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Course Description

Alternate Methods to Connection Design

May 14, 2015

The AISC Specification provides requirements for connection design while resources such as the Manual and Design Guides present primary recommendations and guidance for the design of connections. This webinar will discuss alternate methods to connection design that are not found in the Manual but may be used given that these methods meet the Specification requirements. Certain connection requirements will be examined such as rotational ductility for simple connections and torsional restraint for beam end connections. Other topics include alternates to the instantaneous center of rotation method of analysis on bolt groups, alternate methods to address prying action, and design of built-up partial penetration welds.

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Learning Objectives

- Gain an understanding of the connection design requirements in the AISC Specification as well as the design recommendations provided in such AISC resources as the Manual and Design Guides.
- Become familiar with alternate methods to connection design that are not found in the AISC Manual recommendations but that follow the AISC Specification requirements.
- Become familiar with connection design requirements such as rotational ductility in simple connections and providing torsional restraint for beam end connections.
- Become familiar with alternative connection design methods that include alternates to the instantaneous center of rotation method of analysis on bolt groups, alternate methods to address prying action, and design of built-up partial penetration welds.

7

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ALTERNATE METHODS TO CONNECTION DESIGN

Larry Muir, P.E.

Patrick McManus, S.E., Ph.D.

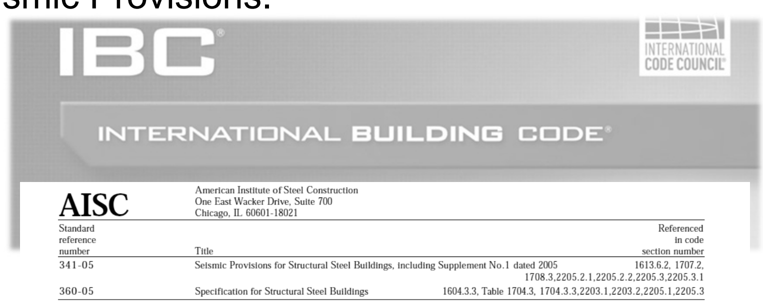
structural STEEL

The Manual is not the Specification

9

The Specification

Typically adopted into law by reference in the building code. The same applies to the AISC Seismic Provisions.



AISC American Institute of Steel Construction
One East Wacker Drive, Suite 700
Chicago, IL 60601-18021

Standard reference number	Title	Referenced in code section number
341-05	Seismic Provisions for Structural Steel Buildings, including Supplement No.1 dated 2005	1613.6.2, 1707.2, 1708.3,2205.2.1,2205.2.2,2205.3,2205.3.1
360-05	Specification for Structural Steel Buildings	1604.3.3, Table 1704.3, 1704.3.3,2203.1,2203.2,2205.1,2205.3

10

The Manual

Typically there is no reference to the Manual in the building code.

AISC American Institute of Steel Construction
One East Wacker Drive, Suite 700
Chicago, IL 60601-18021

Standard reference number	Title	Referenced in code section number
341-05	Seismic Provisions for Structural Steel Buildings, including Supplement No.1 dated 2005	1613.6.2, 1707.2, 1708.3,2205.2.1,2205.2.2,2205.3,2205.3.1
360-05	Specification for Structural Steel Buildings	1604.3.3, Table 1704.3, 1704.3.3,2203.1,2203.2,2205.1,2205.3

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The Specification

Written and intended to be used as a set of requirements related to the design, fabrication and erection of structural steel buildings and similar structures.

12

The Manual

The Manual (other than Part 16) provides guidance. The Manual is not written or intended to be used as a set of requirements.

Statements like, “Design shall conform to the AISC Manual,” can cause confusion and are not consistent with the intent of the Manual.

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Considerations Beyond Strength

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Beyond Strength

- Rotational Ductility of Simple Connections
- Torsional Restraint
- Compatibility
- Stiffness

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Rotational Ductility of Simple Connections

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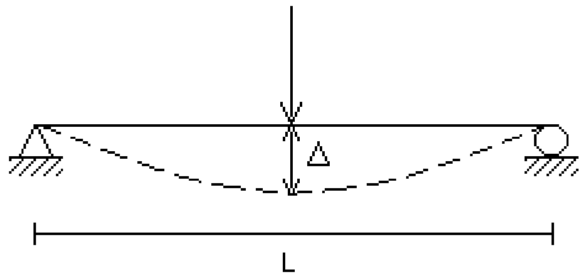
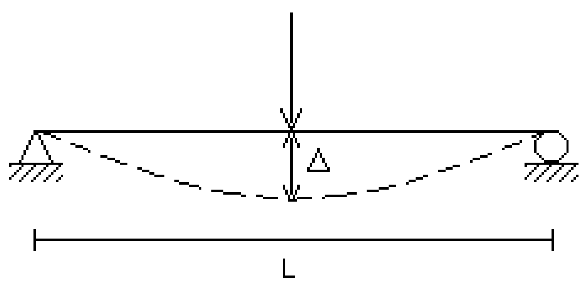
Rotational Ductility of Simple Connections



When a simply supported beam is loaded the end will rotate.

17

Rotational Ductility of Simple Connections



0.03 radians is generally accepted as the target end rotation.

This is an extremely large rotation for a beam in service.

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Rotational Ductility of Simple Connections

Specification B3.6a. Simple Connections

A *simple connection* transmits a negligible moment. In the analysis of the structure, simple connections may be assumed to allow unrestrained relative rotation between the framing elements being connected. A simple connection shall have sufficient *rotation capacity* to accommodate the required rotation determined by the analysis of the structure.

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Rotational Ductility of Simple Connections

Specification J1.2. Simple Connections

Simple connections of *beams*, girders and trusses shall be designed as flexible and are permitted to be proportioned for the reaction shears only, except as otherwise indicated in the design documents. Flexible beam connections shall accommodate end rotations of simple beams. Some inelastic but self-limiting deformation in the connection is permitted to accommodate the end rotation of a simple beam.

20

Rotational Ductility of Simple Connections

Double and single angle, shear end-plate, and tee shear connections - The geometry and thickness of the angles, plate, or tee flange are such that flexing of those connecting elements accommodates rotation.

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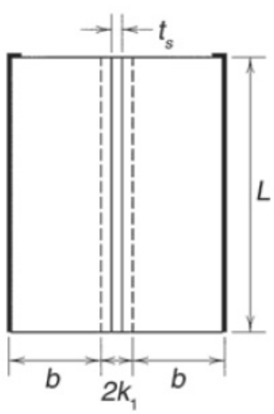
Rotational Ductility of Simple Connections

Framing angles, end-plate, and tee connections



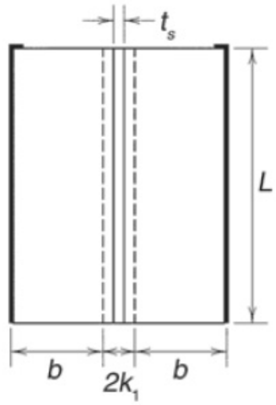
Specification J2.2b.(2)

For *connections* where flexibility of the outstanding elements is required, when *end returns* are used the length of the return shall not exceed four times the nominal size of the weld nor half the width of the part.

22

Rotational Ductility of Simple Connections

Framing angles, end-plate, and tee connections



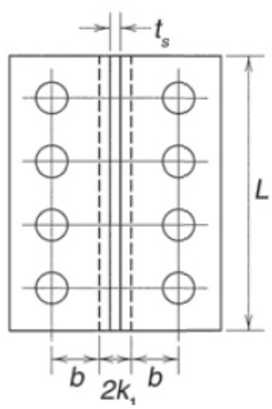
Manual Equation 9-36:

$$w_{min} = 0.0155\frac{F_y {t_f}^2}{b}\left(\frac{b^2}{L^2}+2\right)$$

23

Rotational Ductility of Simple Connections

Framing angles, end-plate, and tee connections



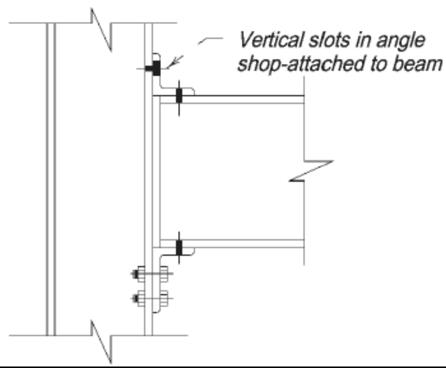
Manual Equation 9-37:

$$d_{min} = 0.163t_f\sqrt{\frac{F_y}{b}\left(\frac{b^2}{L^2}+2\right)}$$

24

Rotational Ductility of Simple Connections

Seated connections - the geometry and thickness of the stability angle is such that flexing of the angle accommodates rotation.



