UNIT 3 RIVETED JOINTS

Structure

3.1 INTRODUCTION

In engineering practice it is often required that two sheets or plates are joined together and carry the load in such ways that the joint is loaded. Many times such joints are required to be leak proof so that gas contained inside is not allowed to escape. A riveted joint is easily conceived between two plates overlapping at edges, making holes through thickness of both, passing the stem of rivet through holes and creating the head at the end of the stem on the other side. A number of rivets may pass through the row of holes, which are uniformly distributed along the edges of the plate. With such a joint having been created between two plates, they cannot be pulled apart. If force at each of the free edges is applied for pulling the plate apart the tensile stress in the plate along the row of rivet hole and shearing stress in rivets will create resisting force. Such joints have been used in structures, boilers and ships.

The development of welding technology in 1940s has considerably reduced the riveted joint applications. Welding is the method of locally melting the metals (sheets or plates – overlapping or butting) with intensive heating along with a filler metal or without it and allowing to cool them to form a coherent mass, thus creating a joint. Such joints can be created to make structures, boilers, pressure vessels, etc. and are more conveniently made in steel. The progress has been made in welding several types of steels but large structure size may impede the use of automatic techniques and heat treatment which becomes necessary in some cases. Welded ships were made in large size and large number during Second World War and failures of many of them spurted research efforts to make welding a better technology.

Objectives

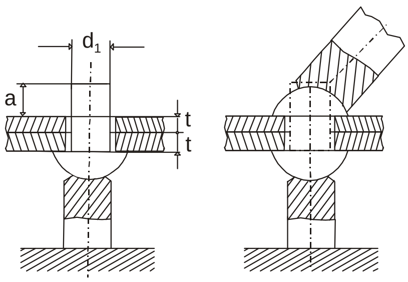
After studying this unit, you should be able to

- describe the types of riveted joint,
- calculate the strength of riveted joints,

- explain how many different ways the riveted joints can fail,
- design riveted joints for boilers, structure and under eccentric loads.

3.2 HEAD FORMING

You know that the riveted joint is created by passing the stem of a rivet through holes in two plates as is shown in Figure 3.1(a). The creation of head by process of upsetting is shown in Figure 3.1(b). The upsetting of the cylindrical portion of the rivet can be done cold or hot. When diameter of rivet is 12 mm or less, cold upsetting can be done. For larger diameters the rivet is first heated to light red and inserted. The head forming immediately follows. The rivet completely fills the hole in hot process. Yet it must be understood that due to subsequent cooling the length reduces and diameter decreases. The reduction of length pulls the heads of rivet against plates and makes the joint slightly stronger. The reduction of diameter creates clearance between the inside of the hole and the rivet. Such decrease in length and diameter does not occur in cold worked rivet.



(a) **(b)**

Figure 3.1 : Typical Head Forming of Rivet

3.3 TYPES OF RIVETS

For steel plates the rivets are normally made in low carbon steel. However, the rivets in copper add to resistance against corrosion and aluminum rivets can be used to reduce the overall weight of the structure. The low carbon steel is standardized in composition particularly for boiler applications.

Rivets with counter sunk head as in Figure 3.2(b) and oval counter sunk rivets shown in Figure 3.2(c) are not as strong as button head rivets. They are used only when protrotruding rivet heads are objectionable. Pan heads and conical heads, Figures 3.2(d) and (e) are less frequently used and are difficult to form. Tubular rivets, Figures 3.2(f) and (g) are special deviation from solid rivet shank. These rivets are used in aircrafts.

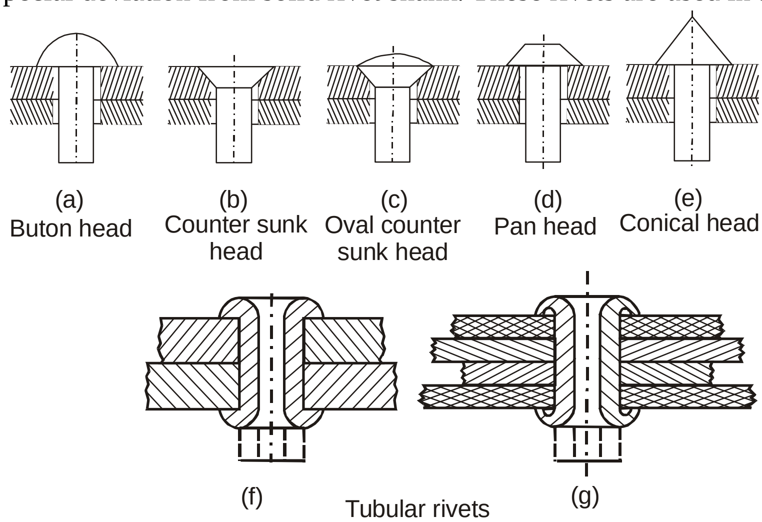


Figure 3.2 : Different Types of Rivet Heads

3.4 TYPES OF RIVETED JOINTS

The classification of riveted joints is based on following :

(a) According to purpose,

(b) According to position of plates connected, and

(c) According to arrangement of rivets.

According to purpose the riveted joints are classified as :

Strong Joints

In these joints strength is the only criterion. Joints in engineering structure such as beams, trusses and machine frames are strong joints.

Tight Joints

These joints provide strength as well as are leak proof against low pressures. Joints in reservoirs, containers and tanks fall under this group.

Strong Tight Joints

These are joints applied in boilers and pressure vessels and ensure both strength and leak proofness.

This classification has no sound basis and is arbitrary. However, it helps understand the basis of design and manufacturing. The hot working of rivets is one-way of making intimate contact between plates in the areas of joint. Further, the holes are drilled and reamed to required tolerances and burrs removed for good contact before rivets are placed in the holes. The edge of the plate is upset by means of a hammer and a caulking tool so that edge is strongly pressed against the plate surface to help leak proofing (Figure 3.3).

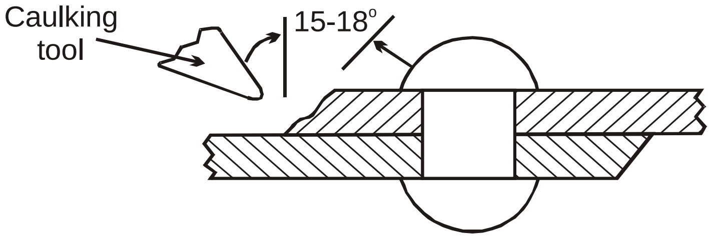


Figure 3.3 : Caulking of Riveted Joint

The riveted joints are classified as (i) **lap joint** and (ii) **butt joint** according to position of plates. In a lap joint the edges of plates are simply laid over each other and riveted. Figures 3.4(a) and (d) show lap joints. If we pull the plates by application of tensile forces, they do not fall in the same line and hence cause the rivets and plates to bend. Plates placed end-to-end and jointed through cover plates form **single cover butt joint**. Such joints are shown in Figures 3.4(b) and (e). You can see that pulling plates apart by colinear tensile forces may still cause bending of rivets. Figures 3.4(c) and (f) show the butting plates covered by two straps and then riveted. Such joints are called **double cover butt joint**. Plate bending and rivet bending are eliminated.

According to arrangement of rivets, the joints are called **single riveted**, (Figures 3.4(a), (b) and (c)) It may be noted that in a single riveted lap joint there is only one row of rivets passing through both plates while in a single riveted butt joint either of single cover or double cover type one row of rivets will pass through each of the plates. Similarly as shown in Figures 3.4(d) and (e) when two rows of rivets pass through both plates of lap joint it is called **double riveted** lap joint and two rows of rivets pass through each of butting plates the joint is a double riveted single cover butt joint. A double riveted double cover butt joint is shown in Figure 3.4(f).

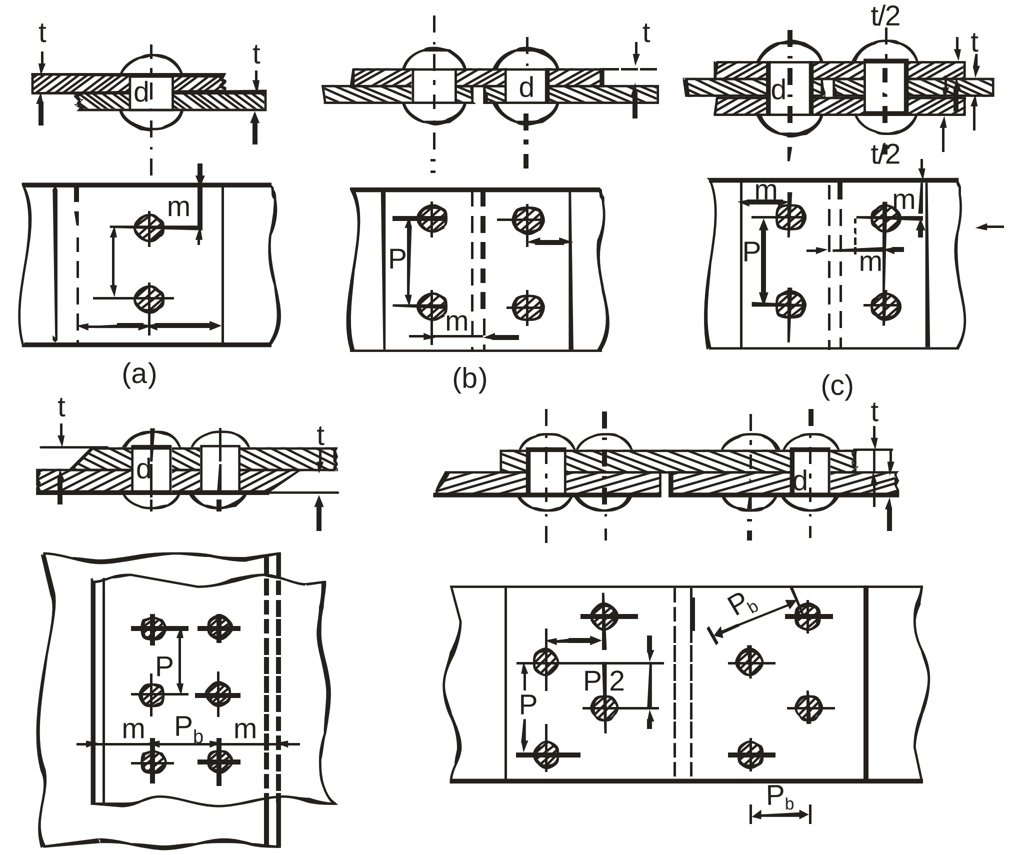


Figure 3.4 : Types of Riveted Joints : (a) Single Riveted Lap Joint; (b) Single Riveted-single Cover Butt Joint; (c) Single Riveted Double Cover Butt Joint; (d) Double Riveted Lap Joint; (e) Double Riveted Single Cover Butt Joint; and (f) Double Riveted Double Cover Butt Joint

The arrangement of rivets in Figure 3.4(d) can be described that in both the rows the rivets are opposite to each other while in Figure 3.4(e) the rivets in the adjacent rows are staggered. The joint in Figure 3.4(d) is said to be **chain riveted** while that in Figure 3.4(e) is **zig-zag riveted** joint. In zig-zag riveting the rivet in one row is placed at the middle level of the two rivets in the adjacent row.

