




**Night School 28:
Vertical Bracing
Connections**


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Vertical Bracing Connections, Session 3: Details and Prying Action
April 19, 2022 | William A Thornton



**Smarter.
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Steel.**



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Course Description

Vertical Bracing Connections

Bracing Connection Details and Prying Action

April 19, 2022

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.





Learning Objectives

1. List the advantages and disadvantages of three bracing connection details.
2. List the limit states for the three bracing details.
3. Describe the impact of prying action on certain bracing connection details.
4. Explain prying action through the presentation of a design example.



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April 19, 2022

William A. Thornton, corporate consultant to Cives Steel



**Smarter.
Stronger.
Steel.**

Vertical Bracing Connections

By: William Thornton, Rafael Sabelli, and Carol Drucker



9

Course Outline

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



10

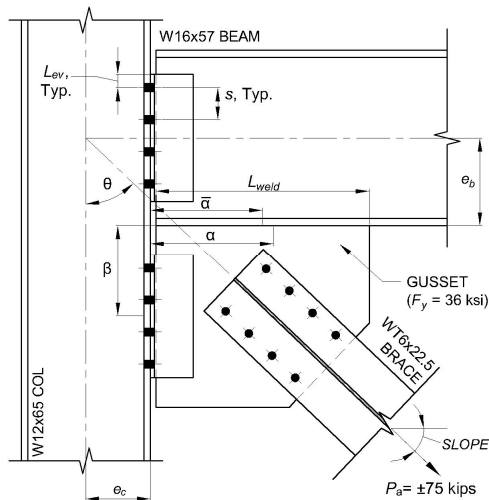
Session Outline

- Comparison of Bracing Connection Details
- Development of the 15th Edition *Manual* Prying Action Method
- Design Algorithms
- Examples of Prying Action in Bearing and Slip Critical Connections
- Summary



11

Example Connection Details



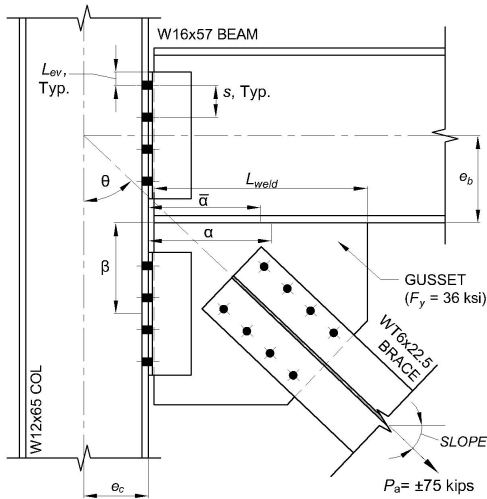
Connection with Clip Angles

Prying action must be considered.



12

Example Connection Details

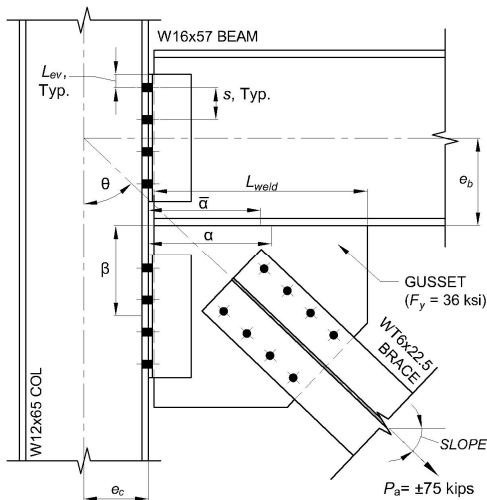


Connection with Clip Angles

- Advantages
 - Ease of fabrication
 - Commonly used
 - Easily resists low to moderately high transfer and H_c forces

13

Example Connection Details

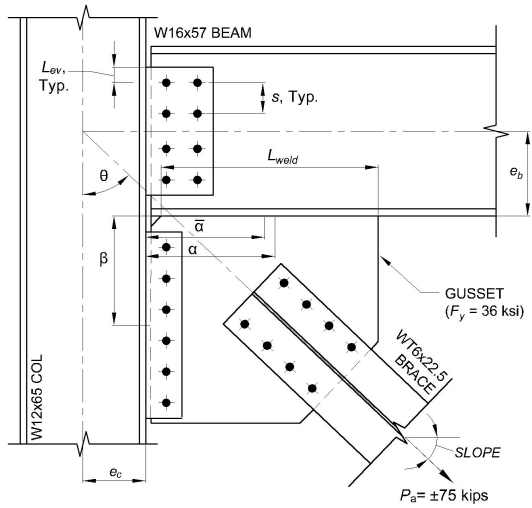


Connection with Clip Angles

- Disadvantages
 - May need to drill through thick column flanges
 - Difficult to use at column webs with stiffeners
 - Upper limit on available angle thickness ($1 \frac{3}{8}$ in.)
 - Prying of column flange may control strength

14

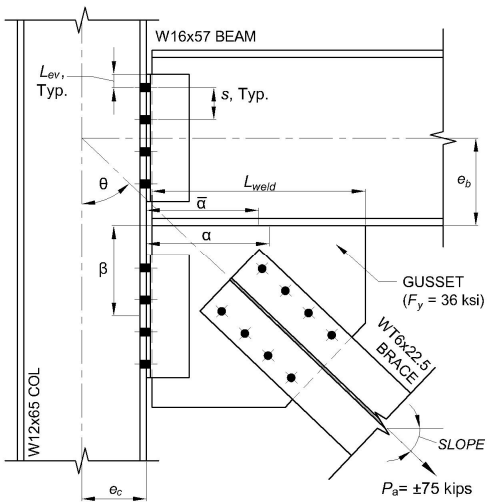
Example Connection Details



Connection with Shear Plates

15

Example Connection Details

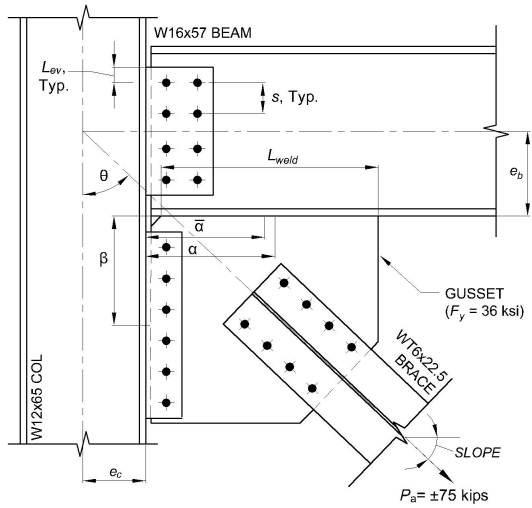


Connection with Clip Angles

Prying action must be considered.