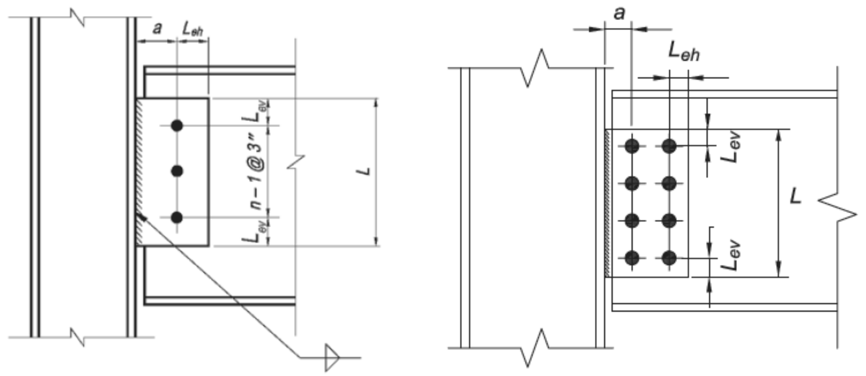
Rotational Ductility of Simple Connections

Single-plate connections, the geometry and thickness of the plate are configured so that the plate will yield, bolt group will rotate, and/or the bolt holes will elongate to accommodates rotation.

26

Rotational Ductility of Simple Connections

$t \leq \frac{d_b}{2} \pm {}^{1}/_{16}"$ $\text{weld} = \frac{5}{8} t_p$ $t_{max} = \frac{6M_{max}}{F_y d^2}$



When The Earth Moves

Seismic Provisions F2.6b. Beam-to-Column Connections

Where a brace or gusset plate connects to both members at a beam-to-column connection, the connection shall be a simple connection meeting the requirements of *Specification* Section B3.6a where the required rotation is taken to be 0.025 rad.

When The Earth Moves

Seismic Provisions F2.6b. Beam-to-Column Connections

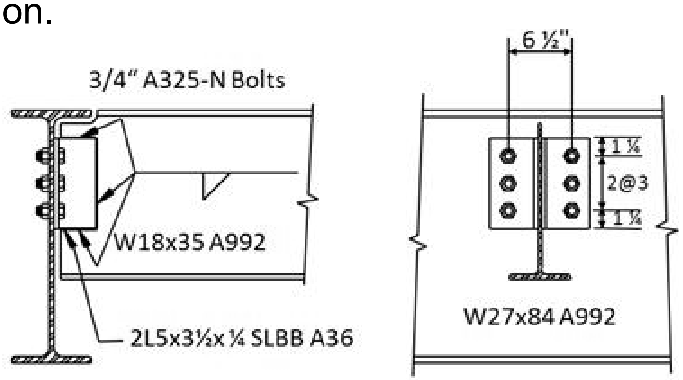
Where a brace or gusset plate connects to both members at a beam-to-column connection, the connection shall be a simple connection meeting the requirements of *Specification* Section B3.6a where the required rotation is taken to be 0.025 rad.

Connections in Part 10 of the Manual should be capable of accommodating 0.03 radians.

29

Rotational Ductility of Simple Connections

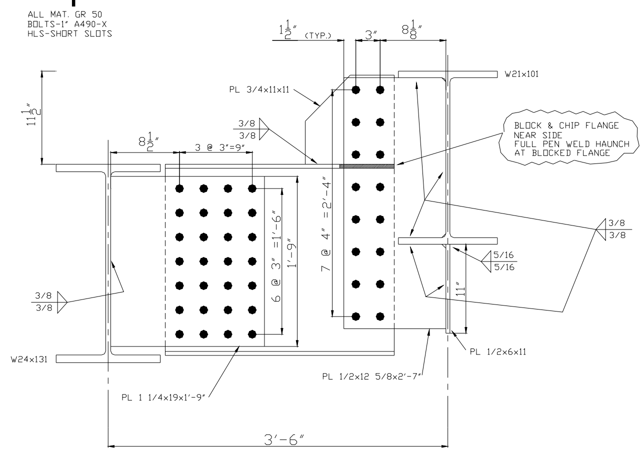
With no back-up connection the web of the support can simply flex to accommodate the simple beam rotation.



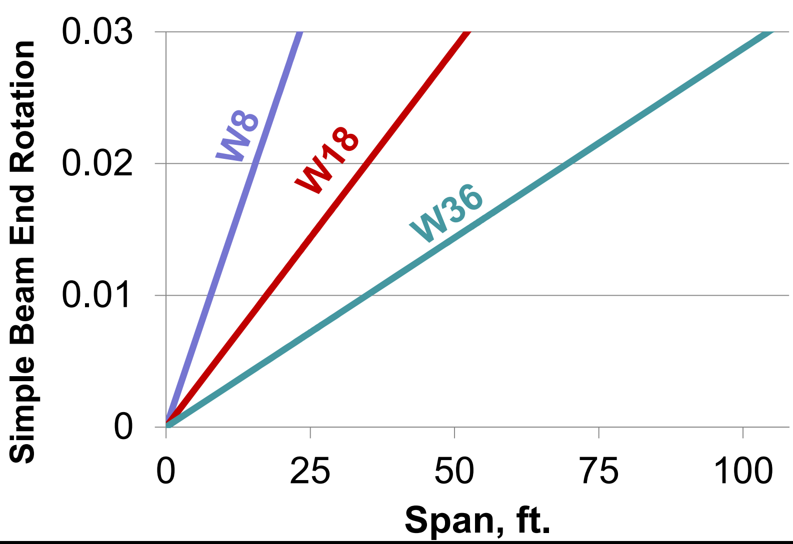
30

Rotational Ductility of Simple Connections

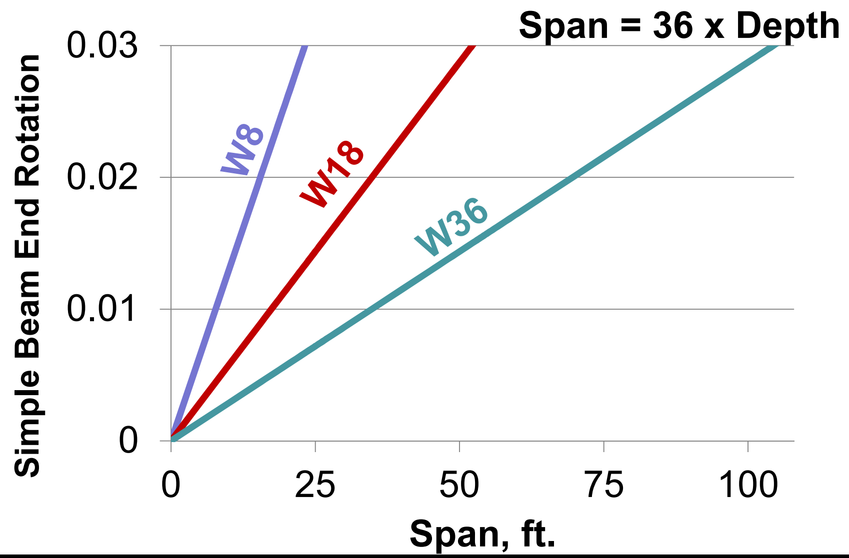
Short, deep beams have little end rotation.



