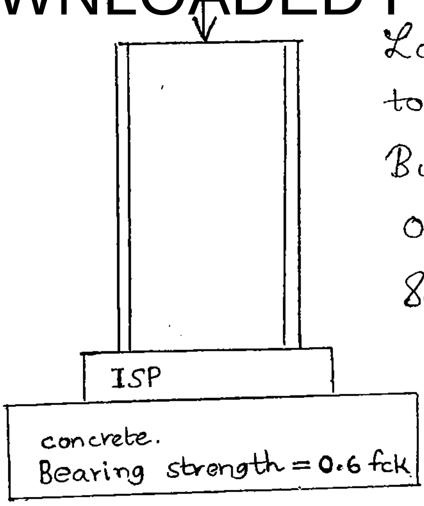
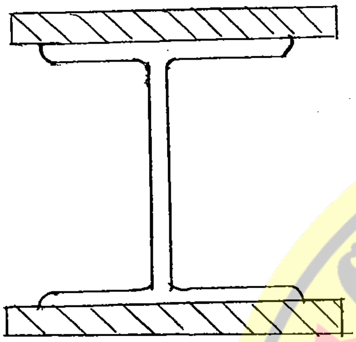


Load transferred by steel sections to the concrete foundation will be high. But bearing strength of concrete is only 0.6 fck.

So plates are used.

Bearing strength on plates $= \frac{P}{L \times B} < 0.6\ f_c$



$M \leq M_d$

$M_d = f(z)$.

Design moment should be greater than the ultimate bending moment acting on the beams. To increase the M_d, I_{zz} value is increased making use of built up I-sections with flanged plates.

- Sheets are used as coverings.
- Flats are used as lacings and battens for built-up colum

→ Structural Steel vs. Aluminium.

Physical Properties	Steel	Aluminium
Density. ($\rho_a \approx \frac{1}{3} \rho_s$)	$\rho_s = 7850\ kg/m^3$.	$\rho_a = 2700\ kg/m^3$.
Youngs modulus. ($E_a \approx \frac{1}{3} E_s$)	$E_s = 2 \times 10^5$ MPa	$E_a = 0.7 \times 10^5$ MPa.
Coeffecient of Thermal expansion. ($\alpha_a \approx 2\alpha_s$)	$\alpha_s = 12 \times 10^{-6} /°c$.	$\alpha_a = 23 \times 10^{-6} /°c$.

(i) $\left(\frac{\text{Strength}}{\text{weight}}\right)_{\text{Al. sections}} > \left(\frac{\text{Strength}}{\text{weight}}\right)_{\text{structural steel sections}}$

But $E_a \approx \frac{1}{3} E_s$.

$P_{cr} = \frac{\pi^2 E A}{(l/r)^2}$ ⇒ For lighter compressive loads, Al section have more chances of buckling.

∴ Al is not used in civil construction applications. But for aeroplane constructions, Al is used as weight is more important parameter there. Aerospace constructions like missiles, space structures make use of Al.

(ii) Al sections are more corrosive resistant than structural steel sections. Hence maintenance may be lesser for Al sections

→ Method of Design.

(i) Working Stress Method (WSM) – FOS
(ii) Ultimate Load Design (ULD) – Load Factor
(iii) Limit State Design (LSD) – Partial Safety Factor.

$$FOS = \frac{\text{yield stress}}{\text{working stress}}$$

$$\text{Load Factor} = \frac{\text{ultimate load}}{\text{working load}}$$

Partial Safety Factor – safety norm for load and material strength

⊙ Design is based on analysis of :-

(i) Design Force – shear force & axial force.
(ii) Design moments – twisting moments & bending moment.

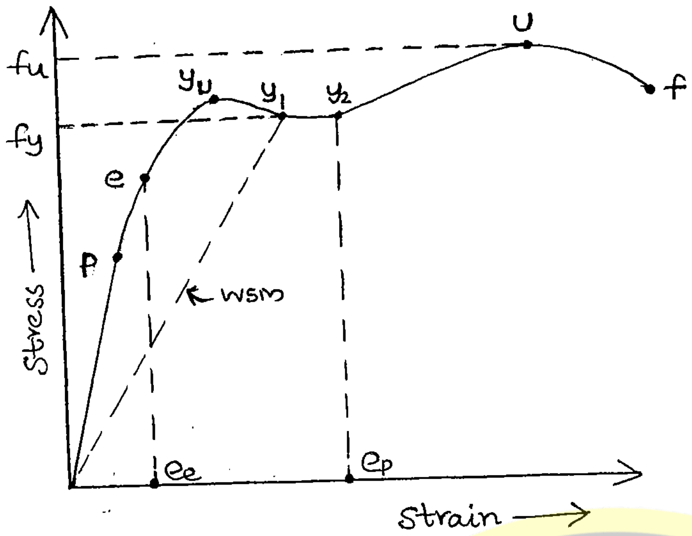
⊙ Design is done to obtain :

(i) Shape (Eg: I section).
(ii) Size (Eg: ISMB 400).
(iii) Connection details.

⊙ Design requirements :

(i). Anticipated loads.
(ii) Deflection to be
(iii) Economical sections
(iv). Life span.

8th Aug, THURSDAY → Working Stress Method: (WSM)



P: Proportionality limit

e: elastic limit.

Y_U: upper yield point.

y_1: lower yield point.

y_1y_2: plastic yielding

U: ultimate stress point.

f: Breaking stress point.

e_p : Plastic strain ≃ 10 to 15 times e_e

e_e : elastic strain.

