Design of Tension Member with Bolted Connection

Example:

Design a double angle tension member with a bolted end connection
Given : Pu = 500 kN
Steel A36, Fy =250 MPa, Fu = 400 MPa
A325 Bolts, Fub= 620 MPa, Fvb= 400 MPa
Consider the connection is Slip Critical Connection with μ = 0.50, and with standard holes

Solution :

1- Estimation of Bolts (as Slip Critical Connection)

a- Slip Critical Connection

$$Ø R_n = Ø * 1.13 * \mu * 0.7 * (\pi * d^2_b/4) * Fu_b * N_b * Ns$$

$$\phi \; Rn = 1.0 \times 1.13 \times 0.50 \times 0.70 \times (\pi * d^2_b/4) \times 620 \times N_b \times 2 \geq 500 \times 10^3$$

$$\boxed{d^2_b \times N_b \geq 1298}$$

b- Bolt shear Failure

$$Ø R_n = 0.75 * Fv_b * A_b * Ns * Nb$$

$$Ø R_n = 0.75 \times 400 \times (\pi * d^2_b/4) \times N_b \times 2 \geq 500 \times 10^3$$

$$\boxed{d^2_b \times N_b \geq 1061.03}$$

Then $\boxed{d^2_b \times Nb \geq 1298 \text{ Governs the design of bolts}}$

If d_b = 16 mm, then, N_b = 5.07, Take N_b = 6 bolts
If d_b = 18 mm, then, N_b = 4.01, Take N_b = 5 bolts
If d_b = 20 mm, then, N_b = 3.25, Take N_b = 4 bolts

Choose 4 bolts with diameter d_b = 20 mm

Spacing (S) = 3 d → 6 d = 60mm → 120 mm, take S = 80 mm
Take edge distance (Le) = 40 mm

c – Bearing failure

$$\text{Ø } R_n = 0.75 * 2.4 * Fu * d_b * t_{min} * N_b$$

$$\text{Ø } R_n = 0.75 \text{ x } 2.4 \text{ x } 400 \text{ x } 20 \text{ x } t_{min} \text{ x } 4 \geq 500 \text{ x } 10^3$$

$t_{min} \geq 8.68$ mm, for one angle $t_{min} \geq 8.68/2 = 4.34$ mm,
for guest plate $t_{min} \geq 8.68$ mm

Choose angle thickness = 6.40 mm (from LRFD standard section tables)
And guest plate thickness = 12 mm

2- Estimation of Angle Sizes

a- Yielding of gross area

$$\text{Ø } R_n = 0.9 \text{ x Ag x Fy}$$
$$= 0.9 \text{ x Ag x } 250 \geq 500 \text{ x } 10^3$$

$Ag \geq 2222.2 \text{ mm}^2$

b- Fracture of net area

$$\text{Ø } R_n = 0.75 \text{ x } A_n \text{ x U x Fu,}$$

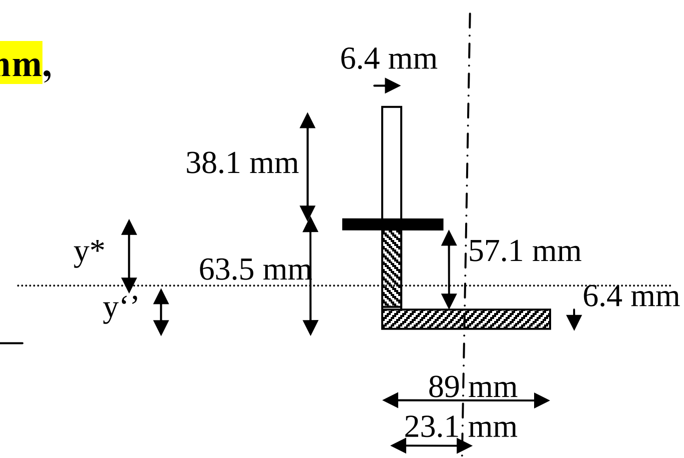
assume U = 0.85 for $N_b \geq 3$
$d_h = 20 + 3 = 23$ mm

$$= 0.75 \text{ x (Ag} - 2 \text{ x } 23 \text{ x } 6.40 \text{) x } 0.85 \text{ x } 400 \geq 500 \text{ x } 10^3$$

$Ag \geq 2255 \text{ mm}^2$

Therefore, $Ag \geq 2255 \text{ mm}^2$ governs the design of angles
Area of one angle $\geq 2255 / 2 = 1128 \text{ mm}^2$

