Chapter 7.5-6 – Slip-Critical, Bearing

1

Chapter 7.5 – High-Strength Bolts

- ***High-strength bolts*** can be installed to such a degree of tightness that they are subjected to ***extremely large tensile forces***.
- For example, the initial tension in a ⅝-*in*, ***Group 120*** bolt can be as high as 19 *k*.

2

Chapter 7.5 – High-Strength Bolts

- A complete list of minimum tension values, for those connections in which a minimum tension is required, is given in ***AISC Table J3.1, "Minimum Bolt Pretension."***

TABLE J3.1
Minimum Bolt Pretension, kips

Bolt Size, in.	Group 120[a]	Group 144[b] and Group 150[b]	Group 200, Grade 2[c]
½	12	15	–
⅝	19	24	–
¾	28	35	–
⅞	39	49	–
1	51	64	90
1⅛	64	80	113
1¼	81	102	143
1⅜	97	121	–
1½	118	148	–

[a]Equal to 0.70 times the minimum tensile strength of bolts as specified in ASTM F3125/F3125M for Grade A325 rounded off to nearest kip.
[b]Equal to 0.70 times the minimum tensile strength of bolts as specified in ASTM F3125/F3125M for Grade A490 rounded off to nearest kip. Group 144 (F3148) assemblies have the same specified minimum pretension as Group 150.
[c]Equal to 0.70 times the minimum tensile strength of bolts as specified in ASTM F3043 and F3111 for Grade 2, rounded off to the nearest kip.

3

Chapter 7.5 – High-Strength Bolts

- Each value is equal to 70% of the ***minimum tensile strength*** of the bolt.

TABLE J3.1
Minimum Bolt Pretension, kips

Bolt Size, in.	Group 120[a]	Group 144[b] and Group 150[b]	Group 200, Grade 2[c]
½	12	15	–
⅝	19	24	–
¾	28	35	–
⅞	39	49	–
1	51	64	90
1⅛	64	80	113
1¼	81	102	143
1⅜	97	121	–
1½	118	148	–

[a]Equal to 0.70 times the minimum tensile strength of bolts as specified in ASTM F3125/F3125M for Grade A325 rounded off to nearest kip.
[b]Equal to 0.70 times the minimum tensile strength of bolts as specified in ASTM F3125/F3125M for Grade A490 rounded off to nearest kip. Group 144 (F3148) assemblies have the same specified minimum pretension as Group 150.
[c]Equal to 0.70 times the minimum tensile strength of bolts as specified in ASTM F3043 and F3111 for Grade 2, rounded off to the nearest kip.

4

Chapter 7.5 – High-Strength Bolts

- The purpose of such a ***large tensile force*** is to achieve a clamping force. Such bolts are said to be ***fully tensioned***.

TABLE J3.1
Minimum Bolt Pretension, kips

Bolt Size, in.	Group 120[a]	Group 144[b] and Group 150[b]	Group 200, Grade 2[c]
½	12	15	–
⅝	19	24	–
¾	28	35	–
⅞	39	49	–
1	51	64	90
1⅛	64	80	113
1¼	81	102	143
1⅜	97	121	–
1½	118	148	–

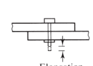
[a]Equal to 0.70 times the minimum tensile strength of bolts as specified in ASTM F3125/F3125M for Grade A325 rounded off to nearest kip.
[b]Equal to 0.70 times the minimum tensile strength of bolts as specified in ASTM F3125/F3125M for Grade A490 rounded off to nearest kip. Group 144 (F3148) assemblies have the same specified minimum pretension as Group 150.
[c]Equal to 0.70 times the minimum tensile strength of bolts as specified in ASTM F3043 and F3111 for Grade 2, rounded off to the nearest kip.

5

Chapter 7.5 – High-Strength Bolts

- Consider two plates ***bolted*** together without any external load.