16

Example Connection Details

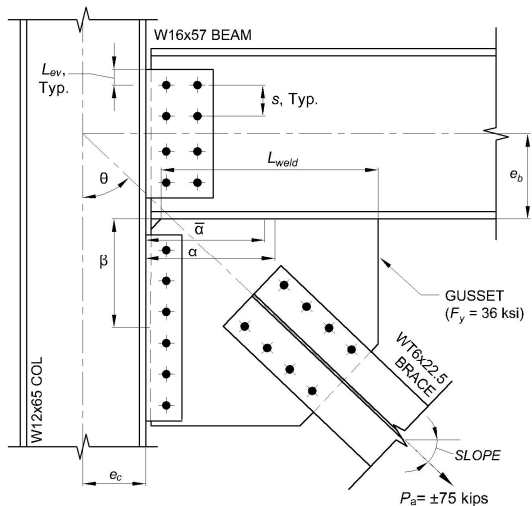


Connection with Shear Plates

- 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

17

Example Connection Details

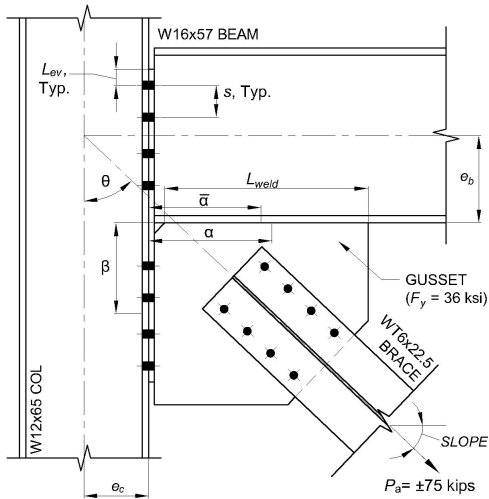


Connection with Shear Plates

- 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

18

Example Connection Details



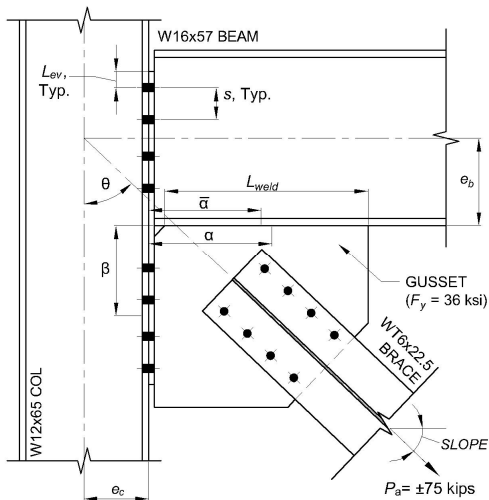
Connection with End-Plate

Prying action must be considered.



19

Example Connection Details



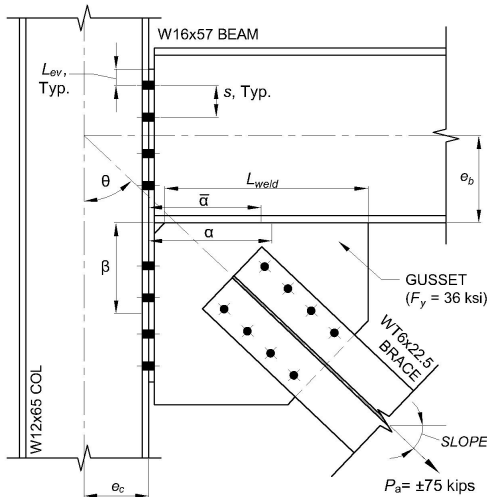
Connection with End-Plate

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



20

Example Connection Details



Connection with End-Plate

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

21

The Development of the 15th Edition *Steel Construction Manual* Method for Prying Action



22

The History and Development of the Current AISC Prying Action Solution Method



23

History of Prying in the AISC *Specification* and associated *Manual*

6th Edition *Manual* and *Specification*

- Nothing in *Specification*.
- Commentary to paragraph 1.5.2.1 says, “Any additional fastener tension resulting from prying action due to distortion of the connection details should be added to the stress calculated directly from the applied tension in proportioning fasteners for an applied tension force, using the specified working stresses. Depending upon the relative stiffness of the fasteners and the connection material, this prying action may be negligible or it may be a substantial part of the total tension in the fasteners.**”.

**The double asterisk refers to the 1956 ASCE Transactions, p. 1265.

- There is also nothing in the 6th Edition *Manual*.



24

History of Prying in the AISC *Specification* and associated *Manual*

7th Edition *Manual* and associated *Specification*

- *Specification* paragraph 1.5.2.1: “The applied load shall be the sum of the external load and any tension resulting from prying action produced by deformation of the connected parts.”
- The *Manual* had a procedure based on work of Birkemoe and Nair (1969). This procedure was restricted to specific bolt-plate combinations and did not work well unless these combinations or close variations were used. It generally resulted in thick plates (angles, WT flanges) and was not acceptable for general use.



25

History of Prying in the AISC *Specification* and associated *Manual*

8th Edition *Manual* and associated *Specification*

- *Specification* paragraph 1.5.2.1; “The applied load shall be the sum of the external load and any tension resulting from prying action produced by deformation of the connected parts.”
- The *Manual* had a design procedure based on the Struik-de Back (1969) model as presented in “*Guide to Design of Bolted and Riveted Joints*”, J.W Fisher and J.H.A. Struik, Wiley-Interscience, 1974. This book is referred to as the ‘**Bolt Guide**’. The *Manual* attempted a solution to the problem as the ‘Bolt Guide’ presented it, as shown on the next slide.



26

The original Bolt Guide Formulation
 Fisher and Struik, 1974
 Kulak, Fisher, and Struik, 1987

$$B = \phi F_{nt} A_b$$

$$B \geq T \left[1 + \frac{\delta \alpha}{1 + \delta \alpha} \frac{b'}{a'} \right]$$

$$t_{reqd} = \sqrt{\frac{4B_c a' b'}{p \phi F_y (a' + \delta \alpha (a' + b'))}}$$

If $\alpha < 1.0$, $B_c = B$
 If $\alpha \geq 1.0$, use

$$\alpha = 1, B_c = T \left[1 + \frac{\delta}{1 + \delta} \frac{b'}{a'} \right]$$

What is wrong with this formulation?



27

The original Bolt Guide Formulation
 Fisher and Struik, 1974
 Kulak, Fisher, and Struik, 1987

$$B = \phi F_{nt} A_b$$

$$B \geq T \left[1 + \frac{\delta \alpha}{1 + \delta \alpha} \frac{b'}{a'} \right]$$

$$t_{reqd} = \sqrt{\frac{4B_c a' b'}{p \phi F_y (a' + \delta \alpha (a' + b'))}}$$

If $\alpha < 1.0$, $B_c = B$
 If $\alpha \geq 1.0$, use

$$\alpha = 1, B_c = T \left[1 + \frac{\delta}{1 + \delta} \frac{b'}{a'} \right]$$

What is wrong with this formulation?
 There is no way provided to calculate α .



