Example 1:

Design a double angle tension member with a bolted end connection

Given:

Pu= 350 Kn

Steel A36 →F_y=250 Mpa , F_u=400 Mpa

A325 Bolts A36 →F_{ub}=620 Mpa , F_{vb}=400 Mpa

Consider the connection is slip critical connection with μ =0.5 , and with standard holes.

Solution :-

- **For Bolts:**

a) Slip critical connection

$$\emptyset P_n = \emptyset * 1.13 * \mu * 0.7 * (\pi * \frac{d^2{}_b}{4}) * F_{ub} * N_b * N_s \geq P_u$$

$$\emptyset R_n = 1 * 1.13 * 0.5 * 0.7 * \left(\pi * \frac{d^2{}_b}{4}\right) * 620 * N_b * 2 \geq 350 * 10^3$$

$$d^2{}_b * N_b \geq 909.14$$

b) Shearing strength of bolts:

$$\emptyset P_n = 0.75 * F_{vb} * (\pi * \frac{d^2{}_b}{4}) * N_b * N_s \geq P_u$$

$$\emptyset P_n = 0.75 * 400 * \left(\pi * \frac{d^2{}_b}{4}\right) * N_b * 2 \geq 350 * 10^3$$

$$d^2{}_b * N_b \geq 743.1$$

$$d^2{}_b * N_b \geq 909.14 \ \ Governs\ the\ design\ of\ bolts$$

d_b	N_b	Use
16	3.55	4
18	2.81	3
20	2.27	3

Chose 4 bolts with diameter d_b=16 mm

Spacing (S) = 3 d_b →6 d_b Use 5d_b=80 mm   Le=40mm

c) Bearing strength of bolts:

$$\emptyset P_n = 0.75 * 2.4 * F_u * d_b * t_{min} * N_b \geq P_u$$

$$\emptyset P_n = 0.75 * 2.4 * 400 * 16 * t_{min} * 4 \geq 350 * 10^3$$

$$t_{min} = \begin{bmatrix} For\ one\ angle = \frac{7.6}{2} = 3.8\ mm \\ For\ guest\ plate\ = 7.6\ mm \end{bmatrix}$$

Choose angle thickness =6.4 mm (from LRFD)
And guest plate thickness =12 mm

○ For double Angle:

a) Gross yielding design strength:

$$\emptyset_t P_n = \emptyset_t A_g F_y = 0.9 \times A_g \times 250 \geq 350 * 10^3$$

$$A_g \geq 1555.56\ mm^2$$

b) Net section fracture strength:

Assume U = 0.85 for $N_b \geq 3$

$$A_n = A_g - \sum (d_b + 3)t$$

$$A_n = A_g - (2 \times 19 \times 6.4) = (A_g - 243.2)\ mm^2$$

$$A_e = UA_n$$

$$A_e = 0.85 \times (A_g - 243.2)$$

$$\emptyset_t P_n = 0.75 \times 0.85 \times (A_g - 243.2) \times 400 \geq 350 * 10^3$$

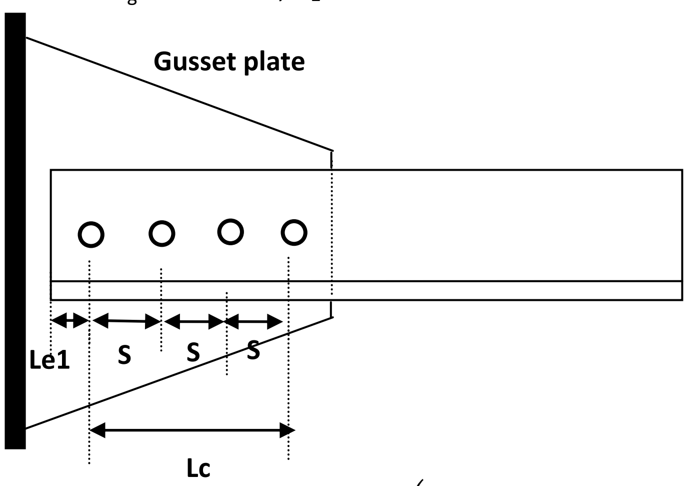
$$A_g \geq 1615.75\ mm^2$$

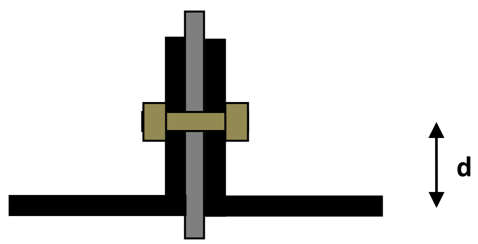
Therefore, $A_g \geq 1615.75\ mm^2$ *governs the design of angles*