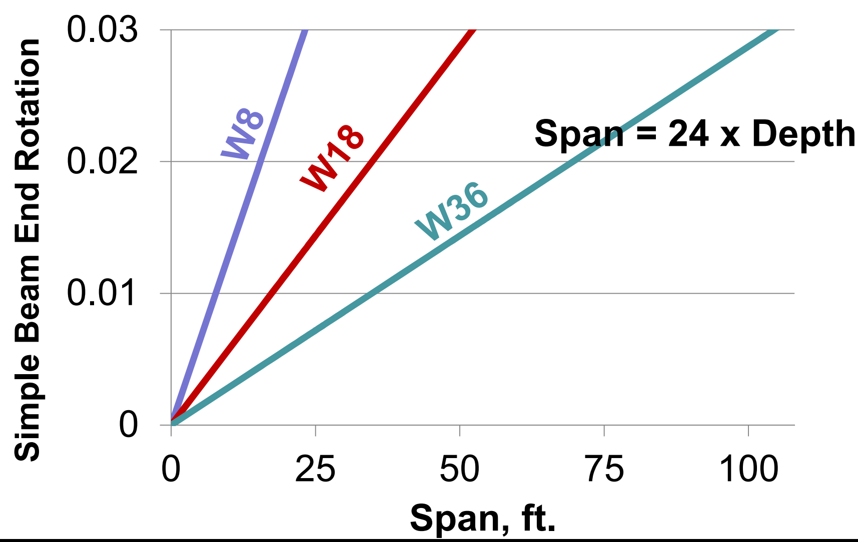
Rotational Ductility of Simple Connections

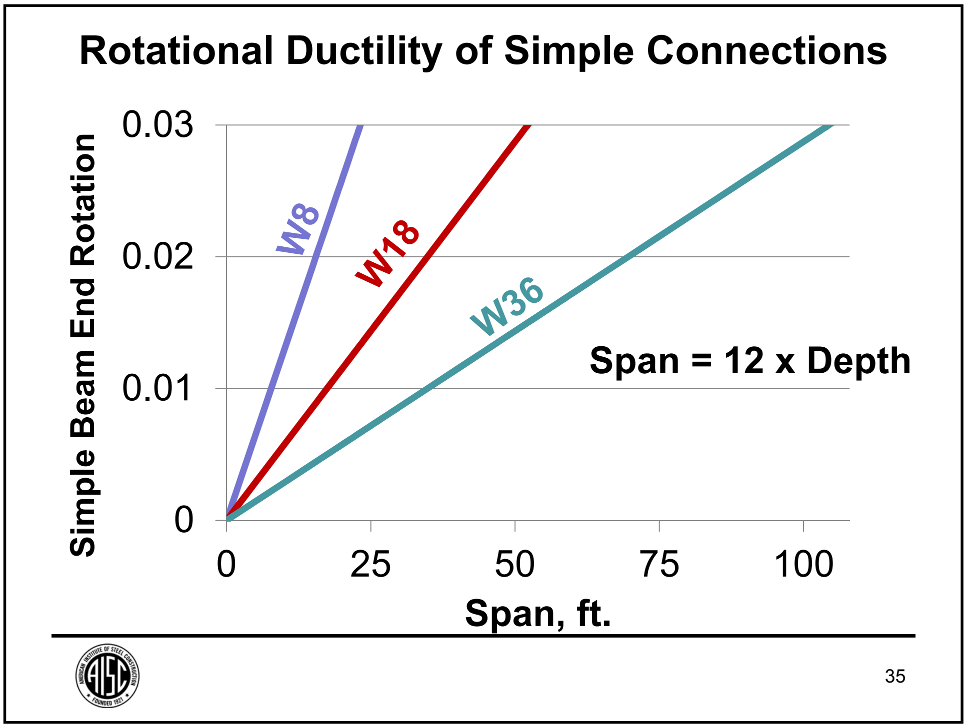


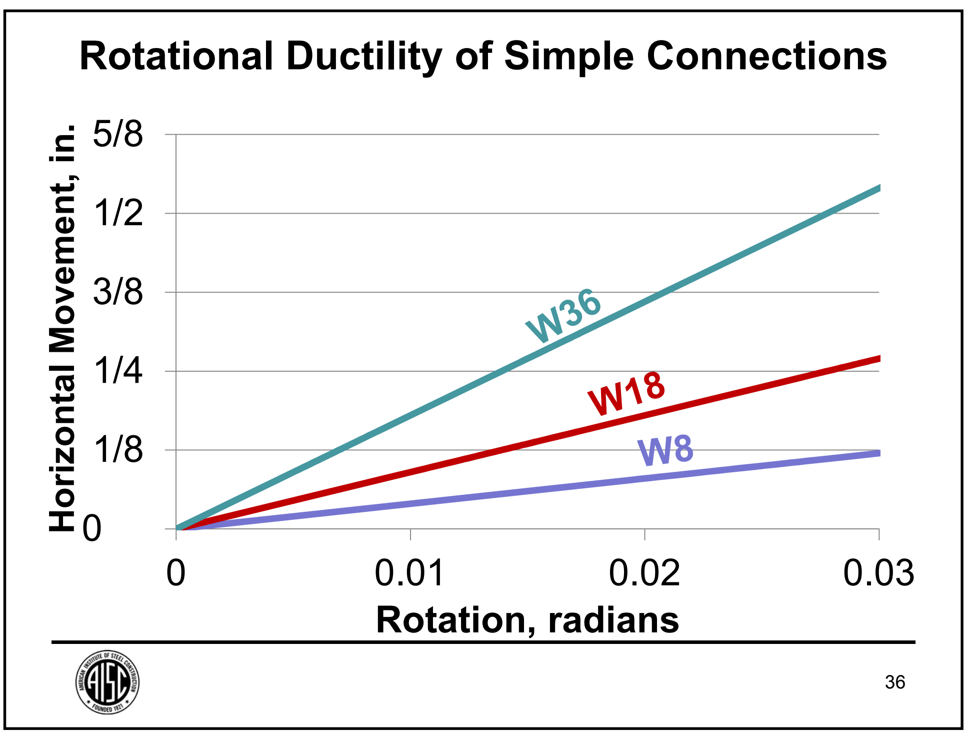
Rotational Ductility of Simple Connections



Rotational Ductility of Simple Connections




Rotational Ductility of Simple Connections
Simple Beam End Rotation
0.03
0.02
0.01
0
W8
W18
W36
Span = 12 x Depth
0
25
50
75
100
Span, ft.
35


Rotational Ductility of Simple Connections
Horizontal Movement, in.
5/8
1/2
3/8
1/4
1/8
0
W36
W18
W8
0
0.01
0.02
0.03
Rotation, radians
36

Rotational Ductility of Simple Connections

Sources of Deformation

- Connection flexural yielding
- Connection bearing deformations at bolt holes
- Beam web bearing deformations at bolt holes
- Rotations at support
- Bolt shear deformation
- Weld deformation

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Rotational Ductility of Simple Connections

Part 7 of the Manual summarizes data from tests where the total deformation was about 3/8” with a 3/4“ A325 bolt.

Short slots offer about 1/4“ of movement.

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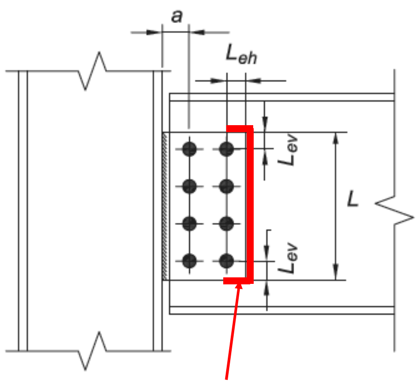
Rotational Ductility of Simple Connections



Weld stopped short of holes

What About All-Welded Shear Tabs?

- "Behavior of Single and Double Row Bolted Shear Tab Connections and Weld Retrofits" by Matthew Marosi (McGill University)

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Rotational Ductility of Simple Connections

Summary

- The Manual procedures are adequate to address most conditions
- Beams will rarely experience 0.03 radians of end rotation
- There are lots of sources of rotational capacity
- Shear connections with the largest strength demands rarely have the greatest rotational demands

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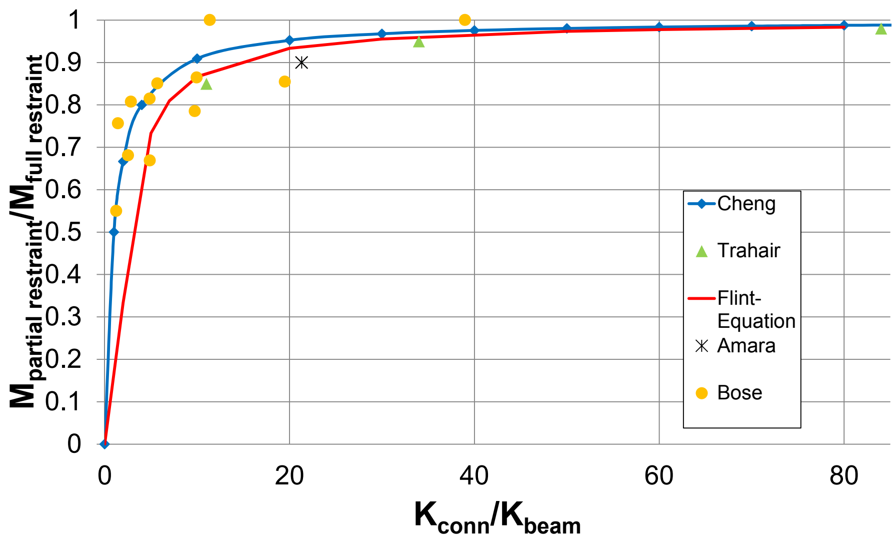
Torsional Restraint

Torsional Restraint

Specification F1.(2) GENERAL PROVISIONS

The provisions in this chapter are based on the assumption that points of support for *beams* and girders are restrained against rotation about their longitudinal axis.