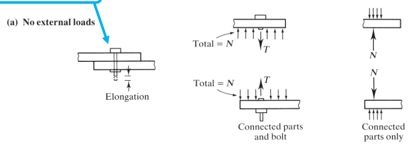
(a) No external loads



6

Chapter 7.5 – High-Strength Bolts

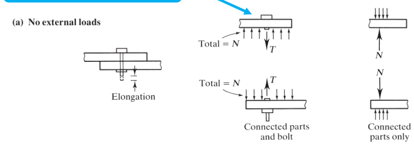
- As a nut is turned and advanced along the threads of a bolt, the ***connected parts undergo compression***, and the bolt elongates.



7

Chapter 7.5 – High-Strength Bolts

- The free-body diagrams below show that the total ***compressive force*** acting on the connected part is numerically equal to the ***tension in the bolt***.



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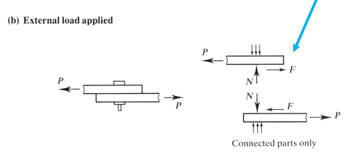
Chapter 7.5 – High-Strength Bolts

- If an external load ***P*** is applied, a ***friction force*** will develop between the ***connected parts***.



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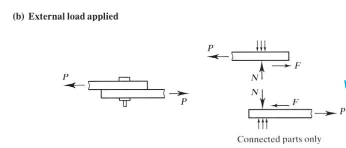
Chapter 7.5 – High-Strength Bolts

- The maximum possible value of this force is ***P*** = μ***N***, where μ is the coefficient of static friction between the connected parts.



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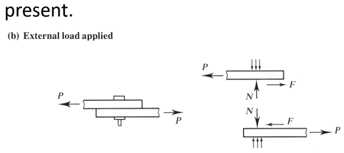
Chapter 7.5 – High-Strength Bolts

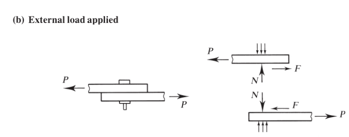
- The value of μ will depend on the ***surface condition*** of the steel—for example, whether it is painted or whether rust is present.



11

Chapter 7.5 – High-Strength Bolts

- Each bolt in the connection is capable of a load of ***P*** = ***F***, even if the ***bolt shank does not bear on the connected part***.



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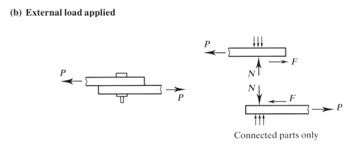
Chapter 7.5 – High-Strength Bolts

- If this ***frictional force is not exceeded***, there is **no bearing or shear.**



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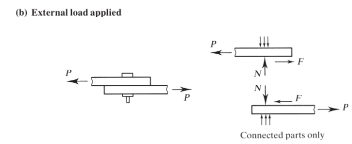
Chapter 7.5 – High-Strength Bolts

- If ***P*** > ***F*** and ***slippage occurs***, shear and bearing will then exist and will affect the capacity of the connection.



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Chapter 7.5 – High-Strength Bolts

- How is this ***high tension*** accurately achieved?
- There are currently four authorized procedures for the ***installation of high-strength bolts*** (RCSC, 2020).

  1. ***Turn-of-the-nut method.*** This procedure is based on the load-deformation characteristics of the fastener and the connected parts.

     One full turn of a nut corresponds to a fixed length of travel along the bolt threads, which can be correlated to the elongation of the bolt.

     The stress–strain relationship for the bolt material can then be used to compute the tension in the bolt.

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Chapter 7.5 – High-Strength Bolts

- How is this ***high tension*** accurately achieved?
- There are currently four authorized procedures for the ***installation of high-strength bolts*** (RCSC, 2020).

  2. ***Calibrated wrench tightening.*** Torque wrenches are used for this purpose.

     The torque required to attain a specified tension in a bolt of a given size and grade is determined by tightening this bolt in a tension-indicating device.

     This calibration must be done daily during construction for bolts of each size and grade.

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Chapter 7.5 – High-Strength Bolts

- How is this ***high tension*** accurately achieved?
- There are currently four authorized procedures for the ***installation of high-strength bolts*** (RCSC, 2020).

  3. ***Twist-off-type bolts.*** These are specially designed bolts that must be installed with specially designed power wrenches.