3.5 NOMENCLATURE

Several dimensions become obviously important in a riveted joint and a design will consist in calculating many of them. These dimensions and their notations as to be used in this text are described below.

Pitch

As seen from Figures 3.4(a), (b) and (c) pitch, denoted by p, is the center distance between two adjacent rivet holes in a row.

Back Pitch

The center distance between two adjacent rows of rivets is defined as back pitch. It is denoted by p_b and is shown in Figures 3.4(d) and (e).

Diagonal Pitch

The smallest distance between centres of two rivet holes in adjacent rows of a zig-zag riveted joint is called diagonal pitch. Denoted by p_d, the diagonal pitch is shown in Figure 3.4(e).

Margin

It is the distance between centre of a rivet hole and nearest edge of the plate. It is denoted by m as shown in Figures 3.4(b), (c) and (d).

The plates to be jointed are often of the same thickness and their thickness is denoted by t. However, if the thicknesses are different, the lower one will be denoted by t_1. The thickness of the cover plate (also known as strap) in a butt joint will be denoted as t_c.

The rivet hole diameter is denoted by d. This diameter is normally large than the diameter of the rivet shank which is denoted by d_1.

A problem of designing of a riveted joint involves determinations of p, p_b, p_d, m, t, t_c and d, depending upon type of the joint.

3.6 MODES OF FAILURE OF A RIVETED JOINT

A riveted joint may fail in several ways but the failure occurs as soon as failure takes place in any one mode. Following is the description of modes of failures of a riveted joint. These modes are described with the help of a single riveted lap joint, which is subjected to tensile load P. In general the description will be applicable to any other type of joint. Reference is made in Figure 3.5 in which a single riveted lap joint is shown loaded.

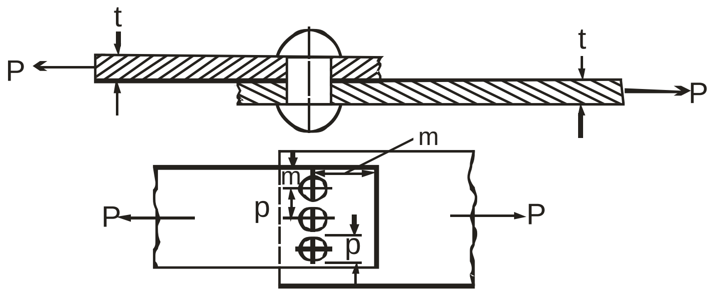


Figure 3.5 : Single Riveted Lap Joint

(a) **Tearing of Plate at the Section Weakened by Holes**

Figure 3.6 shows this mode of failure. The plate at any other section is obviously stronger, and hence does not fail. If tensile force P is to cause tearing, it will occur along weakest section, which carries the row of rivets. If only one pitch length p is considered; it is weakened by one hole diameter d. The area that resists the tensile force is

$$A_t = (p - d)\, t$$

If the permissible stress for plate in tension is σ_t, then tensile strength of the joint or tensile load carrying capacity of the joint

$$P_t = \sigma_t\ (p - d)\, t \qquad \text{. . . (3.1)}$$

If P is the applied tensile force per pitch length then the joint will not fail if

$$P_t \geq P \qquad \text{. . . (3.2)}$$

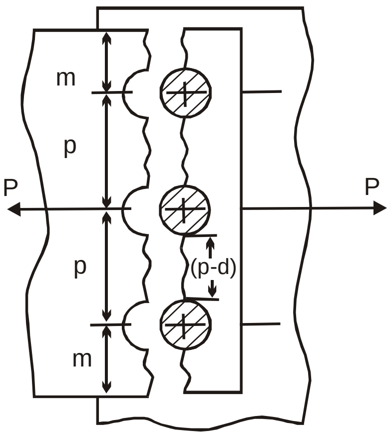


Figure 3.6 : Tearing of Plate at the Section Weakened by Holes

(b) **Shearing of Rivet**

Figure 3.7 shows how a rivet can shear. The failure will occur when all the rivets in a row shear off simultaneously. Considers the strength provided by the rivet against this mode of failure, one consider number of rivets in a pitch length which is obviously one. Further, in a lap joint failure due to shear may occur only along one section of rivet as shown in Figure 3.7(a). However, in case of double cover butt joint failure may take place along two sections in the manner shown in Figure 3.7(b). So in case of single shear th0e area resisting shearing of a rivet,

$$A_s = \frac{\pi}{4} d^2$$

(Since the difference between diameter of hole and diameter of rivet is very small, diameter of hole is used for diameter of the rivet).

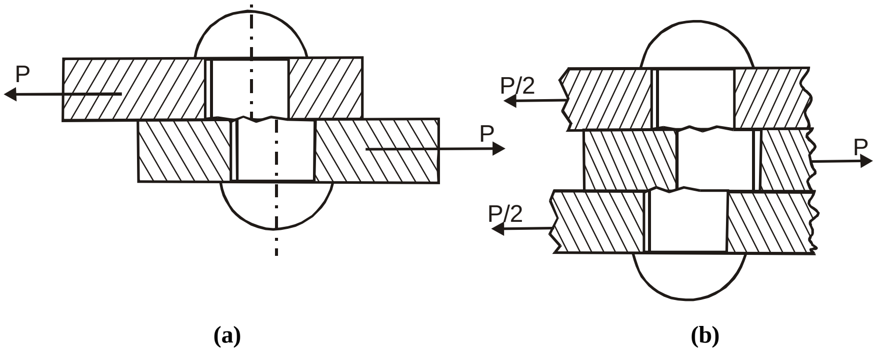


Figure 3.7 : Shearing of Rivet : (a) Single Shear; and (b) Double Shear

If permissible shearing stress in single shear of rivet is τ_s, then the shearing strength or shearing load carrying capacity of the joint.

$$P_s = \tau_s \frac{\pi}{4} d^2 \quad \text{. . . (3.3)}$$

The failure will not occur if

$$P_s \geq P \quad \text{. . . (3.4)}$$

We may also write if *n* is the number of rivets per pitch length,

$$P_s = n \, \tau_s \frac{\pi}{4} d^2 \quad \text{. . . (3.5)}$$

If the rivet is in double shear as in Figure 3.7(b) the effective area over which failure occurs in 2 A_s. The permissible stress in double shear is 1.75 times that in single shear. Hence in double shear

$$P_s = n \times 1.75 \, \tau_s \frac{\pi}{4} d^2 \quad \text{. . . (3.6)}$$

(c) **Crushing of Plate and Rivet**

Due to rivet being compressed against the inner surface of the hole, there is a possibility that either the rivet or the hole surface may be crushed. The area, which resists this action, is the projected area of hole or rivet on diametral plane. The area per rivet is (see Figure 3.8).

$$A_c = dt$$

If permissible crushing or bearing stress of rivet or plate is σ_c the crushing strength of the joint or load carrying capacity of the joint against crushing is,

$$P_c = dt \, \sigma_c \quad \text{. . . (3.7)}$$

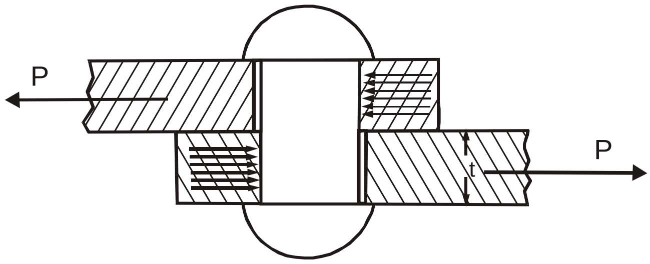


Figure 3.8 : Crushing of Rivet

The failure in this mode will not occur if

$$P_c \geq P \qquad \text{. . . (3.8)}$$

where P is applied load per pitch length, and there is one rivet per pitch. If number of rivets is n in a pitch length then right hand side in Eq. (3.7) is multiplied by n.

(d) **Shearing of Plate Margin near the Rivet Hole**

Figure 3.9 shows this mode of failure in which margin can shear along planes *ab* and *cd*. If the length of margin is m, the area resisting this failure is,

$$A_{ms} = 2\,mt$$

If permissible shearing stress of plate is τ_s then load carrying capacity of the joint against shearing of the margin is,

$$P_{ms} = 2\;mt\;\tau_s \qquad \text{. . . (3.9)}$$

The failure in this case will not occur if

$$P_{ms} \geq P \qquad \text{. . . (3.10)}$$

where P is the applied load per pitch length.

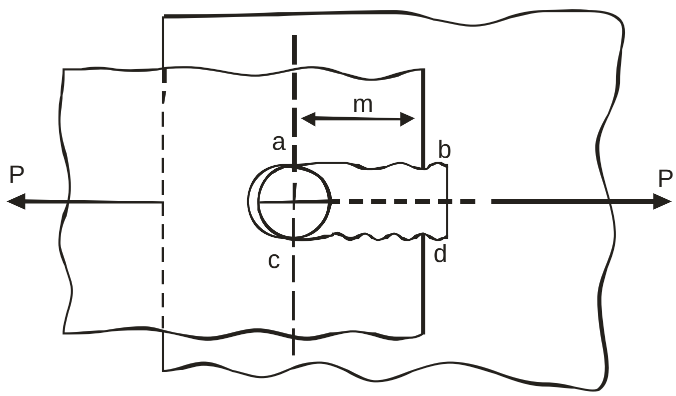


Figure 3.9 : Shearing of Margin

The modes of failure discussed above are primary in nature and in certain cases they have to be considered uniquely. One such case is when rivets are arranged in lossenge form or diamond shape. This case will be discussed at proper stage.

