



**Night School 28:  
Vertical Bracing  
Connections**

Thank you for joining our live webinar. We will begin shortly. Please stand by.

**AISC Night School**




**Vertical Bracing Connections, Session 2: Uniform Force Method**  
April 12, 2022 | William A Thornton



**Smarter.  
Stronger.  
Steel.**

**AISC Night School**

**Vertical Bracing Connections, Session 2: Uniform Force Method**  
April 12, 2022 | William A Thornton




**AISC Night School**

**Today's live webinar will begin shortly. Please stand by.**

Today's audio will be broadcast through the internet. Please be sure to turn up the volume on your speakers.

Please type any questions or comments in the Q&A window.




**AISC Night School**

**AIA Credit**

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 has been submitted for 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.





### Copyright Materials

This presentation is protected by US and International Copyright laws. Reproduction, distribution, display and use of the presentation without written permission of AISC is prohibited.

© The American Institute of Steel Construction 2022

The information presented herein is based on recognized engineering principles and is for general information only. While it is believed to be accurate, this information should not be applied to any specific application without competent professional examination and verification by a licensed professional engineer. Anyone making use of this information assumes all liability arising from such use.



### 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.



### 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



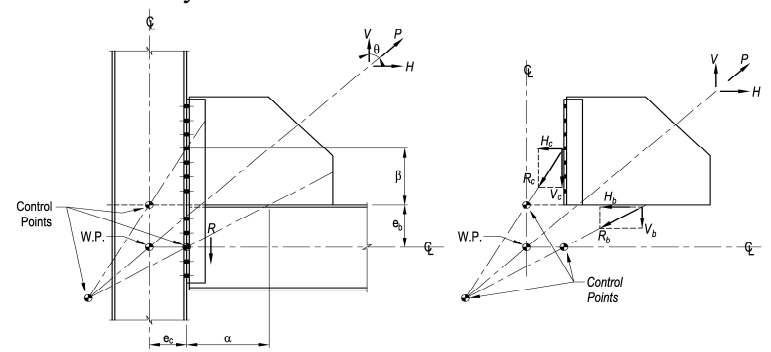
12

### 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

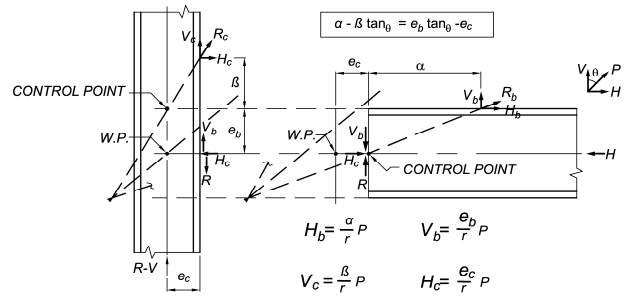


### Uniform Force Method (UFM) Geometry Control Points and Admissible Force Field



### Geometry of UFM

All Parts are in Equilibrium



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

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

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



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

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

$\alpha$  and  $\beta$  locate the gusset connection centroids

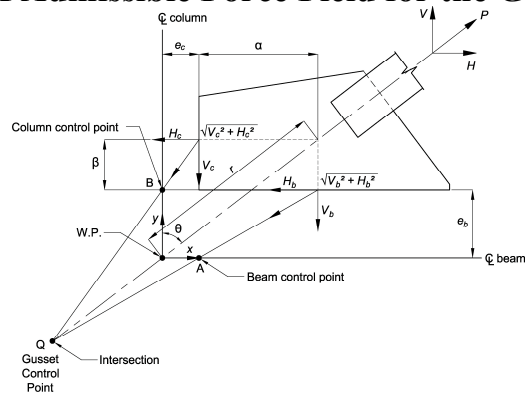


$\alpha$  and  $\beta$   
 vs  
 $\bar{\alpha}$  and  $\bar{\beta}$

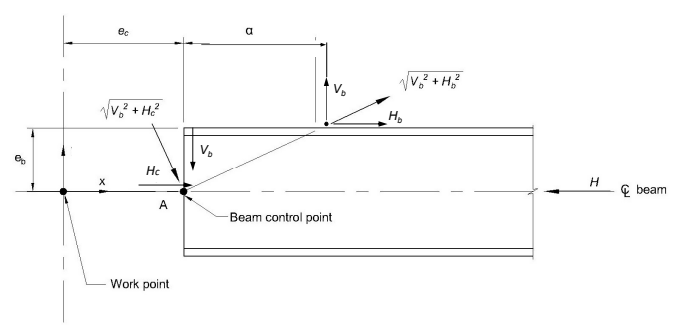
When designing a connection,  $\alpha$  and  $\beta$  can **always** be chosen to satisfy the geometric constraint.  
 When checking a connection designed by some other method the connection centroids may not satisfy the geometric constraint.  
 This is where  $\bar{\alpha}$  and  $\bar{\beta}$  appear. These locate the actual connections centroids and will not satisfy the constraint. Therefore, couples will exist on the gusset edges. Manual 15<sup>th</sup> Ed. Part 13 addresses this.



**UFM Admissible Force Field for the Gusset**



**UFM Admissible Force Field for the Beam**





### 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.



### 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,

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

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

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

The component forces are

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

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

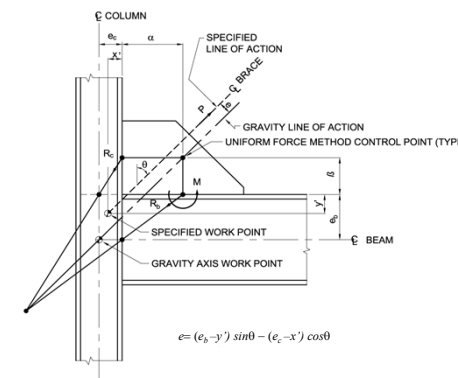
Note:  $H_b + H_c = H$

Note:  $V_b + V_c = V$



### UFM Special Case I

Non-Concentric Work Point



### 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

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

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

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

or

$$\eta = \frac{M_p \text{ Beam}}{\sum M_p \text{ Beam + Columns}}$$

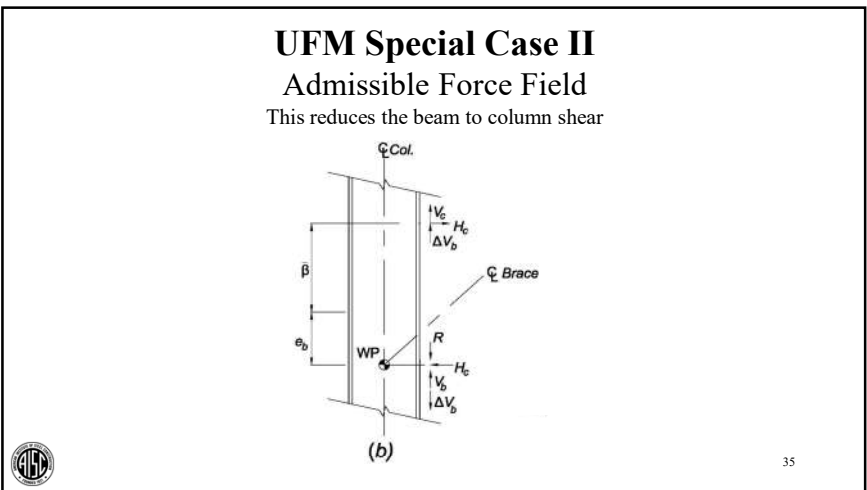
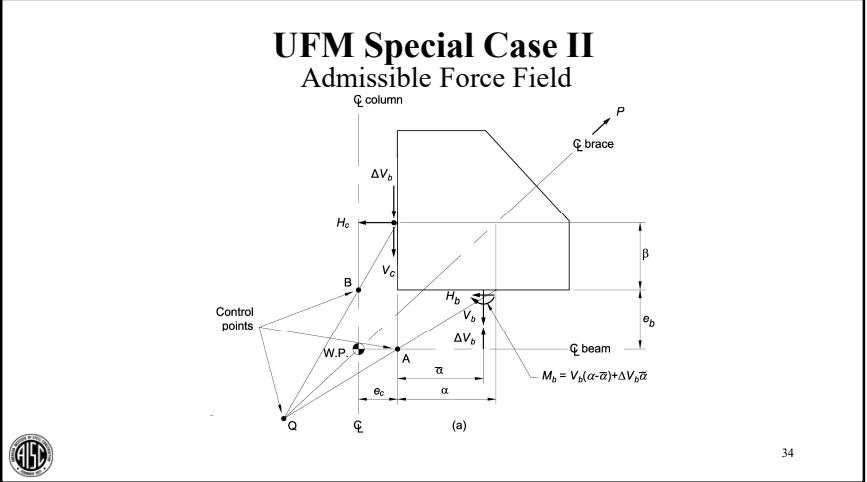
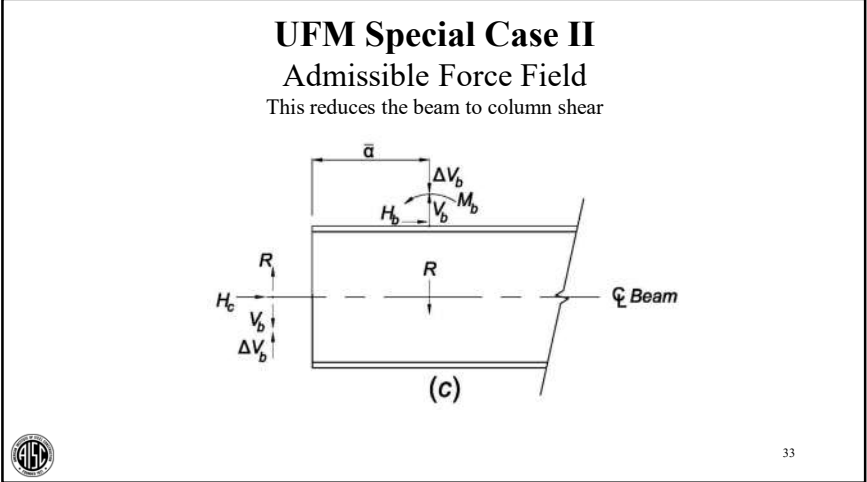
**CONNECTION FORCE DISTRIBUTION DUE TO MOMENT M**