28

The original Bolt Guide Formulation
 Fisher and Struik, 1974
 Kulak, Fisher, and Struik, 1987

$$B = \phi F_{nt} A_b$$

$$B \geq T \left[1 + \frac{\delta \alpha}{1 + \delta \alpha} \frac{b'}{a'} \right]$$

$$t_{reqd} = \sqrt{\frac{4B_c a' b'}{p \phi F_y (a' + \delta \alpha (a' + b'))}}$$

If $\alpha < 1.0$, $B_c = B$
 If $\alpha \geq 1.0$, use

$$\alpha = 1, B_c = T \left[1 + \frac{\delta}{1 + \delta} \frac{b'}{a'} \right]$$

The key to the solution of this problem is α .
 What is α ?



29

What is α ?

- α is the actual ratio of the fitting moment at the bolt line to that at the stem line.

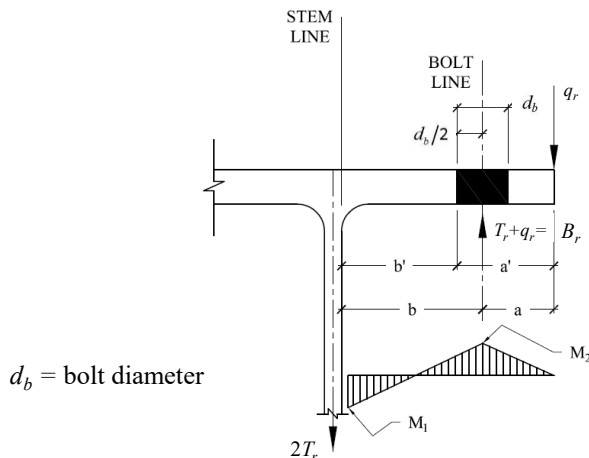
$$\alpha = \frac{M_2}{\delta M_1}$$

δ is the ratio of the flange area at the bolt line to that at the stem line.



30

Prying Action – Definition of α



31

History of Prying in the AISC *Specification* and associated *Manual*

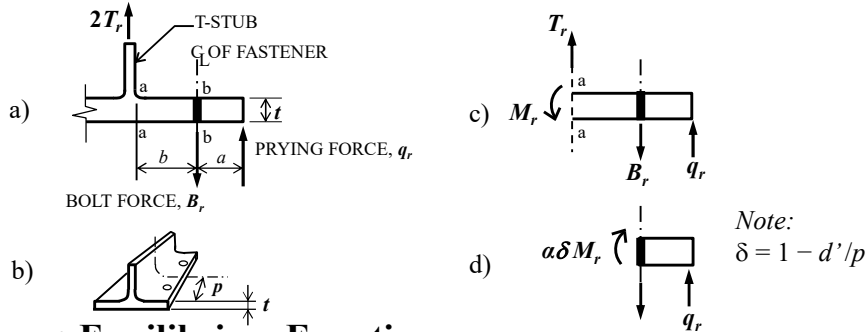
8th Edition *Manual* and associated *Specification*-continued

- The *Manual* solution to the prying action problem was unsatisfactory. You basically had to know the solution to calculate α , so you just verified that the solution you already had was satisfactory. Kind of a ‘circular’ calculation. This circular calculation gave rise to the procedure which will now be presented. This procedure, based on my paper, “Prying Action, A General Treatment”, *AISC Engineering Journal*, 1985, is the basis for the prying action solution method used in every AISC *Manual* since the 8th Edition *Manual*. This includes the 9th ASD, the 1st LRFD, the 2nd LRFD, the 3rd LRFD, and the 13th, 14th, 15th, and the forthcoming 16th Edition combined ASD/LRFD *Manuals*.



32

Derivation of Prying Equations (Equilibrium and Limit States)



• **Equilibrium Equations**

$$M_r - T_r b + q_r a = 0$$

$$T_r + q_r - B_r = 0$$

$$q_r a - \alpha \delta M_r = 0$$

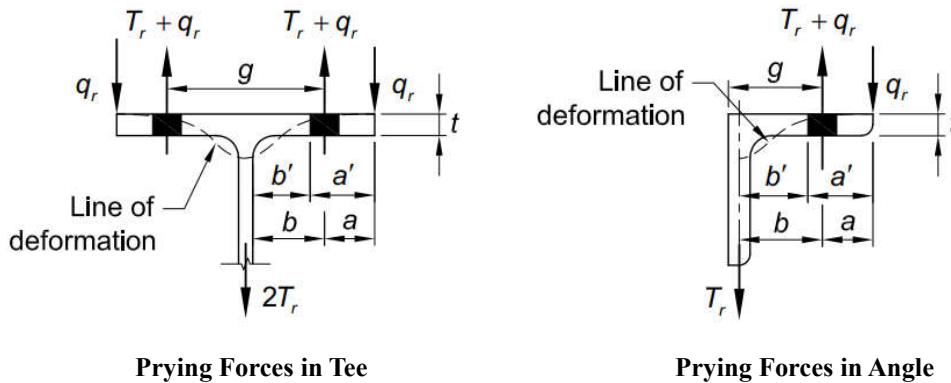
where:

- 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



Prying Action - General

• *Manual Prying Action Terminology*



Prying Forces in Tee

Prying Forces in Angle

(from AISC Manual Figure 9-4)



What is α ?

- α is the actual ratio of the fitting moment at the bolt line to that at the stem line.

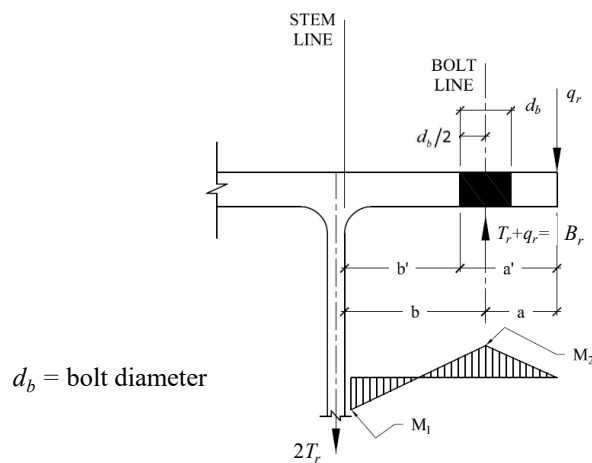
$$0 \leq \alpha = \frac{M_2}{\delta M_1} \leq 1$$



35

Prying Action - General

- Manual Prying Action Terminology*



36

Re-arranging the Equilibrium Equations

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

$$\frac{T_r b'}{1 + \delta\alpha} = M_r$$

$$T_r \left(1 + \frac{\delta\alpha}{1 + \delta\alpha} \rho \right) = B_r$$



37

Introduce the Limit States

- For the flange

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

- For the bolts

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



38

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.



