

## RIVETED AND WELDED JOINTS

### **Riveted Joints**

Riveting consists of inserting a pin made of ductile material (called rivet) with or without head in the holes drilled in two or more plates (to secure them) and forming heads so that the plates are held together firmly.

Riveting is a permanent type of joint and hence it is possible to dismantle the joint only by breaking the rivet heads. Rivets are driven both in hot and cold state.

*Figure-7.1*

In *hot riveting*, the rivet is heated to *high temperature* and then quickly inserted through the holes formed in the plates to be joined and second head is formed using a die. This method of riveting finds applications for large rivets of structural joints.

In *cold riveting*, as the name indicates, the riveting is done at *room temperature*. This is generally applicable to riveting done using small rivets of *soft metals such as aluminum, brass, etc.*,

*Table -1: Rivet and rivet hole diameter ( $d$ ,  $d_h$ )*

Rivet holes punched or drilled in the plates to assembled should be slightly larger than the diameter of the rivet. Standard values of rivet diameter  $d$  and the corresponding hole diameter  $d_h$  are given in table-1. The holes in the plates to be riveted are made by *drilling* or *punching*. The holes drilled in the plates are usually drilled about 1 mm lesser in diameter than the diameter of hole  $d$  required and the drilled holes are further reamed to the required size  $d_h$ .

### **Classification of Riveted joint**

Riveted joints are broadly classified into two types namely

- i) *Lap Joint.*
- ii) *Butt Joint.*

In a *lap joint*, the plates to be riveted are *overlapped* one over the other and riveting is done using one, two or three rows of rivets depending on the load the joint has to withstand. A

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*double riveted lap joints* will have *two rows* of rivets where as a *triple riveted joint* has *three rows of rivets* and so on. While designating a riveted joint as single, double, etc, the total rows of rivets used on each of overlapped plates is considered in case of lap joints.

In the arrangement of rivets, the arrangement could be *chain* or *zig-zag riveting*.

In the *zig-zag* arrangement, the longitudinal pitch of rivets may be same in all rows or different such as *pitch in the outer row twice that in the inner row, etc.*,

In *butt joints*, the plates to be riveted are placed end to end (butt together) and riveting is done using one, two or three rows of rivets on each plate. In single riveted butt joint, only one row of rivets is used on each plate. Similarly two rows of rivets are used on each plate in a double riveted butt joint and so on.

Butt joints are made using *single cover plate* or *double cover plates* of *equal width* or *unequal width*.

### **Shear Failure of Rivets (Refer figure-7.2 and 7.3)**

The rivets are said to fail by *single shear* or *double shear* depending on the *number of area of cross section resisting shear force*.

*It is to be noted that the rivets in lap joints and butt joints with single cover plates irrespective of the arrangement of rivets fail by single shear only and no rivet fails by double shear.* The number of rivets failing by single shear in lap joints are determined by counting the total number of rivets present in *one pitch length* of rivets along width of plate.

*In case of Butt joints having single cover plate, the number of rivets failing by single shear* is obtained by considering *one pitch length* along the width on any *one plate*.

**Figure-7.2**

In *Butt joints* using *double cover plates (or butt straps)* of equal width, irrespective of arrangement of rivets (chain or zig-zag), the rivets in the joint undergo *double shear* and no rivet fails by *single shear*. The number of rivets failing by double shear is determined by considering one pitch length of rivets along the width on any one plate.

**Figure-7.3**

In *Butt joints* using *cover plates of unequal width*, some rows (usually one row) fail by *single shear* and the remaining rows by double shear as shown in figure-7.4.

**Figure-7.4: Double riveted butt joint with double cover plates of unequal widths  $b_1$  and  $b_2$ .**

**Figure-7.5: Double riveted butt joint with double cover plates of equal width with rivets under both single and double shear.**

**Important Note:** It is assumed that the rivets failing by double shear in butt joints are twice stronger than the rivets of same diameter failing by single shear. But in actual practice they are only 1.875 times stronger than rivets failing by single shear.

### **Efficiency of Riveted Joint**

The following three efficiencies are calculated for each joint

- 1) The efficiency of plate ( $\eta_p$ )
- 2) The efficiency of rivets ( $\eta_r$ )
- 3) The efficiency in crushing ( $\eta_c$ )

The least of the above three efficiencies is the efficiency of joint.

### **Mode of failure of Riveted Joint**

- i) if  $\eta_p$  is the least efficiency, then the joint fails by the tearing of the plate and we term the mode of failure as tearing of plate.
- ii) If  $\eta_r$  is the least efficiency, then the mode of failure is by shearing of rivets.
- iii) If  $\eta_c$  is the least efficiency, then the mode of failure is by crushing of plates or rivets.

### **Lap Joints**

- a) **Single riveted lap joint (refer figure-7.5)**

Figure-7.5

#### **Proportions of single riveted lap joint**

If,  $h =$  Plate thickness, then diameter of rivet ' $d$ ' is given by

$$d = 0.19\sqrt{h} \text{ to } 0.2\sqrt{h} \quad \dots \text{T(13-14)}$$

Where,  $d$  and  $h$  are in meter

$$p = \text{Longitudinal pitch} \\ = 1.31h + 40$$

Where,  $p$  and  $h$  are in mm

$$m = \text{Margin} = 1.5d$$

$$\text{Length of overlap} = m + m = 2m = 3d$$

In a single riveted lap joint, the plates to be riveted are overlapped one over the other

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and riveting is done using *single row* of rivets as shown in figure-7.5

While carrying out the riveting operation, it is necessary to maintain the distance between rivets called *longitudinal pitch* 'p' equal to  $(1.31h + 40)$  where 'p' and 'h' are in mm. the *minimum distance between the centre of rivets and the edges of plate called margin* 'm' is to be  $1.5d$ , where 'd' is diameter of rivet so that no tearing of plate occurs between the rivet hole and the edge of the plate. The *length of overlap (or overlap)* is taken as  $3d$ .

### b) *Double riveted lap joint with chain riveting (refer figure-7.6)*

Figure-7.6

#### *Proportions of double riveted lap joint*

If 'h' is the thickness of plates to be joined, then the diameter

$$d = 0.19\sqrt{h} \text{ to } 0.2\sqrt{h} \quad \dots \text{T(13-14)}$$

Where,  $d$  and  $h$  are in meter

$$p = \text{Longitudinal pitch} \\ = 2.62h + 40$$

Where,  $p$  and  $h$  are in mm

$$p_t = \text{Transverse pitch (or row pitch)} \\ = 2d$$

$$m = \text{Margin} = 1.5d$$

$$\text{Overlap} = p_t + 2m \\ = 2d + 2(1.5d) = 5d$$

In a *double riveted lap joint*, using chain riveting, the plates to be joined by riveting are overlapped one over the other and the joint is made by using two rows of rivets. In this joint, the distance between rivets in each row called longitudinal pitch 'p' is to be  $(2.62h + 40)$  where 'p' and 'h' are in mm. The distance between the rows (first and second row or second and third row) of rivets called *transverse pitch*  $p_t$  or *row pitch* and is to be maintained at  $2d$  i.e.,  $p_t = 2d$ .

