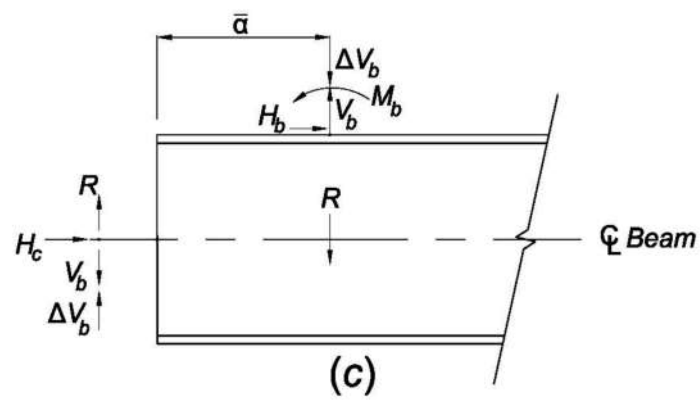


32

UFM Special Case II

Admissible Force Field

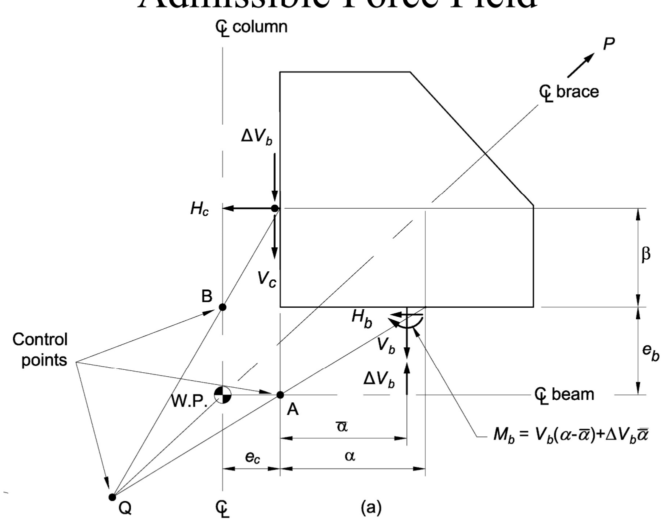
This reduces the beam to column shear



33

UFM Special Case II

Admissible Force Field

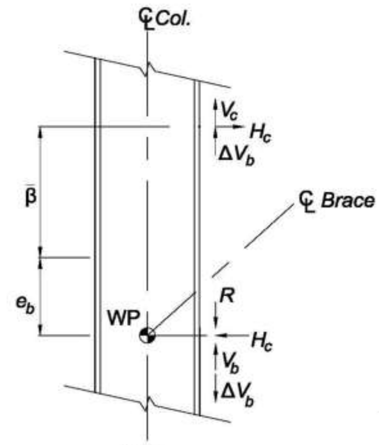


34

UFM Special Case II

Admissible Force Field

This reduces the beam to column shear



(b)

35

What causes the use of Special Case II

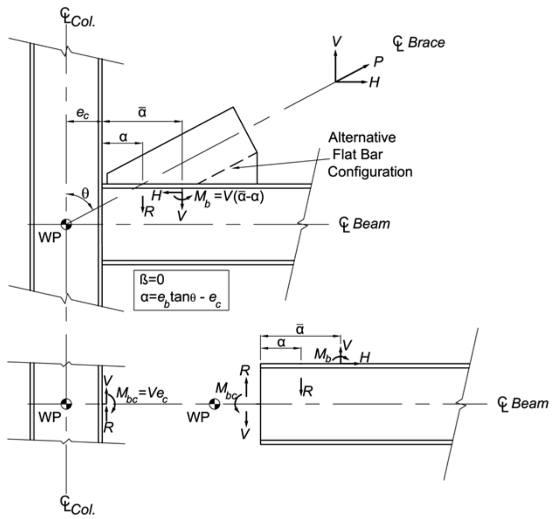
- Beam shear reactions based on beam strength rather than floor loads
- Most beams, especially those part of the lateral bracing system, are designed for stiffness, not strength
- This results in beams many times stronger than those required for strength, and larger shear reactions than those required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

36

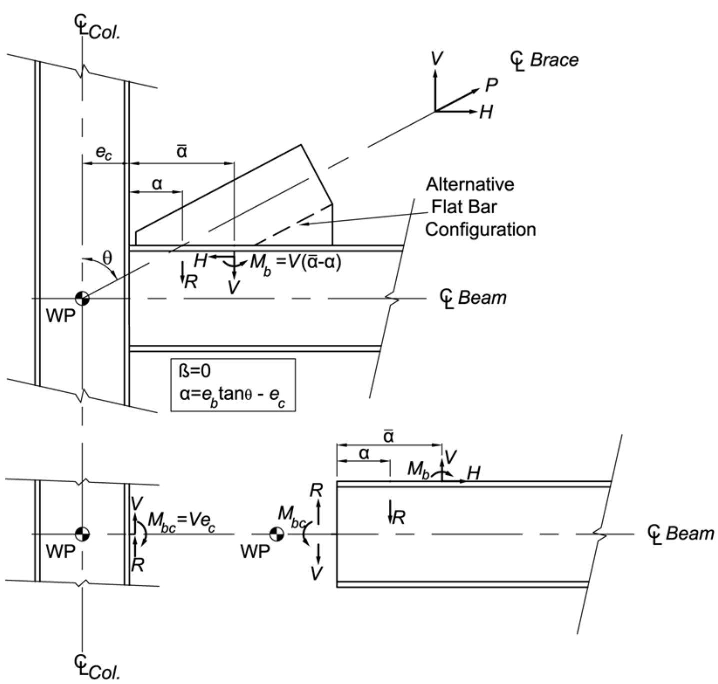
UFM Special Case III

Admissible Force Field

Connection to beam or column only

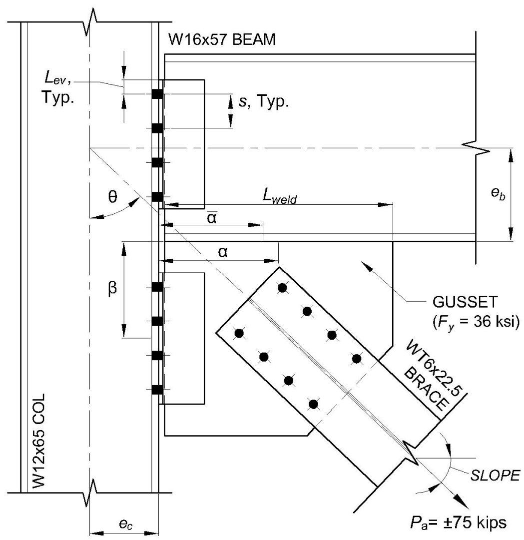


37



38

Example of Brace-to-Beams/Column Connection



39

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

Given:

1. AISC 15th 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°

40

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

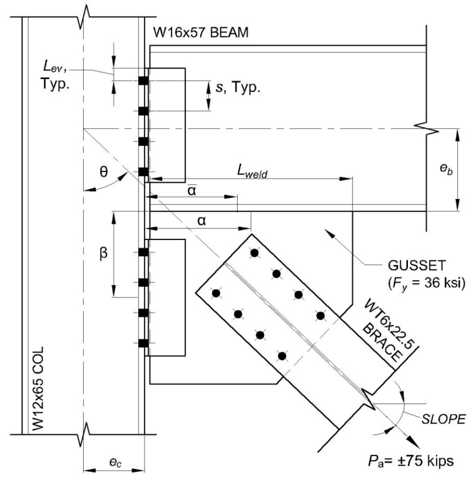
Solution:

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)



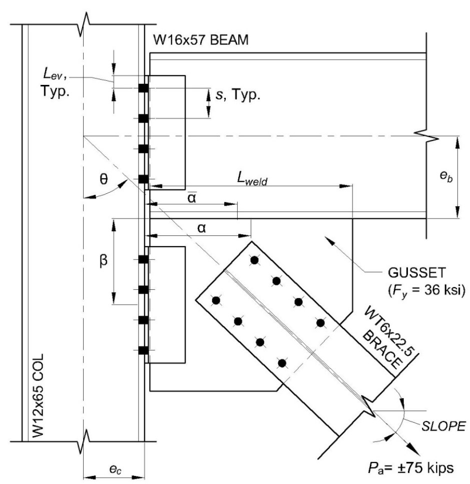
41

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

β = distance to center of gusset-to-column connections

From geometric layout, H_{gusset} = 16.875 in.
Place bolts in approximate center of gusset,
$\beta = 8.5$ in.
Let $\bar{\beta} = \beta$

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

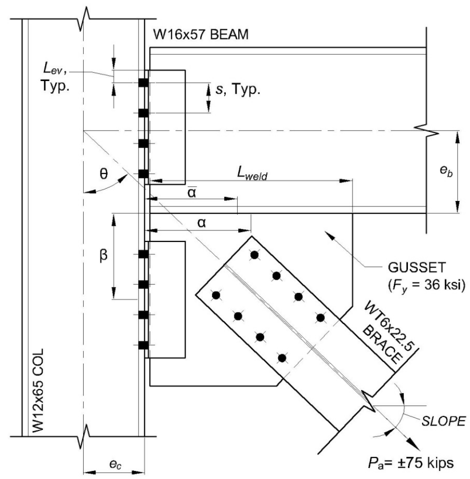


42

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.