31

### UFM Special Case II

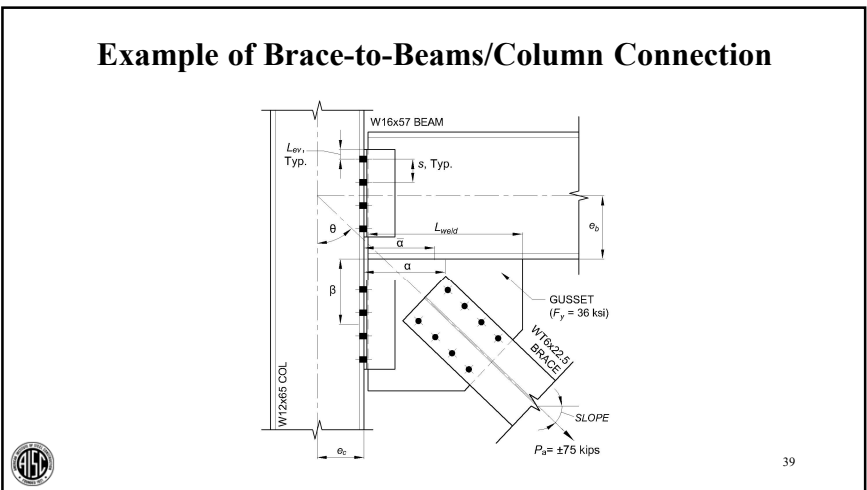
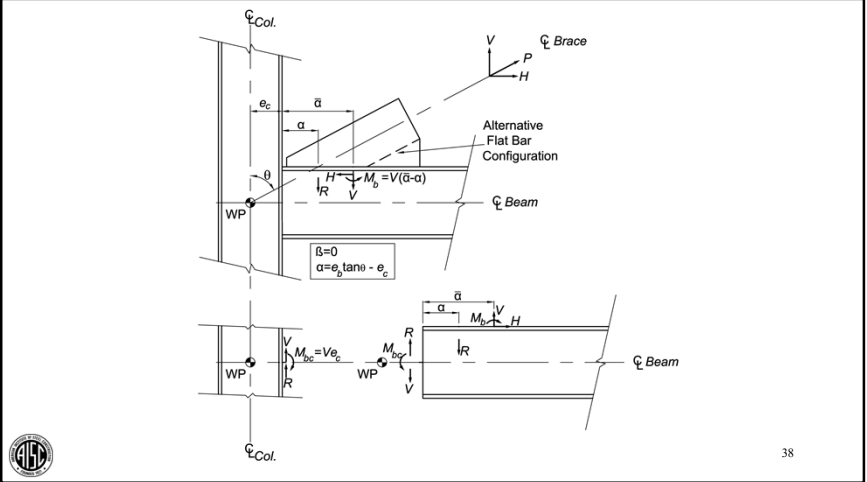
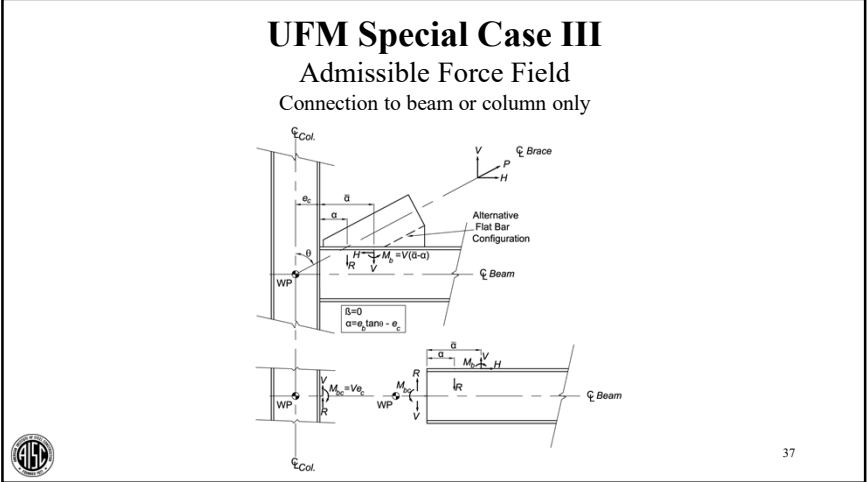
Admissible Force Field

32



### 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



- ### Example of Brace-to-Beams/Column Connection (cont.)
- Given:**
1. AISC 15<sup>th</sup> Edition, ASD
  2. Beam-to-Column and Gusset-to-Column:  $n = 4$
  3.  $L_{weld} = 20$  in. min. with  $1/4$ " min. weld
  4.  $3/4$ " 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,  $P_a = \pm 75$  kips with slope =  $43.6^\circ$ ,  $\theta = 46.4^\circ$
- 40

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

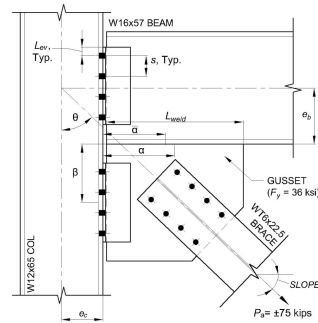
**Solution:**  
 Determine Gusset Forces using UFM

$$\tan\theta = 1.05$$

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

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

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



41

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

$\beta$  = 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.

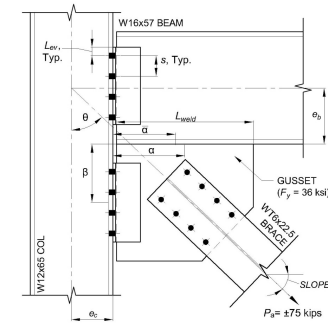
Let  $\bar{\beta} = \beta$

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

$$= (8.2 \text{ in.} \times 1.05) - 6.05 \text{ in.}$$

$$+ (8.5 \text{ in.} \times 1.05)$$

$$= 11.5 \text{ in.}$$



42

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

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

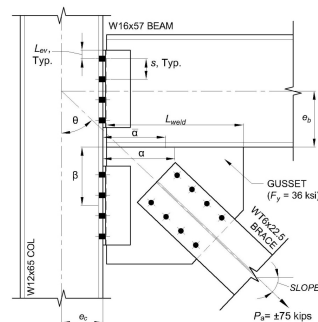
$$= 20 \text{ in.}/2 + 0.5 \text{ in.}$$

$$= 10.5 \text{ in. min.} \rightarrow \text{does not equal } \alpha$$

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

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

$$= 24.2 \text{ in.}$$



43

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

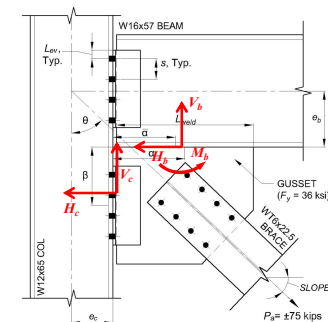
Note: If AISC Special Load Case 2 is selected, then:

$$V_B \rightarrow \text{transfer portion, } \Delta V_B, \text{ to } V_C$$

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

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

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



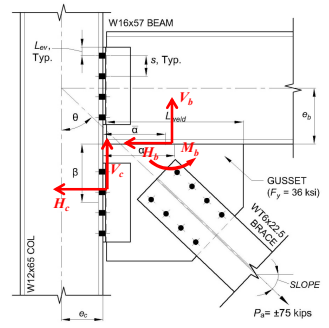
44

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

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

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

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



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

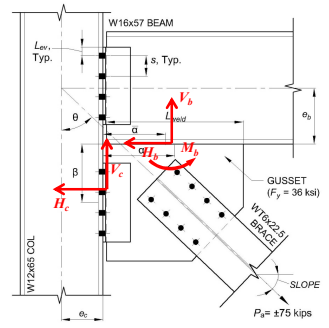
$$M_B = V_B (\alpha - \bar{\alpha}) = 25.4 \text{ kips}(11.5 \text{ in.} - 10.5 \text{ in.}) = 25.4 \text{ kip-in.}$$

