① - ⑨

JOINTS

Introduction

Joints facilitate the assembly and disassembly of machine parts. The joints to be discussed are those used to fix two or more parts, and not the movable joints (or kinematic pairs).

The joints are divided into two main groups.

(i) Permanent joints
(ii) Temporary (detachable) joints.

(i) Permanent joints

These are the type of joints in which the disassembly of the parts ~~may~~ would cause damage to the joint and the parts at the area of the joint. These are such as riveted, welded, brazed, soldered, adhesive and interference fits

(ii) Temporary (detachable) joints

These are the type of joints in which the parts can be disassembled without damage to the parts and the components of the joint. These are such as threaded, pinned, keyed, splined joints etc. Note: in splined connection only relative rotary motion is prevented. Axial motion is permitted.

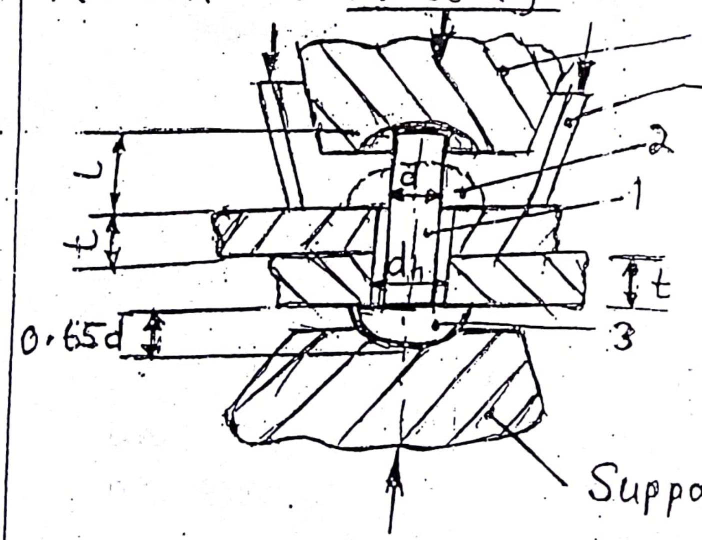
1(b) 1. PERMANENT JOINTS

1.1 RIVETED JOINTS

Until recently, riveted joints were the main type of permanent joints extensively used in the construction of boilers, ships, bridges etc. The rapid development of welding methods has reduced considerably the sphere of application of the riveted joints.

A rivet (fig. below) is a one-piece fastener consisting of a round shank (body) 1 and a set head 3. It is used to fasten two or more pieces together.

The rivet is applied by passing its shank through the holes in the members to be fastened, after which the protruding part of the shank is upset to form a second closing head 2. The forming of the second head is what is known as riveting.



d = dia. of rivet shank

d_h = dia. of hole

$d = d_h - 1$ mm for drilled hole

t = plate thickness

l = height of protruding shank $\approx (1.5-1.7)d$

Fig: Riveting

1mm is clearance btn d and dh.

Note: Riveting can be done by hand or by means of machines. To facilitate the entrance of the rivet, the hole should be slightly larger than the rated diameter of the shank. In machine riveting the hole is filled with metal better.

Methods of forming

Two methods i.e. (i) Cold riveting
(ii) Hot riveting

(i) Cold riveting

Steel rivets up to 12 mm diameter are driven cold.

(ii) Hot riveting

For steel rivets greater than 12 mm diameter, the shank is heated partially or wholly to the necessary temperature and then riveted.

Materials for rivets

Materials of rivets should be ductile so that they can be easily clinched. Common materials are such as mild steel, copper, brass and aluminium.

Classification of Riveted Joints

Riveted joints can be classified according to the following;

(a) Functions they are to serve
(b) Method of fastening.
(c) Application of the load.

(a) <u>functions they are to serve</u>.

There are;

(i) Strong joint – used in structural work like bridges.

(ii) Strong and tight joint – used in pressure vessels like boilers, tanks.

(b) <u>Methods of fastening</u> (fig. below)

There are:

(i) Lap joint – (Strong joint)

(ii) Butt joint – (Strong and tight joint)

(c) <u>Application of the joint</u> (fig. below)

