UNIT 4 RIVETED AND WELDED JOINTS

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4.1 INTRODUCTION

A steel structure may have any size or shape depending upon the design requirements. However, the component members are manufactured and marketed only in a few definite shapes and sizes. Hence, they have to be joined together to produce the desired final structural form. These *joints* or *connections* play a very important role in steel design, and they have to be strong and rigid enough to transmit all the forces and moments from one member to another. Failure of a joint is as bad as the failure of a member and can render the entire structure unsuitable for use. Hence, special attention is necessary in design and fabrication of these joints.

In steel structures, mainly two types of joints are found, namely **riveted joints** and **welded joints**. In the former case, holes of the required diameter are drilled through the members to be joined and the rivets are then driven into these holes. In the latter case, molten metal is deposited, joining the members at the joints by special electric or gas heating appliances, thereby gluing the two members together. In this unit, we shall study the fabrication and design of riveted and welded joints.

Objectives

After studying this unit, you should be able to

- describe the various types of rivets, and their uses,
- explain the allowable working stresses and strength characteristics of these rivets,
- describe the various types of riveted joints and the causes and types of their failures,
- describe the design assumptions and design methods for riveted joints in light of various Indian Standard recommendations,
- determine the efficiency of riveted joints,
- understand welding as a structural connection, its advantages and disadvantages,
- design various types of welded joints, and
- design welded connections with or without eccentric loads.

4.2 RIVETED JOINTS

4.2.1 Types of Rivet

Rivets are manufactured from either mild steel or high tensile steel, and consists of a **head** and a **shank**, which have got definite dimensions as shown in Figure 4.1(a). They are placed inside holes drilled through the members to be joined, the open end of the rivet is then forged to form another rivet head, thus closing the joint rigidly (Figure 4.1(b)). The rivet heads are formed by any one of the following methods :

Power Driven Rivets

In these rivets, pneumatic hammer or any other type of mechanical driving device is used.

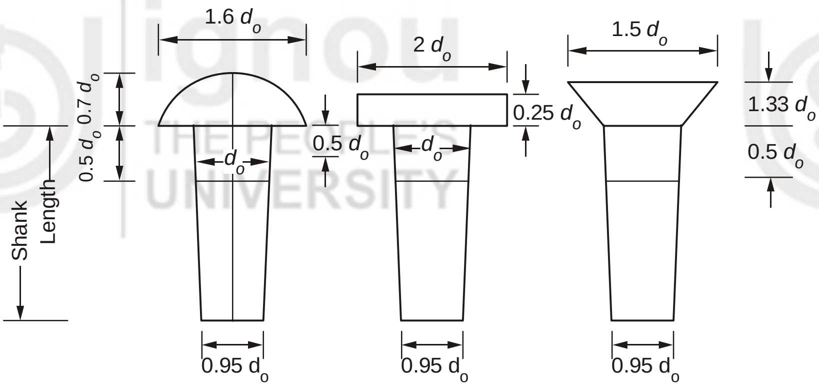
Hand Driven Rivets

In these rivets, driving is done manually by hammers.

Power driven rivets are preferred to hand driven ones and are allowed higher stresses. Also rivets may be either **shop rivets** or **field rivets** depending upon the conditions under which they are driven. Shop rivets are driven in workshops under controlled conditions and expert supervision and hence allowed 10% higher stresses than fields rivets which are driven by semi-skilled field workers at work sites.

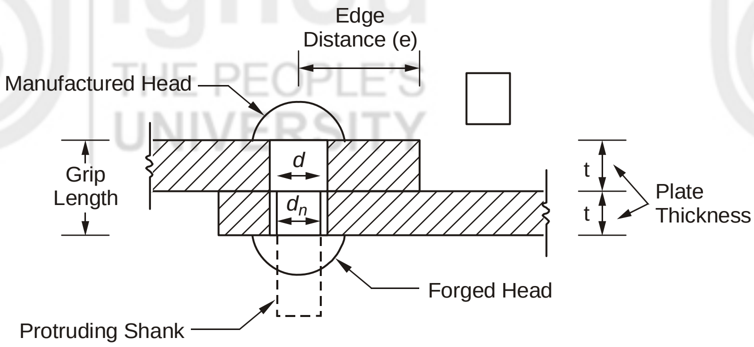
The rivet holes are made slightly larger than the diameter of the shank of the undriven rivets.

The rivets heads are made of different shapes and they are sometimes named after the shape of their heads, e.g. **Round head**, **Flat-head**, or **Counter-sunk head rivets** (Figure 4.1(a)).



(i) Round Head Rivet (ii) Flat Head Rivet (iii) Counter Sunk Head Rivet

(a) Various Types of Rivets



(b) Riveted Connection of Plates

Figure 4.1

More detailed information regarding rivets are available in IS 1929 : 1982 (Rivets for General Purposes (12-48 mm diameter)) and IS 2155 : 1962 (Rivets for General Purpose (below 12 mm diameter)).

4.2.2 Definitions

Nominal Diameter of Rivet (d_n)

It is the diameter of the shank of the rivet before driving.

Gross Diameter of the Rivet (d)

It is the diameter of the rivet hole, which is given by the following equation.

$$d = d_n + 1.5 \text{ mm, for } d_n \leq 25 \text{ mm} \qquad \ldots (4.1(a))$$

$$d = d_n + 2.0 \text{ mm, for } d_n > 25 \text{ mm} \qquad \ldots (4.1(b))$$

It is assumed that the shank of the original rivet during driving will expand and, thus, completely fill up the slightly larger area of the rivet hole.

Pitch of the Rivets (s)

It is the distance, centre to centre, between two consecutive rivets measured parallel to the direction of the force in the structural member.

Gauge Distance of the Rivets (g)

It is the transverse distance between two adjacent rivet lines and is measured at right angles to the direction of member forces as shown in Figure 4.2.

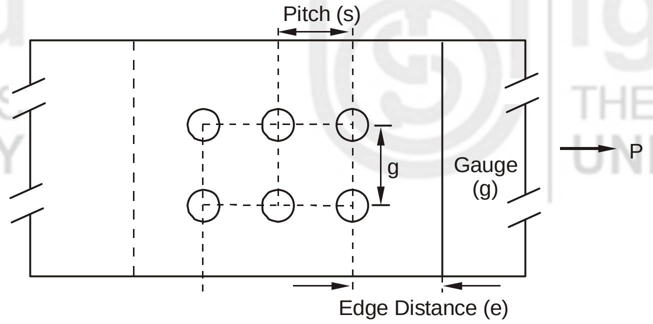


Figure 4.2 : Pitch and Gauge

4.2.3 Forces Acting on a Riveted Joint

The forces acting on a rivet or riveted joint may be any one of the following or their combination :

Direct Shear

This is caused by a direct tensile or compressive force in the connecting members acting in line with the rivet or rivets, and lying in the plane of the holes.

Eccentric Shear

It acts when the line of action of the direct force does not pass through the centre of the single rivet hole (or through the CG of the group of holes, when there are more than one rivet). Here, a direct shear exists along with a twisting moment.

Direct Tension/Compression

This produces a tension or compression in the rivet shank.

Bending Moment

This produces a direct tension in some rivets and compression on others placed on opposite sides of the neutral axis.

4.2.4 Failure of a Riveted Joint

A riveted joint may fail in any of the following manners or their combination :

Shearing of Rivets

The forces in the connecting members cause a direct uniform shear force across the cross-sectional area of the rivet. When the shear stress in the rivet cross-section reaches its maximum permissible value, τ_{vf}, failure is supposed to occur.

The resistance of a rivet in single shear is given by following equation :

$$F_s = \frac{\pi}{4} d^2 . \tau_{vf} \qquad \ldots (4.2)$$

where d is the gross diameter of the rivet.

Sometimes, there can be two shearing planes when more than two plates are used (Figure 4.3(a)). Resistance of a rivet failing in double shear is twice the above value.

Tearing of Plates

If the rivets are stronger than the plate, then the latter may tear off before the rivets fail in shear (Figure 4.3(b)). The plate fails along the smallest or net sectional area, which is equal to the gross area of the plate minus the area of the rivet hole, i.e. $A_{net} = bt - dt = (b - d)\,t$ (Figure 4.3(b)).