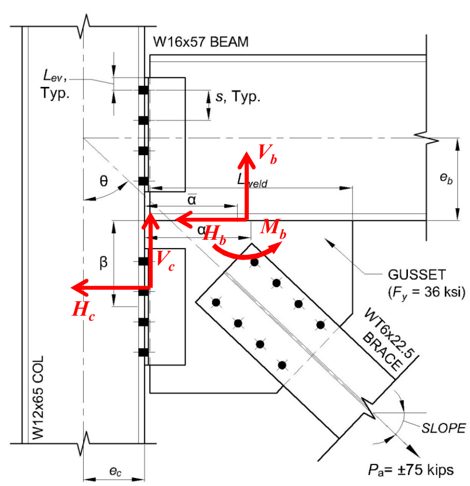
43

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
$V_C = P_a(\beta/r) + \Delta V_B$
$M_B = V_B(\alpha - \bar{\alpha}) + (\Delta V_B)\bar{\alpha}$

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



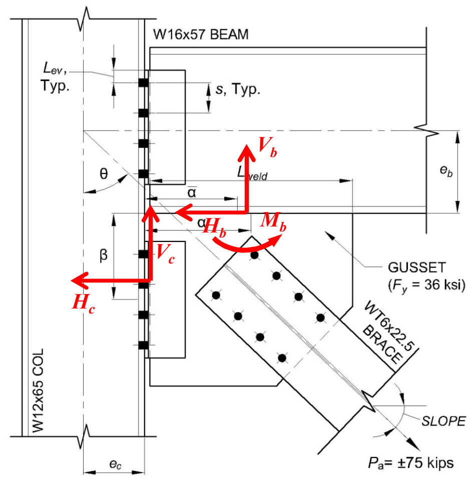
44

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

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

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

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



45

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

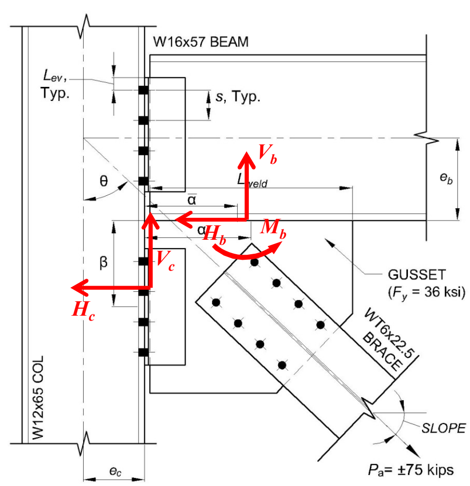
$M_B = V_B(\alpha - \bar{\alpha})$
$\quad = 25.4 \text{ kips}(11.5 \text{ in.} - 10.5 \text{ in.})$
$\quad = 25.4 \text{ kip-in.}$

$V_C = P_a\,(\beta/r)$
$\quad = 75 \text{ kips}(8.5 \text{ in.}/24.2 \text{ in.})$
$\quad = 26.3 \text{ kips}$

$H_C = P_a\,(e_c/r)$
$\quad = 75 \text{ kips}(6.05 \text{ in.}/24.2 \text{ in.})$
$\quad = 18.8 \text{ kips}$

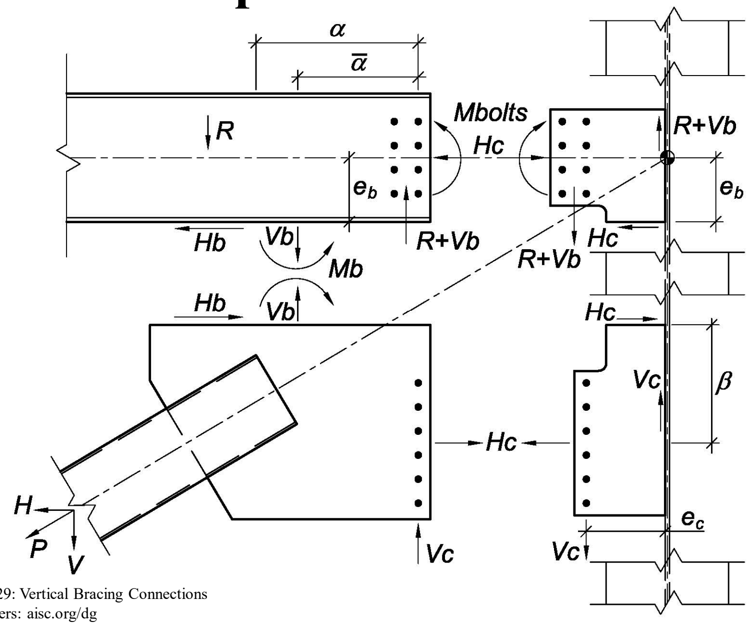
(Note: $H_C = 0$ kips for connections to column web, except Special Case IV)

$M_C = 0 \quad \text{since } \beta = \bar{\beta}$



46

Special Case IV



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47

Special Case IV

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

48

Special Case IV

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

49

Special Case IV

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

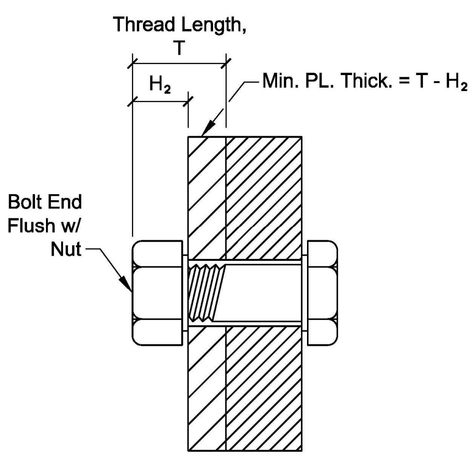
50

Special Case IV

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

51

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.

