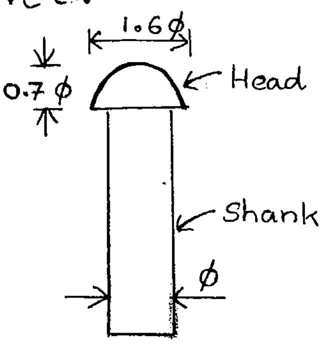
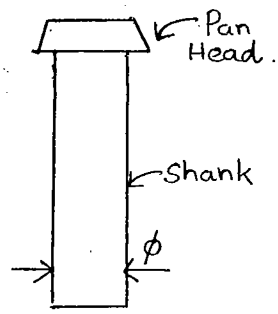
28th Aug,
THURSDAY

# 2. BOLTED CONNECTIONS

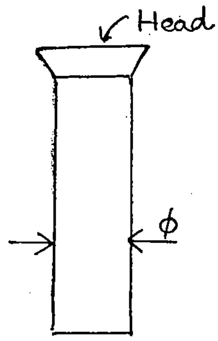
## Rivet:



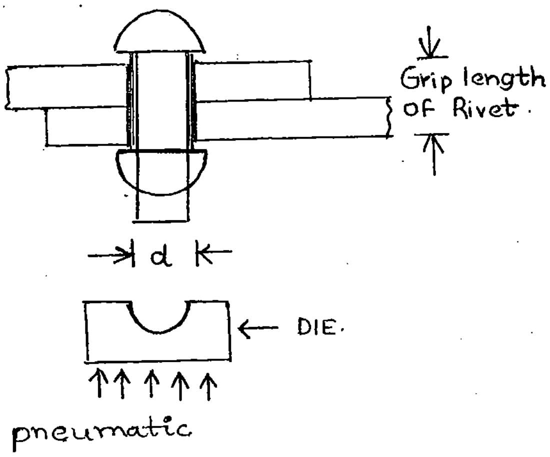

Snap Head or
Round Head Rivet.




Pan Head
Rivet




Flat counter
Shank rivet.




**Nominal Diameter(φ):**

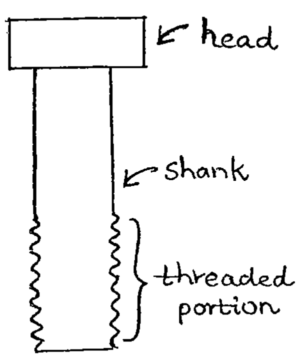
It is the diameter of rivet be rivetting process. It is same as sha diameter, φ

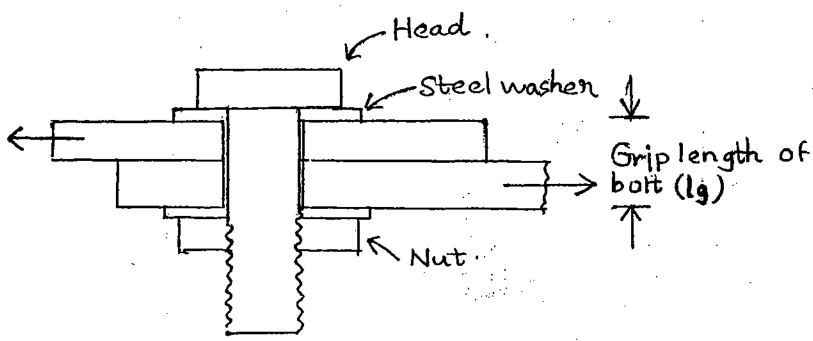
**Effective Diameter or Gross Diameter(d**

It diameter of rivet after rivet process. which is also same as dia. rivet hole (d).

$$d = \phi + 1.5\,mm \quad (\text{when } \phi \leq 25\,mm)$$
$$= \phi + 2.0\,mm \quad (\text{when } \phi > 25\,mm)$$
= diameter of rivet hole

## Bolt & Bolting:




Hole diameter > 1 to 3mm than shank diameter

A bolt may be designated as :

M d x L

- d → Shank diameter
- L → length of bolt
- M → metric size.

## → Types of Bolts :

(i) Unfinished Bolts / Ordinary / Rough / Black bolts.
(ii) High strength Friction grip bolts. (HSFG bolts)
(iii) Unfinished bolts / Black bolts / Ordinary bolts.

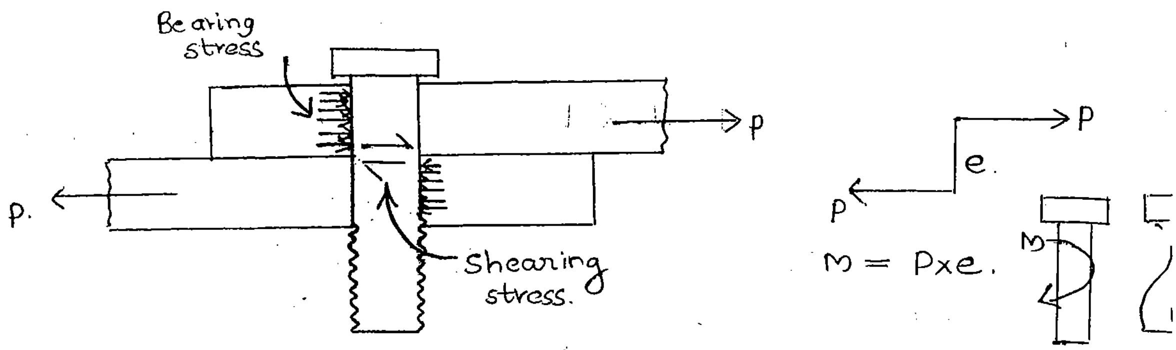
- Bolts are normally made from mild steel round bars. with square or hexagonal head shapes.
- Diameter of bolt available in market : 5 mm – 36 mm or designated as M5 to M36. However most commonly used ones a M16, M20, M24, M30.
- These bolts are recommended to use in connections which ar subj. to static loads and also used in secondary structures such as purlins, bracing members, tension or compression member in roof trusses.
- These are not recommended in structural connections which are subj. to dynamic loads and impact loads.
- Mechanical properties of these bolts are specified with grade c property class.

Grade 4.6 to Grade 8.8 are available in market. However, most commonly used one is grade 4.6. Connection with the help of black bolt or unfinished bolt is eg. for bearing type connection or slip type connection or non-frictional connection.

Grade 4.6

- 4 → $\frac{1}{100}$ UTS, $f_{ub} = 400$ MPa
- 6 → $0.6 = \frac{f_{yb}}{f_{ub}}$

$f_{yb} = 0.6 \times 400$
$= 240$ MPa.

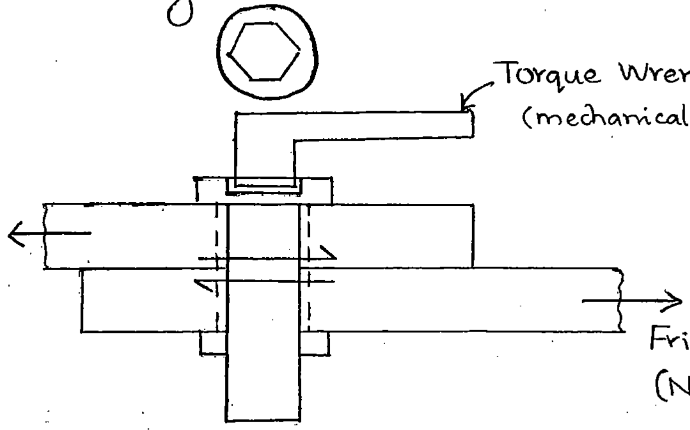



Force gets transmitted through bearing stress (compressive). Further if the grip length is more (e ↑), eccentricity will be more and bolt may fail due to tension caused by the moment (M = Pxe).

