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Course Description

Bracing Connections and Prying Action

October 13, 2014

In this session the advantages and disadvantage of three different types of common bracing details will be discussed. For two of the three types of details presented prying action is an important consideration. This session also will include a discussion of prying action and its application in design.



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Learning Objectives

- Understand the advantages and disadvantages of three bracing connection details.
- Develop an understanding of the limit states for the three bracing details.
- Gain an understanding of the impact of prying action on certain bracing connection details.
- Gain an understanding of prying action through the presentation of a design example.



Bracing Connections and Related Topics Session 3: Bracing Connection Details and Prying Action



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Bracing Connections and Related Topics

By: William Thornton



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Course Outline

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



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Session Outline

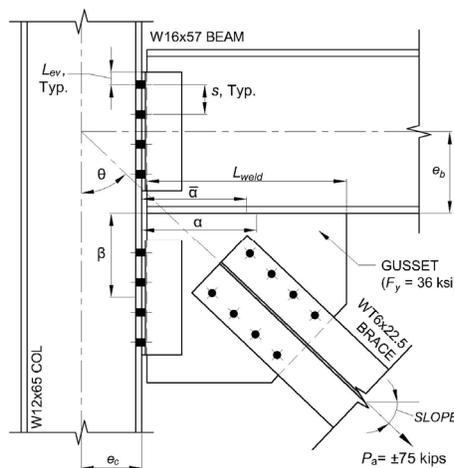
- Comparison of Bracing Connection Details
- Development of the 14th Edition *Manual* Prying Action Method
- Design Algorithms
- Examples of Prying Action in Bearing and Slip Critical Connections
- Summary



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Example Connection Details



Connection with Clip Angles

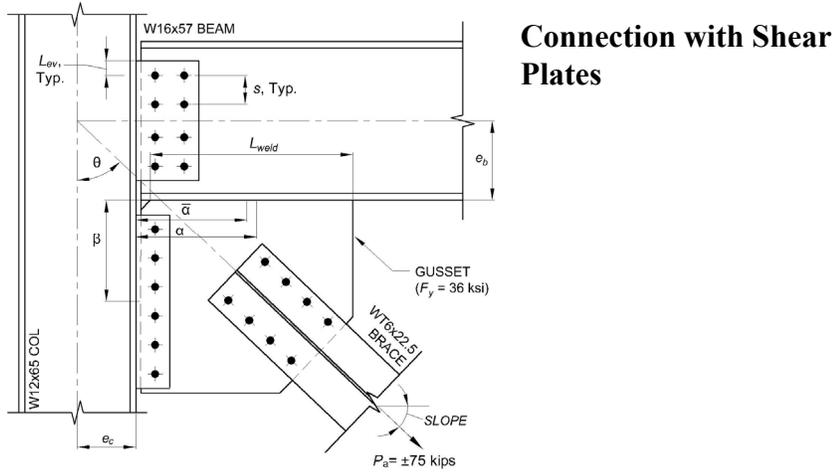
Prying action must be considered.



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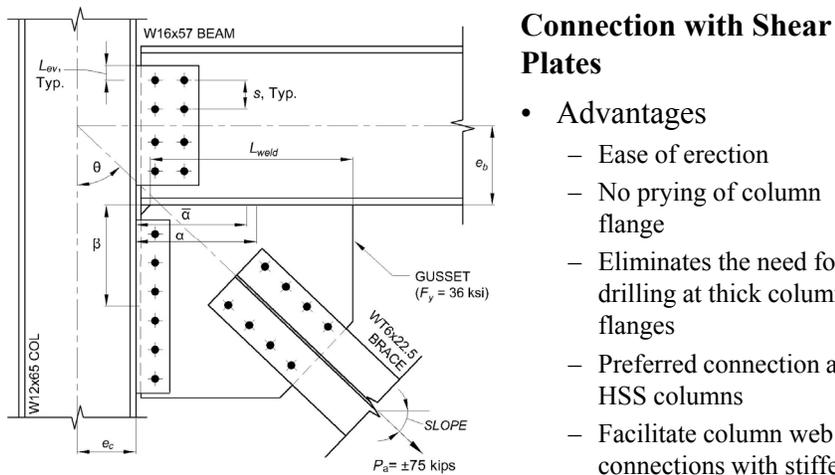
Example Connection Details



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Example Connection Details



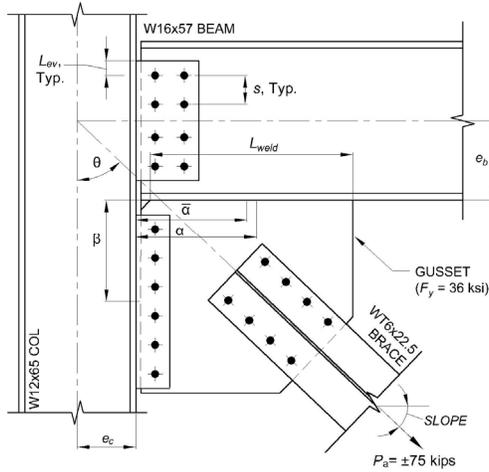
- Advantages
 - Ease of erection
 - No prying of column flange
 - Eliminates the need for drilling at thick column flanges
 - Preferred connection at HSS columns
 - Facilitate column web connections with stiffeners



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Example Connection Details



Connection with Shear Plates

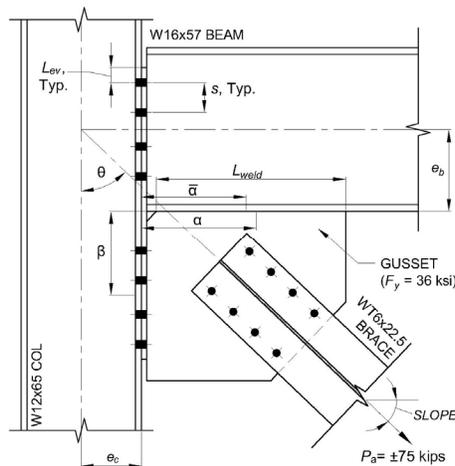
- Disadvantages
 - May require multiple lines of bolts
 - May require heavy plate and welds for high forces
 - Tab weld size = $\frac{5}{8}t_p$ each side of plate (if ductility is required)
 - SC bolts required if slots and axial load in tabs



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Example Connection Details



Connection with End-Plate

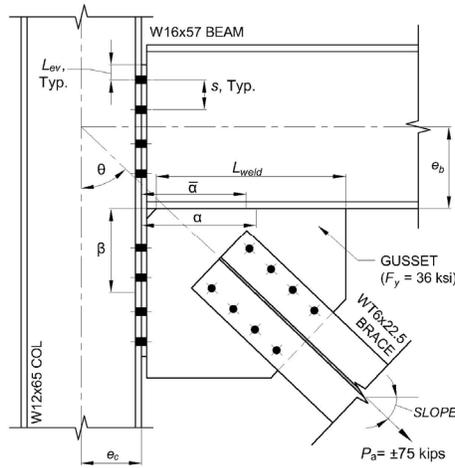
Prying action must be considered.