$$Area\ of\ one\ angle \geq \frac{1615.75}{2} = 807.87\ mm^2$$

From LRFD choose angle $76X76X6.4$

A_g= 932 mm^2, X_1= 21.4 mm





$$g = \frac{\sum A * d}{\sum A} = \frac{\left((76 - 6.4) * 6.4 * \frac{6.4}{2}\right) + \left(38 * 6.4 * \frac{38}{2}\right)}{\left((76 - 6.4) * 6.4\right) + (38 * 6.4)} = 8.8$$

$x_2 = 38 - 8.8 = 29.2\ mm$

$\bar{x}\ is\ the\ larger\ of\,(\ x1, x2)$

$U = 1 - \frac{29.2}{240} = 0.88 < 0.9$

Recalculate the Net section fracture strength:

$$A_n = 932 - (2 \times 19 \times 6.4) = 681.12\ mm^2$$
$$\emptyset_t P_n = 0.75 \times 0.85 \times (A_g - 243.2) \times 400 \geq 350 * 10^3$$
$$\emptyset_t P_n = 2 * 0.75 \times 0.88 \times 681.12 \times 400 = 359.6\ KN \geq 350\ KN$$

c) Block shear strength:

$l_v = 2 * (3 * S + Le1) = 560\ mm$

$l_t = 2 * 38 = 76mm$

$A_{gt} = 76 \times 6.4 = 486.64\ mm^2$

$A_{nt} = 486.4 - 2 * (0.5 \times 19 \times 6.4) = 364.8\ mm^2$

$A_{gv} = 560 \times 6.4 = 3584\ mm^2$

$A_{nv} = 3584 - 2 * (3.5 \times 19 \times 6.4) = 2732.8\ mm^2$

$0.6F_u A_{nv} = 0.6 \times 400 \times 2732.8 \times 10^{-3} = 655.872\ kN$

$F_u A_{nt} = 400 \times 364.8 \times 10^{-3} = 145.92\ kN$

$0.6F_u A_{nv} > F_u A_{nt}$

$\therefore \emptyset_t R_n = \emptyset_t [0.6F_u A_{nv} + F_y A_{gt}]$

$$\therefore \emptyset_t R_n = 0.75[0.6 \times 400 \times 2732.8 + 250 \times 486.64] \times 10^{-3}$$
$$= \mathbf{583.149\ kN} \geq 350\ KN$$

Example 2:

Design a single channel tension member with a bolted end connection

Given:

Pu= 450 Kn

Steel A36 →F_y=250 Mpa , F_u=400 Mpa

A325 Bolts A36 →F_{ub}=620 Mpa , F_{vb}=400 Mpa

Consider the connection is slip critical connection with μ =0.5 , and with standard holes.

Solution :-

For Bolts:

a) Slip critical connection

$$\emptyset P_n = \emptyset * 1.13 * \mu * 0.7 * (\pi * \frac{d^2{}_b}{4}) * F_{ub} * N_b * N_s \geq P_u$$

$$\emptyset R_n = 1 * 1.13 * 0.5 * 0.7 * \left(\pi * \frac{d^2{}_b}{4}\right) * 620 * N_b * 1 \geq 450 * 10^3$$

$$d^2{}_b * N_b \geq 2337.79$$

b) Shearing strength of bolts:

$$\emptyset P_n = 0.75 * F_{vb} * (\pi * \frac{d^2{}_b}{4}) * N_b * N_s \geq P_u$$

$$\emptyset P_n = 0.75 * 400 * \left(\pi * \frac{d^2{}_b}{4}\right) * N_b * 1 \geq 450 * 10^3$$

$$d^2{}_b * N_b \geq 1910.82$$

$$d^2{}_b * N_b \geq 2337.79 \ \ \textit{Governs the design of bolts}$$

d_b	N_b	Use
16	9.13	10
18	7.22	8
20	5.84	6

Chose 6 bolts with diameter d_b=20 mm

Spacing (S) = 3 d_b →6 d_b Use 5d_b=100 mm   Le=50mm

c) Bearing strength of bolts:

$$\emptyset P_n = 0.75 * 2.4 * F_u * d_b * t_{min} * N_b \geq P_u$$

$$\emptyset P_n = 0.75 * 2.4 * 400 * 20 * t_{min} * 6 \geq 350 * 10^3$$

$$t_{min} = \begin{bmatrix} For\ channel = 5.21\ mm \\ For\ guest\ plate\ = 5.21\ mm \end{bmatrix}$$