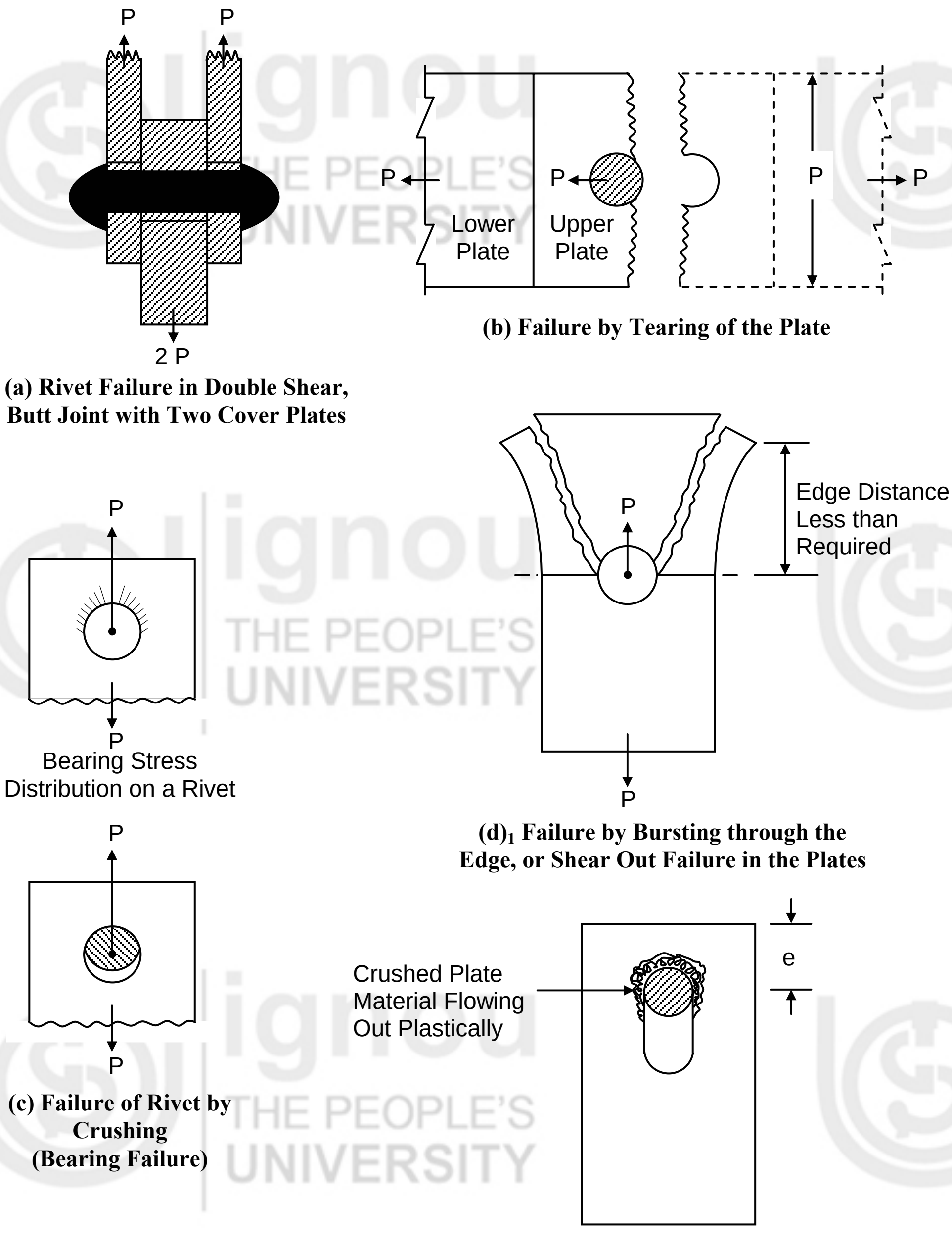
The tearing force, F_t, is given by

$$F_t = (b - d)\,t \times \sigma_{at} \qquad \ldots (4.3)$$

where σ_{at} is the allowable tensile strength of the plate.

Bearing of Rivets

Here, the rivets do not fail due to shear, but due to crushing of the rivet shank (area = $d \times t$) which is pressed against the plate contact area as shown in Figure 4.3(c).



(a) Rivet Failure in Double Shear, Butt Joint with Two Cover Plates

(b) Failure by Tearing of the Plate

(c) Failure of Rivet by Crushing (Bearing Failure)

$(d)_1$ Failure by Bursting through the Edge, or Shear Out Failure in the Plates

$(d)_2$ Bearing Failure of Plate

Figure 4.3

Resistance of the joint failing under bearing will be given by

$$F_{br} = dt\,\sigma_{pf} \qquad \ldots (4.4)$$

where σ_{pf} is the maximum permissible bearing stress in rivets.

Tensile Failure of Rivets

This occurs only when there are bending moments at a joint and

$$F_t = \frac{\pi}{4} d^2 \ \sigma_{tf} \qquad \ldots (4.5)$$

where σ_{tf} is the allowable tensile stress in rivets.

Bearing Shearing or Splitting at Edges of the Plate

This failure occurs because of insufficient *edge distance* (Figure 4.3(d)). This can be provided by giving a minimum edge distance '*e*' from centre of any hole to the edge of a plate as given in Table 4.1 (IS 800 : 1984) or 1.5 times the gross-diameter of the rivet, whichever is greater.

The resistance to failure is given by

$$F_e = \left(e - \frac{d}{2} \right) \cdot t \ \sigma_{at} \qquad \ldots (4.6)$$

where *e* is the edge distance to centre of rivets as shown in Figure 4.3(d).

Table 4.1 : Edge Distance of Holes (As per IS 800 : 1984)

Diameter of Hole (mm)	Distance to Sheared or Hand-flame Cut Edge (mm)	Distance to Rolled Machine-flame Cut, Sawn or Planed Edge (mm)
13.5 and below	19	17
15.5	25	22
17.5	29	25
19.5	32	29
21.5	32	29
23.5	38	32
25.5	44	38
29.0	51	44
32.0	57	51
35.0	57	51

[**Note :** Where two or more parts are connected together, a line of rivets shall be provided at a distance of not more than 37 + 4*t* (in mm) from the nearest edge, where *t* is the thickness of the thinner outside plate.]

4.2.5 Working Stresses in Rivets

The maximum permissible stress in rivets as per IS 800 : 1984 are given in Table 4.2. Here the area and effective diameter of the rivet is the area and diameter of rivet hole as calculated in Eqs. (4.1(a)) and (4.1(b)). The value of f_y in the last column is the yield stress in steel of the connected part.

Table 4.2 : Maximum Permissible Stress in Rivets (As per IS 800 : 1984) (in MPa)

Description	Axial Tension (σ_{tf})	Shear (τ_{vf})	Bearing on Rivet (σ_{pt})	Bearing on Connected Part (σ_p)
Power-driven Shop Rivets	100	100	300	1.2 f_y
Power-driven Field Rivets	90	90	270	1.2 f_y
Hand-driven Shop Rivets	80	80	250	f_y
Hand driven Field Rivets	72	72	225	f_y

[**Note :** For countersunk heads, one half of the countersinking depth is neglected in calculating σ_{pt}. In such rivets, the tensile stress σ_{tf} is reduced by 33.3%. However, no reduction is made in τ_{vf}.]

4.2.6 Assumptions in the Theory of Riveted Joints

The following assumptions are made in the design of riveted joints :

(a) The friction between the plates is neglected;

(b) The shear stress across the cross-section of a rivet is uniform;

(c) The direct stress distribution on the plate cross-section between rivet holes is uniform;

(d) All rivets in a rivet group subjected to a direct load passing through their CG share the load equally;

(e) Rivet shanks, after driving, fill the rivet holes completely.

Rivets subjected to both shear and axial tension shall be so proportioned that the calculated shear and axial stresses ($\tau_{vt,\ cal}$ and $\sigma_{tf,\ cal}$) do not exceed maximum permissible shear and axial stresses (τ_{vf} and σ_{tf}) respectively and also the following expression is satisfied :

$$\frac{\tau_{vf,\ \mathrm{cal}}}{\tau_{vf}} + \frac{\sigma_{tf,\ \mathrm{cal}}}{\sigma_{tf}} \leq 1.4 \qquad \ldots (4.7)$$

4.2.7 Types of Rivetted Joint

Riveted joints are broadly classified into two types :

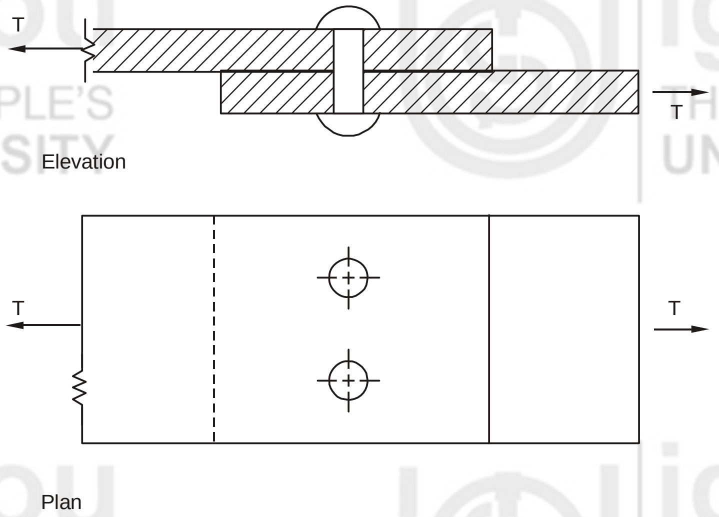
Lap Joint

Where one member is placed overlapping over the other, and the connections are made by either a single or double row of rivets (Figure 4.4(a)). In double row the rivets may be arranged in a *chain-form* or *zig-zag* form as shown in Figures 4.4(c) and (d).

