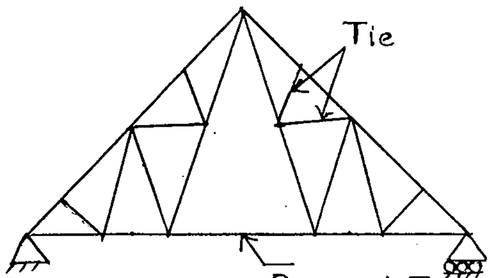
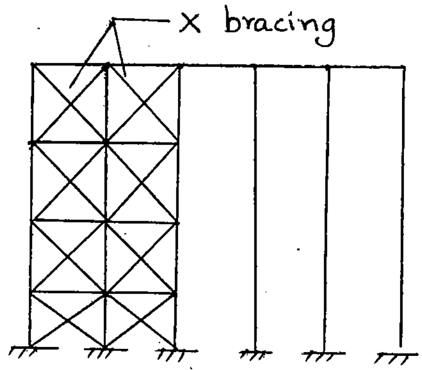
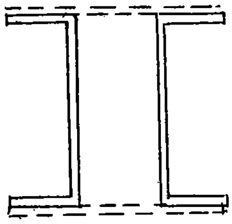
5. TENSION MEMBERS

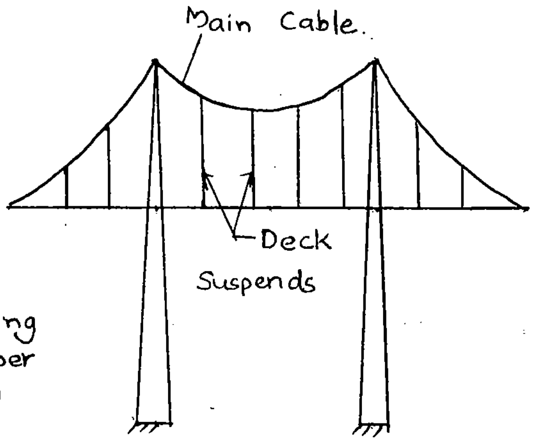


ROOF TRUSS

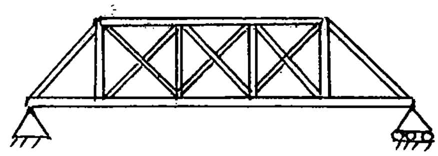


BRACED FRAME

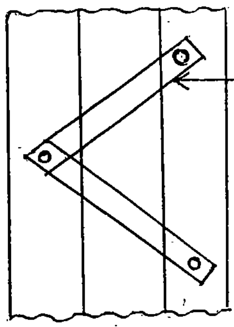




SUSPENSION BRIDGE.