Choose channel thickness =7.9 mm (from LRFD)
And guest plate thickness =12 mm

○ For channel:

a)Gross yielding design strength:

$$\emptyset_t P_n = \emptyset_t A_g F_y = 0.9 \times A_g \times 250 \geq 450 * 10^3$$
$$A_g \geq 2000\ mm^2$$

b) Net section fracture strength:

Assume U = 0.85 for $N_b \geq 3$

$$A_n = A_g - \sum (d_b + 3)t$$
$$A_n = A_g - (2 \times 23 \times 7.9) = (A_g - 363.4)\ mm^2$$
$$A_e = UA_n$$

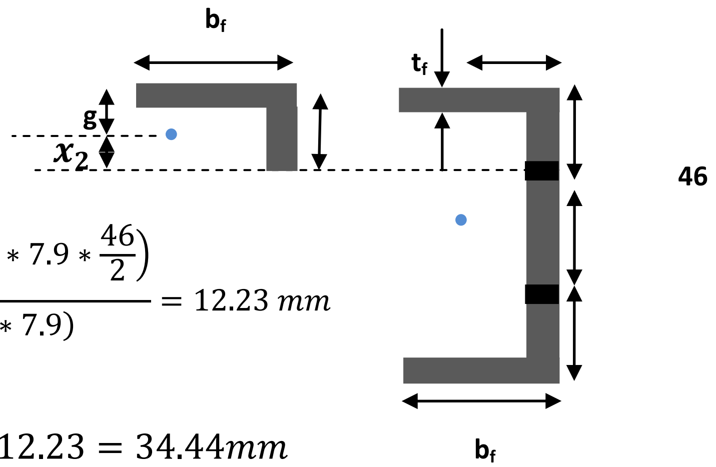
$$A_e = 0.85 \times (A_g - 243.2)$$

$$\emptyset_t P_n = 0.75 \times 0.85 \times (A_g - 363.4) \times 400 \geq 450 * 10^3$$
$$A_g \geq 2128.11 mm^2$$

Therefore, $A_g \geq 2188.11\ mm^2\ governs\ the\ design\ of\ channel$

$$From\ LRFD\ \ choose\ channel\ C\ 150X17.9$$

A_g= 2260 mm^2, X_1= 17.8 mm , t_w=7.9 mm, t_f=9.5 mm ,b_f=63 mm



$$g = \frac{\sum A * d}{\sum A} = \frac{\left((63 - 7.9) * 9.5 * \frac{9.5}{2}\right) + \left(46 * 7.9 * \frac{46}{2}\right)}{\left((63 - 7.9) * 9.5\right) + (46 * 7.9)} = 12.23\ mm$$

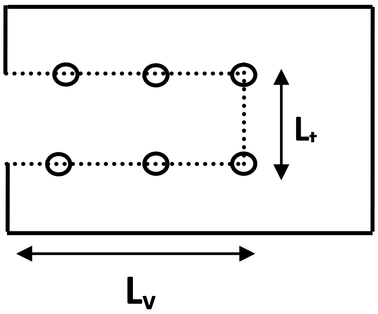
$$x_2 = h - g = 46 - 12.23 = 34.44mm$$

$$\bar{x}\ is\ the\ larger\ of\ (x1, x2)$$
$$U = 1 - \frac{34.44}{250} = 0.865 < 0.9$$

Recalculate the Net section fracture strength:

$$A_n = 2260 - (2 \times 23 \times 7.9) = 1896.6\ mm^2$$
$$\emptyset_t P_n = 0.75 \times 0.865 \times 1896.6 \times 400 = 492.17\ KN \geq 450\ KN$$

C)Block shear strength:



$l_v = 2 * (2 * S + Le1) = 500\ mm$
$l_t = 60mm$
$A_{gt} = 60 \times 7.9 = 474\ mm^2$
$A_{nt} = 474 - (1 \times 23 \times 7.9) = 292.3\ mm^2$
$A_{gv} = 500 \times 7.9 = 3950\ mm^2$
$A_{nv} = 3950 - (5 \times 23 \times 7.9) = 3041.5\ mm^2$