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

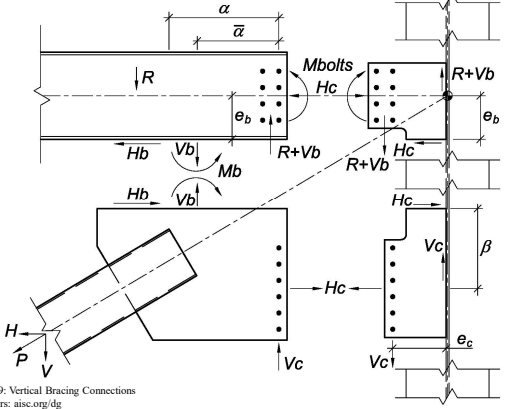
$$H_C = P_a (e_c/r) = 75 \text{ kips}(6.05 \text{ in.}/24.2 \text{ in.}) = 18.8 \text{ kips}$$

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

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

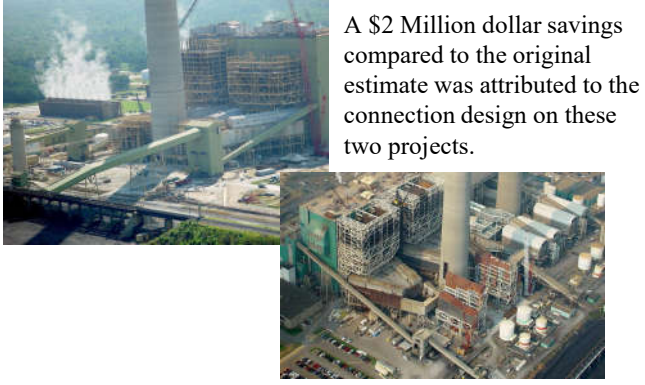


**Special Case IV**



Ref. AISC Design Guide 29: Vertical Bracing Connections  
 Free Download for Members: aisc.org/dg

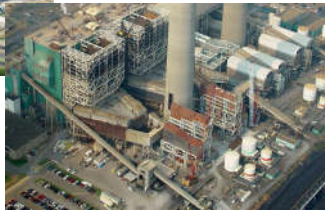
**Special Case IV**



### 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

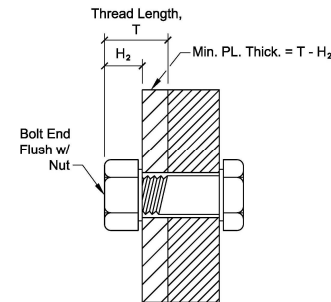


X-bolts were also used wherever the threads excluded condition could be assured without additional inspection.



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.



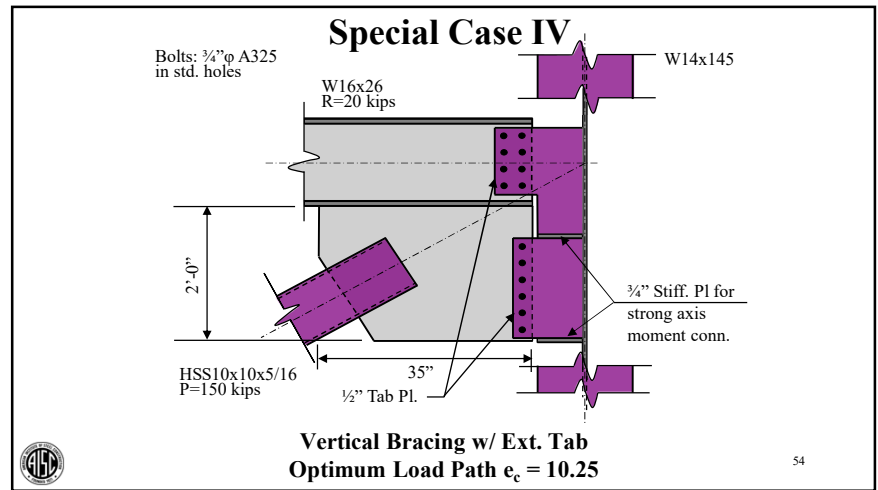
52

### Allow X-Type Bolts Where Appropriate

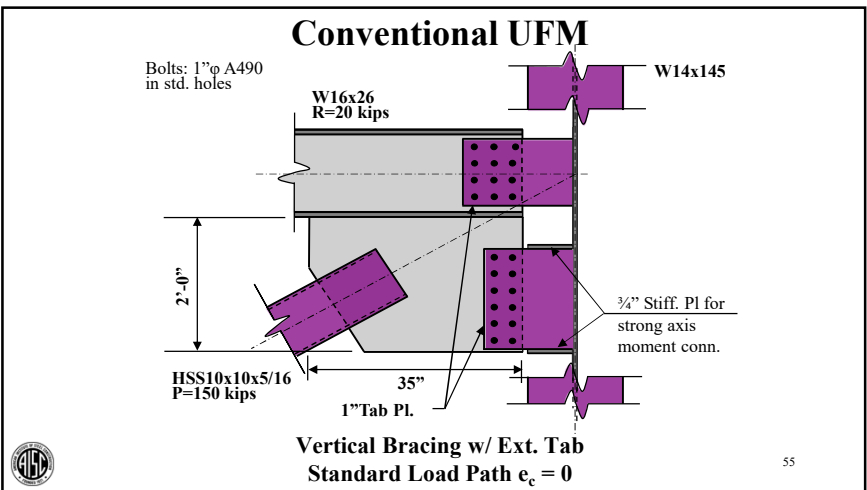
Minimum Ply Thickness for Threads Excluded Condition			
Bolt Dia. (in.)	Min. Ply Thick (in.)	Min. Ply Thick w/ $\frac{5}{32}$ " washer (in.)	Min. Ply Thick w/ $\frac{5}{32}$ " washer & $\frac{1}{4}$ " stick-thru (in.)
$\frac{3}{4}$	0.641	0.485	0.235
$\frac{7}{8}$	0.641	0.485	0.235
1	0.766	0.610	0.360
$1\frac{1}{8}$	0.891	0.735	0.485
$1\frac{1}{4}$	0.781	0.625	0.375