39

Introduce the Limit States

- For the flange

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

- For the bolts

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



40

Prying Action Terminology

Introduce the quantity t_c

$$t_c = \sqrt{\frac{4(B_c)(b')}{\phi(p)(F_u)}} \quad \text{This is *Manual* Equation (9-26a)}$$

t_c is the material thickness required to develop the design bolt tensile strength B_c . Any greater material thickness will not increase connection capacity.

t_c is a property of the system. It has the same numerical value in both LRFD and ASD formulations



41

Dimensionless Form of the Analysis Equations

• Introducing t_c , the analysis inequations are

• For the flange $\frac{T_r}{B_c} \leq (1 + \delta\alpha) \left(\frac{t}{t_c}\right)^2$ Inequality 1

• For the bolts $\frac{T_r}{B_c} \leq \frac{1 + \delta\alpha}{1 + \delta\alpha(1 + \rho)}$ Inequality 2



42

Dimensionless Form of the Analysis Equations

- All solutions of the prying problem must satisfy the inequalities

$$\frac{T_r}{B_c} \leq (1 + \delta\alpha) \left(\frac{t}{t_c}\right)^2$$

$$\frac{T_r}{B_c} \leq \frac{1 + \delta\alpha}{1 + \delta\alpha(1 + \rho)}$$



43

The current *AISC Manual*, 15th Edition, has Three Prying Action Solutions

- Solution I
 - This solution provides for joint separation
 - There is no prying action
- Solution II
 - Analysis
- Solution III
 - Design



44

Solutions to the Prying Problem in the Manual

- The current AISC *Manual* prying action solutions II and II are optimal solutions. They provide the least required material thickness (angle leg, plate, or flange thickness) for a given load (Solution III) or the greatest tension capacity for a given material thickness (Solution II).
- These are lower bound theorem solutions.
- What is the lower bound theorem? This has been discussed in Sessions 1 and 2.
- The first solution (Solution I) given in the *Manual* is also a lower bound solution, but it is not optimal in terms of strength or material.
- It can be considered “optimal” in terms of design time.



45

Manual Prying Solutions- There are three solutions provided

Solution I- No Prying

- With no prying, $q = 0$, hence α equals 0
- and inequality 2 becomes

$$\frac{T_r}{B_c} \leq 1$$

which must be satisfied,

- and inequality 1 becomes

$$t = t_{np} \geq \sqrt{\frac{T_r}{B_c}} t_c = \sqrt{\frac{4T_u b'}{\phi p F_u}}$$

This is *Manual*
 Equation (9-17a)



46

Manual Prying Solutions –

Solution II Analysis

- Given: t, a', b', p, F_u, B_c (the connection properties)
- Find the maximum tensile capacity of the connection that satisfies the two inequalities

$$\frac{T_r}{B_c} \leq (1 + \delta\alpha) \left(\frac{t}{t_c}\right)^2$$

$$\frac{T_r}{B_c} \leq \frac{1 + \delta\alpha}{1 + \delta\alpha(1 + \rho)}$$



47

Solution II

- Set the two inequalities for $\frac{T_r}{B_c}$ on the previous slide equal to each other and
- Solve for α . The result is α'

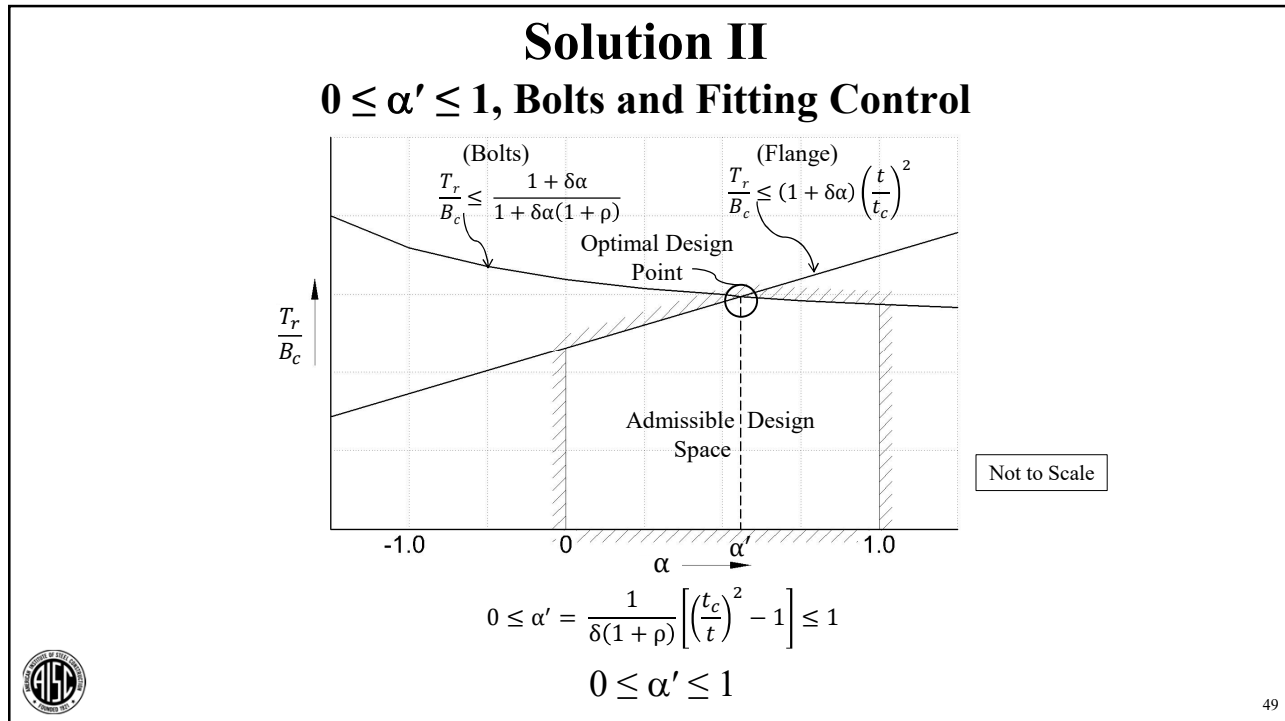
$$\alpha' = \frac{1}{\delta(1+\rho)} \left[\left(\frac{t_c}{t}\right)^2 - 1 \right]$$

This is *Manual* Equation (9-28)

α' is a calculational “stand-in” for α . It is used to determine the design space.



