Chapter Two: Tension Members

AISC manual / Chapter D

2.1 General

Defined are structural elements that subjected to axial tensile forces along their longitudinal axis such as truss members, bracing for buildings and bridges, cables in suspension bridge, bars and rods.

2.2 Design Methods for Structural Steel Members

Two design methods are acceptable for deigning structural steel members and connections:

1. Allowable Strength Design. (**ASD**).
2. Load and Resistance Factor Design (**LRFD**)

2.2.1 ASD Design Method

The mean properties of this method:

1. Older but still use
2. Use service level loads (actual loads) to structure:

$$P_a = P_L + P_D$$

3. The actual stress

$$f_t = \frac{Pa}{A_g}$$

where:

f_t: The actual tension stress, *ksi*.

Pa: Applied tensile force, kips

A_g: the gross sectional area, in^2

4. Use factor of safety Ω Omega, where:

$$Allowable\ strength\ (Pa) \leq \frac{Nominal\ strength\ (P_n)}{\Omega}$$

a) Based on the Yielding in the gross section (A_g), Allowable strength:

$$\frac{P_n}{\Omega} = F_t\ A_g = 0.6\ Fy\ A_g$$

Here $\boldsymbol{\Omega} = 1.67$ (factor of safety)

$\boldsymbol{Fy}$ = Minimum yield stress. (AISC Table (2-3), (2-4))

b) Based on the Fracture on the effective section (A_e), Allowable strength:

$$\frac{P_n}{\Omega} = F_t\ A_e = 0.5\ Fu\ A_e$$

Here $\boldsymbol{\Omega} = 2$ (factor of safety)

$\boldsymbol{Fu}$: Minimum tensile stress. (AISC Tables (2-3), (2-4))

$\boldsymbol{A_e}$: Effective area of the tension member. $A_e = U \cdot A_n$

A_n: Net area of the tension member

U: shear lag factor

2.2.2 Load and Resisting Factor Design (LRFD)

The mean properties of this method:

1. More recent and common
2. Use Ultimate loads:

$$P_u = 1.6P_L + 1.2P_D$$

3. The actual stress

$$f_t = \frac{P_u}{A_g}$$

4. Use factor of safety Ø Phi, where:

$$Ultimate\ strength(P_u) \leq \emptyset \times Nominal\ strength(P_n)$$

a) Based on the Yielding in the gross section (A_g), Ultimate strength:

$$\emptyset P_n = \emptyset\ Fy\ A_g$$

Here $\emptyset = 0.9$ (factor of safety)

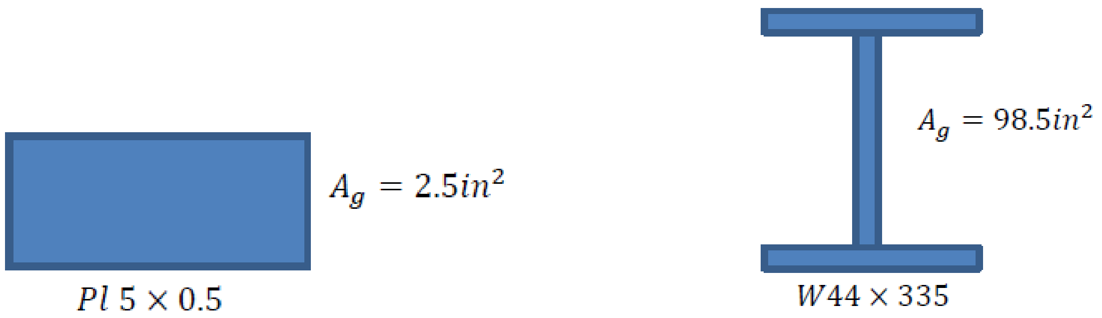
b) Based on the Fracture on the effective section (A_e), Ultimate strength:

$$\emptyset P_n = \emptyset Fu\ A_e$$

Here $\emptyset = 0.75$ (factor of safety)

2.3 How to Calculate Gross Area, Net Area and Effective Area

a) Gross Area (A_g):



b) Net Area (A_n)

The net area is described as follows:

$$A_n = A_g - n\, d_h\, t + \sum \frac{s^2}{4\,g} t$$

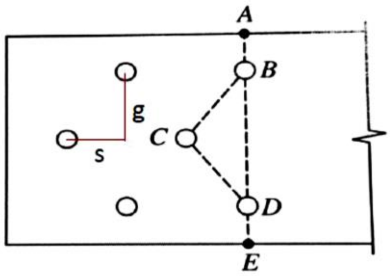
$$d_h = d_b + \frac{1}{8}$$

where:

d_h: hole diameter

d_b: bolt diameter

t: thickness



- From Figure the net area through the line **ABDE** calculate as follow:

$$A_n = A_g - n\, d_h\, t$$

- To calculate the net area through the line **ABCDE**, another term ($\frac{s^2}{4\,g} t$) is added to the above equation and became as following:

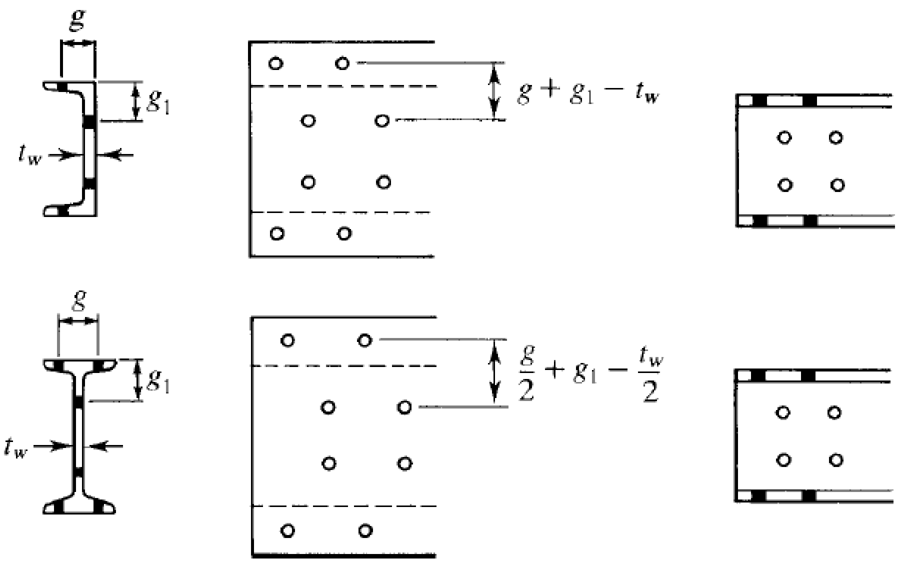
$$A_n = A_g - n\, d_h\, t + \sum \frac{s^2}{4\,g} t$$

Where:

s: Longitudinal center to center spacing between two consecutive holes.

g: Transverse center to center spacing between two consecutive holes.

Staggered connections in sections:



c) Effective area (A_e):

When the section has many parts (like angles, channels and W, M and S sections), and the connection attached not to all these parts, shear lag phenomena will reduce the strength capacity of the section. This reduction factor introduces by AISC manual (section D3.3 Part 16 Page 28) Table D3.1.

The effective area of a tension member is described as follows:

- For bolted connections, the effective net area is,

$A_e = U \cdot A_n$

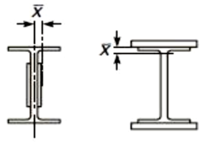
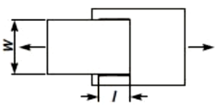
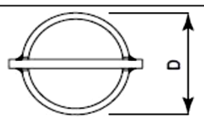
- For welded connections, effective area is,

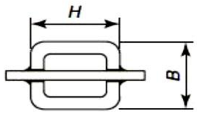
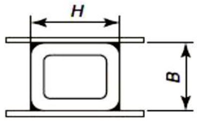
$A_e = U \cdot A_g$

Where:

U = Shear lag factor, is determined as shown in AISC Table D3.1.

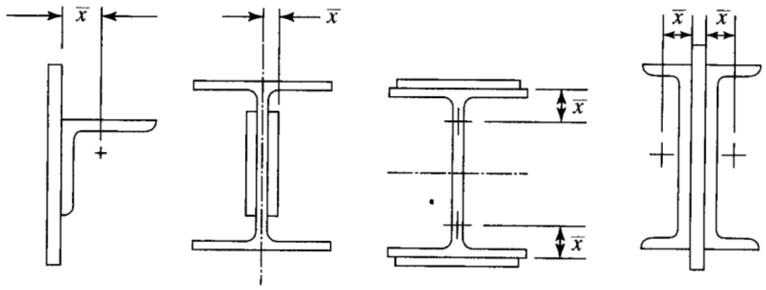
TABLE D3.1
Shear Lag Factors for Connections to Tension Members

Case	Description of Element	Shear Lag Factor, U	Example
1	All tension members where the tension load is transmitted directly to each of cross-sectional elements by fasteners or welds. (except as in Cases 3, 4, 5 and 6)	$U = 1.0$	——
2	All tension members, except plates and HSS, where the tension load is transmitted to some but not all of the cross-sectional elements by fasteners or longitudinal welds (Alternatively, for W, M, S and HP, Case 7 may be used.)	$U = 1 - \bar{x}/l$	
3	All tension members where the tension load is transmitted by transverse welds to some but not all of the cross-sectional elements.	$U = 1.0$ and A_n = area of the directly connected elements	——
4	Plates where the tension load is transmitted by longitudinal welds only.	$l \geq 2w \ldots U = 1.0$ $2w > l \geq 1.5w \ldots U = 0.87$ $1.5w > l \geq w \ldots U = 0.75$	
5	Round HSS with a single concentric gusset plate	$l \geq 1.3D \ldots U = 1.0$ $D \leq l < 1.3D \ldots U = 1 - \bar{x}/l$ $\bar{x} = D/\pi$	