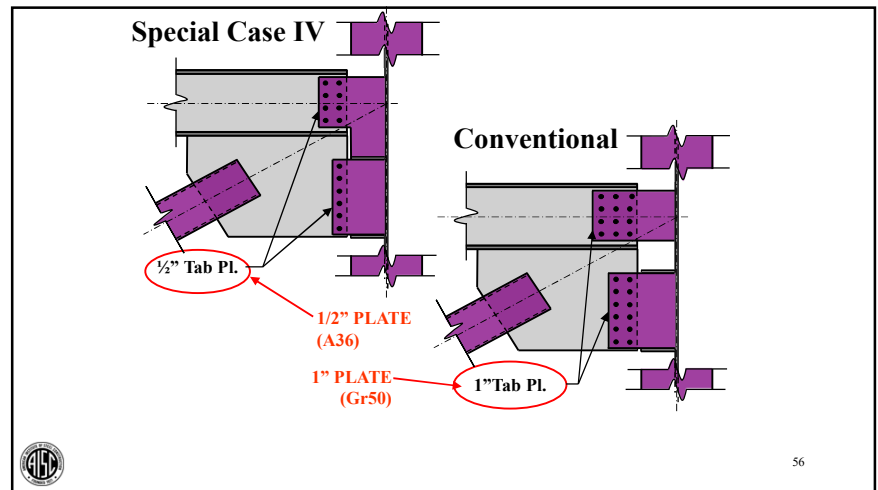
53



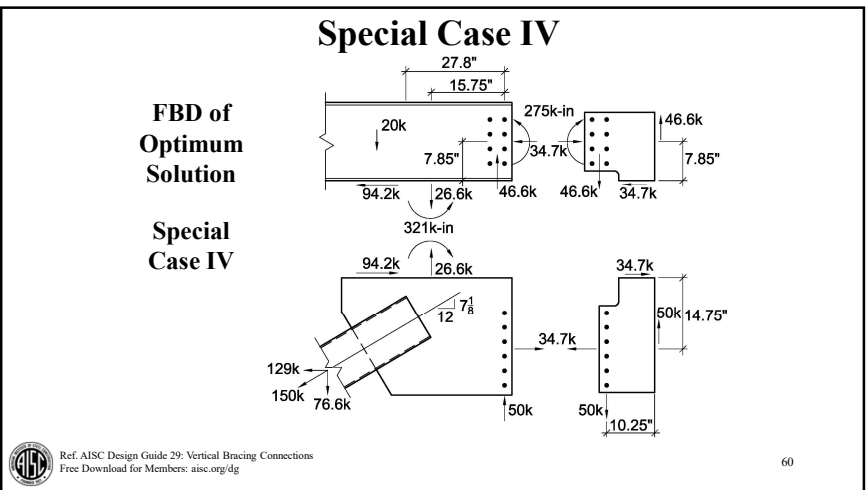
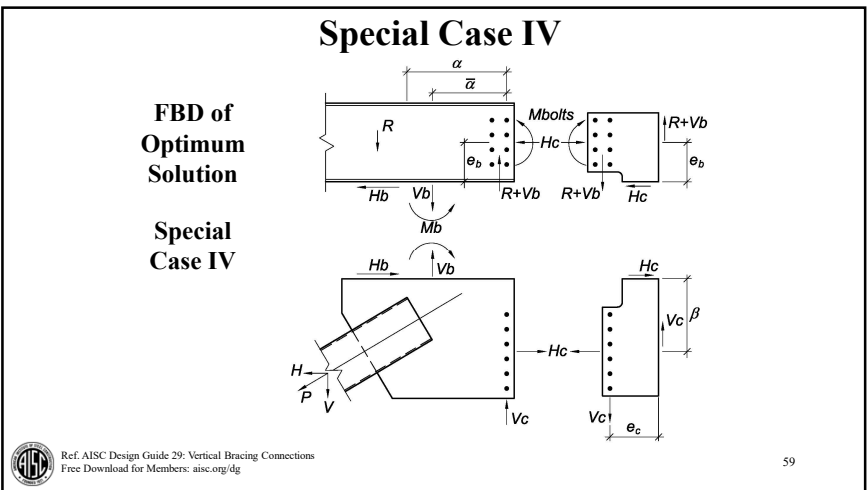
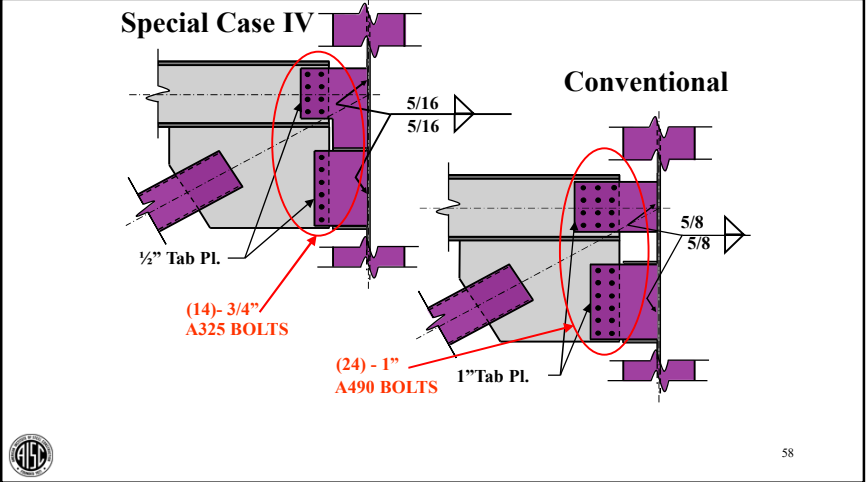
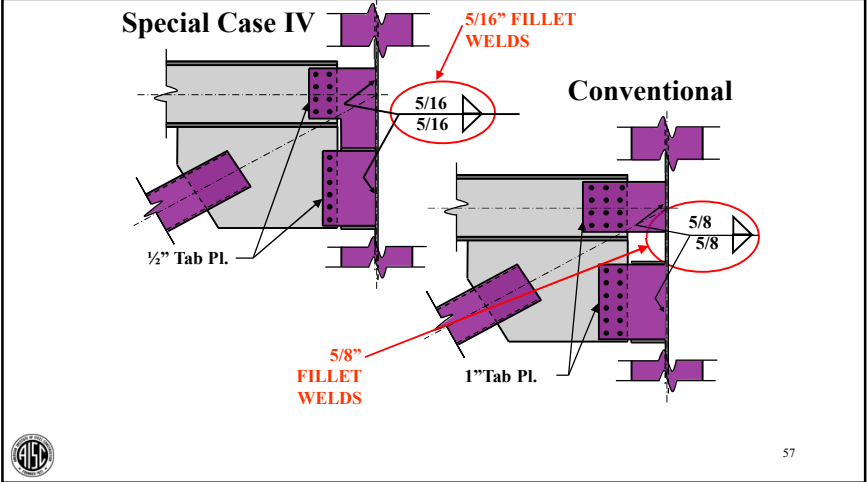
54



55



56



### Comparison of Design Results

COMPARISON OF DESIGNS RESULTING FROM DIFFERENT LOAD PATHS															
	DRILLING				WELDING				MATERIAL					Weight Connection Plates (lbs)	
	# of Holes	Plate Thick. (in.)	Area Holes (in. <sup>2</sup> )	Vol. of Holes (in. <sup>3</sup> )	Weld Size (in.)	Length (in.)	Volume (in. <sup>3</sup> )	Length Single Pass Weld (in.)	Area of Tabs (ft <sup>2</sup> )	Thick. Tabs (ft)	Volume Tabs (ft <sup>3</sup> )	Area of Gusset (ft <sup>2</sup> )	Thick. Gusset (ft)		Volume Gusset (ft <sup>3</sup> )
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



### Comparison of Design Results

COMPARISON OF DESIGNS RESULTING FROM DIFFERENT LOAD PATHS															
	DRILLING				WELDING				MATERIAL					Weight Connection Plates (lbs)	
	# of Holes	Plate Thick. (in.)	Area Holes (in. <sup>2</sup> )	Vol. of Holes (in. <sup>3</sup> )	Weld Size (in.)	Length (in.)	Volume (in. <sup>3</sup> )	Length Single Pass Weld (in.)	Area of Tabs (ft <sup>2</sup> )	Thick. Tabs (ft)	Volume Tabs (ft <sup>3</sup> )	Area of Gusset (ft <sup>2</sup> )	Thick. Gusset (ft)		Volume Gusset (ft <sup>3</sup> )
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



### Comparison of Design Results

COMPARISON OF DESIGNS RESULTING FROM DIFFERENT LOAD PATHS															
	DRILLING				WELDING				MATERIAL					Weight Connection Plates (lbs)	
	# of Holes	Plate Thick. (in.)	Area Holes (in. <sup>2</sup> )	Vol. of Holes (in. <sup>3</sup> )	Weld Size (in.)	Length (in.)	Volume (in. <sup>3</sup> )	Length Single Pass Weld (in.)	Area of Tabs (ft <sup>2</sup> )	Thick. Tabs (ft)	Volume Tabs (ft <sup>3</sup> )	Area of Gusset (ft <sup>2</sup> )	Thick. Gusset (ft)		Volume Gusset (ft <sup>3</sup> )
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



### Comparison of Design Results

COMPARISON OF DESIGNS RESULTING FROM DIFFERENT LOAD PATHS															
	DRILLING				WELDING				MATERIAL					Weight Connection Plates (lbs)	
	# of Holes	Plate Thick. (in.)	Area Holes (in. <sup>2</sup> )	Vol. of Holes (in. <sup>3</sup> )	Weld Size (in.)	Length (in.)	Volume (in. <sup>3</sup> )	Length Single Pass Weld (in.)	Area of Tabs (ft <sup>2</sup> )	Thick. Tabs (ft)	Volume Tabs (ft <sup>3</sup> )	Area of Gusset (ft <sup>2</sup> )	Thick. Gusset (ft)		Volume Gusset (ft <sup>3</sup> )
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