### c) *Double riveted lap joint with zig-zag riveting (refer figure-7.7)*

Figure-7.7

If 'h' is the thickness of plate, then

$$d = 0.19\sqrt{h} \text{ to } 0.2\sqrt{h} \quad \dots \text{T(13-14)}$$

Where,  $d$  and  $h$  are in meter

$$p = \text{Longitudinal pitch} \\ = 2.62h + 40$$

Where,  $p$  and  $h$  are in mm

$$p_t = \text{Transverse pitch (or row pitch)} \\ = 0.33p + 0.67d$$

$$m = \text{Margin} = 1.5d$$

$$h = \text{Plate thickness}$$

$$\text{Overlap} = p_t + 2m$$

In a *double riveted lap joint using zig-zag riveting*, the plates to be joined are overlapped one over the other using two rows of rivets, keeping the distance between rows of rivets ( $p_t$ ) equal to  $(0.33p + 0.67d)$ . The distance between rivets in each row i.e., 'p' is taken as  $(2.62h + 40)$ , and margin  $m = 1.5d$ .

**Note:**

- 1) *The lap joints are designated as single riveted, double riveted etc., depending on the total number of rows of rivets used in the joint. A single riveted lap joint has one row of rivets used in the joint. A double riveted joint will have two rows and so on.*
- 2) *It is a convention in section of solids that machine elements such as rivets, nuts, bolts, gib, cotters, etc., used in mechanical joint are not shown sectioned. Hence, in the above joint even though rivet in the first row is cut by the section plane S-S, it is not shown hatched in the sectional front view.*

### **Butt Joint (with single strap)**

Figure-7.8

- a) *Single riveted butt joint with single cover plate (refer figure-7.8)*

If  $h = \text{Plate thickness,}$

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Then  $Diameter\ of\ rivet\ d = 0.19\sqrt{b}\ to\ 0.2\sqrt{h}$

Where,  $d\ and\ h\ are\ in\ meter$

$$p = 1.53h + 40$$

Where,  $p\ and\ h\ are\ in\ mm$

$$h_1 = 1.125h$$

$$m = Margin = 1.5d$$

In a *single riveted butt joint using single cover plate*, the plates to be riveted are placed with their *ends touching each other* and riveting is made using *one row of rivet on each plate*. The longitudinal pitch of rivets ' $p$ ' is to be  $(1.53h + 40)$  where ' $p$ ' and ' $h$ ' are in mm and margin  $m = 1.5d$ .

**Example 7.1: Design a single riveted butt joint with single cover plate for plates of 16mm thickness.**

$$h = 16mm$$

$$d = 0.2\sqrt{h}$$

$$= 0.2\sqrt{\frac{16}{1000}} = 0.025m = 26mm$$

$$p = 1.53h + 40$$

$$= 1.53 \times 16 + 40 = 64.48 = 65mm$$

$$m = 1.5d$$

$$= 1.5 \times 26 = 39mm$$

*Thickness of cover plate*

$$h_1 = 1.125h$$

$$= 1.125 \times 16 = 18mm$$

*Diameter of rivet head*

$$= 1.6d$$

$$= 1.6 \times 26 = 41.6mm$$

*Height of rivet*

$$= 0.7d$$

$$= 0.7 \times 26 = 18.2mm$$

**b) Double Riveted Butt Joint (using single strap) with chain riveting (refer figure-**

7.9)

Figure-7.9

If  $h = \text{Plate thickness,}$  $h_1 = \text{Thickness of cover plate (butt strap)}$ 

$$= 1.125h$$

Diameter of rivet,

$$d = 0.19\sqrt{b} \text{ to } 0.2\sqrt{h} \quad \dots \text{T(13-14)}$$

Where,

 $d \text{ and } h \text{ are in meter}$ 

$$p = 3.06h + 40$$

Where,

 $p \text{ and } h \text{ are in mm}$ 

$$p_t = 2d$$

$$m = \text{Margin} = 1.5d$$

In a *double riveted butt joint* using *single cover plate* and *chain riveting*, the plates to be riveted are brought together *end to end* and riveting is done using a single cover plate as shown in figure-7.9.

**Note:** A butt joint is designated as *single riveted*, *double riveted* or *triple riveted*, etc., depending on the number of rows of rivets on each plate to be joined. Hence a *double riveted joint* will have two rows of rivets on each plate, at *triple riveted joint* will have three rows of rivets on each plate and so on.

The distance between rivets in each row is called *longitudinal pitch*  $p$  and is  $(3.06h + 40)$  and the distance between rows of rivets called *row pitch* or *transverse pitch*  $p_t = 2d$  and *Margin*  $m = 1.5d$ .

c) **Double Riveted Butt Joint (using single strap) with zig-zag riveting (refer figure-7.10)**

Figure-7.10

If  $h = \text{Thickness of plates to be joined}$  $h_1 = \text{Thickness of cover plate (butt strap)}$

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$$= 1.125h$$

Then, diameter of rivet,

$$d = 0.19\sqrt{b} \text{ to } 0.2\sqrt{h} \quad \dots \text{T(13-14)}$$

Where,  $d$  and  $h$  are in meter

$$p = 3.06h + 40$$

Where,  $p$  and  $h$  are in mm

$$p_t = 0.33p + 0.67d$$

Where,  $p_t$  and  $d$  are in mm

$$m = \text{Margin} = 1.5d$$

In a double riveted butt joint using single cover plate and having zig-zag arrangement of rivets, two rows of rivets are used on each plate keeping the distance between rivets in each row i.e., ( $p = 3.06h + 40$ ) and distance between rows of rivets  $p_t$  (transverse pitch) ( $p_t = 0.33p + 0.67d$ ), Margin  $m = 1.5d$  is provided. Refer figure-7.10.

### ***Design procedure of riveted joints***

The following procedure is followed while designing a riveted joint.

#### ***Step I: Selection of type of joint (refer table 13-14)***

Select suitable joint such as double riveted lap joint with chain or zig-zag riveting, triple riveted butt joint with cover plates of equal or unequal width depending on the requirement.

#### ***Step II: Calculation of diameter of rivet, $d$***

The diameter of rivet ' $d$ ' depends on ' $h$ ', the plate thickness.

i) If  $h > 8\text{mm}$ , use  $d = 0.2\sqrt{h}$  where ' $d$ ' and ' $h$ ' are in meter.

ii) If  $h < 8\text{mm}$ , equate  $F_t$  and  $F_c$  for the joint under consideration to obtain ' $d$ '.

The value of ' $d$ ' obtained above is rounded off to the standard size by referring table (13-2). Also the rivet hole diameter  $d_h$  to be drilled in the plates is noted down.

#### ***Step III: Calculation of pitch ( $p, p_t, p_d$ ), margin $m$ , and cover plate thickness***

$$h_c (h_1 \text{ or } h_2)$$

a) ***Longitudinal pitch  $p$***

'p' is calculated for lap and butt joints by equating  $F_\tau$  and  $F'_\theta$

Where,  $F_\tau =$  Shear resistance of rivets.

$F'_\theta =$  Tearing resistance of perforated plate.

**b) Transverse pitch ( $p_t$  or row pitch)**

Transverse pitch is obtained from table (13-14).