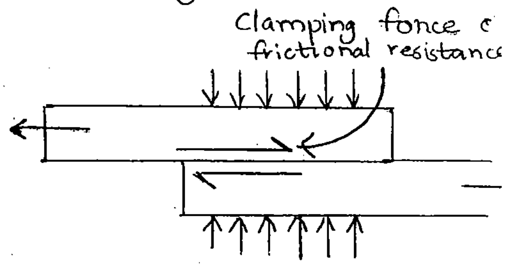
$$\therefore \frac{\text{Grip length}}{\text{Shank diameter}} \leq 8 \quad \text{ie} \quad \frac{l_g}{d} \leq 8$$

## High Strength Friction Grip Bolts: (HSFG bolts).

- Made from medium carbon steel or high tensile strength steel.




Frictional type Connections
(Non slip type connections).




Proof load ≤ Yield strength of a bolt.

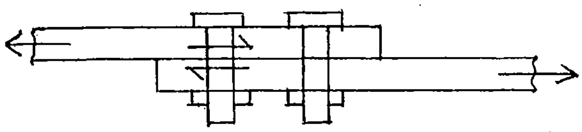
- Grade 10.9s – 12.9s

UTS $f_{ub} = 1040$ MPa

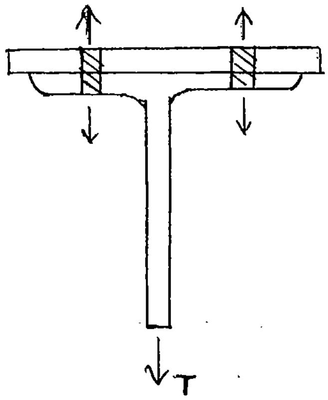
$f_{yb} = 940$ MPa

30th Aug,
SATURDAY → Classification of Bolted Connection Based on Force experienced by the Bolt:

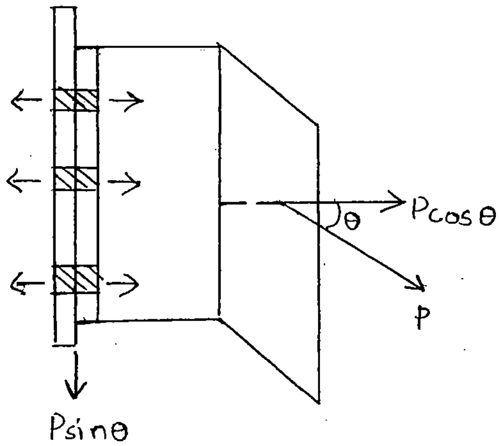
- Shear connections
- Tension connections
- Combined shear and tension connection.



Shear Connection

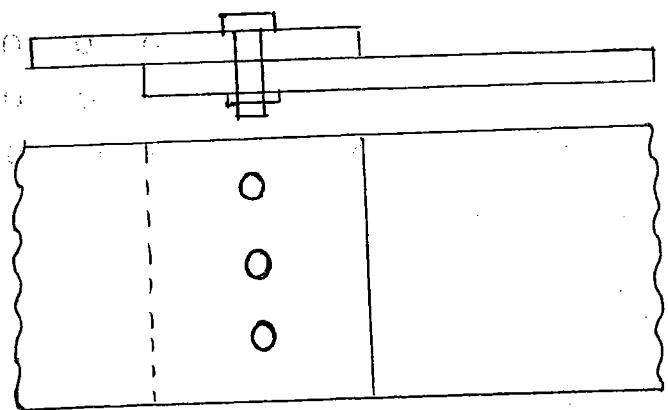



Hanger Connection

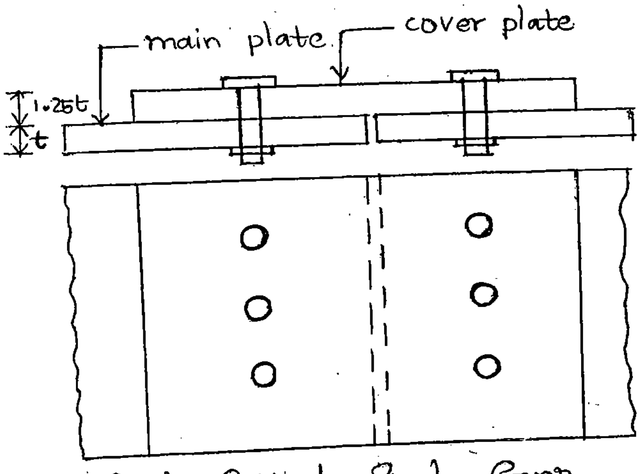



→ Types of Shear Connections:

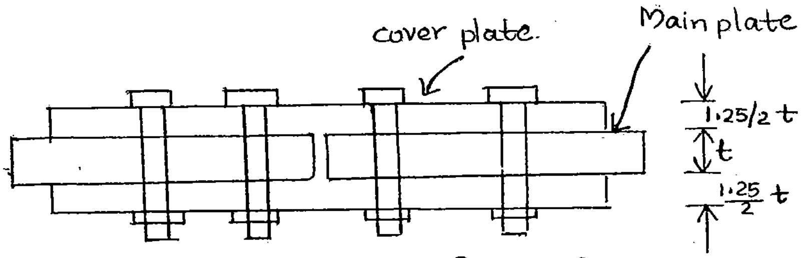
- Lap Connection
  - Single cover Butt connection
  - Double cover butt connection
- Butt connection



Single Bolted Lap Connection




Single Bolted Single Cover Butt connection.




Double Bolted Double Cover Butt connection

**NOTES:**

⊙ It is desirable to use double cover butt connection fo[r] following reasons:

(i) In double cover butt connection, CG of load in one connected member is lying with CG of load in another connect[ed] member. Hence connection is free from moment, whereas eccentricity of a load exist in lap connection & single cover butt connection

(ii) Nominal shear capacity of bolt in double cover butt connection (2 no. of shear plates) is twice the nominal shear capacity of bolt in lap connection or single cover bolt conne[ction]

→ Specifications for Bolted Connections:

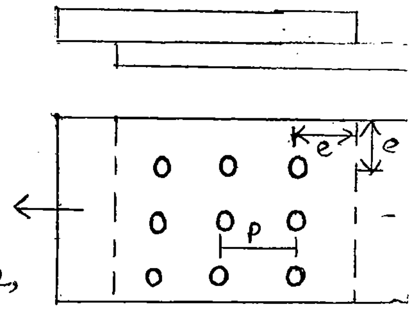
– No: of bolts, $n = \dfrac{\text{Design load}}{\text{Design strength of bolt.}}$

– Bolts are to be arranged in suitable pattern:

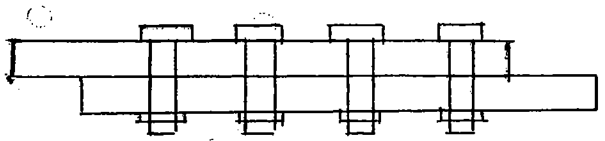
a) Chain pattern

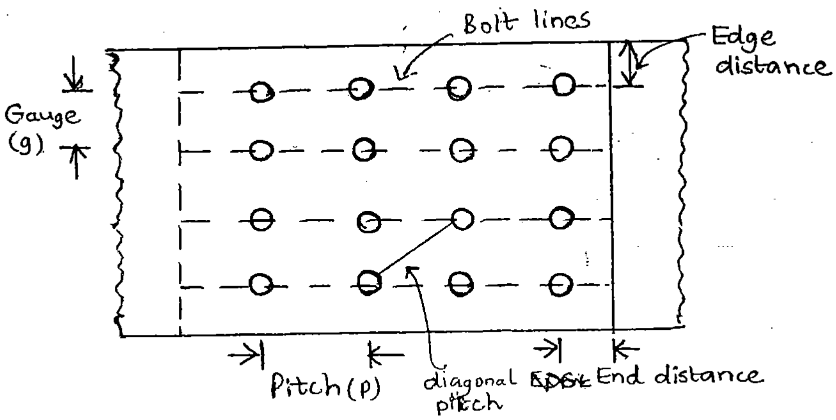
b) Staggered pattern.

c) Diamond pattern.