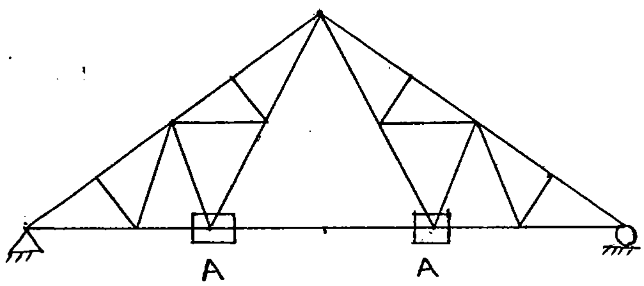
TRUSS BRIDGE

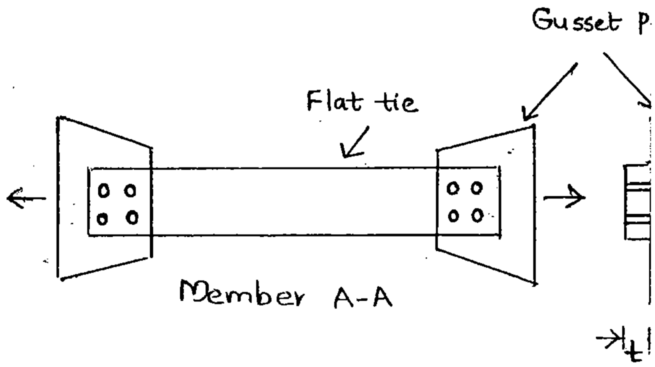


BUILT UP COLUMN WITH LACING SYSTEM

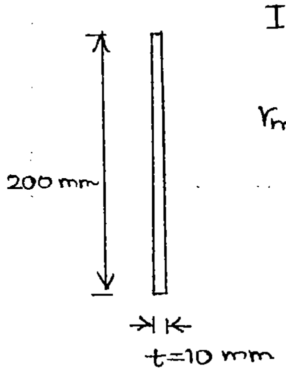
→ Types of Failures in a Tension Member:

- Gross section yielding failure (T_{dg})
- Net section rupture (or) fracture failure. (T_{dn})
- Block shear failure. (T_{db})





In olden constructions, flat members were used as tension members. Although flat members are strong in tension, they are weak in compression due to small value of radius of gyration. ($P_{cr} = \frac{\pi^2 EA}{(l/r)^2}$). So, angle sections now replace flat members as tension members.

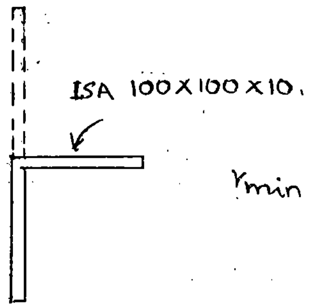


$$I_{min} = \frac{bt^3}{12}$$

$$r_{min} = \sqrt{\frac{I_{min}}{A}}$$

$$= \sqrt{\frac{bt^3}{12 \cdot bt}} = \frac{t}{\sqrt{12}}$$

$$= \frac{10}{\sqrt{12}} = 2.88 \text{ mm}.$$



$r_{min} = r_{vv}$

$= 19.1$ mm

In the above eg, angle section with c/s area as that of a flat member has more radius of gyration.

In flat members, load reversals and bolt holes are th factors of failures. But in angle sections, along with these two factors, eccentricity of loading (causing moment) must also be taken into consideration.

→ Design Tensile Strength of a Tension Member (T_d)

T_d is minimum of T_{dg} or T_{dn} or T_{db}.

* Based on Gross Section Yielding Failure, (T_{dg})

$$T_{dg} = \frac{A_g \cdot f_y}{\gamma_{m0}}$$

; A_g → gross sectional area of a member

f_y → yield strength of a material.

γ_{m0} → partial safety factor against yield stress (1.10)

* Based on Net Section Rupture (or) Fracture Failure (T_{dn})

(i) For Plates and Flats.

$$T_{dn} = \frac{0.9 \times A_n f_u}{\gamma_{m1}}$$

A_n → net sectional area = gross sectional area − Area of bolt hole

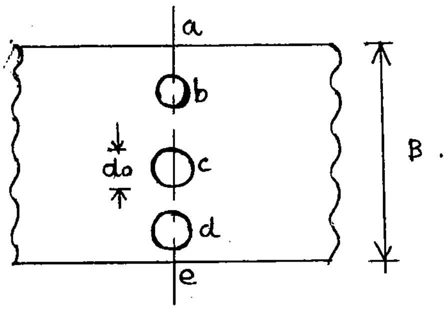
– For chain pattern of bolting:

$A_n = A_g$ − area of bolt holes.

Along section, a–b–c–d–e:

$= Bt - n d_o t$

$A_n = (B - n d_o) t$

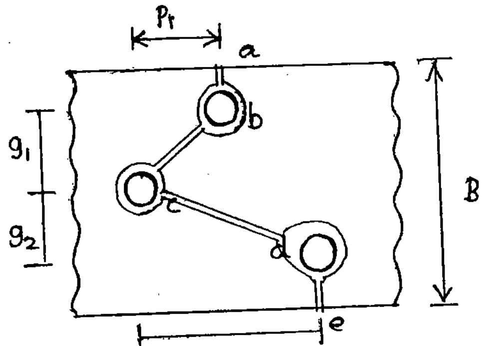


– For staggered (or) zig-zig pattern of bolting

Along section a–b–c–d–e,

area connections

$$A_n = (B - n d_o) t + \frac{P_1^2 t}{4 g_1} + \frac{P_2^2 t}{4 g_2}$$



P_1 & P_2 → staggered pitches

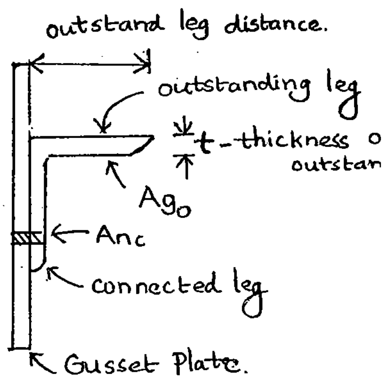
g_1 & g_2 → gauge distances.

▪ For n inclination, n number of area connections.

(ii) For Angle, Channel & Other types of Rolled Steel sections

A_{nc} = Net sectional area of connected leg

A_{go} = gross sectional area of outstanding leg.



$$T_{dn} = 0.9 A_{nc} \frac{f_u}{\gamma_{m1}} + \beta \cdot A_{go} \frac{f_y}{\gamma_{m0}}$$

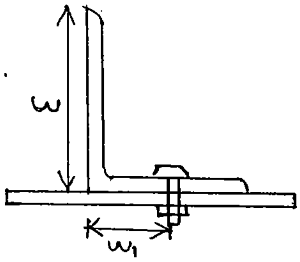
$$\beta = \left\{ 1.4 - 0.076 \left(\frac{w}{t}\right)\left(\frac{f_y}{f_u}\right)\left(\frac{b_s}{L_c}\right) \right\} \geq 0.7, \quad \leq \left(\frac{f_u}{f_y} \cdot \frac{\gamma_{m0}}{\gamma_{m1}}\right)$$

$b_s \rightarrow$ shear leg distance.

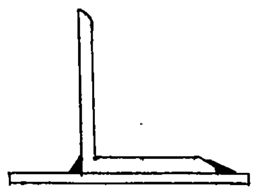
$L_c \rightarrow$ length of end connection

$w \rightarrow$ outstanding leg distance.

$t \rightarrow$ thickness of outstand.



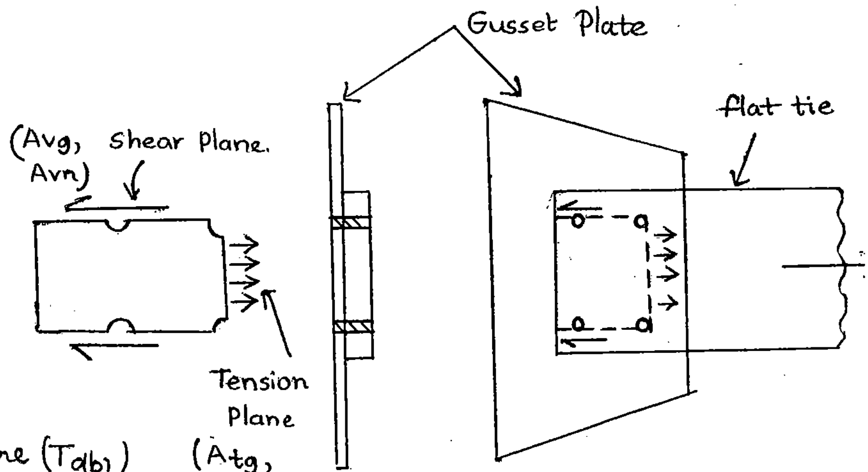
$b_s = w + w_1 - t$. (bolted angle)



$b_s = w$ (welded angle)

- It is better to use unequal angle section for better tensile strength. Longer leg is connected to gusset plate (higher A_{nc}) and correction factor (β) is reduced.