52

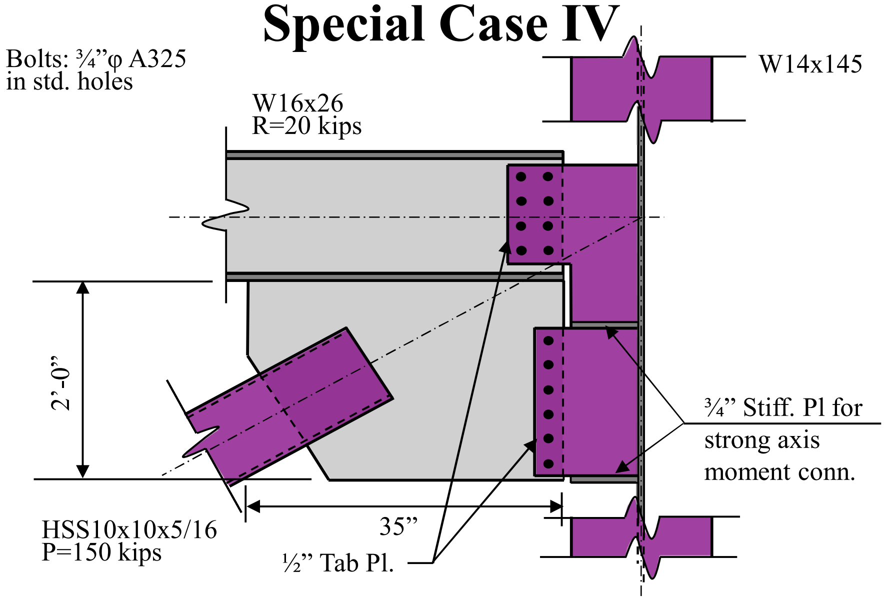
Allow X-Type Bolts Where Appropriate

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

53

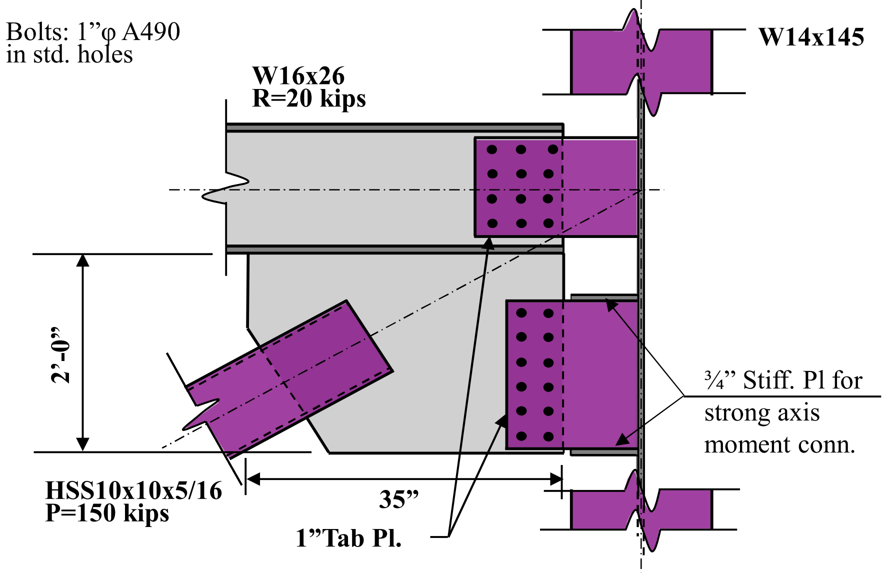
Special Case IV



Vertical Bracing w/ Ext. Tab
Optimum Load Path e_c = 10.25

54

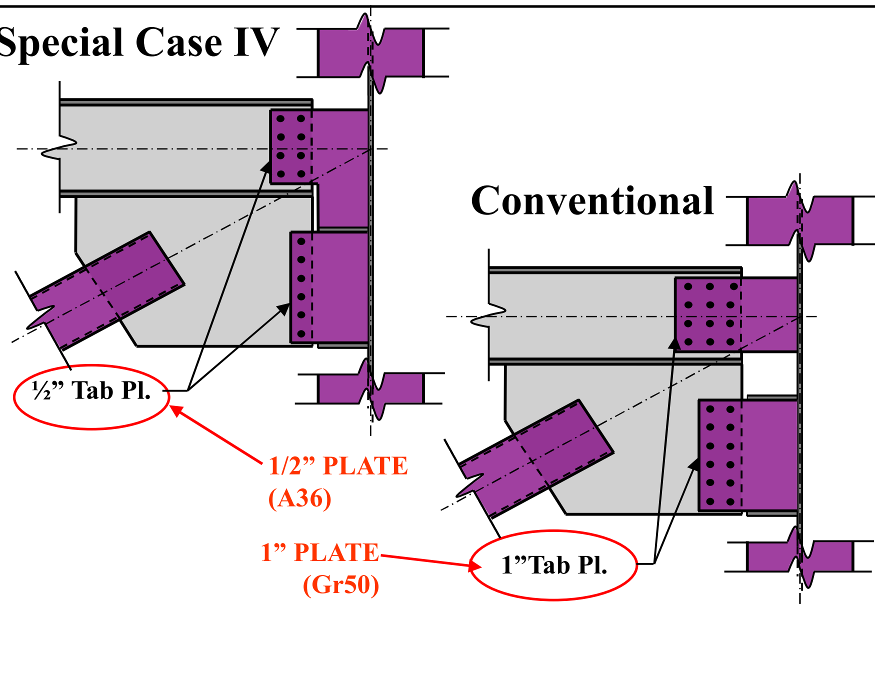
Conventional UFM



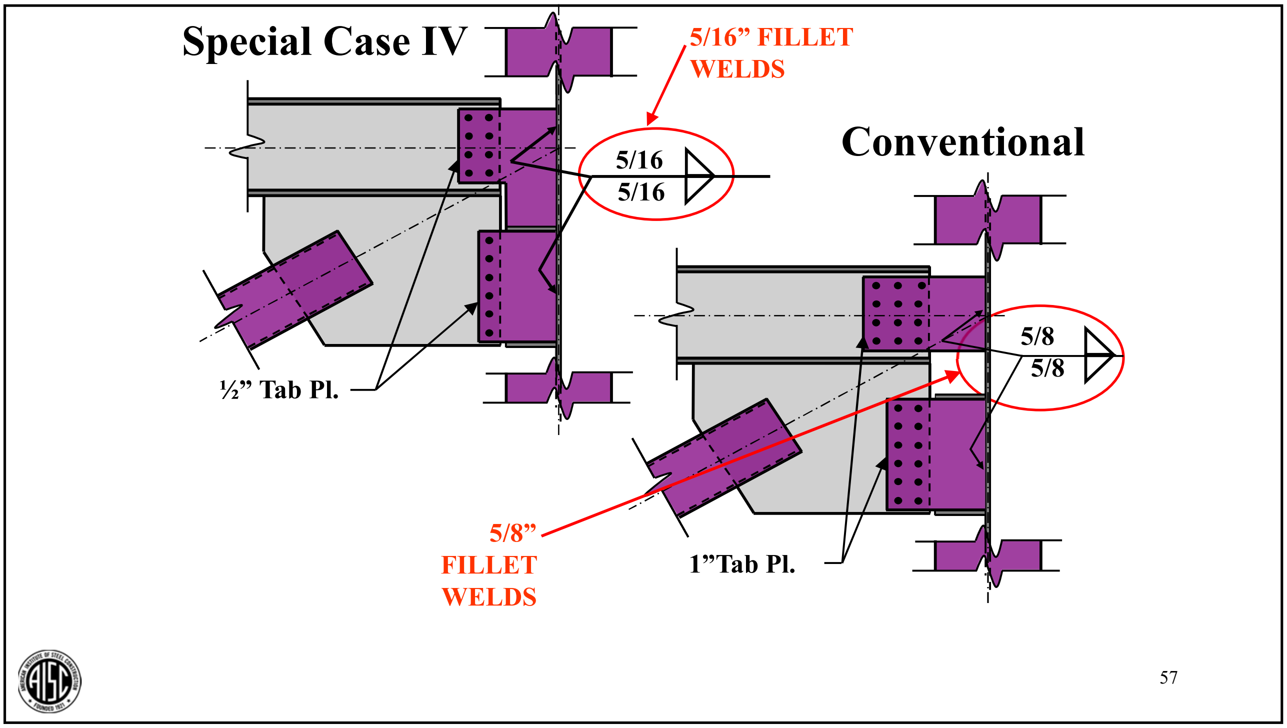
Vertical Bracing w/ Ext. Tab
Standard Load Path $e_c = 0$

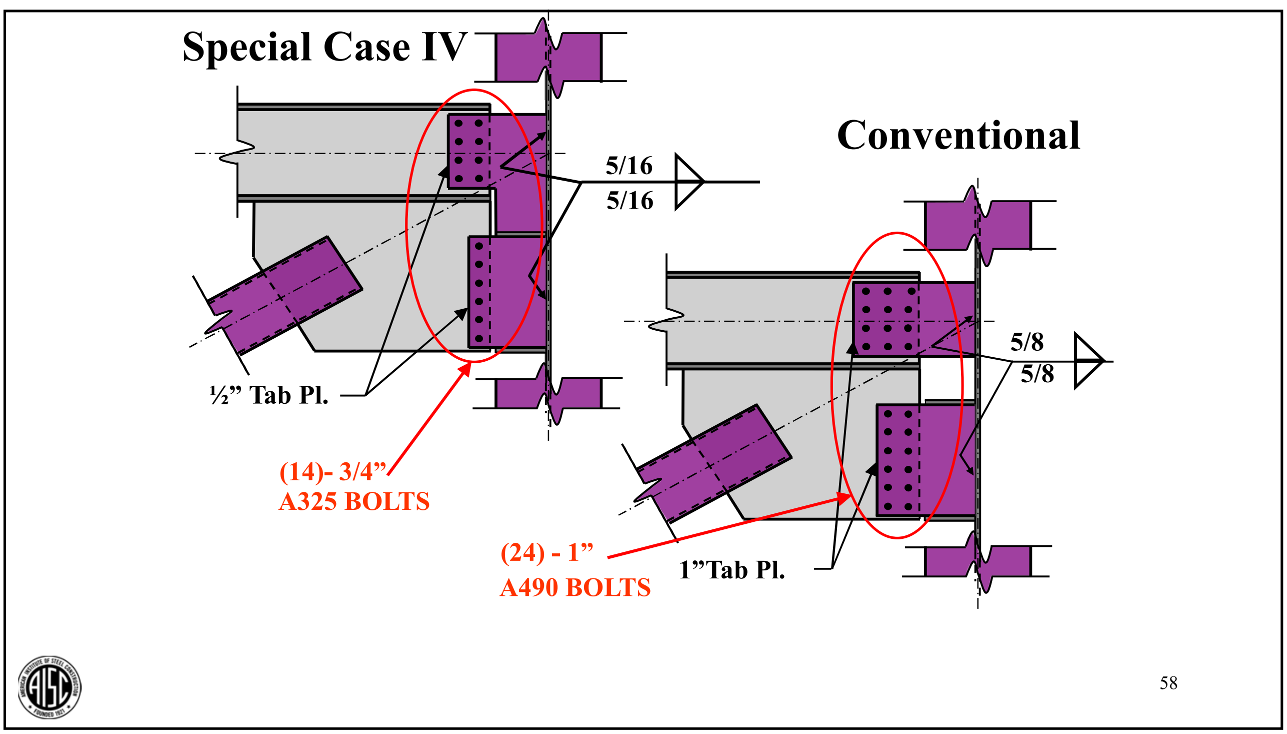
55

Special Case IV



56

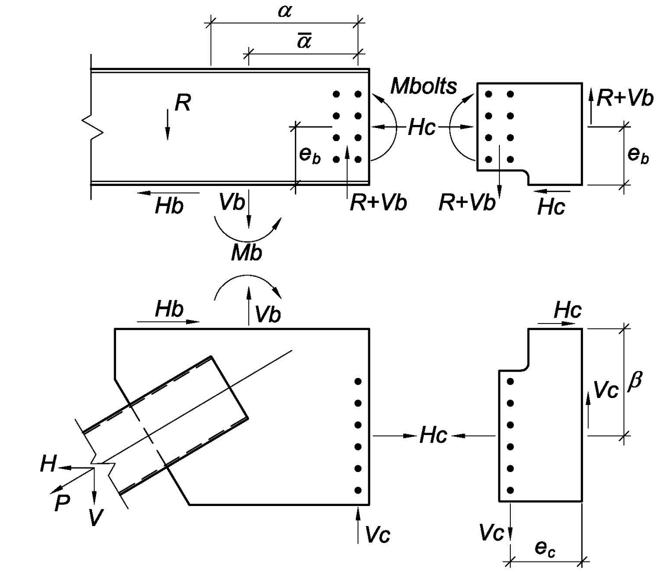

Special Case IV
5/16" FILLET
WELDS
5/16
5/16
Conventional
5/8
5/8
½" Tab Pl.
5/8"
FILLET
WELDS
1"Tab Pl.
57


