AISC Night School

Thank you for joining our live webinar today.
We will begin shortly. Please standby.

Thank you.

Need Help?
Call ReadyTalk Support: 800.843.9166

AISC Live Webinars

Today's audio will be broadcast through the internet.

Alternatively, to hear the audio through the phone, dial 888-504-7949.

Passcode: 956659

AISC Live Webinars

Today's live webinar will begin shortly.
Please standby.
As a reminder, all lines have been muted. Please type any questions or comments through the Chat feature on the left portion of your screen.

Today's audio will be broadcast through the internet.
Alternatively, to hear the audio through the phone, dial
888-504-7949.
Passcode: 956659

AISC Live Webinars

AISC is a Registered Provider with The American Institute of Architects Continuing Education Systems (AIA/CES). Credit(s) earned on completion of this program will be reported to AIA/CES for AIA members. Certificates of Completion for both AIA members and non-AIA members are available upon request.

This program is registered with AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation

AISC Live Webinars

Copyright Materials

Course Description

Session 6: November 14, 2017 – Moment Connections Part II.

This live webinar covers the basics of prying as needed for the design of connections where prying forces are a concern. Tee-stub-web bolted moment connections and end-plate moment connections are discussed. Column side limit states for these connections are presented. Design examples are included.

Learning Objectives

At the end of this program, participants will be able to:

- **Describe the characteristics of prying action.**
- **Describe the design steps of bolted tee stub moment connections.**
- **List the column side limit states for tee-stub-web moment connections.**
- **Describe the design methodologies in Design Guide 16: Flush and Extended Multiple-Row Moment End-Plate Connections.**

There's always a solution in steel.

Fundamentals of Connection Design

Session 6: Moment Connections – Part II

November 14, 2017

Presented by
Thomas M. Murray, Ph.D., P.E.
Emeritus Professor
Virginia Tech, Blacksburg, Virginia

structural STEEL

SCHEDULE

- October 03, 2017 Fundamental Concepts Part I
- October 10, 2017 Fundamental Concepts Part II
- October 17, 2017 Shear Connections Part I
- October 24, 2017 Shear Connections Part II
- November 07, 2017 Moment Connections Part I
- **November 14, 2017 Moment Connections Part II**
- **November 28, 2017 Introduction to Seismic Connections**
- **December 05, 2017 Bracing Connections and More**

VirginiaTech *Invent the Future*

9

MOMENT CONNECTIONS PART II

VirginiaTech *Invent the Future*

10

Lecturer: Tom Murray, P.E., PhD
Emeritus Professor, Virginia Tech

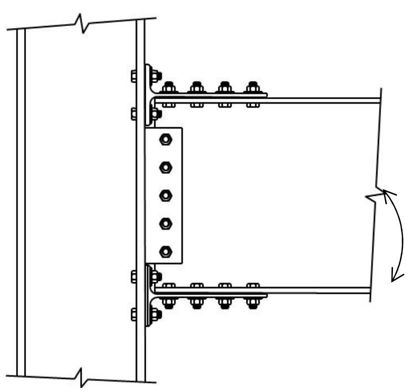
TOPICS

FR Moment Connections

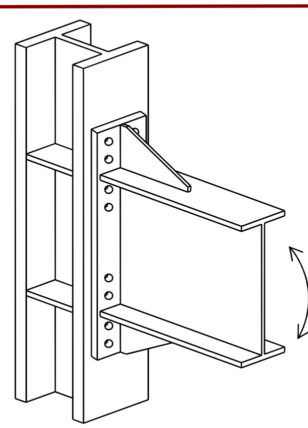
- Connections with Prying Forces
- Basics of Prying
- Tee-Stub / Web Bolted Connections
- Column Side Limit States
- End-Plate Moment Connections
- Design Examples

VirginiaTech Invent the Future 11

CONNECTIONS WITH PRYING FORCES



Tee-Stub/Web Bolted

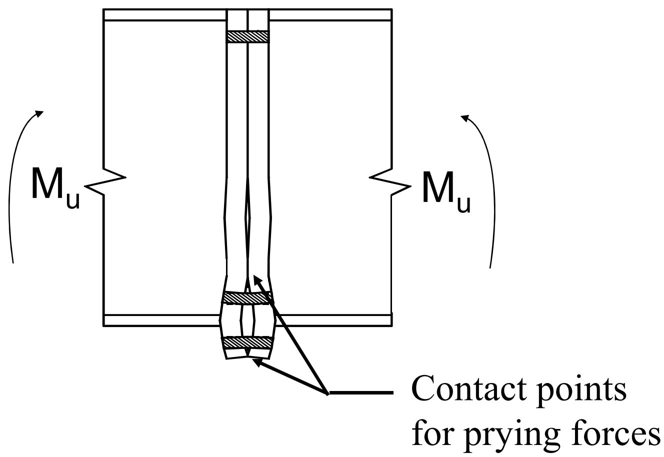


End-Plate Moment

VirginiaTech Invent the Future 12

Lecturer: Tom Murray, P.E., PhD
Emeritus Professor, Virginia Tech

Prying Forces



VirginiaTech
Invent the Future

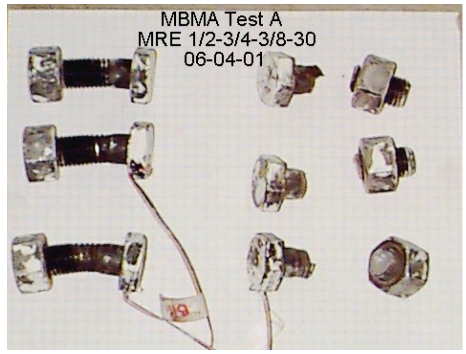
13

Prying Forces

VirginiaTech
Invent the Future

14

Prying Forces



VirginiaTech
Invent the Future

15

Prying Forces

Design Models

- "Prying Action" in *Manual* pages 9-10 to 9-14.
- "Kennedy Split-Tee" used for End-Plate Moment Connections.
- Both are basically the same but details differ.
- Nomenclature is entirely different.
- "Thick" Plate Behavior is recommended for Tee-Stub Connections (no prying force).