In writing down the above equations for strength of the joint certain assumptions have been made. It is worthwhile to remember them. Most importantly it should be remembered that most direct stresses have been assumed to be induced in rivet and plate which may not be the case. However, ignorance of actual state of stress and its replacement by most direct stress is compensated by lowering the permissible values of stresses σ_t, τ_s and σ_c, i.e. by increasing factor of safety.

The assumptions made in calculations of strengths of joint in Eq. (3.1) through (3.10) are :

(a) The tensile load is equally distributed over pitch lengths.

(b) The load is equally distributed over all rivets.

(c) The bending of rivets does not occur.

(d) The rivet holes do not produce stress concentration. The plate at the hole is not weakened due to increase in diameter of the rivet during second head formation.

(e) The crushing pressure is uniformly distributed over the projected area of the rivet.

(f) Friction between contacting surfaces of plates is neglected.

3.7 EFFICIENCY OF RIVETED JOINTS

If only a pitch length of solid or hole free plate is considered then its load carrying capacity will be

$$P_1 = pt\ \sigma_t \qquad \ldots (3.11)$$

P_1 will apparently be greater then P_t, P_s, P_c or P_{ms}. The ratio of any of P_t, P_s, P_c or P_{ms} to P_1 is defined as the efficiency of the joint in that particular mode. Ideally P_t, P_s, P_c and P_{ms} all must be equal, but actually it may not be the case. The efficiency of the joint will be determined by least of P_t, P_s, P_c, and P_{ms}. Thus efficiency of the joint is,

$$\eta = \frac{\text{Least of } P_t, P_s, P_c \text{ and } P_{ms}}{P_t\ \sigma_t} \qquad \ldots (3.12)$$

The ideal that strengths in different modes of failure are equal is not achieved in a design because the rivet hole diameters and rivet diameters are standardized for technological convenience. Table 3.1 describes the average and maximum efficiencies of commercial boiler joints.

Table 3.1 : Efficiencies of Commercial Boiler Joints

Type of Joint	Average Efficiency %	Maximum Efficiency %
Lap Joints		
Single riveted	45-60	63.3
Double riveted	63-70	77.5
Triple riveted	72-80	86.5
Butt Joints		
Single riveted	55-60	63.3
Double riveted	70-83	86.6
Triple riveted	80-90	95.0
Quadruple riveted	85-94	98.1

3.8 CALCULATION OF HOLE DIA AND PITCH

For an ideal joint the rivet should be equally strong against shearing and crushing. Hence, from Eqs. (3.3) and (3.7), making $P_s = P_c$

$$\frac{\pi}{4} d^2\ \tau_s = dt\ \sigma_c$$

$$\therefore \qquad d = 1.274\ \frac{\sigma_c}{\tau_s}\ t \text{ (in single shear)} \qquad \ldots (3.13)$$

If rivet is in double shear,

$$d = 0.637 \frac{\sigma_c}{\tau_s} t \qquad \text{. . . (3.14)}$$

Generally τ_s = 60 MPa or N/mm^2

σ_c = 130 MPa or N/mm^2

giving $d = 2.75\,t$ in single shear . . . (3.15)

$d = 1.37\,t$ in double shear

Also equating right hand sides of Eqs. (3.1) and (3.3),

$$(p - d)\, t\, \sigma_t = \frac{\pi}{4} d^2\, \tau_s$$

or

$$p = \frac{\pi d^2}{4t\,\sigma_t} \tau_s + d$$

Substituting τ_s = 60 MPa

σ_t = 75 MPa

$$p = 0.628 \frac{d^2}{t} + d$$

Using Eq. (3.15) in above equation

$p = 2.73\,d$ (in single shear)

$p = 1.86\,d$ (in double shear) . . . (3.16)

Equating right hand sides of Eqs. (3.7) and (3.9)

$$2mt\, \tau_s = dt\, \sigma_c$$

or

$$m = \frac{d}{2} \frac{\sigma_c}{\tau_s}$$

Substituting σ_c = 130 MPa

τ_s = 60 MPa

$m = 1.08\,d$ . . . (3.17)

There are several practical considerations due to which the design dimensions are modified. Most important of these is the pressure tightness of the joint, which is mainly achieved by caulking of the plate edges. The caulking becomes easier with short pitches and smaller rivets. It also makes it desirable that margin should be 1.5 *d* but not greater. The results in this section are indicative of calculation procedure and by no means be treated as standard formulae. These results are valid only for particular case and permissible stresses adopted. As a common practice for plate thickness greater than 8 mm the diameter of rivet hole is determined by

$$d = 6\sqrt{t} \qquad \text{. . . (3.18)}$$

This is known as Unwin's formula.

It has been pointed out in the last sections that no attempt was made to derive formulae. The expressions for various load carrying capacities were written by examining the geometry. Therefore, you must see that in each problem the geometry is understood and then the expressions for forces are written. In the examples here we would see how we can approach to design a riveted joint.

Example 3.1

Design a double riveted lap joint for MS plates 9.5 mm thick. Calculate the efficiency of the joint. The permissible stresses are :

σ_t = 90 MPa, τ_s = 75 MPa, σ_c = 150 MPa

Solution

The joint to be designed is shown schematically in Figure 3.10.

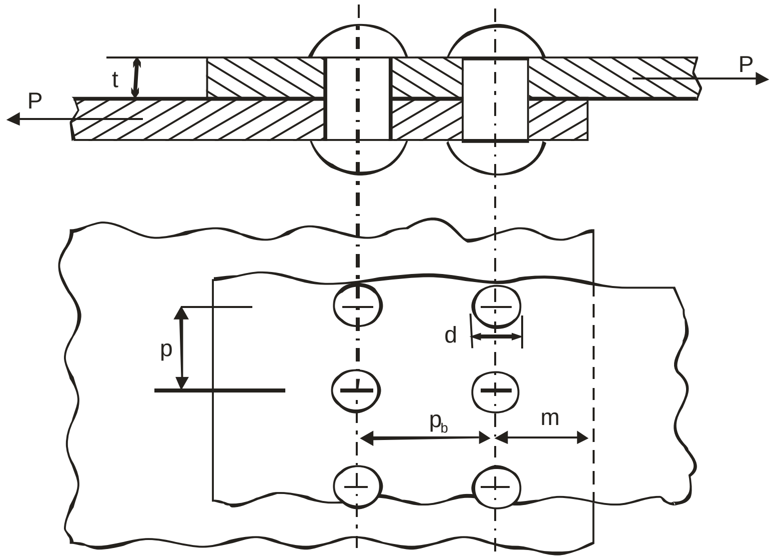


Figure 3.10

(a) **Dia. of Rivet Hole *d* :** It is determined by Unwin's formula, Eq. (3.18)

$$d = 6\sqrt{t}$$

or $$d = 6\sqrt{9.5} = 18.5 \text{ mm} \quad \ldots \text{(i)}$$

(b) **Pitch of the Joint, *p* :** In a double riveted joint there are 4 rivets in a pitch length. The rivet diameter will be taken as diameter of the hole as difference between them is small. The rivets can fail in shear or due to crushing. We will first determine the shearing and crushing strength of a rivet and equate the smaller of two to the plate tearing strength to determine *p*.

Shearing strength of one rivet

$$= \frac{\pi}{4} d^2 \tau_s = \frac{\pi}{4} (18.5)^2 \; 75 = 20.16 \text{ kN} \quad \ldots \text{(a)}$$

Crushing strength of one rivet

$$= \sigma_c \; dt = 150 \times 18.5 \times 9.5 = 26.36 \text{ kN} \quad \ldots \text{(b)}$$

From (a) and (b) it is seen that the rivet is weaker in shear.

∴ We will equate tearing strength of plate with shearing strength of rivets in a pitch length. There are two rivets in the pitch length.

∴ $$\sigma_t \; (p - d) \; t = 2 \times \frac{\pi}{4} d^2 \tau_s$$

or $$p = \frac{\pi}{2} \frac{d^2}{t} \frac{\tau_s}{\sigma_t} + d = \frac{\pi}{2} \frac{(18.5)^2}{9.5} \frac{75}{90} + 18.5$$

or $$p = 65.55 \text{ mm say } 65.7 \text{ mm} \quad \ldots \text{(ii)}$$

The pitch should be such that head forming operation is not hindered. The practice dictates that $p \geq 3\,d$ so that head forming is permitted.
$3\,d$ = 55.5 mm, and hence the value of p obtained in (ii) is acceptable.

(c) **The back Pitch p_b :** It must be between 2.5 d to 3.0 d. For chain riveting the higher value is preferred for the reason of head forming

$$p_b = 3d = 3 \times 18.5 = 55.5 \text{ mm} \qquad \ldots \text{(iii)}$$

(d) **Margin, m :** m is determined by equating shearing strength of rivet (smaller of shearing and crushing strengths of rivet). Remember that there are two rivets per pitch length :

$$\therefore \qquad 2mt\ \tau_s = 2\,\frac{\pi}{4}\,d^2\,\tau_s$$

$$\therefore \qquad m = \frac{\pi}{4}\,\frac{d^2}{t} = \frac{\pi}{4}\,\frac{(18.5)^2}{9.5} = 28.3 \text{ mm} \qquad \ldots \text{(iv)}$$

The minimum acceptable value of m is 1.5 d = 27.5 mm hence

m = 28.3 mm is acceptable.

Thus the design is completed with

d = 18.5 mm, p = 65.7 mm, p_b = 55.5 mm, m = 28.3 mm

The diameter is standardized, apparently based on drill size. Normally fractions like 18.5 mm may not be accepted. The rivet diameters are less than hole diameter by 1 mm. Yet the head formation process increases rivet diameter. We are not yet describing standard hole and rivet diameters.
We postpone it for the time being.