6	Rectangular HSS	with a single concentric gusset plate	$l \ge H \ldots U = 1 - \bar{x}/l$ $\bar{x} = \dfrac{B^2 + 2BH}{4(B+H)}$	
		with two side gusset plates	$l \ge H \ldots U = 1 - \bar{x}/l$ $\bar{x} = \dfrac{B^2}{4(B+H)}$	
7	W, M, S or HP Shapes or Tees cut from these shapes. (If U is calculated per Case 2, the larger value is permitted to be used)	with flange connected with 3 or more fasteners per line in direction of loading	$b_f \ge 2/3d \ldots U = 0.90$ $b_f < 2/3d \ldots U = 0.85$	—
		with web connected with 4 or more fasteners in the direction of loading	$U = 0.70$	—
8	Single angles (If U is calculated per Case 2, the larger value is permitted to be used)	with 4 or more fasteners per line in direction of loading	$U = 0.80$	—
		with 2 or 3 fasteners per line in the direction of loading	$U = 0.60$	—

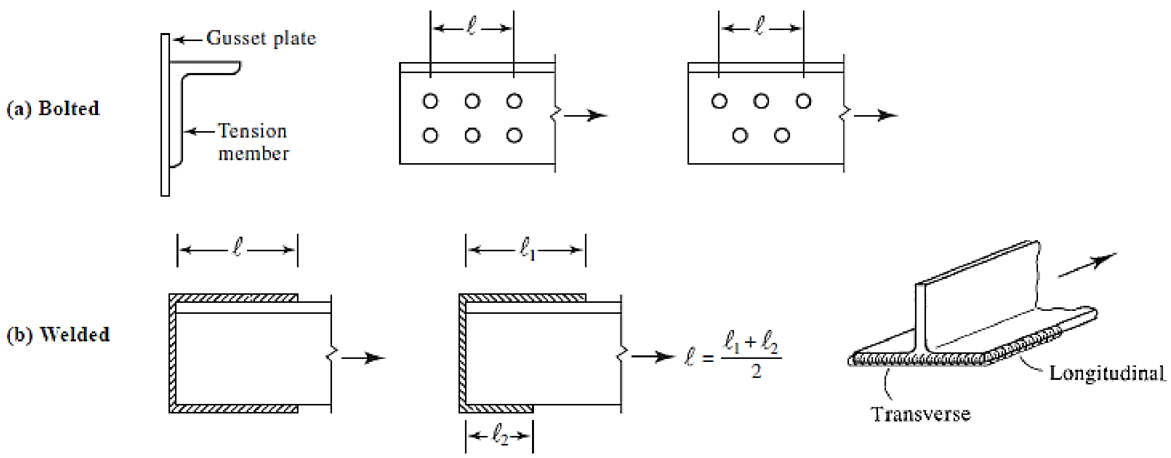
l = length of connection, in. (mm); w = plate width, in. (mm); $\bar{x}$ = connection eccentricity, in. (mm); B = overall width of rectangular HSS member, measured 90 degrees to the plane of the connection, in. (mm); H = overall height of rectangular HSS member, measured in the plane of the connection, in. (mm)

Measurement of Connection Centroid:



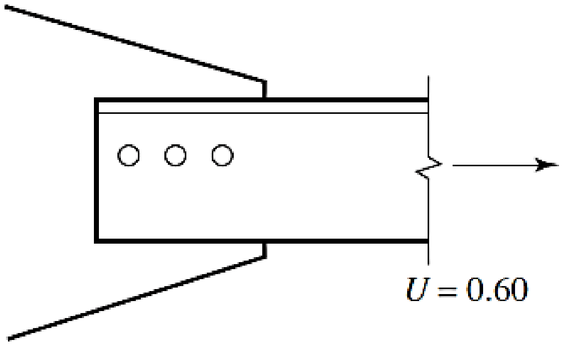
(a) (b) (c) (d)

$\bar{x}$: connection eccentricity, *in*. It is the distance from the center of the section to the place of attachment obtained from the code.



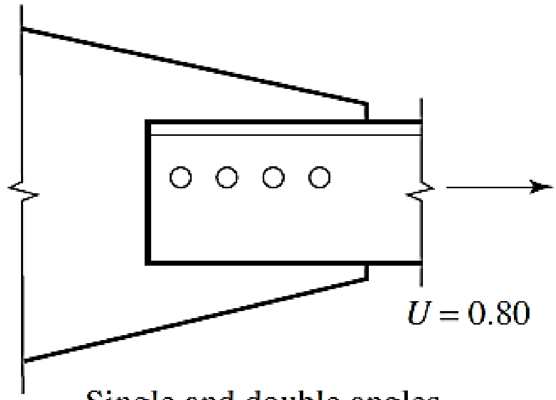
ℓ: length of connection, *in*.