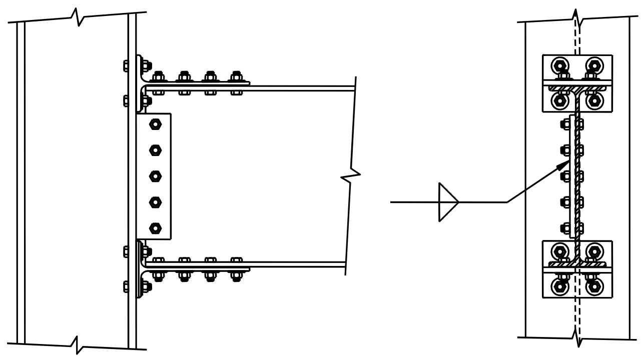
VirginiaTech
Invent the Future

16

Prying Forces

Flange Tee-Stub Bolted/Web Bolted

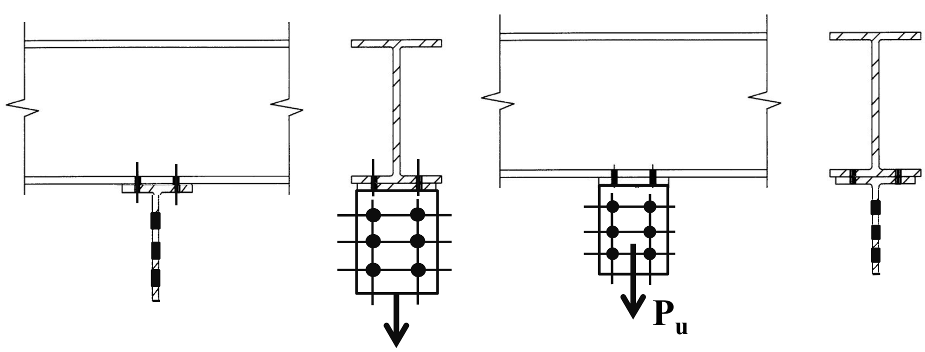
- Tee Stub → Bolted Hanger Connection



VirginiaTech
Invent the Future

17

Bolted Hanger Connections



New Limit States from *Manual* Design Model

- Tee Flange Bending
- Bolt Tension Rupture

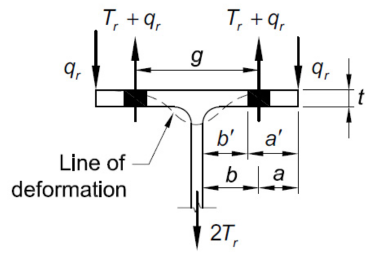
VirginiaTech
Invent the Future

18

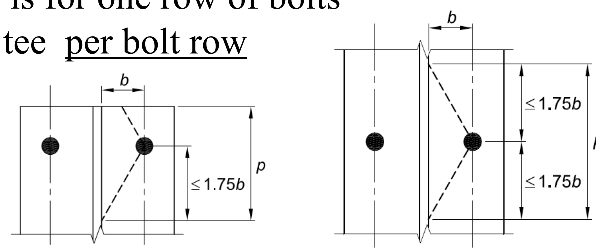
Bolted Hanger Connections

- Tee Flange Bending

  d_b = bolt diameter
  $a' = a + d_b/2$
  $b' = b - d_b/2$
  ρ(rho) $= b'/a'$



  Design model is for one row of bolts
  p = length of tee <u>per bolt row</u>



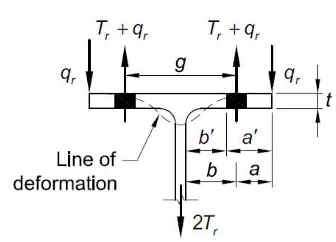
Bolted Hanger Connections

- Tee Flange Bending

  For LRFD (T_r and $q_r \Rightarrow T_u$ and q_u)

  $2T_u = 2r_{ut}$ = Required Strength per bolt row
  q_u = Prying Force
  $b_u = T_u + q_u = r_{ut} + q_u$ = Required Bolt Force
  $b_u \leq \phi r_{nt} = 0.75 r_{nt}$

  For "thick" plate behavior
  (no prying force) $q_u = 0$.



Bolted Hanger Connections

- Tee Flange Bending

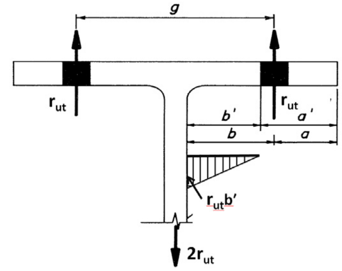
  "Thick" Plate Behavior

  No Prying Force: $q_u = 0$

  $M_u = r_{ut}\, b' \le \phi_b\, M_p$

  $\phi\ = 0.9$

  $M_p = F_u\, Z_x = F_u\, (p\, t_f^2/4)$



On substitution, the required no prying flange thickness is:

$$t_{np} = \sqrt{\frac{4\, r_{ut}\ b'}{\phi_b p\ F_u}}$$

Note: F_u not F_y

Bolted Hanger Connections

- Tee Flange Bending w/o Prying Summary

  Bolts:

  $\phi_t\ = 0.75$

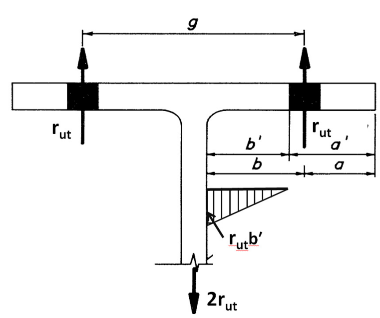
  $q_u = 0$

  $b_u = r_{ut} \le \phi_t r_{nt}$

  Flange:

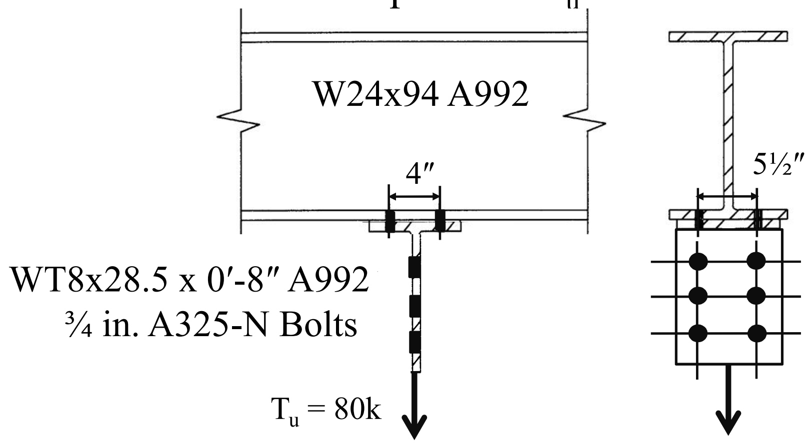
  $\phi_b = 0.9$

  $$t_{np}\ = \sqrt{\frac{4\ r_{ut}\ \ b'}{f_b p\ F_u}}$$



BOLTED HANGER CONNECTION EX.

Example: Determine if the hanger connection shown is adequate for P_u = 80k.

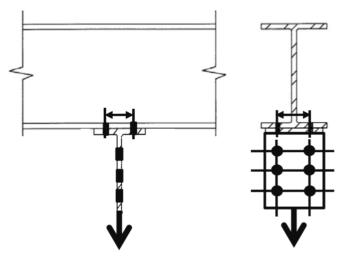


Bolted Hanger Connection Example

Limit States

WT:

1. Flange Bending,
2. Flange Shear Yielding
3. Flange Shear Rupture
4. Web Tension Yielding
5. Tension Rupture
6. Block Shear
7. Shear Transfer at Elements



Bolts:

8. Tension Rupture

Beam:

9. Flange Bending
10. Web Local Yielding

Bolted Hanger Connection Example

Properties

W24x94 t_f = 0.875 in.
b_f = 9.07 in
t_w = 0.515 in.
k_{design} = 1.38 in.

A992 F_y = 50 ksi
F_u = 65 ksi
A325 Bolts
F_{nt} = 90 ksi

WT8x28.5 b_f = 7.12 in.
t_f = 0.715 in.
t_w = 0.430in.

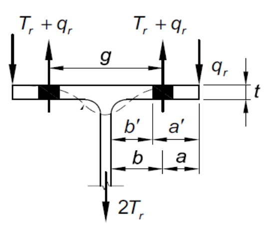
3/4 in. A325 Bolt
ϕr_u = 0.75 x 90 x 0.4418 = <u>29.8k</u>

VirginiaTech Invent the Future

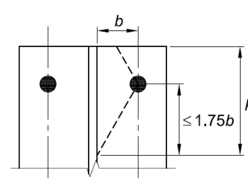
25

Bolted Hanger Connection Example

Tee-Stub Parameters



b = (g - t_w)/2 = (4.0 - 0.430)/2 = 1.79 in.
a = (b_f - g)/2 = (7.12 - 4)/2 = 1.56 in.
b′= b - d_b/2 = 1.79 - 0.75/2 = 1.42 in.
a′ = a + d_b/2 = 1.56 + 0.75/2 = 1.94 in.
L = length of tee = 8.0 in.
s = bolt spacing = 5.5 in.
s/2 = 5.5/2
= 2.75 in. < 1.75b = 1.75(1.79) = 3.13 in. OK
p = flange length/bolt
= s/2 + l_{eh} = 2.75 + (8.0 – 5.5)/2 = 4.0 in.

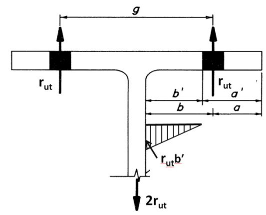


VirginiaTech Invent the Future

26

Bolted Hanger Connection Example

Required Tee Flange Thickness



$$t_{np} = \sqrt{\frac{4\ r_{ut}\ b'}{\phi_b p\ F_u}}$$ No Prying

$$= \sqrt{\frac{4 \text{ x } 20.0 \text{ x} 1.42}{0.9 \text{ x } 4.0 \times 65}}$$

$= 0.697$ in. < 0.715 in. for the WT8x28.5 <u>OK</u>

Check Bolt Strength

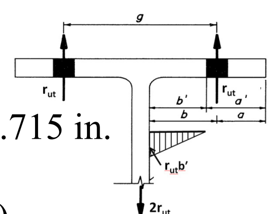
$B_u = r_{ut} = 80/4$
$= 20\text{k} \leq \phi r_n = 29.8\text{k}$ <u>OK</u>

VirginiaTech Invent the Future

27

Bolted Hanger Connection Example

Tee Flange Strength Checks



- Shear Yielding of Flange with $t_f = 0.715$ in.
  $\phi R_n = 1.0(0.6F_y)A_{gv}$
  $= 1.0(0.6 \text{ x } 50)\ (2 \text{ x } 8.0 \text{ x } 0.715)$
  $= 343$ k > 80 k <u>OK</u>
- Shear Rupture of Flange with $d_h' = 7/8$ in.
  $\phi R_n = 0.75(0.6F_u)A_{nv}$
  $= 0.75\ (0.6\text{x}65)\ (2)\ (8.0\text{–}2\text{x}0.875)\ (0.715)$
  $=$ <u>261 k</u> > 80 k <u>OK</u>

VirginiaTech Invent the Future

28

Lecturer: Tom Murray, P.E., PhD
Emeritus Professor, Virginia Tech

Bolted Hanger Connection Example

Required Beam Flange Thickness

W24x94 $b_f = 9.07''$ $t_f = 0.875''$ $t_w = 0.515''$

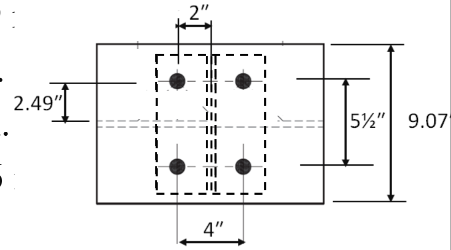
$b = (5.50 – 0.515)/2 = 2.49$

$b' = 2.49 – 0.75/2 = 2.12$ in.

