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Course Description

Basic Principles

September 22, 2014

This session will introduce the course, discuss the limit states related to connection design as well as explore the methods of specifying connections as described in the AISC *Code of Standard Practice.* The session will then discuss that connection design is based on first principles, without the aid of complex computer models and with little codification. It will address the three basic principles of structural mechanics: equilibrium, constitutive equations (limit states), and compatibility. The presentation will then focus on the Lower Bound Theorem and look at it from a practical approach: satisfying equilibrium, not exceeding any limit states, and taking measures to ensure ductility. A simplified example demonstrating the concepts of the Lower Bound Theorem will be presented.

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Learning Objectives

- Become familiar with the common limit states of connection design and where they can be found in the AISC *Specification*.
- Gain an understanding of the three methods of specifying connections described in the AISC *Code of Standard Practice*.
- Gain an understanding of the basic principles of structural mechanics: equilibrium, constitutive equations and compatibility.
- Become familiar with the Lower Bound Theorem.

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Bracing Connections and Related Topics

Session 1: Basic Principles

Presented by
William A. Thornton, Ph.D., P.E.
Corporate Consultant to Cives Corporation
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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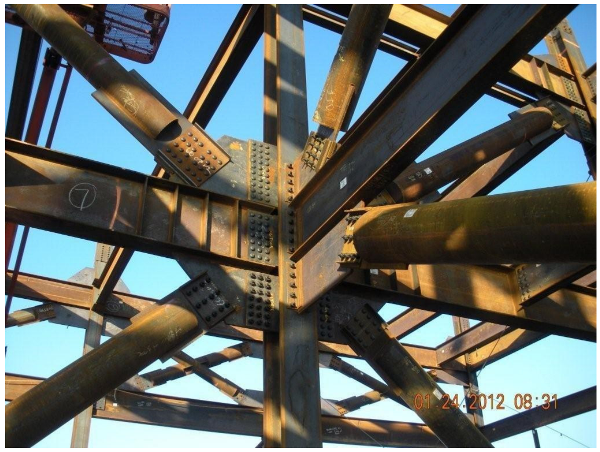
Course Outline

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

Session Outline

1. Introduction
2. Limit States - the Specification, Manual, and Other Documents
3. Code of Standard Practice
4. Principles of structural mechanics
5. Lower Bound Theorem
6. Comparison of methods

Introduction to Course



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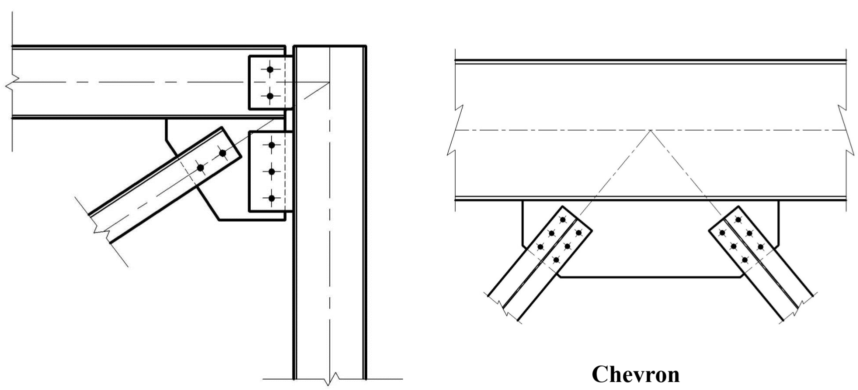
Introduction to Course



Chevron

Corner

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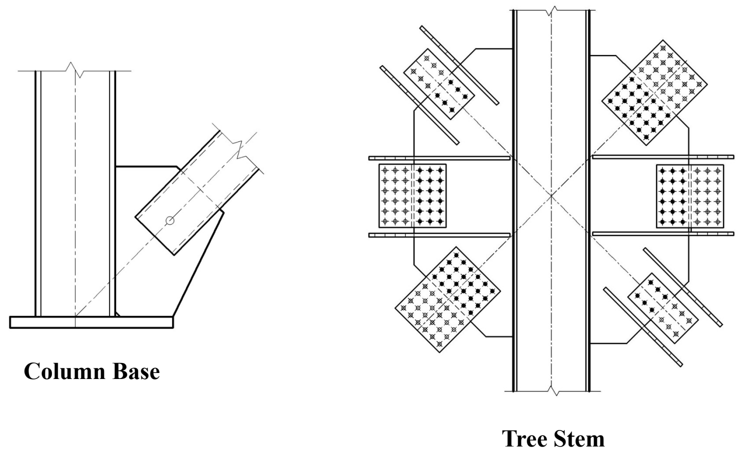
Introduction to Course



Session Outline

1. Introduction to connection design
2. Limit States - the Spec., Manual, and Other Documents
3. Lower Bound Theorem

Limit States - the *Specification*, *Manual*, and Other Documents

Connection Limit States

- In this section we will briefly discuss common connection limit states and where they can be found in the AISC Specification.
- The organization of the Steel Construction Manual as it relates to connection design will be reviewed.
- Finally, since not everything can be contained in these two documents, other useful resources are also presented.

Connection Limit States

The Limit States Governing Connection Design are found in:

1. Chapter B: Local Buckling
2. Chapter D: Net Tension/Shear Lag
3. Chapter J: Connections
4. Chapter K: HSS Members
5. Appendix 3: Fatigue
6. AISC Seismic Documents:

Chapter D

D3 – Area Determination

D3.2 – Net Area

D3.3 – Effective Net Area (Table D3.1)

D4 – Built-up Members

D5 – Pin-Connected Members

Chapter J

J1 – General Provisions

J2 – Welds

J3 – Bolts and Threaded Parts

J4 – Affected Elements of Members and Connecting Elements

J5 – Fillers

J6 – Splices

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Chapter J (cont.)

J7 – Bearing Strength

J8 – Column Bases and Bearing on Concrete

J9 – Anchor Rods and Embedments

J10 – Flanges and Webs with Concentrated Forces

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AISC Seismic Documents

- Seismic Connections required when using R > 3
- Information regarding Seismic Connections can be found in:
  - Seismic Provisions for Structural Steel Buildings (ANSI/AISC 341-10)
  - Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications (ANSI/AISC 358-10)

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Connection Limit States
Connectors

- Weld Rupture (Section J2.4)
- Bolt
  - Shear (Section J3.6)
  - Tension (Section J3.6)
  - Slip (Section J3.8)
  - Combined Shear and Tension, Bearing (Section J3.7)
  - Combined Shear and Tension, SC (Section J3.9)

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Connection Limit States

Local Effects

- Bolt Bearing (Section J3.10)
  - Bolt Tear-out
- Block Shear (Section J4.3)
- Flange Local Bending (Section J10.1)
- Web Local Yielding (Section J10.2)
- Web Crippling (Section J10.3)
- Web Sidesway Buckling (Section J10.4)
- Web Compression Buckling (Section J10.5)
- Web Panel Zone Shear (Section J10.6)

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Connection Limit States

Connecting Elements

- Yielding
  - Tension (Section J4.1)
  - Shear (Section J4.2)
- Fracture
  - Net Tension (Section J4.1)
  - Net Shear (Section J4.2)
- Buckling (Section J4.4)

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Connection Limit States
Beyond the Specification

- Prying Action
  - Part 9 of the Manual
- Yield Line Analysis
  - Anand and Bertz, *EJ, 2nd Quarter, 1981*
  - Akbar Tamboli, *Handbook of Steel Connection Design and Details*
- Whitmore Section
  - Part 9 of the Manual
  - Thornton and Lini, Steel Wise, *MSC, July 2011*

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The AISC Manual

- Part 7 – Design Considerations for Bolts
- Part 8 – Design Considerations for Welds
- Part 9 – Design of Connection Elements
  - Prying Action
  - Rotational Ductility
  - Copes
- Part 10 – Design of Simple Shear Connections
  - Constructability
  - Shear Connection Tables
  - Extended Gages
  - Skewed, Sloped and Canted Connections

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The AISC Manual

- Part 11 – Design of Flexible Moment Connections
- Part 12 – Design of Fully Restrained Moment Connections
  - Moment Splices
- **Part 13 – Design of Bracing Connections and Truss Connections**
  - **Uniform Force Method and Variations**
- Part 14 – Design of Beam Bearing Plates, Column Base Plates, Anchor Rods, and Column Splices
- Part 15 – Design of Hanger Connections, Bracket Plates, and Crane-Rail Connections

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Other Sources of Information

- **Chapter M of the Specification**
  - Thermal Cutting
  - Welded Construction
  - Bolted Construction
    - Thermally Cut Holes
    - Use of Shims ≤ ¼”
  - Compression Joints

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Other Sources of Information

- **Research Council on Structural Connections (RCSC)**
  – Specification for Structural Joints Using High-Strength Bolts (The Bolt Spec.).
  – Guide to Design Criteria for Bolted and Riveted Joints (The Bolt Guide).
  – The Education section of the RSCS website also contains some valuable information.