* Based on Block Shear Failure (T_{db})



– Shear yielding & Tension Plane rupture (T_{db1})

$$T_{db1} = \frac{A_{vg} f_y}{\sqrt{3} \cdot \gamma_{m0}} + 0.9 A_{tn} \frac{f_u}{\gamma_{m1}}$$

– Shear rupture & Tension Yield (T_{db2})

T_{db} : lesser of T_{db1} & T_{db2}

$$T_{db2} = 0.9 A_{vn} \frac{f_u}{\sqrt{3}\, \gamma_{m1}} + A_{tg} \cdot \frac{f_y}{\gamma_{m0}}$$

A_{vg} & $A_{vn} \rightarrow$ min gross and net area of shear plane resp'ly.

A_{tg} & $A_{tn} \rightarrow$ min gross and net area of tension plane resp'ly.

⊛ Design requirement for Safety of Tension member

- $T \leq T_d$:– min of $\begin{cases} T_{dg} \\ T_{dn} \\ T_{db} \end{cases}$

- λ of member $\leq \lambda_{limit}$

$\lambda_{limit} \rightarrow$ limiting slenderness ratio of tension member as per IS 800 : 2007

→ Design of Axially Loaded Tension Member

* Slenderness ratio of a Tension Member

$$= \frac{\text{unsupported length}}{\text{Min. radius of gyration}} = \frac{l}{r_{min.}}$$

* Limiting Slenderness Ratio (λ_{limit})

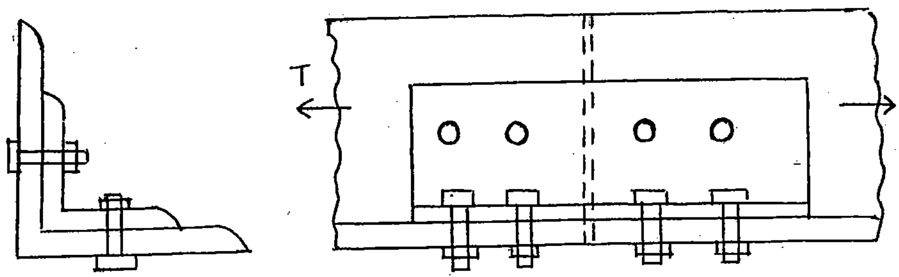
(i) A tension member is subjected to load (or) stress reversals due to loads other than wind (or) earthquake load — 180

(ii) A member used as tie in roof truss (or) in a bracing system subjected to load reversals due to loads resulting from wind (or) earthquake loads — 350

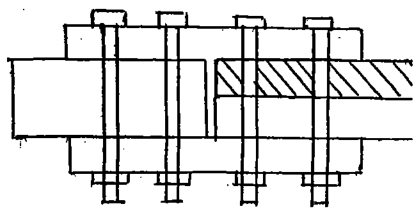
(iii) For any other tension member (other than pretensioned members) — 400

* Tension Splice

Tension splice is a joint for tension member normally used for extending length of a tension member (where the size available from Indian Rolling Mills are limited) and also used for joining two different sizes of tension members



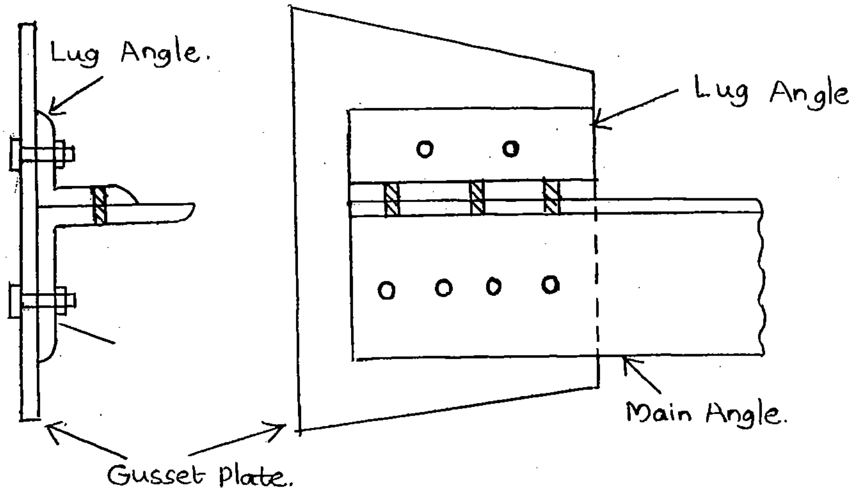
Tension Splice b/w two angle members



Tension splice b/w two diff. sizes of tension members

* Lug Angle.