– Pitch, gauge, end distance, edge distance, diameter of bolt hole.





Pitch: It is the c/c distance b/w two adjacent bolts measured parallel to the direction of a load in a member. For wide plates, it is c/c distance b/w two adjacent bolts measured along length of connection.

* **Diameter of Bolt Hole:**

$$d_0 = d + 1.0 \text{ mm} \quad (12\text{ mm} \leq d \leq 14\text{ mm})$$
$$= d + 2.0 \text{ mm} \quad (16\text{ mm} \leq d \leq 24\text{ mm})$$
$$= d + 3.0 \text{ mm} \quad (d \geq 27\text{ mm}).$$

$d \rightarrow$ shank diameter of bolt.

* **Condition for Optimum Pitch:**

Design strength of bolt per pitch = Design strength of plate per pitch.

* Minimum pitch, $P_{min} \not< 2.5 \times$ shank diameter of bolt.

$$P_{min} \not< 2.5\,d.$$

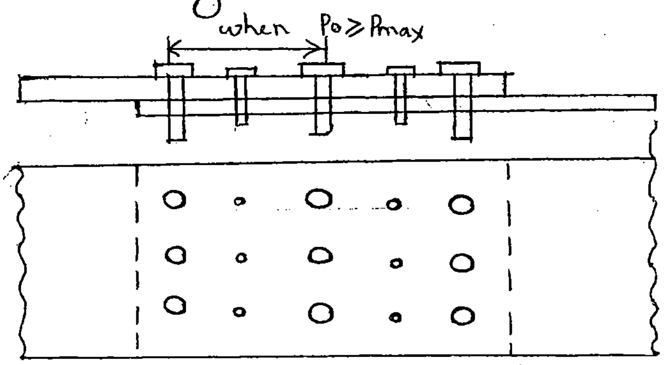
* Maximum pitch, $P_{max} = 12t$ or 200 mm (whichever is less) for comp. member

$= 16t$ or 200 mm (whichever is less) for tension member

$t \rightarrow$ thickness of thinner connected member.

$$P_{min} \leq P_o \leq P_{max}.$$

* **Tacking Bolts or Stitch Bolts**




When $P_o > P_{max}$, buckling b/w members occur. To avoid the tacking bolts are used, which will prevent the unsupported member from buckling.

For plates :

Maximum pitch of tacking or stitch bolts,

$P_{max}$ = 32t or 300 mm (whichever is less, when plates are not exposed to weather

= 16t or 200 mm (whichever is less when plates are ~~not~~ exposed to weather)

For angles :

- $P_{max} \ngtr 600$ mm (for compression member)
- $P_{max} \ngtr 1000$ mm (for tension member.

→ Gauge (g)

It is the c/c distance b/w two adjacent bolts measured normal to the direction of load in a member or it is distance b/w two adjacent bolt lines.

* End distance

It is distance b/w centre of bolt hole to the nearest edge of a main member or cover plate measured parallel to the direction of load in a member

* Edge Distance

It is distance b/w centre of bolt hole to the nearest edge of a main member or cover plate measured normal to the direction of load in a member.

– To ~~provide~~ prevent block shear failure of a member, min. end distance is provided.

$e_{min} \approx 1.5 * $ diameter of bolt hole ($1.5 d_o$)

(Machine flame cut edges) $\approx 1.7 d_o$ (for hand flame cut edges)

— Max. end / edge distance, $e_{max} = 12t\epsilon$ ; $\epsilon = \sqrt{\frac{250}{f_y}}$

For corrosive environment, $E_{max} = 40\text{ mm} + 4t$

$f_y$ = yield strength of a material.

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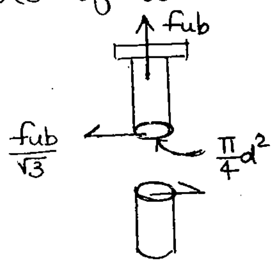
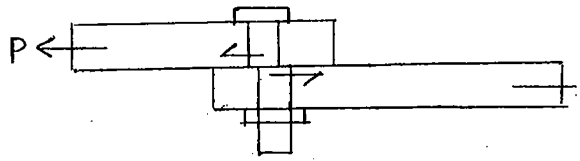
→ Failures of Bolted Connections :

- Shear failure of bolts.
- Bearing failure of bolts.
- Tearing failure of bolts.
- Bearing failure of plate
- Tearing failure of plate.
- Block shear failure of plate.

(i) Shear Failure of bolts.

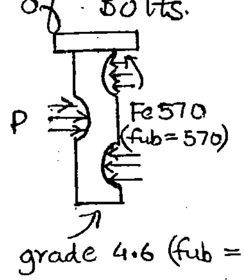


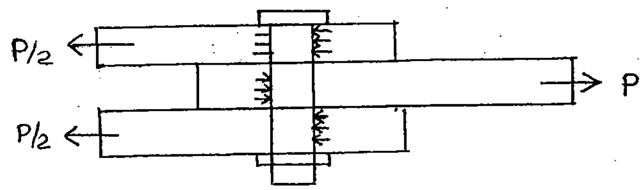




Shear stresses are generated when plates slip due to applied forces. When max. factored SF in the bolt may exceed nominal shear capacity of the bolt, shear failure of bolts may occur at plane of interface

Failure occurs when design action, $P > \frac{\pi}{4} d^2 \cdot \frac{f_{ub}}{\sqrt{3}}$

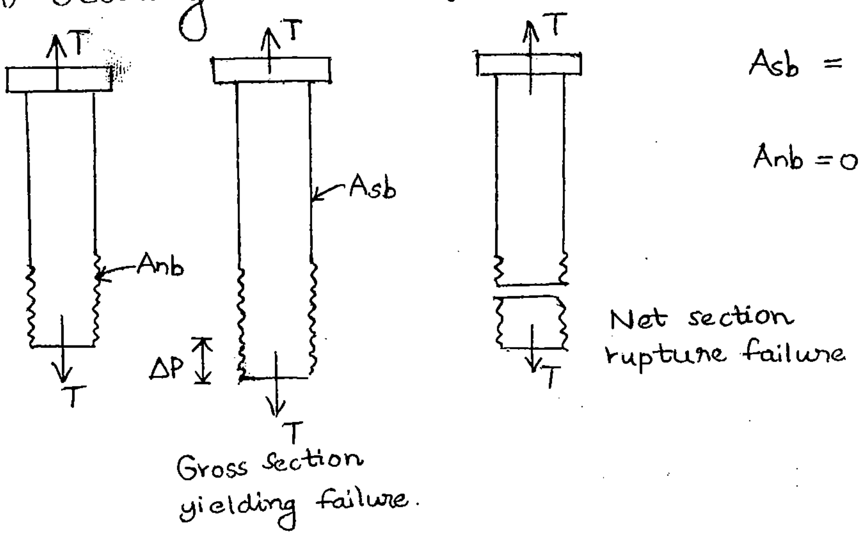
(ii) Bearing Failure of Bolts.