All documents can be downloaded for free at
www.boltcouncil.org

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Other Sources of Information

- **American Welding Society (AWS)**
  – AWS D1.1/D1.1M:2010 Structural Welding Code – Steel
  – AWS D1.8/D1.8M:2009 Structural Welding Code – Seismic Supplement

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Other Sources of Information

- **AISC Design Guides**
  - Base Plate and Anchor Rod Design **(DG1)**
  - Extended End-Plate Moment Connections Seismic and Wind Applications **(DG4)**
  - Partially Restrained Composite Connections **(DG8)**
  - Modification of Existing Steel Welded Moment Frame Connections for Seismic Resistance **(DG12)**
  - Wide-Flange Column Stiffening at Moment Connections **(DG13)**

Other Sources of Information

- **AISC Design Guides (cont.)**
  - Flush and Extended Multiple Row Moment End-Plate Connections **(DG16)**
  - High Strength Bolts – A Primer for Structural Engineers **(DG17)**
  - Welded Connections – A Primer for Engineers **(DG21)**

AISC Design Guides can be downloaded at www.aisc.org (free to members)

Other Sources of Information

- Resources for Steel Design (Modern Steel Construction December 2005)
- AISC's Engineering Frequently Asked Questions (www.aisc.org)
- AISC's Steel Solutions Center (www.aisc.org)
- OSHA 1926 Subpart R – Steel Erection

Connection Design and the Code of Standard Practice

Connection Design and the COSP

Three Options Listed in COSP:

1) The complete connection design is shown on the structural drawings (EOR mandated).
2) Experienced detailer to select connections based on structural drawings or Manual.
3) Connections designated to be designed by licensed engineer working for fabricator.

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Connection Design and the COSP

1) For option 1 (EOR Mandated): all information is needed:
   a. Bolt sizes, spacing, and edge distances
   b. Bolt gage
   c. Weld sizes and type (e.g. fillet, PJP, etc.)
   d. Plate thicknesses, sizes, and grade
   e. Etc.

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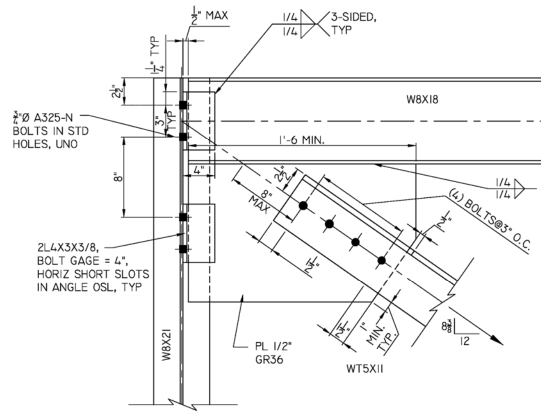
Connection Design and the COSP



Option 1) EOR Mandated Detail

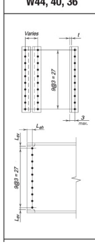
Connection Design and the COSP

2) For option 2 (AISC Manual Tables):

Beam: F_y = 50 ksi, F_u = 65 ksi
Angle: F_y = 36 ksi, F_u = 58 ksi

Table 10-1 (continued)
All-Bolted Double-Angle Connections
7/8-in. Bolts

Bolt and Angle Available Strength, kips

10 Rows	Bolt Group	Thread Cond.	Hole Type	Angle Thickness, in. 1/4 ASD	1/4 LRFD	5/16 ASD	5/16 LRFD	3/8 ASD	3/8 LRFD	1/2 ASD	1/2 LRFD
W44, 40, 36											
	Group A	N	STD	163	245	204	306	245	368	325	487
		X	STD	163	245	204	306	245	368	327	490
		SC Class A	STD	163	245	176	264	176	264	176	264
			OVS	150	225	150	225	150	225	150	225
			SSLT	162	243	176	264	176	264	176	264
		SC Class B	STD	163	245	204	306	245	368	294	441
			OVS	159	238	198	298	238	357	250	375
			SSLT	162	243	203	304	243	365	294	441
	Group B	N	STD	163	245	204	306	245	368	327	490
		X	STD	163	245	204	306	245	368	327	490
		SC Class A	STD	163	245	204	306	221	332	221	332
			OVS	159	238	189	282	189	282	189	282
			SSLT	162	243	203	304	221	332	221	332
		SC Class B	STD	163	245	204	306	245	368	327	490
			OVS	159	238	198	298	238	357	315	471
			SSLT	162	243	203	304	243	365	324	486

Connection Design and the COSP

3) For option 3 (Connections by Fabricator):

A. Fabricator can select connection best suited for their shop. Examples:

a. Shear tabs to double-angles
b. Welded bracing to bolted bracing

B. Connection engineer shall review shop and erection drawings

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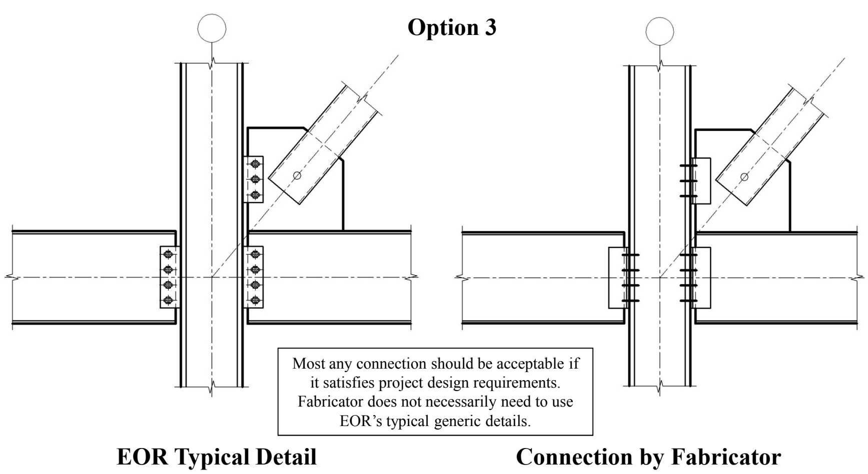
Connection Design and the COSP



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Basis of Connection Design

Basis of Connection Design

- Connection Design Tools and Methods
- Assumptions and Uncertainty
- Lower Bound Theorem
- Connection Design: Art and Science

Connection Design

Connection design has been called the

Last Bastion of Rational Design

Most connection design is accomplished
- based on first principles
- without the aid of complex computer models
- with little codification

Economy Through Connection Design

In no other important industry is the responsibility for design so far removed from the responsibility for production.

~~~Sir Harold Emerson
Minister of the Works
(1962)

It has been estimated that 50% of the cost of erected steel is related to the connection design.
~~~

Connection Design

Primary tools used by the connection designer

- Free body diagrams
- The Lower Bound Theorem
- Empirical Data (distilled into rational design procedures)
- Intuition based on experience

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Analysis of Connections

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We do not know the distribution of forces in the structures we design.

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Assumptions routinely made during the analysis process:

- Isotropic
- Homogenous
- Elastic
- Perfectly Plastic
- Pinned
- Fixed
- Laterally Supported
- Torsionally Restrained
- And Many, Many More

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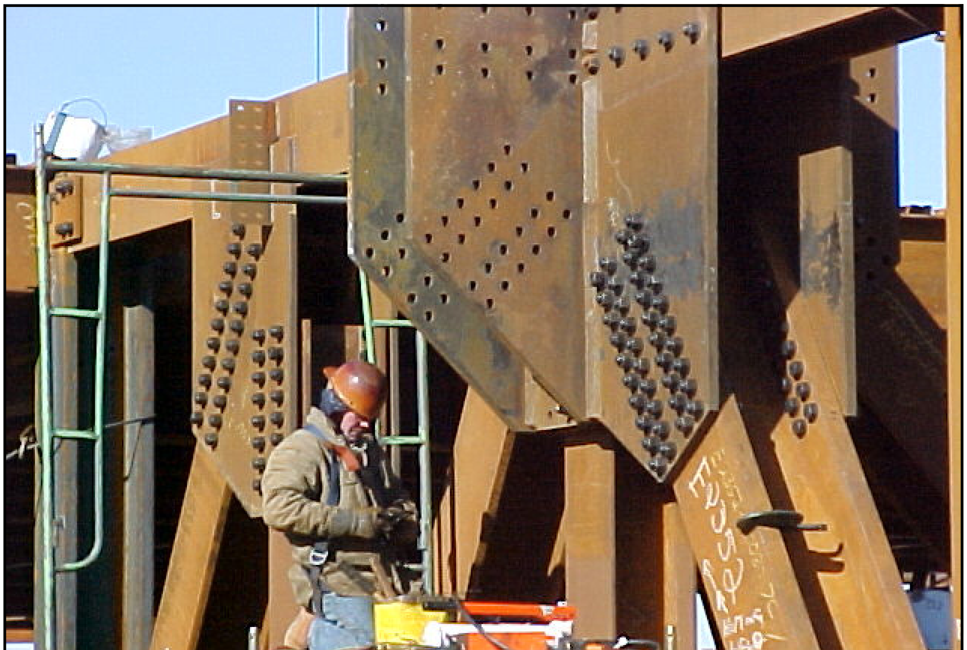

"Pinned" Truss Connections

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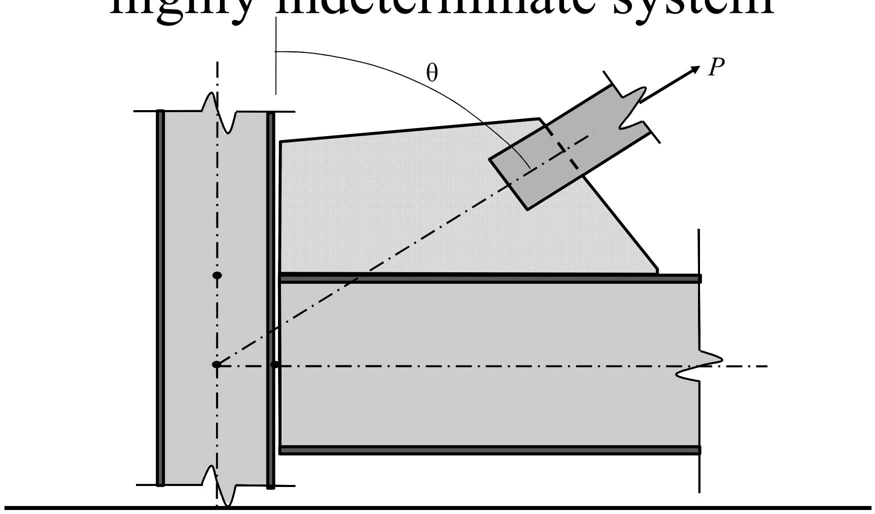
A vertical brace connection is a highly indeterminate system



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Uniform Force Method

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

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

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

These equations represent one of an infinite number of statically admissible force distributions.