**c) Diagonal pitch ( $p_d$ )**

Diagonal pitch for zig-zag riveted joints is obtained from

$$p_d = \frac{2p + d}{3} \quad \dots \text{E(13-13)}$$

**d) Cover plate thickness ( $h_1$  and  $h_2$ )**

For butt joints with single cover plate

$$h_1 = 1.125h \quad \dots \text{E(13-15)}$$

For butt joint with double cover plates of unequal width,

Thickness of narrow strap,  $h_1 = 0.625h$  ... E(13-17a)

Thickness of wide strap,  $h_2 = 0.75h$  ... E(13-17b)

**e) Margin ( $m$ )**

**Note:** For all riveted joints (Lap or Butt) irrespective of arrangement of rivets, use  $m = 1.5d$ .

**Step IV: Calculation of efficiency of joint  $\eta$**

a) Efficiency of plate  $\eta_p = \frac{p-d}{p}$  ... E(13-27)

b) Efficiency of rivets  $\eta_r = (i_1 + i_2 \times 1.875) \frac{\pi d^2 \tau}{4ph\sigma_\theta}$

Where,  $i_1 =$  Number of rivets in single shear.

$i_2 =$  Number of rivets in double shear.

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**Note:**

- i) *The rivets in lap joints and butt joints with single cover plate fail by single shear only and no rivet fails by double shear i.e.,  $i_2 = 0$*
- ii) *The rivets in butt joint with double cover plates of equal width, fail by double shear only and no rivet fails by single shear i.e.,  $i_1 = 0$*
- iii) *In butt joints with double cover plates of unequal width, depending on arrangement of rivets, few rows of (usually one row) rivets fail by single shear and the remaining by double shear.*

c) **Efficiency in crushing**  $\eta_c = \frac{F_c}{F_\theta}$

Where,  $F_c =$  Resistance offered by plate to crushing  
 $= (i_2 h + i_1 h_2) d \sigma_c$  ... E(13-23)

$F_\theta =$  Strength of solid plate  
 $= ph \sigma_\theta$  ... E(13-20)

The least of the above efficiencies is the efficiency of the joint.

### Mode of failures

- i) If  $\eta_p$  is least, the mode of failure is by tearing of plate.
- ii) If  $\eta_r$  is least, the mode of failure is by shearing of rivets.
- iii) If  $\eta_c$  is least, the mode of failure is by crushing of plates on rivets.

**Example 7.2:** Design a double riveted lap joint with chain riveting for mild steel plates 20mm thick using the allowable values of stresses in shear, tension and compression equal to 60, 90 and 120MPa respectively. (VTU-Dec08/Jan09)

**Solution:**

**Step I: Selection of type of joint (refer table 13-14)**

Select type-b joint (i.e., double riveted lap joint with chain riveting) [From machine design data handbook] ... T(13-14)

Figure-7.11

**Step II: Calculation of diameter of rivet 'd'**

The diameter of rivet depends on plate thickness 'h'

**Note:** When  $h \geq 8mm$ , use  $d = 0.19\sqrt{h}$  to  $0.5\sqrt{h}$  ... T(13-14)

Where, 'd' and 'h' are in meter.

Here,  $h = 20mm > 8mm$

Therefore,  $d = 0.2\sqrt{h}$  (maximum value)

$$= 0.2\sqrt{\frac{20}{1000}} \text{meter} = 0.02828m$$

i.e.,  $d = 28.28mm$

Refer table (13-2) for standard rivet diameter. Therefore, adopt  $d = 30mm$  (standard value), and the corresponding hole diameter  $d_h = 31.5mm$

**Step III: Calculation of pitch (longitudinal pitch p, transverse pitch p), and margin m.**  
**i) Longitudinal pitch 'p'**

**Note:** The longitudinal pitch is obtained by equating the shear resistance of rivets to tearing resistance of perforated plate.

Shearing resistance of rivets =  $F_\tau$

Tearing resistance of plates =  $F_\theta$

**Note:**  $F_\tau$  is obtained for the joint under study by deleting the quantity  $ph\sigma_\theta$  from the equation of  $\eta_r$ , from table (13-14)

From table (13-14), for double riveted lap joint with chain riveting

$$\eta_r = \frac{2\pi d^2}{4} \frac{\tau}{ph\sigma_\theta}$$

Deleting  $ph\sigma_\theta$  from  $\eta_r$ , we get

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

$$\left[ \text{Reason: } \eta_r = \frac{F_\tau}{F_\theta} = \frac{\frac{2\pi d^2}{4} \times \tau}{ph\sigma_\theta} \text{ i.e., } F_\tau = \frac{2\pi d^2 \tau}{4} \right]$$

**Note:**  $F_{\tau}$  can also be obtained from equation

$$F_{\tau} = (2i_2 + i_1) \frac{\pi d^2}{4} \tau \quad \dots \text{E(13-22)}$$

Where,  $i_2 = \text{Number of rivets in one pitch length under double shear} = 0$   
 $i_1 = \text{Number of rivets in single shear in one pitch length}$

**Double riveted lap joint with chain riveting**

*Figure-7.12*

In this joint, there are four half rivets in one pitch length 'p' under single shear

Therefore,  $i_1 = 4 \left( \frac{1}{2} \right) = 2 \text{ rivets}$

i.e.,  $F_{\tau} = 2 \frac{\pi d^2}{4} \tau$

$$\begin{aligned} F'_0 &= \text{Strength of perforated plate} \\ &= (p - d) h \sigma_{\theta} \end{aligned} \quad \dots \text{E(13-21)}$$

Equating  $F_{\tau}$  and  $F'_0$

$$2 \frac{\pi d^2}{4} \tau = (p - d) h \sigma_{\theta}$$

Where,  $d = 30\text{mm}$   
 $\tau = \text{Shear stress} = 60\text{MPa}$   
 $h = \text{Plate thickness} = 20\text{mm}$   
 $\sigma_{\theta} = \text{Tensile stress} = 90\text{MPa}$

i.e.,  $\frac{2\pi(30)^2}{4} \times 60 = (p - 30)(20)(90)$

i.e.,  $p = 77.12\text{mm}$

**ii) Transverse pitch ( $p_{\tau}$ ) [Also called row pitch i.e., distance between two adjacent rows of rivets]**

For type *b* joint,  $p_t = 2d$  ... T(13-14)  
 $= 2 \times 30 = 60\text{mm}$

iii) **Margin**  $m = 1.5d$  ... T(13-14)  
 $= 1.5 \times 30 = 45\text{mm}$

**Step IV: Calculation of efficiency of joint ( $\eta$ )**

**Note:** Calculate the values of efficiency upto 4 decimal places for correct prediction of mode of failure.

a) **Efficiency of plate,**  $\eta_p = \frac{p-d}{p}$   
 $= \frac{77.17 - 30}{77.12}$   
 $= 0.61099 = 61.099\%$

b) **Efficiency of rivets,**  $\eta_r = \frac{2\pi d^2 \tau}{4ph\sigma_\theta}$   
 $= \frac{2\pi (30)^2 \times 60}{4 \times 77.12 \times 20 \times 90}$   
 $= 0.061105 = 61.105\%$

c) **Crushing efficiency**  $\eta_c = \frac{F_c}{F_\theta}$

Where,  $F_c = \text{Resistance to crushing}$   
 $= (i_2 h + i_1 h_2) d \sigma_c$  ... E(13-23)

Where,  $i_2 = 0$  for lap joints  
 $i_1 = 2$   
 $h_2 = h$

Therefore,  $F_c = i_1 d h \sigma_c$   
 $= 2 \times 30 \times 20 \times 120$

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$$= 144000N$$

$F_{\theta}$  = Strength of solid plate

$$= ph\sigma_{\theta} \quad \dots E(13-20)$$

$$= 88.12 \times 20 \times 90$$

$$= 138816N$$

Therefore,  $\eta_c = \frac{144000}{138816} = 1.0373 = 103.73\%$

Therefore, efficiency of the joint  $\eta_p = 61.099\%$  (least of the three values of  $\eta$ ).  
The mode of failure is by tearing of plate.