NOTES:

- WSM of design is linear elastic method of design. In this method, it is assumed that the stress and strain varies linear upto yield point.
- In WSM of design, the stress in a member due to various working loads ~~are~~ working load combinations are to be evoluted, which are called 'Working Stress'.
- For safety of structural member, stresses due to various working load combinations must be less than or equal to permissible value of stresses. Permissible stress is a fraction of yield strength. ($K \cdot f_y$; $K < 1.0$)
- Design requirement for safety:
  - (i) Working stress due to DL + LL ≤ Permissible stress.
  - (ii) Working stress due to DL + WL ≤ Permissible stress.
  - (iii) Working stress due to DL + LL + WL ≤ 1.33 × Permissible stress
- Safety norm used in WSM of design is FOS.

$$FOS = \frac{\text{yield stress}}{\text{working stress}}$$

- WSM results in uneconomic sections as permissible stress is a fraction of yield stress. ∴ present code recommends Limit State Design.

→ Limit State Design.

- Types of Limit State.
  - (i) Limit State of strength.
  - (ii) Limit State of serviceability.

Limit State of strength	Limit State of serviceabil
– strength (against yielding (tension) or buckling (column) or flexure (beam))	– deflection or deformations
– stability (against sliding or overturning) (retaining wall)	– vibrations
– fatigue strength (gantry girder)	– corrosions
– plastic strength.	– fire etc

- Design requirements for safety.

  Design action (Sd) ≤ Design strength (Rd)

- Design action (Sd) : design values of internal forces (SF & AF), design moments (BM & TM) due to design loads (Fd).

- Design Load, Fd or Factored load = a partial safety factor or load factor × characteristic loads.

$$F_d = \gamma_L \times \text{characteristic loads.}$$

- Design strength (Rd) = $\dfrac{\text{characteristic strength}}{\text{partial safety factor or resistance factor } (\gamma_m)}$

Resistance factor (or) partial safety factor against :
- yieldi strength, $\gamma_{mo} = 1.10$
- buckling strength, $\gamma_{mo} = 1.10$
- ultimate tensile strength, $\gamma_{m1} = 1.25$

③ A load factor or a partial safety factor (γ_L)

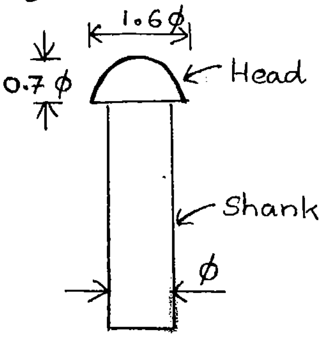
For strength limit state:

Load or load combination	γ_L
DL + LL	1.5
DL + WL	1.5
DL + LL + WL	1.2

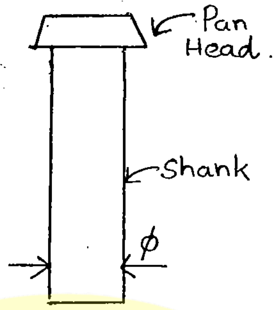
28th Aug,
THURSDAY

2. BOLTED CONNECTIONS

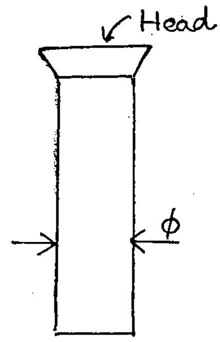
Rivet:



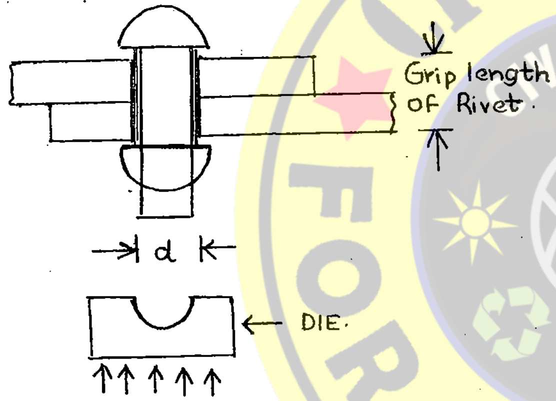
Snap Head or Round Head Rivet.



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

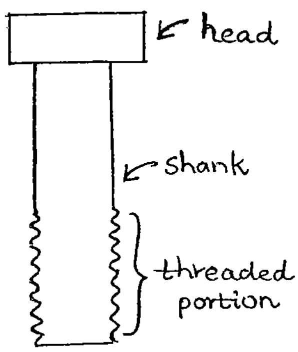
It diameter of rivet after rivet process. which is also same as dia. rivet hole (d).

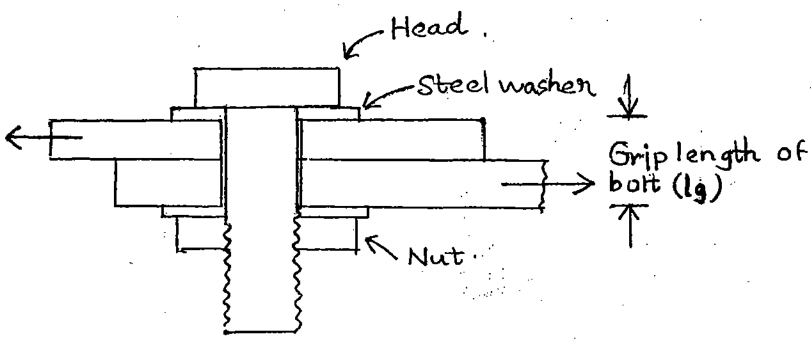
$$d = \phi + 1.5\,mm \quad (\text{when } \phi \leq 25\,mm)$$

$$= \phi + 2.0\,mm \quad (\text{when } \phi > 25\,mm)$$

= 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.