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Example Connection Details



Connection with End-Plate

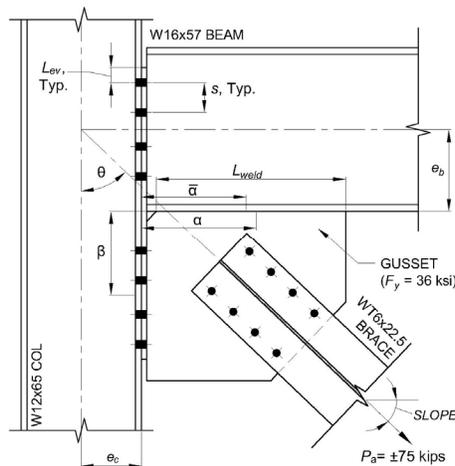
- Advantages
 - Can resist high transfer and H_c forces (can extend end plate to engage beam flanges)
 - Few parts



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Example Connection Details



Connection with End-Plate

- Disadvantages
 - Little erection tolerance (fillers can be used one end for column overrun and overrun considerations)
 - Plates have a tendency to “curl” or “warp” due to heat of welding
 - Prying of column flange may control strength



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The Development of the 14th Edition *Steel Construction* *Manual* Method for Prying Action



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Prying in the AISC *Specification* and Associated *Manual*

2010 *Specification*

Section J3.6

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



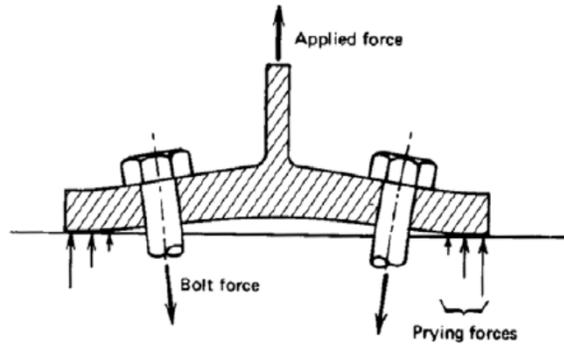
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First, Some Prying Action Discussion

If the connected elements are relatively flexible, then prying forces can develop. Part 9 of the 14th Edition *Manual* has an detailed discussion of prying action.

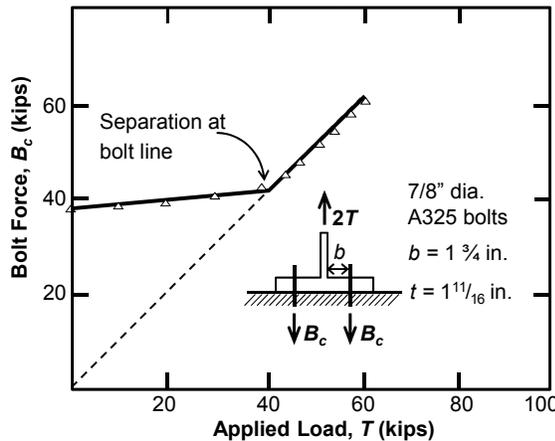


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Prying Action

If the element thickness is greater than t_c , then no prying will develop.



Note:

B = Bolt Strength

B_c = Bolt Force = $T + q$

(Figure is taken from "Guide to Design of Bolted and Riveted Joints", 2nd Ed., Geoffrey L. Kulak, John W. Fisher, and John H. A. Struik, Wiley-Interscience, 1987.)



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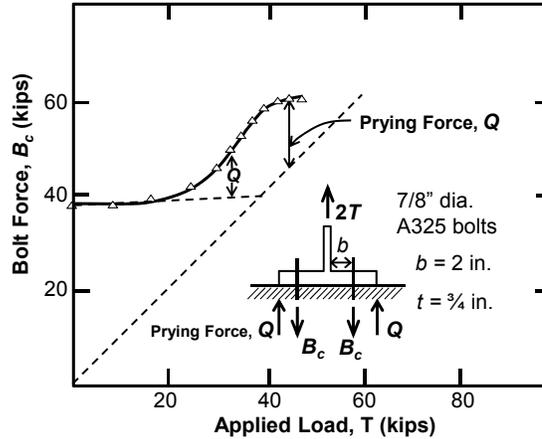
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Prying Action-General

If the element thickness is less than t_c , then prying can occur.

Note:
 B = Bolt Strength
 B_c = Bolt Force = $T + q$

(Figure is taken from "Guide to Design of Bolted and Riveted Joints", 2nd Ed., Geoffrey L. Kulak, John W. Fisher, and John H. A. Struik, Wiley-Interscience, 1987.)



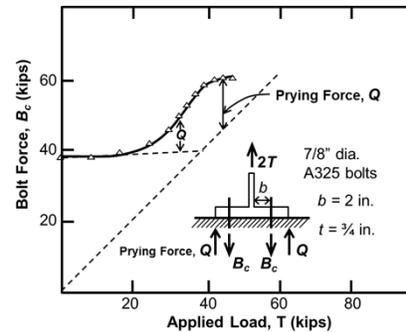
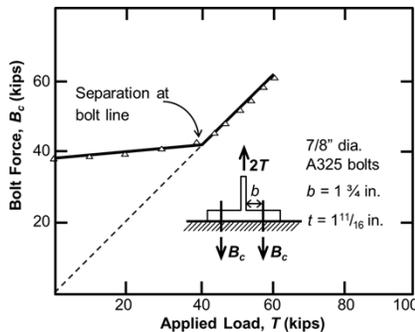
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Prying Action-General

t_c = is the value of plate thickness for which no prying occurs when the bolt strength B is achieved.

Note that these pictures show connections to assumed rigid surfaces. Generally, t_c must be evaluated for both sides of the connection.



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For Instance

7/8 in. Φ A490-X Bolts
STD 15/16 in. Φ Holes
 Beam Col. ASTM A992
 Electrodes E70XX
 Plate ASTM A572-50

Connection Shown
 25'-0 in.
 ±840 kips
 ±718 kips
 ±100 kips
 Typical Bracing Elev.