$a = (9.07 – 5.5)/2 = 1.78$ in.

$p = 1.75(2.49) + 2.0 = 6.36$

Assuming no prying:



$$t_{req} = \sqrt{\frac{4\, r_{ut}\, b'}{\phi_b p\, F_u}} = \sqrt{\frac{4\ x20x2.12}{0.9x6.36x6\ 5}} = 0.675 \text{ in.} < t_f = 0.875\text{in.}$$

OK

VirginiaTech *Invent the Future* 29

Bolted Hanger Connection Example

Beam Flange Strength Checks

Shear Yielding and Shear Rupture are not beam flange limit states.

Beam Local Web Yielding

W24x94: $t_w = 0.515$ in.

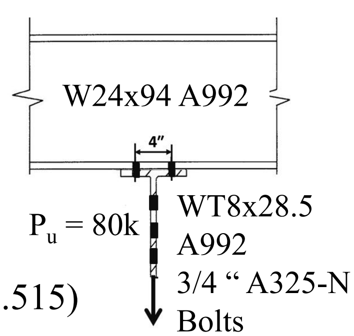
$k_{design} = 1.38$ in.

$\phi = 1.0$ $l_b = 4$ in.

$\phi R_n = 1.0\ (5k_{design} + l_b)F_{yw}\ t_w$

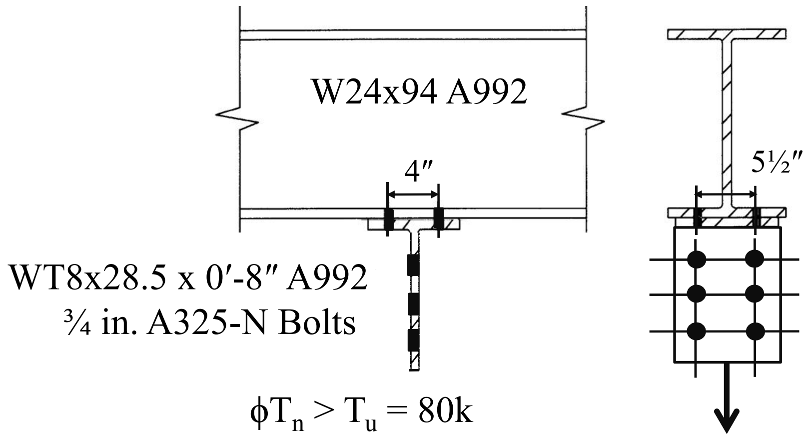
$= 1.0\ (5 \text{ x } 1.38 + 4.0)\ (50 \text{ x } 0.515)$

$= 281\text{k} > R_u = 80\text{k}$ OK



VirginiaTech *Invent the Future* 30

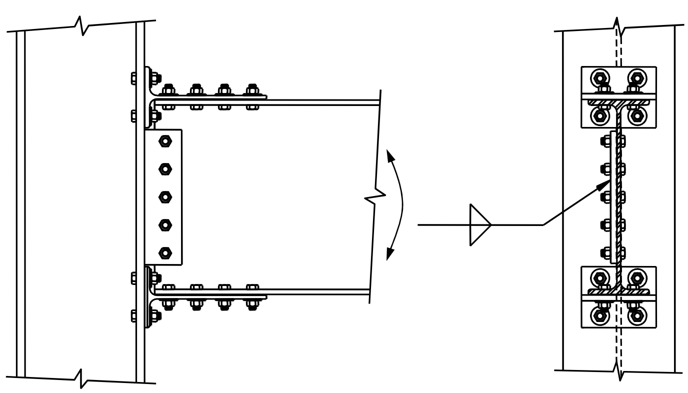
Bolted Hanger Connection Example



$\phi T_n > T_u = 80\text{k}$

The Connection is Adequate

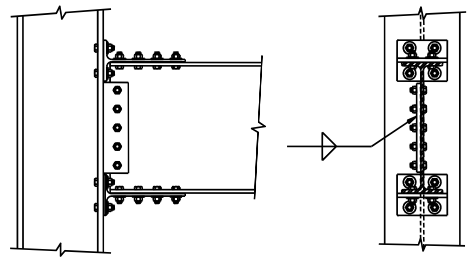
FLANGE TEE-STUB BOLTED / WEB BOLTED



Flange Tee-Stub Bolted / Web Bolted

Limit States

- Tee Stub → Bolted Hanger Connection Design
- Girder → Same as Flange Plate Bolted
- Web Plate → Same as previous (No moment)

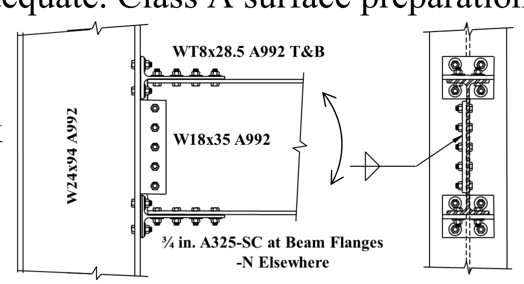


Flange Tee-Stub Bolted Example

Example: For the connection shown:

1. List all limit states.
2. Determine if the tee flange-to-column flange connection is adequate.
3. Determine if the bolt slip resistance of the flange bolts is adequate. Class A surface preparation.

$M_u = 100$ ft-k



Flange Tee-Stub Bolted Example

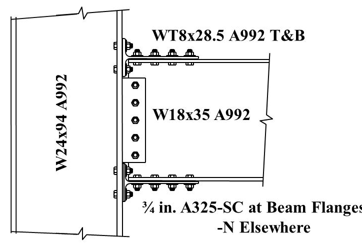
1. Limit States

Beam: Reduced Flexural Strength
Flange Block Shear
Web Shear Yielding

Flange Bolts:
Bolt Slip (-SC Bolts)

Tee-Stub: Stem Block Shear
Stem Tension Rupture
Stem Tension Yielding
Flange Shear Yielding
Flange Shear Rupture
Flange Bending

Tee-Stub Flange Bolts:
Tension Rupture



VirginiaTech Invent the Future

35

Flange Tee-Stub Bolted Example

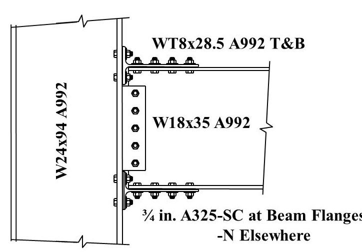
1. Limit States

Shear Transfer at Elements:
Flange Plate-to-Beam Flange

Single Plate:
Bolt Shear Rupture
Shear Rupture
Shear Yielding
Weld Rupture

Shear Transfer at Elements:
Single Plate-to-Beam Web

Column: Flange Bending (Note: Replaces Flange Local Bending)
Web Local Yielding
Web Local Crippling
Flange Shear Rupture Strength at Weld



VirginiaTech Invent the Future

36

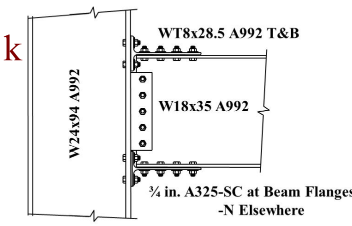
Flange Tee-Stub Bolted Example

2. Check Strength of Tee-Stub Flange Connection

W18x35 A992 d = 17.7 in. WT8x28.5 t_w = 0.430 in.
Assume same geometry as in previous tee-hanger example with one additional row of bolts at stem.