Torsional Restraint



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Torsional Restraint

Connections worthy of special consideration:

- Long, deep copes, especially double copes
- Beam ends supported on bearing plates
- Extended single-plate shear connections without slab or not otherwise braced at beam points of support (NOTE: Bracing req'd in Manual procedure)

44

Torsional Restraint

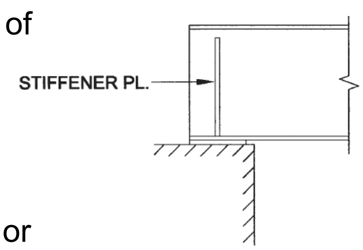
Standard (Manual Part 10), half-depth shear connections are generally assumed to provide sufficient restraint against rotation about the beam's longitudinal axis.

45

Torsional Restraint

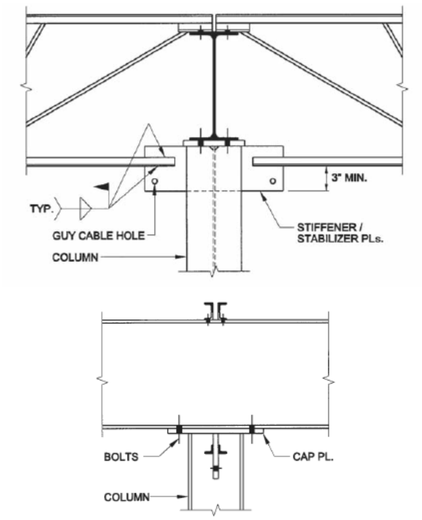
For beam ends supported on bearing plates the Manual states that stability of can be provided by:

1. Building the beam end into solid concrete or masonry using anchorage devices
2. top flange connection with a floor or roof system…
3. a top-flange stability connection
4. an end-plate or transverse stiffeners located over the bearing plate extending to near the top-flange.



46

Torsional Restraint

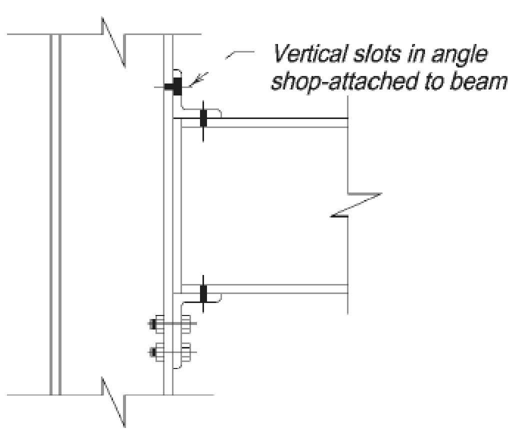


When beams run continuous over the column both the stability of the beam and the column must be considered.

47

Torsional Restraint

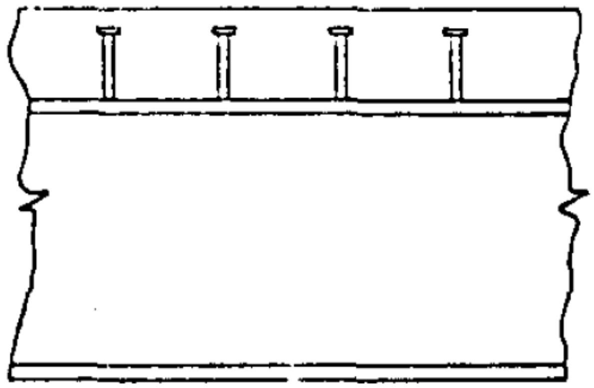
Seated connections - Stability angle provided.



48

Torsional Restraint

End restraint has little effect on fully braced beams.



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Torsional Restraint

Summary

- Half depth connections are generally sufficient to provide torsional end restraint.
- Significantly braced beams are less dependent on end restraint.
- Long, double copes typically provide less restraint than extended tabs.
- It is difficult to apply load without providing restraint.

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Alternate Methods

- Built-up PJP Welds
- Bolt Group Analysis
- Interaction Approach
- Separation Approach
- Prying Action

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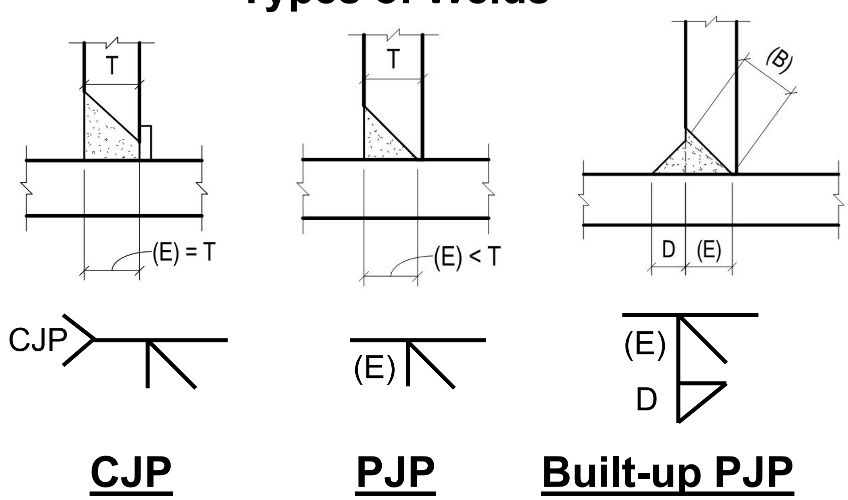
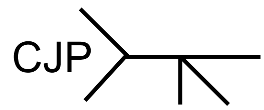
Types of Welds



52

CJP Welds



Advantages
- High nominal stress
- Develops base material

Disadvantages
- Backer bars or back-gouging
- Weld access holes
- Stringent inspection/testing requirements (UT)

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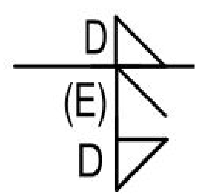
Built-up PJP Welds



Advantages
- No UT requirements
- No weld access holes
- No backing bars or back-gouging

Disadvantages
- Potentially more weld material
- Large FS required (lower nominal stress)

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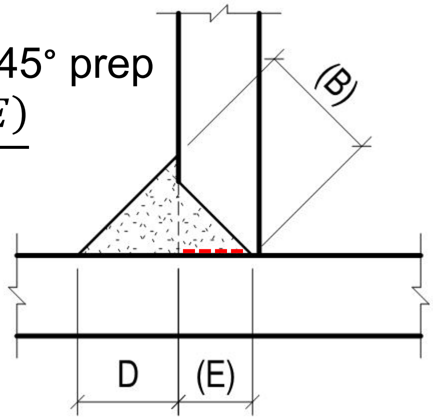
Built-up PJP Welds

Effective Throat

For D>E and 45° prep

$$B = E\sqrt{2} + \frac{(D-E)}{\sqrt{2}}$$



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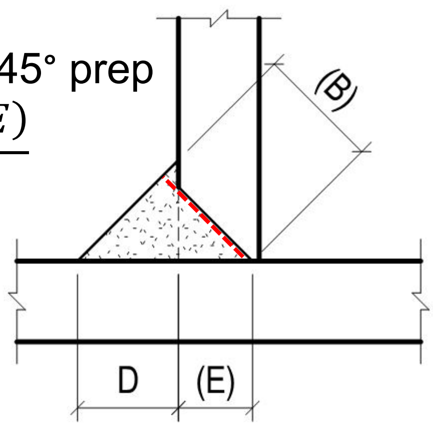
Built-up PJP Welds