For Examples:



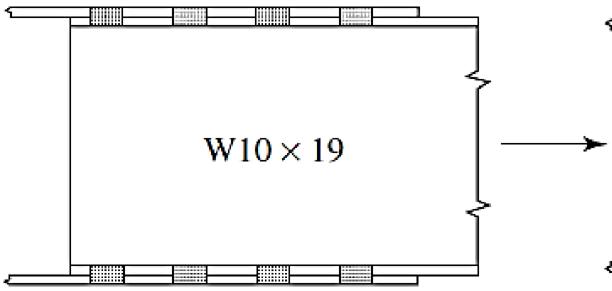
$U = 0.60$

Single and double angles



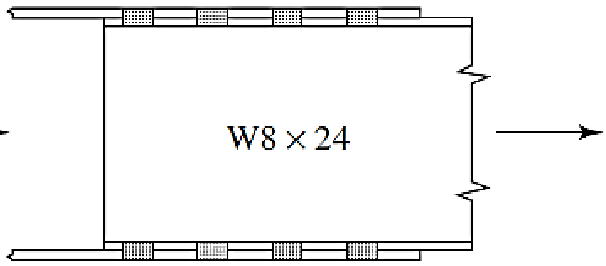
$U = 0.80$

Single and double angles



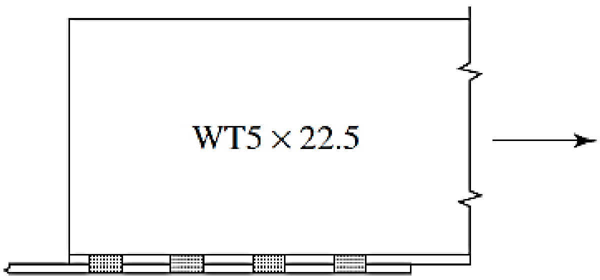
$$\frac{b_f}{d} = 0.394 < \frac{2}{3}$$

$U = 0.85$



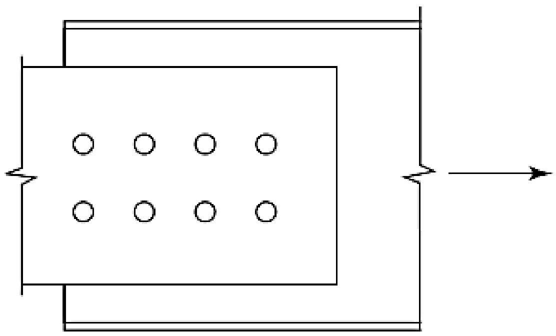
$$\frac{b_f}{d} = 0.820 > \frac{2}{3}$$

$U = 0.90$



$$\frac{b_f}{d} = 0.794 > \frac{2}{3} \quad \text{(for parent shape)}$$

$U = 0.90$



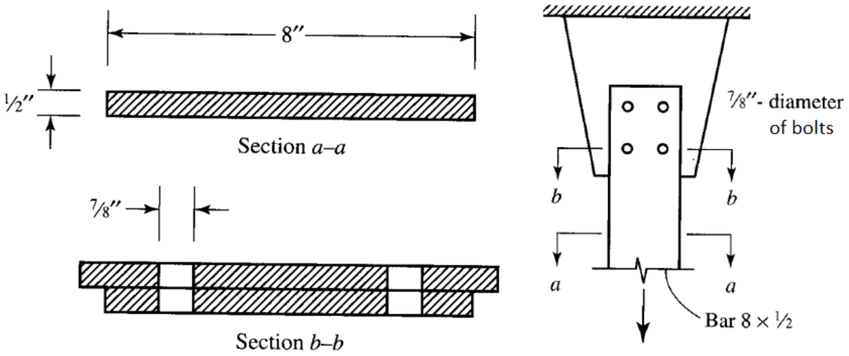
W shape

$U = 0.70$

Example No.1: A plate of dimensions $\left(\frac{1}{2} \times 8\right)$ in made from A36 steel is used as a tension member. It is connected to a gusset plate with four $\left(\frac{7}{8}\ in\right)$ in diameter bolts as shown in Figure.

A) What is the allowable strength for ASD?

B) What is the design strength for LRFD?



Solve:

Steel and section properties:

$Fy = 36\ ksi,\ \ Fu = 58\ ksi$ (from Table 2-4)

$A_g = ½ \times 8 = 4\ in^2$

a) ASD method

From gross area:

$P_n/\Omega = 0.6\ Fy\ A_g = 0.6 \times 36 \times 4 = 86.4\ kips$

From effective area:

$P_n/\Omega = 0.5\ Fu\ A_e$

$A_e = U \cdot A_n, \quad U = 1$

$$A_n = A_g - n\ d_h\ t = 4 - 2 \times \left(\frac{7}{8} + \frac{1}{8}\right) \times \frac{1}{2} = 3\ in^2$$

$P_n/\Omega = 0.5 \times 58 \times 3 = 87\ kips$

Choose small value $Pa = 86.4\ kips$

b) **LRFD method**

From gross area:

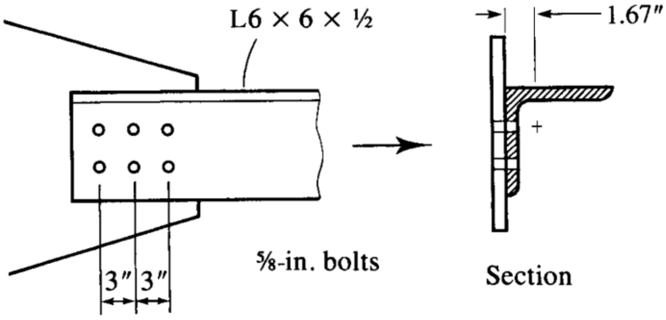
$\emptyset\ Pn = 0.9\ Fy\ A_g = 0.9 \times 36 \times 4 = 129.6\ kips$

From net area:

$$\emptyset Pn = 0.75\ Fu\ A_e = 0.75 \times 58 \times 3 = 130.5\ kips$$

Choose $\emptyset\ Pn = 129.6\ kips$

Example No.2: Determine the effective area for the single angle shown in Figure. The holes are made for 5/8 in diameter bolts.