**Example 7.3:** A double rivetted double cover butt joint with plates 20mm thick made with 20mm diameter rivets at 110mm pitch, the permissible stresses are  $\sigma_t = 120MPa$ ,  $\tau = 100MPa$  and  $\sigma_c = 150MPa$ . Find the efficiency of joint taking strength of rivet in double shear is twice than that of single shear. (VTU-Jan/Feb 2006)

**Solution:**

a) Efficiency of plate  $\eta_p = \frac{p-d}{p}$

$$= \frac{110-25}{110} = 0.7727 = 77.27\%$$

b) Efficiency of rivets  $\eta_r = \frac{3.75\pi d^2 \tau}{4ph\sigma_{\theta}}$

$$= \frac{3.75\pi (25^2) \times 100}{110 \times 20 \times 120} = 0.6937 = 69.73\%$$

c) Efficiency in crushing  $\eta_c = \frac{F_c}{F_{\theta}}$

$$= \frac{(i_2 h + i_1 h_2) d \sigma_c}{ph\sigma_{\theta}}$$

**Note:** For a double rivetted butt joint with double cover plates of equal width,  $i_2 = 2$

and  $i_1 = 0$

$$\begin{aligned} \text{Therefore, } \eta_c &= \frac{(2 \times 20 + 0) 25 \times 150}{110 \times 20 \times 120} \\ &= 0.5682 = 56.82\% \end{aligned}$$

Efficiency of Joint = 56.82% (Least of the three values of  $\eta$ ). The mode of failure is by crushing of plates or rivets.

**Example 7.3:** Design triple riveted lap joint with zig-zag riveting for steel plates 20mm thick using tensile stress  $\sigma_t = 90 \text{ N/mm}^2$ , compressive stress  $\sigma_c = 120 \text{ N/mm}^2$  and shear stress  $\tau = 60 \text{ N/mm}^2$ .

**Solution:**

**Step I: Selection of Type of joint**

... T(13-14)

Select type e-joint (Triple riveted tap joint with zig-zag riveting)

Figure-7.13

**Step II: Calculation of diameter of rivet (d)**

The diameter of rivet, d depends on h, the plate thickness.

Here,  $h = 20\text{mm} > 8\text{mm}$

Therefore, use  $d = 0.2\sqrt{h}$  where 'd' and 'h' are in meter. ... T(13-14)

$$\begin{aligned} &= 0.2\sqrt{\frac{20}{1000}} \\ &= 0.02828\text{m} = 28.28\text{mm} \end{aligned}$$

Adopt  $d = 30\text{mm}$  (standard diameter) and the corresponding diameter of hole  $d_h = 31.5\text{mm}$  ... T(13-2)

**Step III: Calculation of pitch (longitudinal pitch 'p', transverse pitch  $p_t$  and diagonal pitch  $p_d$ ), and margin m.**

a) **Longitudinal pitch (p)**

'p' is obtained by equating  $F_\tau$  and  $F'_\theta$

For the selected joint i.e., type "e" joint

$$F_r = \frac{3\pi d^2 \tau}{4}$$

[Obtained from T(13-14) from the equation  $\eta_r$  by deleting  $ph\sigma_\theta$  from the equation of  $\eta_r$ ]

$$F'_\theta = (p-d)\sigma_\theta \quad \dots \text{E(13-21)}$$

Therefore, 
$$\frac{3\pi d^2}{4} \tau = (p-d)h\sigma_\theta$$

$$\frac{3\pi}{4}(30)^2 \times 60 = (p-30)20 \times 90$$

Therefore, *longitudinal pitch*  $p = 100.68\text{mm}$

**b) Transverse pitch ( $p_t$ )**

For the selected joint,

$$\begin{aligned} p_t &= 0.33p + 0.67d && \dots \text{T(13-14)} \\ &= 0.33 \times 100.68 + 0.67 \times 30 \\ &= 53.32\text{mm} \end{aligned}$$

**c) Diagonal pitch ( $p_d$ )**

$$\begin{aligned} p_d &= \frac{29+d}{3} && \dots \text{E(13-3)} \\ &= \frac{2 \times 100.68 + 30}{3} = 77.12\text{mm} \end{aligned}$$

**d) Margin (m)**

$$\begin{aligned} m &= 1.5d \\ &= 1.5 \times 30 = 45\text{mm} \end{aligned}$$

**Step IV: Efficiency of joint ( $\eta$ )**

a) *Efficiency of plate*  $\eta_p = \frac{p-d}{p}$

$$= \frac{100.68 - 30}{100.68}$$

$$= 0.70203 = 70.203\%$$

b) Efficiency of rivets  $\eta_r = \frac{3\pi d^2 \tau}{4ph\sigma_\theta}$

$$= \frac{3\pi (30)^2 \times 60}{4 \times 100.68 \times 20 \times 90} = 70.208\%$$

c) Crushing efficiency  $\eta_c = \frac{F_c}{F_\theta}$

Where,  $F_c = (i_2 h + i_1 h_2) d \sigma_c$  ... E(13-23)

$i_2 = \text{Number of rivets/Pitch in double shear} = 0$

$i_1 = \text{Number of rivets under single shear} = 3$

$h_2 = h$

Figure-7.14: Triple riveted lap joint with zig-zag riveting

$$i_1 = 1 + 4\left(\frac{1}{2}\right) = 3 \text{ rivets (shown shaded)}$$

Therefore,  $F_c = i h d \sigma_c$

$$= 3 \times 20 \times 30 \times 120 = 216000 N$$

$F_\theta = p h \sigma_\theta$

$$= 100.68 \times 20 \times 90 = 181224 N$$

Therefore,  $\eta_c = \frac{216000}{181244}$

$$= 1.1919 = 119.19\%$$

Therefore, Efficiency of the joint  $\eta_p = 70.203\%$  (Least of the above three efficiencies) and the mode of failure is by tearing of plate.

**Example 7.5:** Design a triple riveted lap joint for steel plates 7mm thick with pitch in the outer row twice that in the inner row. User permissible values of tensile compressive and shear stresses as 90N/mm<sup>2</sup>, 120N/mm<sup>2</sup> and 60N/mm<sup>2</sup> respectively.

**Solution:**

**Step I: Selection of type of joint**

Select type “f” joint (i.e., triple riveted lap joint with pitch in outer row twice than in inner row) ... T(13-14 MDH)

**Figure-7.15: Triple riveted lap joint with pitch in the outer row twice that in the inner row**

Here, Pitch in outer row =  $2 \times$  Pitch in the inner row

i.e.,  $p_0 = 2p_i$

$i_2 = 0$

$i_1 = 1 + 6\left(\frac{1}{2}\right) = 4 \text{ rivets}$

**Step II: Calculation of diameter of rivet, d**

The diameter of rivet depends on h, the thickness of plates to be riveted.