From previous example:
Tee Flange Connection $\phi T_n > 80$ k

$T_u = M_u/(d+t_w)$
$= (100 \times 12)/(17.7 + 0.430)$
$= 66.2$ k < 80 k OK



VirginiaTech Invent the Future

37

Flange Tee-Stub Bolted Example

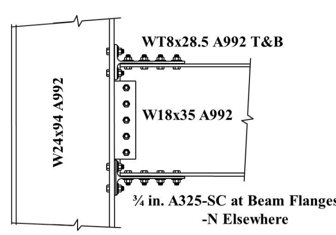
3. Check Beam Flange Bolt Slip Resistance

8 - ¾ in. A325-SC Bolts T_b = 28 k (*Spec.* Table 3.1)

$\phi_{sc} = 1.0$ $\mu = 0.30$ (Class A) $h_f = 1.0$ $n_s = 1$

$\phi_{sc} r_{sc} = \phi_{sc}\,\mu\,D_u\,h_f\,T_b\,n_s$ (*Spec.* Eqn. J3-4)
$= 1.0\text{x}0.30\text{x}1.13\text{x}1.0\text{x}28\text{x}1$
$= 9.49$k

$\phi_{sc} M_n = \sum \phi_{sc} r_{sc} \times d$
$= (8\text{x}9.49)(17.7/12)$
$= 112$ ft-kips $> M_u = 100$ ft-Kips OK



VirginiaTech Invent the Future

38

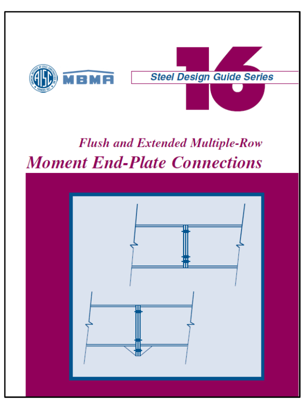
END-PLATE MOMENT CONNECTIONS

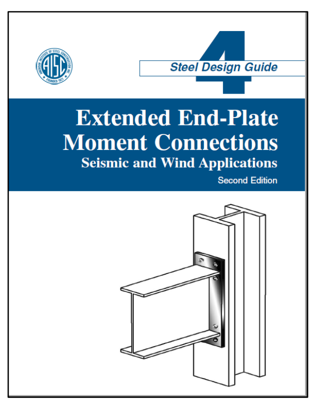
VirginiaTech
Invent the Future

39

End-Plate Moment Connections

AISC MOMENT END-PLATE DESIGN GUIDES





Coming in 2018 Design Guide 4 + 16

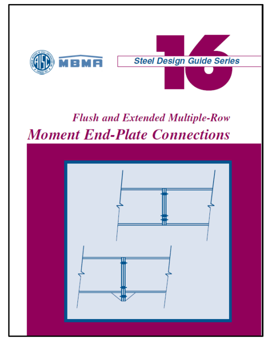
VirginiaTech
Invent the Future

40

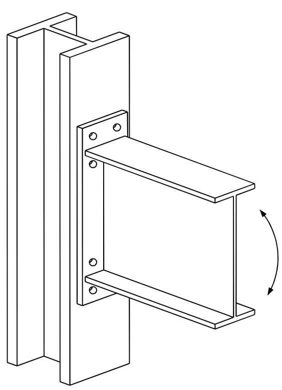
End-Plate Moment Connections

TODAY'S TOPICS

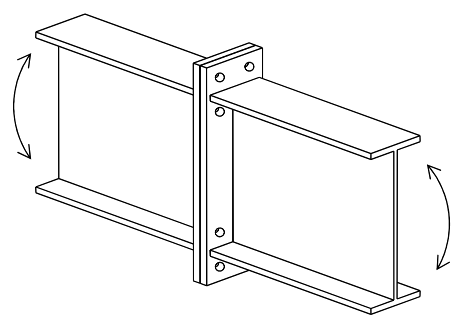
- Types of Moment End-Plate Connections for Wind and Low Seismic
- Basis of AISC Design Guide Procedures
- AISC Design Guide 16
  Wind and Low Seismic Moment End-Plate Connections



End-Plate Moment Connections

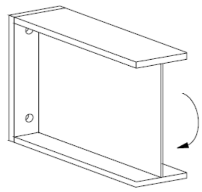


Beam-to-Column

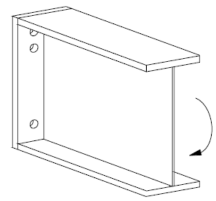


Beam-to-Beam

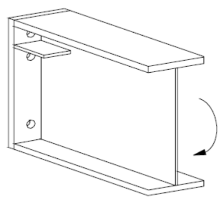
Flush End-Plate Moment Connections



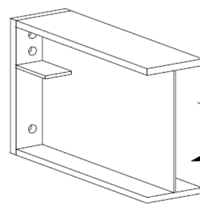
Two Bolt Unstiffened



Four Bolt Untiffened



Four Bolt Stiffened

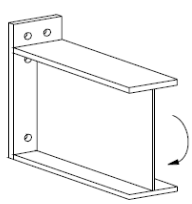


Four Bolt Stiffened

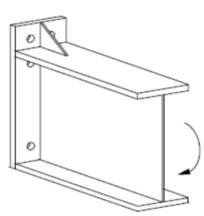
VirginiaTech *Invent the Future*

43

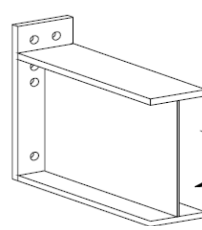
Extended End-Plate Moment Connections



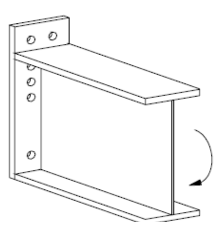
Four Bolt Unstiffened



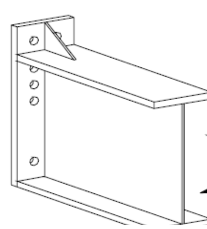
Four Bolt Stiffened



Multiple Row 1/2 Unstiffened



Multiple Row 1/3 Unstiffened



Multiple Row 1/3 Stiffened

VirginiaTech *Invent the Future*

44

Basis of End-Plate Design Procedures

Stiffness Criterion

- Fully Restrained (FR) Construction

End-Plate Strength

- Yield Line Theory

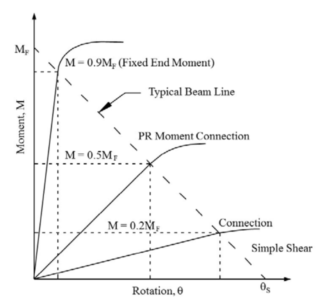
Bolt Force Prediction

- Pretensioned and Snug-Tightened Bolts
- Including Prying Action

End-Plate Connection Classification

Stiffness Criterion

- Extended End-Plate Connections
  Fully Restrained (FR)



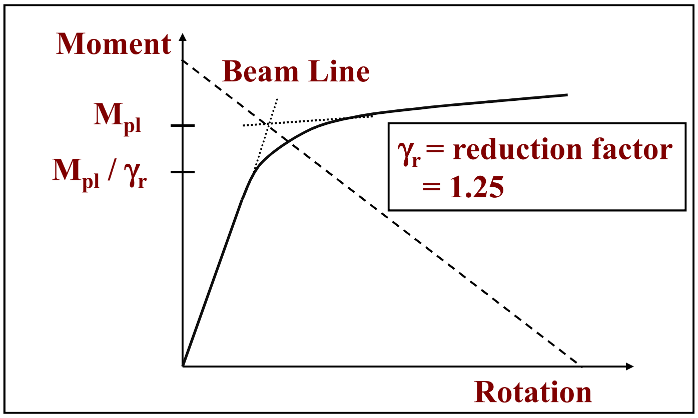
- Flush End-Plate Connections
  Fully Restrained (FR)

Useable end-plate strength is reduced to satisfy stiffness criterion.