The hoff shank of bolt is crushed when plate may be strong in bearing. The heavily stressed plate may thus press the hoff shank of the bolt. Bearing failure of bolt may not occur in practise except plates may be strong in bearing

(iii) Tearing Failure of Bolt.




$Asb = \frac{\pi}{4} d^2$ ; Asb → c/s area of shank

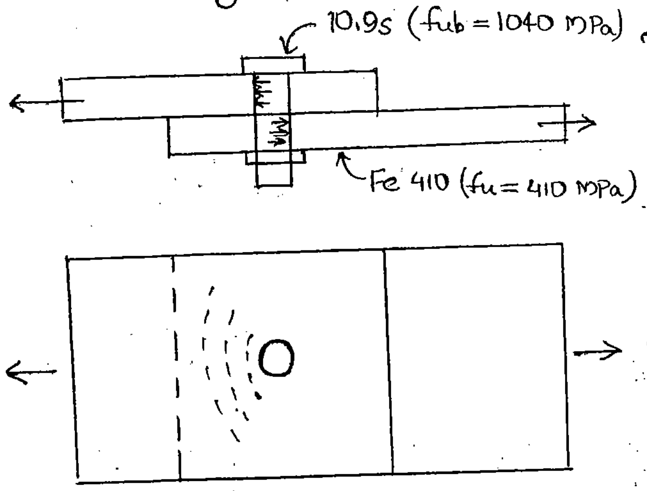
$Anb = 0.78 \frac{\pi}{4} d^2$ ; Anb → net area of threaded portion.

Gross section yielding failure occurs when uniform stress developed in gross area, $\frac{T}{Asb} = fyb$.

If bolt is subj. to tension, tearing failure may occur at threaded portion.

Net section rupture failure occurs when localised stress developed in net area, $\frac{T}{Anb} \approx fub$. Net section will not undergo deformation as it is subjected to localised stress alone.

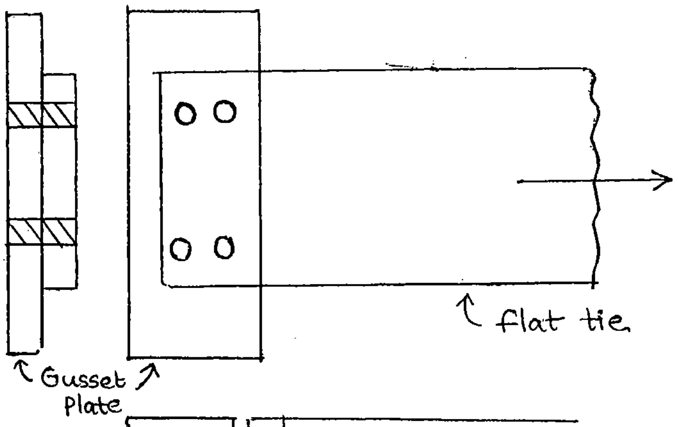
(iv) Bearing Failure of Plate.



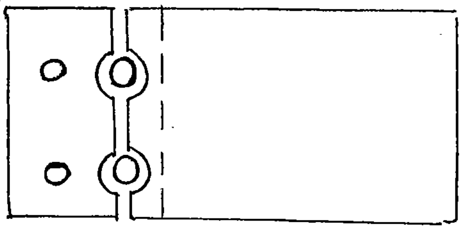

When ordinary bolt is subj. to factored SF, slip may takes place and bolt may come in contact with plate and plate material gets crushed, when plate is weak in bearing

(v) Tearing Failure of Plate.

Tearing failure of a plate may occur when bolts are stronger than plate member.



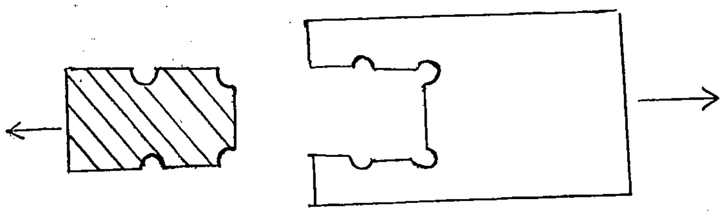

$$\frac{T}{A_n} = \frac{T}{(B-2d_o)t} = f_y.$$



At or near connection, only block shear failure & net sectio rupture take place. But block shear failure can be avoided by providing required end distance. Thus only net section rupture takes place.

(vi) Block Shear Failure of Plate.

When bolts are placed at lesser end distance than min. end distance as per IS 800 guidelines, a block of plate may seperate near end of connection. It can be eliminated by providing min. end distance.

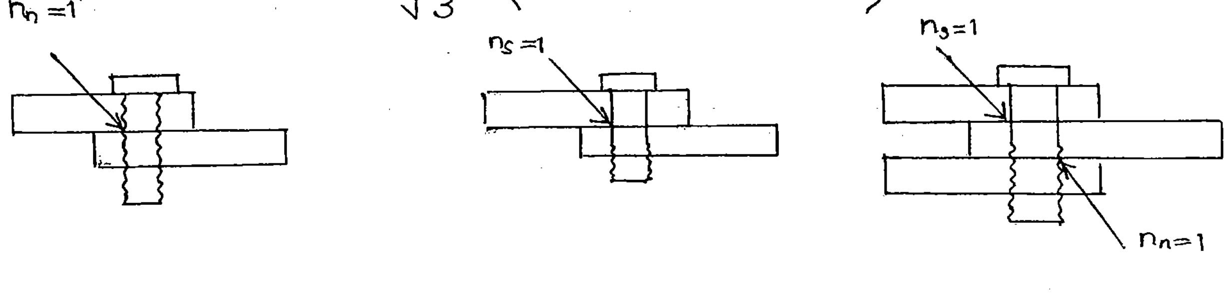


→ Design strength of Bearing Type Bolted Connection ($V_{dc}$)

a) Design shear capacity (or) Strength of bolt ($V_{dsb}$)

$V_{nsb}$ = Nominal shear capacity of bolt.

$$= \frac{f_{ub}}{\sqrt{3}}\left(n_n A_{nb} + n_s A_{sb}\right)$$



Design shear strength of bolt, $V_{dsb} = \frac{V_{nsb}}{\gamma_{mb}}$

$$= \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}}\left(n_n A_{nb} + n_s A_{sb}\right)$$

$f_{ub}$ → ultimate tensile strength of bolt.

$n_n$ → no. of shear planes with thread intersecting shear plane.

$n_s$ → no. of shear planes without thread intersecting shear plane

$A_{sb}$ → nominal plane shank area of bolt. $= \frac{\pi}{4} d^2$

$A_{nb}$ → net tensile area ≈ 78% $A_{sb}$ $= 0.78 \frac{\pi}{4} d^2$.

$\gamma_{mb}$ = partial safety factor for bearing type bolt

= 1.25 for workshop bolting

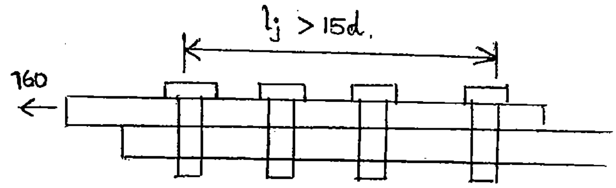
= 1.25 for site or field bolting

For lap connection or single cover butt connection,

$n_n + n_s = 1$

when $n_n = 1$, $n_s = 0$

$n_n = 0$; $n_s = 1$.