From LRFD tables choose angle 102 x 89 x 6.40 mm,
Area gross = 1180 mm^2, c.g x = 23.1 mm
From Table 3.1, g = 2.5 in = 63.5 mm

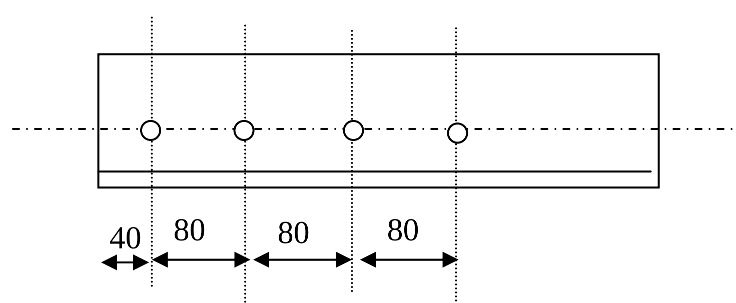


Recalculate the right value of U

$$y'' = \frac{(89 \text{ x } 6.4 \text{ x } 3.2) + (57.1 \text{ x } 6.4 \text{ x } 34.95)}{89 \text{ x } 6.4 + 57.1 \text{ x } 6.4}$$
$$= 15.60 \text{ mm}$$

$y^* = 63.5 - 15.60 = 47.90$ mm

$\bar{x}$ = larger of 23.1 mm or 47.90 mm



Lc = 3 x 80 = 240 mm

U = 1- 47.90 / 240 = 0.80 $\leq$ 0.90

Check fracture at effective area

$\text{Ø } R_n$= 0.75 x (1180 x 2 – 2 x 23 x 6.40)x 0.80 x 400 / 1000 = 495.744 kN < 500 kN
Not O.K

Use larger spacing, take S = 100 mm = 5d, and Le = 50 mm
Lc = 3 x100 = 300 mm, U = 1 – 47.90 / 300 = 0.84
Therefore,

$\text{Ø } R_n$ = 0.75 x (1180 x 2 – 2 x 23 x 6.40) x 0.84 x 400 / 1000 = 520 kN > 500 kN
O.K

3- Check Block Shear Rupture of Angles

Lv = 3S + Le = 300 + 50 = 350 mm, A_{vg} = 350 x 6.4 x 2 = 4480 mm^2
A_{vn} = 4480 – 3.50 x 23 x 6.4 x 2 = 3449.6 mm^2

Lt = 38.1 mm , A_{tg} = 38.1 x 6.4 x 2 = 487.68 mm^2,
$A_{t\,n}$ = 487.68 – 0.5 x 23 x 6.40 = 414 mm^2
Fu A_{tn} = 165600 N, and 0.6 Fu A_{vn} = 827904 N

Therefore, 0.6 Fu A_{vn} > Fu A_{tn}, then.

$\text{Ø } R_n$ = 0.75 (827904 + 250 x 487.68) / 1000 = 712 kN > 500 kN O.K

Note: the strength of Guesst plae should also be checked to be ≥ 500 kN

Use double angles 102 x 89 x 6.40 with 4 M20 A325 bolts, with spacing 100 mm and edge distance = 50 mm, gage distance = 63.5 mm

Design of Tension Member with Welded Connection

Example:
Design a double angle tension member with a welded end connection
Given : Pu = 500 kN
Steel A36, Fy =250 MPa, Fu = 400 MPa
Use Weld, F_{EX} = 500 MPa

Solution :

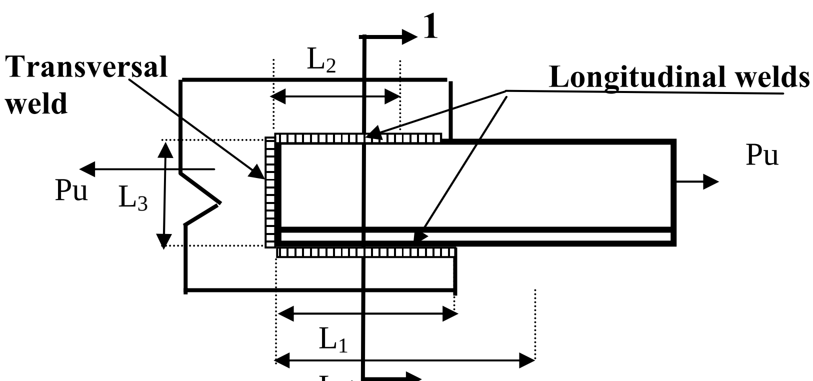
1- Assume that yielding on gross area governs the design