48



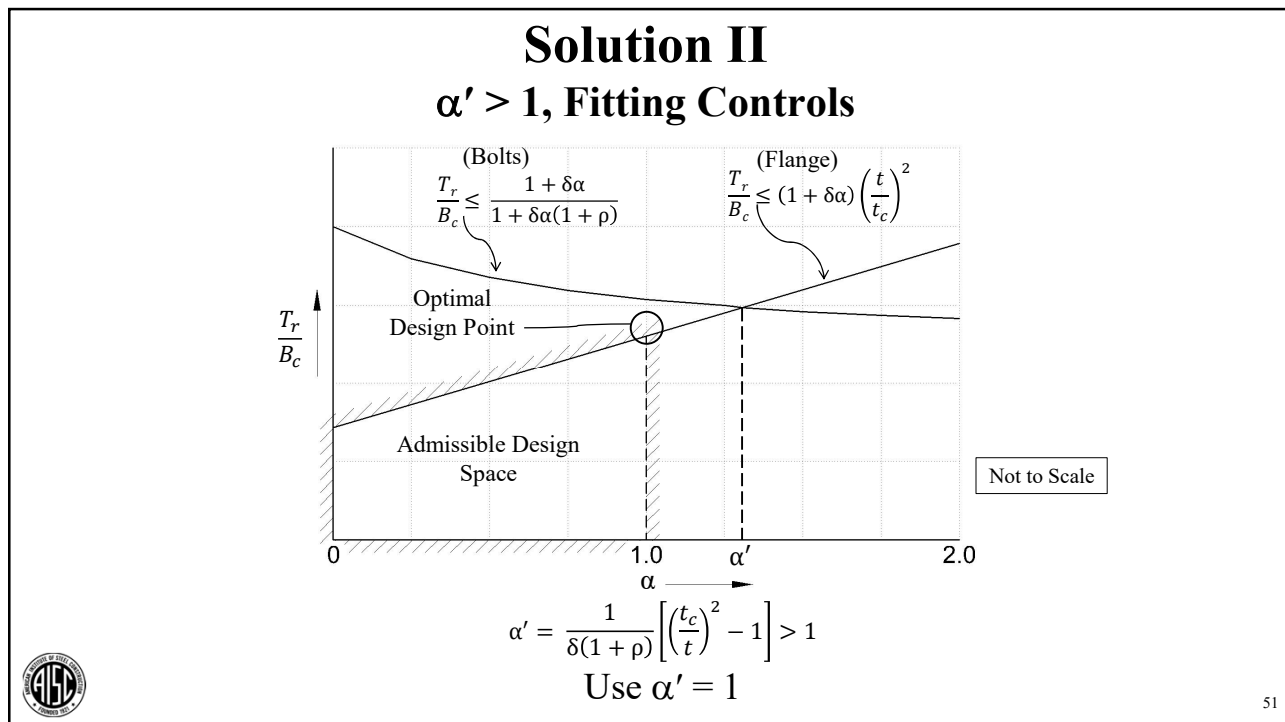
Prying Action Solution II

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

$$T_c = B_c \left(\frac{t}{t_c}\right)^2 (1 + \delta\alpha')$$
 This is *Manual* Equation (9-27)

- The bolts and the fitting both control.
- **This** is the optimal solution, i.e., optimal design

50

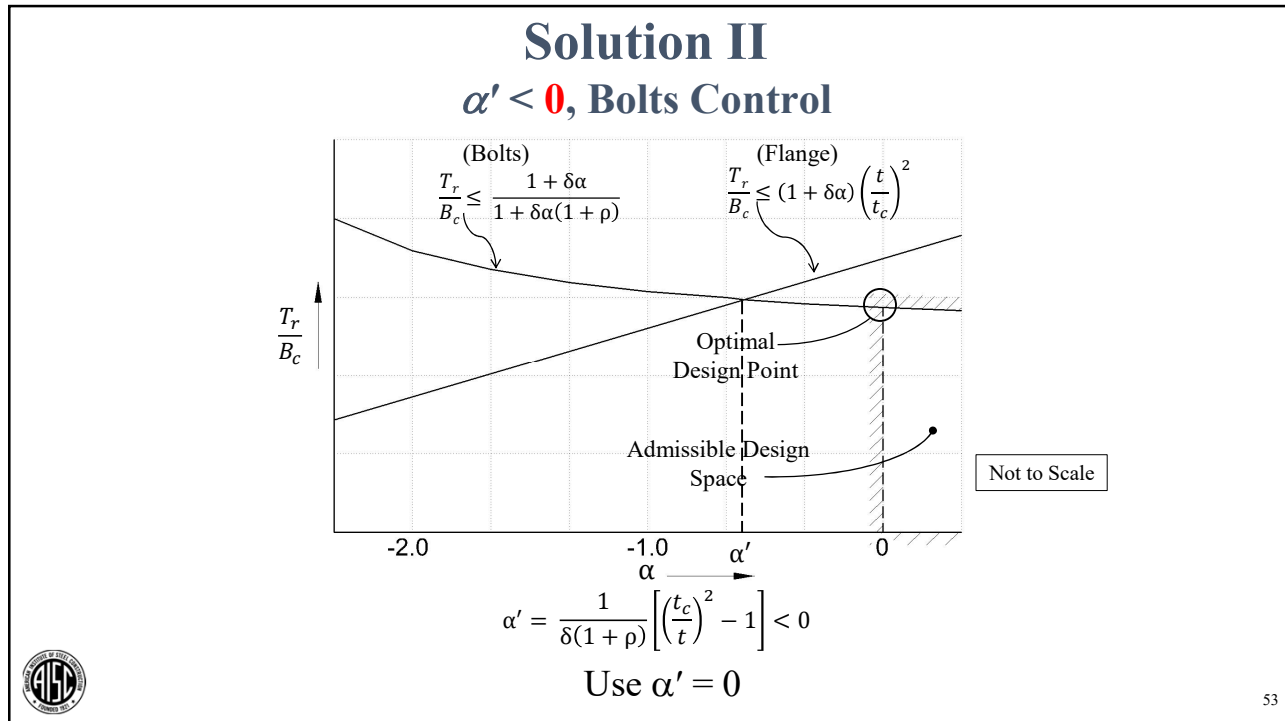


Manual Solution II- continued

- When $\alpha' > 1$ The fitting controls

$$T_c = B_c \left(\frac{t}{t_c}\right)^2 (1 + \delta)$$

52



Manual Solution II -continued

- When $\alpha' < 0$ The bolts control
- $T_c = B_c$

54

Manual Solution III Design

- Given: T_r , a' , b' , p , F_u , and B_c (the connection properties)
- Find: the smallest value of t
- Such that: Inequalities 1 and 2 are satisfied
- $\frac{T_r}{B_c} \leq (1 + \delta\alpha) \left(\frac{t}{t_c}\right)^2$
- $\frac{T_r}{B_c} \leq \frac{1 + \delta\alpha}{1 + \delta\alpha(1 + \rho)}$
- Solution:
 - Check $T_r \leq B_c$
 - If so, proceed; if not, use more or stronger bolts



55

Manual Solution III (cont.)

- Then calculate $\beta = \frac{1}{\rho} \left(\frac{B_c}{T_r} - 1 \right)$ This is *Manual* Equation (9-21)
- If $\beta \geq 1$, set $\alpha' = 1$
- If $0 \leq \beta < 1$, set $\alpha' = \min \left\{ \frac{1}{\delta} \left(\frac{\beta}{1 - \beta} \right), 1 \right\}$
- β is the “prying ratio”



56

Manual Solution III

- With the determined value of α' , calculate

$$t_{\min} = t_c \sqrt{\left(\frac{T_r}{B_c}\right)\left(\frac{1}{1 + \delta\alpha'}\right)} = \sqrt{\frac{4T_u b'}{\phi p F_u (1 + \delta\alpha')}} \quad \text{This is *Manual* Equation (9-19)}$$



57

Prying Action Exercises

- Show that Methods II and III give reciprocal solutions, i.e., if Method II with a given fitting thickness yields a certain capacity T_c , show that using this capacity as a required load will produce the fitting thickness that was a given in Method II.
- Derive *Manual* Equations (9-21) and (9-19). These are the basis for *Manual* Method III.