Effective Throat

For D>E and 45° prep

$$B = E\sqrt{2} + \frac{(D-E)}{\sqrt{2}}$$



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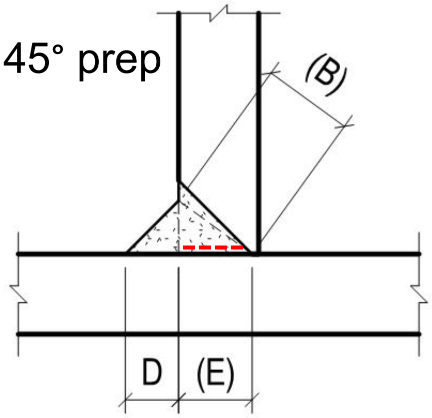
Built-up PJP Welds

Effective Throat

For E>D and 45° prep

$$B = \sqrt{D^2 + E^2}$$



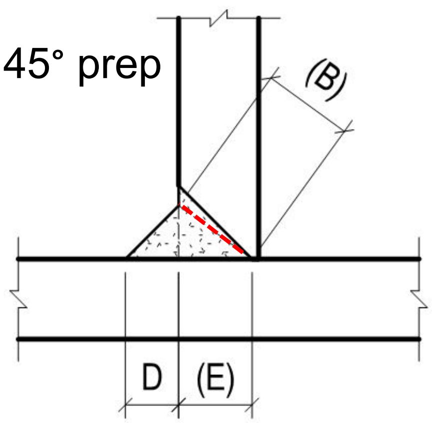
57

Built-up PJP Welds

Effective Throat

For E>D and 45° prep

$$B = \sqrt{D^2 + E^2}$$



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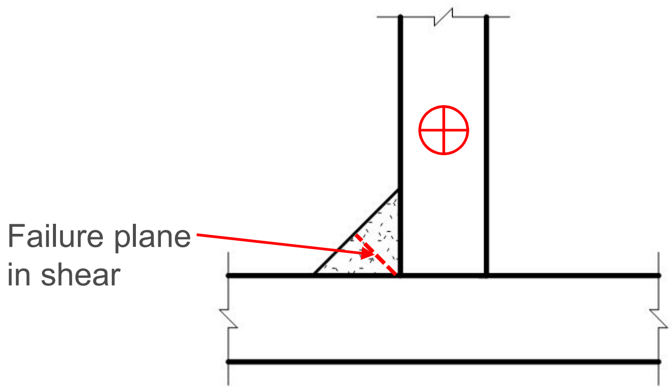
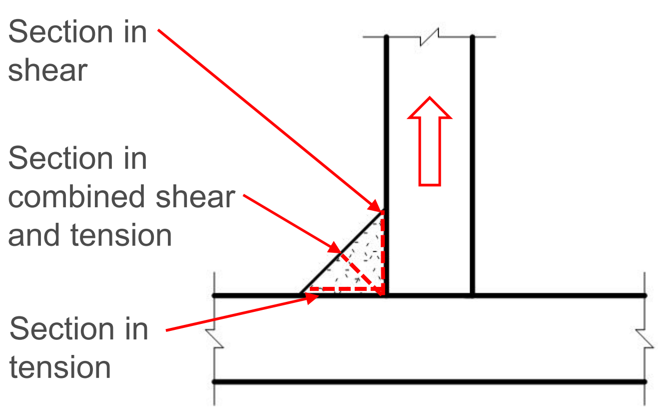
Built-up PJP Welds

Directionality increase?



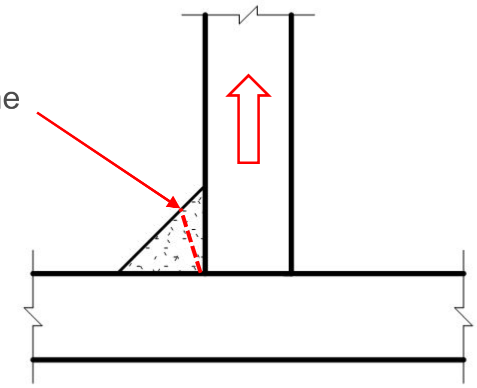
Built-up PJP Welds

Directionality increase?



Built-up PJP Welds

Directionality increase? **NO**



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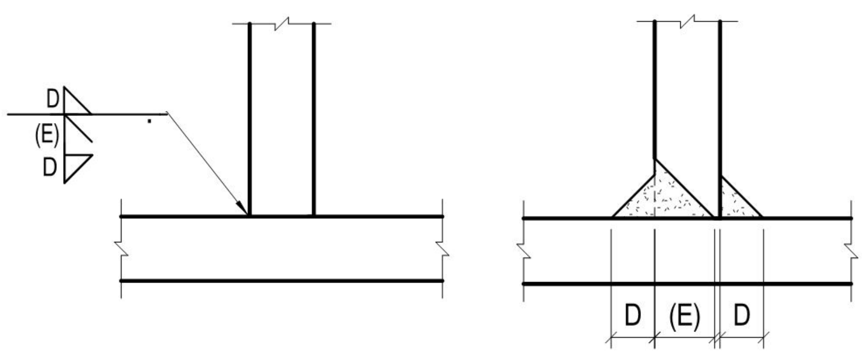
Built-up PJP Welds



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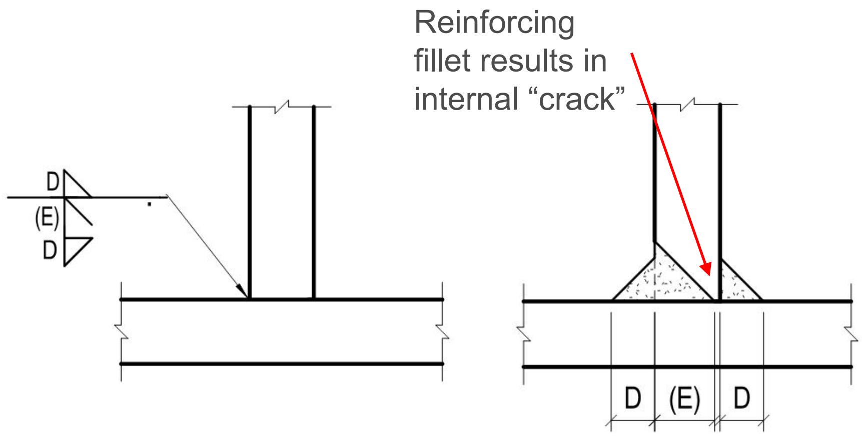
Built-up PJP Welds



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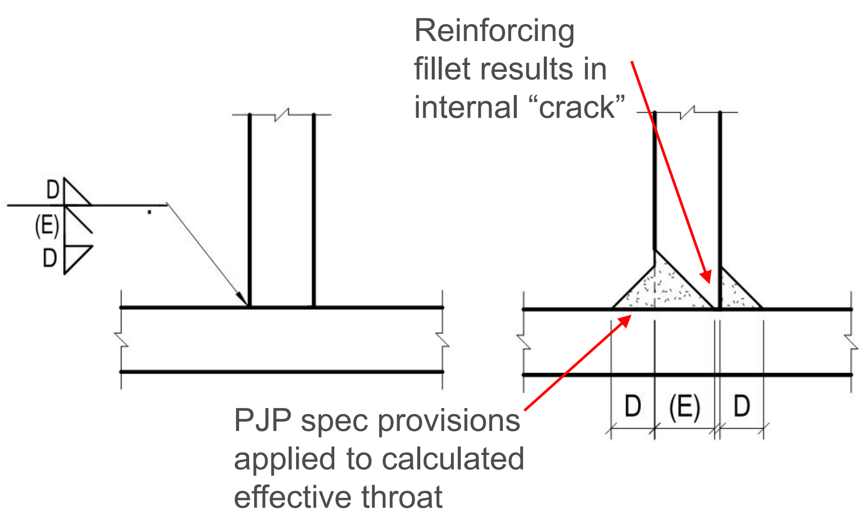
Built-up PJP Welds