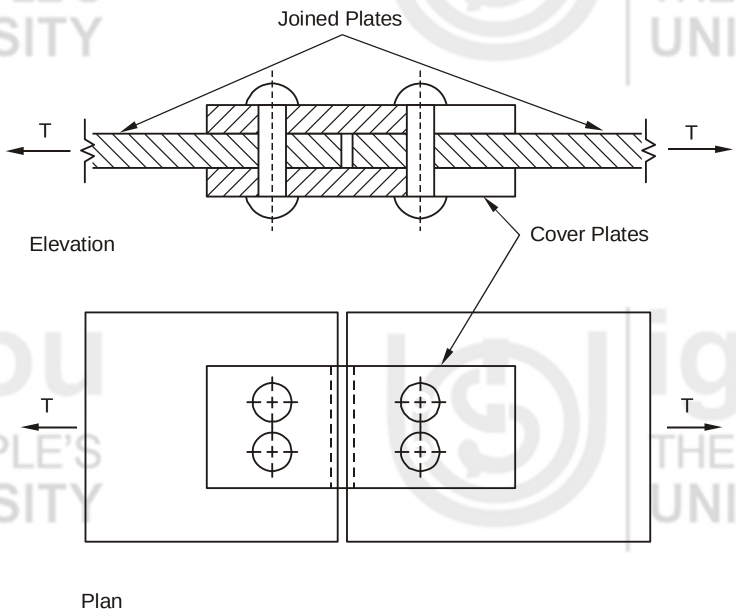
Butt Joint

In this case, the members to be joined are placed end to end with each other and are covered together by means of *cover plates*, which carry the riveted connection.

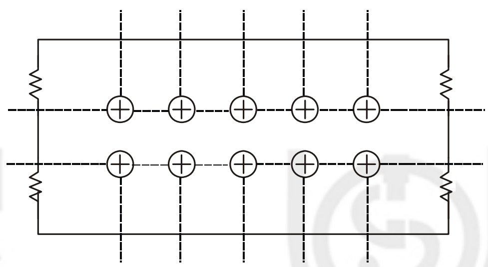
The cover plate may be on one side (*single cover butt joint*), or on both sides (*double cover butt joint*) of the joining members as in Figure 4.4(b).



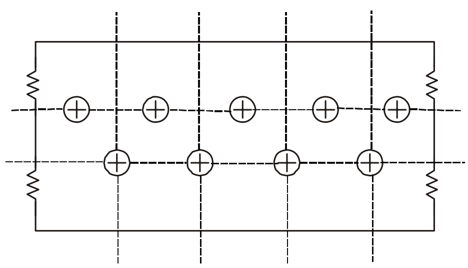
(a) Lap Joint



(b) Butt Joint



(c) Chain Rivetting



(d) Zig-Zag Rivetting

Figure 4.4 : Types of Riveted Joints and Rivetting Arrangements

4.2.8 Pitch of Rivets

Following is the details of pitch as per Indian Standard Specifications :

Minimum Pitch

The distance between centres of rivets should not be less than 2.5 times the nominal diameter of the rivets, i.e.

$$s \geq 2.5\ d_n \qquad \ldots (4.8)$$

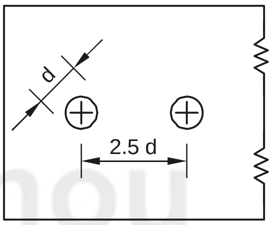


Figure 4.5(a) : Minimum Pitch

Maximum Pitch

The distance between any two adjacent rivets (including tacking rivets) shall not exceed 32 t or 300 mm (whichever is less); t being the thickness of the thinner outside plate.

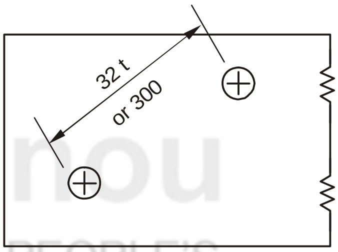


Figure 4.5(b) : Maximum Pitch

(a) In a line lying in the direction of stress

$s \leq 16\ t$ or 200 mm (whichever is less) in *tension members*, and

$s \leq 12\ t$ or 200 mm in *compression members.* . . . (4.9a)

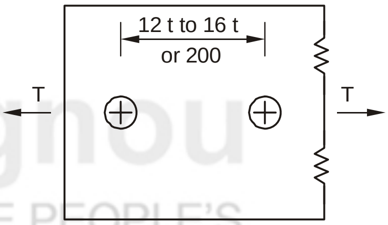


Figure 4.5(c) : Maximum Pitch Line of Stress

(b) In case of butt jointed compression members in which forces are transferred through butting faces :

$s \leq 4.5\ d$ for a distance from the a butting faces (equal to 1.5 times width of the member) . . . (4.9b)

The distance between centres of any two consecutive rivets in a line adjacent and parallel to an edge of an outside plate, shall not exceed 100 + 4t or 200 mm (whichever is less) in compression or tension members. . . . (4.9c)

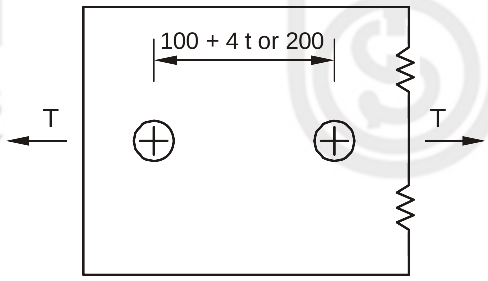


Figure 4.5(d) : Maximum Pitch to Parallel to Edge (in mm)

(d) When rivets are staggered at equal intervals and the gauge (*g*) does not exceed 75 mm; the pitch distances (*s*) specified in (a), (b), (c) above may be increased by 50%.

Tacking Rivets

When the maximum distance provided at (b) and (c) is exceeded, *tacking rivets* (not subjected to calculated stress) are used. They have a pitch line not exceeding 32 *t* or 300 mm whichever is less. The lines of rivets shall not be apart at a distance greater than these pitches. In composite tension members, tacking rivets are provided at a pitch in line not exceeding 1000 mm. In compression members, this maximum pitch is 600 mm.

Grip of Rivets

When the grip of rivets exceed 6*d* the number of rivets required by design calculation shall be increased by 1% for each additional 1.5 mm grip. However, the grip should not exceed 8*d* in any case (Figure 4.1(b)).

4.2.9 Deductions for Holes

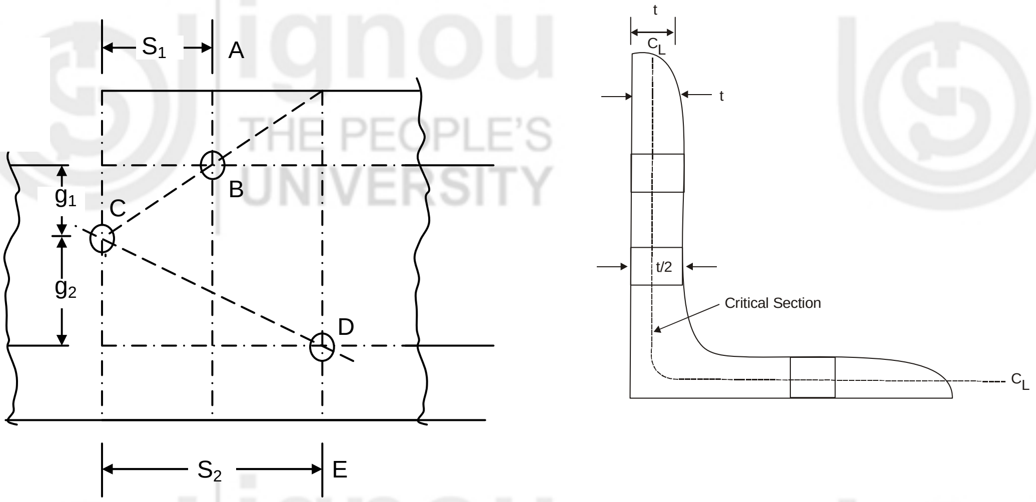
(a) Deductions for rivet holes are made as per Eqs. 4.1(a) and (b).

(b) The areas to be deducted shall be the sum of the sectional areas of the maximum number of holes in any cross-section at right angles to the direction of stress in the members for all axially loaded tension members.

(c) Where bolt or rivet holes are staggererd, the area to be deducted shall be the sum of the sectional areas of all holes in a chain of line progressively across the member, less $\frac{s^2 t}{4g}$ for each line extending between holes at other than right angles to the direction of stress where *s, g* and *t* are respectively the staggered pitch, gauge and thickness associated with the line under consideration (Figure 4.6(a)). The chain of lines shall be chosen to produce maximum such deduction. Thus, from Figure 4.6(a), we get

$$\text{Deduction} = \text{Sum of sectional area of holes } B, C, D + \frac{s_1^2 t}{4\, g_1} + \frac{s_2^2\, t}{4\, g_2}.$$

(d) For non-planar sections such as angles with holes in both legs, the gauge, (*g*), shall be the distance along the centre of the thickness of the section between hole centers as shown in Figure 4.6(b).



(a) Plate **(b) Angle**

Figure 4.6

4.2.10 Design of Riveted Joints

Rivet Value

Rivet value (R) is the least value of the strength of a single rivet and is smaller of the two value, Fs (strength in shearing) or F_{br} (strength in bearing).

Unwin's Formula

It gives the nominal diameter of a rivet in mm, and is stated as follows :

$$d_n = 6.04\sqrt{t} \qquad \text{. . . (4.10)}$$

where t is the thickness of the smallest of the joining plates (in mm).

[As the rivet sizes available are 12, 14, 16, 18, 20, 22, 24, 27, 30, 33, 36, 39, 42 mm the value obtained from Eq. (4.10) is adjusted to the next higher value.]