### Comparison of Design Results

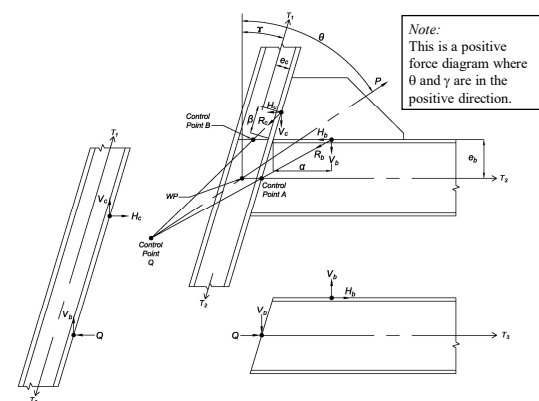
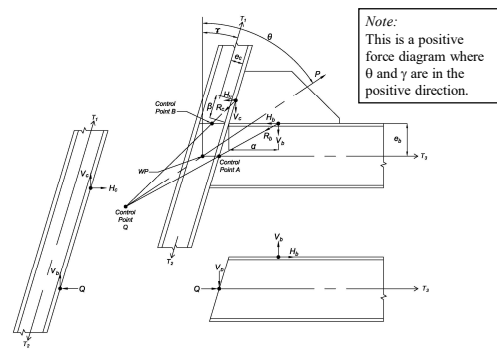
COMPARISON OF DESIGNS RESULTING FROM DIFFERENT LOAD PATHS															
	DRILLING				WELDING				MATERIAL					Weight Connection Plates (lbs)	
	# of Holes	Plate Thick. (in.)	Area of Holes (in. <sup>2</sup> )	Vol. of Holes (in. <sup>3</sup> )	Weld Size (in.)	Length (in.)	Volume (in. <sup>3</sup> )	Length Single Pass Weld (in.)	Area of Tabs (ft <sup>2</sup> )	Thick. (ft)	Volume Tabs (ft <sup>3</sup> )	Area of Gusset (ft <sup>2</sup> )	Thick. (ft)		Volume Gusset (ft <sup>3</sup> )
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



### Non-Orthogonal UFM



### Non-Orthogonal UFM

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

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

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

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

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

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

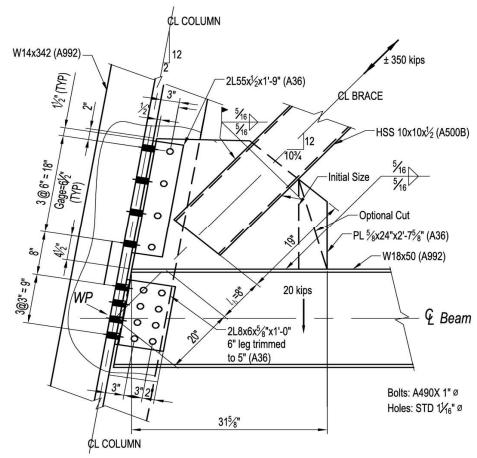
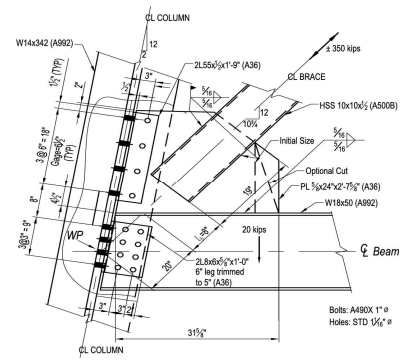
$$r = \sqrt{\left( \alpha + e_c \tan \gamma + \beta \sin \gamma + \frac{e_c}{\cos \gamma} \right)^2 + (e_b + \beta \cos \gamma)^2}$$



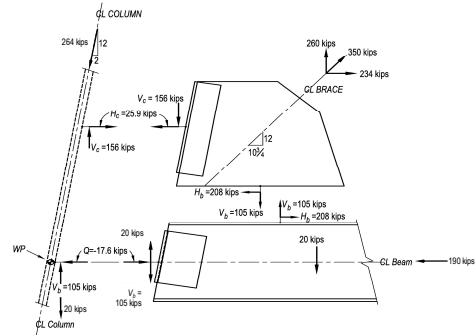
# Another Example

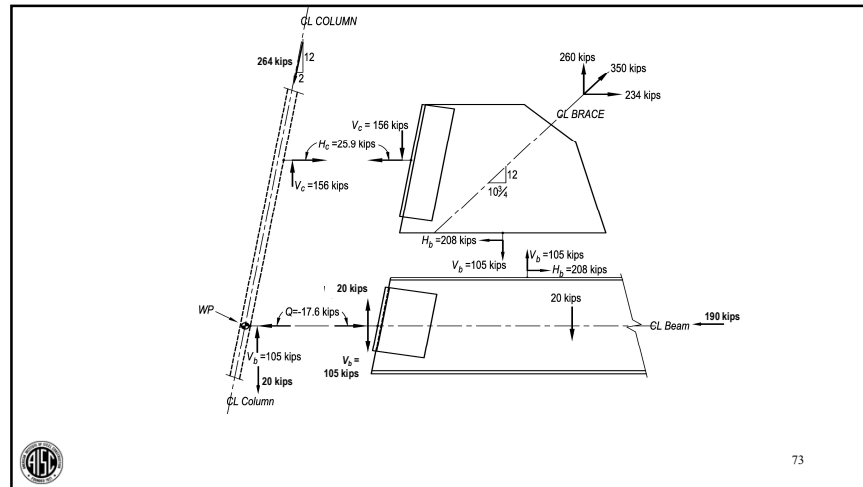


## Bracing Connection with Sloping Column From AISC Bracing Design Guide 29



## Design for a sloping building column Admissible Force Field





### Calculations

$$e_c = 0.0, e_b = 9.0 \text{ in.}$$

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

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

$$\tan \theta = 10.75/12$$

Set  $\beta = 13.5 \text{ in.}$ , 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)

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

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

$$= 30.0 \text{ in.}$$

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

**Calculations** (continued)

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

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

$\Sigma(V_b + V_c) = 261 \text{ kips}$

Brace vertical component =  $350 \cos \theta = 261 \text{ kips OK}$



**Calculations** (continued)

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

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

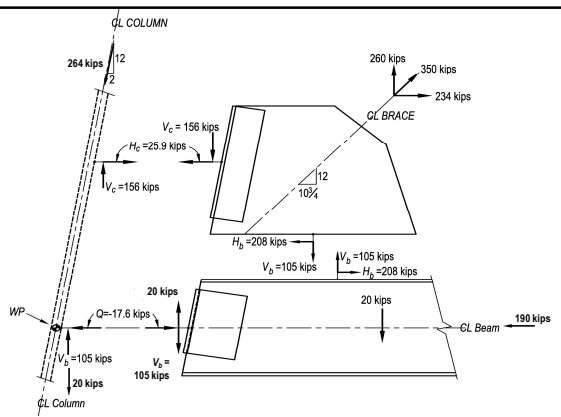
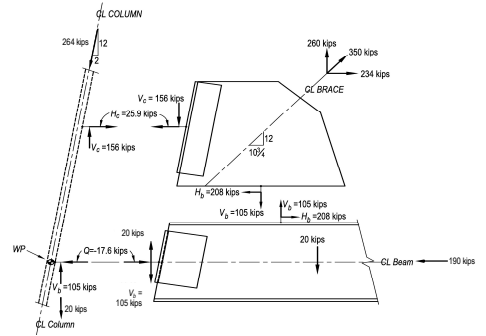
$\Sigma(H_c + H_b) = 234 \text{ kips}$

Brace horizontal component =  $350 \sin \theta = 234 \text{ kips OK}$

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



**Design for a sloping building column**  
 Admissible Force Field



## Jack Truss to Main Truss

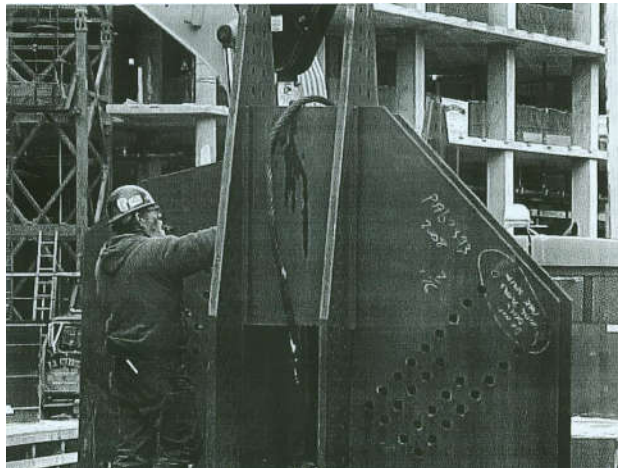
The UFM applied to a truss-to-truss connection