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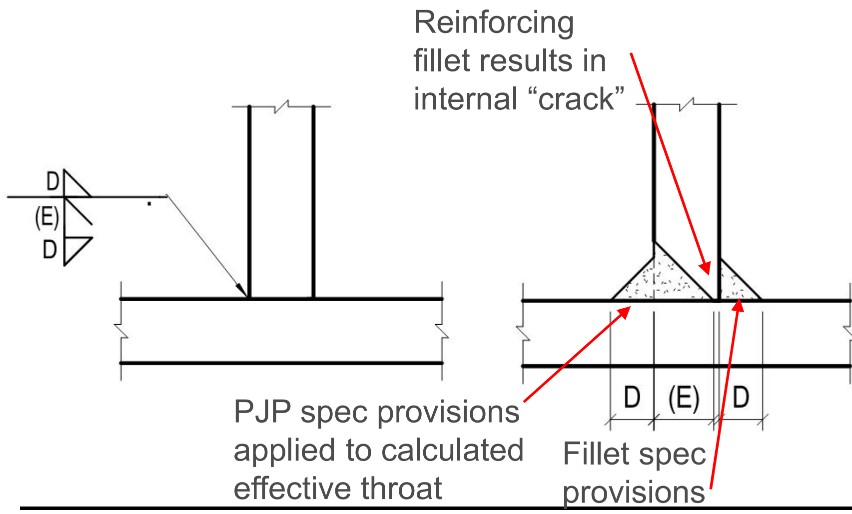
Built-up PJP Welds



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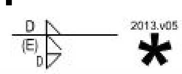
Built-up PJP Welds



FULL CAPACITY WELD SCHEDULE		
CONNECTED FLANGE/PLATE THICKNESS (IN)	FILLET WELD SIZE D (IN)	PARTIAL PENETRATION WELD EFFECTIVE THROAT SIZE E (IN)
≤ 0.37	1/4	NOT REQD
≤ 0.46	5/16	NOT REQD
≤ 0.56	3/8	NOT REQD
≤ 0.65	7/16	NOT REQD
≤ 0.74	1/2	NOT REQD
≤ 0.84	9/16	NOT REQD
≤ 0.93	5/8	NOT REQD
≤ 1	7/16	13/16
≤ 1 1/8	7/16	1
≤ 1 1/4	1/2	1 1/16
≤ 1 3/8	1/2	1 1/4
≤ 1 1/2	9/16	1 5/16
≤ 1 5/8	5/8	1 7/16
> 1 5/8	N/A	CJP (NOTE 2)

NOTES:
1. COMPLETE JOINT PENETRATION WELDS MAY BE USED AS AN ALTERNATE TO FILLET AND BUILT-UP WELDS FOR ANY CONNECTED FLANGE/PLATE THICKNESS.

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Bolt Group Analysis

Everything should be made as simple as possible, but not simpler.

Albert Einstein

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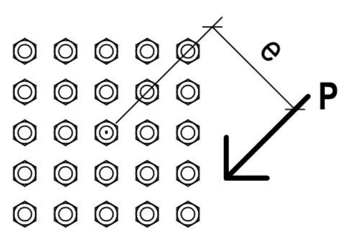
Bolt Group Analysis

AISC Manual – Part 7

Instantaneous Center of Rotation Method (IC)

Elastic Method



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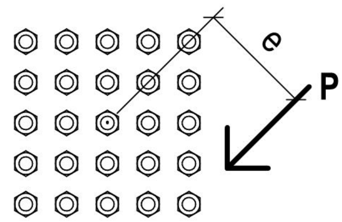
Instantaneous Center of Rotation

Advantages
- Accurate
- Tabularized in manual

Disadvantages
- Iterative
- Cannot be hard coded
- Difficult to check



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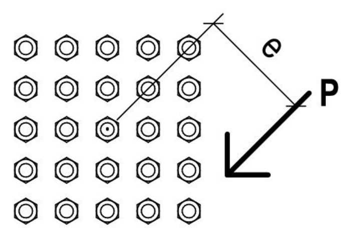
Elastic Method

Advantages
- Can be coded
- Uses basic Mech of Mat principles

Disadvantages
- Conservative
- Relatively complicated



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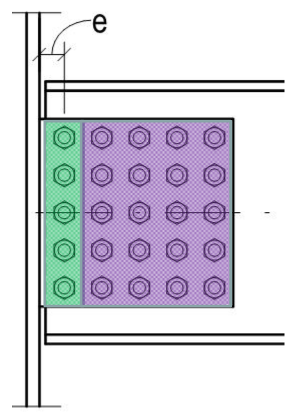
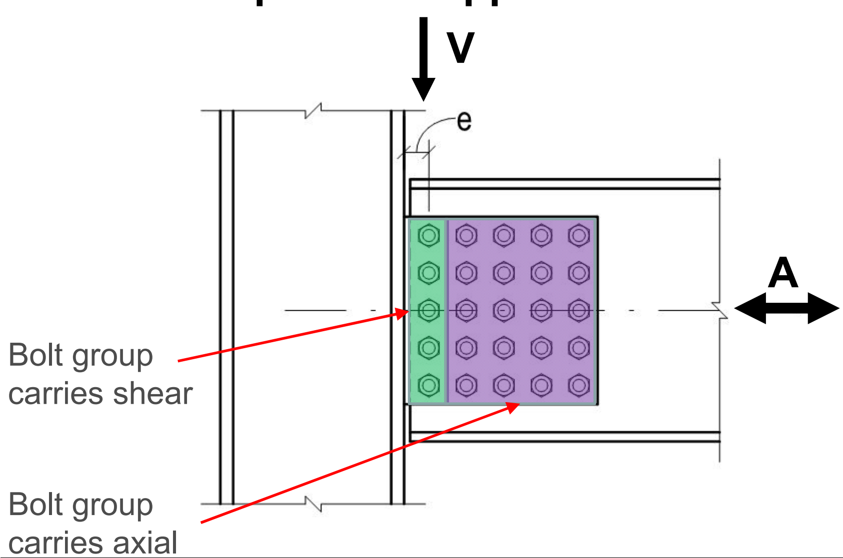
Separation Approach

Advantages
- Conducive to shear/axial capacity tabularization

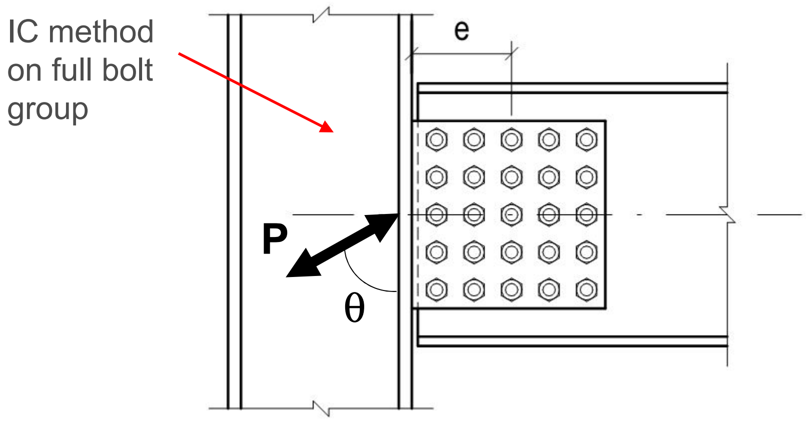
Disadvantages
- Dependent on IC
- Can be conservative



Separation Approach



Separation Approach



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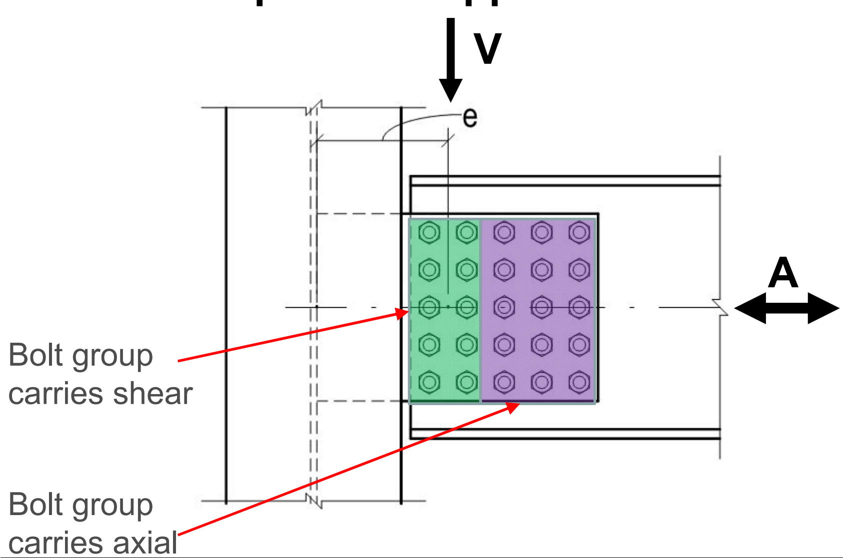
Separation Approach