Group of Rivets

Strength of a group of rivets is equal to the strength of one rivet multiplied by the number of rivets,

i.e. $$F_{group} = n \times F_{single} \qquad \text{. . . (4.11)}$$

Generally, the bearing value of a rivet lies between its single and double shearing values

i.e. $$F_s < F_{br} < 2F_s \qquad \text{. . . (4.12)}$$

4.2.11 Efficiency of Riveted Joints

Due to the rivet holes drilled in the joining plates, the original strength of the full plate section is reduced. The efficiency (η) of a riveted joint is given by the following expression :

$$\text{Efficiency of the joint } (\eta) = \frac{\text{Least strength of riveted joint}}{\text{Strength of solid plate}} \times 100 \qquad \text{. . . (4.13)}$$

Example 4.1

Design a riveted connection for an angle ISA 60 × 40 × 6, connected by the longer leg to a gusset plate 6 mm thick using 16 mm dia power driven shop rivets and carrying a tensile force of 45 kN.

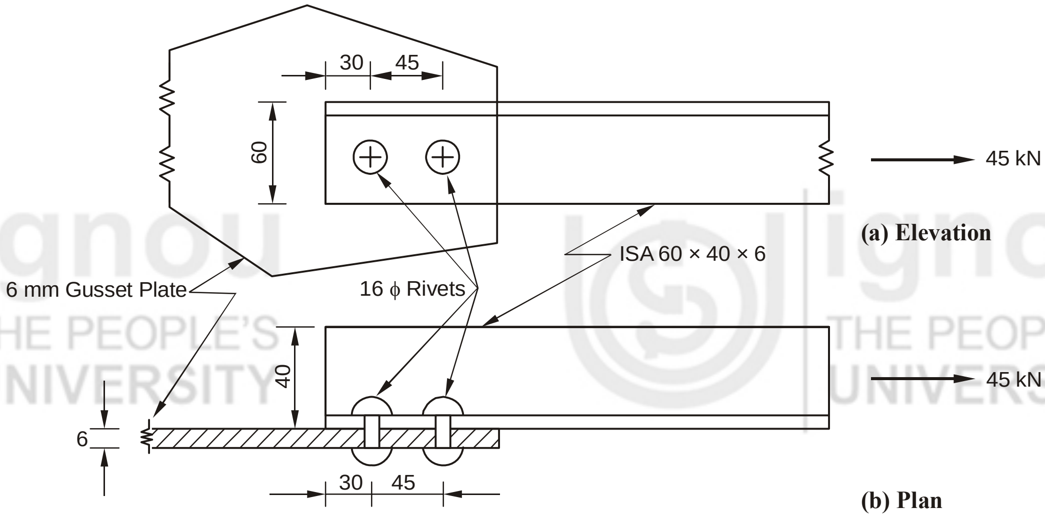


Figure 4.7

Solution

Gross diameter of rivet = 16 + 1.5 = 17.5 mm (Eq. (4.1))

Maximum permissible stresses in power-driven shop rivet (Table 4.2)

Shear (τ_{vf}) = 100 MPa

Bearing on rivet (σ_{pt}) = 300 MPa

Bearing on connected part = 1.2 f_y.

Minimum pitch of rivets = 2.5 ×17.5 ≈ 44 mm, → **provided 45 mm**

Minimum edge distance (Table 4.1) = 29 mm, → **provided 30 mm**

Single shear value of rivets $= \frac{\pi}{4} \times (17.5)^2 \times 100 = 24053$ N

Bearing resistance of rivet = 6 × 17.5 × 300 = 31500 N

∴ Take the lower value **24053 N**

Tensile force = 45000 N

∴ Number of rivets required $= \frac{45000}{24053} = 1.87$

∴ Provide 2 rivets in the same line as shown in Figure 4.7.

Example 4.2

Determine the strength of a single riveted joint of 6 mm thick plates having 20 mm nominal dia rivets at a pitch of 6 cm. (f_y for plates is 150 MPa and rivets are hand-driven shop rivets.)

Solution

Consider one pitch length (60 mm) of joint.

Gross dia of rivet = 20 + 1.5 = 21.5 mm

Maximum permissible stresses in hand-driven shop rivet (Table 4.2)

Shear (τ_{vf}) = 80 MPa

Bearing on rivet (σ_{pt}) = 250 MPa

Bearing on connected Part = f_y= 150 MPa

Strength of rivets in

Single shear = $\frac{\pi}{4} \times (21.5)^2 \times 80 = 29044$ N

Bearing = $6 \times 21.5 \times 250 = 32250$ N

Tearing of plates = (60 – 21.5) × 6 × 150 = 34650 N

The strength of the joint per pitch length is the minimum of the above three, i.e. **29044 N** or 29 kN (say).

Example 4.3

Determine the safe load that a single riveted butt joint with two cover plates as shown in Figure 4.8 can carry if the pitch of the power-driven field rivets is 7.5 cm centers. (Nominal dia of rivets is 20 mm and f_y = 150 MPa.) Determine the efficiency of the joint.

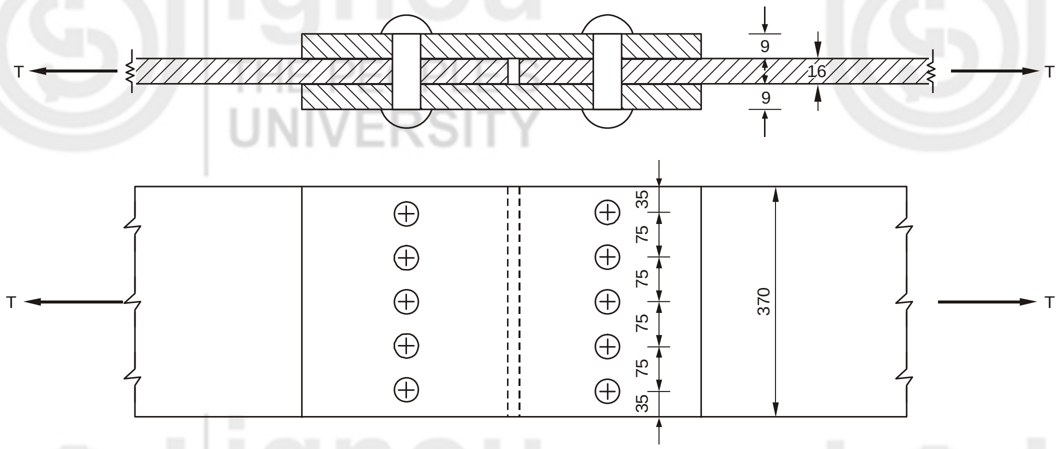


Figure 4.8

Solution

Gross diameter = 20 + 1.5 = 21.5 mm

Minimum edge distance = 32 mm (35 mm say) (Table 4.1)

Minimum pitch = 2.5 × 21.5 = 53.75 m

Maximum pitch = 32 × 9 = 288 mm

∴ The given pitch of 75 mm is OK.

Number of rivets = 5

Maximum permissible stress in power-driven field rivets (Table 4.2)

Shear (τ_{vf}) = 90 MPa

Bearing on rivet (σ_{pt}) = 270 MPa

(a) Strength of rivets in double shear

$$= \left[\frac{\pi}{4} \times 2 \times (21.5)^2 \times 90\right] \times 5 = \mathbf{326745}$$

(b) Strength of rivets in bearing with respect to main plate

$$= [21.5 \times 16 \times 270] \times 5 = \mathbf{464400}$$

(c) Strength of rivets in bearing with respect to cover plates

$$= [21.5 \times 18 \times 270] \times 5 = \mathbf{522450}$$

(d) Tearing strength of main plate = (370 – 5 × 21.5) × 16 × 150

= 630,000 N

(e) Tearing strength of cover plate

$$= (370 - 5 \times 21.5) \times 18 \times 150 = \mathbf{708,750\ N}$$

The safe load is the minimum of the above i.e. **326.7 kN.**

The load that the plate without rivet holes can carry

$$= 370 \times 16 \times 150 = 888000\ \text{N} = 888\ \text{kN}$$

∴ Efficiency of the joint (η) $= \frac{326.7}{888} \times 100 = 36.80\%$.

Example 4.4

A single riveted double covered butt joint is used for connecting two plates 12 mm thick. The power driven field rivets are 24 mm nominal diameter. Tensile strength of the plate f_y = 150 MP_a

Calculate necessary pitch and efficiency of the joint.

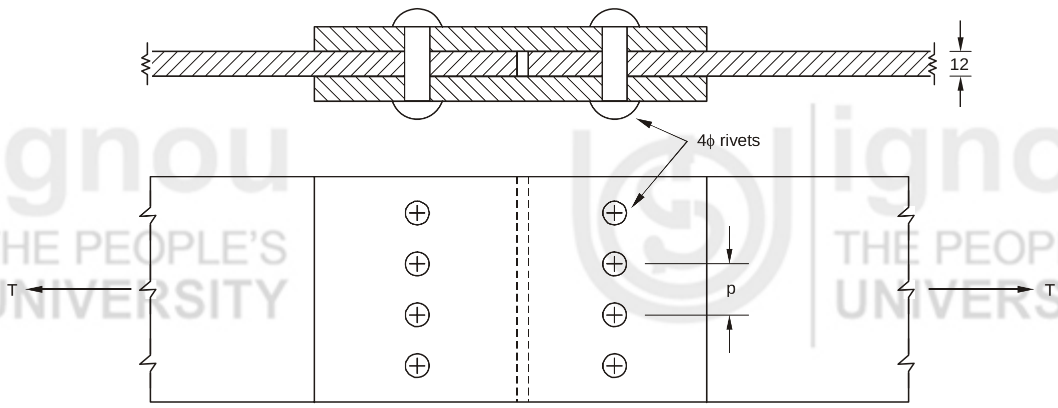


Figure 4.9

Solution

Gross diameter = 24 + 1.5 = 25.5 mm

Considering a pitch length of *p* mm

Taking the maximum permissible stresses in power-driven field rivets from Table 4.2, we have double shear value of rivet

$$= \frac{\pi}{4} \times (25.5)^2 \times 90 \times 2 = 91{,}927 \text{ N}$$

Bearing value of rivet = 12 × 25.5 × 270 = 82,620 N

Tearing strength of plate = $(p - 25.5) \times 12 \times 150$

Equating the plate tearing strength to the smaller of the two rivet values

we have $(p - 25.5) \times 1800 = 82620$

giving $p = 71.4$ mm

Minimum pitch = 2.5 × 25.5 = 63.75 ∴ Adopt 75 mm pitch

Actual tearing strength of plate per pitch (without holes)

$$= 12 \times 75 \times 150 = 135{,}000 \text{ N}$$

$$\therefore \quad \text{Efficiency of the joint} = \frac{82620}{135000} \times 100 = 61.2\ \%$$

4.2.12 Rivets in Several Rows

If the number of rivets required is large and the width of the plate is not sufficient to accommodate them in one row, more than one row of rivets has to be provided. The following example shows the calculation.