Special Case IV
5/16
5/16
Conventional
5/8
5/8
½" Tab Pl.
(14)- 3/4"
A325 BOLTS
(24) - 1"
A490 BOLTS
1"Tab Pl.
58

Special Case IV

FBD of Optimum Solution

Special Case IV



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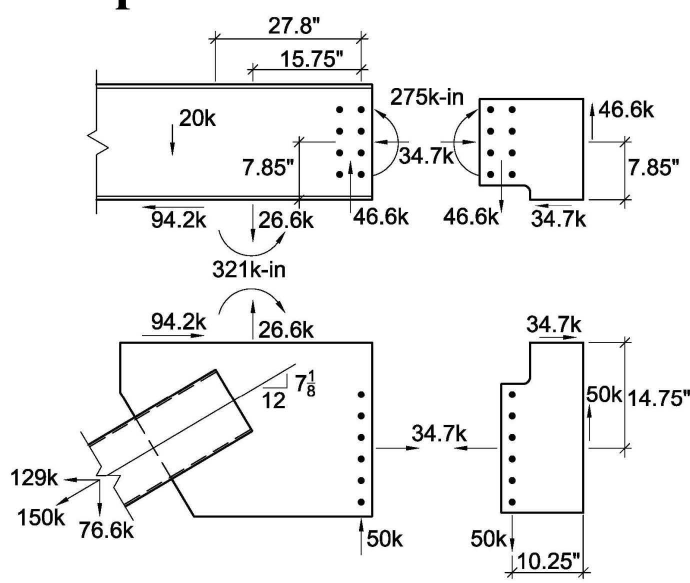
59

Special Case IV

FBD of Optimum Solution

Special Case IV



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60

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%

Note:
Standard Load Path = Ordinary UFM
Optimum Load Path = Special Case IV

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%

Note:
Standard Load Path = Ordinary UFM
Optimum Load Path = Special Case IV

± 80% SAVINGS IN DRILLING TIME

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%

Note:
Standard Load Path = Ordinary UFM
Optimum Load Path = Special Case IV

± 50% SAVINGS IN WELD CONSUMABLES

63

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%

Note:
Standard Load Path = Ordinary UFM
Optimum Load Path = Special Case IV

± 60% SAVINGS IN WELDING LABOR

64

Comparison of Design Results

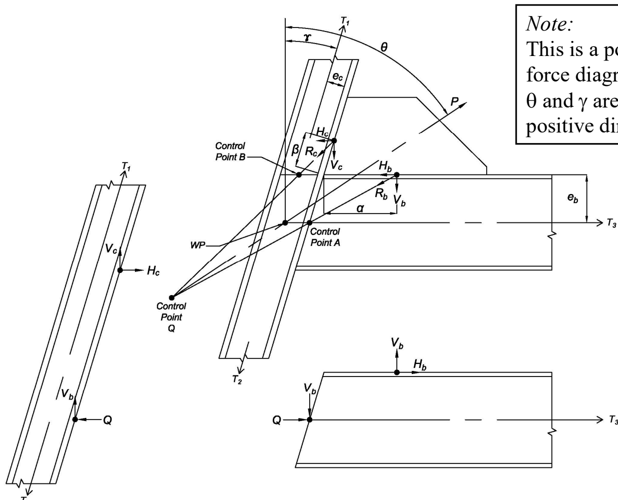
COMPARISON OF DESIGNS RESULTING FROM DIFFERENT LOAD PATHS																
	DRILLING				WELDING				MATERIAL							
	# of Holes	Plate Thick. (in.)	Area Holes (in.^{2})	Vol. of Holes (in.^{3})	Weld Size (in.)	Length (in.)	Volume (in.^{3})	Length Single Pass Weld (in.)	Area of Tabs (ft^2)	Thick. Tabs (ft)	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%

Note:
Standard Load Path = Ordinary UFM
Optimum Load Path = Special Case IV

± 30% SAVINGS IN MATERIAL

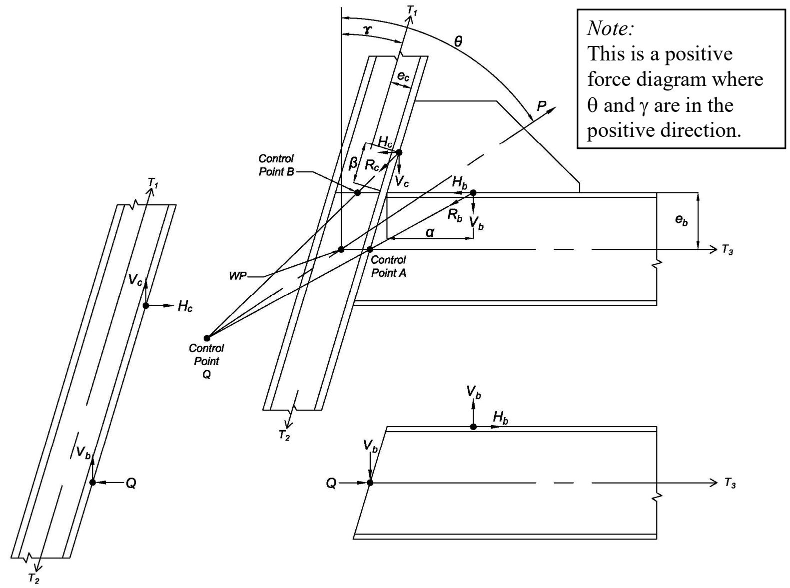
65

Non-Orthogonal UFM



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

66



67

Non-Orthogonal UFM

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

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

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

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

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

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

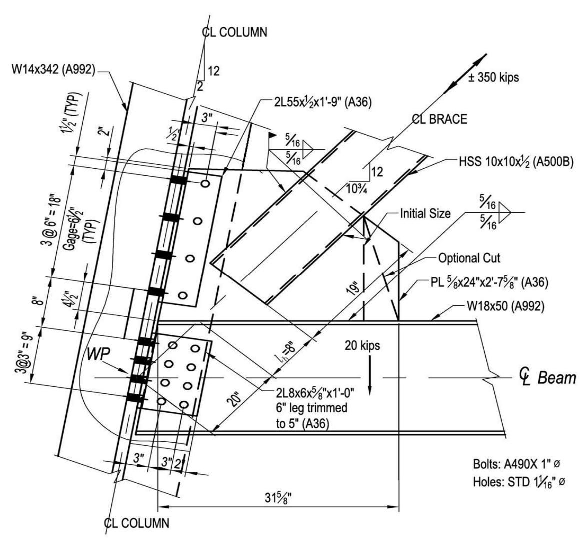
$$r=\sqrt{\left(\alpha+e_c\tan\gamma+\beta\sin\gamma+\frac{e_c}{\cos\gamma}\right)^2+(e_b+\beta\cos\gamma)^2}$$