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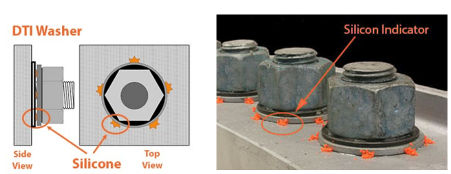
Chapter 7.5 – High-Strength Bolts

- How is this ***high tension*** accurately achieved?
- There are currently four authorized procedures for the ***installation of high-strength bolts*** (RCSC, 2020).

  4. ***Direct tension indicators.*** The most common of these devices is a washer with protrusions on its surface.



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Chapter 7.5 – High-Strength Bolts

- Not all high-strength bolts need to be tightened to the fully tensioned condition.
- ***AISC J3.2(a)*** (**16.1**-134) permits the bolts in some connections to be snug tight.
- These include ***bearing-type connections*** (see Section 7.6), most ***tension connections*** (Section 7.8), and most combined ***shear and tension connections*** (Section 7.9).
- ***AISC J3.2(b)*** (**16.1**-135) describes the connections for which fully tensioned bolts are required.

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Chapter 7.6 – Slip-Critical, Bearing

- A connection with ***high-strength bolts*** is classified as either a ***slip-critical*** connection or a ***bearing-type*** connection.
- A ***slip-critical connection*** is one in which no slippage is permitted—that is, the friction force must not be exceeded.
- In a ***bearing-type connection***, slip is acceptable, and shear and bearing occur.

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Chapter 7.6 – Slip-Critical, Bearing

- In some types of structures, notably bridges, the load on connections can undergo ***many cycles of reversal***.
- In such cases, fatigue of the fasteners can become critical if the connection is allowed to slip with each reversal, and ***a slip-critical connection is advisable***.
- In most structures, however, ***slip is perfectly acceptable***, and a bearing-type connection is adequate.
- Proper installation and achievement of the prescribed ***initial tension is necessary for slip-critical connections***.

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Chapter 7.6 – Slip-Critical, Bearing

- In ***bearing-type connections***, the only practical requirement for the installation of the bolts is that they be ***tensioned enough so that the surfaces of contact*** in the connection firmly bear on one another.
- This installation produces the ***snug-tight condition*** referred to earlier in the discussion of the ***turn-of-the-nut*** method.

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Chapter 7.6 – Slip-Critical, Bearing

- The ***resistance to slip*** will be a function of the coefficient of static friction and the normal force between the connected parts.
- This relationship is reflected in the provisions of the ***AISC Specification J3-9***.

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Chapter 7.6 – Slip-Critical, Bearing

16.1-142 BOLTS, THREADED PARTS, AND BOLTED CONNECTIONS [Sect. J3.

The available shear stress of the fastener shall equal or exceed the required shear stress, f_{rv}.

User Note: Note that when the required stress, f, in either shear or tension, is

9. High-Strength Bolts in Slip-Critical Connections

9.

Slip-critical connections shall be designed to prevent slip and for the limit states of bearing-type connections. When slip-critical bolts pass through fillers, all surfaces subject to slip shall be prepared to achieve design slip resistance.

The single bolt available slip resistance for the limit state of slip shall be determined as follows:

$$\boxed{R_n = \mu D_u h_f T_b n_s \qquad \text{(J3-4)}}$$

(a) For standard size and short-slotted holes perpendicular to the direction of the load

$$\phi = 1.00 \text{ (LRFD)} \qquad \Omega = 1.50 \text{ (ASD)}$$

(b) For oversized and short-slotted holes parallel to the direction of the load

$$\phi = 0.85 \text{ (LRFD)} \qquad \Omega = 1.76 \text{ (ASD)}$$

(c) For long-slotted holes

$$\phi = 0.70 \text{ (LRFD)} \qquad \Omega = 2.14 \text{ (ASD)}$$

as follows, or as established by tests.