(i) Centrically loaded

(ii) Eccentrically loaded

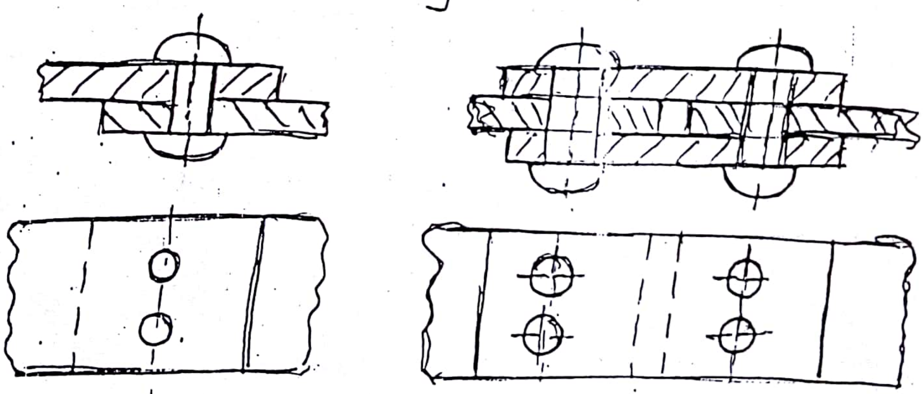
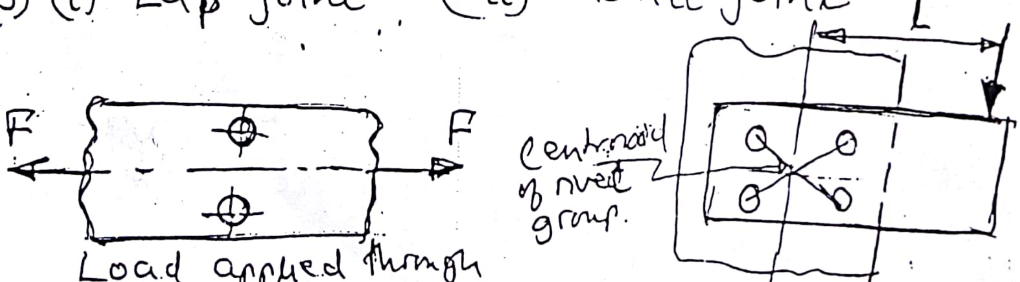


Fig: (b) (i) Lap joint (ii) Butt joint



Load applied through C.G. of rivet group.

Fig: (C) (i) Centrically Loaded

(ii) Eccentrically loaded

i.e. Load offset by a distance 'L' from C.G. of rivet group.

Advantages and Disadvantages of Riveted joints

Advantages

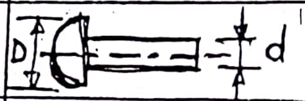
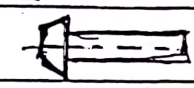
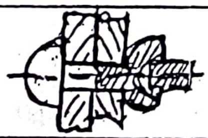
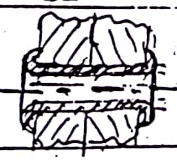
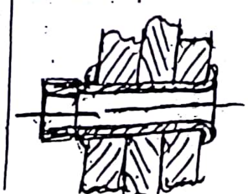
- Can withstand vibration loads
- Used at a place where heat application is prohibited.

Disadvantages

- Joining plate becomes weak due to holes.
- The weight of the structure increases.
- Higher manufacturing costs.

Types of Rivets

By form of their cross-sections, rivets fall into two categories – i.e. solid or tubular. (table below)

	Type of rivet.	Diameter of shank d [mm].	Sketch
Solid	Button-head rivets (most widely used)	1 – 36	
	Pan-head rivets	2 – 36	
	Half-countersunk rivets (tinsmith's)	2 – 36	
	Explosive rivets (used if closing head can not be formed by conventional methods)	1 – 10	
	Flanged tubular rivets (connect metal parts)	1 – 10	
Tubular	Beaded-tubular rivets (join parts of elastic material e.g. leather, fabric etc)	1 – 10	

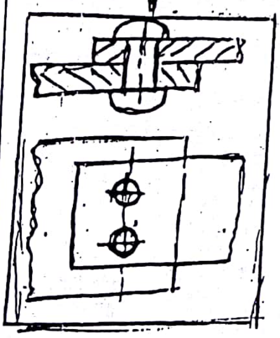
Tubular rivets are for aircraft and m/c building

TYPES OF RIVETED JOINTS

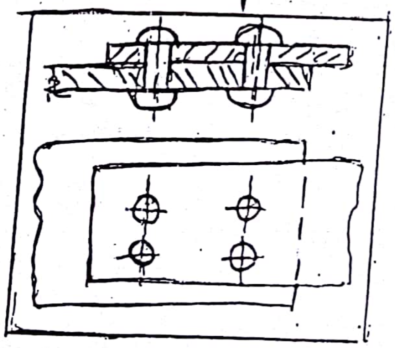
- RIVETED JOINTS
  - STRONG JOINTS
    - LAP JOINTS
  - TIGHT – STRONG JOINTS
    - BUTT – JOINTS
      - ONE-STRAPPED
      - TWO-STRAPPED