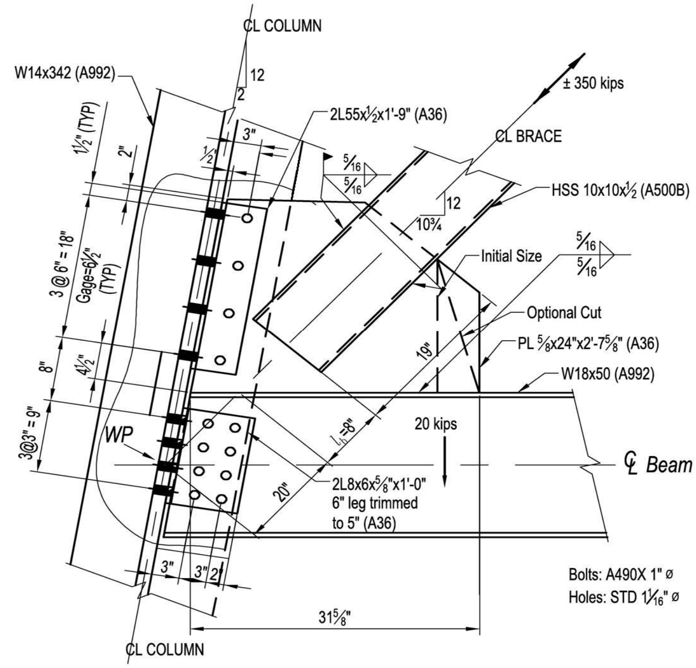
68

Another Example

Bracing Connection with Sloping Column

From AISC Bracing Design Guide 29

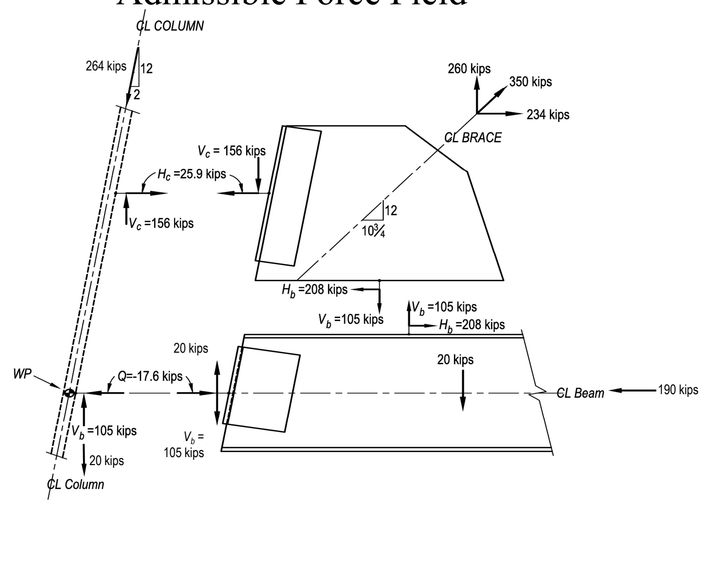




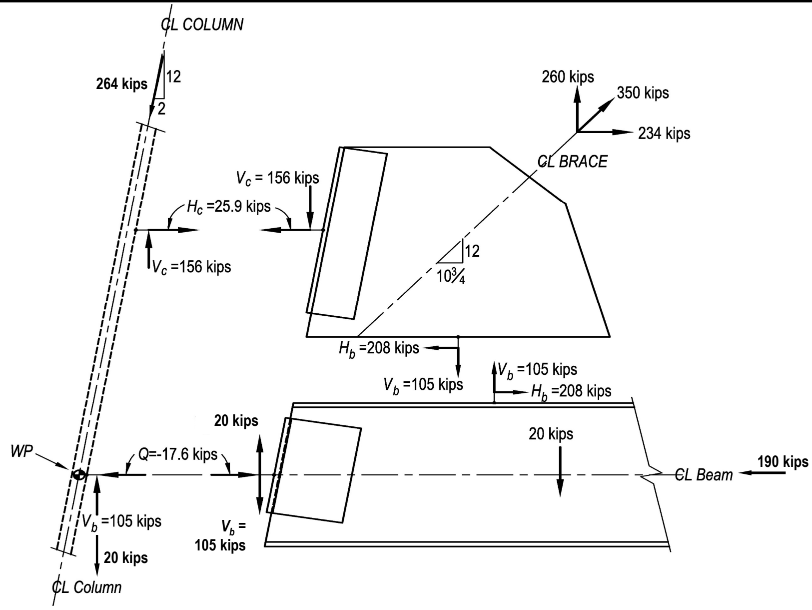
71

Design for a sloping building column

Admissible Force Field



72



73

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

74

Calculations

From the constraint,

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

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

$= 16.3$ in.

75

Calculations (continued)

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

$r = [(16.3 + 9.0 \times 0.167 + 13.5 \times 0.164 + 0)^2 + (9.0 + 13.5 \times 0.986)^2]^{1/2}$

$= 30.0$ in.

$P/r = 350$ kips/30.0 in. $= 11.7$ kips/in.

76

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

77

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

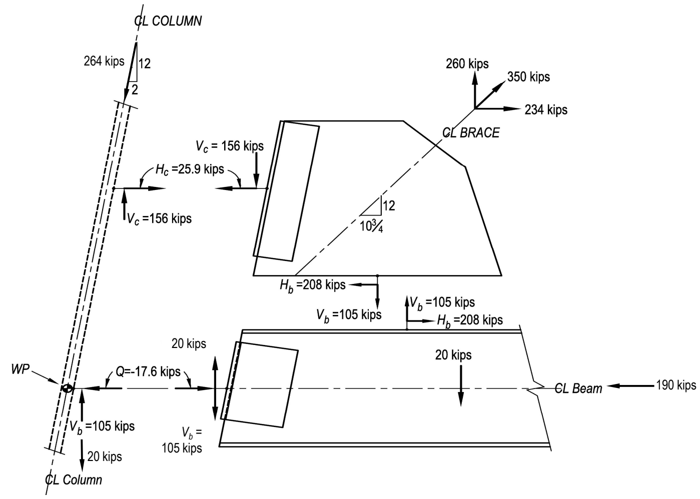
Brace horizontal component = 350 sinθ = 234 kips OK