Here,  $h = 7\text{mm} < 8\text{mm}$

Therefore,  $d = 0.2\sqrt{h}$  cannot be applied ... T(13-14)

Hence, equate  $F_t$  and  $F_c$  to obtain ‘d’

For the given joint,

$F_t = \frac{4\pi d^2 \tau}{4}$  ... T(13-14)

[Obtained from  $\eta_r$  for type f joint by deleting  $ph\sigma_\theta$  from it]

$F_c = (i_2 h + i_1 h_2) d \sigma_c$  ... E(13-23)

Where,  $i_2 = 0$  (for lap joints)

$i_1 = 4$

$h_2 = h = 7\text{mm}$

$d = 30\text{mm}$

$\sigma_c = 120\text{ N/mm}^2$

Therefore,  $F_c = 4 \times 7 \times 30 \times 120$   
 $= 100800\text{N}$

$$F_{\tau} = \frac{4\pi d^2}{4} \times 60$$

$$= 188.5d^2$$

$$\text{i.e., } 188.5d^2 = 100800$$

$$d = 23.13\text{mm}$$

Referring to table (13-12), select standard diameter for rivet i.e.,  $d = 24\text{mm}$  and the corresponding hole diameter  $d_h = 25\text{mm}$

**Step III: Calculation of pitch (pitch in the outer row  $p_0 = p$ , transverse pitch  $p_t$ ) and margin  $m$ .**

a) **Longitudinal pitch ( $p$ )**

' $p$ ' is obtained by equating  $F_{\tau}$  and  $F_{\theta}'$

$$\text{i.e., } \frac{4\pi d^2 \tau}{4} = (p - d)h\sigma_{\theta}$$

$$\pi (24)^2 \times 60 = (p - 24)7 \times 90$$

$$p = 196.34\text{mm} = p_0 = \text{Pitch in the outer row}$$

Therefore, Pitch in the inner row

$$p_i = \frac{p_0}{2}$$

$$= \frac{196.34}{2} = 98.17\text{mm}$$

b) **Transverse pitch ( $p_t$ )**

$$p_t = (0.33p + 0.67d) \text{ or } 2d \text{ whichever is greater}$$

$$\text{Now, } 0.33p + 0.67d = 0.33 \times 196.34 + 0.67 \times 24$$

$$= 80.87\text{mm}$$

$$\text{and } 2d = 2 \times 24 = 48\text{mm}$$

Therefore, adopt  $p_t = 80.87\text{mm}$  (greater value)

c) **Margin ' $m$ '**

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$$\begin{aligned}m &= 1.5d \\ &= 1.5 \times 24 = 36\text{mm}\end{aligned}$$

**Step IV: To calculate the efficiency of joint ( $\eta$ )**

a) Efficiency of plate  $\eta_p = \frac{p-d}{p}$

$$\begin{aligned}&= \frac{196.34 - 24}{196.34} \\ &= 0.877763 = 87.7763\%\end{aligned}$$

b) Efficiency of rivets  $\eta_r = \frac{4\pi d^2 \tau}{4ph\sigma_\theta}$

$$\begin{aligned}&= \frac{4\pi (24)^2 \times 60}{4 \times (196.34) \times 7 \times 90} \\ &= 0.877757 = 87.7757\%\end{aligned}$$

c) Crushing efficiency  $\eta_c = \frac{F_c}{F_\theta}$

Where,  $F_c = (i_2 h + i_1 h_2) d \sigma_c$  ... E(13-23)

Here,  $i_2 = 0$

$$i_1 = 4$$

Hence,  $F_c = 4hd\sigma_c$

$$h_2 = h = 7\text{mm}$$

$$d = 24\text{mm}$$

$$\sigma_c = 120\text{ N/mm}^2$$

Therefore,  $F_c = 4 \times 7 \times 30 \times 120$

$$= 100800\text{N}$$

$$F_\theta = ph\sigma_\theta$$

$$= 196.34 \times 7 \times 90$$

$$= 123694.2\text{N}$$

$$\begin{aligned} \text{Therefore, } \eta_c &= \frac{100800}{123694.2} \\ &= 65.193\% \end{aligned}$$

Therefore, Efficiency of the joint  $\eta = 65.193\%$  (Least of the three values of efficiency). The mode of failure is by crushing of rivets or plates.

**Example 7.6:** Design a double riveted butt joint with single strap and zig-zag riveting for plates 20mm thick taking permissible values of stresses in shear, tension and compression as 60, 90 and 120MPa respectively.

**Solution:**

**Step-I: Selection of joint**

Select type “c” joint (i.e., double riveted butt joint with single strap and zig-zag riveting) ... T(13-14)

*Figure-7.16: Double riveted butt joint with zig-zag riveting (using single cover plate)*

**Step II: Calculation of diameter of rivet (d)**

Diameter of rivet ‘d’ depends on thickness of plates ‘h’ to be riveted.

Here,  $h = 20\text{mm} > 8\text{mm}$

Therefore,  $d = 0.2\sqrt{h}$  ... T(13-14)

Where,  $d$  and  $h$  are in meter

$$\begin{aligned} \text{Therefore, } d &= 0.2\sqrt{\frac{20}{1000}} \\ &= 0.02828\text{m} = 28.28\text{mm} \end{aligned}$$

Select  $d = 30\text{mm}$  (standard diameter from T(13-2)), the corresponding diameter of hole  $d_h = 31.5\text{mm}$

**Step III: Calculation of pitch (longitudinal pitch  $p$ , transverse pitch  $p_t$ ), thickness of cover plate ( $h_1$ ) and margin  $m$ .**

a) **Longitudinal pitch  $p$**

‘ $p$ ’ is obtained by equating  $F_\tau$  and  $F'_\theta$

Where,  $F_\tau =$  Resistance offered by rivets to shearing

$$= 2 \left( \frac{\pi d^2}{4} \right) \tau$$

[Obtained from table (13-14) for the joint under study by deleting  $ph\sigma_\theta$  from  $\eta_r$ ]

$$F'_\theta = (p-d)h\sigma_\theta \quad \dots \text{E(13-21)}$$

Therefore, equating  $F_\tau$  and  $F'_\theta$  we get

$$\frac{2\pi d^2}{4} \tau = (p-30)20 \times 90$$

$$\frac{2\pi (28.28)^2 \times 60}{4} = (p-30)20 \times 90$$

Therefore,  $p = 77.12\text{mm}$

**b) Transverse pitch ( $p_t$ )**

For type 'c' joint

$$\begin{aligned} p_t &= 0.33p + 0.67d && \dots \text{T(13-14)} \\ &= 0.33 \times 77.12 + 0.67 \times 30 \\ &= 45.55\text{mm} \end{aligned}$$

**c) Thickness of cover plate (butt strap)  $h_1$**

$$\begin{aligned} h_1 &= 1.125h && \dots \text{T(13-14)} \\ &= 1.125 \times 20 = 22.5\text{mm} \end{aligned}$$