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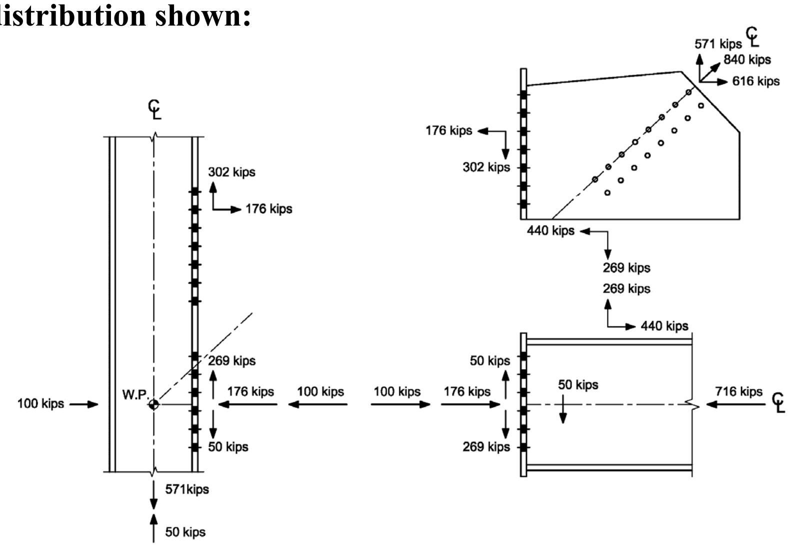
In a specific connection the UFM produces the force distribution shown:



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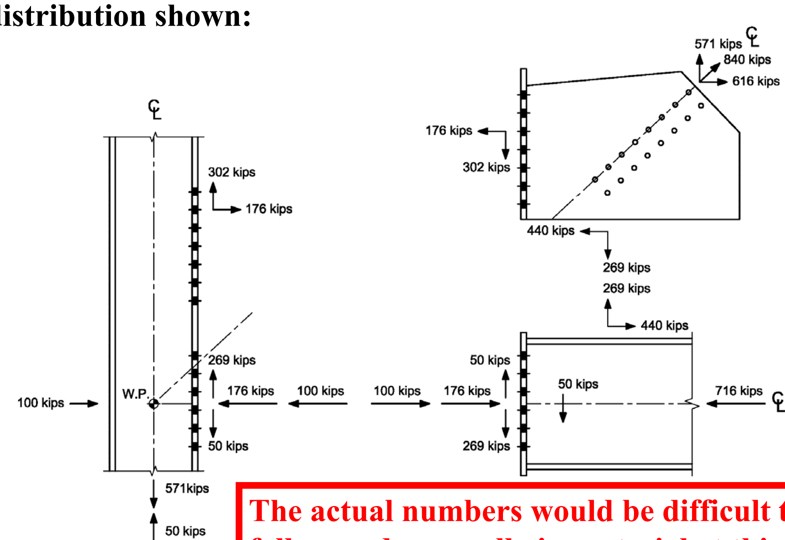
In a specific connection the UFM produces the force distribution shown:



The actual numbers would be difficult to follow and are really immaterial at this point.

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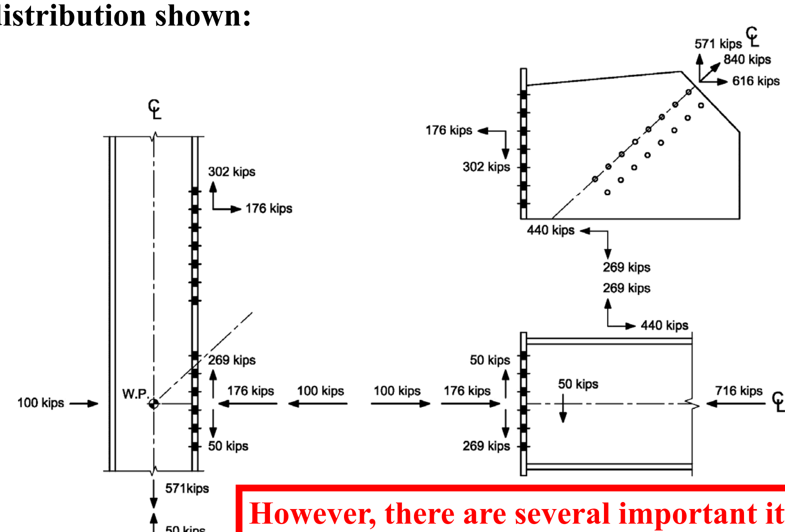
In a specific connection the UFM produces the force distribution shown:



However, there are several important items to note in the final force distribution.

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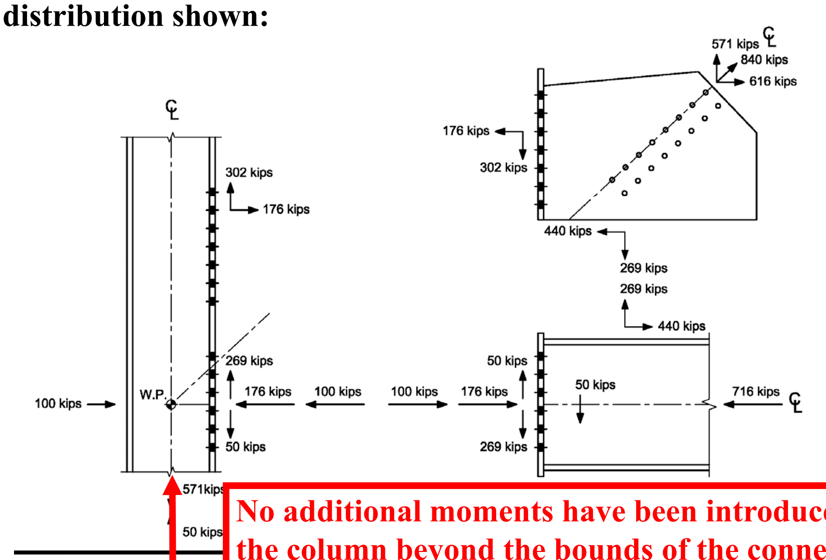
In a specific connection the UFM produces the force distribution shown:



No additional moments have been introduced to the column beyond the bounds of the connection

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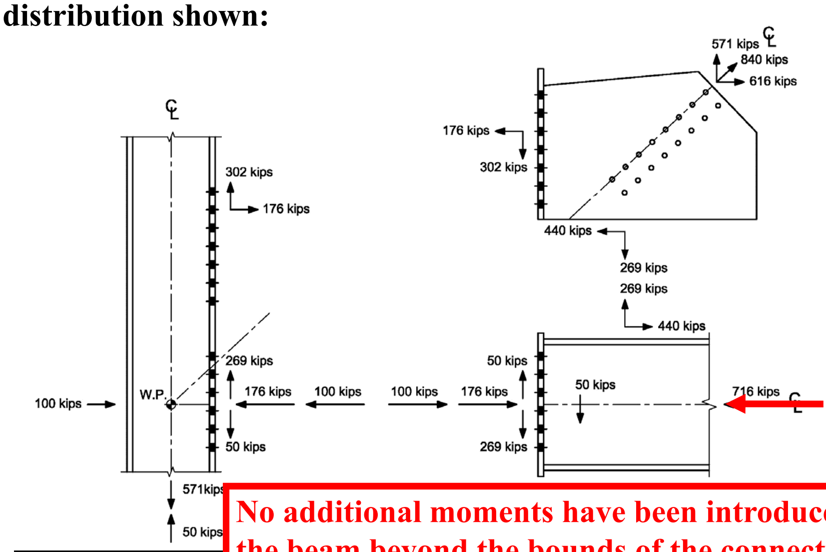
In a specific connection the UFM produces the force distribution shown:



No additional moments have been introduced to the beam beyond the bounds of the connection

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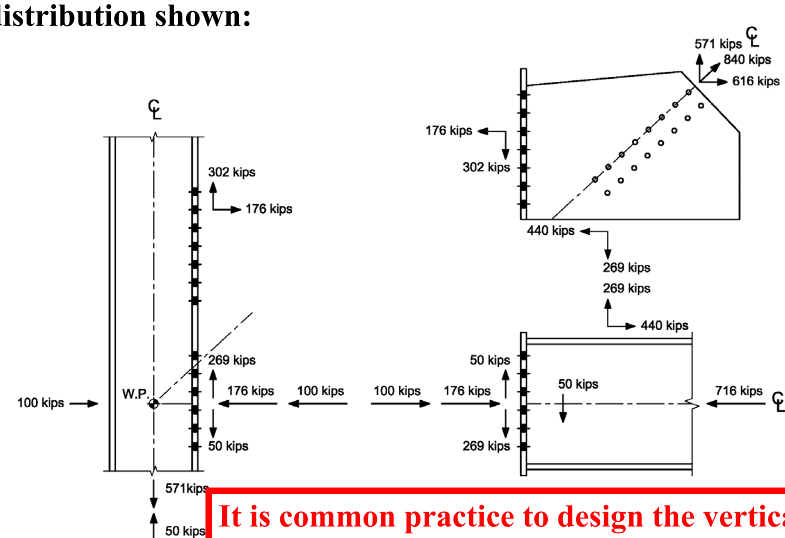
In a specific connection the UFM produces the force distribution shown:



It is common practice to design the vertical bracing system as a pinned truss.