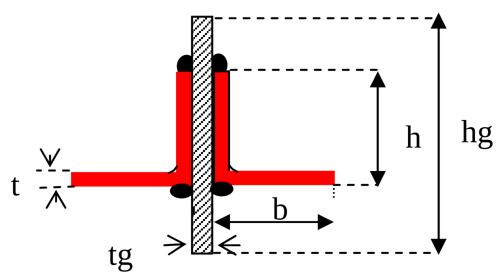
$$\text{Ø } R_n = 0.90 \text{ Fy Ag} = 0.9 \times 250 \times \text{Ag} \geq 500 \times 10^3$$

Ag ≥ 2222.2 mm^2 , therefore each angle gross area ≥ 1111.1 mm^2

From LRFD Tables, choose double angles 88.9 x 63.5 x 7.9 mm
Ag of one angle = 1148 mm^2

2- Estimation of weld Length (Take weld size = 6 mm)





section (1-1)

Longitudinal welds strength per unit length

a) Weld Fracture, $\text{Ø } R_n = 0.75 \times 0.6 \times F_{Ex} \times 0.707 \times S_w \times 2$
$= 0.75 \times 0.6 \times 500 \times 0.707 \times 6 \times 2 = 1909$ **N/mm**

b) Shear fracture of angles, $\text{Ø } R_n = 0.75 \times 0.6 \times Fu \times 2\, t_{angle}$
$= 0.75 \times 0.6 \times 400 \times 2 \times 7.90 = 2844$ **N/mm**

c) Shear rupture of guest plate (take t_{guesst} = 12 mm)
$\text{Ø } R_n = 0.75 \times 0.6 \times Fu \times t_{guesst}$
$= 0.75 \times 0.6 \times 400 \times 12 = 2160$ **N/mm**

Therefore the strength of longitudinal weld = 1909 N/mm

Transversal weld strength per unit length

a) **Weld fracture,** $\text{Ø } R_n = 0.75 \times 0.6 \times F_{Ex} \times 0.707 \times S_w \times 2 \times 1.5$
$= 0.75 \times 0.6 \times 500 \times 0.707 \times 6 \times 2 \times 1.5 = 2863.5$ **N/mm**

b) **Tensile rupture of guesst plate ,** $\text{Ø } R_n = 0.75 \times 0.6 \times F_u \times t_{guesst}$
$= 0.75 \times 0.6 \times 400 \times 12 = 3600$ **N/mm**

Therefore the strength of transversal weld = 2863.5 N/mm

Length of required welds

Take L3 = long angle leg = 88.90 mm, and take $L_1 = L_2$

Then resistance of welds = $88.9 \times 2863.5 + (2\, L_1)\, 1909 \geq 500 \times 10^3$

Therefore $L_1 = L_2 \geq 55.2$ **mm**

Take $L_1 = L_2 = 60$ **mm**

3- Check Tensile fracture of angles

c.g , x of angle = 16.17, $L_c = L_1 = 60$ **mm**

For both transversal and longitudinal welds, $U = 1 - (16.17 / 60) = 0.73$

Ag of two angles $= 1148 \times 2 = 2296\ mm^2$

$\text{Ø } R_n = 0.75 \times 400 \times (0.73 \times 2296) = 503\ kN > 500\ kN$ **O.K**

4- Check Block shear of angles

Lv = L1 = 60 mm , Av = 60 x 2 x 7.9 = 948 mm2

Lt = 88.9 – 7.90 = 81 mm, At = 81 x 2 x 7.90 = $1279.8\ mm^2$

0.6 Fu Av = 0.6 x 400 x 948 = 227520 N

Fu At = 400 x 1279.8 = 511920 N > 0.6 Fu Av

Therefore, $\text{Ø } R_n = 0.75\,(511920 + 0.6 \times 250 \times 948) / 1000 = 490.6\ kN < 500\ kN$ **Not O.K**

Therefore choose a larger longitudinal weld length, Take L1= L2 = 70 mm

Lv= L1 = 65 mm, Av = 70 x 2 x 7.9 = $1106\ mm^2$

0.6 Fu Av = 0.6 x 400 x 1106 = 265440 < Fu At

Therefore, $\text{Ø } R_n = 0.75\,(511920 + 0.6 \times 250 \times 1106) / 1000 = 508\ kN > 500\ kN$

O.K

Use double angles 88.9 x 63.5 x 7.9 with longitudinal welds $L_1 = L_2 = 70$ **mm, and** $L_3 = 88.90$ **mm**