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

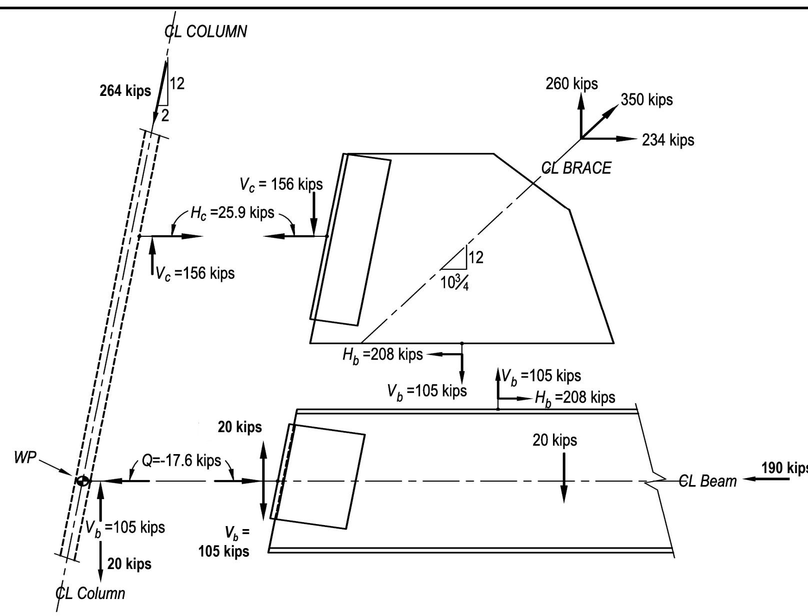
78

Design for a sloping building column

Admissible Force Field



79



80

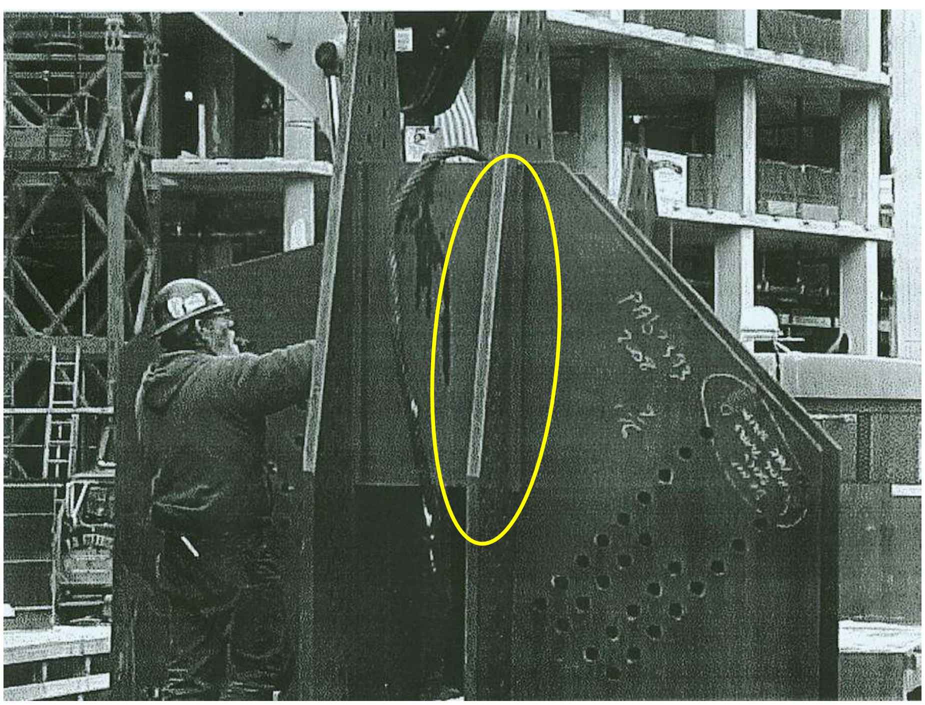
Jack Truss to Main Truss

The UFM applied to a truss-to-truss connection

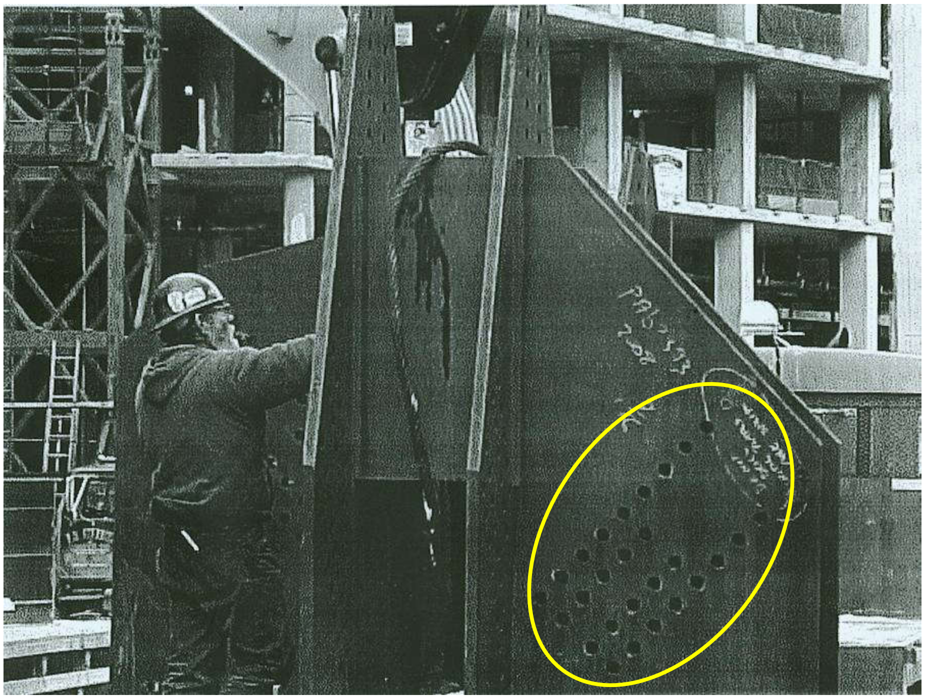
81

82

83

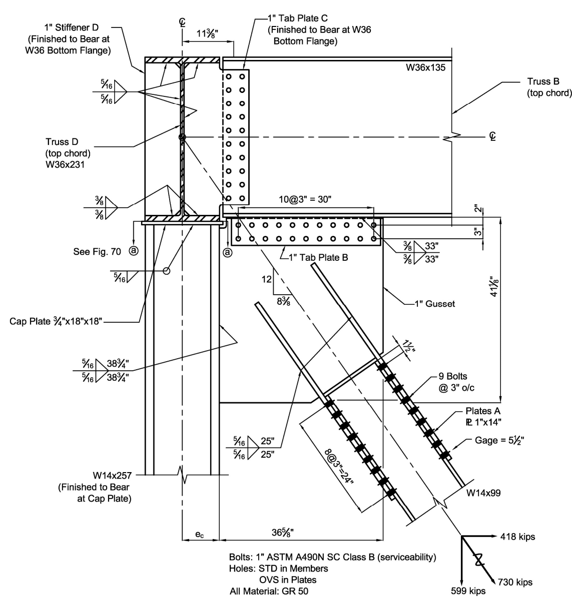


84

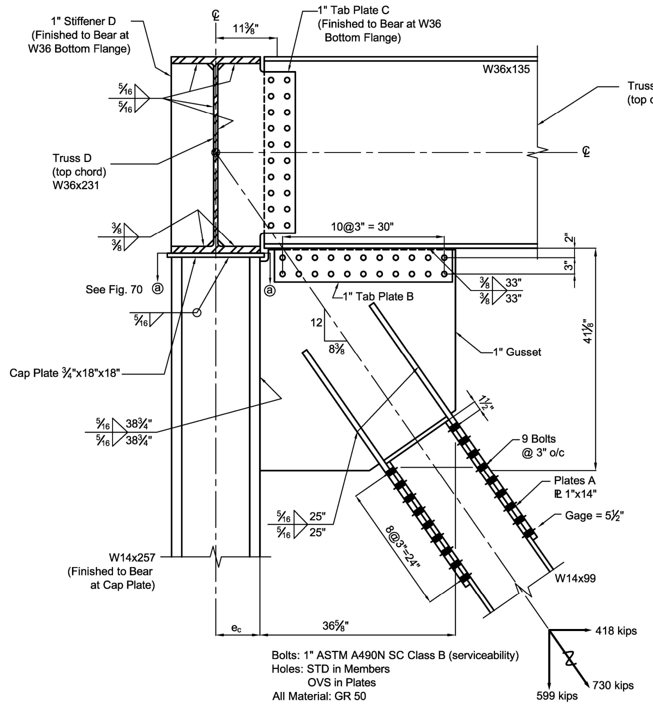


85

A Jack Truss to Main Truss Connection

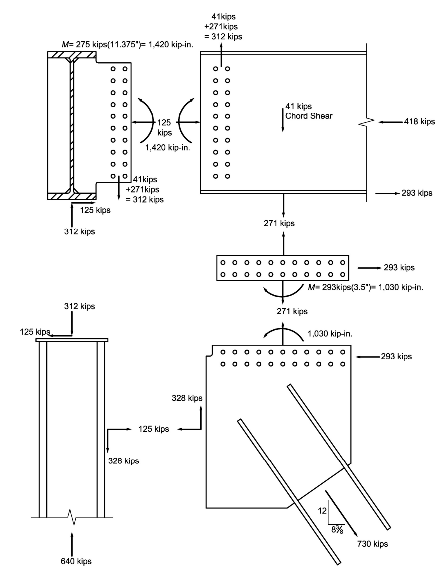


86



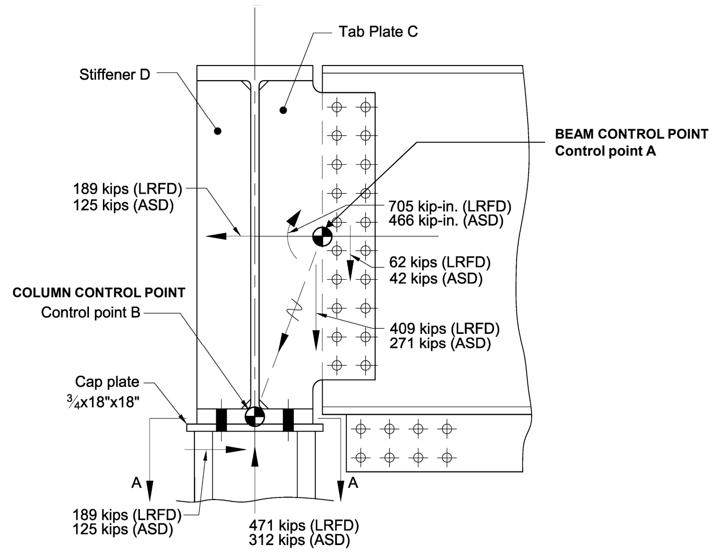
87

Admissible Force Field



88

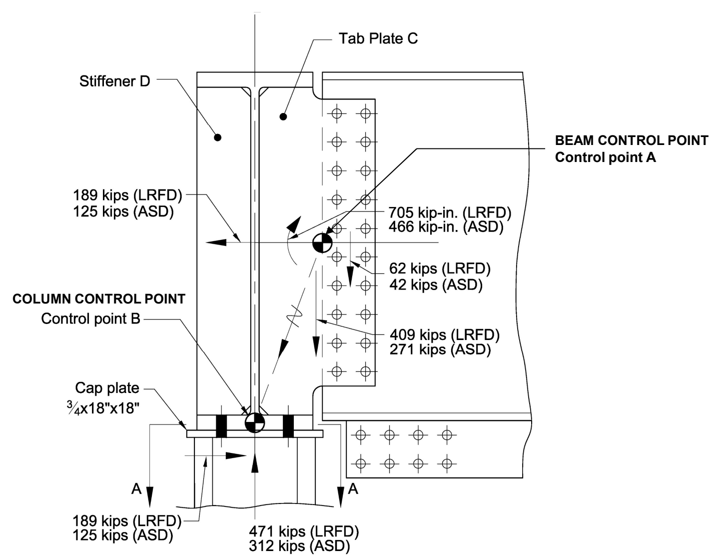
Use of Control Points



89

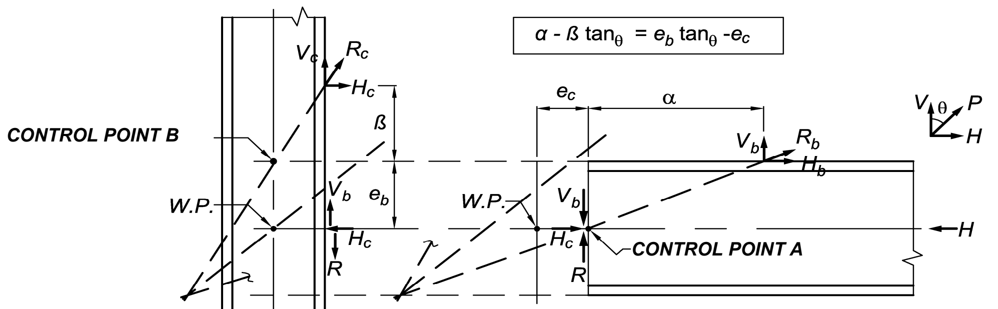
Column Control Point (B)

simplifies interface force calculation



90

Geometry of UFM



$$\alpha - \beta \tan_{\theta} = e_b \tan_{\theta} - e_c$$

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

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

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

91

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.

92

Analytical and Physical Testing

Origins of Uniform Force Method

93

STEEL CONNECTION DESIGN

BASED ON

INELASTIC FINITE ELEMENT ANALYSIS

A DESIGN REPORT PREPARED FOR

AMERICAN INSTITUTE OF STEEL CONSTRUCTION

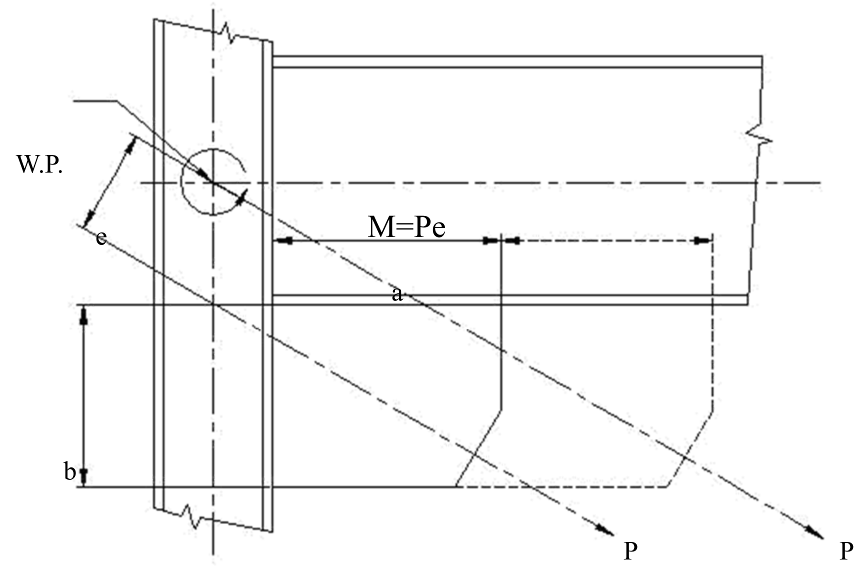
GEORGE C. WILLIAMS, Ph.D.