LAP JOINTS

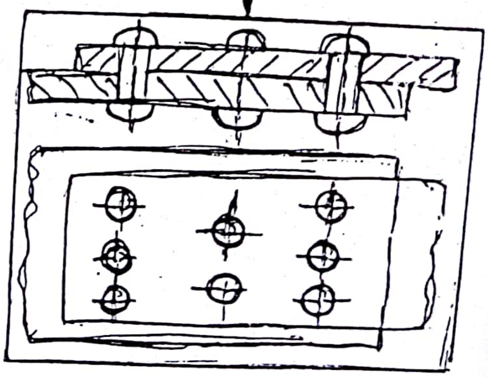
- SINGLE – RIVETED (SINGLE – ROW



- DOUBLE – RIVETED



- TRIPLE – RIVETED (MULTIPLE – ROW)

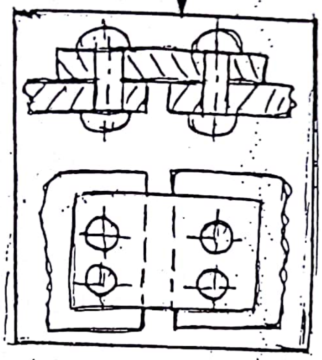


BUTT – JOINTS

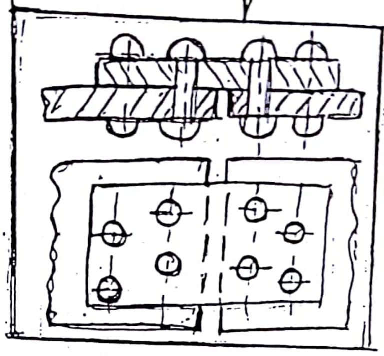
- ONE – STRAPPED SINGLE COVER
- TWO – STRAPPED

ONE - STRAPPED BUTT - JOINTS

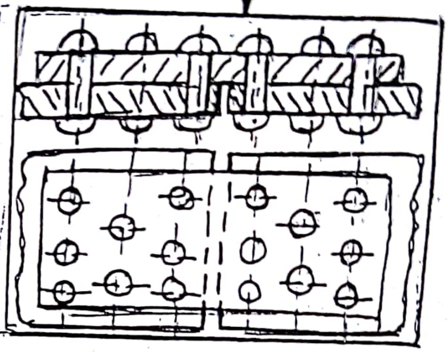
SINGLE-RIVETED



DOUBLE RIVETED

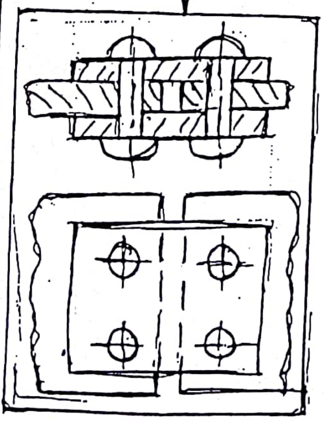


TRIPLE-RIVETED (MULTIPLE-ROW)

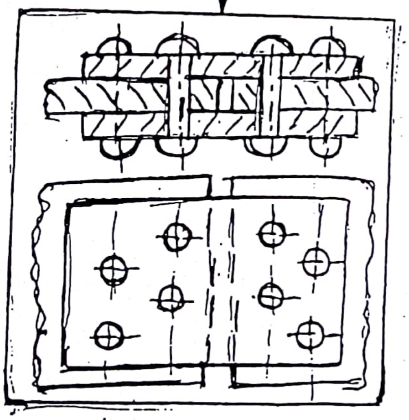


TWO - STRAPPED BUTT - JOINTS

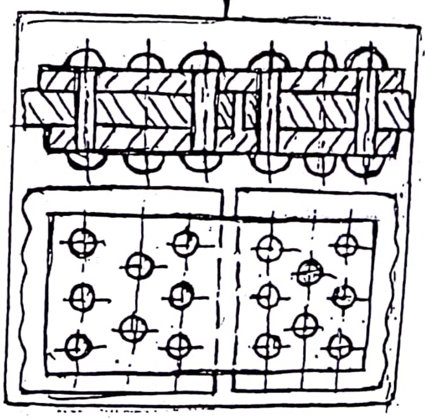
SINGLE- RIVETED



DOUBLE-RIVETED



TRIPLE-RIVETED



Note: The number of rivets in each row can be any.

DESIGN OF RIVETED JOINTS

General: They are generally designed to carry transverse loads. (either centrically or eccentric

A riveted joint may fail due to either of the following ways:-
(i) Failure of rivets
(ii) Failure of the plates.