**d) Margin, ( $m$ )**

$$\begin{aligned} m &= 1.5d \\ &= 1.5 \times 30 = 45\text{mm} \end{aligned}$$

**Step IV: Calculation of efficiency of joint ( $\eta$ )**

a) Efficiency of plate  $\eta_p = \frac{p-d}{p}$

$$= \frac{77.12 - 30}{77.12}$$

$$= 0.520228 = 52.0228\%$$

b) Efficiency of rivets  $\eta_r = \frac{2\pi d^2 \tau}{4ph\sigma_\theta}$

$$= \frac{2\pi(30^2) \times 60}{4 \times 77.12 \times 20 \times 90}$$

$$= 0.61105 = 61.105\%$$

c) Crushing efficiency  $\eta_c = \frac{F_c}{F_\theta}$

Where,  $F_c = (i_2 h + i_1 h_2) d \sigma_c$  ... E(13-23)

$$i_2 = 0$$

$$i_1 = 2$$

$$h_2 = h = 20\text{mm}$$

$$d = 30\text{mm}$$

$$\sigma_c = 120\text{ N/mm}^2$$

Therefore,  $F_c = (0 \times 20 + 2 \times 20) 30 \times 120$

$$= 144000\text{N}$$

$$F_\theta = ph\sigma_\theta$$

$$= 77.12 \times 20 \times 90$$

$$= 138816\text{N}$$

Therefore,  $\eta_c = \frac{1744000}{138816}$

$$= 1.0373 = 103.73\%$$

Therefore, efficiency of joint = 52.0228% (i.e.,  $\eta_p$  is the least value of efficiency) and the mode of failure is by tearing of plate.

**Example 7.7: Design a double riveted butt joint with single cover plate for steel plates 25mm thick. The pitch of rivets in the outer row is to be twice that in the inner row. The**

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*permissible values of stresses in tension, shear and compression may be taken as 90MPa, 60MPa and 120MPa respectively.*

**Solution:**

**Step I: Selection of joint**

Select type 'd' or type 'e' joint: Say type 'd' joint (i.e., double riveted butt joint with single cover plate and pitch in outer row twice that in the inner row) ... T(13-14)

$$\begin{aligned} \text{i.e., } i_1 &= 1 \text{ full rivet} + 4 \text{ number of } \frac{1}{2} \text{ rivet} \\ &= 1 + 4 \times \frac{1}{2} \\ &= 3 \text{ rivets} \end{aligned}$$

*Figure-7.17: Double riveted butt joint with single cover plate with zig-zag riveting*

**Step II: Calculation of diameter of rivet, 'd'**

'd' depends on 'h', the plate thickness.

Here,  $h = 25\text{mm} > 8\text{mm}$

Therefore,  $d = 0.2\sqrt{h}$  ... T(13-14)

Where,  $d$  and  $h$  are in meter

$$\begin{aligned} d &= 0.2\sqrt{\frac{25}{1000}}\text{m} \\ &= 0.03162\text{m} = 31.62\text{mm} \end{aligned}$$

Referring to table (13-12), adopt  $d = 33\text{mm}$  (standard diameter) and the corresponding hole diameter  $d_h = 34.5\text{mm}$

**Step III: Calculation of pitch (longitudinal pitch  $p = p_0$ , transverse pitch  $p_t$ , thickness of cover plate  $h_2$ ) and margin  $m$ .**

**a) Longitudinal pitch ( $p$ )**

Equate  $F_r$  and  $F'_0$  to obtain  $p$

For the selected type 'c' joint

$$F_{\tau} = \frac{3\pi d^2 \tau}{4} \quad \dots \text{T(13-14)}$$

$$F'_{\theta} = (p-d)h\sigma_{\theta} \quad \dots \text{E(13-21)}$$

Therefore,  $\frac{3\pi d^2 \tau}{4} = (p-d)h\sigma_{\theta}$

$$\frac{3\pi}{4} \times (33)^2 \times 60 = (p-33)25 \times 90$$

Therefore,  $p = 101.42 \text{ mm}$

**b) Transverse pitch is  $(0.33p + 0.67d)$  or  $2d$  whichever is greater**

$$p_t = 0.33 \times 101.42 + 0.67 \times 33$$

$$= 67.138 \text{ mm}$$

Now,  $2d = 2 \times 33$

$$= 66 \text{ mm}$$

Therefore, adopt  $p_t = 67.138 \text{ mm}$  (higher of two values of  $p_t$ )

**Step IV: Calculation of efficiency ( $\eta$ )**

a) Efficiency of plate  $\eta_p = \frac{p-d}{p}$

$$= \frac{101.42 - 33}{101.42}$$

$$= 0.6746 = 67.46\%$$

b) Efficiency of rivets  $\eta_r = \frac{3\pi d^2 \tau}{4ph\sigma_{\theta}}$

$$= \frac{3\pi (33)^2 \times 60}{101.42 \times 25 \times 90 \times 4}$$

$$= 0.6746 = 67.46\%$$

c) Crushing efficiency  $\eta_c = \frac{F_c}{F_{\theta}}$

$$\begin{aligned} \eta_c &= \frac{F_c}{F_\theta} = \frac{(i_2 h + i_1 h_2) d \sigma_c}{p h \sigma_\theta} \\ &= \frac{(0 + 3 \times 25) 33 \times 120}{101.42 \times 33 \times 90} \\ &= 1.1092 = 110.92\% \end{aligned}$$

Therefore, efficiency of joint = 67.46% (i.e.,  $\eta_p$  is the least value of efficiency) and the mode of failure is by tearing of plate.

**Example 7.8:** Design a double riveted butt joint to connect two plates 20mm thick. The joint is zig-zag riveted and has equal width cover plates. The allowable tensile stress for the plate is 100MPa. The allowable shear and crushing stress for the rivet material are 60MPa and 120MPa respectively. Calculate the efficiency of the joint. The joint should be leak proof. (VTU-February 2004)

**Solution:**

**Step I: Selection of type of joint**

... T(13-14)

Select type 'h' joint [i.e., double riveted butt joint with double cover plates of equal width]

Figure-7.18: Double riveted butt joint with double cover plates of equal width and zig-zag riveting

For butt joint with cover plates of equal width

$$i_1 = 0 \text{ (Because no rivet fails by single shear)}$$

$$i_2 = 1 + 2 \left( \frac{1}{2} \right)$$

$$= 2 \text{ rivets (shown filled)}$$

**Step II: Calculation of diameter of rivet, d**

'd' depends on 'h', the plate thickness

Here,  $h = 20\text{mm} > 8\text{mm}$

$$d = 0.2\sqrt{h}$$

Where, 'd' and 'h' are in meter

$$d = 0.2 \sqrt{\frac{20}{1000}} m$$

$$= 0.02828m = 28.28mm$$

Referring table (13-2) adopt  $d = 30mm$  (standard diameter) and the corresponding hole diameter  $d_h = 31.5mm$