(e) **Efficiency of Joint**

Tensile strength of plate without holes, per pitch length

$$P_1 = \sigma_t\ pt = 90 \times 65.7 \times 9.5 = 56.2 \text{ kN} \qquad \ldots \text{(c)}$$

Shearing strength of rivets in a pitch length

$$P_s = 2 \times \tau_s \times \frac{\pi}{4}\,d^2 = 2 \times 75 \times \frac{\pi}{4}\,(18.5)^2 = 40.3 \text{ kN} \qquad \ldots \text{(d)}$$

Crushing strength of rivets in a pitch length

$$P_c = 2 \times \sigma_c \times d \times t = 2 \times 150 \times 18.5 \times 9.5 = 52.7 \text{ kN} \qquad \ldots \text{(e)}$$

The tearing strength of plate with one hole in a pitch length

$$P_t = \sigma_t\ (p - d)\ t = 90\ (65.7 - 18.5)\ 9.5 = 40.36 \text{ kN} \qquad \ldots \text{(f)}$$

The shearing strength of margin

$$P_{ms} = 2\ \tau_s\ mt = 2 \times 75 \times 28.3 \times 9.5 = 40.32 \text{ kN} \qquad \ldots \text{(g)}$$

Out of all P_s, P_c, P_t and P_{ms}, the lowest is P_m

$$\eta = \frac{P_s}{P_1} = \frac{40.3}{56.2} = 71.7\% \qquad \ldots \text{(h)}$$

The design values are

d = 18.5 mm, p = 65.7 mm, p_b = 55.5 mm, m = 28.3 mm, η = 71.7%

3.9 RIVETED JOINTS IN STRUCTURES

For trusses, bridges or girders, etc. where the width of the plates is known in advance lozenge type or diamond shaped joints are preferred. These joints have uniform or equal strengths in all modes of failure. Marginal adjustments in calculated dimensions may slightly reduce or increase strength in any particular mode. The joints are usually of double cover butt type with rivets so arranged that there is only one rivet in the outermost row and their number increases towards inner row. (See Figure 3.11). Since the plate width is known in advance, its strength in tension can be determined. Thus the load carrying capacity of the joint

$$P = \sigma_t \ (b - d)\ t$$

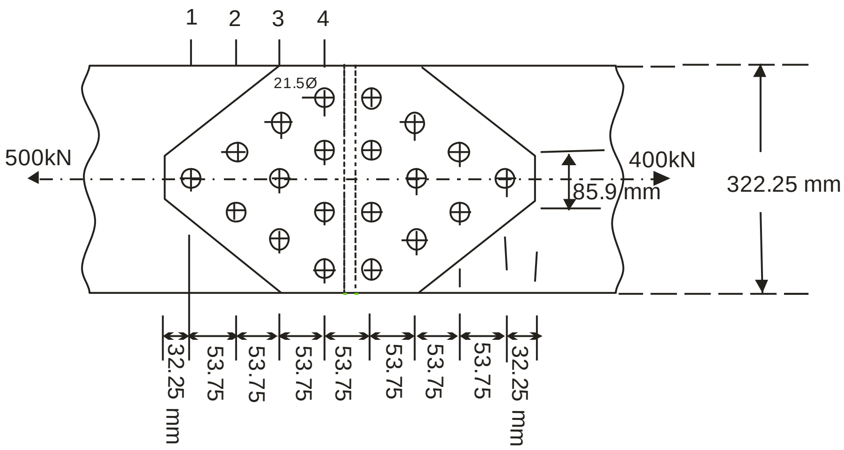


Figure 3.11

Here *b* is the plate width, *t* is thickness and *d*, the diameter of the hole. σ_t is the permissible tensile stress. The rivet diameter is determined by Unwin's relationship. The determination of number of rivets is the main task for the required force that is carried by the member. Of course we would first determine whether the strength of rivet is less in shear or in crushing which would depend upon relative magnitudes of τ_s and σ_c as well as on the cross sectional area of the rivet and its projected area. The next step would be to arrange the rivets in diamond shape as shown in Figure 3.11. Then we decide upon the pitch, back pitch and margin.

The joint is designed not to tear in the outer most row, i.e. row 1 in Figure 3.11. Then the row 2, which is the next inner row and weakened by two rivet holes, is subjected to tearing. Note that this tearing is possible if rivet in the outermost row (or row 1) shears or is crushed at the same time. That means this type of joint has one more possible mode of failure which comprises tearing along an inner row accompanied by shearing or crushing of rivets in all outer rows. The strength in this mode is denoted by P_{ts} or P_{tc} and one more suffix may be used to denote the row in which tearing will occur.

Thus $$P_{ts2} = \sigma_t\ (b - 2d)\ t + \tau_s\ \frac{\pi}{4}\ d^2$$

or $$P_{tc2} = \sigma_t\ (b - 2d)\ t + \sigma_c\ dt$$

And $$P_{ts3} = \sigma_t\ (b - 3d)\ t + 3\tau_s\ \frac{\pi}{4}\ d^2$$

or $$P_{tc3} = \sigma_t\ (b - 3d)\ t + 3\sigma_c\ dt$$

Example 3.2

Two steel plates 12.5 mm thick are required to carry a tensile load of 500 kN in a double cover butt joint. Calculate the width of the plate if it is not to be weakened by more than one rivet hole. Design the butt joint completely and show dimensions on a sketch. The ultimate values of strengths are as follow :

Plates in tension	–	600 MPa
Rivet in Shear	–	490 MPa
Plate and rivet in crushing	–	920 MPa

Use a factor of safety of 4.5.

Also use following standards :

Rivet Holes

From 13.5 mm to 25.5 mm in steps of 2 mm and from 27 mm to 42 mm in steps of 3 mm.

Rivets

1.5 mm less than rivet hole diameter upto 24 mm in steps of 2 mm and
2 mm less than rivet hole diameter from 25 mm to 39 mm in steps of 3 mm.

Solution

The permissible stresses are :

$$\sigma_t = \frac{600}{4.5} = 133 \text{ N/mm}^2$$

$$\tau_s = \frac{490}{4.5} = 109 \text{ N/mm}^2$$

$$\sigma_c = \frac{920}{4.5} = 204 \text{ N/mm}^2$$

Diameter of the Rivet Hole : Use 'Unwin's Formula

$$d = 6\sqrt{t} = 6\sqrt{12.5} = 21.21 \text{ mm}$$

From standards

$$d = 21.5 \text{ mm}$$

Hence the rivet dia, $d_1 = 20$ mm . . . (i)

Compare shear strength and crushing strength of one rivet.

$$P_s = \tau_s \frac{\pi}{4} d_1^2 = 109 \times \frac{\pi}{4} \times (20)^2 = 34 \text{ kN}$$

$$P_c = \sigma_c \, d_1 \, t = 204 \times 20 \times 12.5 = 51 \text{ kN}$$

Thus rivet in crushing is stronger than in shear.

Width of the Plate

Consider the tensile strength of the weakest section of the plate, i.e. the row which is weakened by one rivet hole.

$$P = \sigma_t \ (b - d) \ t$$

or $$500 \times 10^3 = 133 \, (b - 21.5) \, 12.5 \qquad \text{. . . (ii)}$$

$$b = 300.75 + 21.5 = 322.25 \text{ mm}$$

Number of Rivets

The rivets are in double shear in double cover butt joint. The strength in double shear is 1.75 the strength in single shear. Also we assume that the head formation does not change rivet diameter.

$$P_s = 1.75\ \tau_s\ \frac{\pi}{4}\ d_1^2 = 1.75 \times 34 = 59.5 \text{ kN}$$

$$n\ P_s = P \text{ i.e. } n\ 59.5 = 500 \text{ kN}$$

Also crushing strength

$$n\ P_c = P \text{ i.e. } n \times 51 = 500$$

or $$n = \frac{500}{51} = 9.8 \text{ say } 10 \qquad \ldots \text{(iii)}$$

We will see that 10 rivets are better arranged.

Rivet Arrangement

Ten rivet can be easily arranged in four rows : 1, 2, 3 and 4 can be arranged in rows 1, 2, 3, and 4 which will be a good arrangement. We should ensure that 10 rivets should not weaken the plate. The arrangement is shown in Figure 3.11. The pitch of the rivets is determined by geometric consideration. The innermost or 4th row should have a margin of 1.5 d = 1.5 × 21.5 = 32.25 mm from the edge.

Thus, the distance between centers of two extreme rivets in row 4

$$b - 2\ m = 322.25 - 2 \times 32.25 = 257.75 \text{ mm}$$

Obviously this distance is equal to 3 p

$$p = \frac{257.75}{3} = 85.9 \text{ mm} \qquad \ldots \text{(iv)}$$

The distance between the rows, p_b should be between 2.5 to 3 d

$$p_b = 2.5 \times 21.5 = 53.75 \text{ mm} \qquad \ldots \text{(v)}$$

Cover Plate

Theoretically the cover plate may have thickness of t/2 but practically the thickness t_c = 0.62 t

$$t_c = 0.625 \times 12.5 = 7.8 \text{ mm} \qquad \ldots \text{(vi)}$$

The cover plates are given the diamond shape so as to accommodate all the rivets (See Figure 3.11).

Efficiency

Shearing strength of 10 rivets is double shear

$$P_s = 1.75 \times 10 \times \frac{\pi}{4}\ d_1^2\ \tau_s$$

$$= 1.75 \times 10 \times \frac{\pi}{4}\ (20)^2 \times 109 = 17.5 \times 34 = 595 \text{ kN} \qquad \ldots \text{(a)}$$

Crushing strength of 10 rivets

$$P_c = 10 \times \sigma_c\ d_1\, t = 10 \times 51 = 510 \text{ kN} \qquad \ldots \text{(b)}$$

Tearing strength of plate along weakest section, i.e. along row 1

$$P_{t1} = (b - d)\ t\ \sigma_t$$

$$= 133\ (322.25 - 21.5)\ 12.5 = 500 \text{ kN} \qquad \ldots \text{(c)}$$

Strength for tearing along second row and crushing of one rivet in row 1

$$P_{tc2} = 133\,(322.25 - 2 \times 21.5)\,12.5 + \sigma_c\, d_1\, t$$

$$= 133 \times 279.25 \times 12.5 + 204 \times 20 \times 12.5$$

$$= 464.25 + 51 \text{ kN}$$

or $\quad P_{tc2} = 515.5$ kN . . . (d)

Strength for tearing along third row and crushing of 3 rivets in row 1 and 2

$$P_{tc3} = 133\,(322.25 - 3 \times 21.5)\,12.5 + \sigma_c \times 3 d_1\, t$$

$$= 133 \times 257.75 \times 12.5 + 3 \times 51 \times 10^3 = 428.5 + 3 \times 51 \text{ kN} \quad . . . \text{(e)}$$

or $\quad P_{tc3} = 581.5$ kN

Strength for tearing along fourth row and crushing of rivets in other rows

$$P_{tc4} = 133\,(322.25 - 4 \times 21.5)\,12.5 + 6 \times 51 \times 10^3$$

or $\quad P_{tc4} = 699$ kN . . . (f)

(e) and (f) were expected to be more than (d), yet the calculations have been made for the sake of completeness.