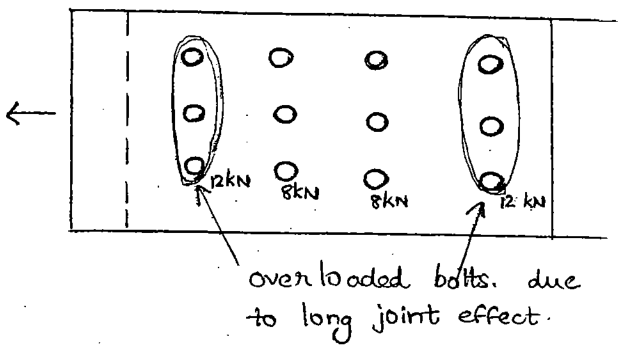

For double cover butt connection,

$n_n + n_s = 2$

when $n_n = 1$, $n_s = 1$

$n_n = 2$, $n_s = 0$

$n_n = 0$, $n_s = 2$.



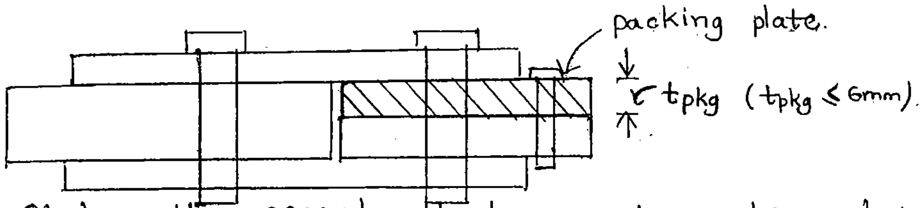

⊙ Nominal shear capacity of bolt is modified for long joint (when $l_j > 15d$), long grip bolt (when $l_g > 5d$) and thicker packing plate (when $t_{pkg} > 6$ mm)

$$V_{nsb} = \frac{f_{ub}}{\sqrt{3}}\left(n_n A_{nb} + n_s A_{sb}\right) \beta_{lj} \cdot \beta_{lg} \cdot \beta_{pkg}$$

$$V_{dsb} = \frac{V_{nsb}}{\gamma_{mb}} = \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}}\left(n_n A_{nb} + n_s A_{sb}\right) \beta_{lj} \cdot \beta_{lg} \cdot \beta_{pkg}$$

* Reduction factor for Long grip bolt ( $\beta_{lg}$ ) [when $l_g > 5d$]

$$\beta_{lg} = \frac{8d}{3d + l_g}$$ ; $l_g$ = grip length of bolt ( $l_g \ngtr 8d$ )




Higher the ~~accent~~ thickness of packing plate, higher will be eccentricity and the moment. To avoid that, tacking bolts are provided when $t_{pkg} \leq 6mm$. But when $t_{pkg} > 6$ mm, reduction for thickness, $\beta_{pkg}$ is applied.

* Reduction factor for Thicker packing plate (when $t_{pkg} > 6$mm)

$$\beta_{pkg} = 1.0 - 0.0125\, t_{pkg}$$ ; $t_{pkg}$ → thickness in mm.

b) Design Bearing strength of Bolt & Plate ( $V_{dpb}$ )

Bearing area of bolt = $\pi d t$.

But hole diameter will have a tolerance of 1 mm, 2mm or 3mm

∴ bearing area is 80% $\pi d t$.

$$80\% \, \pi d t = 2.5\, dt.$$

Nominal bearing strength of bolt and plate,

$$V_{npb} = 2.5\, dt . f_u . k_b .$$

$$V_{dpb} = \frac{V_{npb}}{\gamma_{mb}} = \frac{2.5\, dt . f_u . k_b}{\gamma_{mb}}.$$

$K_b$, the bearing factor is minimum of

⊙ $\frac{e}{3d_0}$ , $\frac{P}{3d_0} - 0.25$ , $f_{ub}/f_u$ , 1.0

e & p are end distance and pitch distance respectively measured parallel to bearing direction.

$d_0$ → diameter of bolt.

$f_u \rightarrow$ minimum value of UTS of bolt ($f_{ub}$) or plate.

c) Design Tensile Strength of Bolt, ($T_{db}$)

$T_{nb}$ = Nominal tensile strength of bolt.

$$T_{nb} = 0.9 \, A_{nb} \, f_{ub} \leq A_{sb} \cdot f_{yb} \cdot \frac{\gamma_{mb}}{\gamma_{mo}}$$

(0.9 as a safety factor as $f_{ub}$ is used)

$$T_{db} = \frac{T_{nb}}{\gamma_{mb}} = \frac{0.9 \, A_{nb} \, f_{ub}}{\gamma_{mb}} \leq \frac{A_{sb} \cdot f_{yb}}{\gamma_{mo}}.$$

* Design Strength of Bolt ($V_{db}$):

It is minimum strength of bolt based on design strength of bolt in shear ($V_{dsb}$), design strength of bolt in bearing ($V_{dpb}$) and design strength of bolt in tension ($T_{db}$)

$$V_{db} = \text{minimum of} \begin{cases} V_{dsb} \\ V_{dpb} \\ T_{db} \text{ (if exist)} \end{cases}$$

* No. of bolts required for Concentric connection (n):

$$n = \frac{\text{Factored or design load}}{\text{Design strength of one bolt}} = \frac{P}{V_{db}}$$ (rounded off to nearest highest value)

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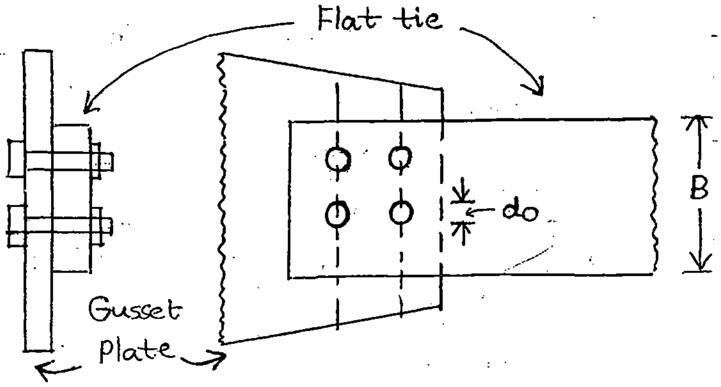
d) Design Tensile Strength of Plate

$T_{np}$ = nominal tensile strength of plate.

$= 0.9 \, A_n f_u$

$$T_{dp} = \frac{T_{np}}{\gamma_{m1}} = \frac{0.9 A_n f_u}{\gamma_{m1}}; \ \gamma_{m1} = 1.25$$




$A_n$ = Net effective sectional area = $(B - n d_o) t$ (for chain bolting)

* Design strength of Connection ($V_{dc}$)

It is the minimum of $V_{dsb}$, $V_{dpb}$, $T_{db}$ (if exist) and design tensile strength of plate

For safety connection (design requirement):

Design Action(P) ≤ Design strength of connection ($V_{dc}$)

$$V_{dc} = \text{minimum of} \begin{cases} V_{dsb} \\ V_{dpb}. \\ T_{db} \text{ (if exist)} \\ T_{dp} \end{cases}$$

→ Efficiency of a Bolted Connection ($\eta$)

(Percentage Strength of a Bolted Connection)

$$\eta = \frac{\text{design strength of bolted connection } (V_{dc})}{\text{design strength of main plate } (T_{mp})} \times 100$$

$$\boxed{\eta = \frac{V_{dc}}{T_{mp}} \times 100}$$

* For wide plates:

$$\eta = \frac{\text{design strength of a bolted connection per pitch}}{\text{design strength of main plate per pitch}}$$

$$\boxed{\eta = \left(\frac{V_{dc}}{T_{mp}}\right)_{\text{per pitch}} \times 100}$$

* If $T_{dp} \leq V_{db}$,

$$\eta = \frac{V_{dc}}{T_{mp}} \times 100$$

$$= \frac{T_{dp}}{T_{mp}} \times 100$$

* Design strength of main plate ($T_{mp}$)

- $T_{mp} = \dfrac{A_g f_y}{\gamma_{mo}}$ (Based on gross section yielding)

$\dfrac{T}{A_g} = f_y$.