(i). Failure of the rivets

A rivet may fail due to:-
(a) Shearing
(b) Crushing (or bearing).

(a) Shearing of the rivet

The load applied to the riveted joint may cause the rivet to shear off. The shearing of the rivet may be single shear or double shear depending on the design of the joint. (figs: below).

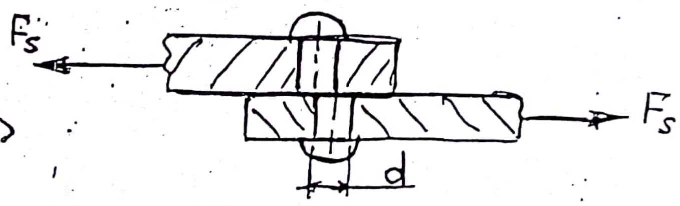


Fig: Single shear (All types except two-strapped Lap and butt-joints)

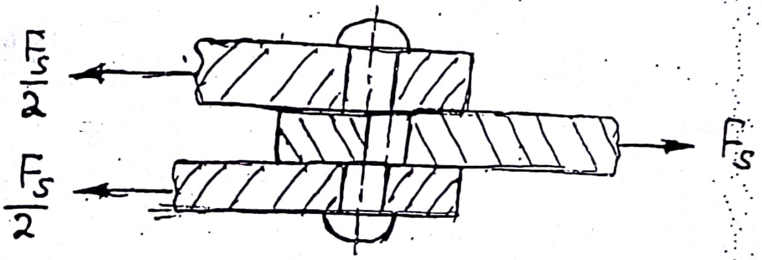


Fig: Double shear (All two-strapped butt and Lap joints)

The rivet strength in shear 'F_s' is given by

$$\boxed{F_s = \tau_A \cdot A_s} \quad (1)$$

where τ_A = allowable shear stress of the rivet material

A_s = Area of shear

$= \frac{\pi d^2}{4}$ single shear

$= 2 \cdot \frac{\pi d^2}{4}$ double shear.

d = diameter of rivet (hole completely filled)

Note: Multiple row rivets total area $A = N \cdot A_s$
where $N = 2$ for double riveted, 3 = triple riveted etc.

(b) Crushing of the rivet

The load applied to the joint may cause the rivet to fail by crushing as shown in fig. below.

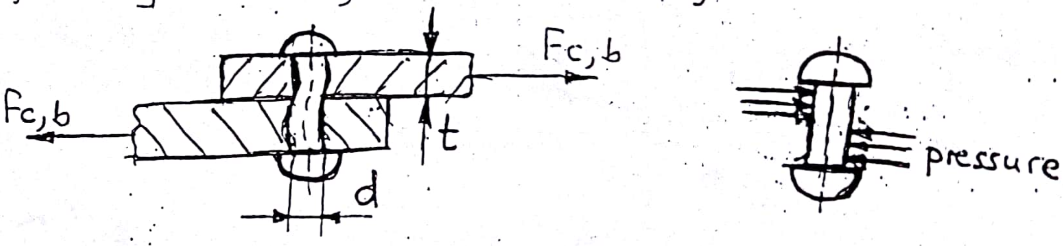


Fig: Crushing of the rivet

The crushing strength of the rivet '$F_{c,b}$' is then given by:

$$\boxed{F_c = \sigma_{CA} \cdot A_c} \quad (2)$$

where σ_{CA} = allowable crushing/bearing stress of the rivet

A_c = Area of crushing (projected area of bearing)

$= d \cdot t$; d = rivet dia/hole
t = plate thickness

Note: t = minimum thickness of plates

For multiple-row $A = N \cdot A_c$ where $N = 2, 3$ etc.

> **Rivet value 'F_V'**

Rivet value F_V is the LEAST of F_s and F_c above.

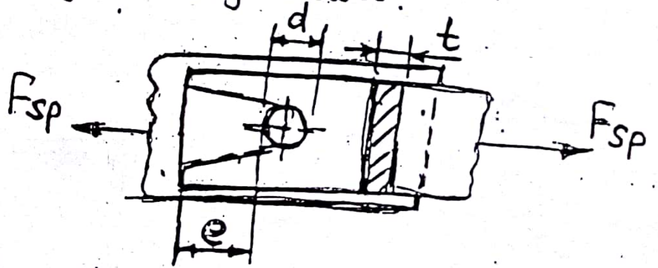
(ii) Failure of the plates

Plates of the riveted joint may fail in the following ways:-

(a) Shearing ('tear off') of the plates.
(b) Bearing failure of the plates
(c) Tensile failure of the plates.