58

An Example

This example will show the equivalence of three solution methods

- The 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.

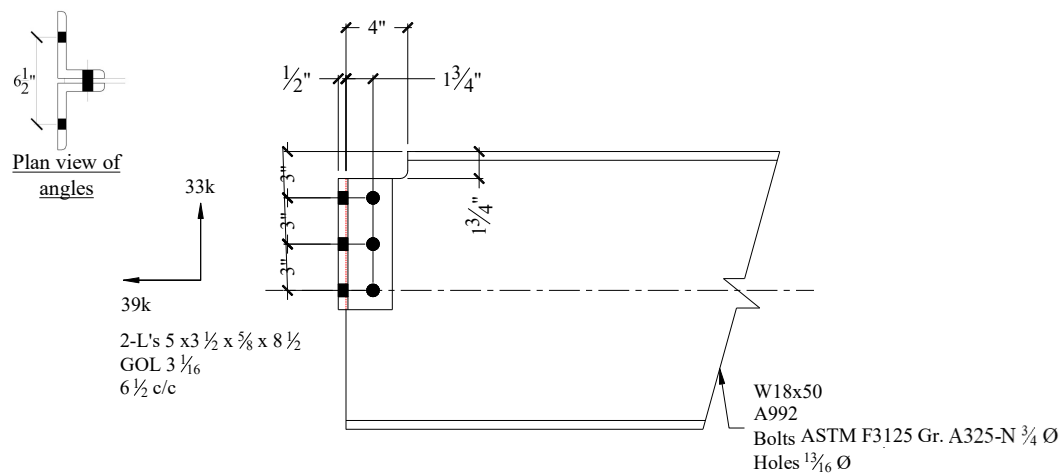


59

Part 1: Shear and Axial Example

Bearing type connection

Use Method II – Analysis



60

Shear and Axial Example Bearing Bolts

$\frac{3}{4}$ in. ϕ ASTM F3125 Grade A325-N Bolts

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

The shear/bolt $V_r = 33/6 = 5.5$ kips

Bolt shear design strength;

$\phi r_v = 17.9$ kips/bolt in single shear per Table 7-1 or *Spec.* Table J3.2

Bolt shear strength of 17.9 kips > 5.5 kips OK



61

Shear and Axial Example Bearing Bolts

$\frac{3}{4}$ in. ϕ ASTM F3125 Grade A325-N Bolts

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

The tension/bolt $T_r = 39$ kips/6 = 6.5 kips/bolt

The bolt tension design strength;

$\phi r_t = 29.8$ kips/bolt – *Manual* Table 7-2 or *Spec.* Table J3.2

Bolt tensile strength of 29.8 kips > 6.5 kips OK



62

Shear and Axial Example Bearing Bolts

$\frac{3}{4}$ in. ϕ ASTM F3125 Grade 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

$$V_r > \phi r_v \quad \text{or} \quad T_r > \phi r_t$$

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



63

Shear and Axial Example Bearing Bolts

$\frac{3}{4}$ in. ϕ ASTM F3125 Grade A325-N Bolts

Shear – Tension Interaction

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

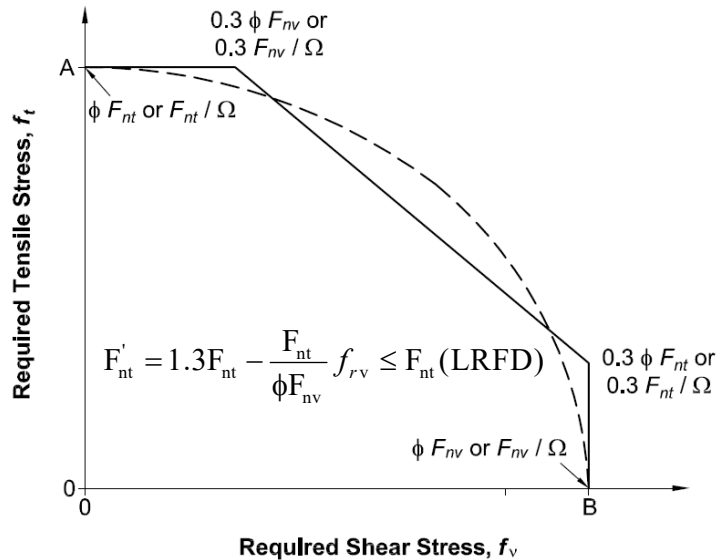
$$F'_{nt} = 1.3F_{nt} - \frac{F_{nt}}{\phi F_{nv}} f_{rv} \leq F_{nt}$$

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



64

Combined Shear and Tension - Bearing



65

Shear and Axial Example Bearing Bolts

$\frac{3}{4}$ in. ϕ ASTM F3125 Grade A325-N Bolts
 Shear – Tension Interaction

This is exactly the form needed for the prying calculations,

$$B_c = \phi F_{nt} A_b - \text{no shear}$$

$$B_c = \phi F'_{nt} A_b - \text{with shear}$$



66

Shear and Axial Example

Shear and Tension must be considered

Bolt shear / tension interaction (J3.7)

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

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



67

Shear and Axial Example

Interaction

Tension Capacity Per Bolt = B_c

$$B_c = \phi F'_t A_b$$

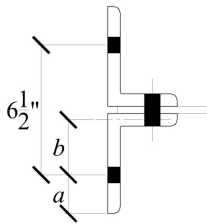
$$B_c = 67.0 \text{ ksi} \times 0.442 \text{ in.}^2 = 29.6 \text{ kips/bolt}$$

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



68

Shear and Axial Example (cont.)



Geometry

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

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

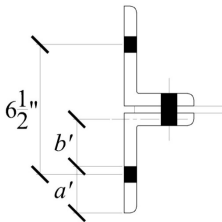
$$p = 8.5 \text{ in.}/3 \text{ bolts} = 2.83 \text{ in. (average bolt spacing)}$$

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



69

Shear and Axial Example



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 $a = 1.93 \text{ in.}$

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

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

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



70

Shear and Axial Example

Prying action (continued)