Strength of solid plate without hole

$$P_t = \sigma_t\, bt = 133 \times 322.25 \times 12.5 = 535.74 \text{ kN} \quad . . . \text{(g)}$$

The least of all strengths from (a) through (f) is P_{t1} = 500 kN

$$\eta = \frac{P_{t1}}{P_t} \times 100 = \frac{500}{535.74} \times 100$$

$$= 93.3\% \quad . . . \text{(vii)}$$

SAQ 1

(a) Describe types of riveted joints.

(b) What are different modes of failure of riveted joints?

(c) Define pitch, back pitch, margin and diagonal pitch.

(d) Define efficiency of a riveted joint and write expression for various strengths.

(e) A structural joint of double cover butt type has an efficiency of 85% with the condition that the lowest strength is in tearing mode of 10.5 mm thick plate in outer most row which is weakened by one hole. Find the tensile force carried by the joint and the number of rivets if permissible stresses for plate and rivet are; σ_t = 105 N/mm^2, τ_s = 75 N/mm^2 and σ_c = 150 N/mm^2. Design the joint completely and show d, d_1, p, p_b and m on the sketch. Also give dimension of cover plate.

3.10 JOINTS FOR BOILERS AND PRESSURE VESSELS

The boiler and pressure vessels are cylindrical in shape and withstand internal pressure. The vessels are required to be leak proof. The maintenance of pressure and safety of boilers have prompted several standards. ASME boiler code, Board of Trade (BOT) Rules, Indian Boiler Regulations (IBR) and ISI standards are available for design of boilers and pressure vessels.

The cylindrical pressure vessel is identified by two dimensions, viz., the length and diameter. The cylinders are made from plates and whole length may not be obtained from single sheet hence cylindrical sections are obtained by bending sheets and joining edges by riveted joint. The sections are then joined together by another riveted joint along circumference. Thus there are two types of joint longitudinal and circumferential (see Figure 3.12). The longitudinal joint will bear hoop stress (σ_h) and circumferential joint bears longitudinal stress (σ_l). Since $\sigma_h = 2\sigma_l$, the longitudinal joint will have to be two times as strong as circumferential joint. Therefore, longitudinal joints are always made butt joints whereas the circumferential joints are mode as lap joints.

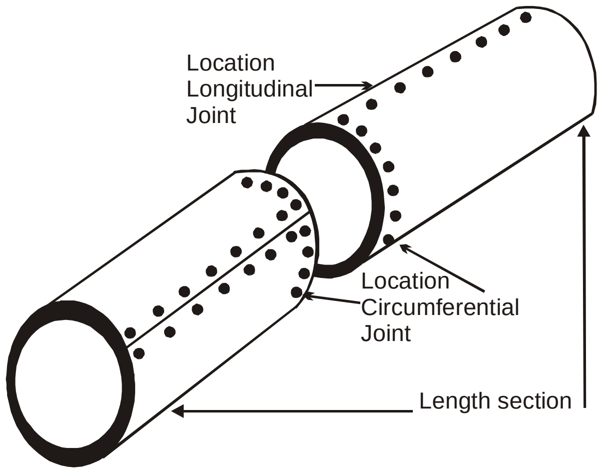


Figure 3.12 : Longitudinal and Circumferential Location for Riveted Joints

The steps followed in design of boiler riveted joints are same as followed in any joint design. They are mentioned here as described in IBR.

3.11 DESIGN PROCEDURE FOR LONGITUDINAL BUTT JOINT

Determine Thickness of Boiler Shell (*t*)

The efficiency of the joint is chosen from Table 3.1 and for pressure σ_r, inner diameter D and permissible tensile stress σ_t, the thickness is calculated from,

$$t = \frac{\sigma_r D}{2\sigma_t \eta} + 1 \text{ mm} \qquad \ldots (3.19)$$

The diameter and thickness will further guide in respect of rivet arrangement. Table 3.2 can be used for this purpose.

Table 3.2 : Suggested Rivet Arrangement

Dia. of Shell (mm)	Thickness of Shell (mm)	Rivet Arrangement
610-1830	6-12.5	Double riveted
915-2130	8-25.0	Triple riveted
1525-2740	9.5-31.75	Quadruple riveted

Determine Rivet Hole Diameter (*d*) and Rivet Diameter (d_1)

Unwin's formula, giving $d = 6\sqrt{t}$ is used if $t \geq 8$ mm. In very rare case if $t < 8$ mm, *d* is calculated by equating shearing strength and crushing strength of rivet. The diameter of hole must be rounded off to the nearest standard value with the help of Table 3.3, and the diameter of rivet also established.

Table 3.3 : Standard Rivet Hole and Rivet Diameters

***d* (mm)**	13	15	17	19	21	23	25	28.5	31.5	34.5	37.5	41	44
d_1 (mm)	12	14	16	18	20	22	24	27	30	33	36	39	42

Determine Pitch of the Rivet (*p*)

The minimum pitch is 2 *d* to accommodate the dies to form head. The pitch is calculated by equating tearing strength with shearing or crushing strength of rivet(s). However, the pitch should not exceed certain value for leak proof nature of the joint. The maximum value of *p* is given by following equation.

$$p_{max} = C \times t + 41.28 \text{ mm} \quad \text{. . . (3.20)}$$

The value of *C* is given in Table 3.4. If by calculation *p* turns out to be less than p_{max}, it will be acceptable.

Table 3.4 : The Value of Constant for Maximum Pitch

Number of Rivets	**Lap Joint**	**Butt Joint Single Cover**	**Butt Joint Double Cover**
1	1.31	1.53	1.75
2	2.62	3.06	3.50
3	3.47	4.05	4.63
4	4.17	–	5.52
5	–	–	6.00

Determine Back Pitch (p_b)

(a) For both lap and butt joints having equal number of rivets in different rows p_b is given as

$$p_b = (0.33\, p + 0.67\, d) \text{ mm for zig-zag} \quad \text{. . . (3.21)}$$

and

$$p_b = 2\, d \quad \text{. . . (3.22)}$$

(b) For joints in which number of rivets in outer rows is half of that in inner rows which are chain riveted p_b should be greater of the values calculated from Eqs. (3.21) and (3.22). However, the value of p_b for rows having full number of rivets will not be less than 2 *d*.

(c) The third case arises for joints having inner rows zig-zag riveted and outer rows having half the number of rivets as inner rows where

$$p_b = (0.2\, p + 1.15\, d) \text{ mm} \quad \text{. . . (3.23)}$$

The back pitch for zig-zag riveted inner rows will be

$$p_b = (0.165\, p + 0.67\, d) \text{ mm} \quad \text{. . . (3.24)}$$

The pitch *p* in above equations is the one in outer row, i.e. away from butting edges.

Determine Thickness of the Cover Plate (t_c)

(a) For single butt cover with chain riveting

$$t_c = 1.125\, t \qquad \text{. . . (3.25)}$$

(b) For single cover with pitch in the outer row being twice that in the inner row

$$t_c = 1.125 \left(\frac{p - d}{p - 2d} \right) t \qquad \text{. . . (3.26)}$$

(c) For double cover of equal width and chain riveting

$$t_c = 0.625\, t \qquad \text{. . . (3.27)}$$

(d) For double cover of equal width with pitch in the outer row being twice that in the inner row

$$t_c = \left(\frac{p - d}{p - 2d} \right) t \qquad \text{. . . (3.28)}$$

(e) For double cover of unequal width (wider cover on the inside)

$$\left.\begin{aligned} t_{c1} &= 0.75\, t && \text{(for cover on the inside)} \\ t_{c2} &= 0.625\, t && \text{(for cover on the outside)} \end{aligned}\right\} \qquad \text{. . . (3.29)}$$

Determine margin, $m = 1.5\, d$ . . . (3.30)

Determine Caulking Pitch, p_t

The pitch of rivets in the row nearest to the edge must be as small as possible to avoid leakage. This pitch is called caulking pitch and helps edges to be caulked effectively (see Figure 3.3). A rough rule is that this pitch should not be greater than S_{tc}. The caulking pitch is, however, calculated from following :

$$p_c = d + 13.8 \frac{t_c^{\frac{3}{4}}}{(\sigma_{12})^{\frac{1}{4}}} \qquad \text{. . . (3.31)}$$

This is an empirical relation in which σ_r the pressure is used in N/mm^2.

3.12 DESIGN PROCEDURE FOR CIRCUMFERENTIAL LAP JOINT

The thickness of the shell, the diameter of the rivet hole, back pitch and margin are calculated in the same way as for longitudinal butt joint. The other quantities are presented under.

Number of Rivets (n)

The rivets are in single shear and all of them are subjected to shear when pressure, σ_r acting on the circular section of the cylindrical space tends to separate two length sections of the vessel.

$$n\, \tau_s\, \frac{\pi}{4} d_1^2 = \sigma_r\, \frac{\pi}{4} D^2$$

$$n = \frac{\sigma_r}{\tau_s} \frac{D^2}{d_1^2} \qquad \text{. . . (3.32)}$$

Pitch, (*p*)

Efficiency of the lap joint η can be taken as half of the efficiency of the longitudinal butt joint. The efficiency of the lap joint is calculated on the basis of tearing load capacity of the joint which turns out to be least of strengths in all modes.

Thus, $$\eta = \frac{p - d}{p} \qquad \ldots (3.33)$$

Number of Rows, (*N*)

The rivets are placed all along the circumferences of the shell. Hence number of rivets in one row.

$$n_1 = \frac{\pi (D + t)}{p}$$

Hence total number of rivets in $N n_1 = n$.

$$N = \frac{n p}{\pi (D + t)} \qquad \ldots (3.34)$$

Whether the joint will be single riveted or multiple riveted will be decided by *N*. If *N* turns out to be less than 1, a single riveted joint will serve the purpose. In any case the pitch will have to satisfy the condition of caulking.

Overlap of Shell Length Section (*l*)

$$l = (N - 1)\ p_b + 2m \qquad \ldots (3.35)$$

Example 3.3

Inner diameter of a boiler is 1500 mm and the steam pressure is 2 N/mm^2. Use a proper joint along the length and design it completely. Use following permissible values of stress.