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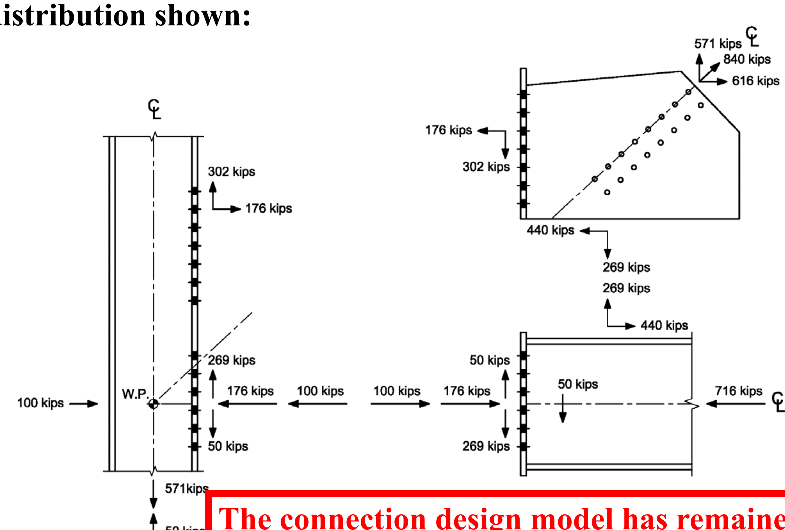
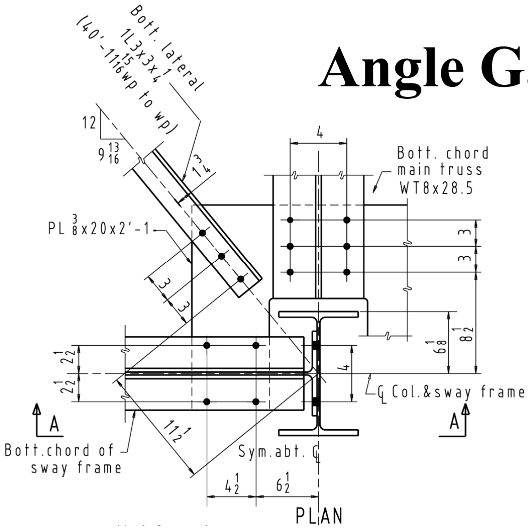
In a specific connection the UFM produces the force distribution shown:

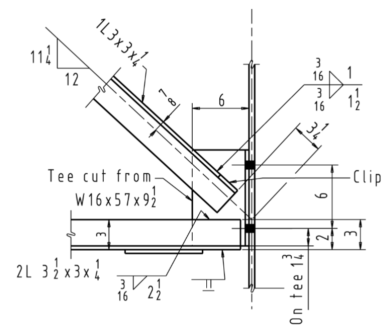


The connection design model has remained true to the main member design assumptions. This is a basic tenet of connection design.

Angle Gages



Bolted



Welded

Angle Gages Bolted

Table 1-7A
Workable Gages in Angle Legs, in.

	Leg	8	7	6	5	4	$3^1/_2$	3	$2^1/_2$	2	$1^3/_4$	$1^1/_2$	$1^3/_8$	$1^1/_4$	1
	g	$4^1/_2$	4	$3^1/_2$	3	$2^1/_2$	2	$1^3/_4$	$1^3/_8$	$1^1/_8$	1	$^7/_8$	$^7/_8$	$^3/_4$	$^5/_8$
	g_1	3	$2^1/_2$	$2^1/_4$	2										
	g_2	3	3	$2^1/_2$	$1^3/_4$										

Note: Other gages are permitted to suit specific requirements subject to clearances and edge distance limitations.

Question:
But how do we know this is the force distribution in the connection?

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Answer:
We Don't

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Answer:

We Don't

And it probably isn't.

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Steel is smarter than the engineers who design it.

~~~ Jim Wooten

MSC 2nd Qtr 1971

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Lower Bound Theorem

The applied external forces in equilibrium with the internal force field are less than or, at most, equal to the applied external force that would cause failure, provided that all the limit states are satisfied and sufficient ductility exists to allow redistribution of the forces.

~~~From Baker, Neal, etc.

Lower Bound Theorem
A Practical Approach

1. Choose a force distribution that satisfies equilibrium.
2. Do not exceed any limit states.
3. Take reasonable measures to ensure ductility.
~~~

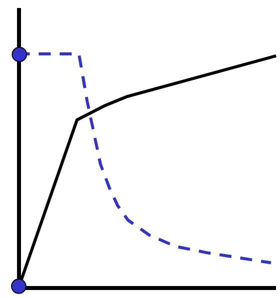
What Does This Mean?

- A designer has the freedom to choose any convenient force distribution as long as:
  - Equilibrium is satisfied
  - No limit states are exceeded
  - And loads can redistribute without fracture

Why?

- Force is attracted to stiffness.
- When a member yields it becomes less stiff and sheds loads to other elements.
- If there is somewhere for the load to go, it will go there.
- Steel is inherently ductile.

Change in Stiffness Related to Yielding



- The black line represents stress versus strain.
- The blue dashed line represents the modulus of elasticity, E, versus strain.
- As the material yields the effective E, and therefore the stiffness, decreases and the load redistributes.

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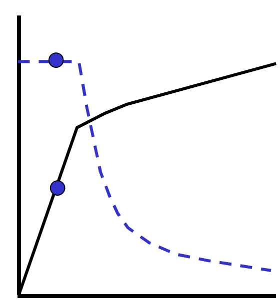
Change in Stiffness Related to Yielding



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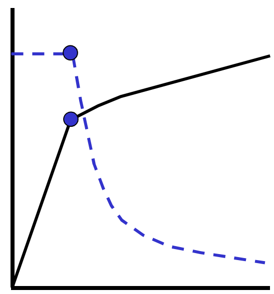
Change in Stiffness Related to Yielding



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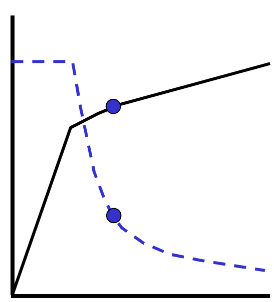
Change in Stiffness Related to Yielding



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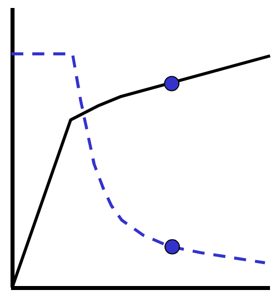
Change in Stiffness Related to Yielding



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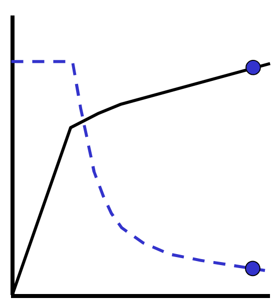
Change in Stiffness Related to Yielding



- The black line represents stress versus strain.
- The blue dashed line represents the modulus of elasticity, E, versus strain.
- As the material yields the effective E, and therefore the stiffness, decreases and the load redistributes.

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Connections: Art and Science

- The ART of load paths - An intuitive knowledge of how a system will transmit loads.
- The SCIENCE of equilibrium and limit states - an understanding of structural mechanics.

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The art involves finding the load path which maximizes the external load.

~~~ Bill Thornton

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Corollary to the Lower Bound Theorem

The admissible internal force field that maximizes the capacity is closest to the collapse solution.

Admissible is just another way of saying a system of forces that satisfies equilibrium.

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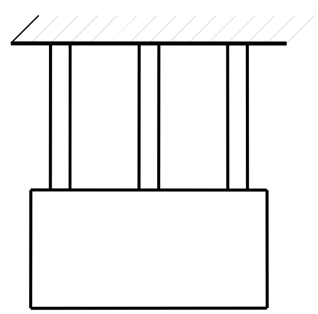
An Example

As an example

- Assume a simple system of three identical tension members supporting a load.
- This is an indeterminate structure, though intuitively we know each bar supports an equal load.
- However if we assume the center bar supports a percentage of the load, x, and the results are plotted, we have a very simple example of the Lower Bound Theorem.