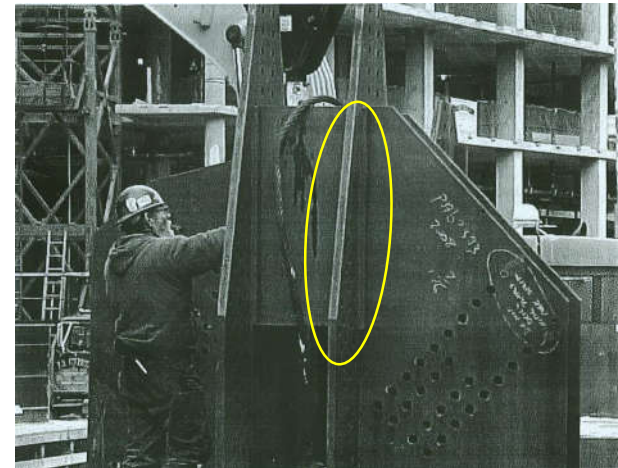
81



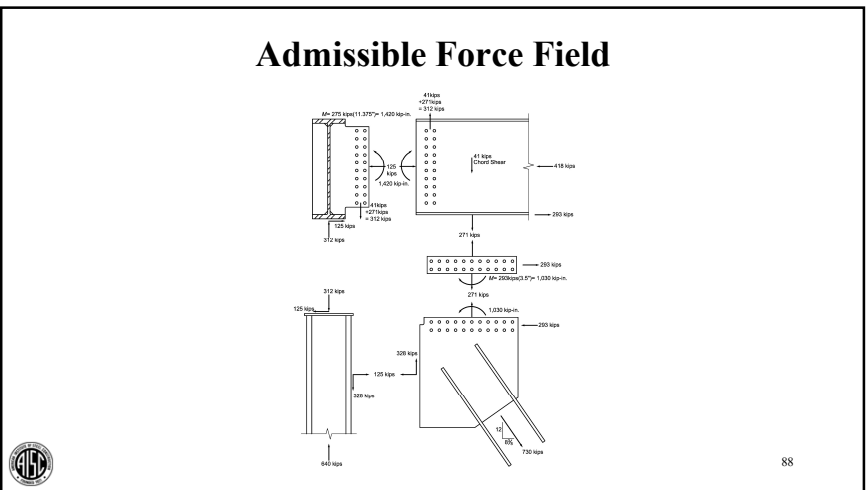
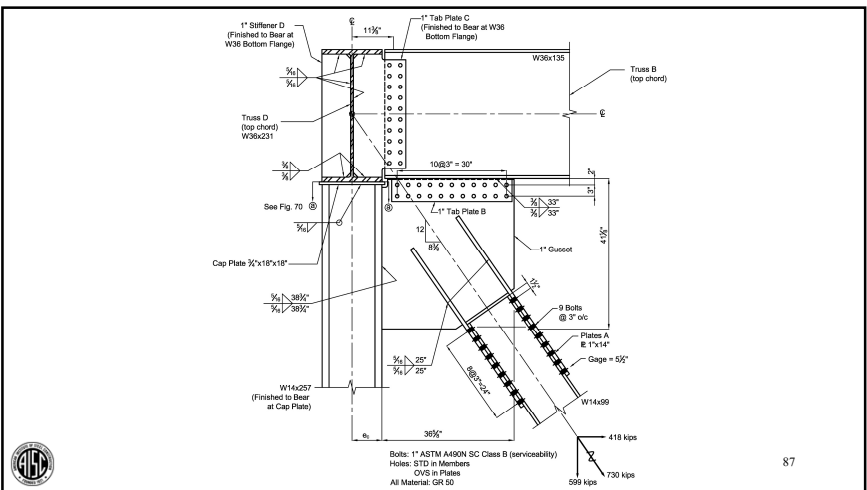
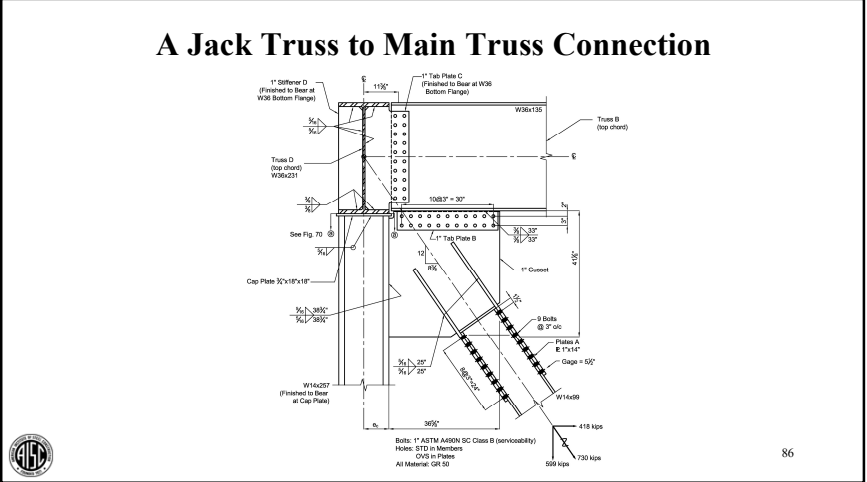
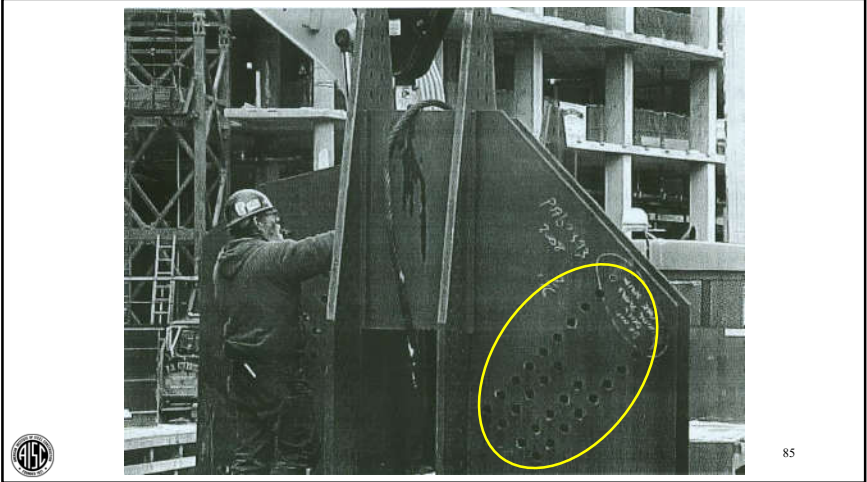
82

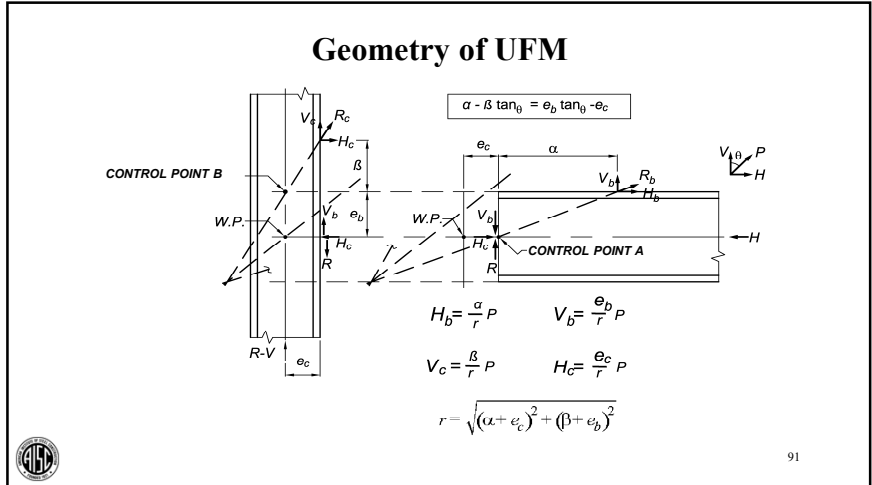
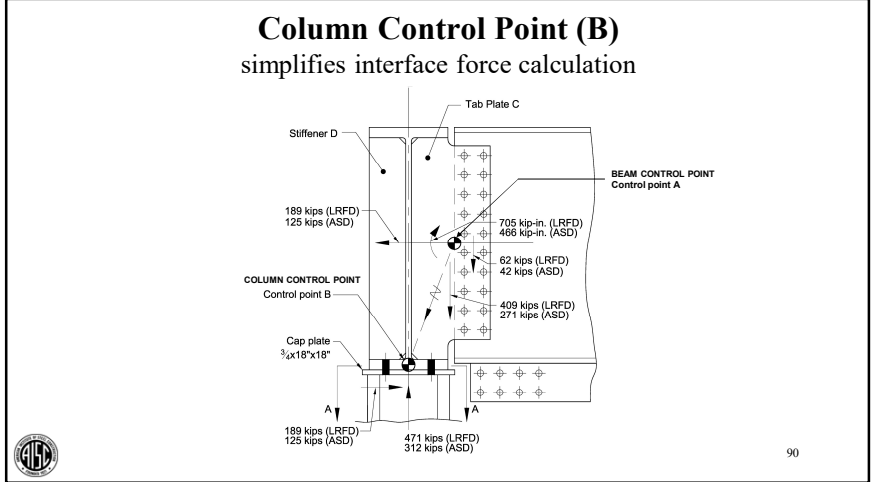
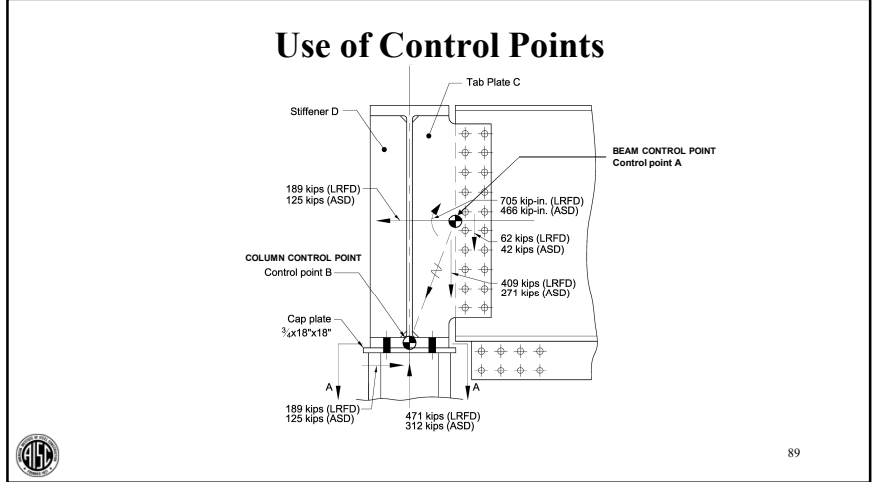