Tension σ_t = 90 MPa

Shear τ_s = 75 MPa

Crushing σ_c = 150 MPa

Solution

Thickness of the Shell (*t*)

From Table 3.2 for shell diameter of 1500 mm a double riveted butt joint is recommended and from Table 3.1 we can use an efficiency of 80%.
From Eq. (3.17).

$$t = \frac{\sigma_r D}{2\sigma_t \eta} + 1 \text{ mm}$$

$$= \frac{2 \times 1500}{2 \times 90 \times 0.8} + 1 = 20.8 + 1$$

or $t = 21.8$ mm say 22 mm

Rivet Hole Diameter (*d*)

From Eq. (3.18)

$$d = 6\sqrt{t} = 6\sqrt{22} = 28.14 \text{ mm}$$

The nearest standard value of hole diameter is 28.5 mm, and corresponding rivet diameter is 27 mm. d_1 = 27 mm.

Pitch (p)

In one pitch length there are two rivets which may shear or crush (Figure 3.13).

The shear strength of one rivet in double shear

$$P_{s1} = 1.75 \times \frac{\pi}{4} d_1^2 \tau_s = 1.75 \times \frac{\pi}{4} (27)^2 \times 75 = 75.2 \text{ kN}$$

The crushing strength of one rivet

$$P_{c1} = t\, d_1\, \sigma_c = 22 \times 27 \times 150 = 89.1 \text{ kN}$$

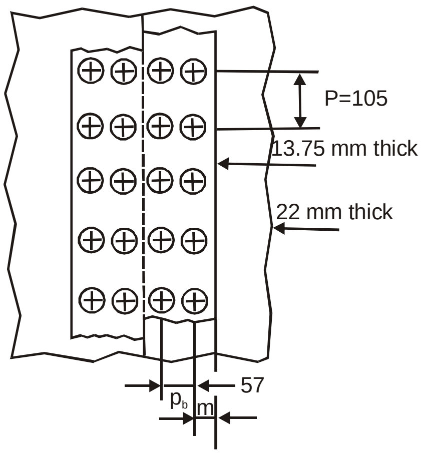


Figure 3.13

The rivet is weaker in shearing. Equating tearing strength of plate with shearing strength of 2 rivets in a pitch length,

$$(p - d)\, t\, \sigma_t = 2 \times 1.75 \times \frac{\pi}{4} d_1^2 \tau_s$$

$$p = 3.5 \times \frac{\pi}{4} (27)^2 \times \frac{75}{22 \times 90} + 28.5 = 104.4 \text{ mm}$$

Check for maximum value of pitch from Eq. (3.20). From Table 3.4 for 2 rivets in a pitch length for a double cover double riveted joint the value of C = 3.5.

$$\therefore \quad p_{max} = C \times t + 41.28 = 3.5 \times 22 + 41.28 = 118.28 \text{ mm}$$

The min. pitch is 2 d. Hence calculated value of p = 104.4 mm is acceptable. We may choose p = 105 mm.

Back Pitch (p_b)

$$p_b = 0.33\, p + 0.67\, d = 0.33 \times 105 + 0.67 \times 28.5$$

$$p_b = 34.65 + 19.1 = 53.75 \text{ mm}$$

However, p_b should not be less than 2 d or 57 mm

p_b = 57 mm.

Thickness of Cover Plate (t_c)

The joint has two equal cover plates. From Eq. (3.27)

$$t_c = 0.625\, t = 13.75 \text{ mm}$$

Margin (m)

$$m = 1.5\, d = 42.75 \text{ mm}$$

Efficiency (η)

The shearing strength of the joint

$$P_s = 2 \times 75.2 = 150.4 \text{ kN}$$

The crushing Strength of the joint

$$P_c = 2 \times 89.1 = 178.2 \text{ kN}$$

The tearing strength of plate with holes

$$P_t = (p - d)\ t\ \sigma_t = (105 - 28.5)\ 22 \times 90$$

or $$P_t = 151.47 \text{ kN}$$

The tensile strength of plate without holes

$$P = pt\ \sigma_t = 105 \times 22 \times 90 = 208 \text{ kN}$$

P_s is least of P_s, P_c and P_t

$$\therefore \quad \eta = \frac{P_s}{P} = \frac{150.4}{208} = 72.3\%$$

Example 3.4

Design a circumferential lap joint for boiler shell of Example 3.3.

Solution

The thickness of the shell t and rivet hole diameter d (and rivet diameter d_1) will remain same, i.e.

$$t = 22 \text{ mm},\ d = 28.5 \text{ mm},\ d_1 = 27 \text{ mm}$$

Number of rivets (n) : Use Eq. (2.32)

$$n = \frac{\sigma_r}{\tau_s} \frac{D^2}{d_1^2} \qquad \sigma_r \text{ is pressure in boiler}$$

$$n = \frac{2}{75} \left(\frac{1500}{27}\right)^2 = 82.3 \text{ say } 83$$

Pitch (p)

These rivets (83 in number) have to be placed along circumference and preferably in two rows for better leak proofing. However, arranging rivets in two rows will alter the number of rivets. We will first determine pitch from efficiency, making efficiency in plate tearing mode as the least. At best it is required that efficiency of the circumferential joint should be 50% of the efficiency of the longitudinal joint. So in the case

$$\eta = \frac{0.8}{2} = 0.4$$

$$\eta = \frac{p - d}{p} = 0.4 \text{ so that } p - 0.4p = d$$

or $$p = \frac{d}{0.6} = \frac{28.5}{0.6} = 47.5 \text{ mm}$$

Number of Rows (N)

Apparently n number of rivets are to be distributed with p = 47.5 mm around a circumference of $\pi\ (D + t)$

$$\therefore \quad N = \frac{n\,p}{\pi\,(1500 + 28.5)} = \frac{83 + 47.5}{\pi \times 1528.5} = 0.82$$

To make $N = 2$ and keeping $p = 47.5$ mm, n will increase,

$$2 = \frac{n \times 47.5}{\pi \times 1528.5} \text{ giving } n = 202$$

Now choosing $n = 202$ will alter p

$$p = \frac{2 \times \pi \times 1528.5}{202} = 47.54 \text{ mm}$$

With number of rivets 2 per pitch length the constant C from Table 3.4 is 3.06 and using Eq. (3.20)

$$p_{max} = Ct + 41.28 = 3.06 \times 22 + 41.28 = 108.6 \text{ mm}$$

But for convenience of caulking p should be at least 2 d.

$$\therefore \quad p = 2 \times 28.5 = 57 \text{ mm}$$

This will further alter number of rivets as

$$n = \frac{2\pi \times 1528.8}{57} = 168.5 \text{ say } 168$$

So that $$p = \frac{2\pi \times 1528.8.5}{168} = 57.16 \text{ mm}$$

$$\therefore \quad n = 168,\ p = 57.16 \text{ mm},\ N = 2$$

$$\eta = \frac{p - d}{p} = \frac{57.16 - 28.5}{57.16} = 50.44\%$$

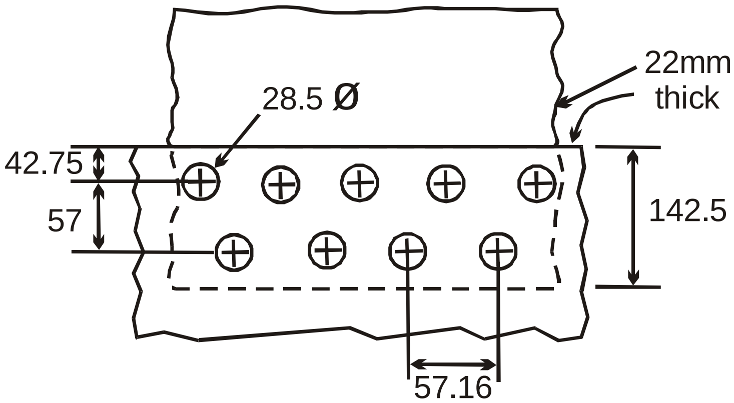


Figure 3.14

Back Pitch (P_b)

The rivets can be arranged in zig-zag rows so that

$$p_b = 2\,d = 57 \text{ mm}$$

Margin (m) : $m = 1.5\,d = 1.5 \times 28.5 = 42.75$ mm

Overlap (l) : $l = (N - 1)\,p_b + 2$ m

or $l = 57.0 + 2 \times 42.75 = 142.5$ mm.

The joint is shown in Figure 3.14.

3.13 TORSIONAL LOADING AND ECCENTRIC LOADING OF RIVETED JOINT

Plate *A* is riveted to structural element *B*. A torque is applied to the Plate *A*. The plate will rotate, of course by slight elastic amount, about some point as *o* in Figure 3.15(a). It is not wrong to assume that any straight line such as *oc* which passes through the centre of a rivet, remains straight before and after application of the torque. Then the deformation, hence strain and so the average shearing stress across the section of the rivet will be proportional to the distance between *o* and the centre of the rivet. Since the average shearing stress is equal to the shearing force divided by area of cross section of the rivet, the shearing force on the rivet will be proportional to the distance between *o* and centre of the rivet. The direction of this force will be perpendicular to the joining line.

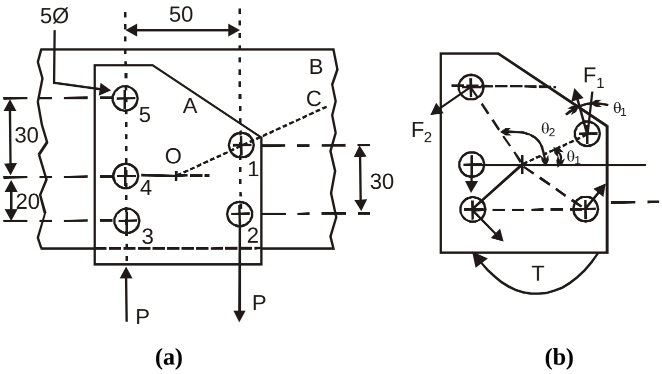


Figure 3.15

The forces F_1, F_2, etc. on individual rivets are shown in Figure 3.15(b). For satisfying condition of equilibrium, components of forces in vertical direction should sum up to zero. If the forces F_1, F_2, etc. make angles θ_1, θ_2, etc. respectively with *y*-axis, then

$$F_1 \cos \theta_1 + F_2 \cos \theta_2 + \ldots + F_n \cos \theta_n = 0$$

or $$\sum_{i=1}^{n} F_i \cos \theta_i = 0 \qquad \ldots \text{(i)}$$

But $$F_i = \tau_i A_i = \frac{\tau_i}{r_i} r_i A_i$$

And since $$\tau_i \propto r_i \quad \text{or} \quad \tau_i = k\, r_i$$

$\therefore$ $$F_i = k\, r_i\, A_i \qquad \ldots \text{(ii)}$$

Here *k* is a constant, τ_i = shearing stress in i^{th} rivet whose area of cross section is A_i and its centre is at a distance r_i from *o*.