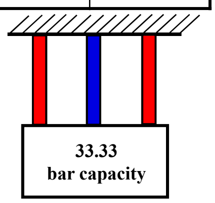


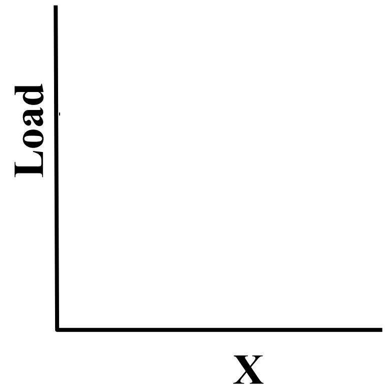
There's always a solution in steel

80

An Example

X	P
0.00	66.67
0.10	
0.13	
0.25	
0.33	
0.50	
0.67	
0.75	
0.88	
1.00	





x = the % of total load supported by center member

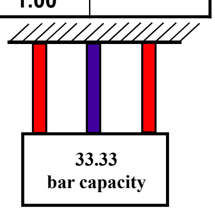
P = total load supported with assumed load distribution

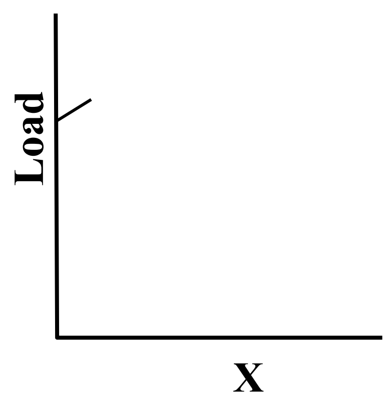
There's always a solution in steel

81

An Example

X	P
0.00	66.67
0.10	74.07
0.13	76.19
0.25	
0.33	
0.50	
0.67	
0.75	
0.88	
1.00	





x = the % of total load supported by center member

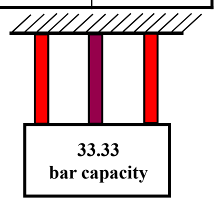
P = total load supported with assumed load distribution

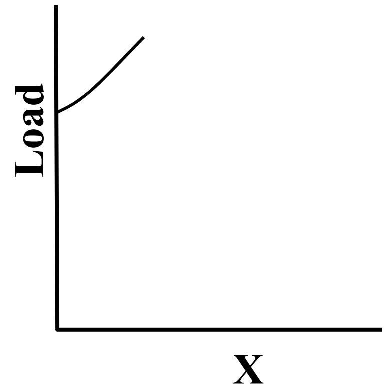
There's always a solution in steel

82

An Example

X	P
0.00	66.67
0.10	74.07
0.13	76.19
0.25	88.89
0.33	
0.50	
0.67	
0.75	
0.88	
1.00	





x = the % of total load supported by center member

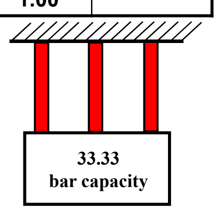
P = total load supported with assumed load distribution

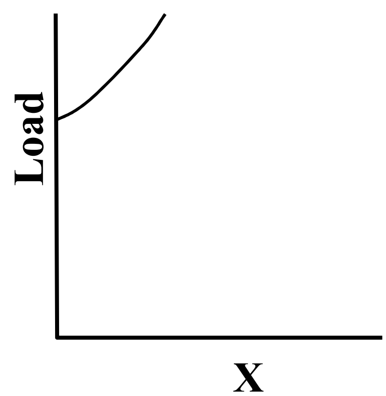
There's always a solution in steel

83

An Example

X	P
0.00	66.67
0.10	74.07
0.13	76.19
0.25	88.89
0.33	100.00
0.50	
0.67	
0.75	
0.88	
1.00	





x = the % of total load supported by center member

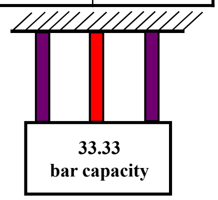
P = total load supported with assumed load distribution

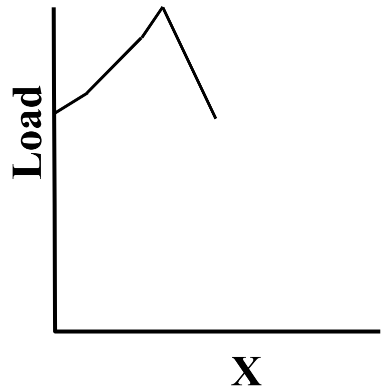
There's always a solution in steel

84

An Example

X	P
0.00	66.67
0.10	74.07
0.13	76.19
0.25	88.89
0.33	100.00
0.50	66.67
0.67	
0.75	
0.88	
1.00	





x = the % of total load supported by center member

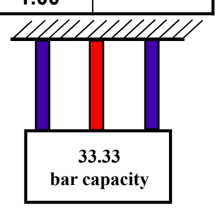
P = total load supported with assumed load distribution

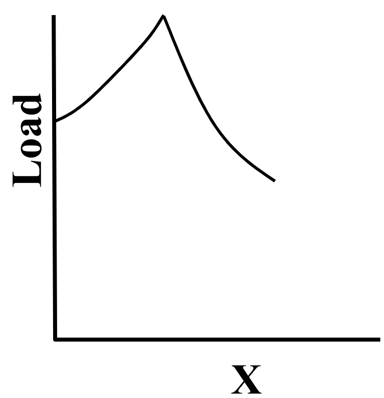
There's always a solution in steel

85

An Example

X	P
0.00	66.67
0.10	74.07
0.13	76.19
0.25	88.89
0.33	100.00
0.50	66.67
0.67	50.00
0.75	
0.88	
1.00	





x = the % of total load supported by center member

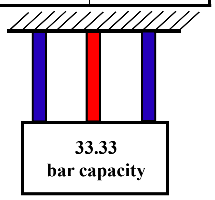
P = total load supported with assumed load distribution

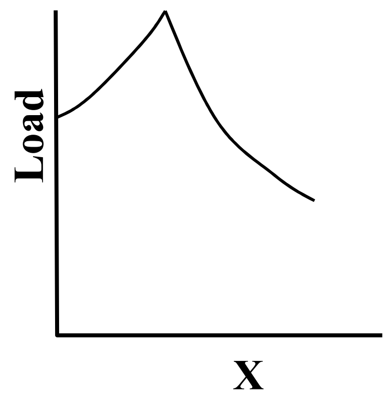
There's always a solution in steel

86

An Example

X	P
0.00	66.67
0.10	74.07
0.13	76.19
0.25	88.89
0.33	100.00
0.50	66.67
0.67	50.00
0.75	44.44
0.88	
1.00	



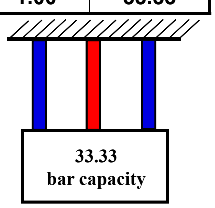


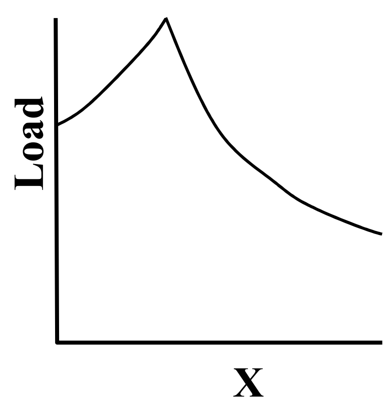
x = the % of total load supported by center member

P = total load supported with assumed load distribution

An Example

X	P
0.00	66.67
0.10	74.07
0.13	76.19
0.25	88.89
0.33	100.00
0.50	66.67
0.67	50.00
0.75	44.44
0.88	38.10
1.00	33.33

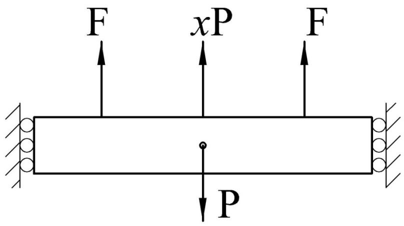




x = the % of total load supported by center member

P = total load supported with assumed load distribution

Lower Bound Solution
Three Bar Structure



x = % of Total Load P

Equilibrium: $2F + xP - P = 0$

Limit States: $F \leq 33.3$

$xP \leq 33.3$

$P \leq 100$

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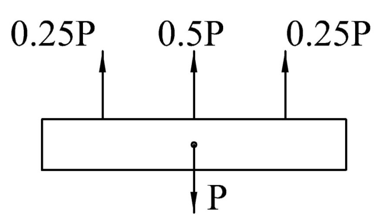
Lower Bound Solution
Three Bar Structure

Example: Let $x = 0.5$



$0.5P \leq 33.3 \rightarrow P = 66.7 < 100$ OK

$0.25P \leq 33.3 \rightarrow P = 133 > 100$ NG

Solution: $P = 66.7$

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More Information on Ductility and Behavior of Steel

Basic Concepts in Ductile Detailing of Steel Structures
by Michael D. Engelhardt

From the 2009 NASCC series "Top Hits from Top Profs"

Comparison of Bracing Design Methods and Load Paths

Comparison of Methods

The next several slides will demonstrate the savings that can be obtained through a careful use of the topics discussed in this presentation.

A special emphasis is placed on load paths, but all the other considerations have also been accounted for in these optimal designs.

There's always a solution in steel

93

Load Paths Have Consequences

In Other Words…

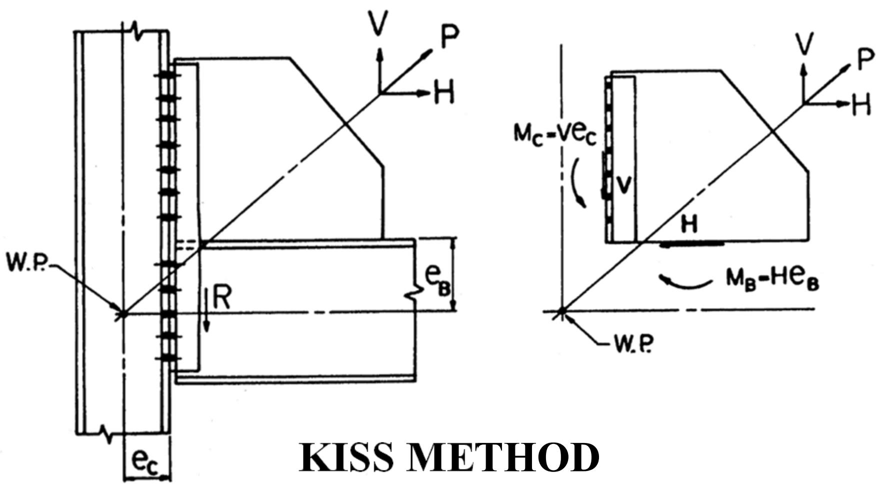
There's always a solution in steel

94

Let's Look at the Bottom Line

There's always a solution in steel

95



KISS METHOD

(Keep it Simple, Stupid!)