(a) Shearing of the plates

The plates of the riveted joint may 'tear off' at the edges. Fig. below.



The shearing strength of the plates 'F_{sp}' is given by

$$\boxed{F_{sp} = \tau_A \cdot A_s} \quad (3)$$

Where τ_A = allowable shear stress of the plates.
A_s = Shear area
$= 2et$; t = plate thickness, e = minimum edge distance (margin).

Code: Margin $e = (1.5 \ldots 2, \ldots 3)\,d$
where d = dia of rivet/hole.

Provided proper margin is kept, then no need to check for tear out.

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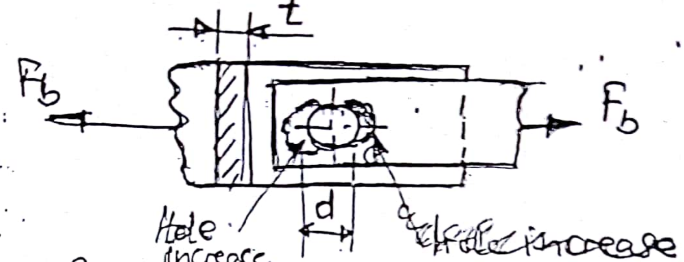
(b) Bearing failure of plates

Plates may fail in bearing as shown in fig. below (i.e. tendency of the rivet hole to increase).



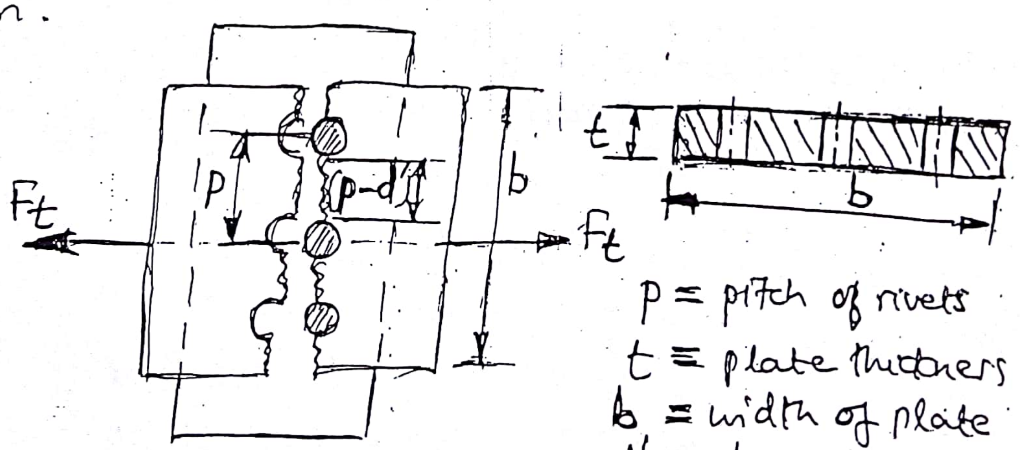
F_b = Bearing strength of the plate.

Fig: Bearing failure of plate

Note: Eqn (2) above for rivet crushing apply. i.e. $F_b = F_c$ the values may be different if the rivet and plate are of different materials. [i.e. if $\sigma_{allowable}$ is different, otherwise d, t are same]

(c) Tensile failure of plates

Plates may fail in tension as shown in fig. below. That is the plate may tear off across the row of the rivets as shown.



p = pitch of rivets
t = plate thickness
b = width of plate
d' = diameter of rivet hole.

Fig: Tensile failure of plate

The tensile strength of the plate 'F_t' is given by

$$\boxed{F_t = \sigma_{tA} \cdot A_t} \quad (4)$$

Where σ_{tA} = allowable tensile stress of the plate

$$A_t \begin{cases} = \text{tensile stress area} \\ = (b - n d')t \quad \text{small joint length} \\ = (p - d')t \quad \text{Long joint e.g. boiler} \end{cases}$$

n = no. of rivets in the weakest row

<u>Note:</u> 1) $$d' \begin{cases} = d + 1 \text{ mm (drilled)} \\ = d + 2 \text{ mm (punched hole)} \end{cases} \text{Steel}$$
$$= d + 0.1 \cdots 0.2 \text{ mm} \quad \text{Aluminium}$$

d = diameter of rivet

Exceptions in special cases where rivets have to fill hole completely.

2) If the joint is <u>continuous</u> (as in the case of boilers) the strength is calculated <u>per pitch length</u>. If the joint is <u>small</u> the strength is calculated for the <u>whole length</u> of the plate.