- $T_{mp} = \dfrac{0.9 A_g f_y}{\gamma_{m1}}$ (Based on net section rupture)

Min. of above two will be used; but variation will be less.

$$\Rightarrow \quad \eta = \frac{0.9 A_n f_u / \gamma_{m1}}{0.9 A_g f_u / \gamma_{m1}} \times 100$$

$$= \frac{A_n}{A_g} \times 100 = \frac{(B - n d_o) t}{B \times t} \times 100$$

$$\boxed{\eta = \left(\frac{B - n d_o}{B}\right) \times 100}$$

$\eta$ will be maximum, when no. of bolt holes in failure is minimum. For diamond pattern of bolting, $n = 1$.

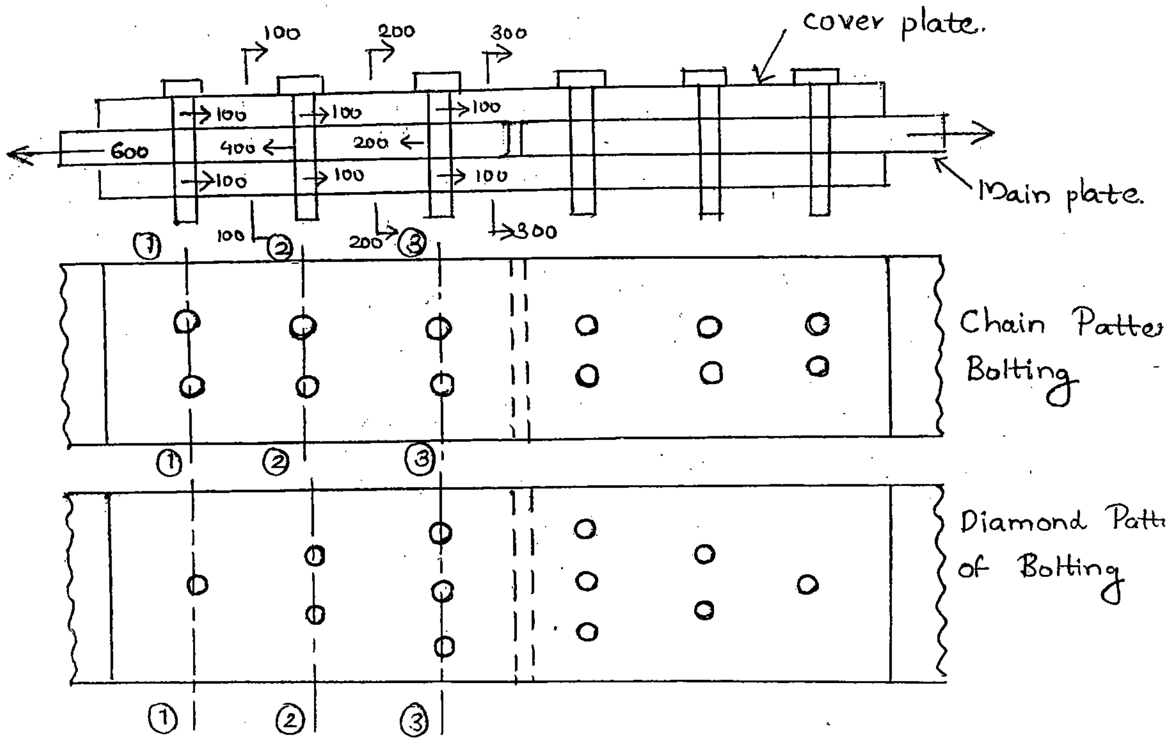
For staggered and chain pattern, $n = 3, 4, 5 \ldots$

$$\eta_{\substack{\text{diamond} \\ \text{pattern}}} = \left(\frac{B - d_o}{B}\right) \times 100$$

Assume,

$P = 600$ kN

$V_{db} = 100$ kN.



* It is desirable to use diamond pattern of bolting :-

(i) Efficiency of diamond pattern of bolting is higher.

(ii) Cover plate material may be saved with diamond pattern of bolting.

(iii) Width of main plate required for diamond pattern of arrangement is less compared to chain or staggered pattern of bolting.

$$P = T_{dp} \leq V_{db}$$

$$= 0.9 A_n \frac{f_u}{\gamma_{m1}}$$

$$\frac{P}{0.9 \frac{f_u}{\gamma_{m1}}} = A_n \Rightarrow \frac{P}{\left(0.9 \frac{f_u}{\gamma_{m1}}\right) t} + n d_o = B.$$

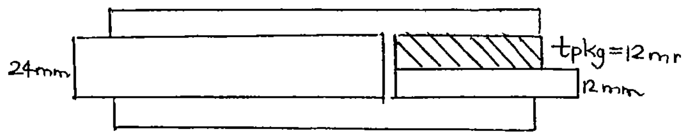
Critical section for main plate = Section 1-1 (max loading)

No: of bolts in section 1-1 at chain bolting = 2.

" diamond bolting = 1.

16.

Q.1. $V_{dsb} = \frac{f_u}{\sqrt{3}\,\gamma_{mb}} \left(n_n A_{nb} + n_s A_{sb}\right) \beta_{pkg}$




Reduction factor for thickness packing plate (when $t_{pkg} \geq 6\,mm$)

$$\beta_{pkg} = 1 - 0.0125\, t_{pkg}$$

$$= 1 - 0.0125 \times 12 = 0.85.$$

$V_{dsb}$ reduced by <u>15%</u>

Q.2. $P = 600$ kN

$V_{dsb} = 40$ kN ; $V_{dpb} = 60$ kN ; $T_{dp} = 50$ kN.

$$n = \frac{\text{design load}}{\text{design strength of one bolt}} = \frac{P}{V_{db}} = \frac{600}{40} = 15 \text{ no.s}$$

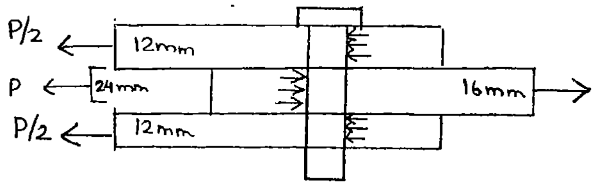
Q.3. $V_{dsb} = \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}}(n_n A_{nb} + n_s A_{sb})$

For triple bolted double cover butt joint, $n_s = 3 \times 2 = 6$.

For one bolt in single shear, $n_s = 1$.

$\therefore \quad \underline{n = 6}$

Q.5 For M16 Bolt, $d = 16$ mm




$f_{ub} = 400$ MPa, $f_y = 240$ MPa

$\gamma_{mb} = 1.25$

Bearing factor, $k_b = 0.5$.

* Since it is a double cover butt joint, only shearing and bearing failure occurs. There won't be tearing failure.