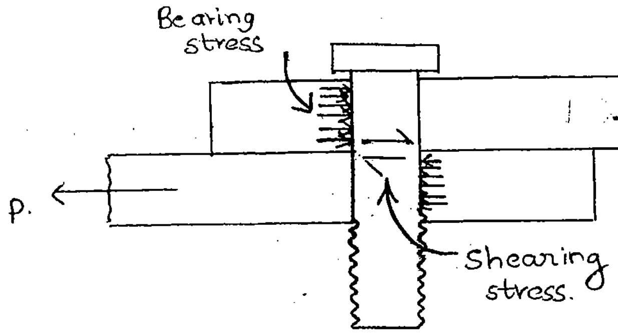
– Mechanical properties of these bolts are specified with grade (property class.

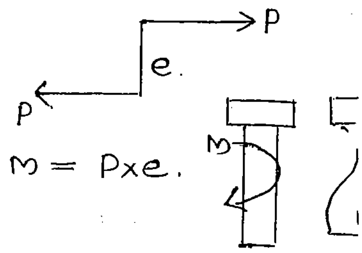
Grade 4.6 to Grade 8.8 are available in market. However, most commonly used one is grade 4.6. Connection with the help of black bolt or unfinished bolt is eg. for bearing type connection or slip type connection or non-frictional connection.

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.



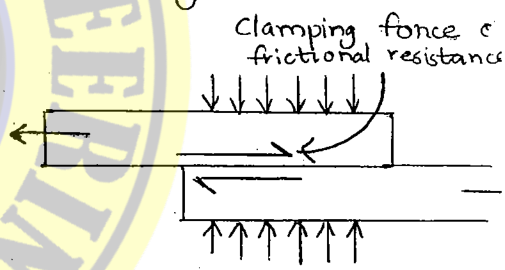


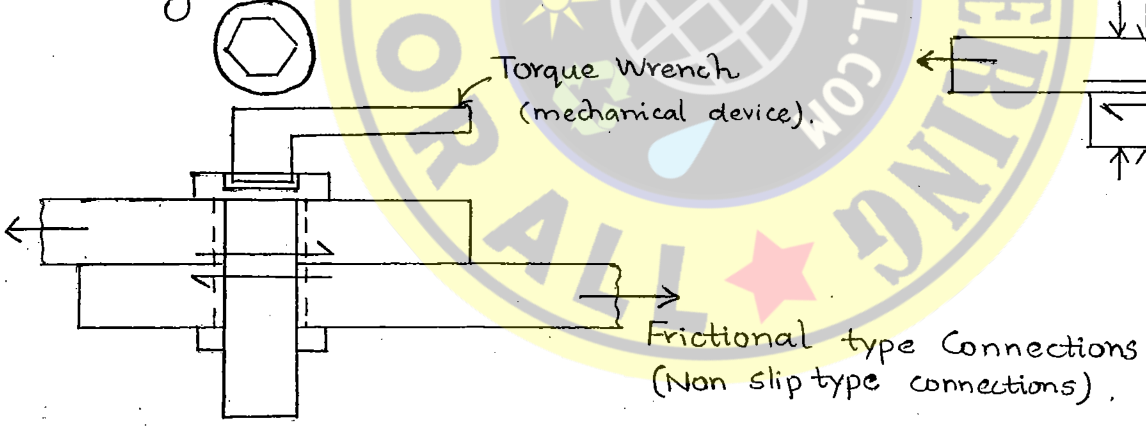
Force gets transmitted through bearing stress (compressive). Further if the grip length is more ($e\uparrow$), eccentricity will be more and bolt may fail due to tension caused by the moment ($M = P\times e$).

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

High Strength Friction Grip Bolts: (HSFG bolts).

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





Proof load $\leq$ Yield strength of a bolt.

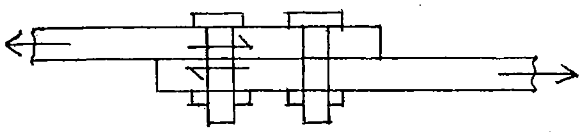
- Grade 10.9 s – 12.9 s

UTS $f_{ub} = 1040$ MPa

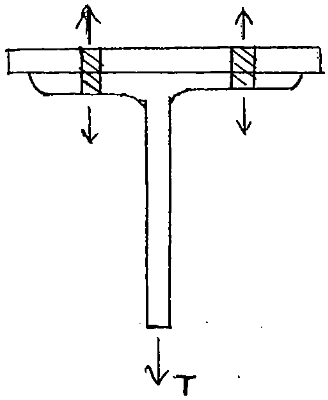
$f_{yb} = 940$ MPa

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

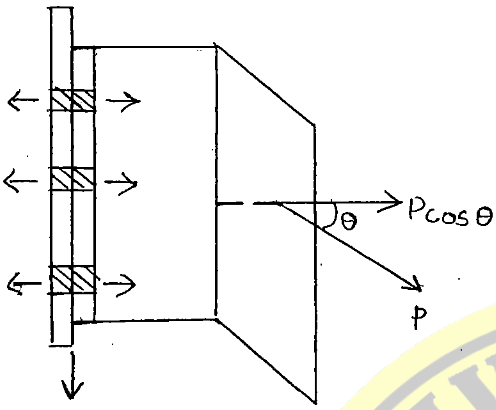
- Shear connections
- Tension connections
- Combined shear and tension connection.