83



84





## 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

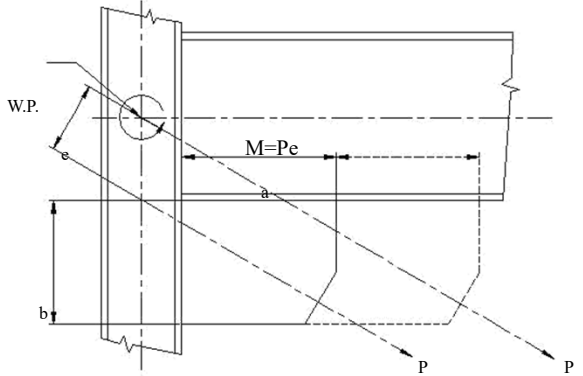


93

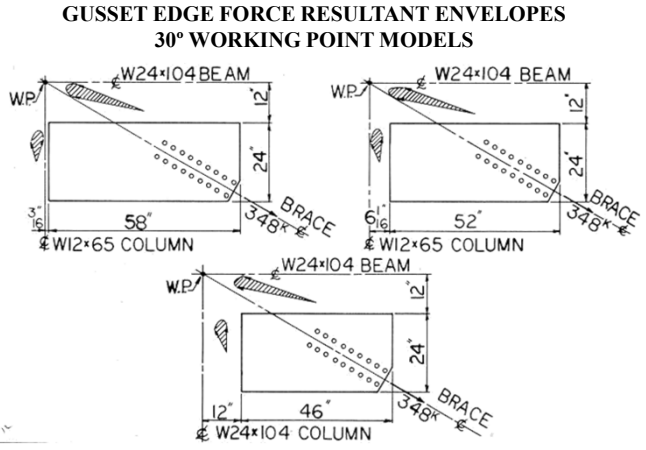
STEEL CONNECTION DESIGN  
BASED ON  
INELASTIC FINITE ELEMENT ANALYSIS  
A DESIGN REPORT PREPARED FOR  
AMERICAN INSTITUTE OF STEEL CONSTRUCTION  
GEORGE C. WILLIAMS, Ph.D.  
RALPH M. RICHARD, Ph.D., P.E.  
UNIVERSITY OF ARIZONA  
  
ALSO PROCEEDINGS, AISC NATIONAL STEEL  
CONSTRUCTION CONFERENCE, NASHVILLE, TN, 1986



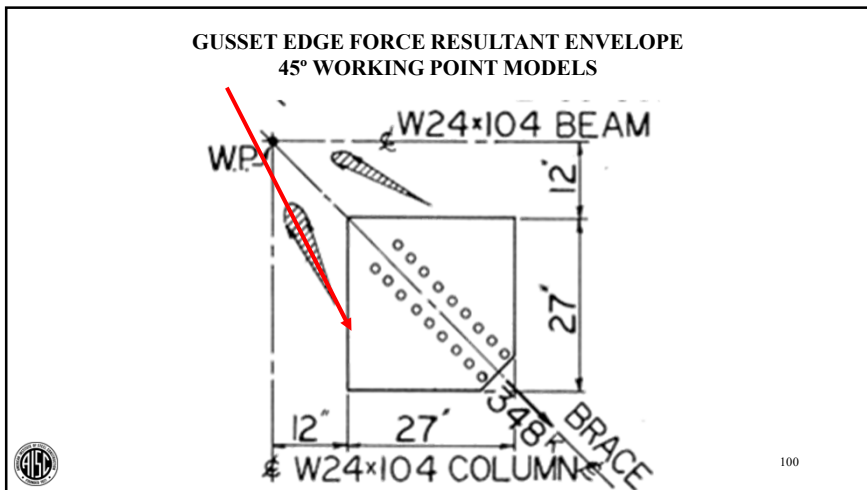
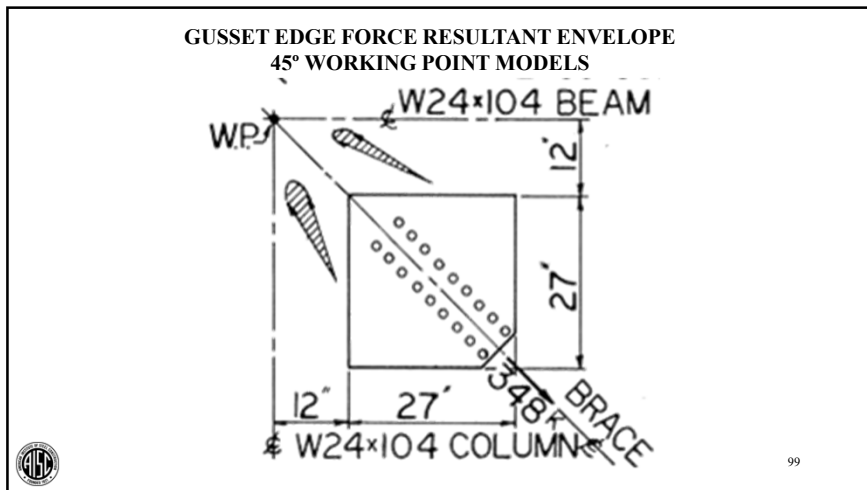
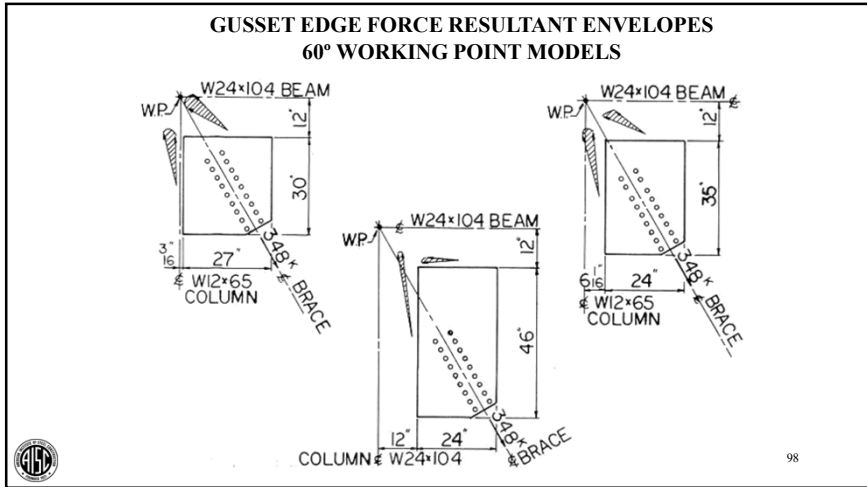
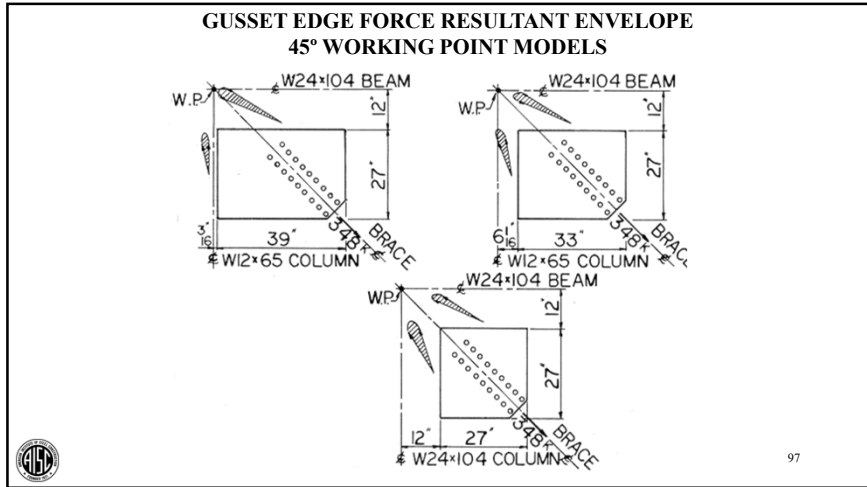
94