W14x90
 2L's 8x6x1 LLBB
 840 kips
 1 1/2 in. x 2'-0 1/2 in. x 2'-10 3/4 in.
 1 in. x 2'-0 1/2 in. x 2'-10 3/4 in.
 optional cut
 snip 3/4 x 3/4
 3 in.
 1 1/2 in.
 7 @ 3 in.
 W21x83
 18 kips
 W.P.
 50 kips
 2-1 1/2 in.
 1 in. (typical)
 1/2 in. (Web only, 1 in. return at flanges)
 1/2 in. x 10 in. x 3'-11 1/4 in.
 571 kips 3/4
 6 @ 3 in. (typ.)
 gage = 5 1/2 in.
 3 in.
 5 @ 3 in.
 100 kips

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Prying Action

Applies to the end plate and to the column

W.P.
 100 kips
 50 kips
 269 kips
 176 kips
 100 kips
 571 kips
 50 kips

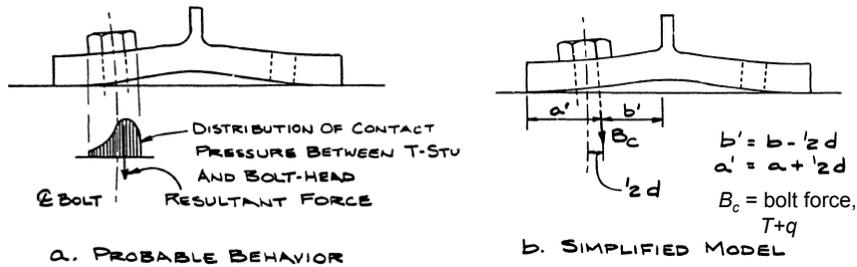
176 kips
 301 kips
 571 kips
 840 kips
 616 kips
 439 kips
 269 kips
 269 kips
 439 kips
 50 kips
 50 kips
 269 kips
 176 kips
 716 kips

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Probable Behavior and Simplified Model The Struik-de Back Model

These pictures are from the "Bolt Guide"



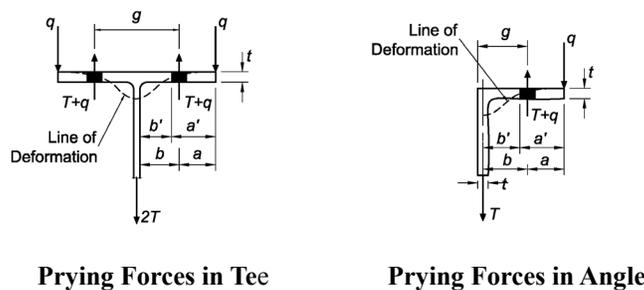
Note: The "Bolt Guide" is a commonly used name for the "Guide to Design of Bolted and Riveted Joints," 2nd Ed.



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Prying Action - General

Manual Prying Action Terminology



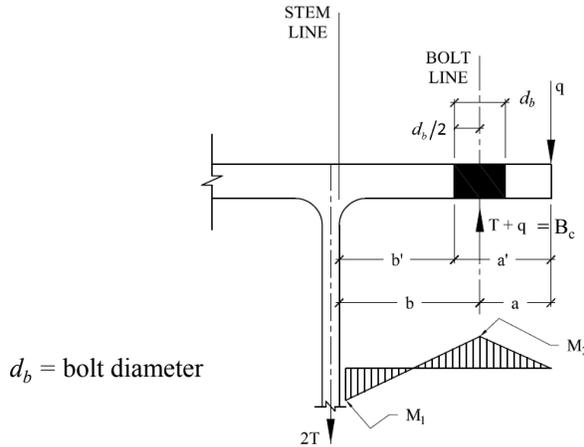
(from AISC Manual Figure 9.4.)



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Prying Action - General

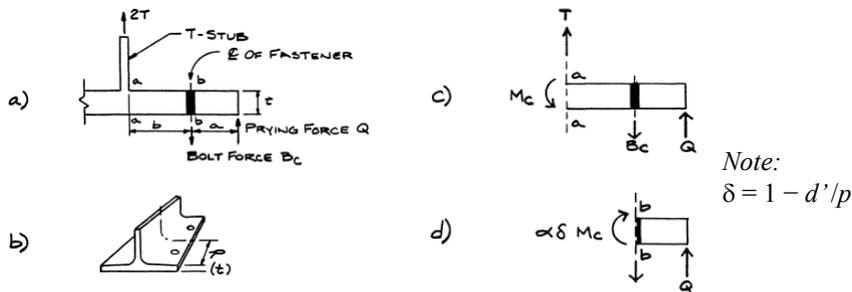
Manual Prying Action Terminology



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Derivation of Prying Equations



Equilibrium Equations

$$M_c - Tb + Qa = 0$$

$$T + Q - B_c = 0$$

$$Qa - \delta \alpha M_c = 0$$

where:

α = the ratio between the moment per unit width at the centerline of the bolt line and the flange moment at the web face
 d' = width of hole along connection length



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Re-arranging the Equilibrium Equations

- Replace a with a' , b with b' , define $\rho = b'/a'$
- The equilibrium equations can be written as:

$$\frac{Tb'}{1 + \delta\alpha} = M_c$$

$$T \left(1 + \frac{\delta\alpha}{1 + \delta\alpha} \rho \right) = B_c$$



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Introduce the Limit States

- For the flange

$$M_c \leq \frac{1}{4} \phi F_y p t^2$$

- For the bolts

$$B_c \leq \phi F_{nt} A_b \triangleq B$$



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Change from F_y to F_u

- Based on research by J. Swanson at Georgia Tech, *AISC Engineering Journal* (2002), it was determined that the use of F_u in place of F_y gave much better agreement of this theory with physical tests.
- Starting with the 13th Edition *Manual*, F_y has been replaced with F_u . The resistance factor ϕ and the safety factor Ω were maintained at 0.9 and 1.67, respectively, because the failure mode in Swanson's tests was yield of the Tee flange, not fracture.



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Introduce the Limit States

- For the flange

$$M_c \leq \frac{1}{4} \phi F_u p t^2$$

- For the bolts

$$B_c \leq \phi F_{nt} A_b \triangleq B$$



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Prying Action Terminology

Introduce the quantity t_c

$$t_c = \sqrt{\frac{4(B)(b')}{\phi(p)(F_u)}}$$

t_c is the material thickness required to develop the design bolt tension $B = \phi F_{nt} A_b$ or $\phi F'_{nt} A_b$. Any greater material thickness will not increase connection capacity.

Where:

F_{nt} = Nominal tensile strength of bolt, ksi

F'_{nt} = Nominal tensile strength of bolt modified to include effects of shear stress, ksi



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Dimensionless Form of the Design Equations

Introducing t_c , the design equations are

For the flange $\frac{T}{B} \leq (1 + \delta\alpha) \left(\frac{t}{t_c}\right)^2$

For the bolts $\frac{T}{B} \leq \frac{1 + \delta\alpha}{1 + \delta\alpha(1 + \rho)}$



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The Design Problem Is:

Given: t, a', b', p, F_u, B

Find T and α such that

$$\text{Flange; } \quad \frac{T}{B} \leq (1 + \delta\alpha) \left(\frac{t}{t_c} \right)^2$$

$$\text{Bolts; } \quad \frac{T}{B} \leq \frac{1 + \delta\alpha}{1 + \delta\alpha(1 + \rho)}$$



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The Design Problem Is:

Given: t, a', b', p, F_u, B

Find T and α such that

$$\text{Flange; } \quad \frac{T}{B} \leq (1 + \delta\alpha) \left(\frac{t}{t_c} \right)^2$$

$$\text{Bolts; } \quad \frac{T}{B} \leq \frac{1 + \delta\alpha}{1 + \delta\alpha(1 + \rho)}$$

These two inequalities involve equilibrium and the limit states. The solution to this problem is what is called a 'lower bound' solution in the terminology of the Lower Bound Theorem of limit analysis.