End-Plate Connection Classification

Stiffness Criterion

- FR Flush End-Plate Connections



VirginiaTech Invent the Future

47

End-Plate Flexural Strength

End-Plate Flexural Strength: Yield-Line Analysis

- Flexural Strength of Plate:

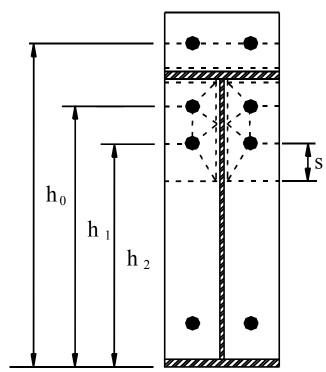
  $M_{pl} = F_{py} t_p^2 Y$

  where:

  F_{py} = end-plate material yield stress

  t_p = end-plate thickness

  Y = geometric yield-line parameter



VirginiaTech Invent the Future

48

End-Plate Strength

End-Plate Strength from Yield-Line Analysis

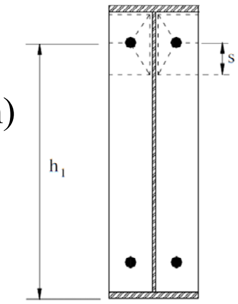
- Internal Work Ex.

$$W_i = \frac{4m_p}{h}(h_1)\left[\frac{b_p}{2}\left(\frac{1}{p_f}+\frac{1}{s}\right)+\frac{2}{g}(p_f+s)\right]$$

where $m_p = F_{py} Z = F_{py}(1)\, t_p^2 / 4$
(m_p is the plastic moment per unit length)

- External Work Ex.

$$W_e = M_u \theta = M_u\left(\frac{1}{h_1}\right)$$



VirginiaTech Invent the Future

49

End-Plate Strength

End-Plate Strength from Yield-Line Analysis

- Equating $W_i = W_e$

$$M_n = M_{pl} = F_{py} t_p^2 (h_1)\left[\frac{b_p}{2}\left(\frac{1}{p_f}+\frac{1}{s}\right)+\frac{2}{g}(p_f+s)\right]$$

$$\text{with} \quad s=\frac{1}{2}\sqrt{b_p g} \quad \text{from} \quad \frac{dWi}{ds}=0$$

Note: Yield-line solutions are upper bound solutions and therefore the least internal work is the least upper bound.

VirginiaTech Invent the Future

50

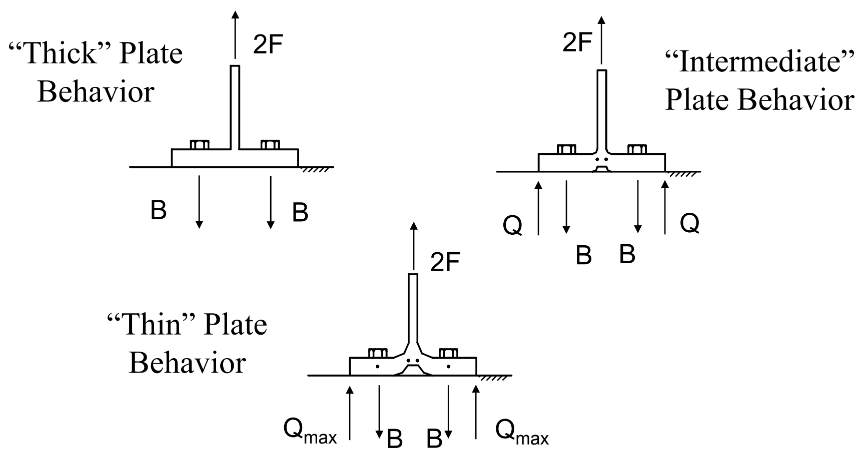
Bolt Forces/Prying Forces

Bolt Force Predictions

- Split-tee analogy
- Connection fails when first bolt reaches its tensile strength
  $\phi r_{nt} = 0.75 F_{nt} A_b$
- Three stages of plate behavior possible.
- Prying forces in bolts considered.

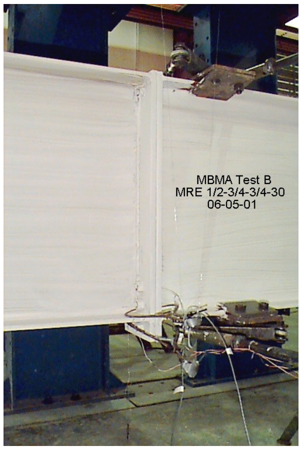
Bolt Forces/Prying Forces

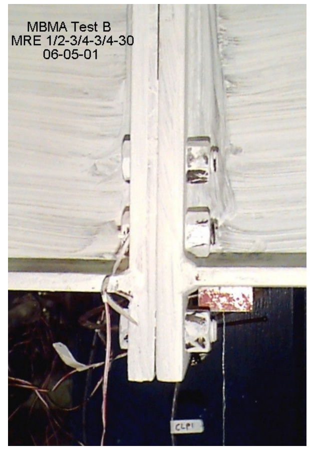
Split-Tee Analogy



Bolt Forces/Prying Forces

Thick Plate Response



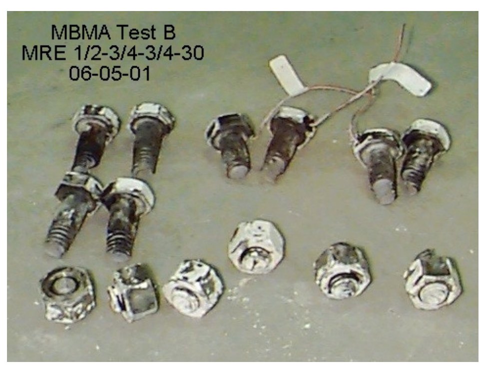


VirginiaTech
Invent the Future

53

Bolt Forces/Prying Forces

Thick Plate Response



VirginiaTech
Invent the Future

54

Bolt Forces/Prying Forces

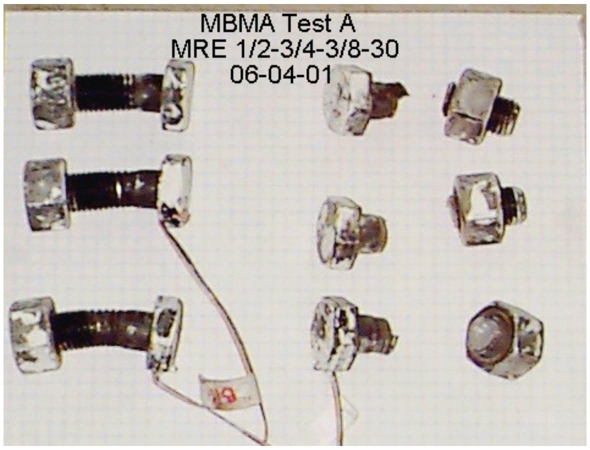
Thin Plate Response

VirginiaTech
Invent the Future

55

Bolt Forces/Prying Forces

Thin Plate Response

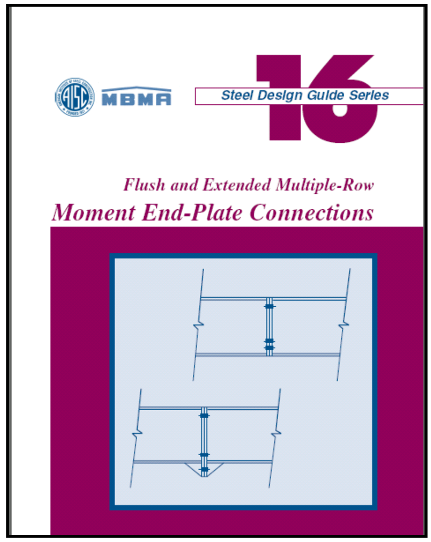


VirginiaTech
Invent the Future

56

AISC Design Guide 16

For Wind and Low Seismic Applications ($R \leq 3$ Designs)



VirginiaTech
Invent the Future

57

AISC Design Guide 16

<u>Overview of Design Guide 16</u>

- Background
- Flush End-Plate Design Procedures
  2-Bolt, 4-Bolt, and 4-Bolt Stiffened
- Extended End-Plate Design Procedures
  4-Bolt, 4-Bolt Stiffened, MRE 1/2, MRE 1/3, and MRE 1/3 Stiffened
- Gable Frame Panel Zone Design

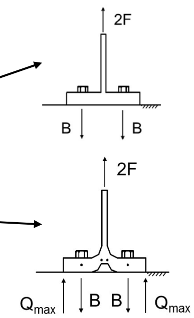
VirginiaTech
Invent the Future

58

AISC Design Guide 16

Overview of Design Guide 16

- Two Design Options:
  - "Thick" end-plate option
    (thicker plate, smaller bolts)
  - "Thin" end-plate option
    (thinner plate, larger bolts)



- Two Bolt Pretension Levels:
  - Fully Pretensioned (AISCS Table J3.1)
    (Note: Not Slip-Critical)
  - Snug Tightened

VirginiaTech *Invent the Future* 59

AISC Design Guide 16

"Thick" Plate Design Option

- Plate yielding does not occur prior to bolt rupture.
- Minimum diameter bolts
- Thicker end-plate
- Prying forces are negligible
- Design requirement: $\phi_b M_{pl} \geq \phi_t 1.11 M_{np}$
  (end-plate stronger than the bolts)
- M_{np} = no prying flexural strength of bolts
- Design procedure is straight forward.