$0.6F_u A_{nv} = 0.6 \times 400 \times 3041.58 \times 10^{-3} = 729.96\ kN$
$F_u A_{nt} = 400 \times 292.3 \times 10^{-3} = 116.92\ kN$
$0.6F_u A_{nv} > F_u A_{nt}$
$\therefore \emptyset_t R_n = \emptyset_t [0.6F_u A_{nv} + F_y A_{gt}]$
$\therefore \emptyset_t R_n = 0.75[0.6 \times 400 \times 3041.58 + 250 \times 474] \times 10^{-3}$
$\emptyset_t R_n = \mathbf{636.345\ kn} \geq 450\ Kn$

○ For Plate:

a) Gross yielding design strength:

$\emptyset_t P_n = \emptyset_t A_g F_y = 0.9 \times A_g \times 250 \geq 450 * 10^3$
$A_g \geq 2000\ mm^2$

b) Net section fracture strength:

$A_n = A_e = A_g - (2 \times 23 \times 12) = A_g - 552$

$\emptyset_t P_n = \emptyset_t A_e F_u = 0.75 \times (A_g - 552) \times 400 \geq 450 * 10^3$
$A_g \geq 2052\ mm^2$

Therefore, $A_g \geq 2052\ mm^2$ *governs the design of plate*

$$L \geq \frac{2052}{12} \rightarrow L \geq 171\ mm \quad use\ plate\ (175 * 12)$$

c) Block shear strength:

Section 1:

$l_v = 2 * (2 * S + Le1) = 500\ mm$
$l_t = 60mm$
$A_{gt} = 60 \times 12 = 720\ mm^2$
$A_{nt} = 720 - (1 \times 23 \times 12) = 444\ mm^2$
$A_{gv} = 500 \times 12 = 6000\ mm^2$
$A_{nv} = 6000 - (5 \times 23 \times 12) = 4620\ mm^2$

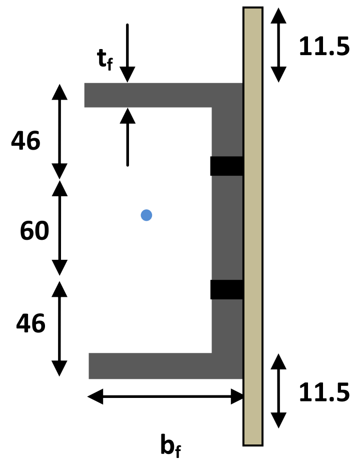
$0.6F_u A_{nv} = 0.6 \times 400 \times 4620 \times 10^{-3} = 1108.8\ kN$

$F_u A_{nt} = 400 \times 444 \times 10^{-3} = 177.6\ kN$
$0.6 F_u A_{nv} > F_u A_{nt}$
$\therefore \emptyset_t R_n = \emptyset_t [0.6 F_u A_{nv} + F_y A_{gt}]$

$$\therefore \emptyset_t R_n = 0.75[0.6 \times 400 \times 4620 + 250 \times 720] \times 10^{-3}$$

$$\emptyset_t R_n = \mathbf{966.6\ kn} \geq 450\ Kn$$

Section 2



$l_v = (2 * S + Le1) = 250\ mm$
$l_t = 60 + 46 + 14 = 117.5 mm$
$A_{gt} = 117.5 \times 12 = 1410\ mm^2$
$A_{nt} = 1410 - (1.5 \times 23 \times 12) = 996\ mm^2$
$A_{gv} = 250 \times 12 = 3000\ mm^2$
$A_{nv} = 3000 - (2.5 \times 23 \times 12) = 2310\ mm^2$

$0.6 F_u A_{nv} = 0.6 \times 400 \times 2310 \times 10^{-3} = 554.4\ kN$
$F_u A_{nt} = 400 \times 996 \times 10^{-3} = 398.4\ kN$
$0.6 F_u A_{nv} > F_u A_{nt}$
$\therefore \emptyset_t R_n = \emptyset_t [0.6 F_u A_{nv} + F_y A_{gt}]$

$$\therefore \emptyset_t R_n = 0.75[0.6 \times 400 \times 2310 + 250 \times 1410] \times 10^{-3}$$

$$\emptyset_t R_n = \mathbf{680.175\ kn} \geq 450\ Kn$$