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For Connections Lower Bound Theorem

Given: Admissible Internal Force Field
(internal forces in equilibrium with applied load)

Given: Satisfaction of the Limit States

Result: The applied load in equilibrium with the internal force field is less than or at most, equal to the connection capacity.



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The Design Problem Is:

Given: t, a', b', p, F_u, B

Find T and α such that

$$\text{Flange; } \frac{T}{B} \leq (1 + \delta\alpha) \left(\frac{t}{t_c} \right)^2$$

$$\text{Bolts; } \frac{T}{B} \leq \frac{1 + \delta\alpha}{1 + \delta\alpha(1 + \rho)}$$

These two inequalities involve equilibrium and the limit states. The solution to this problem is what is called a 'lower bound' solution in the terminology of the Lower Bound Theorem of limit analysis.



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Solution to the Design Problem

Set the two inequalities for $\frac{T}{B}$ on the previous slide equal to each other and solve for α . The result is α'

$$\alpha' = \frac{1}{\delta(1+\rho)} \left[\left(\frac{t_c}{t} \right)^2 - 1 \right]$$

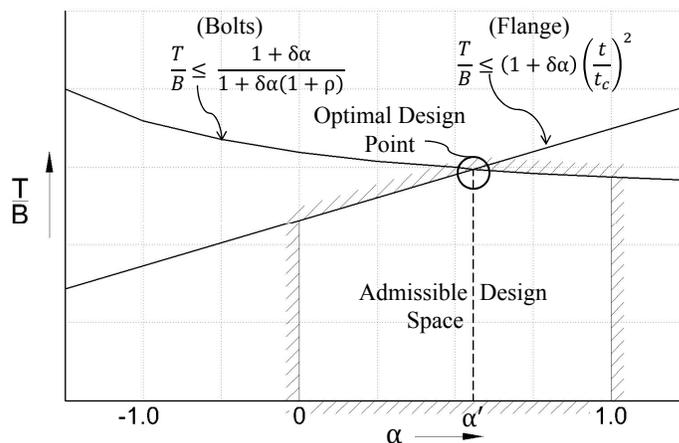


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Solution to the Design Problem

$0 \leq \alpha' \leq 1$, Bolts and Fitting Control

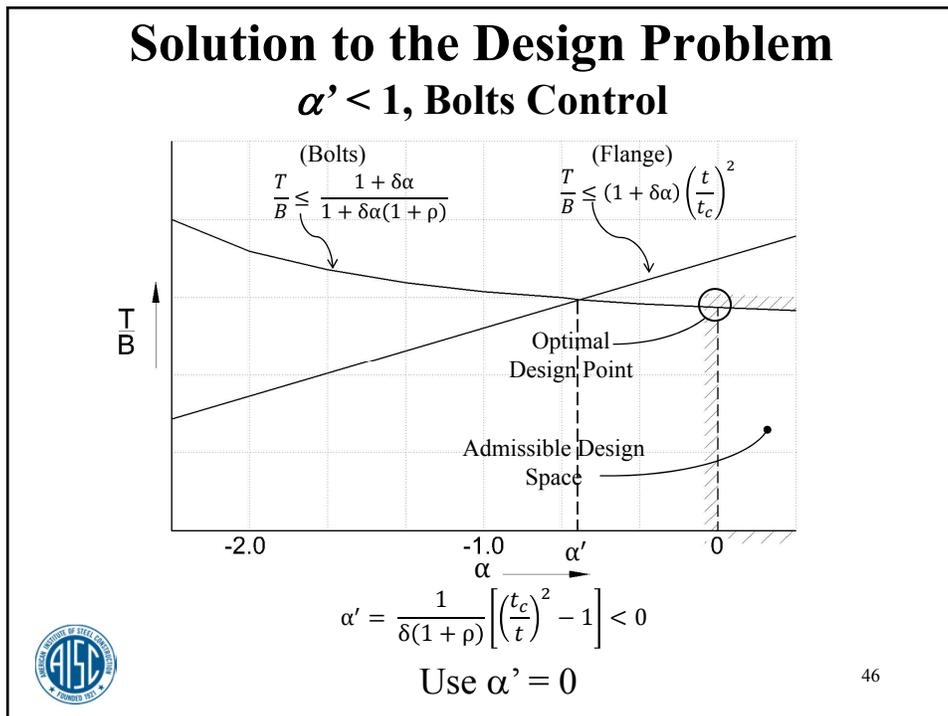
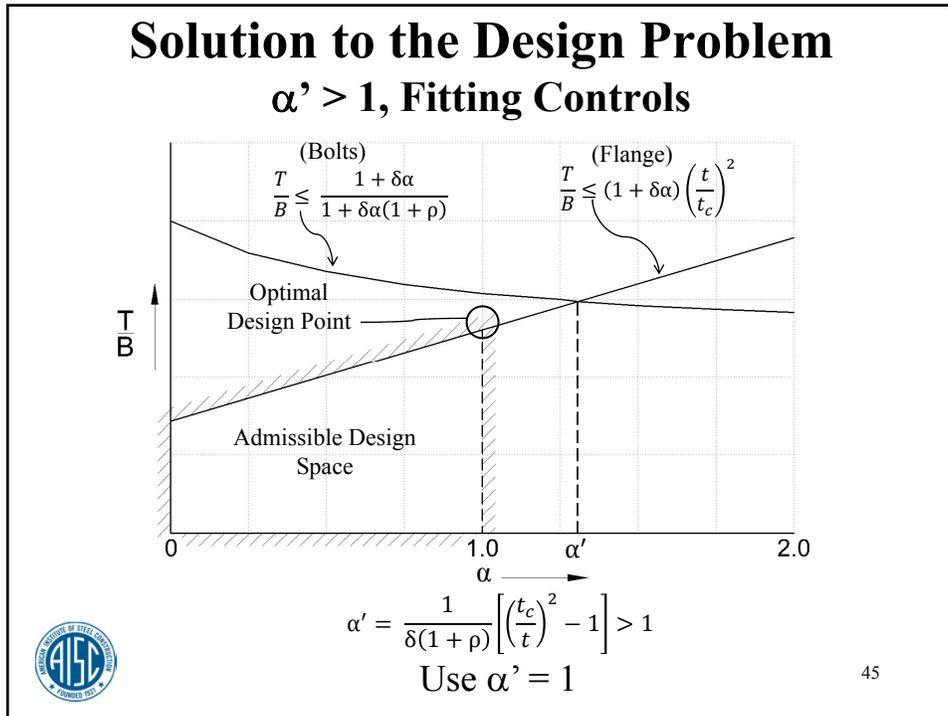


$$0 \leq \alpha' = \frac{1}{\delta(1+\rho)} \left[\left(\frac{t_c}{t} \right)^2 - 1 \right] \leq 1$$

$$0 \leq \alpha' \leq 1$$



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What Is α' ?