VirginiaTech *Invent the Future* 60

AISC Design Guide 16

"Thin" Plate Design Option

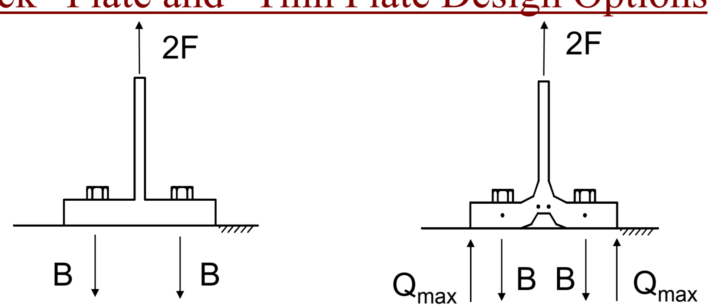
- Plate yielding occurs prior to bolt rupture.
- Minimum end-plate thickness
- Larger diameter bolts
- Prying forces assumed to be maximum
- Design requirement: $\phi_b M_{pl} < \phi_t 1.11 M_{np}$
  (bolts stronger than end-plate)
- Design procedure is complicated.

VirginiaTech
Invent the Future

61

AISC Design Guide 16

"Thick" Plate and "Thin Plate Design Options



"Thick" Plate
$\phi_b M_{pl} \geq 1.11 \phi_t M_{np}$
$Q = 0$

"Thin" Plate
$\phi_b M_{pl} < 1.11 \phi_t M_{np}$
$Q = Q_{max}$

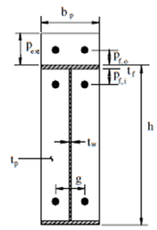
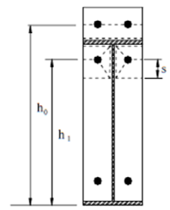
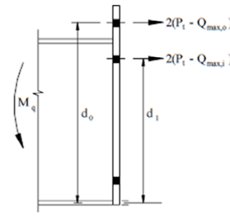
M_{np} is the "no prying" moment strength of the bolts

VirginiaTech
Invent the Future

62

AISC Design Guide 16

Table 4-2 Summary of Four-Bolt Extended Unstiffened Moment End-Plate Analysis

Geometry	Yield-Line Mechanism	Bolt Force Model
		
End-Plate Yield	$\phi M_n = \phi_b M_{pl} = \phi_b F_{py} t_p^2 Y$ $Y = \frac{b_p}{2}\left[h_1\left(\frac{1}{p_{f,i}} + \frac{1}{s}\right) + h_0\left(\frac{1}{p_{f,o}}\right) - \frac{1}{2}\right] + \frac{2}{g}\left[h_1\left(p_{f,i} + s\right)\right]$ Note: Use $p_{f,i} = s$, if $p_{f,i} > s$ $s = \frac{1}{2}\sqrt{b_p g}$ $\phi_b = 0.90$	
Bolt Rupture w/Prying Action	$\phi M_n = \phi M_q = \max \begin{vmatrix} \phi[2(P_t - Q_{max,o})d_0 + 2(P_t - Q_{max,i})d_1] \\ \phi[2(P_t - Q_{max,o})d_0 + 2(T_b)(d_1)] \\ \phi[2(P_t - Q_{max,i})d_1 + 2(T_b)(d_0)] \\ \phi[2(T_b)(d_0 + d_1)] \end{vmatrix}$ $\phi = 0.75$	
Bolt Rupture No Prying Action	$\phi M_n = \phi M_{np} = \phi[2(P_t)(d_0 + d_1)]$ $\phi = 0.75$	

VirginiaTech
Invent the Future

63

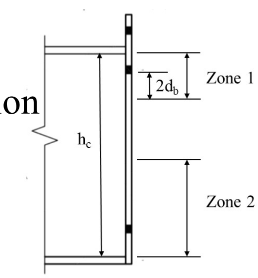
AISC Design Guide 16

Weld Strength Requirements (*Manual* p. 12-10)

- Beam Flange to End-Plate Weld

$$T_u = \max \begin{vmatrix} M_u/(d - t_f) \\ 0.6[F_y\,(b_f \times t_f)] \quad \text{(60\% of beam flange yield str.)} \end{vmatrix}$$

- Beam Web to End-Plate Weld
  Zone 1: Max. of calculated web tension stress and $0.6(F_y\, t_w)$, k/in.
  Zone 2: Min. $(h_c - 2d_b,\ h_c/2)$
  $V_u \le \phi V_n$



VirginiaTech
Invent the Future

64

AISC Design Guide 16

Ex.4-Bolt Extended Unstiffened "Thick" Plate

- Plate Design Strength: $\phi_b M_{pl}$

$\phi_b = 0.9$

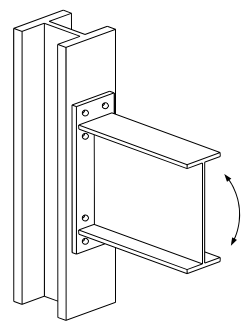
M_{pl} = plate nominal flexural strength

$= F_{py}\, t_p^2\, Y$

F_{py} = end-plate material yield stress

t_p = end-plate thickness

Y = the yield line parameter



VirginiaTech Invent the Future

65

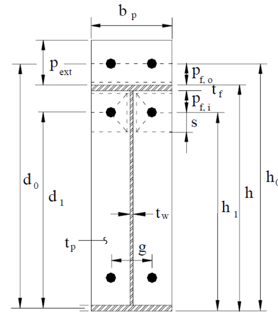
AISC Design Guide 16

Ex.4-Bolt Extended Unstiffened "Thick" Plate

- Plate Design Strength $\phi_b M_{pl} = 0.9 F_{py}\, t_p^2\, Y$

$$Y = \frac{b_p}{2}\left[h_1\left(\frac{1}{p_{f,i}} + \frac{1}{s}\right) + h_0\left(\frac{1}{p_{f,o}}\right) - \frac{1}{2}\right] + \frac{2}{g}\left[h_1\left(p_{f,i} + s\right)\right]$$

where $s = \frac{1}{2}\sqrt{b_p g}$



VirginiaTech Invent the Future

66

AISC Design Guide 16

Ex.4-Bolt Extended Unstiffened "Thick" Plate

- No Prying Bolt Moment Strength: $\phi_t M_{np}$

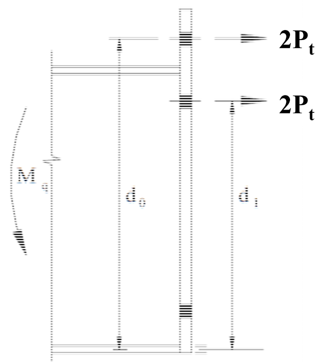
$$\phi_t M_{np} = \phi_t \left[\sum_{i=1}^{N_i} \left(2P_t d_i \right) \right]$$

where $\phi_t = 0.75$

$P_t = F_{nt} A_b$ (nominal strength)

$F_{nt} = 90$ ksi for A325 bolts

$= 113$ ksi for A490 bolts



VirginiaTech
Invent the Future

67

AISC Design Guide 16

Ex.4-Bolt Extended Unstiffened "Thick" Plate

- For "Thick" Plate Design

$\phi_b = 0.90 \quad \phi_t = 0.75$

To avoid prying:

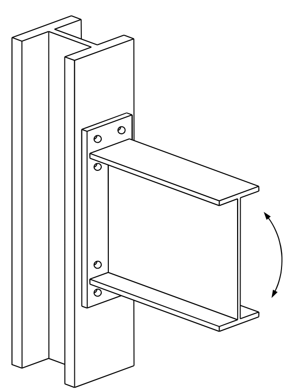
$\phi_b M_{pl} \geq 1.11 \phi_t M_{np}$

Required strength:

$M_u \leq \phi_b M_{pl} / \gamma_r$

with $\gamma_r = 1.0$ (Extended E-P)

1.25 (Flush E-P)



VirginiaTech
Invent the Future

68

AISC Design Guide 16

Assumption and Limitations for All Configurations

- Assumption:
  - Compression side bolts resist all vertical shear.
- Limitations:
  - Bolt diameter $\leq 1\frac{1}{2}$ in.
  - $F_y \leq 50$ ksi
  - Width of end-plate taken in calcs to be $\leq b_f + 1$ in.
  - Bolt gage, $g \leq b_f$
  - With CJP welds, weld access holes not recommended.
- Minimum Pitch Recommendations
  - $p_f \geq d_b + \frac{1}{2}$ in. if $d_b \leq 1$ in. $p_f \geq d_b + \frac{3}{4}$ in. if $d_b > 1$ in.