Shear Connection

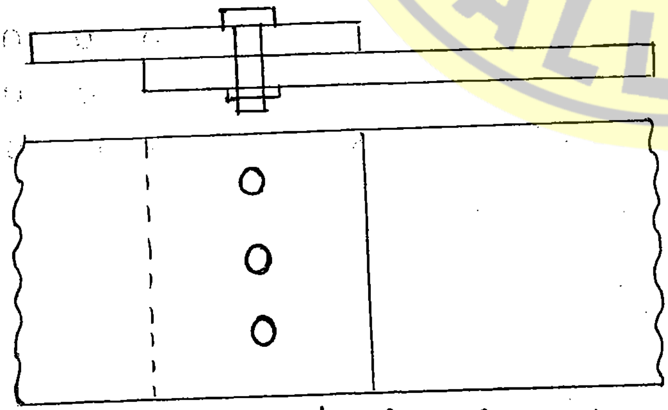


Hanger Connection

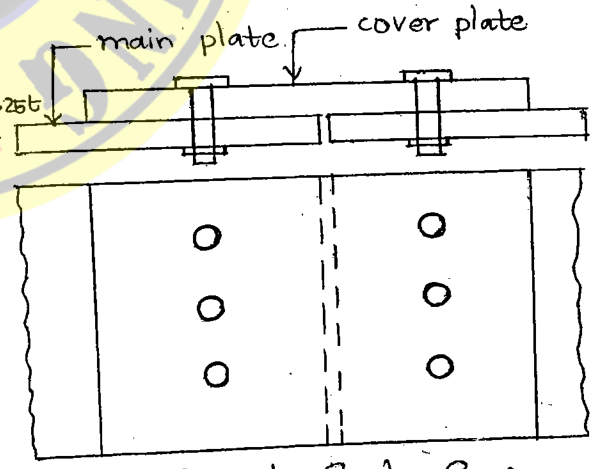


→ Types of Shear Connections:

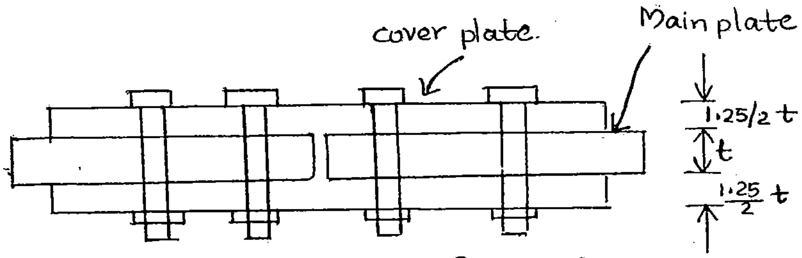
- Lap Connection
- Butt connection
  - Single cover Butt connection
  - Double cover butt connection



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 following reasons:

(i) In double cover butt connection, CG of load in one connected member is lying with CG of load in another connect 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 connec

→ Specifications for Bolted Connections:

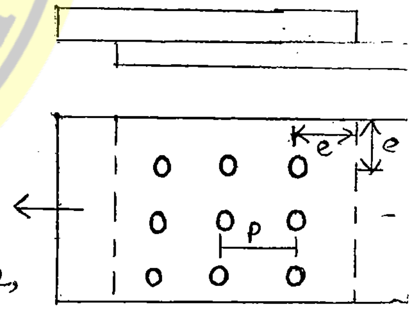
– No: of bolts, n $= \dfrac{\text{Design load}}{\text{Design strength of bolt.}}$

– Bolts are to be arranged in suitable pattern:

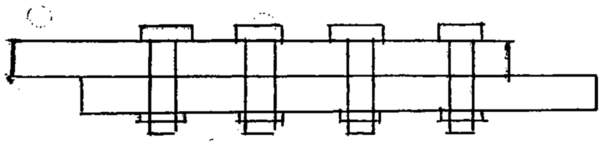
a) Chain pattern

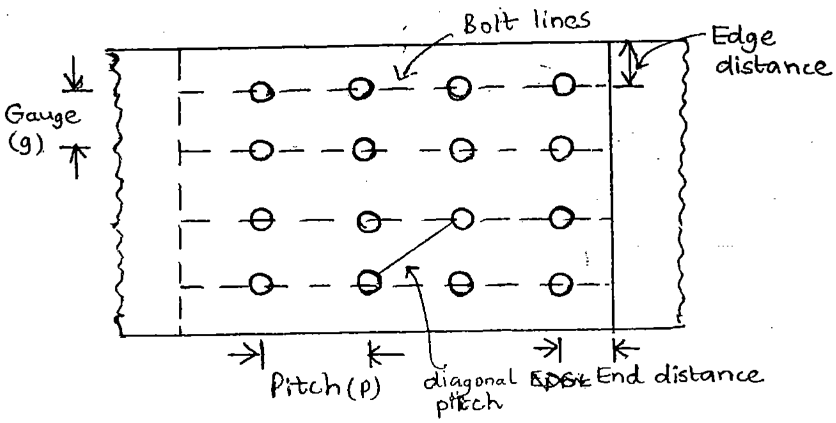
b) Staggered pattern.

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 :

$d_0 = d + 1.0$ mm $(12 \text{ mm} \leq d \leq 14 \text{ mm})$

$= d + 2.0$ mm. $(16 \text{ mm} \leq d \leq 24 \text{ mm})$

$= d + 3.0$ mm $(d \geq 27 \text{ mm})$.

d → shank diameter of bolt.

* Condition for Optimum Pitch :

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

* Minimum pitch, $P_{min} \nless 2.5 \times$ shank diameter of bolt.

$P_{min} \nless 2.5\, d$.