Example 4.5

Find the safe strength of the double covered butt joint shown in Figure 4.10, where power driven shop rivets of 20 mm nominal diameter are used. All plates are 18 mm thick, and f_y = 150 MPa.

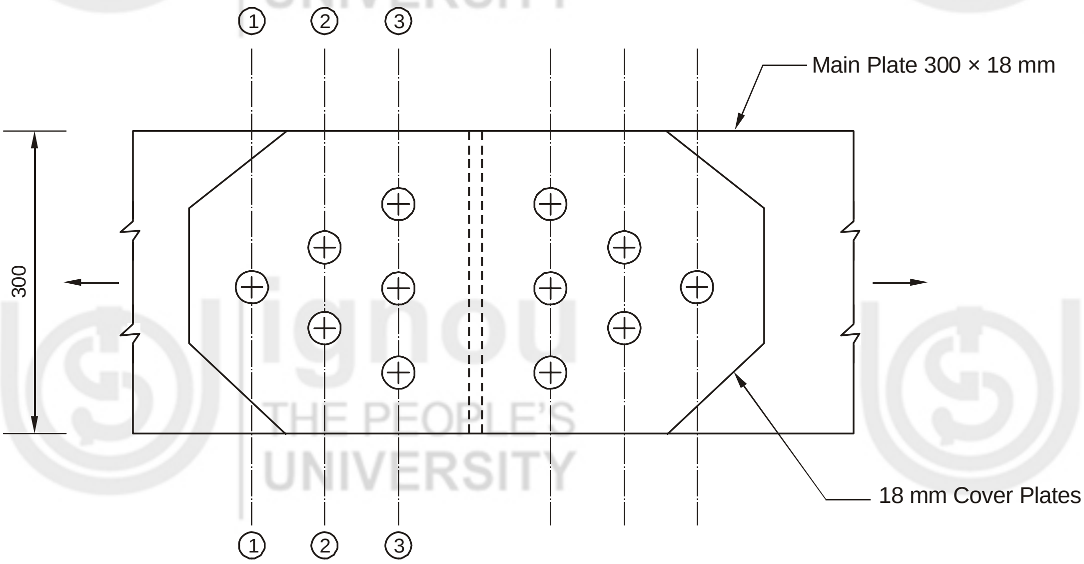


Figure 4.10

Solution

Gross diameter of rivets = 20 + 1.5 = 21.5 mm

The maximum permissible stresses for power-driven shop rivets have been taken from Table 4.2.

Shearing strength of 6 rivets in double shear

$$= [2 \times 100 \times \frac{\pi}{4} \times (21.5)^2] \times 6 = 435,660 \text{ N}$$

Strength of six rivets in bearing

$$= (18 \times 21.5 \times 300) \times 6 = 696,600 \text{ N}$$

Tearing strength of main plate along plane (1)-(1)

$$= (300 - 21.5) \times 18 \times 150 = \mathbf{751,950 \text{ N}}$$

Tearing strength of main plate along plane (2)-(2)

$$= (300 - 2 \times 21.5) \times 18 \times 150 = \mathbf{693,900 \text{ N}}$$

But tearing along (2)-(2) can take place only when rivet at (1)-(1) also fails in shear, the value of which is

$$\left[2 \times 100 \frac{\pi}{4} \times (21.5)^2\right] \times 1 = 72610 \text{ N}$$

$\therefore$ Tearing strength along (2)-(2) = 693,900 + 72,610 = **766, 510 N**

Similarly, tearing along (3)-(3) along with shear failures of 3 rivets at (1)-(1) and (2)-(2)

$$= (300 - 3 \times 21.5) \times 18 \times 150 + 2 \times 100 \times \frac{\pi}{4} \times (21.5)^2 \times 3$$

$$= 853,680 \text{ N}$$

Taking the least value of above, the safe strength of the joint is **435, 660 N**

$\cong$ **435 kN**.

SAQ 1

(a) What is the 'gauge distance' and 'pitch' of rivets? Determine the least effective width of the plate shown in Figure 4.11. Nominal dia of rivets is 20 mm.

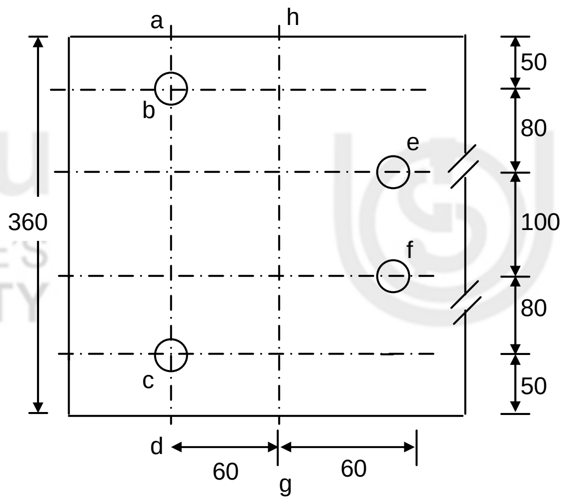


Figure 4.11

(b) Determine the strength and efficiency of a single riveted lap joint of 8 mm thick plates having 27 mm diameter rivets at a pitch of 8 cm. Use power-driven field rivets (f_y = 150 MPa).

(c) A double riveted butt joint, in which the pitch of the rivets in the outer row is double of pitch of inner row, connects two 1.6 cm plates with double cover plates, each of 0.9 cm thickness. Determine the pitch of the 22 mm (nominal) diameter power-driven shop rivets (f_y = 150 MPa).

4.3 WELDED JOINTS

Welding is a process of joining two pieces of metals by establishing a metallurgical bond. This is established by rendering the joining pieces molten or liquid by application of heat or pressure (or both). This is widely used in structural connections and has several advantages which has caused its widespread adoption.

4.3.1 Advantages of Welding

(a) It is silent, safe and quick; the joints have better appearance.

(b) More rigid than riveted joints, as there are no holes in the member or no extra gusset plates needed for them.

(c) The efficiency of the joint is more; it permits design based on support continuity and joint rigidity.

(d) The process of joining as well as the resulting structure is more economical. Its weight is also less.

However, there are certain disadvantages :

(a) It requires better expertise from the welding team;

(b) Inspection of joints are not easy;

(c) There are possibilities of fatigue stresses and brittle failure.

4.3.2 Classification

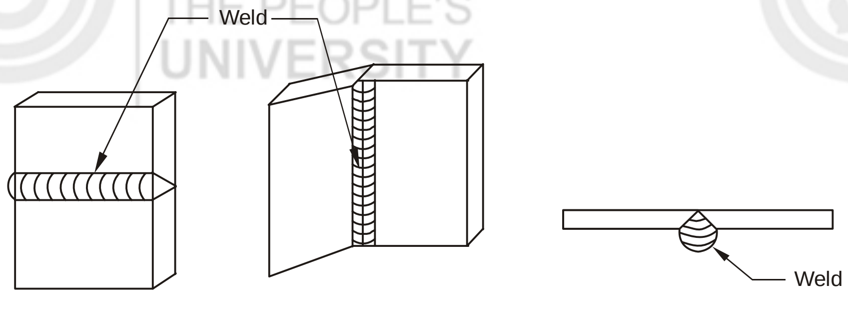
Welds are classified according to their **position**, **shape** and **type of joint**.

According to their **position** (Figure 4.12), welds are classified as

(a) Horizontal;

(b) Vertical; and

(c) Overhead.



(a) Horizontal Weld **(b) Vertical Weld** **(c) Overhead Weld**

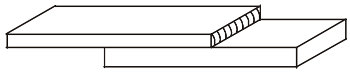
Figure 4.12

According to their **shape** (Figure 4.13), welds are classified as

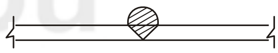
(a) Fillet weld;

(b) Groove weld; and

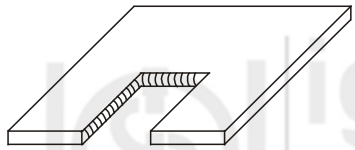
(c) Slot weld.