Use (ii) and (i) to obtain

$$k \sum_{1}^{n} r_i A_i \cos \theta_i = 0$$

See from Figure 2.15(b) that $r_i \cos \theta_i = x$

$\therefore$ $$k \sum_{1}^{n} x A_i = 0$$

Which is same as $k\, \bar{x}\, A_t = 0$.

Where $\bar{x}$ is the *x*-coordinate of centroid of all the rivet and sum of their areas of cross sections is A_t. And since neither *k* nor A_t is zero therefore, $\bar{x} = 0$. If then we consider sum of forces along *x*-axis we would arrive at the result $\bar{y} = 0$. This means that *o* is the point coinciding with the centroid of the rivet area system.

Example 3.5

In Figure 3.15(a) the distances between columns and rows of rivets are shown. Each rivet is 5 mm in diameter and force P = 1 kN. Calculate the maximum shearing stress in rivet.

Solution

The five rivets have been numbered as 1, 2, . . . , 5. Take centre of rivet 3 as origin and x and y axes along 32 and 35 respectively. Areas of all rivets is

$A = \frac{\pi}{4}(5)^2 = 19.64\ \text{mm}^2$. If $\bar{x}$ and $\bar{y}$ are the coordinates of the centroid, then

$$50A + 50A = 5A\,\bar{x}$$

Hence, $\bar{x} = 20$ mm

Also, $50A + 20A + 30A = 5A\,\bar{y}, \quad \bar{y} = 20$ mm

Hence centroid is on the horizontal line through rivet 4. We can calculate various distances of rivet centres from centroid.

$$r_1 = \sqrt{10^2 + 30^2} = 10\sqrt{10}$$

$$r_2 = \sqrt{20^2 + 30^2} = 10\sqrt{13}$$

$$r_3 = \sqrt{20^2 + 20^2} = 10\sqrt{8}$$

$$r_4 = \sqrt{20^2 + 0} = 10 \times 2$$

$$r_5 = \sqrt{30^2 + 20^2} = 10\sqrt{13}$$

Now $F_1 = k\,r_1 = k\,10\sqrt{10}$, moment of F_1 about O,

$$M_1 = k\,r_1^2 = 1000\,k$$

$$F_2 = k\,r_2 = k\,10\sqrt{13},\ \ M_2 = 1300\,k$$

$$\frac{F_1}{F_2} = \frac{r_1}{r_2} = \frac{\sqrt{10}}{\sqrt{13}} \quad \text{or} \quad F_1 = \sqrt{\frac{10}{13}}\,F_2$$

We can find each of F_1, F_2, F_3, F_4 and F_5 in terms of k or we can find each force in terms of F_2. We may like to choose F_2 because F_2 is grater than all other forces because r_2 is larger than all other r.

$$F_3 = \sqrt{\frac{8}{13}}\,F_2,\ F_4 = \frac{2}{\sqrt{13}}\,F_2,\ F_5 = F_2$$

Taking moments of all forces about O and equating with the applied moment of 50 P = 50000 N mm.

$$\sqrt{\frac{10}{13}}\,F_2\,10\sqrt{10} + F_2\,10\sqrt{13} + \sqrt{\frac{8}{13}}\,F_2\,10\sqrt{8} + \frac{2}{\sqrt{13}}\,F_2\,10 \times 2 + F_2\,10\sqrt{13} = 5 \times 10^4$$

$$\frac{100F_2}{\sqrt{13}} + \frac{130F_2}{\sqrt{13}} + \frac{80F_2}{\sqrt{13}} + \frac{40F_2}{\sqrt{13}} + \frac{130F_2}{\sqrt{13}} = 5 \times 10^4$$

$\therefore$ $$F_2 = \frac{500\sqrt{13}}{4.8} = 375.6\ \text{N}$$

$\therefore$ Maximum shearing stress $= \frac{F_2}{A} = \frac{375.6}{19.64} = 19.12\ \text{N/mm}^2$

This stress will be in rivets 2 and 5.

Example 3.6

Figure 3.16(a) shows a plate riveted on to a vertical column with three rivets placed at three corners of an equilateral triangle of size 75 mm. A load of 37 kN acts on the plate at a distance of 125 mm from vertical line through a rivet as shown in Figure 3.16(a). If the permissible stress in rivet is 60 N/mm^2 calculate the diameter of the rivet.

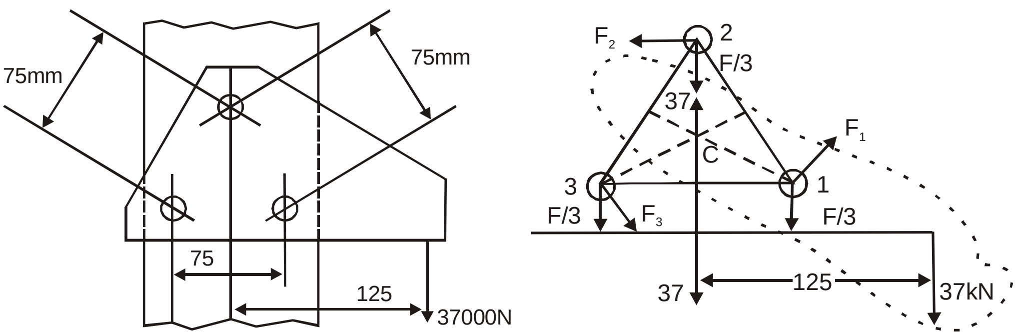
The rivets are at corners of equilateral triangle hence their centroid will be at the centroid of the triangle, *C*. Each of rivets 1, 2 and 3 will be at the same distance from *C*.

$$r_1 = r_2 = r_3 = \frac{2}{3}\sqrt{75^2 - 37.5^2} = \frac{2}{3}\sqrt{5625 - 1406.25} = 43.3 \text{ mm}$$

The force of 37 kN is acting at a distance of 125 mm from vertical line through the centroid as shown in Figure 3.16(b). Apply two forces, each equal to 37 kN but in opposite direction at *C*. Combining two 37 kN forces as shown in the figure, we are left with a couple 37 kN by 125 mm and a vertical force 37 kN acting downward. This force will be distributed equally on three rivets, i.e. if F = 37 kN, then $\frac{F}{3}$ will be a direct shearing force acting downward on each rivet as shown in Figure 3.16(b). The moment of the couple, $T = 37 \times 125 = 4625$ kN mm will be balanced by moments of forces F_1, F_2 and F_3 about *C*. F_1, F_2 and F_3 are perpendicular to r_1, r_2 and r_3, respectively and each is proportional to its r. incidentally due to symmetry of equilateral triangle r_i, r_2 and r_3 are mutually equal and hence $F_1 = F_2 = F_3$.

Equate moments $\quad F_1\, r_1 + F_2\, r_2 + F_3\, r_3 = T$

$$3F_1\, r_1 = T$$



(a) (b)

Figure 3.16

Or by putting r_1 = 43.3 mm

$$F_1 = \frac{4625}{3 \times 43.3} = 35.6 \text{ kN}$$

The rivet 1 is loaded by two forces F_1 = 33.6 kN and $\frac{F}{3} = \frac{37}{3} = 12.33 \text{ kN}$ at an angle of 150^o. All three rivets with their forces are shown in Figure 3.17. The net force on each rivet will be the resultant of $\frac{F}{3}$ and F_1, F_2 or F_3. Apparently the largest magnitude will occur where the angle between two forces is minimum. The angle is minimum θ = 30^o in rivet 3.

The resultant of two forces R_1 and R_2 with angle between them being θ is given by

$$R = \sqrt{R_1^2 + R_2^2 + 2R_1\, R_2\, \cos\theta}$$

∴ Resultant force on rivet 3

$$R = \sqrt{\left(\frac{F}{3}\right)^2 + F_3^2 + 2\,\frac{F}{3}\,F_3\,\cos\theta}$$

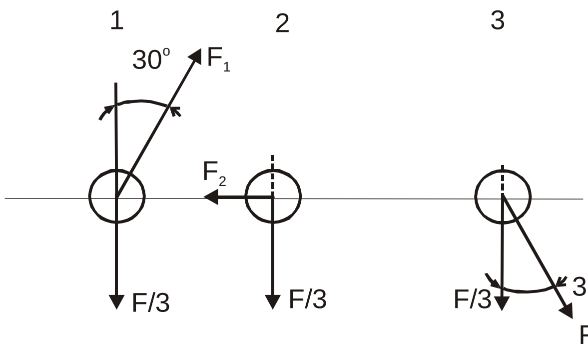


Figure 3.17

Put F = 37 kN, F_3 = 35.6 kN, θ = 30°

$$R = \sqrt{(12.33)^2 + (35.6)^2 + 2 \times 12.33 \times (35.6)\cos 30}$$

$$= \sqrt{152 + 1267.36 + 761} = \sqrt{2180.36} = 46.7 \text{ kN}$$

With τ as permissible shearing stress and d as diameter of rivet

$$R = \frac{\pi}{4}\,d^2\,\tau$$

Use $R = 46.7 \times 10^3$ N, $\tau = 60$ N/mm^2

$$d^2 = \frac{4 \times 46.7}{\pi\,60} \times 10^3 = 991$$

∴ d = 31.5 mm

We had assumed that all rivets have same diameter, that is how we had determined centriod. Hence all three rivets will have the diameter of 31.5 mm each.

SAQ 2

(a) What types of joint are used in a boiler along its length and circumference and why?

(b) Describe the quantities that are required to calculate for riveted joints and show them on sketch.

(c) What do you understand by eccentric loading of a riveted joint? Explain with the help of sketch.

(d) A boiler shell 1 m in diameter is subjected to steam pressure of 2.7 MPa gauge. It is proposed to have a longitudinal double riveted double cover butt joint with number of rivets twice in the inner row. Assume following ultimate strength values.

Ultimate tensile strength σ_u = 352 MPa

Ultimate shearing strength τ_u = 256 MPa

Ultimate crushing strength σ_{uc} = 512 MPa

For plate and rivet materials.

With machine riveting assume a factor of safety of 4. Sketch the joint and show dimensions. Calculate the efficiency of the joint.

(e) Determine diameter of rivets if permissible shearing stress is 65 N/mm^2. Assume all rivets have same diameter in Figures 3.18 and 3.19.