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

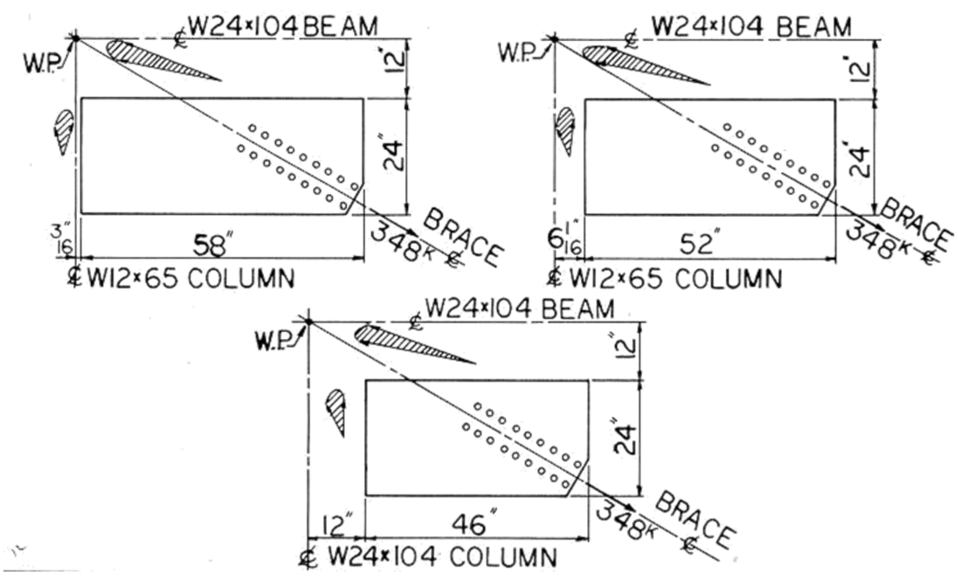
UNIVERSITY OF ARIZONA

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

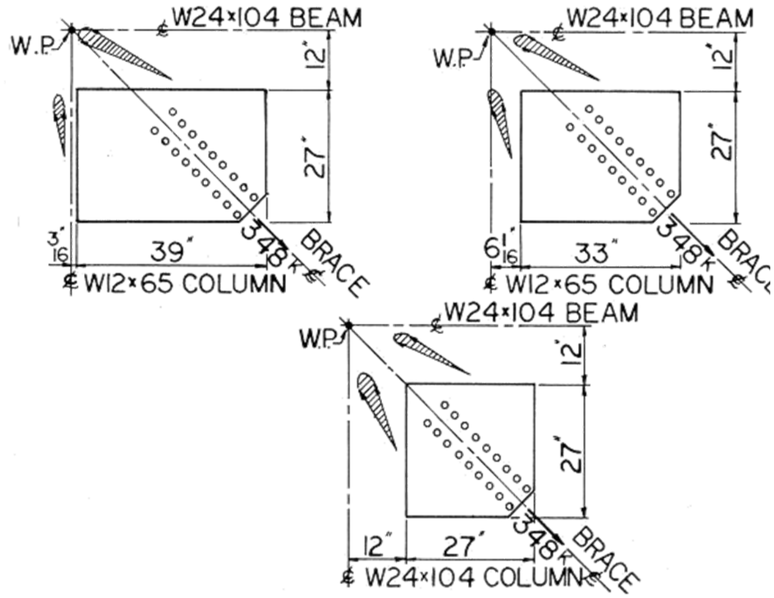
94



GUSSET EDGE FORCE RESULTANT ENVELOPES
30º WORKING POINT MODELS

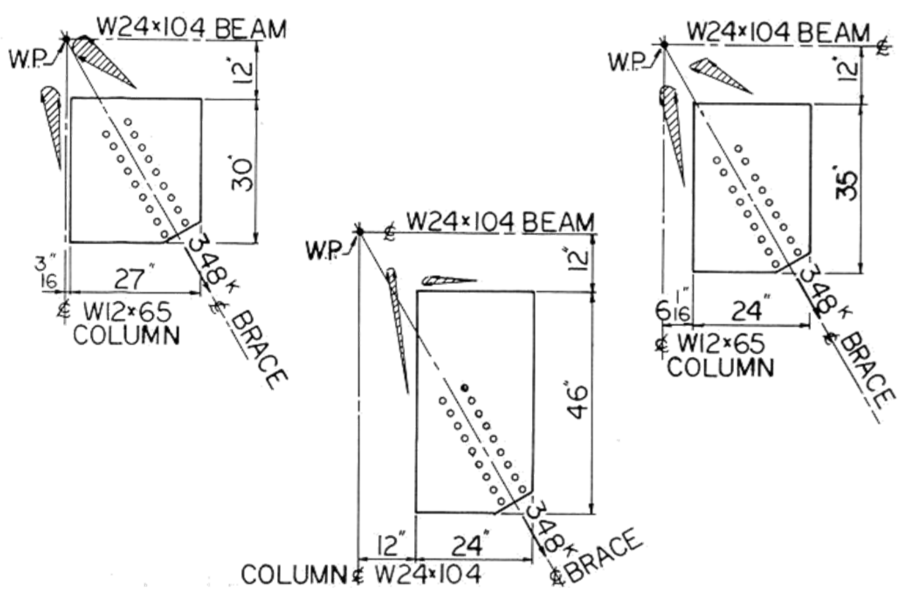


GUSSET EDGE FORCE RESULTANT ENVELOPE
45º WORKING POINT MODELS



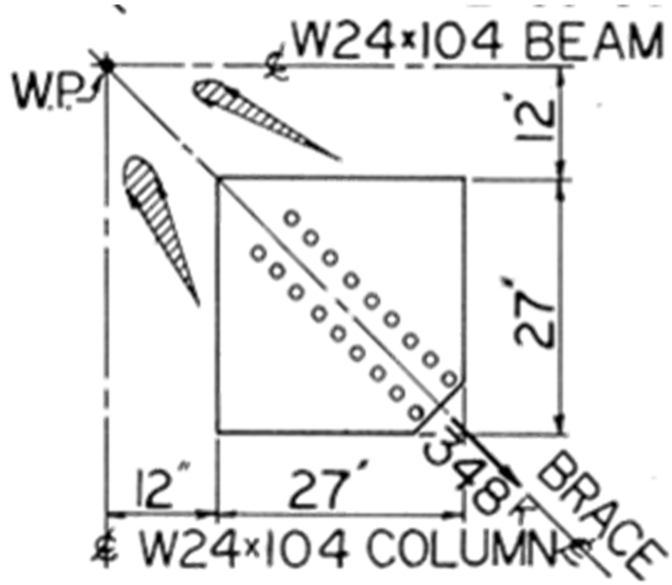
97

GUSSET EDGE FORCE RESULTANT ENVELOPES
60º WORKING POINT MODELS



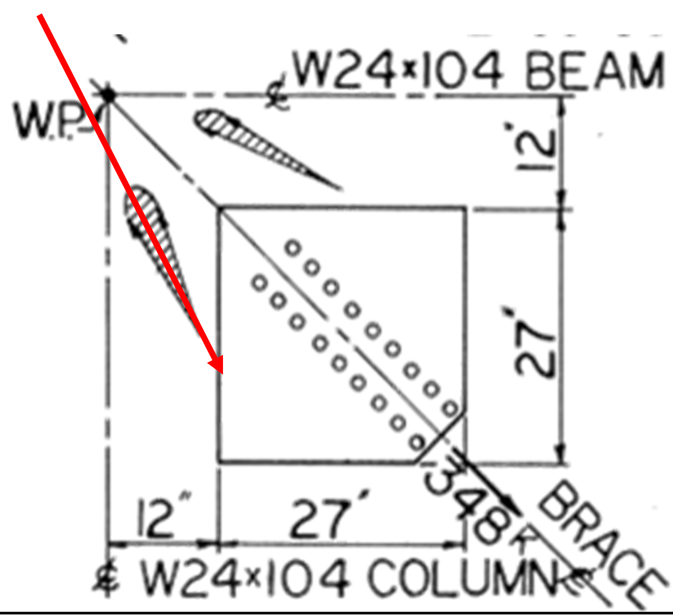
98

GUSSET EDGE FORCE RESULTANT ENVELOPE
45º WORKING POINT MODELS



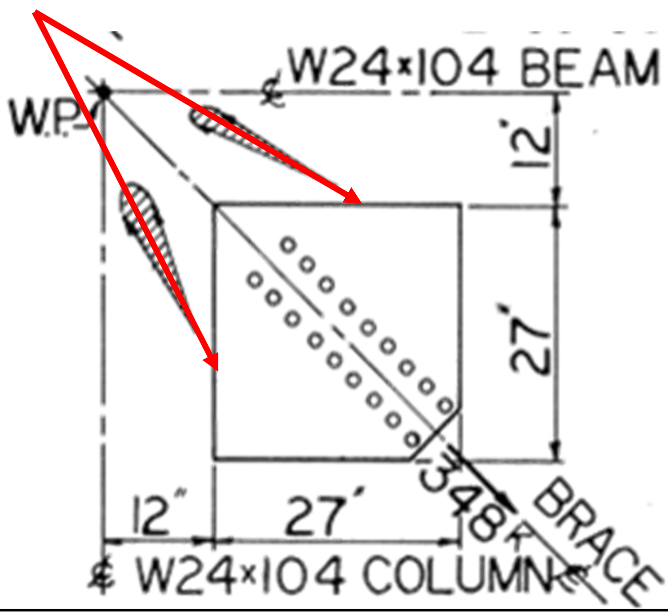
99

GUSSET EDGE FORCE RESULTANT ENVELOPE
45º WORKING POINT MODELS



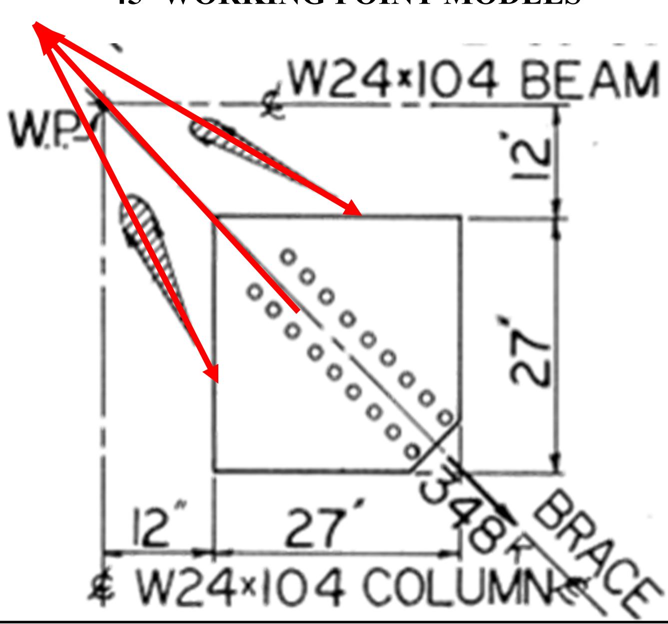
100

GUSSET EDGE FORCE RESULTANT ENVELOPE
45º WORKING POINT MODELS



101

GUSSET EDGE FORCE RESULTANT ENVELOPE
45º WORKING POINT MODELS

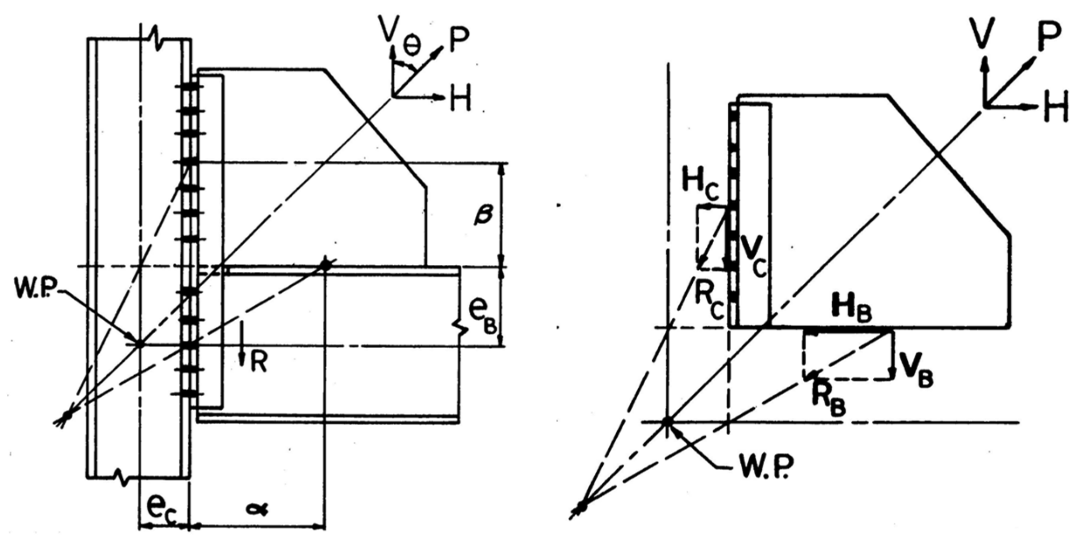


102

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

103

Uniform Force Method (UFM)
Admissible Force Field



104

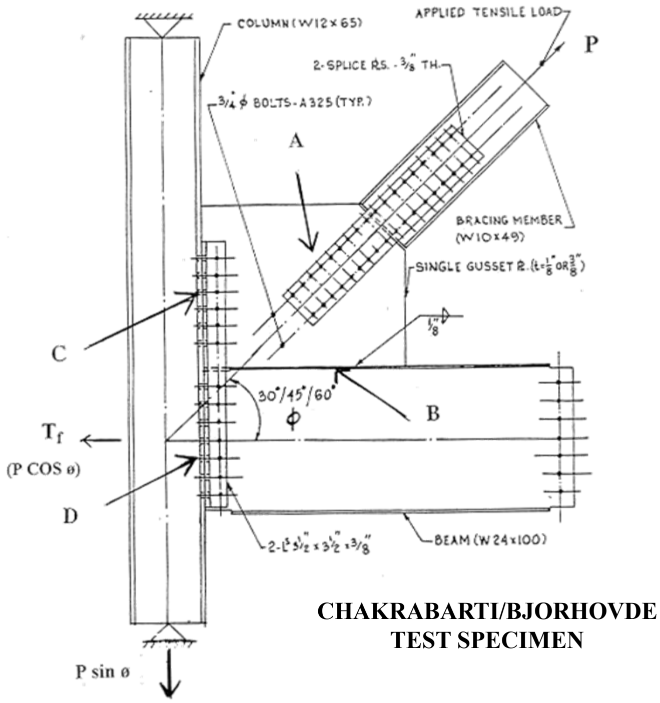
The UFM was first introduced in 1991

- “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

105

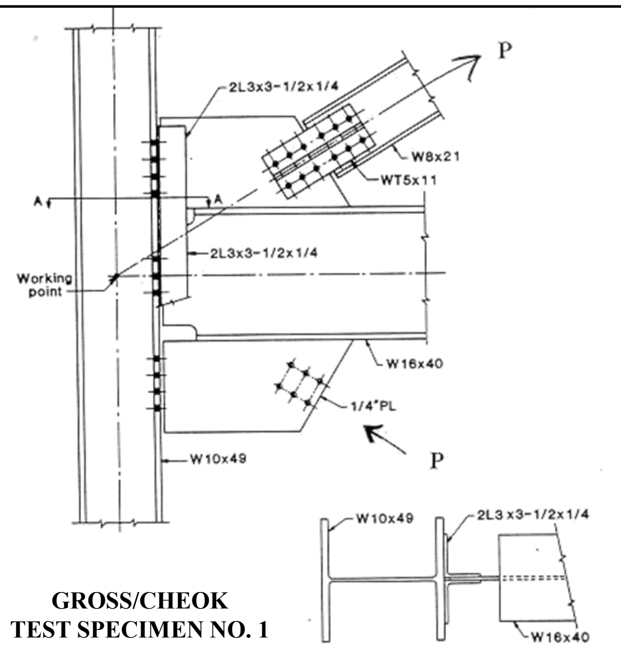
Comparison of the Uniform Force Method with Physical Test Results

106



CHAKRABARTI/BJORHOVDE
TEST SPECIMEN

107



GROSS/CHEOK
TEST SPECIMEN NO. 1

108

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

109

Limit States Considered for Each Interface of the Bracing Connection

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

110

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 30º	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 º	142 (3,5)	182 (7)	164 (5)	210 (12)	142 (3,5)	A (3,5)	148	A (5)	1.04
Chakrabarti/ Bjorhovde 60 º	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

111

General Summary

- Connections can account for 50% of the cost of erected steel
- Rational design of connections requires engineering knowledge

112

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.

113

References

Additional UFM discussion will be found in the following:

1. Tamboli, A.K., 2016, Handbook of Structural Steel Connection Design and Details, 3rd Ed., McGraw-Hill, Chapter 2
2. Brockenbrough, R.L., and Merritt, F.S., 2020, Structural Steel Designer's Handbook, 6th Ed., McGraw-Hill, Chapter 3
3. Muir, Larry S., and Thornton, William A., 2014, Design Guide 29: Vertical Bracing Connections, American Institute of Steel Construction, Chapter 4

114

Vertical Bracing Connections, Session 2: Uniform Force Method, Part 1

April 12, 2022 | William A Thornton

Smarter.
Stronger.
Steel.

Thank you!

AISC | Questions

Smarter.
Stronger.
Steel.