(a) Fillet Weld



(b) Groove Weld



(c) Slot Weld

Figure 4.13

Welds are also classified according to their **type of joint** (Figure 4.14) as

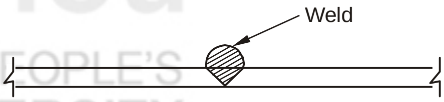
(a) Butt jointed weld;

(b) Lap joint weld;

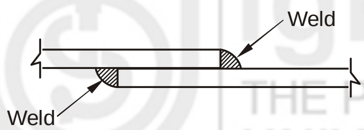
(c) Tee-joint weld;

(d) Corner weld; and

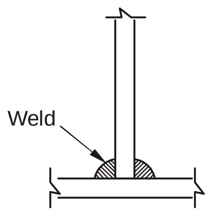
(e) Edge weld.



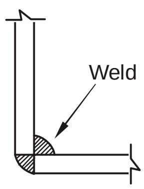
(a) Butt Jointed Weld



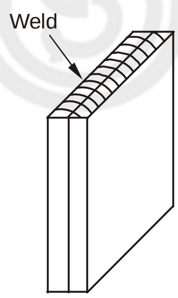
(b) Lap Joint Weld



(c) Tee-joint Weld



(d) Corner Weld



(e) Edge Weld

Figure 4.14

4.4 FILLET WELDS

4.4.1 Geometrical Properties

The geometrical properties and definitions used in case of fillet welds are shown in Figure 4.15.

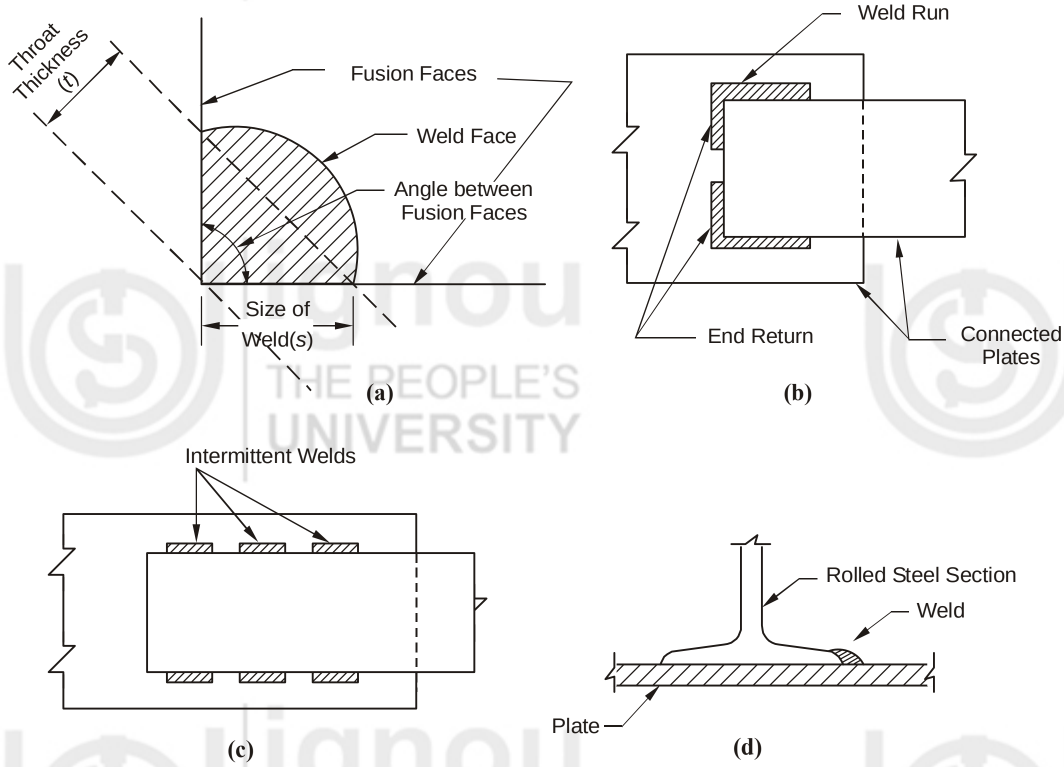


Figure 4.15

(a) *Size of the fillet weld* shall be taken as, either

  (i) The minimum leg length of a convex (or flat) fillet weld; or

  (ii) 1.41 times the effective throat thickness of a concave fillet weld.

(b) The *minimum size of the fillet weld* shall be related to the thickness of the connected plates as in Table 4.3.

(c) The *maximum size of the fillet weld* should be the thickness of the connected part minus 1.5 mm.

Table 4.3 : Minimum Size of Fillet Weld (As per IS 9595 : 1980)

Thickness of Thicker Part (mm)	Minimum Size (mm)
Upto 6	3
7 - 12	4
13 - 18	6
19 - 36	8
37 - 56	10
57 - 150	12

* For greater than 150 mm thick plates, special precautions (like pre-heating) should be taken.

** For rolled steel sections, the size of fillet weld shall be 75% of the thickness of the toe section as shown in Figure 4.15(d).

(d) *Angles between the fusion* faces shall be between 60° to 120° for effective transmission of load.

(e) *The throat thicknesses for various angles* are given in Table 4.4.

Table 4.4 : Throat Thickness of Fillet Weld

Angle between Fusion Faces	Throat Thickness Factor (Fillet Size × Factor)
60° – 90°	0.70
91° – 100°	0.65
101°- 106°	0.60
107° -113°	0.55
114° – 120°	0.50

(f) *End Returns* (Figure 4.15(b)) : Fillet welds terminating at ends must be returned continuously round the corners for a distance not less than twice the size of the weld.

(g) *Effective length* of a fillet weld shall be the length of specified size and required throat thickness. The minimum length shall be not less than *four times* the size of the weld.

(h) *Intermittent welds* (Figure 4.15(c)) shall be spaced not more than 12 t or 16 t of compression/tension respectively (t = thickness of thinner plate).

(i) Effective area of weld = Effective length × Effective throat thickness.

4.4.2 Permissible Stresses

The following are the permissible stresses and design guidelines for fillet welds :

(a) When the welded joints are constructed of mild steel (conforming to IS 226 : 1975) as the parent metal and electrodes (conforming to IS 814 : 1979), the allowable stresses (Table 4.5) will be as for parent metal (Fe 250).

Table 4.5 : Permissible Stresses in Welds

Sl. No.	Kind of Stress	Max. Permissible Stress
1.	Tension/Compression on throat section of butt weld = 0.6 f_y	142.0 N/mm^2
2.	Fibre stresses in bending tension/compression = 0.66 f_y	157.5 N/mm^2
3.	Shear on section through throat of butt and fillet weld = 0.4 f_y	110.00 N/mm^2

(b) The combined stress in fillet welds shall be limited by

$$f_e = \sqrt{f^2 + 1.8q^2} \quad \ldots (4.14(a))$$

$$f_e = \sqrt{f_{bt}^2 + 3q^2} \quad or \quad \sqrt{f_{bc}^2 + 3q^2} \quad \ldots (4.14(b))$$

where, f_e = equivalent combined stress,

f = axial stress,

f_{bt}, f_{bc} = normal stress in tension/compression due to bending forces, and

q = shear stress.

However, f_e should not exceed the value 110 N/mm^2.

(i) A single fillet weld shall not be subjected to bending.

(ii) The load carrying capacity of a fillet weld = $f_e \, \Sigma \, A.L.$

(iii) For site welds this may be reduced by 20%.

(iv) If winds and earthquake stresses are included, the above stresses may be increased by 25%.

Example 4.6

Design the size and length of weld required to develop the full strength of the smaller plate shown in Figure 4.16. Thickness of the plates is 16 mm.

Solution

Permissible tension in plate = $0.6 f_y = 0.6 \times 250 = 150$ N/mm^2

Strength of smaller plate = 80 × 16 × 150 = 192000 N

Maximum size of fillet weld = 16 – 1.5 = 14.5 mm

Throat thickness of fillet weld = 0.7 × 14.5 = 10.15 mm

Strength of weld per mm = 10.15 × 110 = 1116.5 N

$\therefore$ Total length of fillet weld $= \dfrac{192000}{1116.5} = 172$ mm

$\therefore$ Length of weld run on each side $= \dfrac{172}{2} = 86$ mm (say 90 mm)

Length of return welds = 2 × 14.5 = 29 mm (say 30 mm).

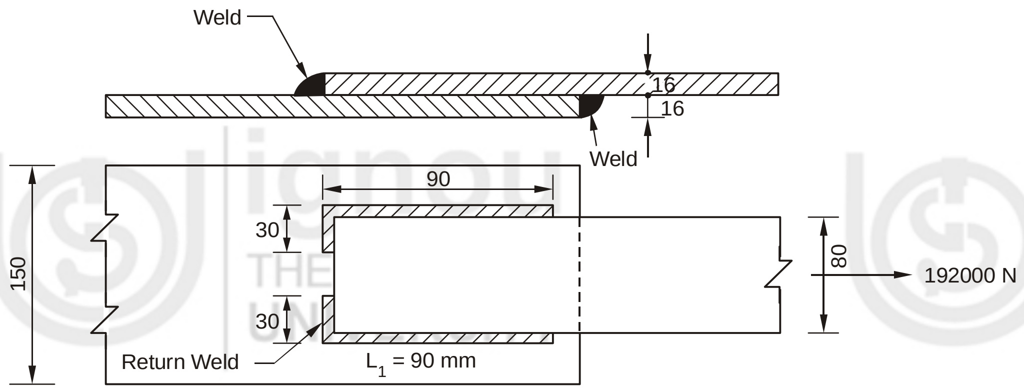


Figure 4.16

Example 4.7

Two ISA 90 × 60 × 10 angles form a tie member of a truss and is subjected to an axial pull of 200 kN. They are connected to both sides of a 10 mm gusset plate as shown in Figure 4.17. Design the welded connection.