(1) For Class A surfaces (unpainted clean mill scale steel surfaces or surfaces with Class A coatings on blast-cleaned steel or hot-dipped galvanized steel whether as-galvanized or hand roughened)

$$\mu = 0.30$$

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Chapter 7.6 – Slip-Critical, Bearing

- The nominal slip resistance of a bolt is given by: $R_n = \mu D_u h_f T_b n_s$

  where μ is the mean slip coefficient = 0.3 for Class A surfaces, and 0.50 for Class B surfaces,

  D_u is the ratio of the mean actual bolt pretension to the specified minimum pretension. This is to be taken as 1.13 unless another factor can be justified

  h_f is the filler factor

  T_b is the minimum fastener tension ***AISC Table J3.1***

  n_s is the number of slip planes (shear planes)

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Chapter 7.6 – Slip-Critical, Bearing

- A ***Class A surface*** is one with clean mill scale (mill scale is an iron oxide that forms on the steel when it is produced).
- A ***Class B surface*** is either an unpainted blast-cleaned steel surface or a surface with Class B coatings on blast-cleaned steel.
- The filler factor, h_f, accounts for the presence of filler plates, which are sometimes added to connections to bring elements into alignment.
- This can occur, for example, when ***members of different depths*** are spliced.

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Chapter 7.6 – Slip-Critical, Bearing

- The ***Specification*** gives the following values for the filler factor:
  - where one filler is used, $h_f = 1.0$
  - where two fillers are used, $h_f = 0.85$
- Filler plates are covered in more detail in the ***Commentary to AISC Section J3.9.***

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Chapter 7.6 – Slip-Critical, Bearing

- The resistance factor for ***LRFD*** are different for different types of bolt holes.
- For ***standard holes*** (the only type considered in this course), the resistance factor is:

  $\phi = 1.00$
- Although slip-critical connections are ***designed not to slip***, if slip does occur because of an overload, the ***bolts must be capable of resisting shear and bearing***.
- ***AISC J3.9*** requires that ***shear*** and ***bearing*** be checked in slip-critical connections.

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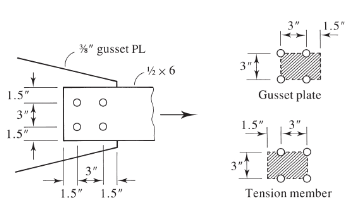
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: The connection shown below uses ¾-*in* **Group 120** bolts with the threads in the shear plane.
  No slip is permitted.
  Both the tension member and the gusset plate are of **A572 Gr. 50** (F_y = 50 ksi; F_u = 65 ksi). Determine the strength of the connection. Steel surfaces are **Class A**.



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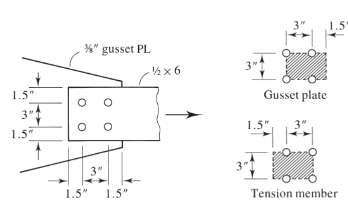
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: Compute the ***LRFD*** design strength.
  For efficiency, the nominal strength for each limit state will be computed before specializing the solution for ***LRFD***.



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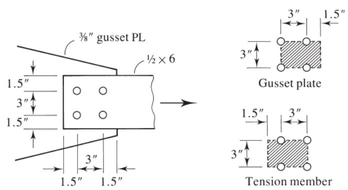
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: ***Shear strength***: For one bolt:

$$A_b = \frac{\pi d^2}{4} = \frac{\pi(3/4\,in)^2}{4} = 0.4418\,in^2$$

From ***AISC Table J3.2*** for a ***Group 120*** type ***N***, ***F_{nv}*** = 54 *ksi*

$$R_n = F_{nv}A_b = 54\,ksi\left(0.4418\,in^2\right) = 23.86\,k\,/\,bolt$$



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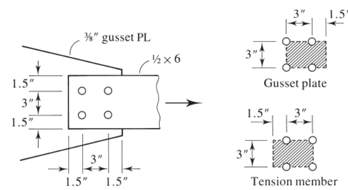
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: ***Slip-critical strength***: Because no slippage is permitted, this connection is classified as slip-critical.

From ***AISC Table J3.1*** for a ***Group 120***, ***T_b*** = 28 *k*

$$R_n = \mu D_u h_f T_b n_s \qquad \textit{AISC Equation J3-4}$$

$$= 0.30(1.13)(1.0)(28\,k)(1.0) = 9.49\,k\,/\,bolt$$



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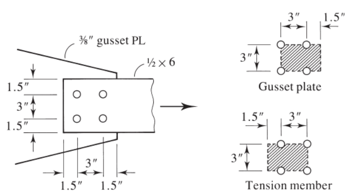
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: ***Slip-critical strength***: Because no slippage is permitted, this connection is classified as slip-critical.