~~Efficiency of a riveted joint~~

Strength of a riveted joint

The strength of a joint may be defined as the maximum force which it can transmit without causing it to fail. Therefore, the strength of the joint is the LEAST OF F_s, F_c and F_t.

Efficiency of a riveted joint.

The efficiency of a riveted joint, is the ratio of the strength of the joint, to the strength of the unriveted plate.

Tensile strength of the unriveted plate 'F' is given by

$$F \begin{cases} \boxed{= \sigma_t \cdot p \cdot t \\ = \sigma_t \, b \cdot t} \quad (5) \\ = \sigma_t (b - d)t \quad \text{considering one rivet hole.} \end{cases}$$

Where σ_t = allowable tensile stress of plate

Therefore efficiency of the joint 'η' is given by

$$\boxed{\eta = \frac{\text{Least of } F_s,\ F_c \text{ and } F_t}{F}} \quad (6)$$

For a long joint if 'F_t' is the strength of the joint.

$$\therefore \boxed{\eta = \frac{F_t}{F} = \frac{\sigma_t (p-d) t}{\sigma_t \cdot p \cdot t} = \frac{p-d}{p}} \quad (7)$$

<u>Rule</u>: Design the joint for maximum efficiency.

General Considerations

In designing a riveted joint, the following assumptions should be made:

(i) The load on the joint is equally shared by all the rivets (for centrically loaded rivets).

(ii) Bending of rivets is neglected.

(iii) All stresses are uniformly distributed (bearing, shearing, tensile)

(iv) Frictional forces between the plates are neglected. (cold riveting).

(v) Plates are rigid.

(vi) Rivets after being driven fill hole completely. (cold riveting).

(vii) Capacity in double shear is twice the capacity in single shear.

In order to design a riveted joint, we have to calculate the following:-

(i) Diameter of the rivets

(ii) Number of rivets

(iii) Pitch of rivets

(iv) Thickness of cover plates (in case of butt joints).

The following rules are observed, while designing a riveted joint.

(i) Diameter of rivets

The diameter of the rivets is obtained by the relation

$$\boxed{d = 1.9\sqrt{t}} \text{ (cm)} \quad \text{or} \quad \boxed{d = 6.05\sqrt{t}} \text{ (mm)} \quad (8)$$

t [mm]

Note: $6.05 \doteq 1.9\sqrt{10}$

$t_{cm} = t \times 10$ m.

where d = dia. of the rivet (cm)

t = thickness of main plate (cm).

> In no way the diameter of the rivet is provided less than the thickness of the main plate.

(ii) Number of rivets

The number of rivets is calculated when the length of the joint is small. For long joints (as in boilers), the number of rivets is not calculated.

In a small joint, the number of rivets 'n' is:

$$\boxed{n = \frac{F}{F_v}} \quad (9)$$

where F = Pull to be transmitted across the joint.

F_v = Rivet value (i.e. LEAST of F_s and F_c).

Note: 'n' should be Integer. (e.g. if 5.3 then take 6).

(iii) Pitch of rivets (P)

It is an important factor while designing a riveted joint. It is calculated on the basis that the plate strength with one rivet hole, which should not exceed the total value of the rivets in charge of a pitch length.

In general $\boxed{F_t \leq F_v}$ (10) where F_v = Rivet value i.e LEAST of F_s & F_c.

Then the value of the pitch 'p' should lie in the range

$$\boxed{2.5d < p < 4d} \quad (11)$$

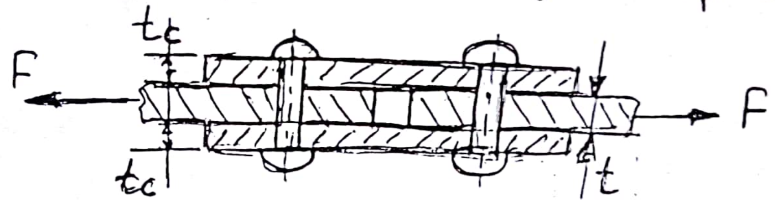
For practical purposes $\boxed{p \geq 2d + 12}$ (mm) (12)

(iv) Thickness of cover plate (t_c) :

The two cover plates are provided each of thickness 't_c' given by

$$\boxed{t_c = \frac{5}{8} t} \quad (13)$$

where t = thickness of main plate.