ADMISSIBLE FORCE FIELD

There's always a solution in steel

96

The KISS method

- Was used with and without the couples M_B and M_C, but mostly without
- Was used with the brace vertical component on the column connection and the brace horizontal component on the beam connection
- Was used without regard to the Work Point position
- INADMISSIBLE FORCE FIELDS

The KISS method

An inadmissible force field does not satisfy what William McGuire of Cornell, in another context, called "The niceties of Structural Mechanics"

McGuire, Steel Structures, Prentice-Hall, 1968, page 933

The KISS method

In particular, the
LOWER BOUND THEOREM IS
INVALID
If an inadmissible force field is
used

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Kiss Method
vs
Uniform Force Method

Is there an economic reason to use
KISS?

It **is** simpler, even with the couples

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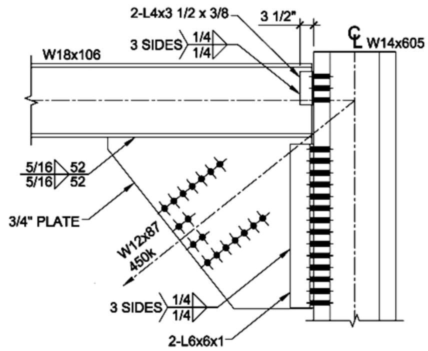
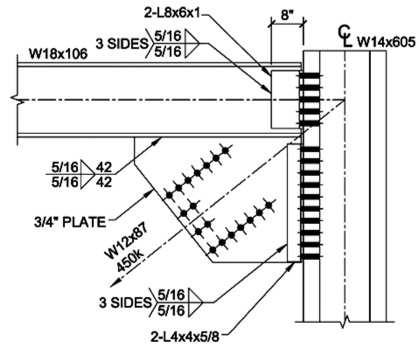


DESIGN BY
THE KISS METHOD
GUSSET 52X43 1/2



DESIGN BY
THE UNIFORM FORCE METHOD
GUSSET 42X31 1/2

COMPARISON OF DESIGNS

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101

KISS =	**$840 PER CONNECTION**
UNIFORM =	**<u>$658</u> PER CONNECTION**
DIFFERENCE =	**$182 PER CONNECTION**

40 STORY BUILDING WITH 32 CONNECTIONS PER FLOOR

EQUALS

$240,000 SAVED

Taken From: Bill Thornton's "Last Bastion of Rational Design"

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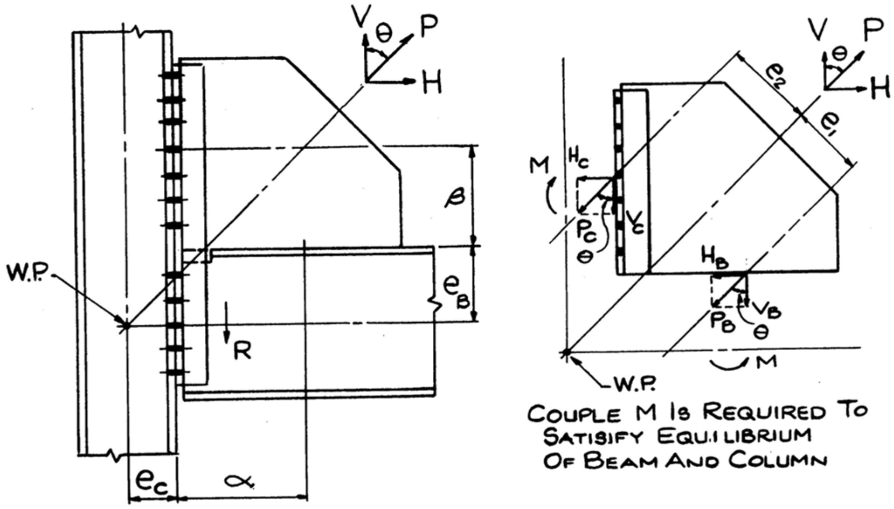
102



PARALLEL FORCE METHOD (PFM)

ADMISSIBLE FORCE FIELD

103

UNIFORM FORCE METHOD

VS

PARALLEL FORCE METHOD

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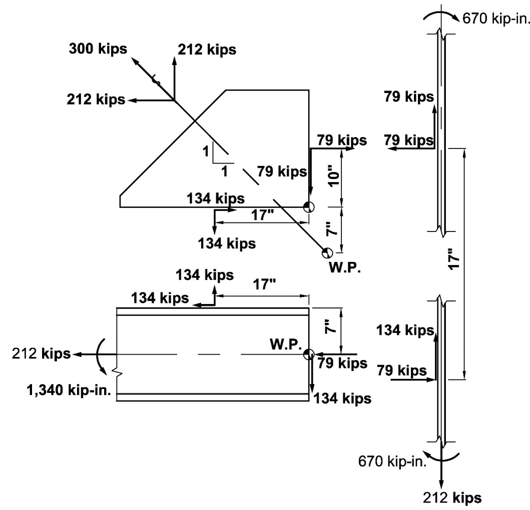
104

Admissible Force Field, PFM



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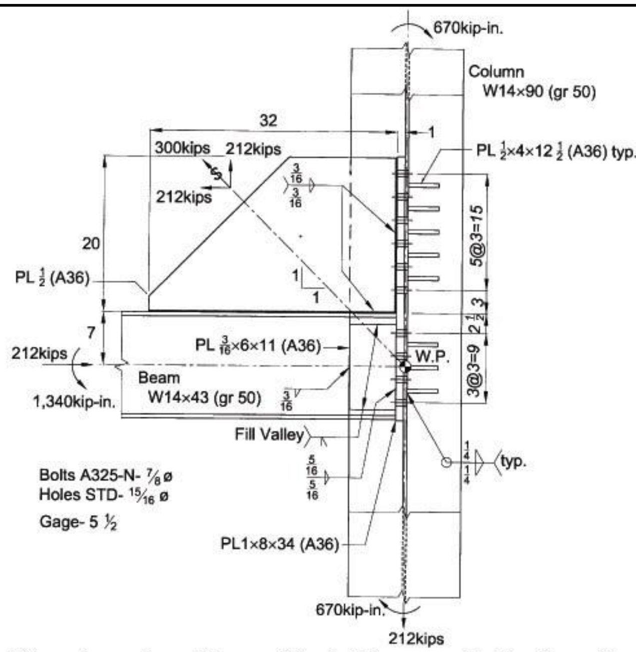
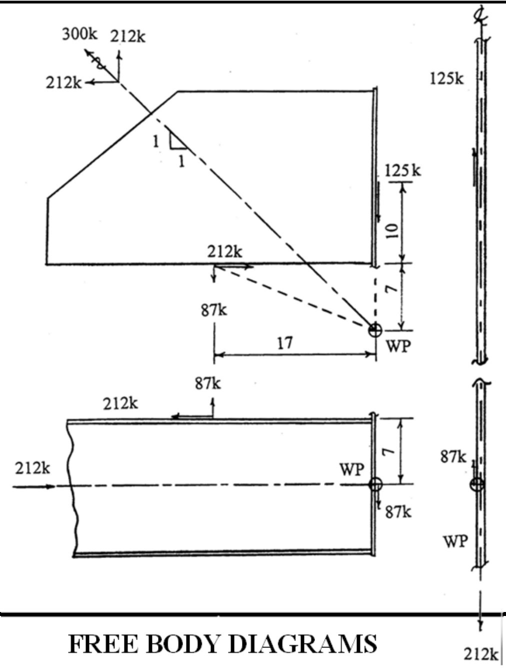
105



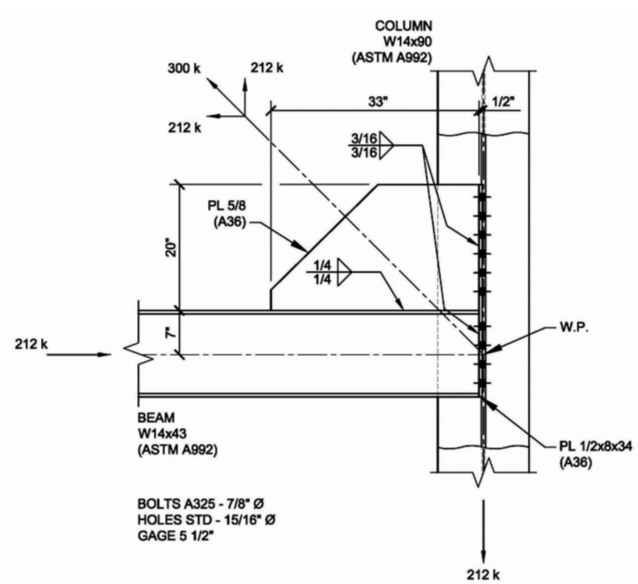
Design by Parallel Force Method

106



FREE BODY DIAGRAMS
UNIFORM FORCE METHOD

107



DESIGN BY
UNIFORM FORCE METHOD

108

LOAD PATHS HAVE CONSEQUENCES

UFM Design with UFM admissible force field

Capacity is 320 kips

LOAD PATHS HAVE CONSEQUENCES

UFM Design with KISS admissible force field

Capacity is 236 kips

LOAD PATHS HAVE CONSEQUENCES

UFM Design with PFM admissible force field

Capacity is 86 kips

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LOAD PATHS HAVE CONSEQUENCES

METHOD	DESIGN	DESIGN STRENGTH
UFM	UFM	320 kips
KISS	UFM	236 kips
PFM	UFM	86 kips

These results are for the design achieved by the UFM.