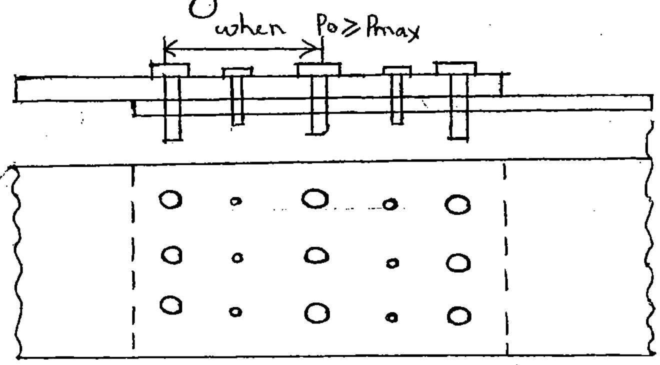
* Maximum pitch, $P_{max} = 12t$ or 200 mm (whichever is le
for comp. member

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

t → thickness of thinner connected member.

$$P_{min} \leq P_0 \leq P_{max}.$$

* Tacking Bolts or Stitch Bolts



When $P_0 > P_{max}$, buckling b/w members occurs. 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, $e_{max} = 40\text{ mm} + 4t$

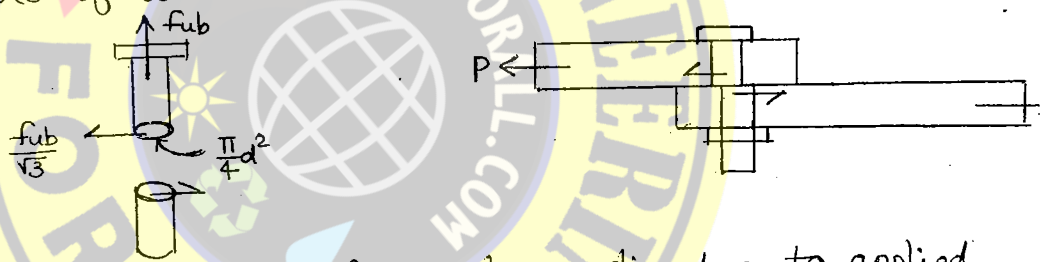
f_y = yield strength of a material.

1st Sept, SUNDAY

→ 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.

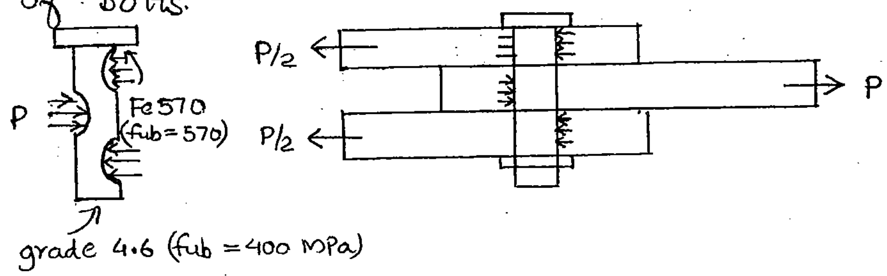
(i) Shear Failure of bolts.



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

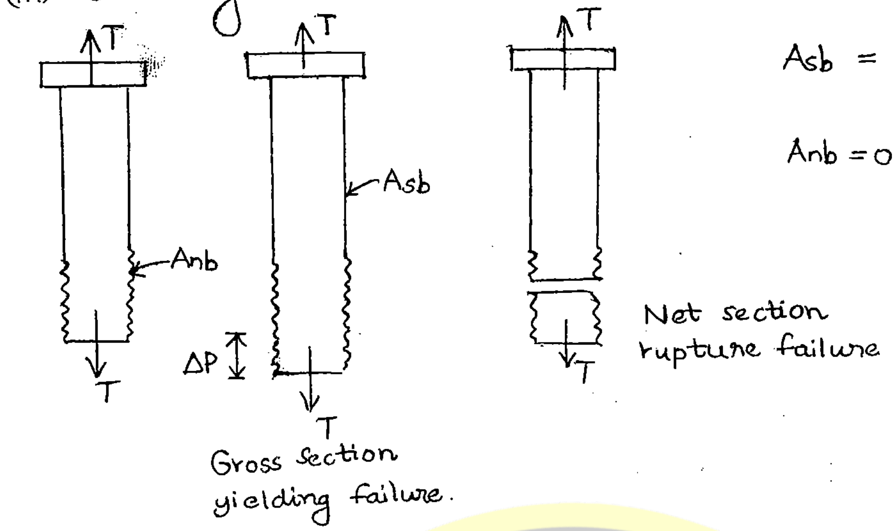
Failure occurs when design action, $P > \frac{\pi}{4}d^2 \cdot \frac{f_{ub}}{\sqrt{3}}$

(ii) Bearing Failure of Bolts.



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

(iii) Tearing Failure of Bolt.



$A_{sb} = \frac{\pi}{4} d^2$; $A_{sb} \rightarrow$ c/s area of shank

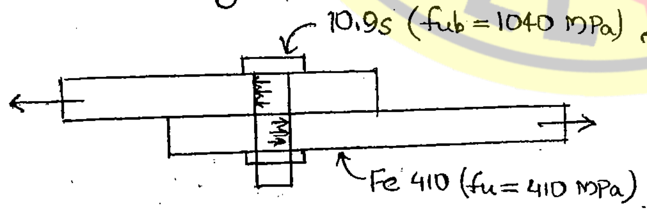
$A_{nb} = 0.78 \frac{\pi}{4} d^2$; $A_{nb} \rightarrow$ net area of threaded portion.

Gross section yielding failure occurs when uniform stress developed in gross area, $\frac{T}{A_{sb}} = f_{yb}$.

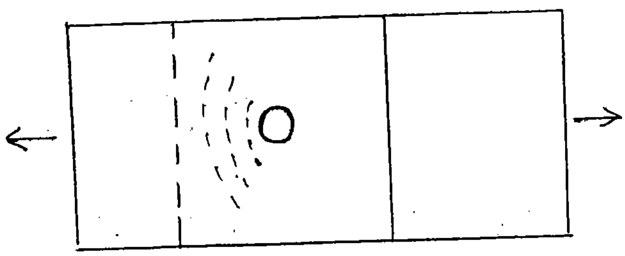
If bolt is subj. to tension, tearing failure may occur at threaded portion.

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

(iv) Bearing Failure of Plate.