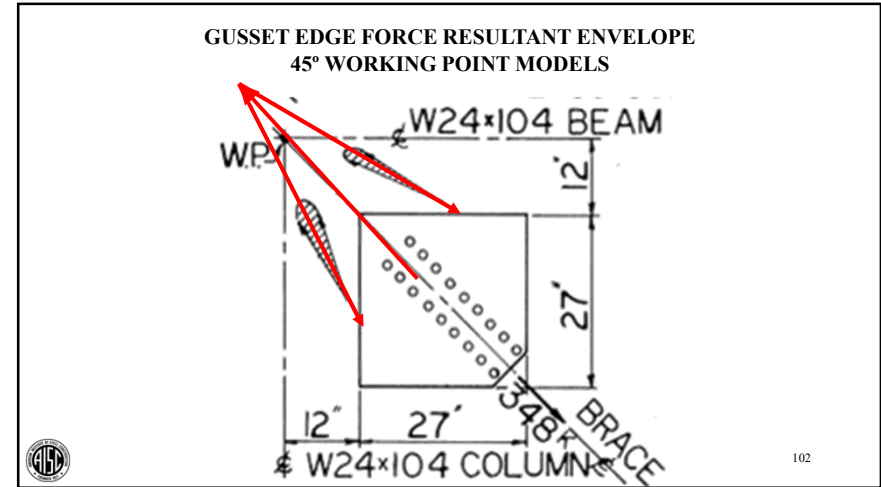
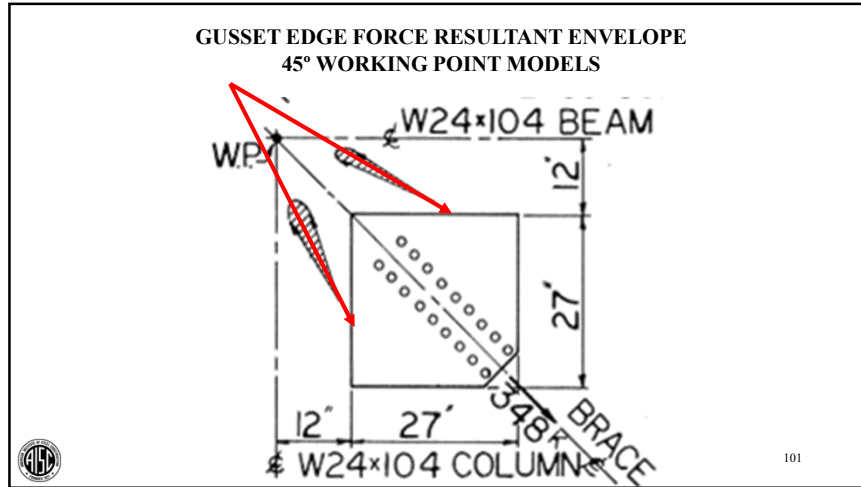


95



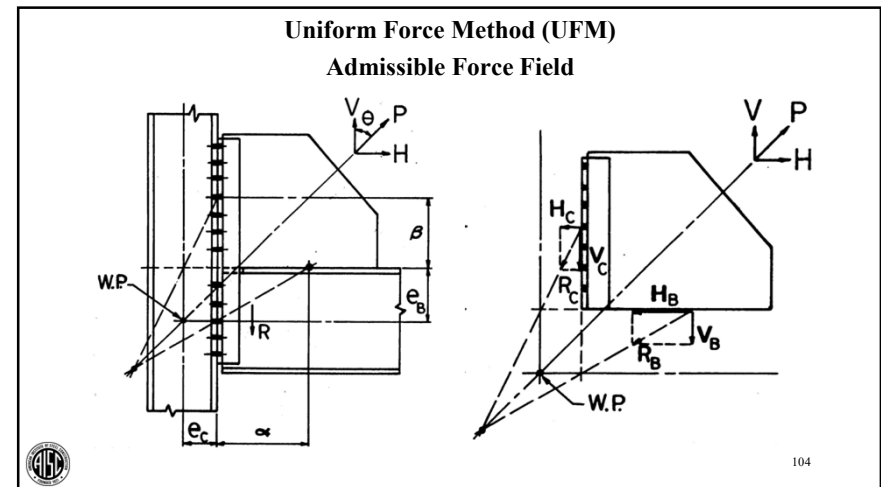
96





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

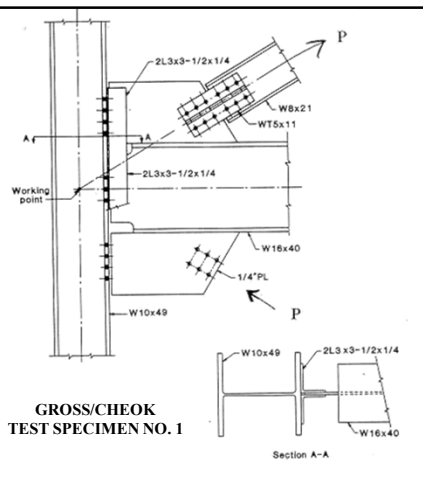
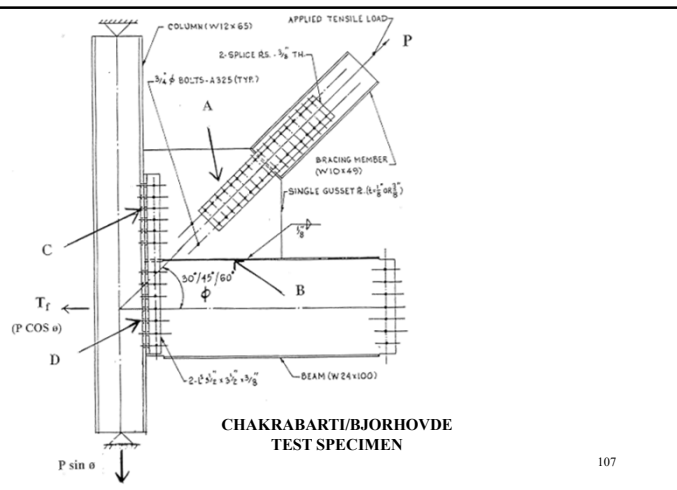


**The UFM was first introduced in 1991**

- “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](http://www.cives.com)



**Comparison of the Uniform Force Method with Physical Test Results**



### 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	1
	Gusset	3,4,5,6
	Bolts to Brace	1
	Brace	5,6,7,8
Gusset to Beam (B)	Splice plates or WTs	5,6,7,8
	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 Column	6,7,8,11,12 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 Column	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 30°	142 (3,5) <sup>(1)</sup>	184 (7)	216 (5)	152 (3,5)	142 (3,5)	A (3,5)	143	A (5)	1.01
Chakrabarti/ Bjorkovde 45°	142 (3,5)	182 (7)	164 (5)	210 (12)	142 (3,5)	A (3,5)	148	A (5)	1.04
Chakrabarti/ Bjorkovde 60°	142 (3,5)	169 (7)	155 (5)	342 (12)	142 (3,5)	A (3,5)	158	C (5)	1.11
Gross/ Cheek No. 1	73 (4)	212 (7)	67 (12)	149 (9)	67 (12)	C (12)	116	A (4)	1.73
Gross/ Cheek No. 2	78 (4)	77 (7)	143 (7)	NL <sup>(2)</sup>	77 (7)	B (7)	138	A (4)	1.79
Gross/ Cheek No. 3	84 (4)	94 (7)	171 (7)	NL <sup>(2)</sup>	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, 3<sup>rd</sup> Ed., McGraw-Hill, Chapter 2
2. Brockenbrough, R.L., and Merritt, F.S., 2020, Structural Steel Designer's Handbook, 6<sup>th</sup> 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



Thank you!

AISC | Questions