Solution

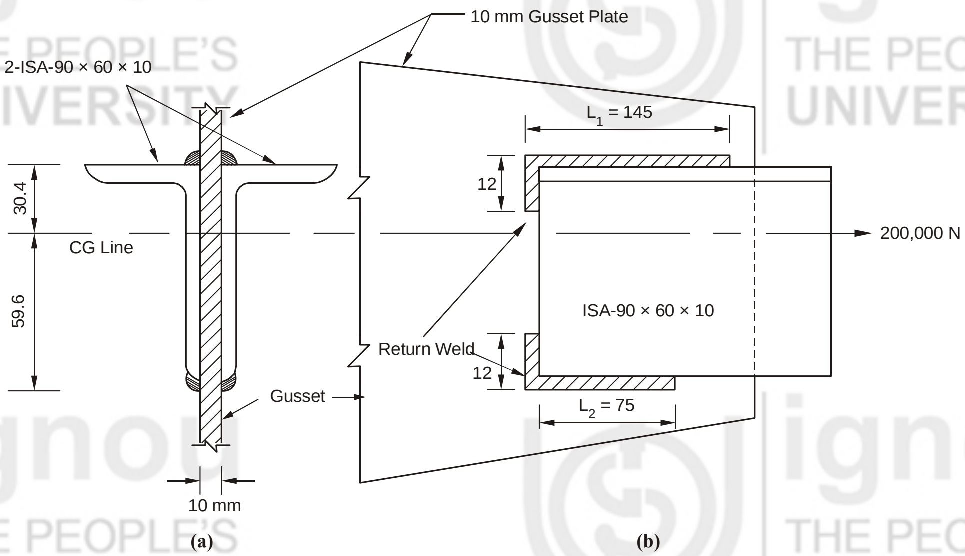


Figure 4.17

Maximum size of the fillet weld $= \frac{3}{4} \times$ toe thickness of angle

$$= \frac{3}{4} \times 10 = 7.5 \text{ mm}.$$

Assuming 6 mm size fillet welds on both sides of gusset plate to each angle axial force in each angle $= \frac{200000}{2} = 100000$ N which is assumed to act through the CG line of the angle. Two runs of fillet welds of length L_1 and L_2 are applied to each angle one at the top edge corner and the other at the bottom tip of the leg as shown in Figure 4.17.

Throat thickness of weld = 0.7 × Size of weld = 0.7 × 6 = 4.2 mm

Permissible shear stress in weld = 110 N/mm^2

∴ Strength of weld per mm length = 110 × 4.2 = 462 N.

Taking moment of forces about the bottom weld line (L_2), we have

$$462 \times L_1 \times 90 = 100000 \times 59.6;$$

giving $L_1 = \frac{100000 \times 59.6}{462 \times 90} =$ **144 mm**.

Similarly, taking moments about the top weld line (L_1)

$$462 \times L_2 \times 90 = 100000 \times 30.4;$$

giving $L_2 = \frac{100000 \times 30.4}{462 \times 90} =$ **74 mm**.

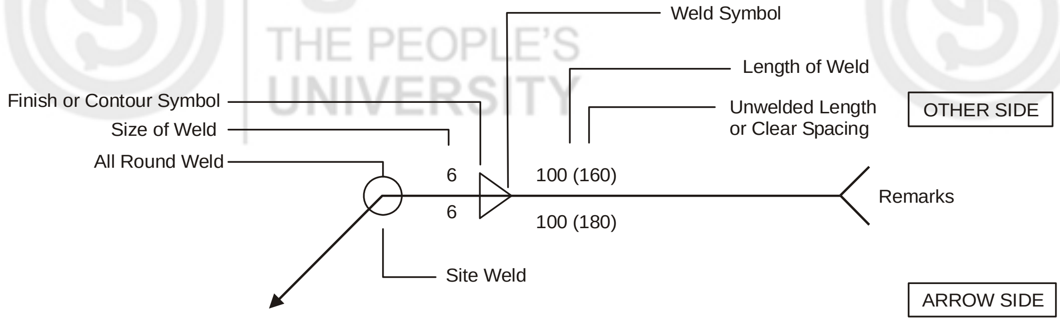
∴ Provide 145 mm long weld at top corner and 75 mm at bottom tip with return welds of length 2 × 6 = 12 mm each as shown in Figure 4.17.

4.4.3 Weld Symbols and Notations

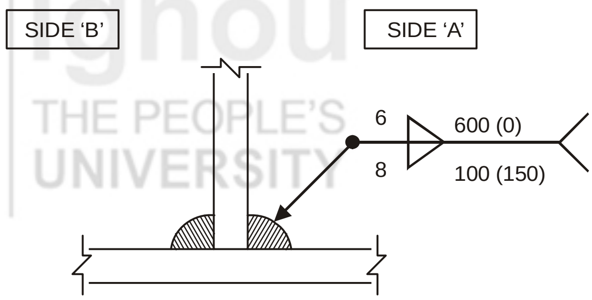
A convenient way to show details of a weld are indicated in Figure 4.18(a) by an inclined arrow attached to a forked horizontal line

For example, in Figure 4.18(b), it is indicated that a 600 mm long fillet weld of 6 mm size without any break is provided on Side 'B' while a 100 mm intermittent weld of 8 mm size with 150 mm clear spacing is provided on Side 'A'.

(On the arrow side of the horizontal line details on nearer side of the arrow point are provided.)



(a)



(b)

Figure 4.18

SAQ 2

(a) Design a connection to join two plates of 250 × 10 mm with f_y = 250 MPa to mobilize the full plate tensile strength using

(i) A lap joint, and

(ii) A butt joint.

Use fillet welds only.

(b) In a truss member, two angles ISA 120 × 120 × 10 mm carrying a load of 400 kN are to be connected to a 14 mm gusset plate on one side. Design the welds eliminating torsional eccentricity.

4.5 BUTT WELDS

4.5.1 Geometrical Properties

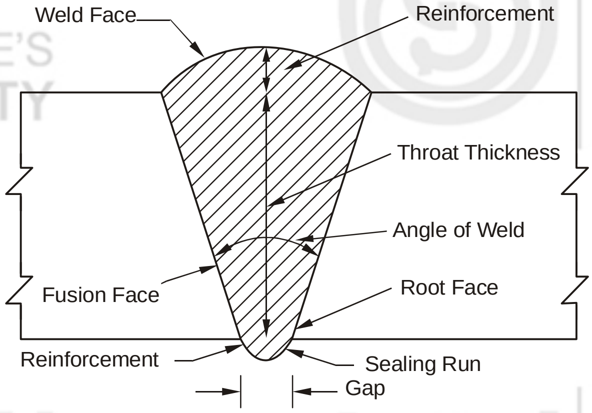
The size of a butt weld is defined by

(a) The throat thickness; or

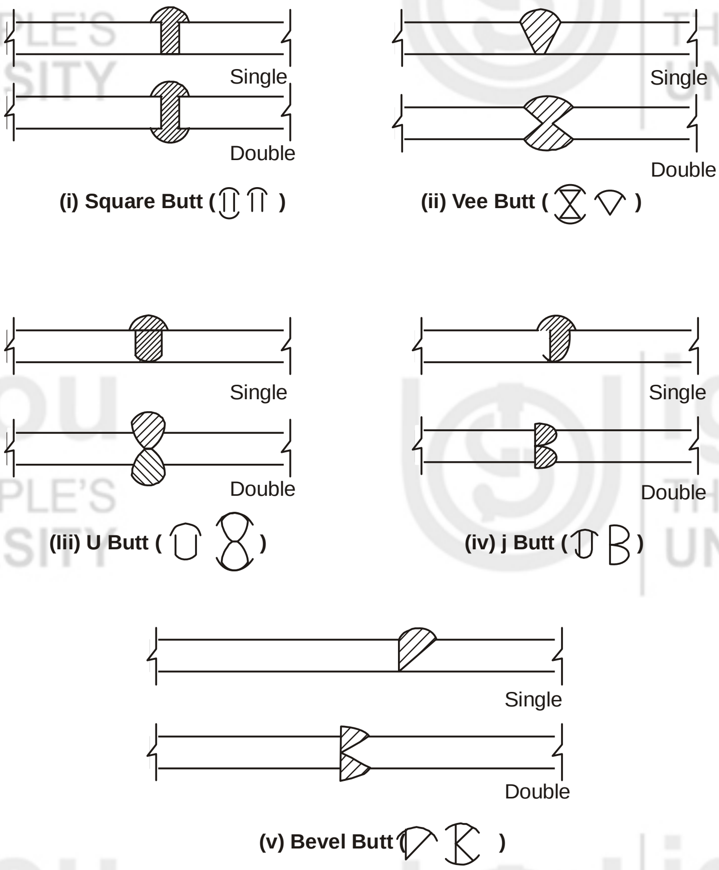
(b) The thickness of the thinner part (for complete penetration with sealing run).

(c) $\frac{5}{8}$ × thickness of thinner part (for incomplete penetration, i.e. no sealing run).