Lug angle is a short length of an angle used at a joint location to join outstanding leg of an angle to the gusset plate (and also to join outstanding flange of a channel to the gusset plate) so that length of connection or joint can be reduced.



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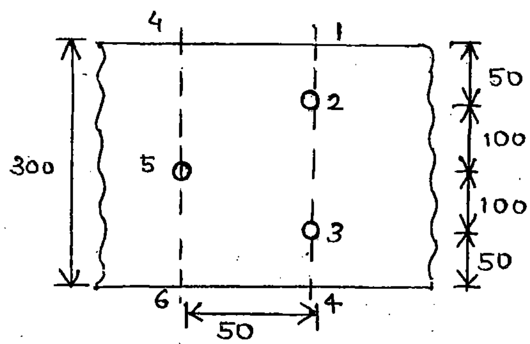
1. $B = 300\text{ mm}$, $t = 10\text{ mm}$, $d = 18\text{ mm}$.

Net sectional area of plate with one bolt hole,

$$A_n = (B - nd_o)t = (300 - 1\times20)\times10 = \underline{\underline{2800}}\text{ mm}^2$$

2. Hole diameter, $d_o = 25\text{ mm}$.



Failure sections are:

a) 1 – 2 – 3 – 4

b) 4 – 5 – 6

c) 1 – 2 – 5 – 6

d) 1 – 2 – 5 – 3 – 4

'An' along 1–2–3–4 : (chain pattern).

$$A_n = (300 - 2\times25)10$$
$$= \underline{\underline{2500}}\text{ mm}^2$$

Along 1-2-5-6 :

$$A_n = (B - n d_o)t + \frac{p^2 t}{4g}$$

$$= (300 - 2\times25)\,10 + \frac{50^2 \times 10}{4\times100} = \underline{\underline{2562.5}}\ mm^2$$

Along 1-2-5-3-4 :

$$A_n = (300 - 3\times25)\,10 + \frac{50^2\times10}{4\times100} + \frac{50^2\times10}{4\times100}$$

$$= \underline{\underline{2375}}\ mm^2$$

Effective sectional area $= \underline{\underline{2375}}\ mm^2$

04. $T_{dn} = 0.9\, A_n \frac{f_u}{\gamma_{m1}}$

$$A_n = (200 - 3\times18)\times12 = 1752\ mm^2$$

$$T_{dn} = 0.9\times1752\times\frac{410}{1.25} = \underline{\underline{517.19}}\ kN$$

05. $A = 1379\ mm^2,\ f_y = 250$

$$T_{dg} = \frac{A_g f_y}{\gamma_{mo}} = \frac{1379\times250}{1.1} = \underline{\underline{313.4}}\ kN$$

06. $f_u = 410$ MPa ; $f_y = 250$ MPa ; $d_o = 18$ mm

$T_{d} \rightarrow$ min of T_{dg} (or) T_{dn} (or) T_{db}

$d_o = 18$ mm

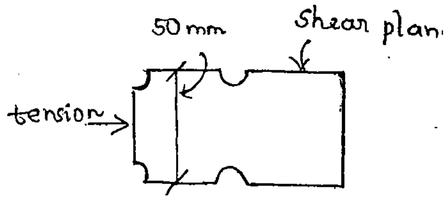
Min end distance, $e_{min} = 1.5\, d_o = 27$ mm.