Solve:

Section Properties:

$$L6 \times 6 \times \frac{1}{2}:\ Ag = 5.77\ in^2,\ \ t = \frac{1''}{2}\ ,\ \ \bar{x} = 1.67''$$

$$Ae = U \cdot An$$

$$U = 0.6\ \ Case\ 8\ (Table\ D3.1)$$

$$U = 1 - \frac{\bar{x}}{\ell}\quad Case\ 2$$

$$U = 1 - \frac{1.67}{3+3} = 0.722$$

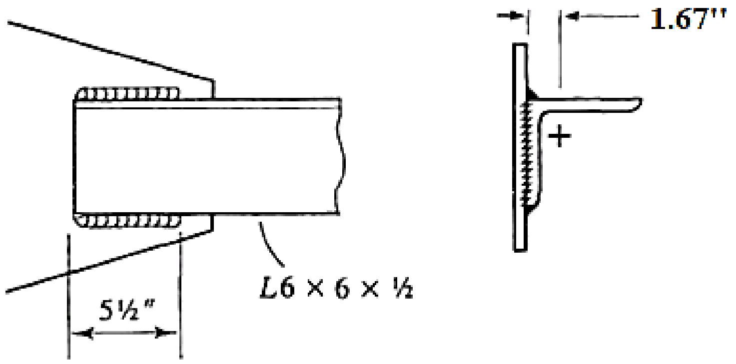
Use the larger U which is 0.722

$$An = Ag - n\ d_h\ t$$

$$An = 5.77 - 2 \times \left(\frac{5}{8} + \frac{1}{8}\right) \times \frac{1}{2} = 5.02\ in^2$$

$$Ae = 5.02 \times 0.722 = 3.624\ in^2$$

Example No.3: Consider the welded single angle $L6 \times 6 \times \frac{1}{2}$ tension member made from A36 steel shown below. Calculate the tension design strength.



Solve:

1) Steel and Section Properties

$$A36: Fy = 36\ ksi, Fu = 58\ ksi\ (Table\ 2-3)$$

$$L6 \times 6 \times \frac{1}{2}:\ Ag = 5.77\ in^2,\ \ t = \frac{1''}{2}\ ,\ \ \bar{x} = 1.67''$$

2) Design strength

$$Pu \leq \emptyset t\ Pn$$

From gross area:

$$\emptyset t\ Pn = 0.9\ Fy\ Ag = 0.9 \times 36 \times 5.77 = 186.95\ kips$$

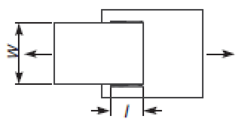
From effective area:

$$\emptyset t\ Pn = 0.75\ Fu\ Ae$$

For welded: $Ae = U \cdot Ag,\quad U = 1 - \frac{\bar{x}}{\ell}\quad Case\ 2$

$$U = 1 - \frac{1.67}{5.5} = 0.696 \approx 0.7$$

or

4	Plates where the tension load is transmitted by longitudinal welds only.	$l \geq 2w \ldots U = 1.0$ $2w > l \geq 1.5w \ldots U = 0.87$ $1.5w > l \geq w \ldots U = 0.75$	

$$\ell = 5.5,\quad w = 6\quad Case\ 4$$

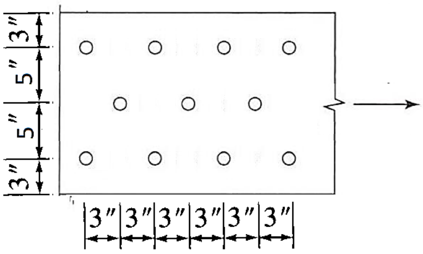
$1.5w = 9 \geq \ell \geq w = 6 \qquad \therefore \; U = 0.75$

Use large value $U = 0.75$

$Ae = 0.75 \times 5.77 = 4.33$

$\emptyset t \; Pn = 0.75 \times 58 \times 4.33 = 188.36 \; kips$

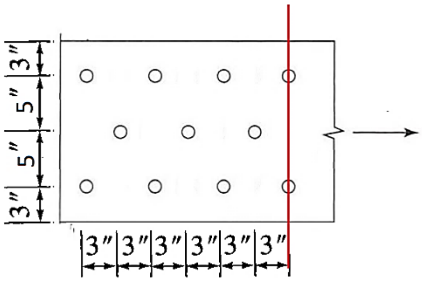
Example No. 4: Compute the smallest net area for the plate shown in Figure. The holes are $(1'')$ diameter bolts. Plate thickness is $(3/4'')$.