α' is the value of α for which
the design tension per bolt
 T_{avail} is a maximum or the
design thickness of the fitting
 t_{min} is a minimum



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How Do α and α' Differ

α is the actual ratio of the fitting moment
at the bolt line to that at the stem line. It
can not be calculated until an acceptable
design has been achieved.

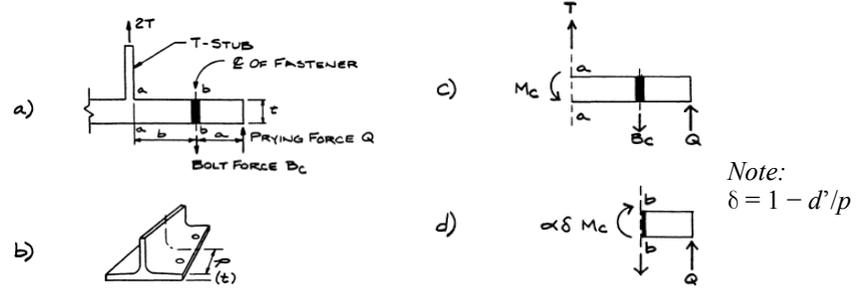
$$\alpha = \frac{M_2}{\delta M_1}$$



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Showing What α Is



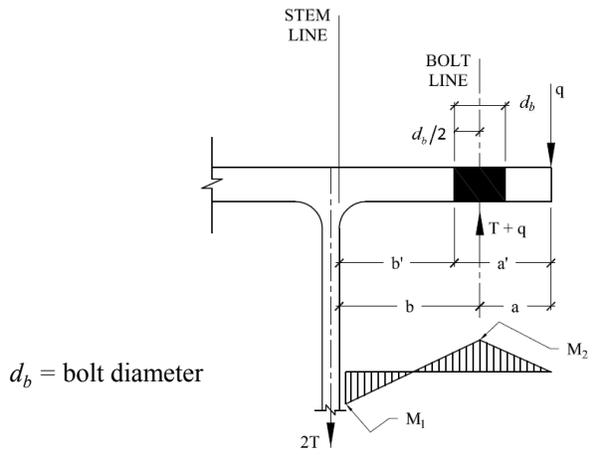
$\alpha \delta M_c$ is the moment at section b-b



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Prying Action - General

Manual Prying Action Terminology



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α vs. α'

For calculation purposes, α can be written as

$$\alpha = \frac{1}{\delta} \left[\frac{T}{B} \left(\frac{t_c}{t} \right)^2 - 1 \right]$$

- α must be between 0.0 and 1.0. A value of α less than 0 or greater than 1 is physically impossible. You cannot use α to obtain a design. Once a design is obtained, you can use α to calculate the prying force q , if desired.



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Calculation of the Prying Force q

$$\alpha = \frac{1}{\delta} \left[\frac{T}{B} \left(\frac{t_c}{t} \right)^2 - 1 \right]$$

$$q = B \left[\delta \alpha \rho \left(\frac{t}{t_c} \right)^2 \right]$$

- The prying force q (or Q) is implicitly included in the *Manual* solution methods. An explicit value is not required, except for fatigue calculations, see *Specification* Appendix 3, Section 3.2



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Calculation of the Prying Force q

- Appendix 3, paragraph 3.2:

“Calculated *stresses* shall be based upon *elastic analysis*. -----”

“For bolts and threaded rods subject to axial tension, the calculated stresses shall include the effects of *prying action*, if any. -----”

The *Manual* prying action formulation is NOT elastic. Use AASHTO provisions to calculate the prying force q . See, for instance, *Standard Specifications for Highway Bridges*, 2002, paragraph 10.32.3.3.2.



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Summary α vs. α'

Unlike α , the calculated value of α' does not need to be between 0 and 1. It is a parameter that locates our position in design space.

When $\alpha' > 1$, use 1 in the calculations. When $\alpha' < 0$, use 0 in the calculations.

When α' is greater than 1, the fitting controls the design.

When α' is less than 0, the bolts control the design.

When α' is less than 1 and greater than 0, both the fitting and the bolts control the design. This is the optimal solution.



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Design Algorithms



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The Design Algorithms

- There are two design algorithms in the *Manual*, Part 9
 1. Analysis – This is the procedure that has just been derived
 2. Design – This procedure is developed in a manner similar to the analysis procedure and will not be developed here. See my 1985 *AISC Engineering Journal* paper



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The Analysis Procedure

- Given: t , a' , b' , p , F_u , and B
- Find: the largest value of T
- Such that: Equilibrium and the limit states are satisfied
- Solution; Calculate $\alpha' = \frac{1}{\delta(1+\rho)} \left[\left(\frac{t_c}{t} \right)^2 - 1 \right]$

If $\alpha' < 0$, set $\alpha' = 0$,

$T_{avail} = B$, the bolts control



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The Analysis Procedure (cont.)

- If $0 \leq \alpha' \leq 1$,

$$T_{avail} = B \left(\frac{t}{t_c} \right)^2 (1 + \delta\alpha')$$

The bolts and the fitting both control.

This is the optimal solution, i.e., optimal design



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The Analysis Procedure (cont.)

- If $\alpha' > 1$, set $\alpha' = 1$,

$$T_{avail} = B \left(\frac{t}{t_c} \right)^2 (1 + \delta)$$

The fitting controls



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The Design Procedure

- Given: T , a' , b' , p , F_u , and B
- Find: the smallest value of t
- Such that: Equilibrium and the limit states are satisfied
- Solution:

Check $T \leq B$

If so, proceed; if not, use more or stronger bolts



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The Design Procedure (cont.)

Then calculate $\beta = \frac{1}{\rho} \left(\frac{B}{T} - 1 \right)$

If $\beta \geq 1$, set $\alpha' = 1$

If $0 \leq \beta < 1$, set $\alpha' = \min \left\{ \frac{1}{\delta} \left(\frac{\beta}{1-\beta} \right), 1 \right\}$



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The Design Procedure (cont.)

With the determined value of α' , calculate

$$t_{\min} = t_c \sqrt{\left(\frac{T}{B} \right) \left(\frac{1}{1 + \delta \alpha'} \right)}$$



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The Design Algorithms Conclusion

- Both algorithms will provide the same required connection.
- The analysis algorithm is transparent as to the meaning of the various values of α' . In the design algorithm, $\alpha' = \alpha$ if t_{\min} is the actual thickness used. Otherwise, $\alpha' > \alpha$.