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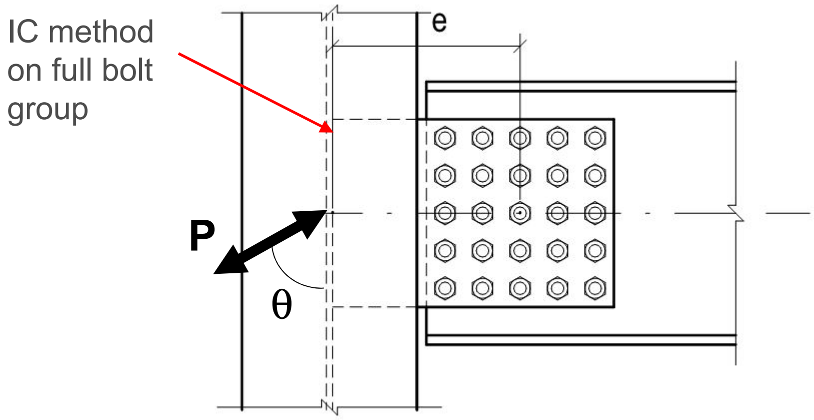
Separation Approach



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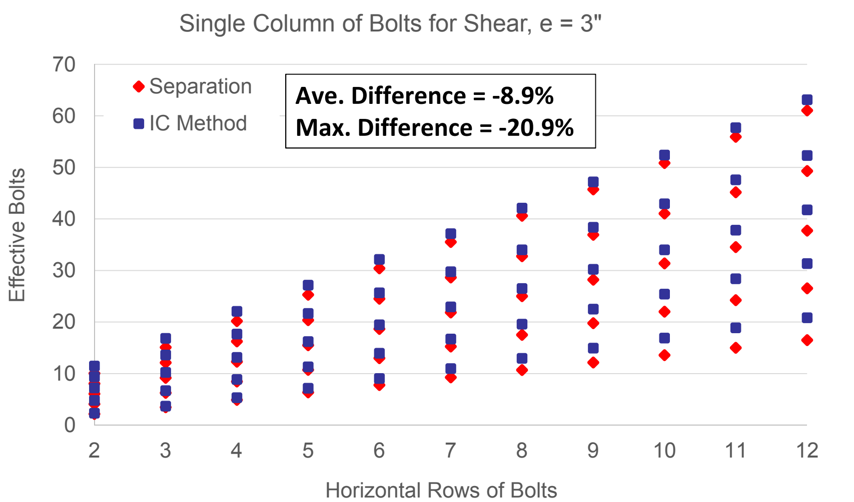
Separation Approach



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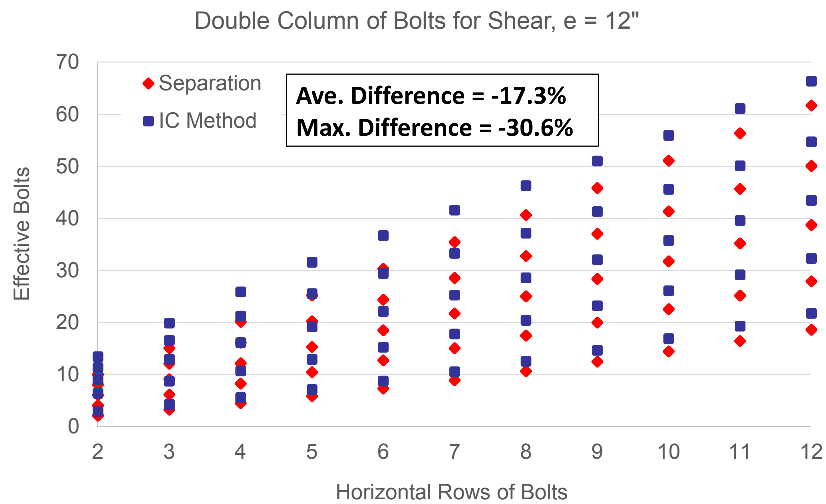
Separation Approach



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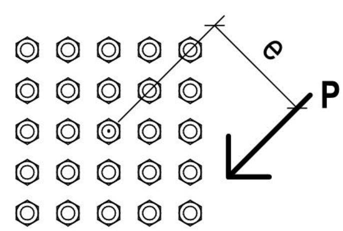
Interaction Approach

Advantages

- Can be coded
- Intuitive
- More accurate than elastic method

Disadvantages

- Less accurate than IC method



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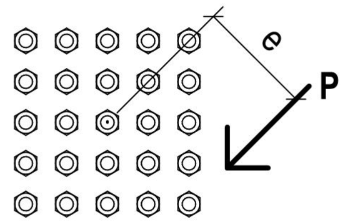
Interaction Approach

$$C' = \sum \left[l_i \left(1 - e^{-\left(\frac{10 l_i \Delta_{max}}{l_{max}}\right)} \right)^{0.55} \right]$$



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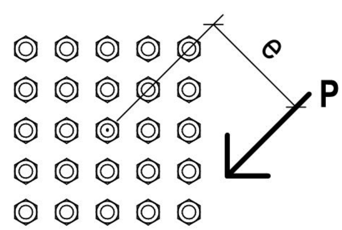
Interaction Approach

$$C' = \sum \left[l_i \left(1 - e^{-\left(\frac{10 l_i \Delta_{max}}{l_{max}}\right)} \right)^{0.55} \right]$$

$$\frac{P_u}{\phi P_n} + \frac{M_u}{\phi M_n} \leq 1.0$$



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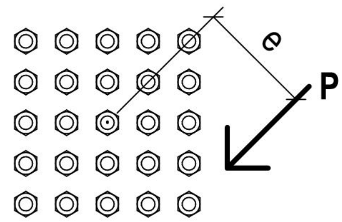
Interaction Approach

$$C' = \sum \left[l_i \left(1 - e^{-\left(\frac{10 l_i \Delta_{max}}{l_{max}}\right)}\right)^{0.55} \right]$$

$$\frac{P_u}{\phi P_n} + \frac{M_u}{\phi M_n} \leq 1.0$$

$$\frac{P_u}{\phi r_n N} + \frac{P_u e}{\phi r_n C'} \leq 1.0$$



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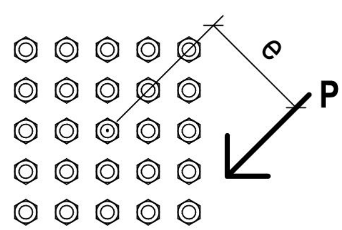
Interaction Approach

$$C' = \sum \left[l_i \left(1 - e^{-\left(\frac{10 l_i \Delta_{max}}{l_{max}}\right)}\right)^{0.55} \right]$$

$$\frac{P_u}{\phi P_n} + \frac{M_u}{\phi M_n} \leq 1.0$$

$$\frac{P_u}{\phi r_n N} + \frac{P_u e}{\phi r_n C'} \leq 1.0$$

$$C = \frac{1.11}{\left(\frac{1}{n} + \frac{e}{C'}\right)}$$



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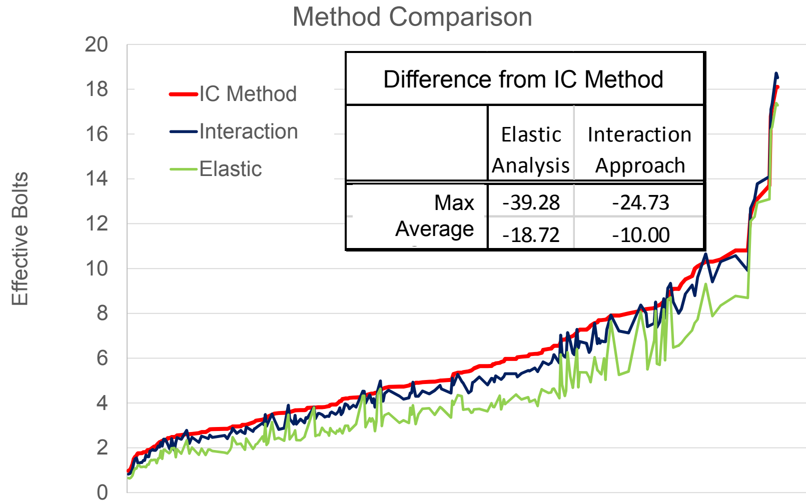
Interaction Approach



Difference from IC Method	Elastic Analysis	Interaction Approach
Max	-39.28	-24.73
Average	-18.72	-10.00

Prying Action

"The *required tensile strength* shall include any tension resulting from *prying action* produced by deformation of the connected parts."