**Step III: Calculation of pitch (longitudinal pitch 'p', transverse pitch  $p_t$ ), thickness of cover plates  $h_1, h_2$  and margin  $m$ .**

a) **Longitudinal pitch (p)**

'p' is obtained by equating  $F_\tau$  and  $F'_\theta$

For the selected joint,

$$F_\tau = 3.75 \left( \frac{\pi d^2}{4} \right) \tau$$

[Obtained from table (13-14) from the equation of  $\eta_r$  by deleting the quantity  $ph\sigma_\theta$ ]

$$F'_\theta = (p - d)h\sigma_\theta$$

Therefore,  $3.75 \frac{\pi d^2}{4} \tau = (p - d)h\sigma_\theta$

$$3.75 \frac{\pi}{4} (30)^2 \times 60 = (p - 30)20 \times 100$$

Therefore,  $p = 109.52mm$

b) **Transverse pitch ( $p_t$ )**

$$p_t = 0.33p + 0.67d \quad \dots \text{T(13-14)}$$

$$= 0.33 \times 109.52 + 0.67 \times 30$$

$$= 56.24mm$$

c) **Thickness of cover plates,  $h_1$  and  $h_2$**

$$h_1 = h_2 = 0.625h$$

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$$= 0.625 \times 20 = 12.5 \text{ mm}$$

d) **Margin 'm'**

$$\begin{aligned} m &= 1.5d \\ &= 1.5 \times 30 = 45 \text{ mm} \end{aligned}$$

**Step IV: Calculation of efficiency ( $\eta$ )**

a) **Efficiency of plates**  $\eta_p = \frac{p-d}{p}$  ... T(13-14)

$$\begin{aligned} &= \frac{109.52 - 30}{109.52} \\ &= 0.726077 = 72.6077\% \end{aligned}$$

b) **Efficiency of rivets**  $\eta_r = \frac{3.75\pi d^2 \tau}{4ph\sigma_\theta}$

$$\begin{aligned} &= \frac{3.75\pi(30)^2 \times 60}{4 \times 109.52 \times 20 \times 100} \\ &= 0.726092 = 72.6092\% \end{aligned}$$

c) **Crushing efficiency**  $\eta_c = \frac{F_c}{F_\theta}$

Where,  $F_c = (i_2 h + i_1 h_2) d \sigma_c$  ... E(13-23)

Here,  $i_2 = 2$

$$h = 20 \text{ mm}$$

$i_1 = 0$  (Since it is a butt joint with double cover plates of equal width and hence no rivet fails by single shear)

Therefore,  $F_c = (i_2 h) d \sigma_c$

$$\begin{aligned} &= 2 \times 20 \times 30 \times 120 \\ &= 144000 \text{ N} \end{aligned}$$

$$\begin{aligned} F_\theta &= ph\sigma_\theta \\ &= 109.52 \times 20 \times 100 \\ &= 219040 \text{ N} \end{aligned}$$

$$\begin{aligned}\text{Therefore, } \eta_c &= \frac{144000}{219040} \\ &= 0.657414 = 65.74\%\end{aligned}$$

Therefore, efficiency of joint = 65.74% (least of three values of efficiencies). The mode of failure is by crushing rivets on plates.

**Example 7.9:** It is required to design the longitudinal joint for a boiler of inner diameter 1.5m. The steam pressure in the boiler is 2MPa. The longitudinal joint is triple riveted double cover plates butt joint of unequal width. The pitch in the outer row is twice the pitch of rivets in the inner rows. The efficiency of joint is 82%. Assume the rivets in double shear are 1.875 times stronger than in single shear. The allowable stresses in shear and crushing of rivets are 60MPa and 120MPa respectively. Tensile stress for material of plate = 80MPa. (VTU-July/August 2002)

**Solution:**

**Step I: Calculation of  $h$ , the thickness of shell**

The thickness of shell for longitudinal joint is given by

$$h = \frac{p_f D_i}{2\eta\sigma_\theta} \quad \dots \text{E(13-1)}$$

Where,  $p_f = \text{Steam pressure} = 2\text{MPa}$

$D_i = \text{Inside diameter of shell} = 1.5\text{m} = 1500\text{mm}$

$\eta = \text{Efficiency of joint} = 82\% = 0.82$

$\sigma_\theta = \text{Tensile stress for the material of plate} = 80\text{MPa}$

$$\text{Therefore, } h = \frac{2 \times 1500}{2 \times 0.82 \times 80} = 22.87\text{mm}$$

Allowing 1mm for corrosion allowance,

$$h = 23.87\text{mm} = 24\text{mm}$$

**Step II: Calculation of rivet diameter,  $d$**

The rivet diameter ' $d$ ' depends on ' $h$ ', the thickness of shell

Here,  $h = 24\text{mm} > 8\text{mm}$

Therefore,  $d = 0.2\sqrt{h}$

Where ' $d$ ' and ' $h$ ' are in meter.

$$d = 0.2\sqrt{\frac{24}{1000}}$$

$$= 0.03098m = 30.98mm$$

Referring table (13-2), select  $d = 33mm$  and the corresponding hole diameter  $d_h = 34.5mm$

**Step III: Calculation of pitch (longitudinal pitch 'p'. transverse pitch  $p_t$ , thickness of cover plate  $h_1$  and  $h_2$  and margin  $m$ )**

*Figure-7.19: Triple riveted butt joint with double cover plates of unequal width with pitch in the outer row twice that in the inner row.*

a) **Longitudinal pitch (p)**

'p' is obtained by equation  $F_\tau$  and  $F'_\theta$

Where, 
$$F_\tau = (i_1 + i_2) \frac{\pi d^2}{4} \tau$$

Here 
$$i_1 = 1$$

And 
$$i_2 = 4 \times 1.875$$

**Note:**  $i_2$  is multiplied by 1.875, because a rivet failing by double shear is 1.875 times stronger than a rivet failing by single shear

Therefore, 
$$F_\tau = (4 \times 1.875 + 1) \frac{\pi}{4} (33)^2 \times 60$$

$$= 436202.29 N$$

$$F'_\theta = (p - d) h \sigma_\theta$$

$$= (p - 33) 24 \times 80$$

Therefore, 
$$436202.29 = (p - 33) 24 \times 80$$

i.e., 
$$p = 260.19mm$$

b) **Transverse pitch ( $p_t$ )**

**Note:** *Minimum transverse pitch*  $p_t$  according to ASME boiler code depends on  $\frac{p}{d}$ .

For the joint being analyzed,

$$\frac{p}{d} = \frac{260.19}{33} = 7.885 \text{ which is greater than } 4$$

When  $\frac{p}{d} > 4$ ,

$$p_t = 1.75d + 0.001(p - d) \quad \dots \text{ E(13-8a)}$$

Where,  $p$ ,  $p_t$  and  $d$  are in metre.

$$\begin{aligned} P_t &= 1.75 \frac{33}{1000} + 0.001 \left( \frac{260.19}{1000} - \frac{33}{1000} \right) \\ &= 0.05775 + 0.0002272 \\ &= 0.05798m \\ &= 57.98mm = 58mm \end{aligned}$$

c) **Thickness of narrow cover plate** ( $h_1$ )

$$\begin{aligned} h_1 &= 0.625h \\ &= 0.625 \times 20 = 12.5mm \end{aligned}$$

**Thickness of wider cover plate** ( $h_2$ )

$$\begin{aligned} h_2 &= 0.75h \\ &= 0.75 \times 20 = 15mm \end{aligned}$$

d) **Margin** ( $m$ )

$$\begin{aligned} m &= 1.5d \\ &= 1.5 \times 33 = 49.5mm \end{aligned}$$

**Example 7.10:** *A triple riveted butt joint with chain riveting and double cover plates of equal width is to be designed for steel plates 25mm thick. Using  $\sigma_o = 90 \text{ N/mm}^2$ ,*

*$\tau = 60 \text{ N/mm}^2$  and  $\sigma_c = 120 \text{ N/mm}^2$*

i) **Select suitable type of joint.**

ii) **Determine the standard size of rivet required and the corresponding hole diam-**

eter.