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Examples of Bearing and Slip Critical Connections



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Example

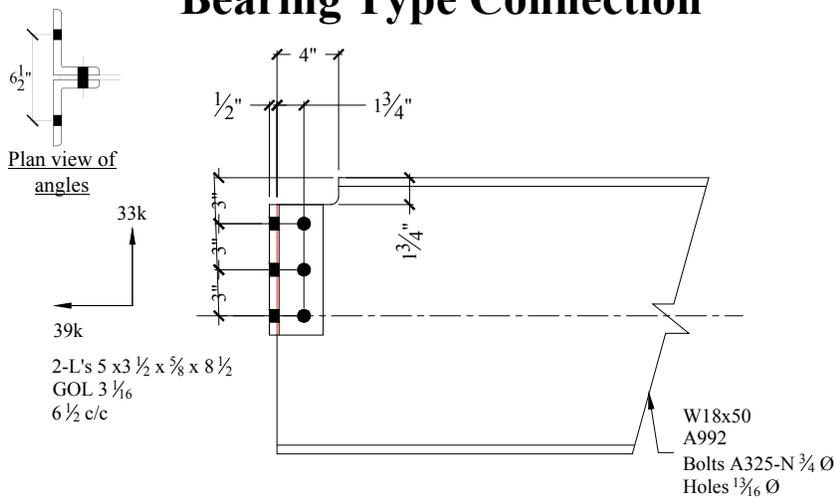
- This example will present only the limit states associated with Prying Action. Many other limit states are required for design of Simple Shear Connections. These will not be considered here.



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Shear and Axial Example Bearing Type Connection



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Shear and Axial Example Bearing Bolts

$\frac{3}{4}$ in. ϕ A325-N Bolts

This connection is subjected to 33 kips shear and 39 kips axial load.

The shear/bolt, $V = 33 \text{ kips}/6 \text{ bolts} = 5.5 \text{ kips}$

Bolt shear design strength:

$$\phi r_v = 17.9 \text{ kips/bolt in single shear per Table 7-1 or Specification Table J3.2}$$

Bolt shear strength of 17.9 kips > 5.5 kips **OK**



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Shear and Axial Example Bearing Bolts

$\frac{3}{4}$ in. ϕ A325-N Bolts

This connection is subjected to 33 kips shear and 39 kips axial load.

The tension/bolt, $T = 39 \text{ kips}/6 = 6.5 \text{ kips/bolt}$

Bolt tension design strength:

$$\phi r_t = 29.8 \text{ kips/bolt per Manual Table 7-2 or Specification Table J3.2}$$

Bolt tensile strength of 29.8 kips > 6.5 kips **OK**



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Shear and Axial Example Bearing Bolts

$\frac{3}{4}$ in. ϕ A325-N Bolts

This connection is subjected to 33 kips shear and 39 kips axial load.

The previous two slides are preliminary to the prying action design checks. If

$$V > \phi r_v \quad \text{or} \quad T > \phi r_t$$

the connection fails and must be revised before prying checks can be made.



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Shear and Axial Example Bearing Bolts

$\frac{3}{4}$ in. ϕ A325-N Bolts

Shear-Tension Interaction

For bearing bolts, the interaction equation is given in *Specification* Section J3.7

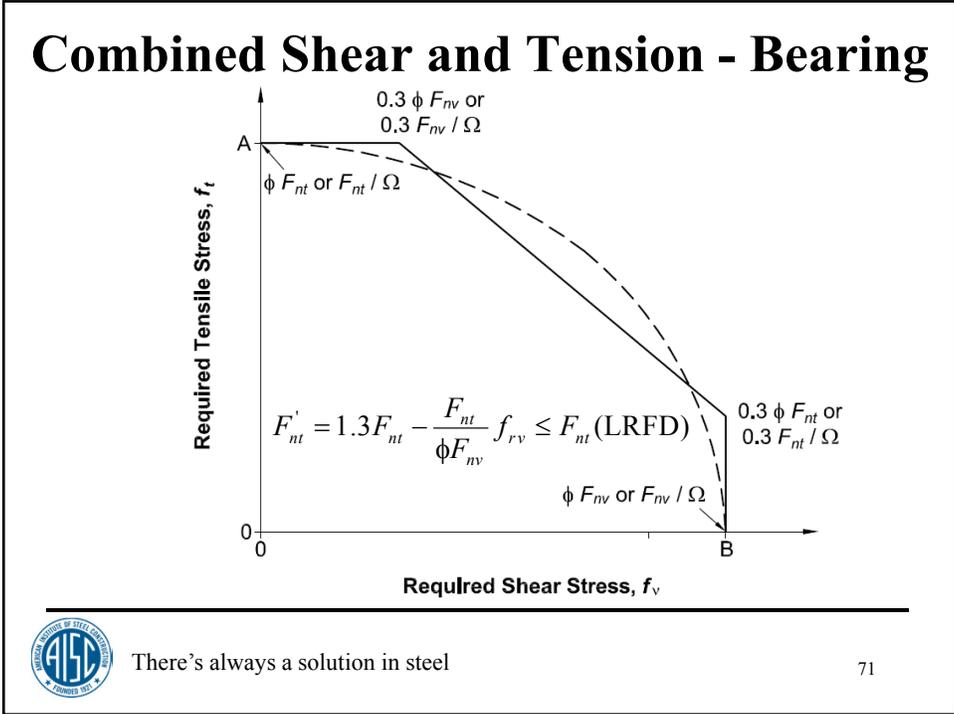
$$F'_{nt} = 1.3F_{nt} - \frac{F_{nt}}{\phi F_{nv}} f_{rv} \leq F_{nt}$$

Note that tensile strength F_{nt} is reduced to F'_{nt} by the bolt shear stress f_{rv} .



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Shear and Axial Example Bearing Bolts 3/4 in. ϕ A325-N Bolts Shear-Tension Interaction

This is exactly the form needed for the prying calculations:

No Shear: $B = \phi F_{nt} A_b$

With Shear: $B = \phi F'_{nt} A_b$

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Shear and Axial Example

Shear and Tension must be considered

Bolt shear / tension interaction (J3.7)

$$\phi F'_{nt} = 0.75 \left[1.3 \times 90 \text{ ksi} - \frac{90 \text{ ksi}}{0.75 \times 54 \text{ ksi}} \left(\frac{33 \text{ kips}}{6(0.75 \text{ in.})^2 \left(\frac{\pi}{4} \right)} \right) \right] = 67.0 \text{ ksi}$$

Note: This cannot exceed $0.75(90 \text{ ksi}) = 67.5 \text{ ksi}$



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Shear and Axial Example (cont.)

Interaction

Tension Capacity Per Bolt = B

$$B = \phi F'_{nt} A_b$$

$$B = 67.0 \text{ ksi} \times 0.442 \text{ in.}^2 = 29.6 \text{ kips/bolt}$$

Tension Capacity = 29.6 kips > 6.5 kips **OK**

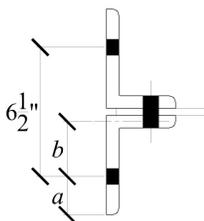


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Shear and Axial Example (cont.)