$e_{provided} > e_{min}$. (no block shear failure).

$$T_{dg} = \frac{A_g f_y}{\gamma_{mo}} = \frac{120\times10\times250}{1.1} = \underline{\underline{272.7}}\ kN$$

$$T_{dn} = 0.9\frac{A_n f_u}{\gamma_{m1}} = 0.9\,(120 - 2\times18)\,10\times\frac{410}{1.25} = \underline{\underline{247.9}}\ kN$$

$A_{tg} = 50 \times 10 = 500 \ mm^2$



$A_{tn} = \left(50 - \frac{d_o}{2} - \frac{d_o}{2}\right) = (50 - 18)10 = 320 \ mm^2$

$A_{vg} = (50 + 35) \times 10 \times 2 = 1700 \ mm^2$

$A_{vn} = \left((50+35) - 18 - \frac{18}{2}\right) \times 10 \times 2 = 1160 \ mm^2$

Shear yield & Tension rupture (T_{db1}) :

$$T_{db1} = A_{vg} \frac{f_y}{\sqrt{3}\, \gamma_{mo}} + 0.9 A_{tn} \frac{f_u}{\gamma_{m1}}$$

$$= 1700 \times \frac{250}{\sqrt{3} \times 1.1} + 0.9 \times 320 \times \frac{410}{1.25} = \underline{317.53 \ kN}$$

Shear rupture & Tension yield (T_{db2}) :

$$T_{db2} = 0.9 A_{vn} \frac{f_u}{\sqrt{3}\, \gamma_{m1}} + A_{tg} \frac{f_y}{\gamma_{mo}}$$

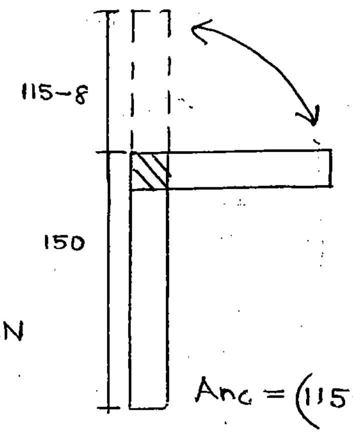
$$= 0.9 \times 1160 \times \frac{410}{\sqrt{3} \times 1.25} + \frac{500 \times 250}{1.1}$$

$$= 311 \ kN.$$

$T_{db} = \text{min of } T_{db1} \ \& \ T_{db2} = \underline{311 \ kN}$

$T_d = \underline{247} \ kN$

07 $f_u = 410 \ MPa, \ f_y = 250 \ MPa.$



$$T_{dg} = A_g \frac{f_y}{\gamma_{mo}}$$

$$= [(150 + 115 - 8) \times 8] \times \frac{250}{1.1} = \underline{467.7 \ kN}$$

$A_{nc} = \left(115 - \frac{8}{2}\right)$

$= 1168$

08. $T_{dn} = 0.9 A_{nc} \frac{f_u}{\gamma_{m1}} + \beta A_{go} \frac{f_y}{\gamma_{mo}}$

$$\beta = 1.4 - 0.076 \left(\frac{w}{t}\right)\left(\frac{f_y}{f_u}\right)\left(\frac{b_s}{L_c}\right) \geq 0.7 \ \& \ \leq \frac{f_u}{f_y} \cdot \frac{\gamma_{mo}}{\gamma_{m1}}$$

$$= 1.4 - 0.076 \times \frac{115}{8} \times \frac{250}{410} \times \frac{115}{140} \geq 0.7 = \underline{0.85}$$

$$A_{nc} = \left(150 - \frac{8}{2}\right) 8 = 1168 \text{ mm}^2$$

$$A_{go} = \left(115 - \frac{8}{2}\right) 8 = 888 \text{ mm}^2$$

$$T_{dn} = 516.3 \text{ kN}$$

09. $\lambda \leq \lambda_{limit}$

$$\frac{l_{max}}{r_{min}} \leq \lambda_{limit}$$

$$\frac{l_{max}}{20} \leq 350 \quad (r_{min} = 20 \text{ mm}).$$

$$l_{max} \leq 350 \times 20$$

$$\leq 7000 \text{ mm}$$

$$\leq 7.0 \text{ m}.$$