Solve:

$Ag = 16 \times \frac{3}{4} = 12 \; in^2$

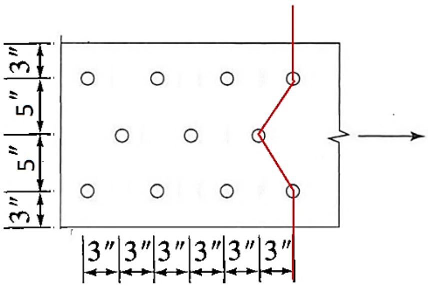
Path 1:



$An = Ag - n \, d_h \, t$

$An = 12 - 2 \times \left(1 + \frac{1}{8}\right) \times \frac{3}{4} = 10.313 \; in^2$

Path 2:



$A_n = A_g - n \, d_h \, t + \sum \frac{s^2}{4 \, g} t$

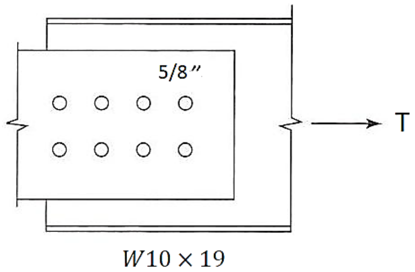
$A_n = 12 - 3 \times \left(1 + \frac{1}{8}\right) \times \frac{3}{4} + \left(2 \; \frac{3^2}{4 \times 5}\right) \times \frac{3}{4}$

$An = 12 - 2.531 + 0.675$

$= 10.14 \; in^2$ $(\textbf{Control})$

Maryam Hameed Nasir

Example No. 5: A $W10\times19$ is connected by 8 bolts in webs arranged in two rows as shown in Figure if the section is made from A992, and loaded by tension force (Dead load= 70 kips, Live load= 100 kips). Check the adequacy of the section by using **LRFD method**. The holes are made for $(5/8)$ in diameter bolts.



Solve:

1) Steel and Section Properties

$Fy = 50\ ksi, Fu = 65\ ksi\ (Table\ 2-3)$

$Ag = 5.62\ in^2, tw = 0.25\ in$

2) Ultimate Applied Load

$Pu = 1.2\ PD + 1.6\ PL = 1.2\times70 + 1.6\times100 = 244\ kips$

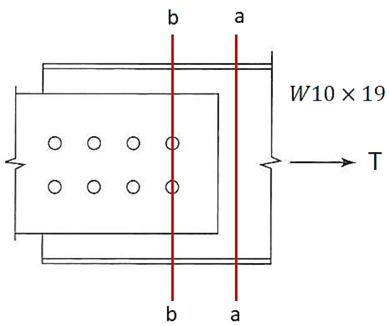
3) Design strength

$Pu \le \emptyset t\ Pn$

From gross area:

$\emptyset t\ Pn = 0.9\ Fy\ Ag = 0.9\times50\times5.62 = 252.9\ kips > 244\ kips$ ∴ ***ok***

From effective area:



$\emptyset t\ Pn = 0.75\ Fu\ Ae$

$Ae = U\cdot An,\quad U = 0.7\ (Case\ 7)\ Table\ D3.1$

$An = Ag - n\ d_h\ t = 5.62 - 2\left(\frac{5}{8}+\frac{1}{8}\right)\times0.25$

$= 5.245\ in^2$

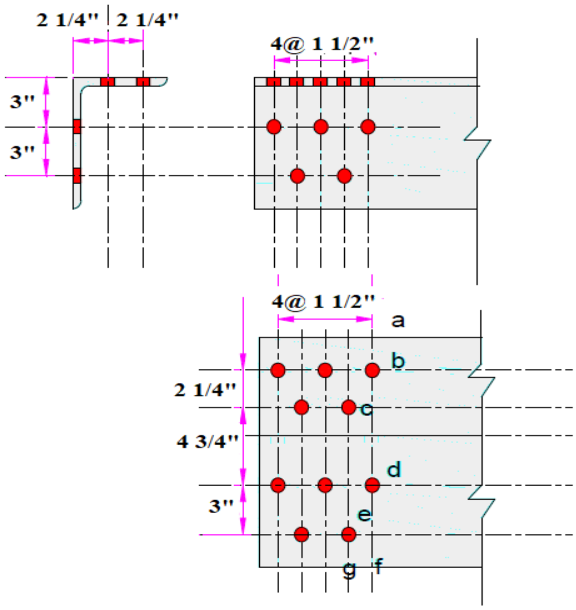
$Ae = 0.7\times5.245 = 3.6715\ in^2$

$\emptyset t\ Pn = 0.75\times65\times3.6715 = 178.99 < 244\ kips$ ∴ ***Not ok***

Example No. 6: A single angle $\left(L\ 8\ \times\ 6\ \times \frac{1}{2}\right)$ with staggered fastener in each leg as shown in figure. A36 steel is used and holes with $(7/8\ \ in)$ bolts diameter.

A) What is the allowable strength for ASD?

B) What is the design strength for LRFD?