ECCENTRICALLY LOADED RIVETS

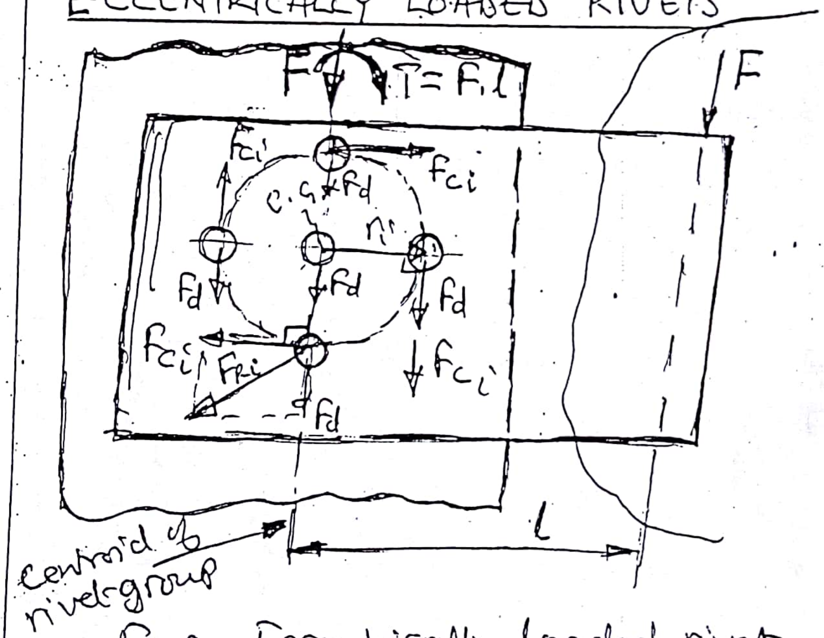


Fig: Eccentrically loaded rivet

The resultant load at the centroid of the rivet group is a direct load F and a couple load T = F.l

∴ Resultant load on each rivet 'F_{Ri}' is given by

$$\boxed{\vec{F}_{Ri} = \vec{F}_d + \vec{F}_{ci}} \quad (14) \text{ vectorially}$$

where $\vec{F}_d$ = rivet direct load (15)

$$= \frac{F}{n}$$ where n = total number of rivets

and $\vec{F}_{ci}$ = couple force on the rivet

$$\boxed{\vec{F}_{ci} = \frac{T \cdot r_i}{\sum_{i=1}^{n} r_i^2}} \qquad (16)$$

r_i = radius of rivet from C.G. of group.

n = no. of rivets taking the couple

Note: the rivet at C.G. $F_{ci} = 0$ i.e. $r_i = 0$.
(i.e. takes no couple)

CONCLUSION

(i) Theory applied to rivets applies as well to bolts and other similar elements.

(ii) Strong Joints under Dynamic Loading

Generally rivets are not recommended for cases with variable loading. In such cases rivets are replaced by high tension friction grip bolts.

(iii) Connection plate design

- Note the number of rivets
- Rivet arrangement.

(a)

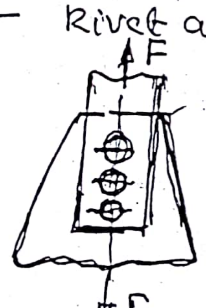


Fig: Chain seam

(b)

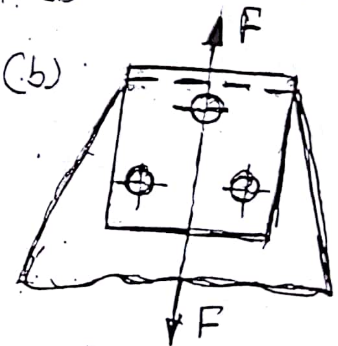


Fig: Scattered seam

(c)

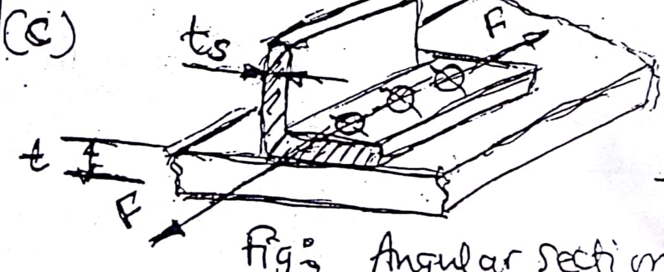


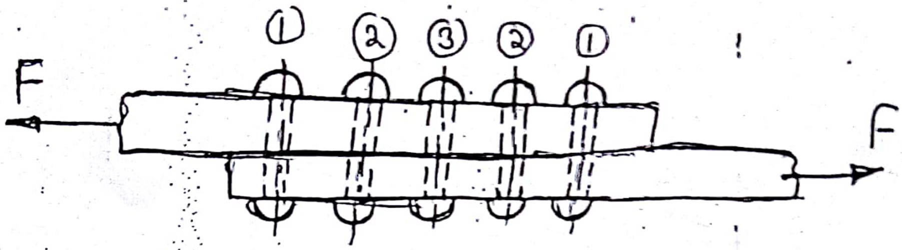
Fig: Angular section.