VirginiaTech Invent the Future

69

4E Moment End-Plate Design Example

Ex. Determine required bolt diameter and end-plate thickness for the 4-Bolt Extended Unstiffened (4E) shown. Use "Thick" End-Plate design.

$M_u = 2{,}000$ k-in. $V_u = 33.0$ k

End-Plate: A572 Gr 50

Bolt Grade: A325-N

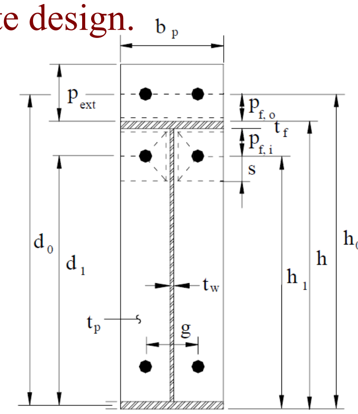
Geometry:

$b_p = b_f = 8$ in. $t_f = 3/8$ in.

$t_w = 1/4$ in. $p_{f,i} = 2$ in.

$h = 18$ in. $p_{f,o} = 2\frac{1}{2}$ in.

$g = 3\frac{1}{2}$ in. $p_{ext} = 3\frac{1}{2}$ in.

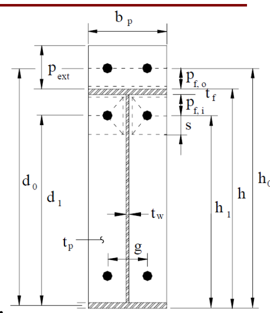


VirginiaTech Invent the Future

70

4E Moment End-Plate Design Example

4-Bolt Extended Unstiffened "Thick" End-Plate



Geometry:
$b_p = b_f = 8$ in.
$t_f = 3/8$ in. $t_w = 1/4$ in.
$g = 3½$ in.
$h = 18$ in.
$p_{f,i} = 2$ in.
$p_{f,o} = 2½$ in.
$p_{ext} = 3½$ in

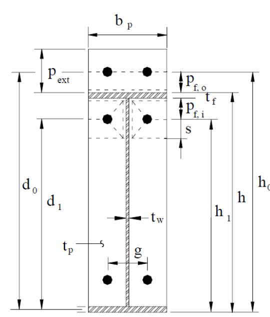
Calculate:
$d_o = 18.0+2.5-0.375/2 = 20.3$ in.
$d_1 = 18.0-0.375-2.0-0.375/2 = 15.4$ in.
$h_o = 18+2.5 = 20.5$ in.
$h_1 = 15.44+0.375/2 = 15.625$ in.
$\sum d_n = 20.31+15.44 = 35.75$

VirginiaTech Invent the Future

71

4E Moment End-Plate Design Example

Required Bolt Diameter



$$\sum d_n = 20.31+15.44 = 35.75$$

$$d_{b\,reqd} = \sqrt{\frac{2M_u}{\pi \phi_t F_t \left(\sum d_n\right)}}$$

$$= \sqrt{\frac{2 \times 2{,}000}{\pi \times 0.75 \times 90 \times 35.75}} = 0.726 \text{ in.}$$

Use 3/4 in. A325-N Bolts

VirginiaTech Invent the Future

72

4E Moment End-Plate Design Example

Required End-Plate Thickness

$$t_{p,reqd} = \sqrt{\frac{1.11\,\gamma_r(\phi_t M_{np})}{\phi_b F_{py} Y}}$$

Extended End-Plate: $\gamma_r = 1.0$

End-Plate Yield Line Parameter, Y:

With $s = \frac{1}{2}\sqrt{b_p g} = \frac{1}{2}\sqrt{8.0 x 3.5} = 2.64$ in.

$$Y = \frac{b_p}{2}\left[h_1\left(\frac{1}{p_{f,i}} + \frac{1}{s}\right) + h_0\left(\frac{1}{p_{f,o}}\right) - \frac{1}{2}\right] + \frac{2}{g}\left[h_1\left(p_{f,i} + s\right)\right]$$

$= 127$ in.

4E Moment End-Plate Design Example

Required End-Plate Thickness

$P_t = (\pi\, d_b^2 /4)\, F_t = \pi\, (0.75)^2\, (90)/4 = 39.8$ kips

$\phi_t M_{np} = \phi_t[\,2\, P_t\, (\Sigma d_n)] = 0.75[2\,(39.8)(35.75)]$
$= 2{,}130$ kip-in.

$$t_{p,reqd} = \sqrt{\frac{1.11\,\gamma_r(\phi_t M_{np})}{\phi_b F_{py} Y}} = \sqrt{\frac{1.11 x 1.0 x 2132}{0.9 x 50 x 127.2}}$$

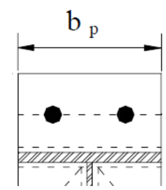
$= 0.643$ in.

Try 3/ 4 in. End-Plate

Lecturer: Tom Murray, P.E., PhD
Emeritus Professor, Virginia Tech

4E Moment End-Plate Design Example

Required End-Plate Thickness



- Check Shear Yielding of Extended Portion of End-Plate

  PL 3/4 x 8 A572 Gr50

  $V_u = M_u/h = 2000/18.0 = 111\text{k}$

  $\phi V_n = 1.0(0.6\text{x}50)(0.75\text{x}8.0) = 180\text{ k} > 111\text{ k}$ OK

- Check Shear Rupture of Extended Portion of End-Plate

  ¾ in. A325-N Bolts

  $\phi V_n = 0.75(0.6\text{x}65)(0.75)(8.0\text{- }2\text{x}7/8)$

  $= 137\text{ k} > 111\text{ k}$ OK

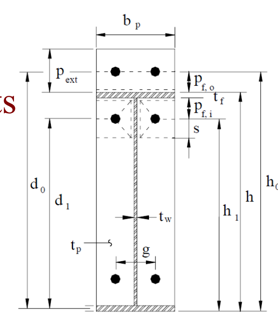
Use 3/4 in. End-Plate

VirginiaTech Invent the Future

75

4E Moment End-Plate Design Example

Compression Side Bolts



- Check Shear Transfer at the Elements

  $V_u = 33\text{k}$

  PL 3/4 x 8 A572 Gr50

  2 - ¾ in. A325-N Bolts

  Brg. $= 2.4F_u dt_p$

  $= (2.4\text{ x }65)(0.75\text{x}0.75) = 87.5\text{k}$

  Tear Out will not control by inspection

  Bolt Shear Rupture 54 x 0.442 = 23.9 k < 87.5 k

  $\phi V_n = 0.75(2\text{ x }23.9) = 35.8\text{ k} > 33\text{ k}$ OK

VirginiaTech Invent the Future

76

4E Moment End-Plate Design Example

Design of Flange Welds

- Beam Flange to End-Plate Weld

$F_{fu} = \max \begin{cases} M_u/(d - t_f) = 2{,}000/(18.0 - 0.375) = \underline{113\text{ k}} \\ 0.6[F_y(b_f \times t_f)] = 0.6[50(0.375\text{x}8.0)] = 90\text{ k} \end{cases}$

Try E70xx fillet welds:

$D = 113/[(1.392\text{x}1.5)(8.0 + 8.0 - 0.25)]$
$= 3.44\ 1/16\text{'s}$

Min. 3/16

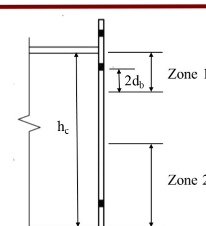
Use ¼ ¼

VirginiaTech *Invent the Future*

77

4E Moment End-Plate Design Example

Design of Web Welds (*Manual* 12-9)



- Beam Web to End-Plate Weld
  Zone 1: $t_w = 0.25$ in.
  Required weld strength is max. of calculated web tension stress and $0.6(F_y\ t_w)$, k/in.

  Conservatively compare with yield strength of web: $F_y t_w = 50\text{x}0.25\text{x}1.0 = 12.5$ k per in. of width

  $D_{req'd} = 12.5/(2\text{x}1.392\text{x}1.5\text{x}1.0) = 2.99\ 1/16\text{'s}$

  Min. 3/16 in.