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

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



71

Shear and Axial Example

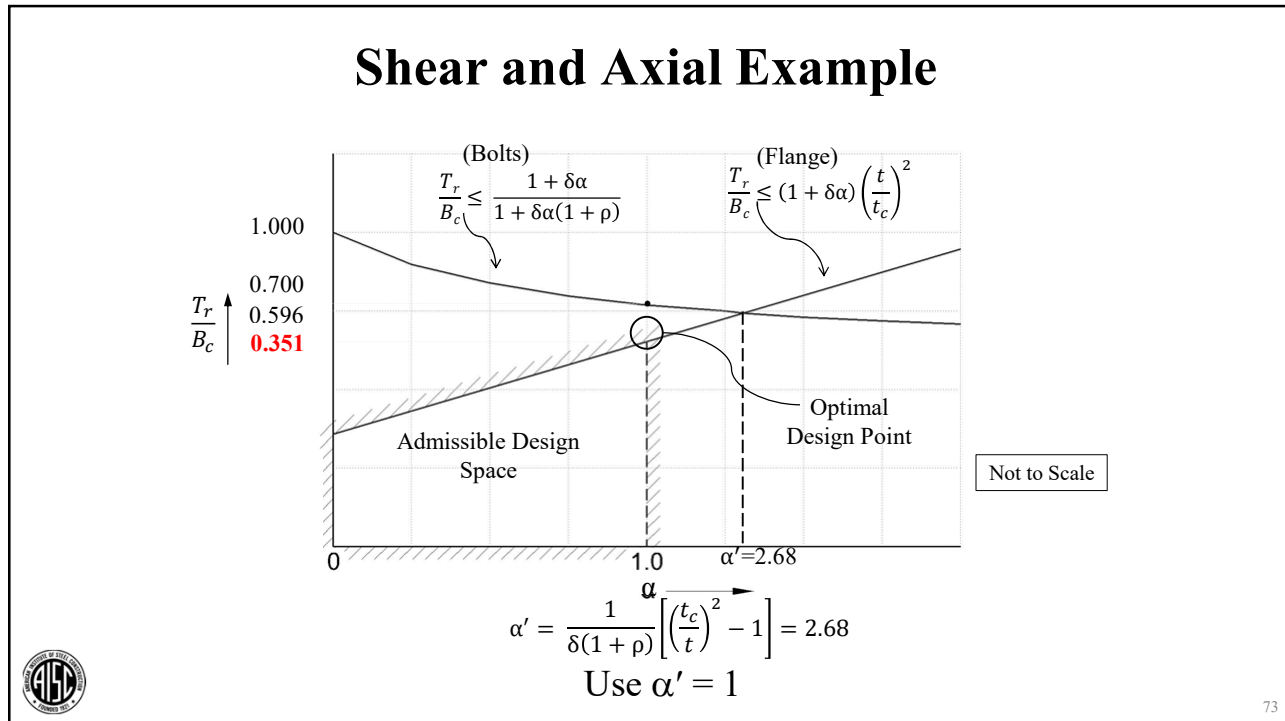
Prying action (continued)

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

Use $\alpha' = 1.0$



72



Shear and Axial Example

Prying action (continued)

Completing the solution:

From the previous slide

$$\frac{T_c}{B_c} = 0.351$$

$$T_c = 0.351B_c = 0.351(29.6) = 10.4 \text{ kips}$$

74

Shear and Axial Example

Prying action (continued)

*Completing the solution
formally:*

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

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



75

Calculation of the Prying Force q_r

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

This is *Manual* Equation 9-25

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

This is *Manual* Equation 9-24

- The prying force q_r 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



76

α VS. α'

For calculation purposes, α can be written as

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

- 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_r , if desired.



77

What Is α' ?

α' is the value of α for which
the design tension per bolt
 T_c is a maximum



78

Shear and Axial Example

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.

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

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

Is $T_r + q_r < B_c$? 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_r is implicitly included in the prying calculations. The value q_r is **never** explicitly required for AISC *Manual* calculations.



79

Shear and axial Example Design Algorithm (Method III)

The solution to the analysis algorithm resulted in $T_c = 10.4 \text{ kips per bolt}$.

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



80

Shear and axial Example Design Algorithm Method III

So, with $T_r = 10.4$ kips, what t is required? Using the design algorithm,

$$\beta = \frac{1}{\rho} \left(\frac{B_c}{T_r} - 1 \right) \qquad \beta = \frac{1}{1.03} \left(\frac{29.6}{10.4} - 1 \right) = 1.79$$

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

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



81

Shear and Axial Example

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 exactly 'reciprocals' of each other.



82

Shear and Axial Example Method I

No prying Action *Manual* Equation 9-17a

Suppose you were given the design problem (Method III) just solved with a tension load of 10.4 kips/bolt. Will the angles $5 \times 3\frac{1}{2} \times \frac{5}{8}$ be satisfactory if the prying action calculations are avoided?

$$t_{np} = \sqrt{\frac{4T_r b'}{\phi p F_u}} = \sqrt{\frac{4(10.4)(2.38)}{0.9(2.83)(58)}} = 0.818 \text{ in.}$$

Without prying, the $\frac{5}{8}$ angles must be changed to $\frac{7}{8}$ angles.



83

Calculation of the Prying Force q_r

- 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, 2020*, paragraph 6.13.2.10.4.



84

Summary α vs. α'

Unlike α , the calculated value of α' does not need to be between 0 and 1. It is a “stand-in” parameter for α 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.

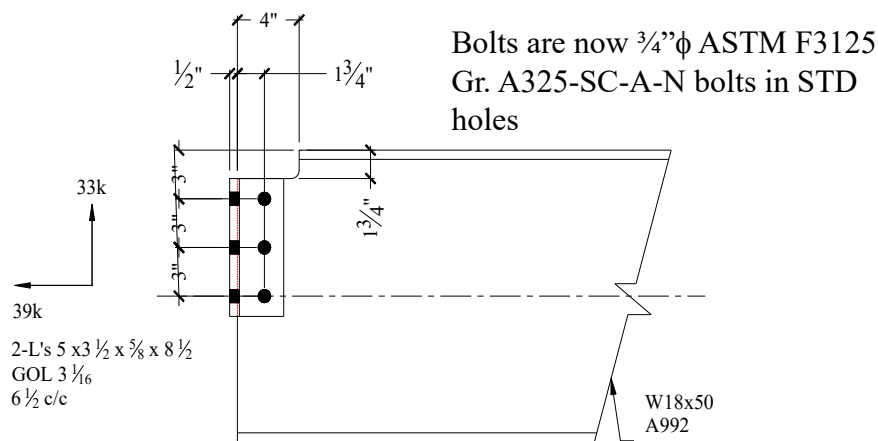
When α' is less than 0, the bolts control the design.

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



85

Part 2: Shear and Axial Example Slip Critical Connection



86

Shear and Axial Example Slip-Critical Connection

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

$$\phi r'_v = \phi r_v k_{sc}$$

$$k_{sc} = 1 - \frac{T_u}{D_u T_b n_b} \geq 0 \quad \text{Equation J3-5a}$$



87

Shear and Axial Example Slip-Critical Connection

and: $\phi r'_v$ = bolt design strength as reduced
by the applied tension T_u (also called T_r)

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

T_u = applied tension per bolt

ϕr_v = bolt shear design strength, *Manual* Table 7-1

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



88

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.