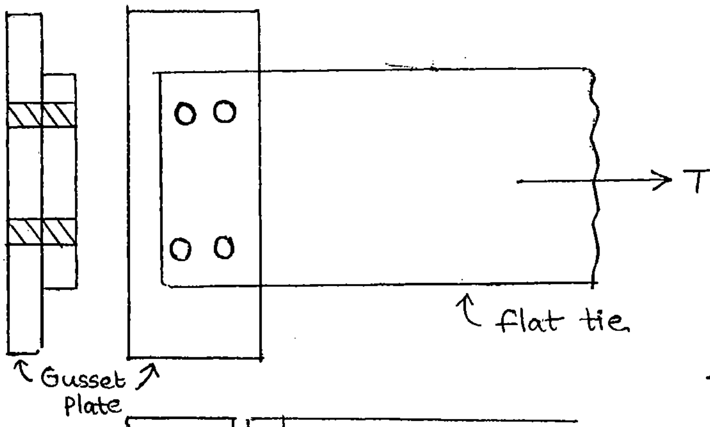


When ordinary bolt is subj. to factored SF, slip may takes place and bolt may come in contact with plate and plate material gets crushed. when plate is weak in bearing

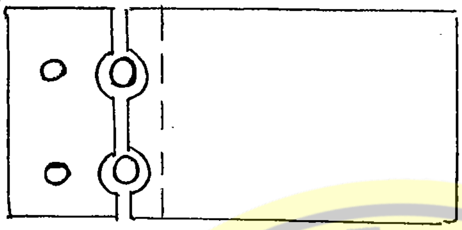


(v) Tearing Failure of Plate.

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



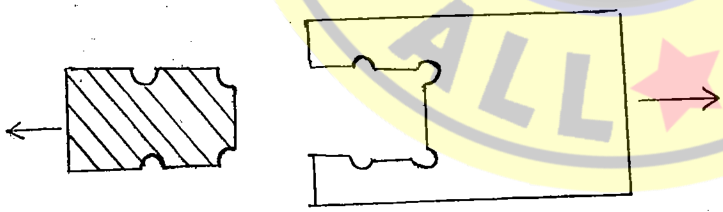
$$\frac{T}{A_n} = \frac{T}{(B-2d_0)t} = f_y.$$



At or near connection, only block shear failure & net section 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.

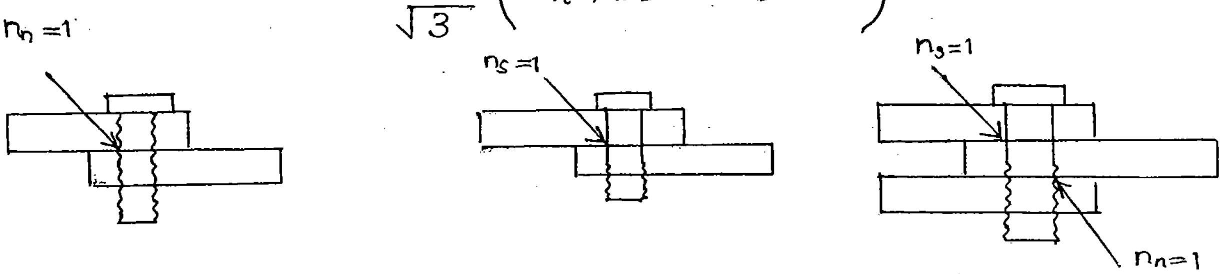


→ Design strength of Bearing Type Bolted Connection (V_{dc})

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, $V_{dsb} = \frac{V_{nsb}}{\gamma_{mb}}$

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

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 % $A_{sb} = 0.78 \frac{\pi}{4} d^2$.

γ_{mb} = partial safety factor for bearing type bolt

= 1.25 for workshop bolting

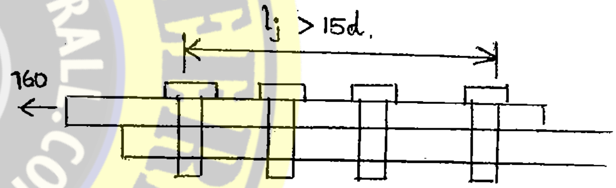
= 1.25 for site on field bolting

For lap connection or single cover butt connection,

$n_n + n_s = 1$

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

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



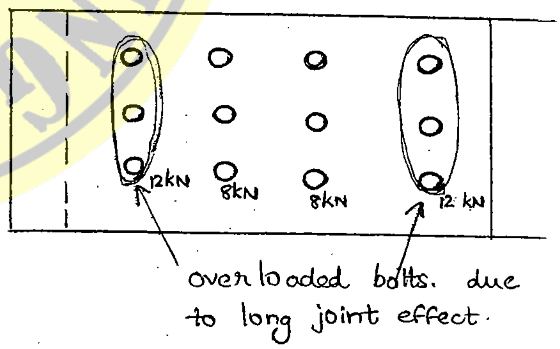
For double cover butt connection,

$n_n + n_s = 2$

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

$n_n = 2$, $n_s = 0$

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



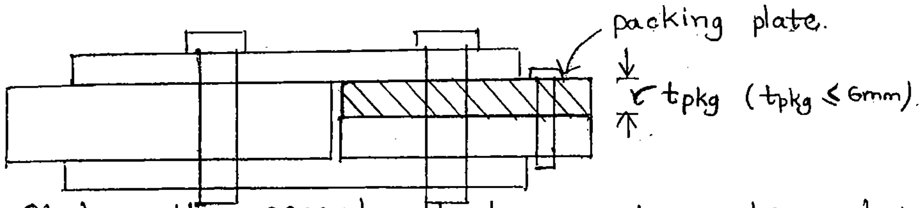
⊙ Nominal shear capacity of bolt is modified for long joint (when $l_j > 15d$), long grip bolt (when $l_g > 5d$) and thicker packing plate (when $t_{pkg} > 6$ mm)

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

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

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

$$\beta_{lg} = \frac{8d}{3d + l_g} \; ; \; l_g = \text{grip length of bolt } (l_g \not> 8d)$$



Higher the ~~eccentr~~ 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, β_{pkg} is applied.