Geometry



$$a = (5 + 5 + 0.355 - 6.5)/2 = 1.93 \text{ in.}$$

$$b = (6.5 - 0.355 - 0.625)/2 = 2.76 \text{ in.}$$

$$p = 8.5 \text{ in.}/3 \text{ bolts} = 2.83 \text{ in. (average bolt spacing)}$$

$$\delta = 1 - 0.8125 \text{ in.}/2.83 \text{ in.} = 0.713$$

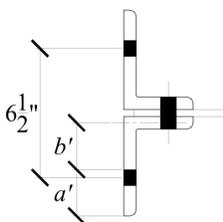


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Shear and Axial Example (cont.)

Check a against $1.25b$



$$a = 1.93$$

$$1.25b = 1.25 \times 2.76 \text{ in.}$$

$$= 3.45 \text{ in.} > 1.93 \text{ in.}$$

→ Use $a = 1.93 \text{ in.}$

$$b' = 2.76 \text{ in.} - 0.75 \text{ in.}/2 = 2.38 \text{ in.}$$

$$a' = 1.93 \text{ in.} + 0.75 \text{ in.}/2 = 2.30 \text{ in.}$$

$$\rho = b'/a' = 2.38 \text{ in.}/2.30 \text{ in.} = 1.03$$



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Shear and Axial Example (cont.)

Prying Action (cont.)

$$t_c = \sqrt{\frac{4(29.6 \text{ kips})(2.38 \text{ in.})}{0.9(2.83 \text{ in.})(58 \text{ ksi})}} = 1.38 \text{ in.}$$

t_c is the material thickness required to develop the design bolt tension $B = 29.6$ kips. Any greater material thickness will not increase the connection capacity. It just wastes material.



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Shear and Axial Example (cont.)

Prying Action (cont.)

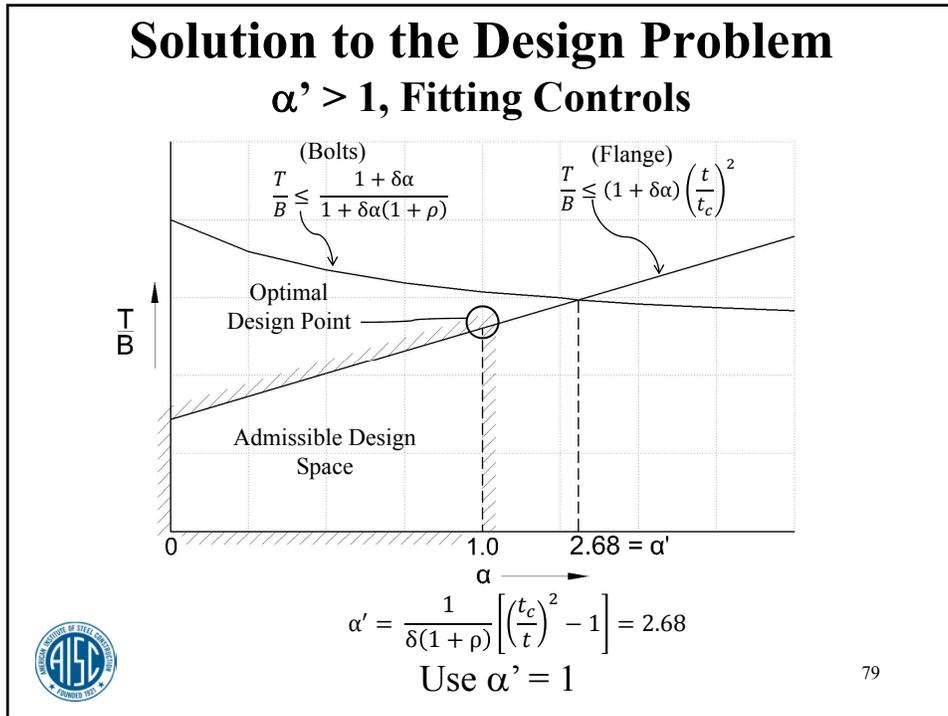
$$\alpha' = \frac{1}{0.713(1+1.03)} \left[\left(\frac{1.38 \text{ in.}}{0.625 \text{ in.}} \right)^2 - 1 \right] = 2.68 > 1.0$$

Use $\alpha' = 1.0$



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Shear and Axial Example (cont.)

Prying Action (cont.)

Completing the solution:

$$T_{avail} = 29.6 \text{ k} \left(\frac{0.625 \text{ in.}}{1.38 \text{ in.}} \right)^2 (1 + 0.713) = 10.4 \text{ kips / bolt}$$

$$T_{avail} = 10.4 \text{ kips} > 6.5 \text{ kips OK}$$

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Shear and Axial Example (cont.)

The prying action calculations for this example are now complete. For information, the values of α , the true moment ratio, and q , the prying force will be calculated.

$$\alpha = \frac{1.0}{0.713} \left(\frac{6.5 \text{ kips}}{29.6 \text{ kips}} \left(\frac{1.38 \text{ in.}}{0.625 \text{ in.}} \right)^2 - 1 \right) = 0.099$$

$$q = 29.6 \text{ kips} \left[(0.713)(0.099)(1.03) \left(\frac{0.625 \text{ in.}}{1.38 \text{ in.}} \right)^2 \right] = 0.441 \text{ kips}$$



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Shear and Axial Example (cont.)

Is $T + q < B$?

Is $6.5 \text{ kips} + 0.441 \text{ kips} = 6.94 \text{ kips} < 29.6 \text{ kips}$?

Yes! It always will be. The prying force q is implicitly included in the prying calculations. The value q is **never** explicitly required for *AISC Manual* calculations, except for fatigue (see AASHTO for fatigue)



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Shear and Axial Example (cont.) Design Algorithm

The solution to the analysis algorithm resulted in $T_{avail} = 10.4$ kips per bolt.

Suppose we now want to determine what thickness of angle is required to carry this tension of 10.4 kips per bolt?



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Shear and Axial Example (cont.) Design Algorithm

So, with $T = 10.4$ kips, what t is required?

Using the design algorithm,

$$\beta = \frac{1}{\rho} \left(\frac{B}{T} - 1 \right) ; \quad \beta = \frac{1}{1.03} \left(\frac{29.6 \text{ kips}}{10.4 \text{ kips}} - 1 \right) = 1.79$$



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Shear and Axial Example (cont.) Design Algorithm

Since $\beta > 1$, set $\alpha' = 1$,

$$t_{\min} = 1.38 \sqrt{\frac{10.4 \text{ kips}}{29.6 \text{ kips}}} \sqrt{\frac{1}{1+0.713}} = 0.625 \text{ in.}$$



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Shear and Axial Example (cont.)

Note that the angles are in fact 5/8 inch thick.

So, you can see that the Analysis and Design algorithms give the same result.

They are essentially 'reciprocals' of each other.



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Shear and Axial Example Slip-Critical Connection

The following is abstracted from a paper by myself and Larry Muir, *AISC Engineering Journal*, 2012.