89

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

$$\phi r'_v = \phi r_v k_{sc}$$

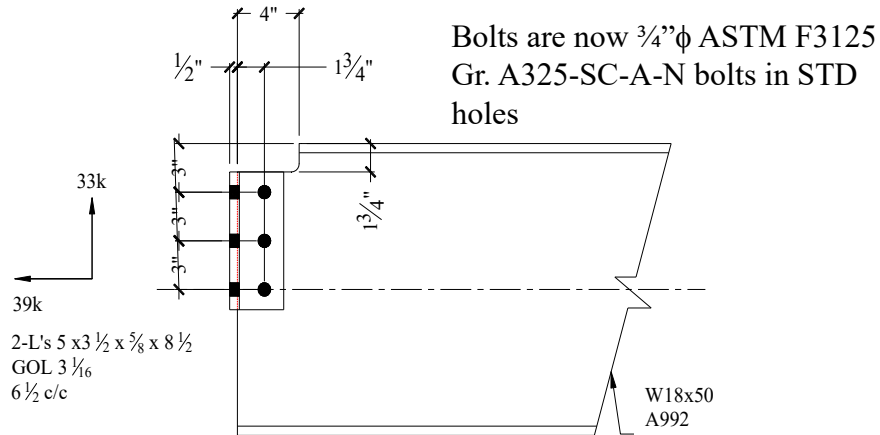
Step 2: If $\phi r'_v < V_r$, where V_r is the shear load per bolt, the slip critical strength is insufficient, the connection fails. Use more or stronger bolts.

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



90

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



91

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

Let the bolts in the previous example
 be ASTM F3125 Grade A325-SC-A-N,
 $\frac{3}{4}$ inch diameter, with STD holes

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

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

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

$$n_b = 1$$



92

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

Step 1:

$$k_{sc} = 1 - \frac{T_u}{D_u T_b n_b} = 1 - \frac{6.5}{1.13(28) \times 1} = 0.795$$

$$\phi r'_v = 9.49 \frac{\text{kips}}{\text{bolt}} \times (0.795) = 7.54 \frac{\text{kips}}{\text{bolt}}$$



93

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

Step 2: Since 7.54 kips > 5.5 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.

Connection shear capacity summary: Bearing = 10.4 kips/bolt
Slip critical = 7.54 kips/bolt



94

Summary



95

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



96

Summary (cont.)

- Three algorithms for prying were developed – one for analysis, one for design, and one to avoid prying
- The first two of 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



97

Further Research on Prying Action – Summary Concluded

- Prying Action -What needs yet to be done.
- Crossed beams- assumption that q_r is uniform is not correct. Original physical research on angles would add to our database
- WT and angle moment connections - q_r is not uniform but is assumed to be



98

Questions?



Vertical Bracing Connections, Session 3: Bracing Connection Details and Prying Action

April 19, 2022 | William A Thornton



Thank you!



AISC | Questions



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Course Resources

Event	Start Date
NS 13 8-Session Package: Night School 13 - Design of Industrial Buildings	1/30/2017 7:00:00 PM
NS 14 8-Session Package: Night School 14 - Fundamentals of Stability	6/5/2017 7:00:00 PM

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Night School Resources



Night School 13: Design of Industrial Buildings

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
NS13 - Design Criteria	1/30/2017 7:00:00 PM	Handouts	View Passcode: NS13DSN	Pass Score: 80	Pending
NS13 - Economic Considerations	2/6/2017 7:00:00 PM	Handouts	Available 02/08/2017 5pm EST	Available 02/08/2017 5pm EST	Pending
NS13 - Lateral Load Systems and Details	2/13/2017 7:00:00 PM	Handouts	Available 02/15/2017 5pm EST	Available 02/15/2017 5pm EST	Pending
NS13 - Preliminary Design Procedures	2/27/2017 7:00:00 PM	Handouts	Available 03/01/2017 5pm EST	Available 03/01/2017 5pm EST	Pending
NS13 - Crane Girder Design and Frame Analysis	3/6/2017 7:00:00 PM	Handouts	Available 03/08/2017 5pm EST	Available 03/08/2017 5pm EST	Pending
NS13 - Frame Member and Connection Design	3/13/2017 7:00:00 PM	Handouts	Available 03/15/2017 5pm EST	Available 03/15/2017 5pm EST	Pending
NS13 - Transfer Crane Girder & Longitudinal Bldg Bracing Dcn	3/27/2017 7:00:00 PM	Handouts	Available 03/29/2017 5pm EST	Available 03/29/2017 5pm EST	Pending
NS13 - Building Envelope and Bracing Design	4/3/2017 7:00:00 PM	Handouts	Available 04/05/2017 5pm EST	Available 04/05/2017 5pm EST	Pending

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- Weekly “quiz and recording” email.
- Weekly updates of the master quiz and attendance record, found at www.aisc.org/nightschool28. Scroll down to Quiz and Attendance records.
 - Updated on Friday mornings.

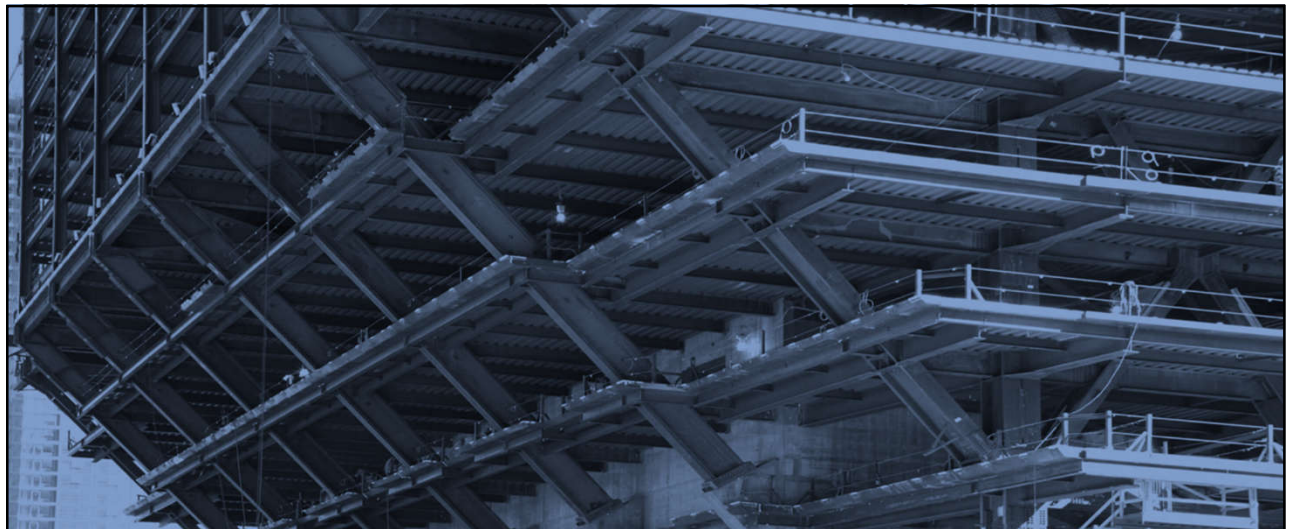


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