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

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

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

Bearing area of bolt = πdt.

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

∴ bearing area is 80% πdt.

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

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.

$d_0 \rightarrow$ diameter of bolt.

f_u → 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

$$T_{nb} = 0.9\, A_{nb}\, f_{ub} \leq A_{sb} \cdot f_{yb} \cdot \frac{\gamma_{mb}}{\gamma_{m0}}$$

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

$$T_{db} = \frac{T_{nb}}{\gamma_{mb}} = \frac{0.9\, A_{nb}\, f_{ub}}{\gamma_{mb}} \leq \frac{A_{sb} \cdot f_{yb}}{\gamma_{m0}}.$$

* 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)

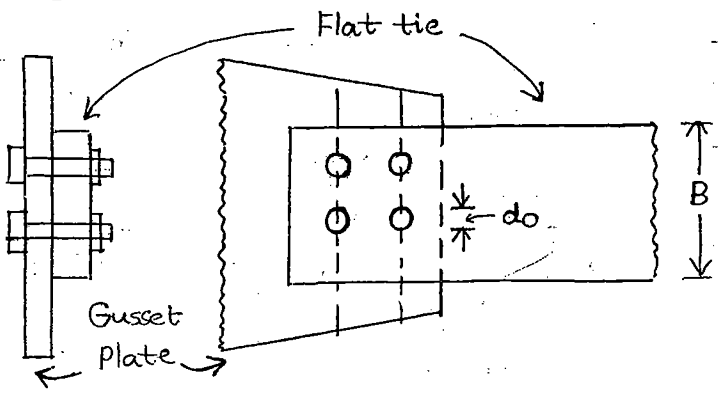
2nd Sept, TUESDAY

d) Design Tensile Strength of Plate

T_{np} = nominal tensile strength of plate.

$= 0.9\, A_n f_u$

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



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 (η)
(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})

⊙ $T_{mp} = \frac{A_g f_y}{\gamma_{m0}}$ (Based on gross section yielding)

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

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

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

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

$= \frac{A_n}{A_g} \times 100 = \frac{(B - nd_0)t}{B \times t} \times 100$

$$\boxed{\eta = \left(\frac{B - nd_0}{B}\right) \times 100}$$

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

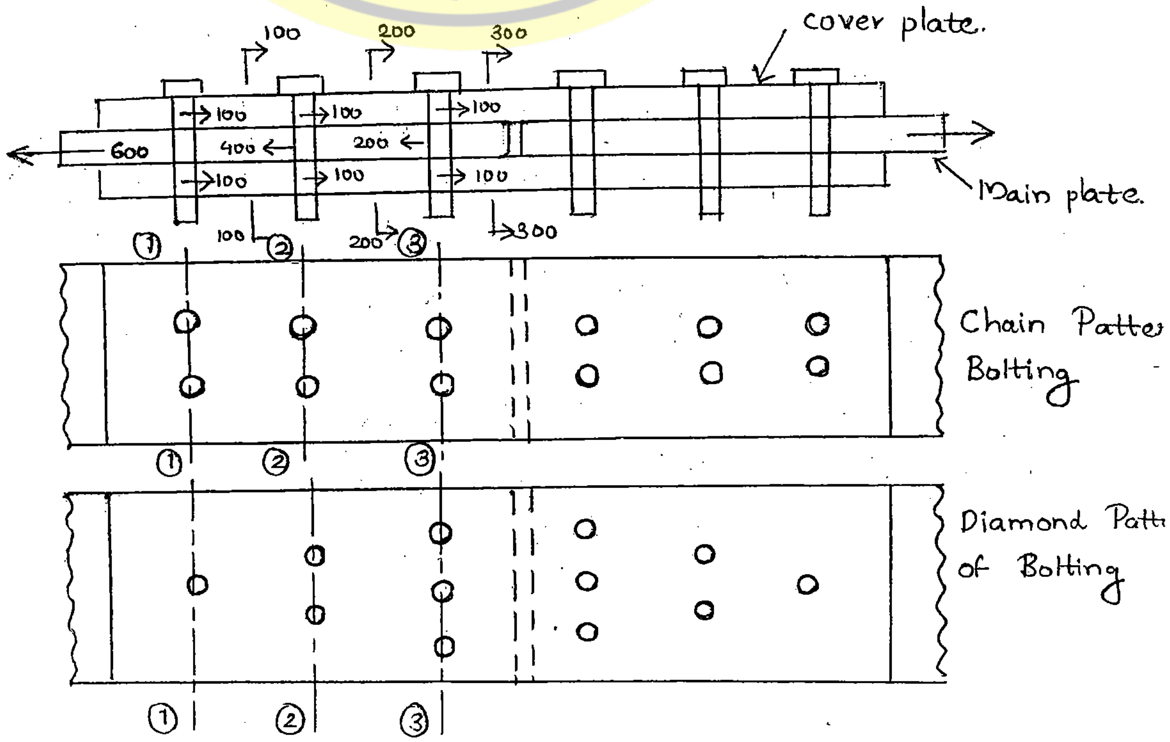
For staggered and chain pattern, $n = 3, 4, 5 \ldots$

$$\eta_{\substack{\text{diamond}\\\text{pattern}}} = \left(\frac{B - d_0}{B}\right) \times 100$$

Assume,

$P = 600$ kN

$V_{db} = 100$ kN.



* It is desirable to use diamond pattern of bolting :- (8 (M)

(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.

P-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.

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

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, $n_s = 1$.