Solve:

Steel and Section Properties

$Fy = 36\ ksi,\ \ Fu = 58\ ksi,\ \ Ag = 6.75\ in^2$

Based on gross area:

A) ASD

$$\frac{Pn}{\Omega t}\ =\ 0.6 * Fy * Ag = 0.6 * 36 * 6.75 = 145.8\ kips$$

B) LRFD

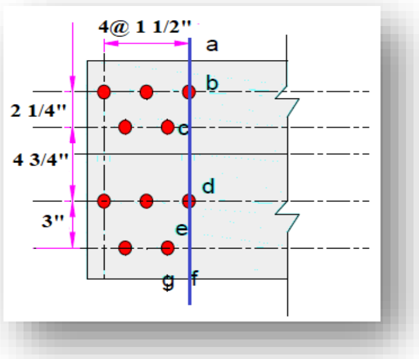
$$\emptyset t\ Pn\ \ = 0.9\ Fy\ Ag = 0.9 * 36 * 6.75 = 218.7\ kips$$

Based on net area:

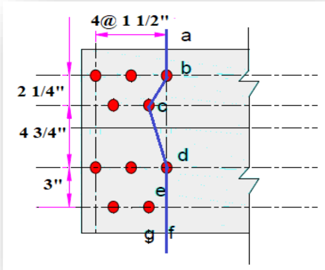
Path 1 (abdf):

$$An = Ag - n\ d_h\ t$$

$$An = 6.75 - 2\left(\frac{7}{8} + \frac{1}{8}\right) \times \frac{1}{2} = 5.75\ in^2$$



Path 2 (abcdf):

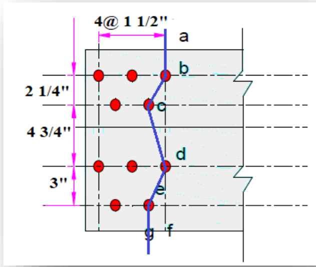


$$A_n = A_g - n\, d_h\, t + \sum \frac{s^2}{4\, g} t$$

$$A_n = 6.75 - 3\left(\frac{7}{8} + \frac{1}{8}\right) \times \frac{1}{2} + \left(\frac{1.5^2}{4 \times 2.25} + \frac{1.5^2}{4 \times 4.75}\right) \times \frac{1}{2}$$

$$A_n = 5.43\ in^2$$

Path 3 (abcdeg):

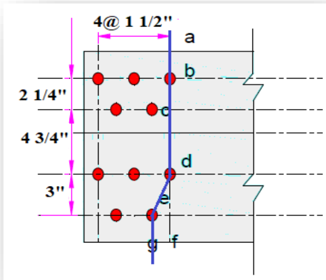


$$A_n = A_g - n\, d_h\, t + \sum \frac{s^2}{4\, g} t$$

$$An = 6.75 - 4\left(\frac{7}{8} + \frac{1}{8}\right) \times \frac{1}{2} + \left(\frac{1.5^2}{4 \times 2.25} + \frac{1.5^2}{4 \times 4.75} + \frac{1.5^2}{4 \times 3}\right) \times \frac{1}{2}$$

$An = 5.03 \quad in^2$ **(Control)**

Path 4 (abdeg):



$$A_n = A_g - n\, d_h\, t + \sum \frac{s^2}{4\, g} t$$

$$An = 6.75 - 3 \times \left(\frac{7}{8} + \frac{1}{8}\right) \times \frac{1}{2} + \left(\frac{1.5^2}{4 \times 3}\right) \times \frac{1}{2}$$

$$An = 5.34\ in^2$$

A) ASD

$Pn/\Omega_t = 0.5\ Fu\ Ae$

$Ae = U \cdot An, \qquad U = 1$

$Pn/\Omega_t = 0.5 \times 58 \times 5.03 = 145.87\ kips$

B) LRFD

$\emptyset t\ Pn = 0.75\ Fu\ Ae = 0.75 * 58 * 5.03 = 218.8\ kips$

For safe design, we choose the lowest value which is:

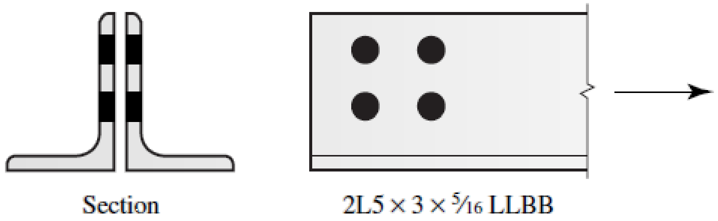
145.8 *kips* by using **ASD** Method

218.7 *kips* by using **LRFD** Method

Example No. 7: A double angle shape is shown in Figure. The steel is A36, and the holes are for $1/2''$ diameter bolts. Assume that $A_e = 0.75\ A_n$.

a. Determine the design tensile strength for LRFD.

b. Determine the allowable strength for ASD.



Solve:

ملاحظة: هنالك طريقتين لحل مسائل الdouble angle :

الطريقة الأولى: اعتبارها زاوية واحدة single angle ومضاعفة كل النتائج كما في المثال

الطريقة الثانية: اعتبارها شكلين منذ البداية.