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112

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

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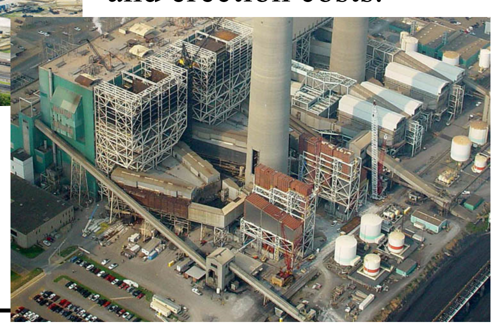
113

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



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114

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

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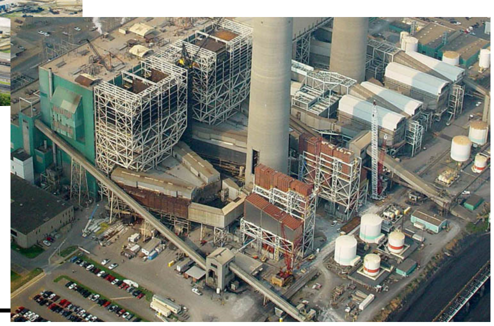
115

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



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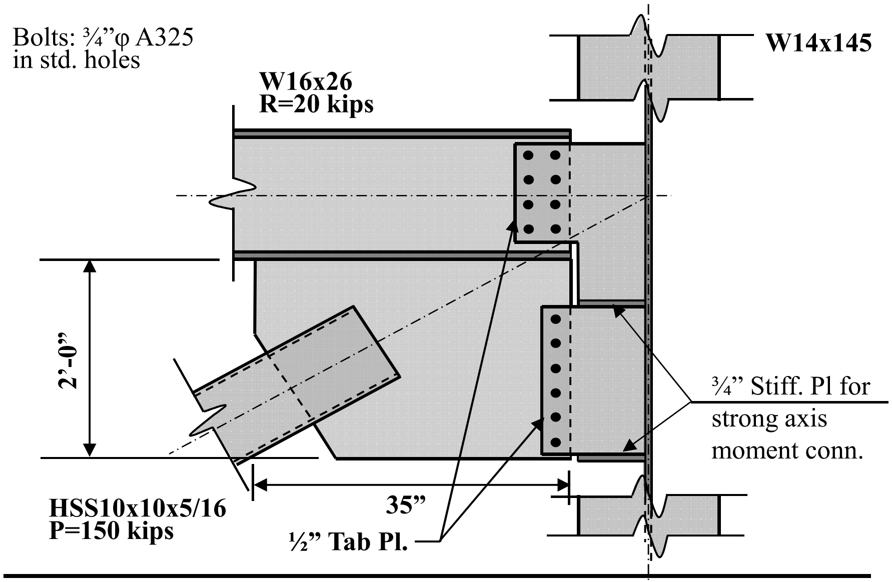
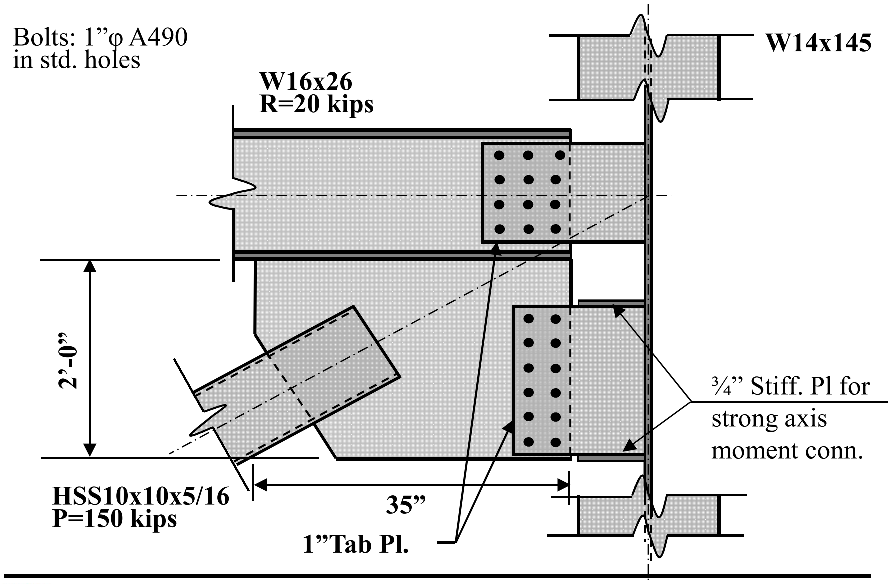
116



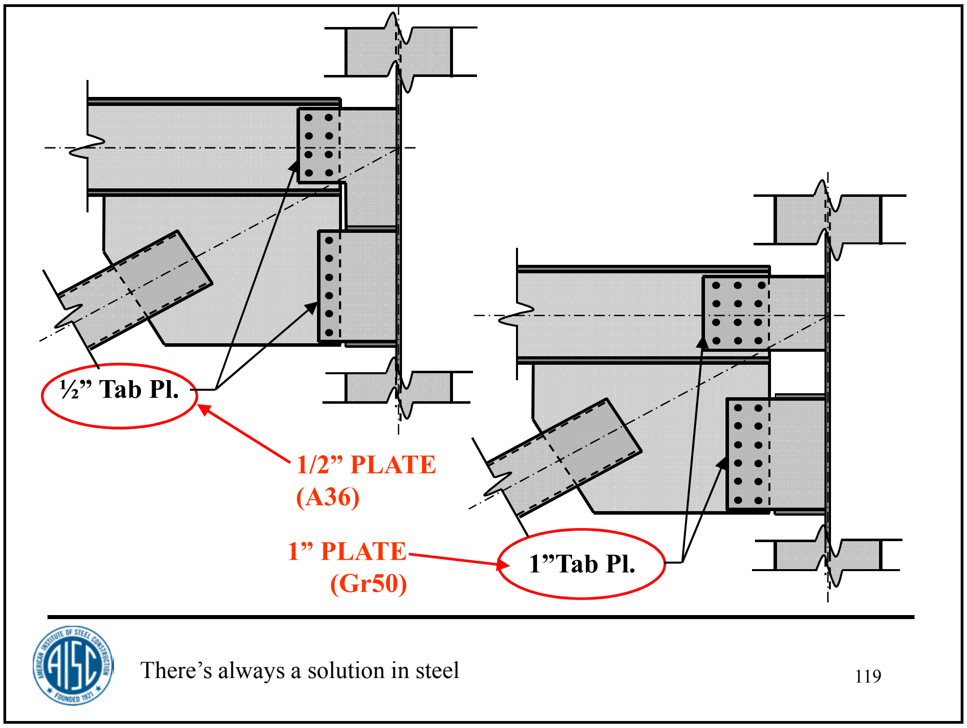
Vertical Bracing w/ Ext. Tab
Optimum Load Path