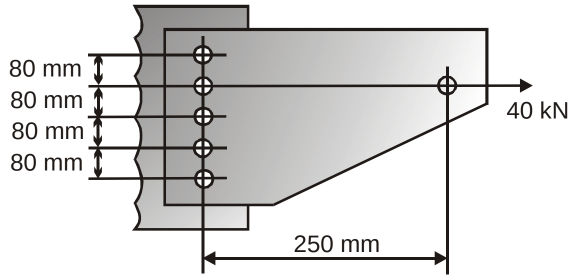


Figure 3.18

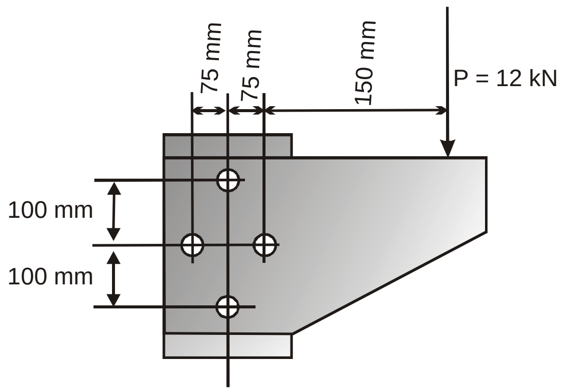


Figure 3.19

3.14 SUMMARY

Riveting has been used for more than two centuries. It was predominant in structure building where sheets and sections were joined. The bridges, boilers, ships and aeroplanes were commonly made with riveted joints.

The joints of the types while offering as convenient technology presented a problem of increased weight because for removing metal for making a rivet hole, at least three times of the removed mass was added in form of screw. Further, for joints like butt joints added more weight in form of covers. The process is not emendable to automation.

The structural problems may still be solved through this method since the alternative welding technology is many situations require heat treatment for stress reliving which may not become possible.

However, the process on the whole is on the decline.

3.15 KEY WORDS

Pitch : The distance between the centre of adjacent rivets holes.

Strong Tight Joints : Joints which are strong and leak proof.

Caulking : Process of pressing rivet edges against the plates and edges of plates against other plate to ensure leak proofness.

Lap Joints : Two plates lapping over the edges and riveted.

Butt Joint : Two plates buttering along the edges, covered with straps and riveted.

Failure Modes : The riveted joint may fail due to fail of plate or rivet. Each failure is due to a particular stress. Combination of stress and part defines the mode.

Efficiency : The ratio of least load carrying capacity to the strength of solid plate.

3.16 ANSWERS TO SAQs

SAQ 1

(e) Follow the method of Example 3.11, Section 3.11 and determine d = 19.5 mm, d_1 = 18 mm

Width of plate = 130 mm

Number of rivets = 5

Cover plate thickness = 6.6 mm

Shearing strength of 5 rivets in double shear

$$P_s = 5 \times 1.75 \times \frac{\pi}{4} (18)^2 \times 75 = 167 \text{ kN}$$

Crushing strength of 5 rivets

$$P_c = 5 \times 18 \times 10.5 \times 150 = 141.75 \text{ kN}$$

Tearing strength of plate along weakest section

$$P_{t1} = (130 - 19.5)\ 10.5 \times 105 = 121.8 \text{ kN}$$

Tearing in second row and crushing in outer most row, strength

$$P_{tc2} = (130 - 2 \times 19.5)\ 10.5 \times \frac{105}{1000} + \frac{141.75}{5} = 128.7 \text{ kN}$$

The strength of tearing in the third row will be still higher.

Strength of solid plate

$$P_t = \sigma_t\, bt = 105 \times 10.5 = 143.325 \text{ kN}$$

$$\therefore \qquad \eta = \frac{121.8}{143.325} = 85\%$$

The pitch is determined from margin, m = 1.5 d = 29.25 mm

$$p = b - 2m = 130 - 58.50 = 71.5 \text{ mm}$$

$$p_b = 2.5d = 2.5 \times 19.5 = 48.75 \text{ mm}$$

The arrangement of 5 rivets is 1, 2, 2 in rows as shown in Figure 3.20.

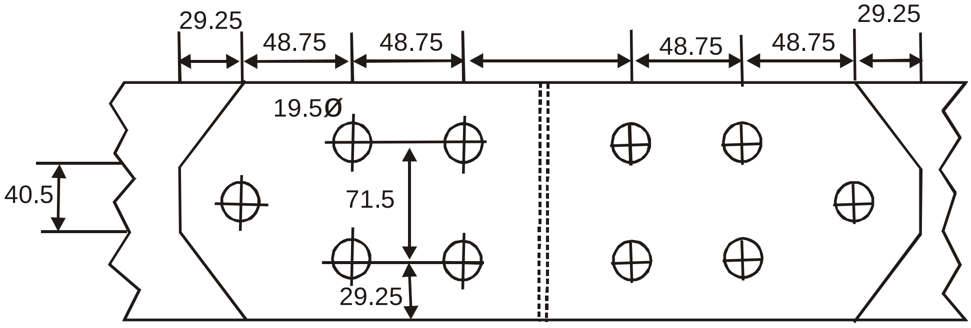


Figure 3.20

(d) Follow the procedure as in Example 3.1, Sections 3.13 and obtain

σ_t = 88 MPa, τ_s = 64 MPa, σ_c = 128 MPa

t = 21.45 mm say 22 mm

d = 28.142 mm chose standard d = 28.5 and d_1 = 27.0 mm.

p = 139.2 mm from equating tensile strength with shearing strength of rivets in a pitch length. Check for maximum pitch

p_b = 65.03 mm, greater of 0.33 p + 0.67 d and 2 d

$$t_c = 0.625 t \frac{p - d}{p - 2d} = 18.52 \text{ say } 18.5 \text{ mm}$$

$$m = 1.5 d = 42.75 \text{ mm}$$

η = 79.5%. The least strength is in shearing of rivets. The joint is shown in Figure 3.21.

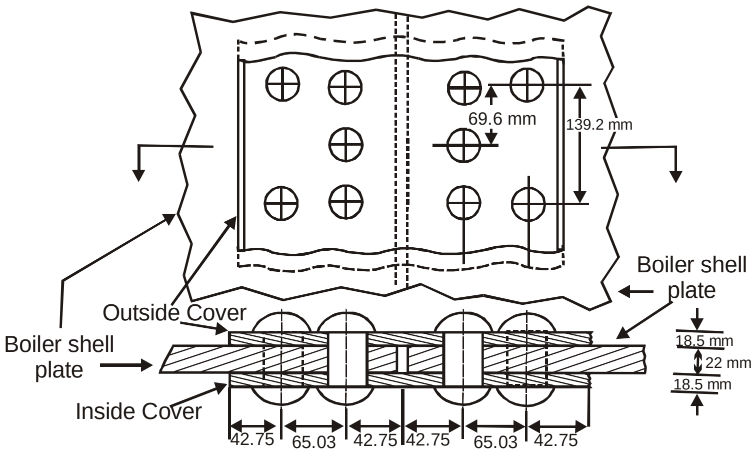


Figure 3.21

(f) Follow the method of Examples 3.1 and 3.2 of Section 3.15. The CG of rivets group is the middle one. $R_{\max}$ = 160 mm.

The primary shearing stress $\tau_1 = \dfrac{40}{A}$ kN/mm^2 acting horicontally to left.

The moment 40 × 250 = 10,000 kN mm will cause secondary shearing stress $\tau_2 = k\ R_2 = 160 k$.

There are two forces on two extreme rivets and two others on middle two Equating moments

$$(2k\ R_2^2 + 2k\ R_1^2)\ A = 10{,}000 \text{ kN mm},\ R_1 = 80 \text{ mm},\ R_2 = 160 \text{ mm}$$

$$k\ (160^2 + 80^2)\ A = 5000$$

$$k = \frac{5000}{32000 A} = \frac{0.15625}{A}$$

$$\tau_2 = \frac{0.15625 \times 160}{A} = \frac{25}{5A} \text{ kN/mm}^2$$

Resultant stress $\tau = \tau_1 + \tau_2$

$$= \frac{5 + 40}{A} \text{ kN/mm}^2$$

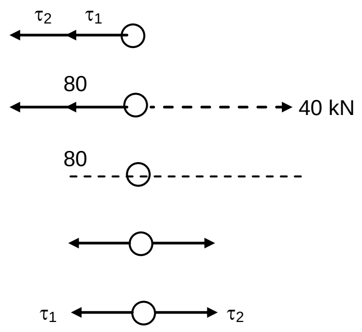


Figure 3.22

$$\therefore \qquad = \frac{45 \times 10^3}{A} = 65$$

$$A = 692 \text{ mm}^2 = \frac{\pi}{4} d^2$$

d = 29.7 mm

(g) Follow the same procedure as in SAQ 5.

The primary shear force acts at CG, which is obviously at the centre of rivet group r_1, r_3 and r_2 r_4 are equal. With $F = k\, r$

$$F_1 r_1 + F_2 r_2 + F_3 r_3 + F_4 r_4 = 12 \times 10^3\ (150 + 75) = 27 \times 10^5 \text{ Nmm}$$

$$2k\ (r_1^2 + r_2^2) = 2k\ [(75)^2 + (100)^2] = 27 \times 10^5$$

$$1250k = 27 \times 10^5 \quad k = 2160$$

$$\therefore \quad F_1 = 2160 \times 75 = 162 \text{ kN}$$

$$F = \frac{12}{4} = 3 \text{ kN}$$

At rivet 1 shearing force $= 162 + 3 = 165$ kN

$$F_4 = 2160 \times 100 = 216 \text{ kN}$$

A rivet 4, shearing force $= \sqrt{F_4^2 + F^2} = \sqrt{216^2 + 3^2} = 216.02$ kN

At rivet 2 and 4 the shearing force is maximum.

$$A = \frac{\pi}{4} d^2 = \frac{216.02}{65} 10^3 = 3323.4$$

$\therefore$ d = 65.1 mm.

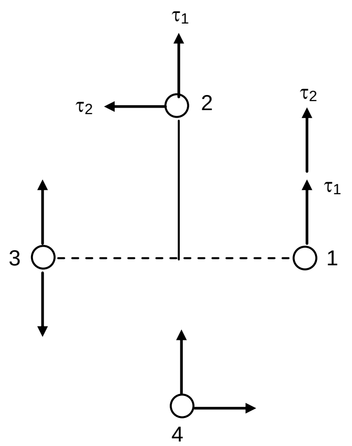


Figure 3.23