في كلتا الحالتين خواص double angle من ناحية المساحة وإلى آخره يتم إيجادها من الكود مباشرة

Steel and Section Properties

$Fy = 36\ ksi,\quad Fu = 58\ ksi\ (Table\ 2-3),\quad Ag = 2.41\ in^2$

a. The design tensile strength for LRFD:

From gross area:

$\emptyset t\ Pn = 0.9\ Fy\ Ag = 0.9 \times 36 \times 2 \times 2.41 = 156.168\ kips$

From effective area:

$\emptyset t\ Pn = 0.75\ Fu\ Ae$

$Ae = 0.75\ An$ **From Example**

$$An = Ag - n\ d_h\ t = 2.41 - 2 \times \left(\frac{1}{2} + \frac{1}{8}\right) \times \frac{5}{16} = 2.02\ in^2$$

$Ae = 0.75 \times 2.02 = 1.515\ in^2$

$\emptyset t\ Pn = 0.75 \times 58 \times 2 \times 1.515 = 131.805\ kips$ **Control**

b. The allowable strength for ASD:

From gross area:

$$\frac{Pn}{\Omega t} = 0.6\,Fy\,Ag = 0.6 \times 36 \times 2 \times 2.41 = 104.11\,kips$$

From effective area:

$$\frac{Pn}{\Omega t} = 0.5\,Fu\,Ae$$

$Ae = 0.75\,An$ **From Example**

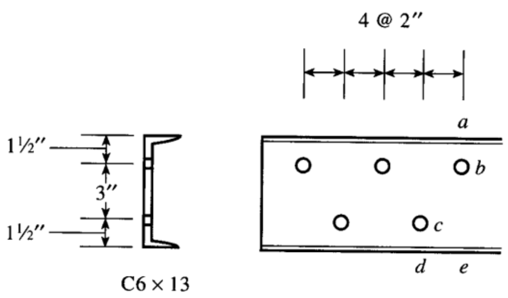
$$An = Ag - n\,d_h\,t = 2.41 - 2 \times \left(\frac{1}{2} + \frac{1}{8}\right) \times \frac{5}{16} = 2.02\,in^2$$

$$Ae = 0.75 \times 2.02 = 1.515\,in^2$$

$$\frac{Pn}{\Omega t} = 0.5 \times 58 \times 2 \times 1.515 = 87.87\,kips$$ **Control**

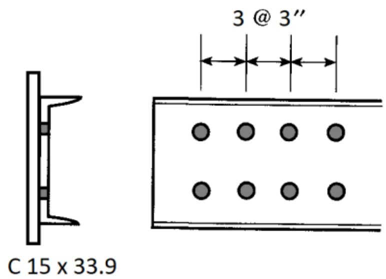
Problem:

1. Determine the smallest net area for the sections shown. The holes are for **5/8"** diameter bolts.



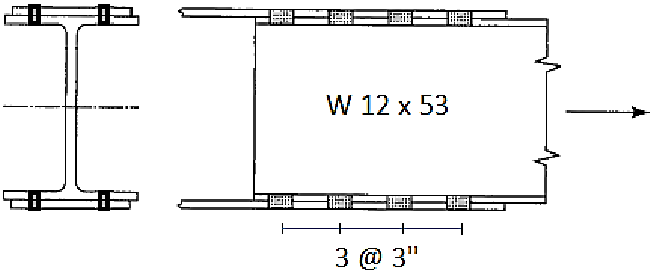
Ans: $An = 3.30\,in^2$

2. A single - channel tension member, a **C15×33.9**, is connected to a gusset plate with **3/4"** diameter bolts as shown in Figure below. Determine the maximum tensile strength by using **LRFD** method and **A36** steel material.



Ans: $\emptyset t\;Pn = 324\,kips$

3. A W-shape member **(W12×53)** has connected by two rows of (**4∅1"**) diameter bolts in each flange as shown in Figure below. Determine the maximum tensile strength by using **LRFD** method and **A992** steel material.

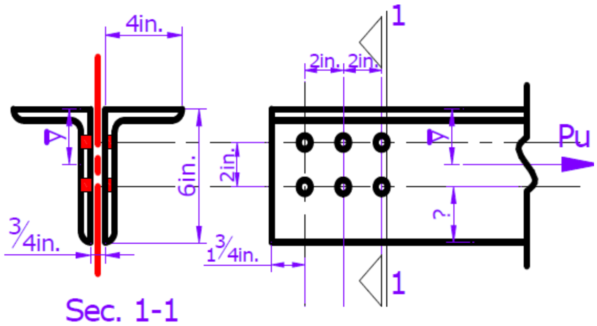


Ans: $\emptyset t\ Pn = 570.37\ kips$

4. Double steel angles **(2 L6×4×5/16)** using **A242** steel subjected to tensile load. Holes are for bolt diameter **7/8"**. Determine:

a) The tension reduction factor U.

b) The ultimate tensile load Pu using **LRFD** method.



Ans: $U = 0.771, \quad \emptyset t\ Pn = 194.67\ kips$