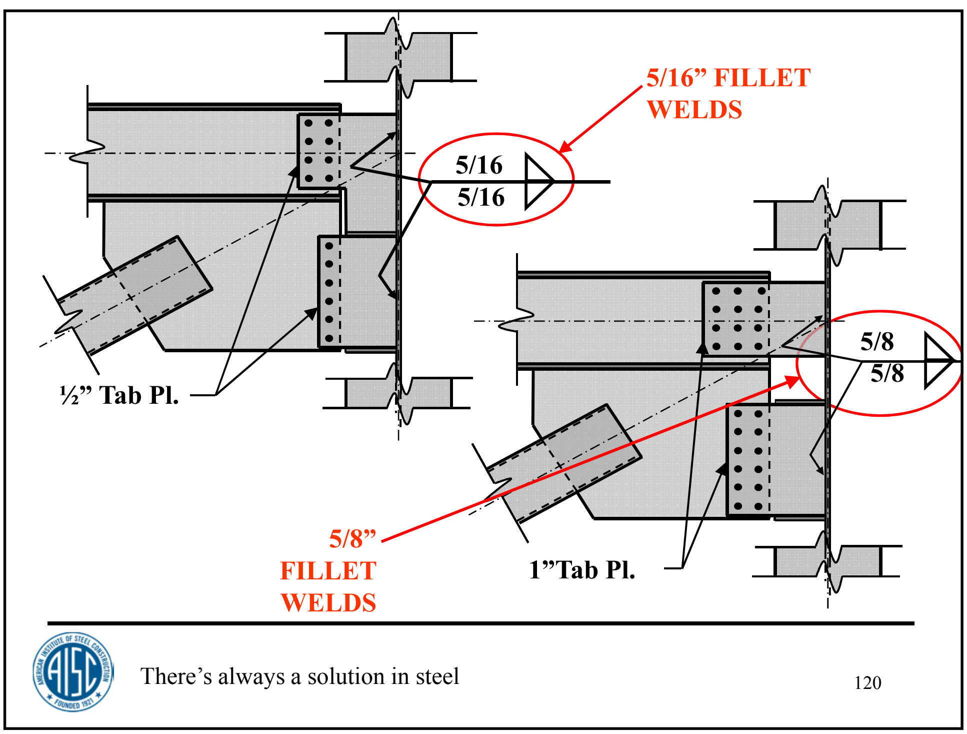
117

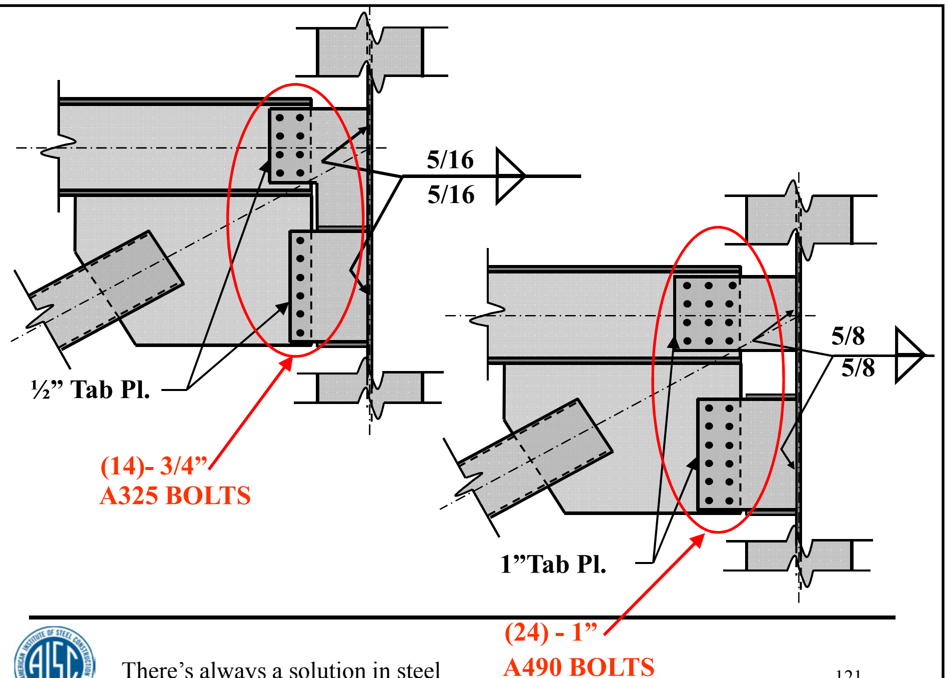


Vertical Bracing w/ Ext. Tab
Standard Load Path

118


½" Tab Pl.
1/2" PLATE
(A36)
1" PLATE
(Gr50)
1"Tab Pl.
There's always a solution in steel
119


5/16" FILLET
WELDS
5/16
5/16
½" Tab Pl.
5/8
5/8
5/8"
FILLET
WELDS
1"Tab Pl.
There's always a solution in steel
120



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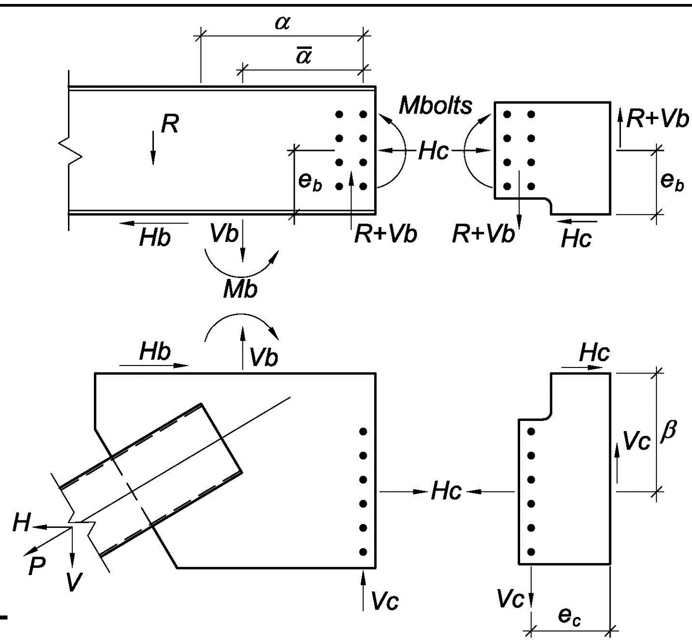
121

FBD of Optimum Solution



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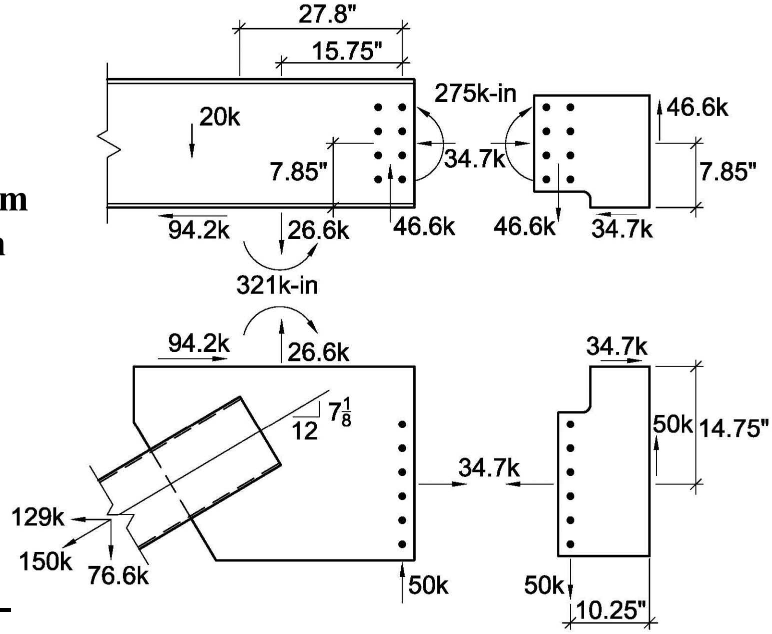
122

FBD of Optimum Solution



There's always a solution in steel

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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 (in.^{2})	Thick. Tabs (in.)	Volume Tabs (in.^{3})	Area of Gusset (in.^{2})	Thick. Gusset (in.)	Volume Gusset (in.^{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	0.417	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	0.417	0.226	172
Optimum / Standard				21%			44%	29%							71%

There's always a solution in steel

124

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 (in.^{2})	Thick. Tabs (in.)	Volume Tabs (in.^{3})	Area of Gusset (in.^{2})	Thick. Gusset (in.)	Volume Gusset (in.^{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	0.417	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	0.417	0.226	172
Optimum / Standard				21%			44%	29%							71%

± 80% SAVINGS IN DRILLING TIME

There's always a solution in steel

125

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 (in.^{2})	Thick. Tabs (in.)	Volume Tabs (in.^{3})	Area of Gusset (in.^{2})	Thick. Gusset (in.)	Volume Gusset (in.^{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	0.417	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	0.417	0.226	172
Optimum / Standard				21%			44%	29%							71%

± 50% SAVINGS IN WELD CONSUMABLES

There's always a solution in steel

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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 (in.^{2})	Thick. Tabs (in.)	Volume Tabs (in.^{3})	Area of Gusset (in.^{2})	Thick. Gusset (in.)	Volume Gusset (in.^{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	0.417	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	0.417	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 (in.^{2})	Thick. Tabs (in.)	Volume Tabs (in.^{3})	Area of Gusset (in.^{2})	Thick. Gusset (in.)	Volume Gusset (in.^{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	0.417	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	0.417	0.226	172
Optimum / Standard				21%			44%	29%							71%

± 30% SAVINGS IN MATERIAL

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Summary

In this presentation we have reviewed the basic principals of structural mechanics and bracing design.

We have shown the design achieved depends on the load path (admissible force field) assumed.

We have shown the importance of the Lower Bound Theorem for design

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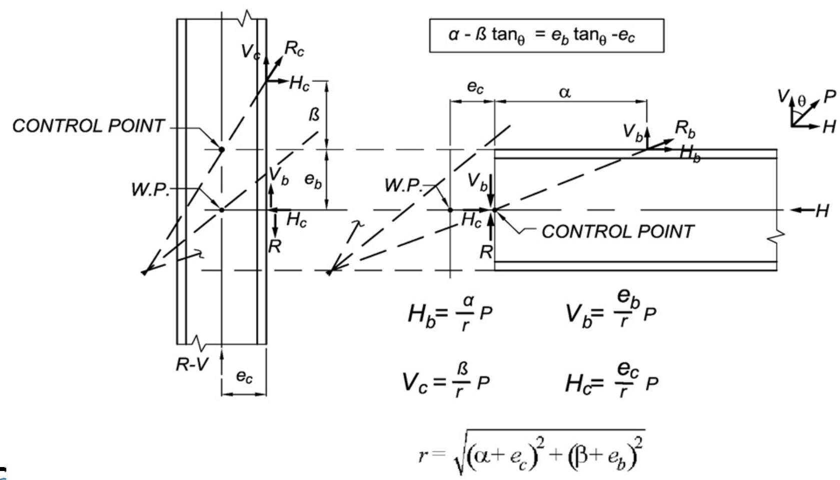
Next Week- UFM in Detail



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Bracing Connections and Related Topics

By: William Thornton

There's always a solution in steel

Questions?

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Individual Webinar Registrants

Within 2 business days…

- **You will receive an email on how to report attendance from: registration@aisc.org.**
- **Be on the lookout: Check your spam filter! Check your junk folder!**
- **Completely fill out online form. Don't forget to check the boxes next to each attendee's name!**

Individual Webinar Registrants

Within 2 business days…

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

8-Session Registrants

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

8-Session Registrants

Access to the quiz: Information for accessing the quiz will be emailed to you by Thursday. It will contain a link to access the quiz. EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG

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

Reasons for quiz:

- **EEU – must take all quizzes and final to receive EEU**
- **CEUs/PDHS – If you watch a recorded session you must take quiz for CEUs/PDHs.**
- **REINFORCEMENT – Reinforce what you learned tonight. Get more out of the course.**

NOTE: If you attend the live presentation, you do not have to take the quizzes to receive CEUs/PDHs.

8-Session Registrants

Access to the recording: Information for accessing the recording will be emailed to you by this Wednesday. The recording will be available for two weeks. For 8-session registrants only. EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG.

CEUs/PDHS – If you watch a recorded session you must take AND PASS the quiz for CEUs/PDHs.

There's always a solution in steel.

Thank You

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

structural STEEL