The interaction equation for slip critical (SC) connections is given in *AISC Specification* sections J3.8 and J3.9:

$$\phi r'_v = \phi r_v \left(1 - \frac{T}{T_e} \right); T \leq \min \{ \phi r_t, T_e \}$$



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Shear and Axial Example Slip-Critical Connection

$$\phi r'_v = \phi r_v \left(1 - \frac{T}{T_e} \right); T \leq \min \{ \phi r_t, T_e \}$$

where: $\phi r'_v$ = bolt design strength as reduced by the applied tension T

T_e = expected mean bolt pretension = $D_u T_b$

T_b = bolt pretension, *AISC Specification* Table J3.1

T = applied tension per bolt

ϕr_v = bolt shear design strength, *Manual* Table 7-3

ϕr_t = bolt tension design strength, *Manual* Table 7-2



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Shear and Axial Example (cont.) Slip-Critical Connection

$$\phi r'_v = \phi r_v \left(1 - \frac{T}{T_e} \right); T \leq \min \{ \phi r_t, T_e \}$$

The term $T \leq \min \{ \phi r_t, T_e \}$ is not part of the AISC *Specification*. It is necessary because for A325 bolts, the bolt tensile strength is based on $F_u = 120$ ksi, whereas T_e is based on an ASTM tensile strength of 105 ksi for bolts of diameter greater than 1 inch.

Thus, for 1-1/8" A325 bolts, $\phi r_t = 67.1$ kips and $T_e = 1.13 \times 56$ kips = 63.3 kips.

If $T > 63.3$ kips, which is possible, $(1 - T/T_e)$ is negative, which is impossible.



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Shear and Axial Example (cont.) Slip-Critical Connection

$$\phi r'_v = \phi r_v \left(1 - \frac{T}{T_e} \right); T \leq \min \{ \phi r_t, T_e \}$$

This interaction equation gives a reduced bolt shear strength caused by the bolt applied tension load, T . For bearing connections, the interaction equation gives a reduced bolt tension strength caused by the bolt shear. There is a reason for the two different forms of interaction equations.



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Shear and Axial Example (cont.) Slip-Critical Connection

For SC connections, all of the shear, until slip occurs, is carried by friction on the faying surfaces. Therefore, applied shear has no effect on the bolt tension strength, until slip occurs! On the other hand, any applied tension has an immediate effect on the connection shear strength because the faying surface compression is reduced with an accompanying reduction in the joint shear strength. The bolts have yet to see any shear load. It is all carried on the faying surface. This is why the SC interaction equation is written as the effect on shear strength that is caused by tension, rather than the effect on tension strength caused by shear as in the bearing joint interaction equation.



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Shear and Axial Example (cont.) Slip-Critical Connection Design Procedure for SC Joints

Step 1: Calculate the slip critical shear strength as reduced by the applied tension

$$\phi r'_v = \phi r_v \left(1 - \frac{T}{T_e} \right); T \leq \min \{ \phi r_t, T_e \}$$

Step 2: If $\phi r'_v < V$, where V is the shear load per bolt, the slip critical strength is insufficient, the connection fails. Use more or stronger bolts.

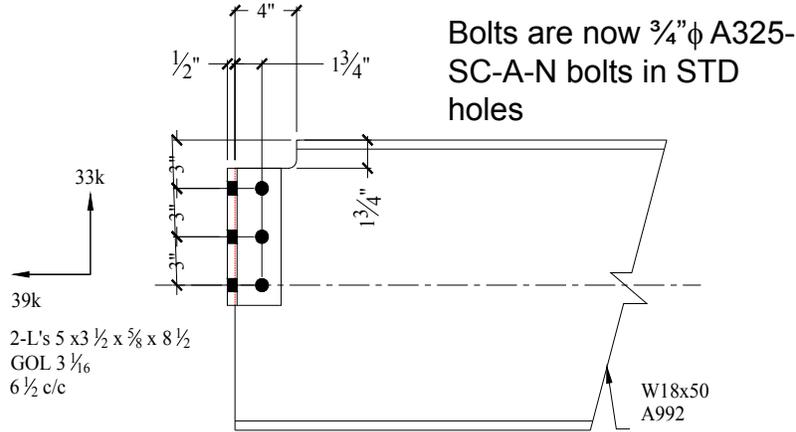
Step 3: If $\phi r'_v \geq V$, the connection is in the “pre-slip” state. The connection is checked for prying as a bearing connection. This completes the design calculations.



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Shear and Axial Example (cont.) Slip-Critical Connection



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Shear and Axial Example (cont.) Slip-Critical Connection

Let the bolts in the previous example be A325-SC-A-N, 3/4 inch diameter, with STD holes

$$\phi r_v = 9.49 \text{ kips/bolt, Manual Table 7-3}$$

$$V = 33.0 \text{ kips} / 6 \text{ bolts} = 5.5 \text{ kips/bolt}$$

$$T = 39.0 \text{ kips} / 6 \text{ bolts} = 6.5 \text{ kips/bolt}$$

$$T_e = 1.13 \times 28 \text{ kips} = 31.6 \text{ kips/bolt}$$

Step 1

$$\phi r'_v = \phi r_v \left(1 - \frac{T}{T_e} \right); T \leq \min \{ \phi r_t, T_e \}$$



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Shear and Axial Example (cont.) Slip-Critical Connection

Step 1:

$$\phi r'_v = \phi r_v \left(1 - \frac{T}{T_e} \right); T \leq \min \{ \phi r_t, T_e \}$$

$\phi r_t = 29.8$ kips/bolt, *Manual* Table 7-2

$T = 6.5$ kips/bolt $\leq \min \{ 29.8, 31.6 \} = 29.8$ kips/bolt **OK**

$$\phi r'_v = 9.49 \text{ kips} \left(1 - \frac{6.5 \text{ kips}}{31.6 \text{ kips}} \right) = 7.54 \text{ kips / bolt} > 5.5 \text{ kips / bolt}$$



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Shear and Axial Example (cont.) Slip-Critical Connection

Step 2: Since $7.54 \text{ kips} > 5.5 \text{ kips}$, the connection is satisfactory for slip. It now needs to be checked for bearing.

Step 3: The connection is in the “pre-slip” state. It now needs to be checked as a bearing connection. The calculations are the same as we have already done for this connection.

This completes this design example.



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Summary



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Summary

- Clips, shear plates, and end plates are commonly used at bracing connections
- Clips at bracing connections facilitate ease of fabrication
- Typically need to consider prying at clip connections to column flanges
- Shear plates at bracing connections facilitate ease of erection
- Shear plates eliminate the need to drill through thick column flanges
- End plates at bracing connections minimize pieces
- Less erection tolerance at end plate connections



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Summary (cont.)

- Two algorithms for prying were developed – one for analysis and one for design
- These were shown to be “reciprocals “ of each other
- The difference between α and α' was explained
- Interaction of shear and tension in bearing and slip-critical connections was explained
- Examples have been worked for the shear/tension interaction case since this must be considered when designing bracing connections to column flanges



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Questions?



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Thank You

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Survey at conclusion of webinar.

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