$V_{dsp} = \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}}(\cancel{n_n A_{nb}}^{\,0} + n_s A_{sb})$.

$= \frac{400}{\sqrt{3} \times 1.25}\left(1 * 2 * \frac{\pi}{4} \times 16^2\right) = 74.2$ kN.

$V_{dpb} = \frac{2.5\, d t f_u k_b}{\gamma_{mb}} = \frac{2.5 \times 16 \times 16 \times 400 \times 0.5}{1.25}$

$= 102.4$ kN.

Design strength of bolt, $V_{db} = \underline{74.2 \text{ kN}}$

Q.5 $d = 20$ mm, $f_{ub} = 400$ MPa, $f_y = 240$ MPa $\qquad d_0 = d + 2 \quad (16 \le d \le 24)$

End distance, $e = 33$ mm, pitch $p = 50$ mm $\qquad = 22$ mm

$V_{dsb} = \frac{f_{ub}}{\sqrt{3}}(n_n A_{nb} + \cancel{n_s A_{sb}})$

↳ thread Intercept shear plane.

$= \frac{400}{\sqrt{3}}\left(0 + 1 \times \frac{\pi}{4} \times 20^2 \times 0.78\right) = 45.2$ kN.

$\frac{e}{3d_0} = \frac{33}{3 \times 22} = 0.5$ $\qquad \Rightarrow$ Bearing factor, $k_b = 0.5$. $\qquad \frac{f_{ub}}{f_u} = \frac{400}{410} = 0.97$

$\frac{p}{3d_0} - 0.25 = 0.507$.

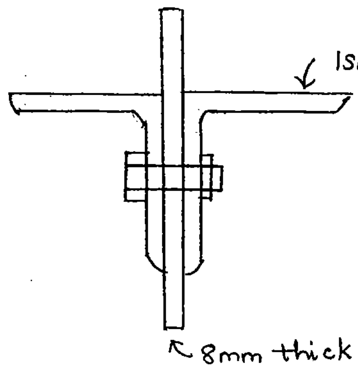
Design bearing strength of bolt, $V_{dpb} = \frac{2.5\, d\, t\, f_{ub}\, k_b}{\gamma_{mb}}$

$$= \frac{2.5 \times 20 \times 12 \times 400 \times 0.5}{1.25}$$

$$= \underline{\underline{96 \text{ kN}}}$$

7. $d = 16$ mm, Grade 4.6 $\Rightarrow$ $f_{ub} = 400$ MPa
$f_y = 240$ MPa.

8. Ultimate load $= P = 150$ kN.
(design load/
factored load)




For grade 4.6 bolt, $f_{ub} = 400$ MPa
$f_y = 240$ MPa

For grade Fe 410 plate, $f_u = 410$ MPa

$e = 30$ mm, $p = 40$ mm

M16 : $d = 16$ mm, $d_o = 18$ mm.

$$n = \frac{P}{V_{db}}$$

$$V_{dsb} = \frac{f_{ub}}{\sqrt{3}\, \gamma_{mb}} \left( n_n A_{nb} + n_s A_{sb} \right)$$

Thread intersecting shear plane, $n_s = 0$, $n_n = 2$.

$$= \frac{400}{\sqrt{3} \times 1.25} \left( 1 \times 2 \times 0.78 \times \frac{\pi}{4} 16^2 \right) = \underline{\underline{57.9 \text{ kN}}}$$

$$V_{dpb} = 2.5 \times d t \; f_{ub} \times \frac{K_b}{\gamma_{mb}} = 2.5 \times 16 \times 8 \times 400 \times \frac{k_b}{1.25}$$

$t_{(AM)} = 6+6 = 12$ m

$t_{(GP)} = 8$ mm

$K_b$ is minimum of :

$$\frac{e}{3d_0} = \frac{30}{3 \times 18} = 0.55$$

$$\frac{P}{3d_0} - 0.25 = \frac{40}{3 \times 18} - 0.25 = 0.49$$

$$\frac{f_{ub}}{f_u} = \frac{400}{410} = 0.97$$

$$V_{dpb} = 2.5 \times 16 \times 8 \times 400 \times \frac{0.49}{1.25} = 50.25 \text{ kN.}$$

$V_{db} = 50.25$ kN

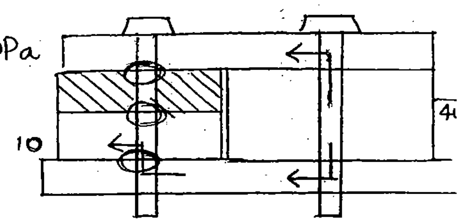
$$n = \frac{150}{50.25} = \underline{\underline{3}}$$

3[rd] Sept,
WEDNESDAY

10. $P = 400$ kN.

For 4.6 grade bolt, $f_{ub} = 400$ MPa, $f_u = 410$ MPa

$K_b = 0.5$ , For M20 bolt , $d = 20$ mm.




No: of bolts required , $n = \frac{P}{V_{db}}$.

$V_{db}$ = design strength of one bolt = minimum of $V_{dsp}$ or $V_{dpb}$.

$$V_{dsp} = \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}} (n_n A_{nb} + n_s A_{sb})$$ ; $n_n = 2$ $n_n \neq 3$

$$= \frac{400}{\sqrt{3} \times 1.25} \left( 2 \times 0.78 \times \frac{\pi}{4} \times 20^2 + 0 \right) \times \beta_{pkg}$$

$\beta_{pkg}$ = reduction factor on thicker packing plate.(when $t_{pkg} > 6$ m

$$\beta_{pkg} = 1 - 0.0125 \times t_{pkg} = 1 - 0.0125 \times 8 = \underline{\underline{0.9}}$$

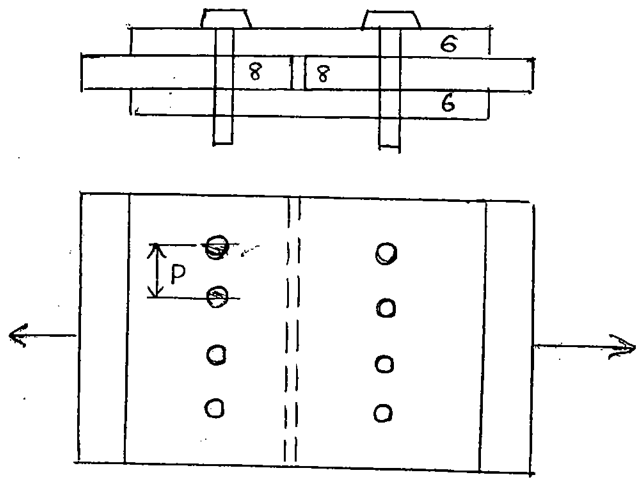
$V_{dsb} = \underline{\underline{81.25}}$ kN

$$V_{dpb} = 2.5\,d t \frac{f_{ub} K_b}{\gamma_{mb}} = 2.5 \times 20 \times 10 \times 400 \times \frac{0.5}{1.25} = \underline{\underline{80}} \text{ kN}$$

$t_{(MP1)} = 18$ mm , $t_{(MP2)} = 10$ mm , $t_{(CP)} = 8+8 = 16$ mm

$$\eta = \frac{P}{V_{db}} = \frac{400}{80} = 5 \text{ bolts}$$

11. Failures are :




SFB → $V_{dsb}$

$f_{ub} = 400$ BFB }
$f_u = 410$ BFP } $V_{dpb}$ ($f_{ub} < f_u$; bolt will fail in bearing)

TFP → $T_{dp}$.