AISC 360-10
Section J3.6

Prying Action – AISC Manual

"Ultimate Strength Prying Models for Bolted T-stub Connections"

Swanson, 2002, Engineering Journal

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Prying Action – AISC Manual

"Ultimate Strength Prying Models for Bolted T-stub Connections"

Swanson, 2002, Engineering Journal

Appears as one limit state

86

Prying Action – AISC Manual

"Ultimate Strength Prying Models for Bolted T-stub Connections"

Swanson, 2002, Engineering Journal

Appears as one limit state

Actually three limit states differentiated by α

87

Prying Action – Limit States Approach

$$T = \frac{(1+\delta)}{4b'}(p \times F_y \times t_f^2)$$

$$T = \frac{B_n \times a'}{a'+b'} + \frac{p \times F_y \times t_f^2}{4(a'+b')}$$

$$T = B_n$$

Swanson, 2002

88

Prying Action – Limit States Approach

$$T = \frac{(1+\delta)}{4b'}(p \times F_y \times t_f^2)$$ Flange Hinging

$$T = \frac{B_n \times a'}{a'+b'} + \frac{p \times F_y \times t_f^2}{4(a'+b')}$$

$$T = B_n$$

Swanson, 2002

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Prying Action – Limit States Approach

$$T = \frac{(1+\delta)}{4b'}(p \times F_y \times t_f^2)$$ Flange Hinging

$$T = \frac{B_n \times a'}{a'+b'} + \frac{p \times F_y \times t_f^2}{4(a'+b')}$$ Combined Mode

$$T = B_n$$

Swanson, 2002

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Prying Action – Limit States Approach

$$T = \frac{(1+\delta)}{4b'}(p \times F_y \times t_f^2)$$

Flange Hinging

$$T = \frac{B_n \times a'}{a'+b'} + \frac{p \times F_y \times t_f^2}{4(a'+b')}$$

Combined Mode

$$T = B_n$$

Bolt Tension (no prying)

Swanson, 2002

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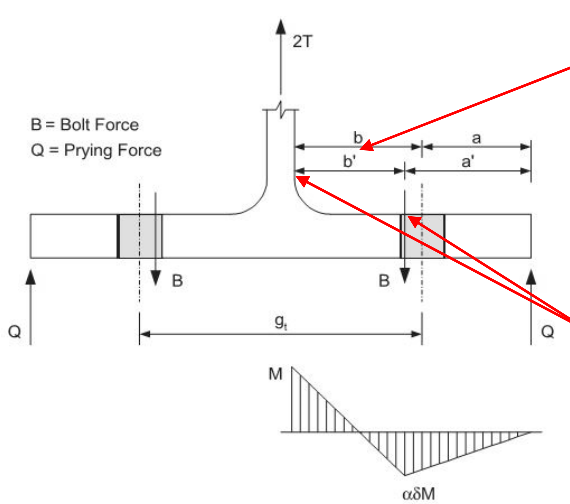
Prying Action – AISC Manual



Assumed distance between hinges

Hinges occur at edge of bolt and face of stem

Swanson, 2002

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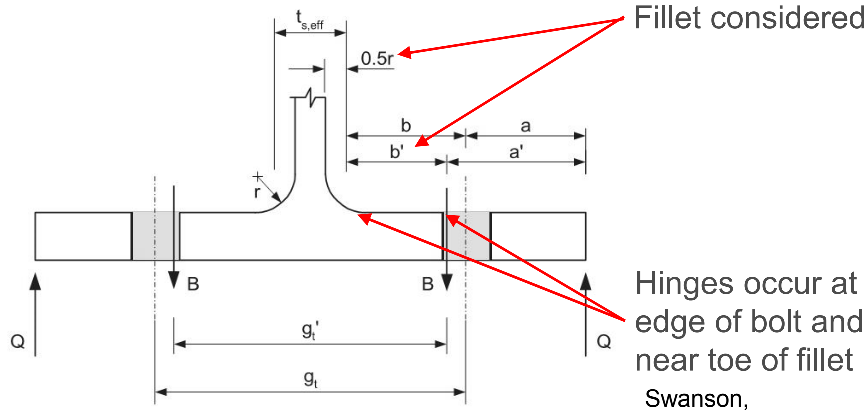
Prying Action – Alternate Methods



Swanson, 2002

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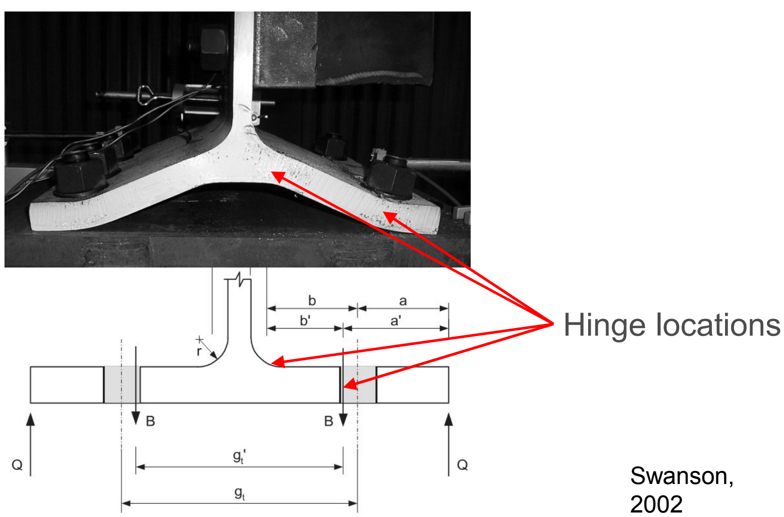
Prying Action – Alternate Methods



Swanson, 2002

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Prying Action – Alternate Methods

Compared Test Data
- $g/t_f \leq 6$
- $t_f > ¾$”

95

Prying Action – Alternate Methods

Compared Test Data
- $g/t_f \leq 6$
- $t_f > ¾$”

Tests with $g/t_f \geq 10$
- AISC Approach predicts first yield
- Alternate methods better capture plastic capacity

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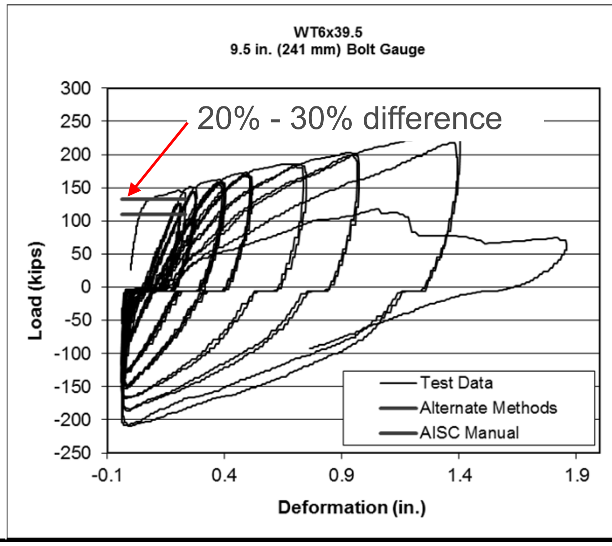
Prying Action – Alternate Methods



$g/t_f = 13$

Alternate Methods

Alternate Methods

Not prohibited

99

Alternate Methods

Not prohibited

Should be scrutinized

100

Alternate Methods

Not prohibited

Should be scrutinized

Engineering judgement required

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CEU/PDH Certificates

Within 2 business days…

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

CEU/PDH Certificates

Within 2 business days…

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

There's always a solution in steel.

Thank You

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