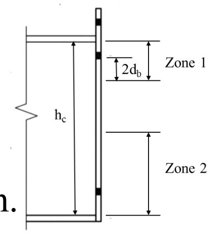
Use 3/16 3/16

VirginiaTech *Invent the Future*

78

4E Moment End-Plate Design Example

Design of Web Welds (*Manual* 12-10)



- Beam Web to End-Plate Weld

  Zone 2: $V_u = 33.0$ k

  $h_c = h - 2T_f = 18.0 - 2 \times 0.375 = 17.25$ in.

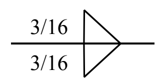
  Max. length of weld:

  $$\min \begin{cases} h_c - p_{f,i} - 2d_b = 17.25 - 2.0 - 2 \times 0.75 = 13.75 \text{ in.} \\ h_c/2 = 17.25/2 = \underline{8.625 \text{ in.}} \end{cases}$$

  $D_{req'd} = 33.0/(2 \text{x} 1.392 \text{x} 8.625) = 1.38$ 1/16's

  Min. 3/16 in.

Use



4E Moment End-Plate Design Example

4-Bolt Extended Unstiffened "Thick" Plate Design

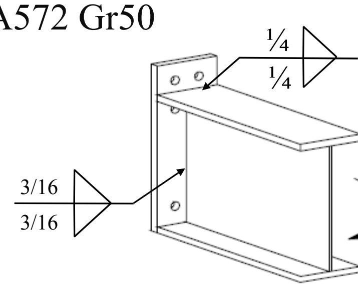
- Final Design

  $M_u = 2{,}000$ in-kips

  $V_u = 33.0$ k

  End-Plate 3/4x8x1′-9½″ A572 Gr50

  ¾ in. A325-N Bolts



AISC Design Guide 16

Other Limit States

- Column Side
  - Flange Bending: $M_f = F_{yf}\, t_f^2\, Y$
  - Web Local Yielding at Compression Side
    $l_b = (6k_{design} + 2t_p + t_{fb})$ from AISC DG4
  - Web Local Crippling at Compression Side
  - Web Compression Buckling
  - Panel Zone Strength

VirginiaTech Invent the Future

81

End of Session 6
Thank You for
Attending

Next Up

VirginiaTech Invent the Future

82

Next Session

- Nov. 28, 2017 Introduction to Seismic Connections

TOPICS

- Ductile Mechanisms and Capacity Design
- Qualification Requirements for Special and Intermediate Moment Frame Connections
- Introduction to Prequalified Connections
- Requirements for Concentrically Braced Frames

VirginiaTech
Invent the Future

83

Individual Webinar Registrants

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!

Individual Webinar Registrants

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.

8-Session Registrants

CEU/PDH Certificates

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

8-Session Registrants

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

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

Reasons for quiz:

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

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

8-Session Registrants

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

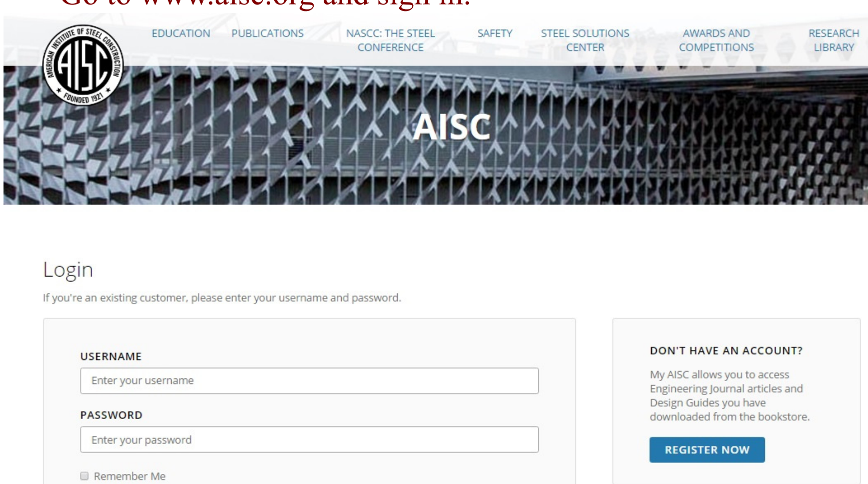
CEUs/PDHS – If you watch a recorded session you must take AND PASS the quiz for CEUs/PDHs.

Night School Resources for 8-session package Registrants

Find all your handouts, quizzes and quiz scores, recording access, and attendance information all in one place!

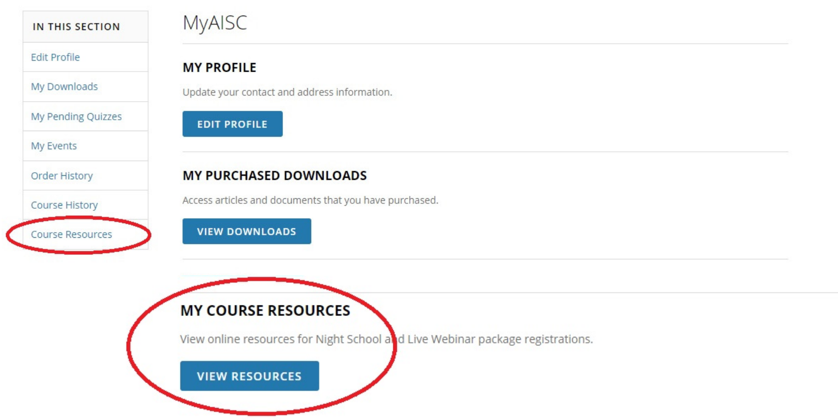
Night School Resources for 8-session package Registrants

Go to www.aisc.org and sign in.

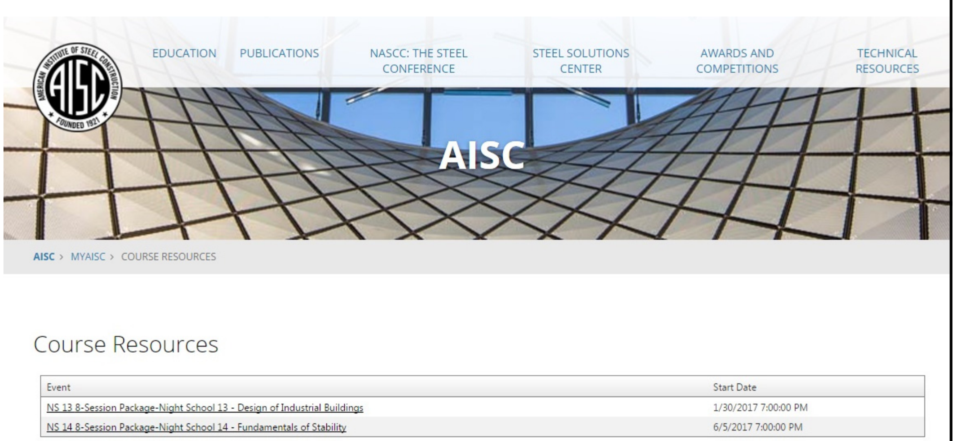


Night School Resources for 8-session package Registrants

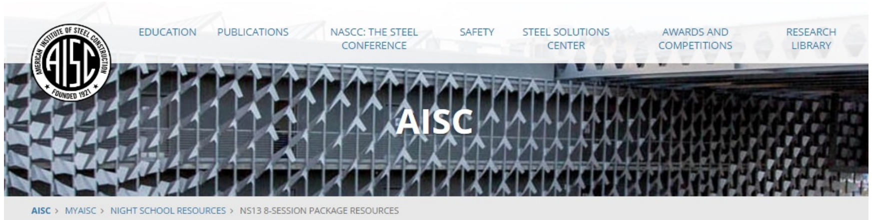
Go to www.aisc.org and sign in.



Night School Resources for 8-session package Registrants



Night School Resources for 8-session package Registrants



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 Dsn	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
NS13 - Final Exam	4/10/2017 7:00:00 PM			Available 04/12/2017 5pm EST	

Night School Resources for 8-session package Registrants

- Weekly "quiz and recording" email.
- Weekly updates of the master Quiz and Attendance record found at www.aisc.org/nightschool. Scroll down to Quiz and Attendance records.
    - Updated on Wednesday mornings.

VirginiaTech
Invent the Future

Night School Resources for 8-session package Registrants

- Webinar connection information:
  - Found in your registration confirmation/receipt.
  - Reminder email sent out Tuesday mornings.
- Link to handouts also found here.

VirginiaTech
Invent the Future

There's always a solution in steel.

Thank You

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

structural STEEL