For wide plate,

Efficiency of the connection

$$\eta = \frac{\text{design strength of connection (per pitch)}}{\text{design strength of main plate (per pitch)}} \times 100 = \left(\frac{V_{dc}}{T_{mp}}\right)_{\text{per pitch}} \times 100$$

$V_{dc}$ per pitch = min. of $V_{dsb}$ or $V_{dpb}$ or $T_{dp}$ per pitch.

$$V_{dsb} = \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}}\left(n_n A_{nb} + n_s A_{sb}\right)$$

$$= \frac{400}{\sqrt{3} \times 1.25}\left(1 \times 2 \times 0.78 \times \frac{\pi}{4} \times 16^2 + 0\right) = \underline{57.95 \text{ kN}}$$

$V_{dpb}$ = design bearing strength of bolt & plate

$$= 2.5\, d t f_{ub} \cdot \frac{K_b}{\gamma_{mb}}$$

$t$ (MP) = 8 mm

$t$ (CP) = 6 + 6 = 12 r

$$= 2.5 \times 16 \times 8 \times 400 \times \frac{0.55}{1.25}$$

$= \underline{56.32 \text{ kN}}$

Design tensile strength of plate per pitch ($T_{dp}$):

$$T_{dp} = \frac{0.9\, A_n f_u}{\gamma_{m1}}$$

Per pitch length:

$B = p$

$n = 1$

$A_n = (B - n d_o) t$

$= (p - n d_o) t$

$= (45 - 1 \times 18)\, 8 = 216 \text{ mm}^2$

$$T_{dp} = 0.9 \times 216 \times \frac{400}{1.25} = \underline{63.7 \text{ kN}}$$

$V_{dc}$ per pitch $= 56.32$ kN.

$T_{mp}$ = design strength of main plate.

$$= \frac{0.9 A_g f_u}{\gamma_{m1}} \quad \text{or} \quad \frac{A_g f_y}{\gamma_{m0}}.$$

$$= \frac{0.9 \times 45 \times 8 \times 410}{1.25} = \underline{106.27} \text{ kN}$$

$$\eta = \frac{56.32}{106.27} \times 100 = \underline{53\%}$$

12. $$V_{dsb} = \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}} (n_n A_{nb} + n_s A_{sb}) = \frac{400}{\sqrt{3} \times 1.25} \left( 2 \times 2 \times 0.78 \times \frac{\pi}{4} \times 16^2 + 0 \right).$$

(2 bolts per pitch length)

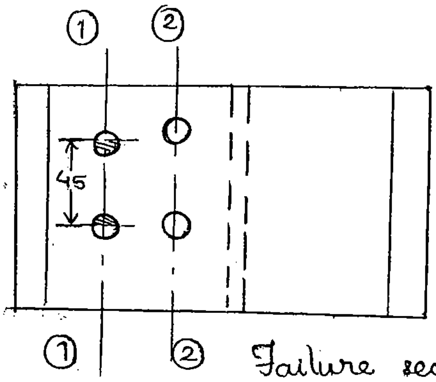
$$= 115.88 \text{ kN}.$$

$$V_{dpb} = 2.5\, d t f_{ub} \cdot \frac{K_b}{\gamma_{mb}} \times (2)$$ → no. of bolts per pitch length

$$= 2.5 \times 16 \times 8 \times 400 \times \frac{0.55}{1.25} \times 2 = \underline{112.64} \text{ kN}$$

$$T_{dp} = \frac{0.9 A_n f_u}{\gamma_{m1}}$$ ; $A_n = (B - n d_0) t$ ; $n$ → no. of bolts in failure section, $n = 1$

$$= \frac{0.9 (45 - 1 \times 18)\, 8 \times 410}{1.25} = \underline{63.7 \text{ kN}}$$




Failure section is ①–①

$$V_{dc} = \underline{63.7} \text{ kN}$$

$$\eta = \frac{63.7}{106.27} \times 100 = \underline{59.99\%}$$

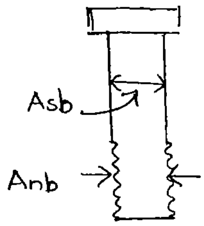
If $T_{dp} \leq V_{db}$, $\quad T_{dp} = 63.7$ kN, $V_{db} = 112.64$ kN.

$$\eta = \left( \frac{B - n d_0}{B} \right) \times 100$$

per pitch length: $B = p$ & $n = 1$ (for any no. of bolts).

$$\eta = \left( \frac{p - d_0}{p} \right) 100 = \left( \frac{45 - 18}{45} \right) \times 100 = \underline{59.99\%}$$

13 . For M16 bolt, $d = 16\,mm$, For grade 4.6 bolt,
$f_{ub} = 400$ MPa, $f_{yb} = 240$ MPa




$$\frac{T}{A_{sb}} = f_{yb}.$$

$$T_{nb} = f_{yb} A_{sb} \times \frac{\gamma_{mb}}{\gamma_{mo}}$$

$$T_{db} = \frac{f_{yb} \cdot A_{sb}}{\gamma_{mo}}.$$

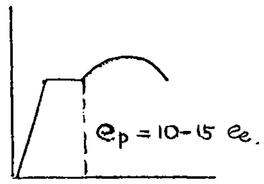
$$T_{db} = 0.9 \cdot A_{nb} \cdot \frac{f_{ub}}{\gamma_{mb}} \leq A_{sb} \cdot \frac{f_{yb}}{\gamma_{mo}}$$

$$= 0.9\left(0.78 \times \frac{\pi}{4} \times 16^2 \times \frac{400}{1.25}\right) \leq \frac{\pi}{4} 16^2 \times \frac{240}{1.1}$$

$$= 45.16 \leq 43.8 \quad \text{(minimum of )}$$

$$T_{db} = \underline{\underline{43.8}}\ kN$$

Stress distribution due to gross ($A_g = A_{sb}$) area is uniform.
∴ it causes deformations.

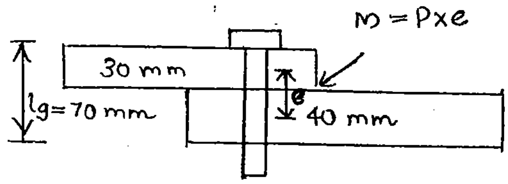



$$T_{nb} = A_{sb} \cdot f_y.$$

$$T_{db} = \frac{T_{nb}}{\gamma_{mb}} = \frac{A_{sb} \cdot f_y}{\gamma_{mb}}.$$

But $\gamma_{mb}$ is used only when there are uncertainities.. But here bolt diameter is same and process of installatio at site and workshop are same and ∴ no uncertainities. So less safety factor of $\gamma_{mo}$ (=1.1) is used..

But in rupture failure, there are uncertainities. like the threaded portion may be less than 78% of Asb. So $\gamma_{mb}$ (=1.25) is used.




14. $\beta_{lg}$ → reduction factor for long grip bolt

$$= \frac{8d}{3d + l_g} \quad (l_g \not> 8d)$$

$8 \times 12 = 96\,mm$

$l_g > 5d\ (5 \times 12) = 60\,mm$

$l_g > 8d \Rightarrow$ increase $d$.

$$\beta_{lg} = \frac{8 \times 12}{3 \times 12 + 70} = 0.9056$$

$$V_{dsb} = \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}} \left( n_n A_{nb} + n_s A_{sb} \right) \cdot \beta_{lg}$$

$V_{dsb}$ reduced by 9.44 % $\left( \frac{1 - 0.9056}{1} \times 100 \right)$