For four bolts:

$$R_n = (4\text{ bolts})(9.49\,k\,/\,\text{bolt}) = 37.97\,k$$



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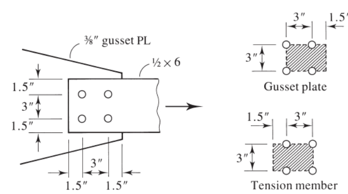
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: ***Bearing strength***: Since both edge distances are the same and the gusset plate is thinner than the tension member, a gusset plate thickness of ⅜-*in* will be used.

For all the holes, bearing strength is:

$$R_n = 2.4dtF_u = 2.4(3/4\,in)(3/8\,in)65\,ksi = 43.88\,k$$



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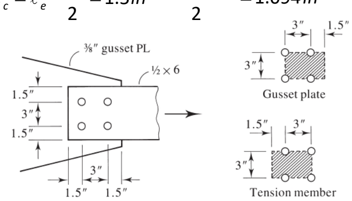
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: For the computation of ***tear-out strength***, use a hole diameter of:

$$\text{If } d < 1.0\,in \quad \text{then:} \quad h = d + \frac{1}{16}in = \frac{3}{4}in + \frac{1}{16}in = \frac{13}{16}in$$

For the holes nearest the edge of the member:

$$\ell_c = \ell_e - \frac{h}{2} = 1.5\,in - \frac{13/16\,in}{2} = 1.094\,in$$



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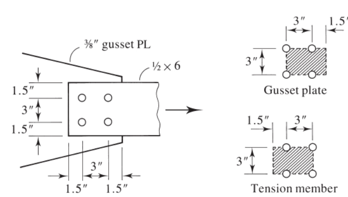
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: For the computation of ***tear-out strength***, use a hole diameter of:

$$R_n = 1.2\ell_c t F_u = 1.2(1.094\,in)(3/8\,in)65\,ksi = 32.0\,k$$

Since 32.0 *k* < 43.9 *k*, edge bolt ***tear-out strength controls***, and ***R_n*** = 32.0 *k*.



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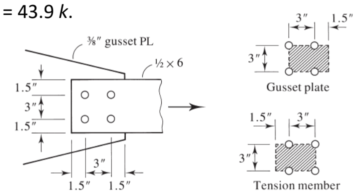
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: For the other holes:

$$\ell_c = s - h = 3in - \frac{13}{16}in = 2.188in$$

$$R_n = 1.2\ell_c t F_u = 1.2(2.188in)(3/8in)65ksi = 64.0k$$

Since 43.9 k < 64.0 k, ***bearing deformation controls***, and ***R_n*** = 43.9 k.



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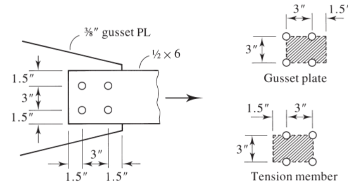
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: The ***shearing strength*** is less than the ***bearing strength*** at each hole, so the nominal strength based on shear and bearing is:

$$R_n = (4 \text{ holes})(23.86k) = 95.44k$$



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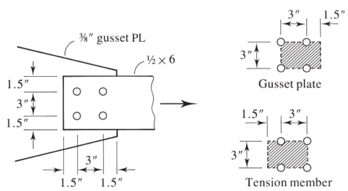
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: Check the strength of the tension member. ***Tension on the gross area***:

$$P_n = F_y A_g = 50ksi(6in)(1/2in) = 150k$$



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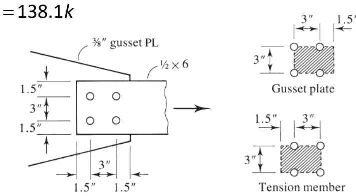
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: ***Tension on the net area***: All elements of the cross-section are connected, so shear lag is not a factor and ***A_e*** = ***A_n***. For the hole diameter, use