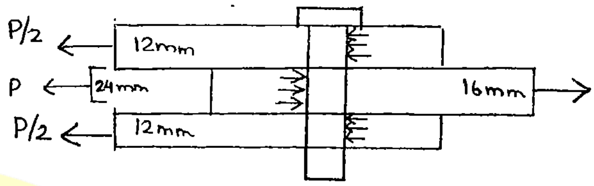
$\therefore \quad \underline{n = 6}$

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.

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

$= \frac{400}{\sqrt{3} \times 1.25} \left(1 \times 2 \times \frac{\pi}{4} \times 16^2\right) = 74.2$ 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, $V_{db} = \underline{74.2}$ kN

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

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

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

$\frac{e}{3d_0} = \frac{33}{3 \times 22} = 0.5$

$\Rightarrow$ 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, $V_{dpb} = \frac{2.5\, d\, t\, f_{ub}\, k_b}{\gamma_{mb}}$

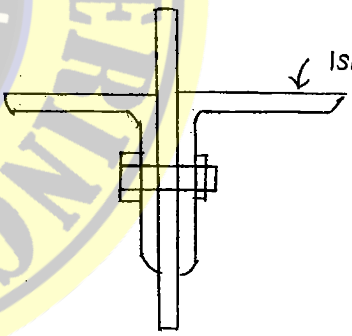
$= \frac{2.5 \times 20 \times 12 \times 400 \times 0.5}{1.25}$

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

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

$f_y = 240$ MPa.

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



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, $d_0 = 18$ mm.

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

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

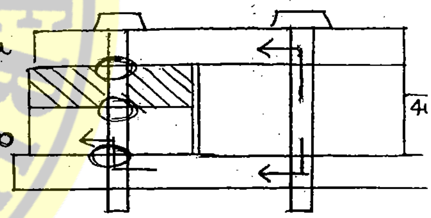
$$n = \frac{150}{50.25} = \underline{\underline{3}}$$

3rd 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}.

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

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

β_{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

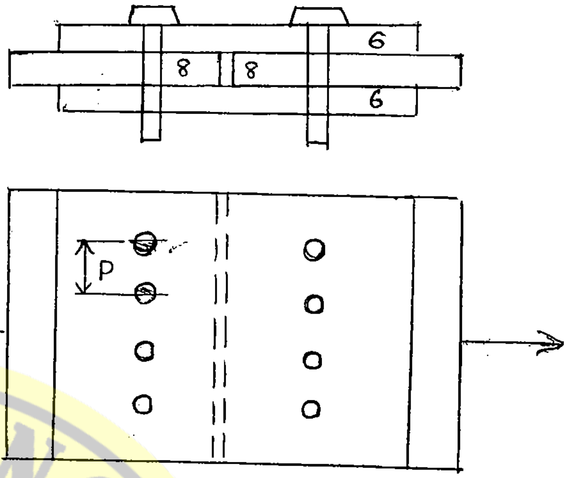
$$\eta = \frac{P}{V_{db}} = \frac{400}{80} = 5 \text{ bolts}$$

11. Failures are :

SFB → V_{dsb}

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

TFP → T_{dp}.



For wide plate,

Efficiency of the connection

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

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

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

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

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

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

$t(MP) = 8mm$
$t(CP) = 6+6 = 12$ r

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

$= 56.32$ kN

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

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

$A_n = (B - n d_o) t$

Per pitch length :
$B = p$
$n = 1$

$= (p - n d_o) t$

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

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

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

T_{mp} = design strength of main plate.

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

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

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

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

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

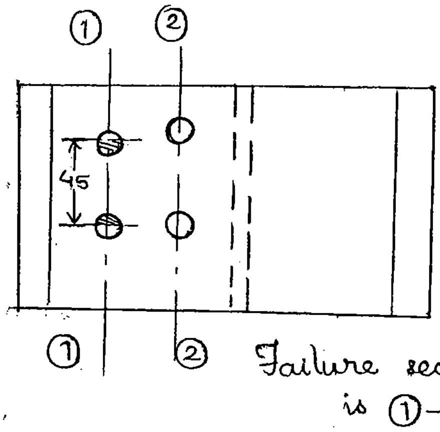
$T_{dp} = \frac{0.9 A_n f_u}{\gamma_{m1}}$; $A_n = (B - n d_o) t$; n → no. of bolts in failure section

$n = 1$

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

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

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



Failure section is ①–①

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

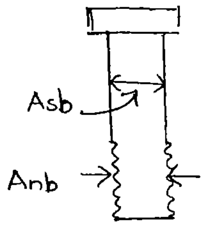
$$\eta = \left(\frac{B - n d_o}{B}\right) \times 100$$

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

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

13. For M16 bolt, $d = 16$ mm, for grade 4.6 bolt,

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



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

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

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

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

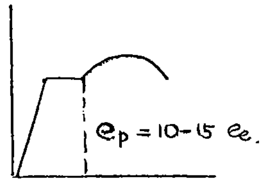
$$= 0.9\left(0.78 \times \frac{\pi}{4} \times 16^2 \times \frac{400}{1.25}\right) \leq \frac{\pi}{4} 16^2 \times \frac{240}{1.1}$$

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

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

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 γ_{mb} is used only when there are uncertainities.

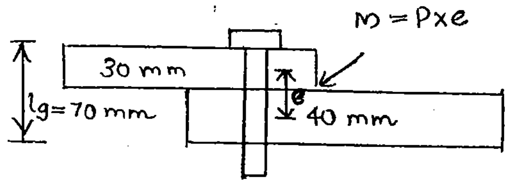
But here bolt diameter is same and process of installatio at site and workshop are same and ∴ no uncertainities.

So less safety factor of γ_{mo} (=1.1) is used.

But in rupture failure, there are uncertainities. like the threaded portion may be less than 78% of A_{sb}.

So γ_{mb} (=1.25) is used.

14. β_{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 % $\left(\frac{1 - 0.9056}{1} \times 100 \right)$