(* The reinforcement portion is not included as throat thickness.)



(a) Butt Details



(b) Butt-welds with Symbols

Figure 4.19

4.5.2 Permissible Stresses

(a) For full stress, butt welds must be reinforced with excess weld metal and sealed as shown in Figure 4.19(a). When sealing run is not possible the effective throat thickness is reduced by the multiplying factor $\frac{5}{8}$ of the thickness of the thinner plate.

(b) In butt weld throat, the stresses in tension, compression or shear shall not exceed those specified for the parent metal. For site welds this may be reduced by 20%.

(c) Combined stress in butt welds shall not exceed the permissible stresses in the parent metal nor the following :

For bending and shear,

$$f_e = \sqrt{f_{bc}^2 + 3q^2} \quad \text{or} \quad \sqrt{f_{bt}^2 + 3q^2} \qquad \ldots (4.15(a))$$

For bending, bearing and shear,

$$f_e = \sqrt{f_{bt}^2 + f_b^2 + f_{bt} f_b + 3q^2} \qquad \ldots (4.15(b))$$

(The symbols have the same meaning as in Eq. (4.14).)

(i) Intermittent welds should resist shear only.

(ii) The load carrying capacity of butt welds, $P = f_e \, . \Sigma \, A.l.$

Example 4.8

A single U-butt weld (without sealing run) joins two plates of 20 mm and 16 mm thickness respectively. Find the strength of the joint in tension if the weld length is 150 mm.

Solution

Due to incomplete penetration effective throat thickness

$$= \frac{5}{8} \times t = \frac{5}{8} \times 16 = 10 \text{ mm}$$

Permissible stress in tension in weld = 142 N/mm^2

Length of weld = 150 mm

$\therefore$ Load carrying capacity of the weld = 10 × 142 × 150

= 213000 N = 213 kN.

SAQ 3

Determine the strength (per mm length of weld) of a butt-welded joint in tension, where two 16 mm thick plates are joined by

(a) A double-V butt weld; and

(b) A single-V butt weld.

4.6 SUMMARY

This unit deals with riveted and welded connections. In riveted connections, you have learnt different types of rivet and various parameters pertaining to riveted joints like types, design and efficiency etc.

Further, in welded connections, you were introduced to various types of welds and welded connections. You have also learnt about the various geometrical parameters of and allowable stresses in structural welds. Towards end, the unit deals with how to design both fillet welded and butt welded structural connections, under the action of direct loads.

4.7 ANSWERS TO SAQs

SAQ 1

(a) Gross diameter of hole = 20 + 1.5 = 21.5 mm

(i) Consider path a-b-c-d

Net width = 360 – 2 × 21.5 = 317 mm

(ii) Considering path h-e-f-g = 360 – 2 × 21.5 = 317 mm

(iii) Consider the path a-b-e-f-c-d, number of rivet holes = 4

Deduction = 4 × 21.5 = 86 mm

$$\Sigma \frac{S^2}{4g} = \frac{(60)^2}{4 \times 80} \times 2 = 22.5$$

$\therefore$ Net width of path = 360 – (86 – 22.5) = 296.5 mm

(iv) Consider path a-b-f-g, number of rivet holes = 2,

Deduction = 2 × 21.5 = 42 mm

$$\Sigma \frac{S^2}{4g} = \frac{(60)^2}{4 \times 180} = 5,$$

$\therefore$ Net width of path = 360 – (42 – 5) = 323 mm.

(v) Consider path a-b-f-c-d, number of rivet hole = 3

Deduction = 3 × 21.5 = 64.5 mm

Addition for curvature

$$\Sigma \frac{S^2}{4g} = \frac{(60)^2}{4 \times 180} + \frac{(60)^2}{4 \times 80} = 5 + 11.25 = 16.25$$

$\therefore$ Net width of path = 360 – (64.5 –16.25) = 311.75 mm

Hence, the least effective width is along the line a-b-e-f-c-d and is 296.5 mm.

(b) From Table 4.2, permissible stresses in hand driven field rivets :

(i) Axial tension (σ_{tf}) = 70 MPa

(ii) Shear (τ_{vf}) = 90 MPa

(iii) Bearing of rivet (σ_{pt}) = 270 MPa

(iv) Bearing on connected part (σ_p) = 1.2 f_y
= 1.2 × 150 = 180 MPa

Consider one pitch length of the joint, i.e. 80 mm width of plate

Gross diameter of rivet = 27 + 2.0 = 29 mm

(i) Strength of rivet in single shear

$$= \frac{\pi}{4} \times (29)^2 \times 90 = 59446 \text{ N}$$

(ii) Strength of rivet in bearing = $8 \times 29 \times 270 = 62640$ N

(iii) Tearing strength of plate = (80 – 29) × 8 × 150 = 61200 N

Taking the smallest of the above values, the strength of the joint per pitch length is 59446 N (or 59.4 kN say).

Strength of the plate without holes = 80 × 8 × 150 = 96000 N

$\therefore$ Efficiency of the joint $\eta = \frac{49197}{96000} \times 100 = 61.9\%$

(c) Gross diameter of hole = 22 + 1.5 = 23.5 mm

σ_{tf} = 100 MPa, τ_{vf} (single) = 100 MPa

σ_{pt} = 300 Mpa. τ_{vf} (double) = 200 MPa

Number of rivets in 2p width of plate is 3

$\therefore$ Shear value (double) $= \frac{\pi}{4} \times (23.5)^2 \times 200 \times 3 = 260,241$ N . . . (A)

Bearing value = 16 × 23.5 × 300 × 3 = 338,400 N

Tearing strength of plates (outer rivet line) = (2p – 23.5) × 16 × 150
= 4800 p – 56400

Tearing strength of plates (inner rivet line) = 2 (p – 23.5) × 16 × 150
= 4800 p – 112800

But before plate at inner rivets row can tear out, outer row must fail in shear.

Shear strength of outer row of rivets = $\frac{\pi}{4} \times (23.5)^2 \times 200 = 86747.$

$\therefore$ Actual strength of inner rivet row = 4800 p – 112800 + 86747
= 4800 p –26053 . . . (B)

Now, equating (B) with (A)

4800 p – 26053 = 260241

Giving, p = 48.8 mm; thus, adopt 50 mm pitch.

SAQ 2

(a) (i) **Lap Joint**

Plate strength = 250 × 10 × (0.6 × 250) = 375000 N

Size of weld, minimum = 5 mm, maximum = 10 – 1.5 = 8.5 mm

Use single pass 6 mm welds, throat thickness
= 0.7 × 6 = 4.2 mm

Strength of 1 mm weld = 110 × 4.2 = 462 N

Length of weld required $= \frac{375000}{462} = 812$ mm

Weld length available at end = 100 × 2 = 200 (Figure 4.20(a))

$\therefore$ Length of weld one side $= \frac{812 - 200}{4} = 153$ mm say = 155 m

(ii) **Butt Joint**

Width of cover plate = 250 – 15 × 2 = 220 mm,

Use 8 mm thick plate.

Area of cover plate, $A_c = 220 \times 8 = 1760 \text{ mm}^2$

$$A_c \text{ required} = \frac{1.05 \times 250 \times 10}{2} = 1312.5 < 1760 \quad \therefore \text{ OK}$$

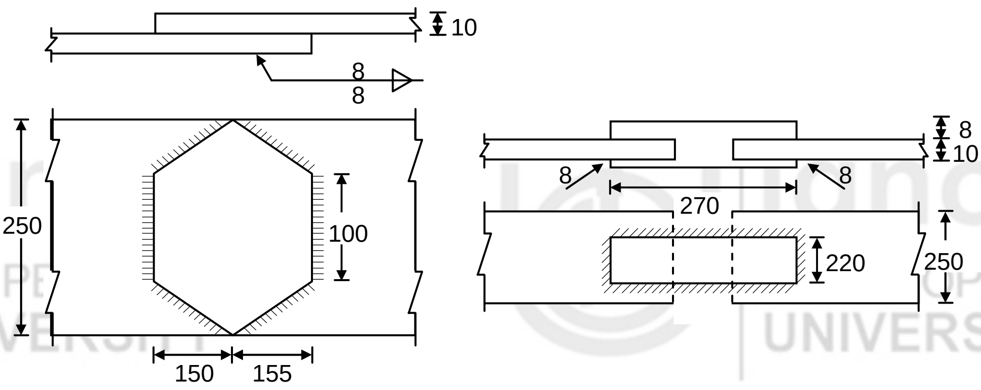
Use 5 mm fillet

Strength of weld per mm = 0.7 × 5 × 110 = 385 N

$$\therefore \text{ Length of weld requried} = \frac{375000}{385} = 974 \text{ mm}$$

$$\text{Length of connection} = \frac{974 - 2 \times 220}{4} \times 2 = 267 \text{ mm}$$

$\therefore$ Size of cover plate = $270 \times 220 \times 8$ mm (say) as shown in Figure 4.20(b).



(a) **(b)**

Figure 4.20

SAQ 3

(a) Complete penetration takes place

$\therefore$ Effective t = 16 mm

σ_{af} = 142 MPa

$\therefore$ Strength per mm = 142 × 16 = 2272 N.

(b) Incomplete penetration

$$\therefore \quad \text{Effective } t = \frac{5}{8} \times 16 = 10 \text{ mm}$$

$\therefore$ Strength per mm = 142 × 10 = 1420 N