$$h = d + 1/8in = 3/4in + 1/8in = 7/8in$$

$$P_u = F_u A_e = F_u t\left(w_g - \sum h\right) = 65ksi(1/2in)\left[6in - 2(7/8in)\right]$$

$$= 138.1k$$



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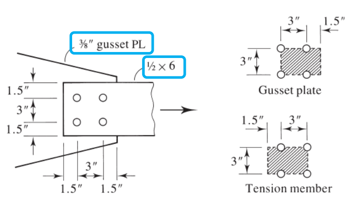
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: ***Block shear strength***: The failure block for the gusset plate has the same dimensions as the block for the tension member except for the thickness.



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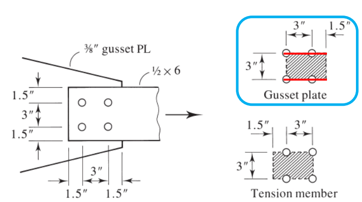
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: ***Block shear strength***: The gusset plate, which is the thinner element, will control. There are two shear-failure planes:

$$A_{gv} = 2(3/8in)[3in + 1.5in] = 3.375in^2$$



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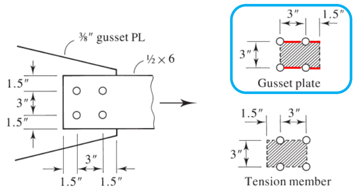
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: ***Block shear strength***: The gusset plate, which is the thinner element, will control. There are two shear-failure planes:

$$A_{gv} = 2(3/8in)[3in + 1.5in] = 3.375in^2$$

$$A_{nv} = 2(3/8in)\left[3in + 1.5in - 1.5(7/8in)\right] = 2.391in^2$$



1.5 hole diameters per horizontal line of bolts

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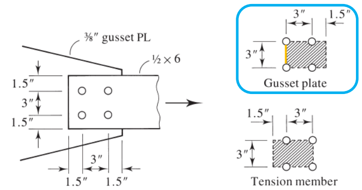
Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: For the ***tension area***:

$$A_{nt} = 3/8in(3in - 7/8in) = 0.7969in^2$$

Since the block shear will occur in a gusset plate, U_{bs} = 1.0



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Chapter 7.6 – Slip-Critical, Bearing

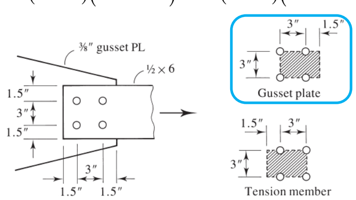
- **Example 7.4**: From ***AISC Equation J4-5***

$$R_n = 0.6F_uA_{nv} + U_{bs}F_uA_{nt}$$

$$= 0.6(65ksi)(2.391in^2) + 1.0(65ksi)(0.7969in^2) \boxed{= 145.0k}$$

$$R_n = 0.6F_yA_{gv} + U_{bs}F_uA_{nt}$$ ***Check the upper limit***

$$= 0.6(50ksi)(3.375in^2) + 1.0(65ksi)(0.7969in^2) = 153.0k$$



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Chapter 7.6 – Slip-Critical, Bearing

- **Example 7.4**: Design Strength for ***LRFD***

Bolt shear/bearing strength: $\phi R_n = 0.75(95.44k) = 71.6k$

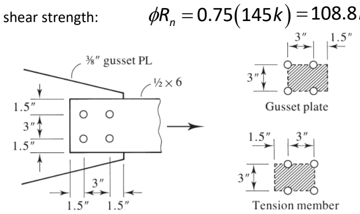
Slip-critical strength: $\phi R_n = 1.0(38.0k) = 38.0k$

Tension on the gross area: $\phi_t P_n = 0.9(150k) = 135.0k$

Tension on the net area: $\phi_t P_n = 0.75(138.1k) = 103.6k$

Block shear strength: $\phi R_n = 0.75(145k) = 108.8k$

Min. value



38.0 *k*

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Let's work on some problems

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Chapter 7.6 – Slip-Critical, Bearing

Any questions?

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