- Thickness t_s approx equal to bar or section (mean) thickness
- For angular sections arrange rivets along the centroid of the section in order to avoid bending.

— At least two rivets for a joint.

Omit

MULTIPLE RIVETED JOINT (Design for Maximum Efficiency)



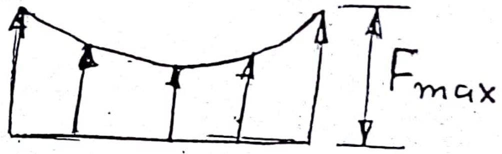


Fig: Actual force distribution on plates at each row.

The actual force on plate on i_{th} row is given by

$$\boxed{F_i = \frac{n - n_i}{n} F} \quad (1)$$

Where F = max. applied load to the joint

n = total number of rivets

n_i = number of rivets in the i_{th} row.

F_i = force on plate in ith row.

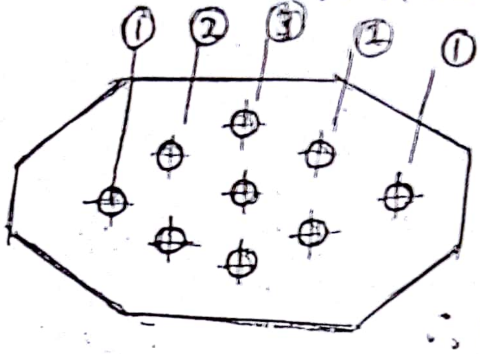
Note: $$\boxed{F_{i\,max} = F_t} \quad (2)$$

F_t = tesile strength of the plate in the i_{th} row.

$$\boxed{F_t = \sigma_{tA}(b - n_i d')t.} \quad (3)$$ at the i_{th} row

Omit

Outer rows will have less rivets than the inner rows e.g.



$n = 9$

middle row 3

$n_3 = 3$

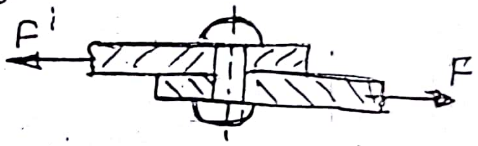
$\therefore F_3 = \dfrac{9-3}{9} F$

and $F_{t_3} = \sigma_{tA}(b - 3d')t < F_{t_1}$

because of more rivet holes made.

FBD of riveted joints.

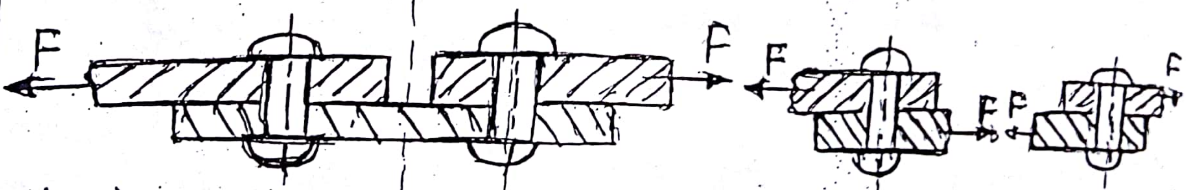
Lap joints



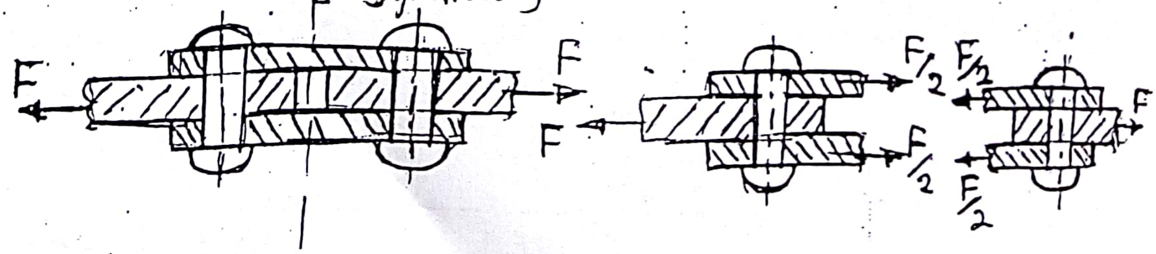
The total load will be shared equally by all rivets in the joint.

Butt joints

(i) Single cover   Symmetry   FBD



(ii) Double cover   Symmetry   FBD



- In all butt joints the total load is shared by all rivets on the other half of the symmetry line.
- The number of rivets and pattern should be same on all sides