- iii) *The longitudinal pitch and row pitch.*
- iv) *Thickness of cover plates and margin.*
- v) *The efficiency of joint and mode of failure.*

**Solution:**

i) *Selection of type of joint*

*Select type 'j' joint (Triple riveted butt joint with double cover plates of equal width using chain riveting)*

*Figure-7.20: Triple riveted butt joint with double cover plates of equal width (chain riveting)*

Therefore,  $i_1 = 0$

$$i_2 = 6 \left( \frac{1}{2} \right) = 3 \text{ rivets}$$

ii) *To calculate the diameter of rivet and hole diameter ( $d, d_h$ )*

The diameter of rivet depends on 'h', the plate thickness

Here,  $h = 25\text{mm} > 8\text{mm}$

Therefore,  $d = 0.2\sqrt{h}$

Where ' $d$ ' and ' $h$ ' are in meter

$$\begin{aligned} d &= 0.2 \sqrt{\frac{25}{1000}} \text{ m} \\ &= 0.03162\text{m} = 31.62\text{mm} \end{aligned}$$

Referring to table (13-2), select  $d = 33\text{mm}$  and the corresponding hole diameter  $d_h = 34.5\text{mm}$

iii) *To calculate longitudinal pitch ( $p$ ) and row pitch ( $p_r$  or  $p_t$ )*

a) *Longitudinal pitch ( $p$ )*

' $p$ ' is obtained by equating  $F_\tau$  and  $F'_\theta$

Where  $F_\tau = (i_2 + i_1) \frac{\pi d^2}{4} \tau$

$$F'_\theta = (p - d) h \sigma_\theta$$

$$(1.875 \times 3 + 0) \frac{\pi}{4} (33)^2 \times 60 = (p - 33) 25 \times 90$$

Therefore,  $p = 161.3 \text{ mm}$

**b) Transverse pitch or row pitch ( $p_t$ )**

$$\begin{aligned} p_t &= 2d && \dots \text{T(13-14)} \\ &= 2 \times 33 = 66 \text{ mm} \end{aligned}$$

**iv) Thickness of cover plates ( $h_c$ ) and margin  $m$**

For butt joint with cover plates of equal width

$$\begin{aligned} h_c = h_1 = h_2 &= 0.625h && \dots \text{T(13-14)} \\ &= 0.625 \times 25 = 15.625 \text{ mm} \end{aligned}$$

**Margin  $m$**

$$\begin{aligned} m &= 1.5d \\ &= 1.5 \times 33 = 49.5 \text{ mm} \end{aligned}$$

**v) Calculation of efficiency ( $\eta$ )**

**a) Plate efficiency**  $\eta_p = \frac{p-d}{p}$

$$= \frac{161.3 - 33}{161.3} = 0.794512$$

**b) Efficiency of rivets**  $\eta_r = \frac{4.625\pi d^2 \tau}{4ph\sigma_\theta}$

$$\begin{aligned} &= \frac{5.625\pi \times 33^2 \times 60}{4 \times 161.3 \times 25 \times 90} \\ &= 0.79538 = 79.538\% \end{aligned}$$

**c) Efficiency in crushing**  $\eta_c = \frac{F_c}{F_\theta}$

Where,  $F_c = (i_2 h + i_1 h_2) d \sigma_c$  ... E(13-23)

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$$i_2 = 3$$

$$i_1 = 0$$

$$h = 25\text{mm}$$

$$h_2 = 15.625\text{mm}$$

$$d = 33\text{mm} \text{ and}$$

$$\sigma_c = 120\text{ N/mm}^2$$

$$\begin{aligned} \text{i.e., } F_c &= (3 \times 25 + 0) 33 \times 120 \\ &= 297000\text{N} \end{aligned}$$

$$F_\theta = ph\sigma_\theta$$

$$161.3 \times 25 \times 90 = 362925\text{N}$$

$$\text{Therefore, } \eta_c = \frac{297000}{362625}$$

$$= 0.8184 = 81.84\%$$

Therefore, efficiency of joint = 79.538% (least of the three values of  $\eta$ ) and the mode of failure is by shearing of rivets.

**Example 7.11:** Design the longitudinal and circumferential riveted joint for a boiler of diameter 2M taking the permissible pressure as 25MPa. Assume the tensile shear and compressive stresses for the material of shell and rivets as 90MPa, 60MPa and 120MPa respectively.

**Solution:**

Design of riveted joint for a boiler includes design of

- a) Longitudinal and
- b) Circumferential joint.

**a) Design of longitudinal joint**

**Note:** The longitudinal joint is a butt joint, double or triple riveted with double cover plates of unequal width depending on the diameter of shell.

The thickness of the shell for the longitudinal joint is calculated using the formula

$$h = \frac{p_f D_i}{2\eta\sigma_\theta} \quad \dots \text{E(13-1)}$$

Where  $h = \text{Thickness of shell of boiler in mm}$   
 $p_f = \text{Pressure of steam in shell} = 2.5\text{MPa}$   
 $D_i = \text{Inside diameter of shell} = 2.0\text{ meter} = 2000\text{mm}$   
 $\sigma_\theta = \text{Tensile stress of material of shell} = 90\text{MPa}$   
 $\eta = \text{Efficiency of joint}$

**To find  $\eta$ , the efficiency (refer table (13-5) and table (13-4))**

Referring to table (13-5), for diameter of shell  $D_1 = 2000\text{mm}$ , the type of joint suggested is triple riveted butt joint.

Now referring table (13-4), for triple riveted butt joint,  
 The efficiency range is 80-88%

Say  $\eta = 84\% = 0.84$

Therefore, 
$$h = \frac{2.5 \times 2000}{2 \times 0.84 \times 90.0}$$

$$= 33.068\text{mm}$$

Providing allowance for *corrosion*, adopt  $h = 35\text{mm}$ .

**Calculation of diameter of rivet ‘d’**

Diameter of rivet ‘d’ depends on plate thickness ‘h’

Here,  $h = 35\text{mm} > 8\text{mm}$

Therefore,  $d = 0.2\sqrt{h}$

Where  $d$  and  $h$  are in meter

$$d = 0.2\sqrt{\frac{35}{1000}}$$

$$= 0.0374\text{m} = 37.4\text{mm}$$

Referring to table (13-2), select *standard diameter*  $d = 39\text{mm}$ . The corresponding *hole diameter*  $d_h = 41\text{mm}$

**Selection of Joint**

Select ‘r’ joint (triple riveted butt joint with double cover plates of unequal width)

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Figure-7.21: Triple riveted butt joint with double cover plates of unequal width (chain riveting)

In one pitch length,

$$i_1 = \frac{1}{2} + \frac{1}{2} = 1 \text{ rivet}$$

$$i_2 = 4 \left( \frac{1}{2} \right) = 2 \text{ rivets}$$

**Calculation of pitch of rivets (longitudinal pitch  $p$ , transverse pitch  $p_t$ , thickness of cover plates  $h_c$  and margin  $m$ )**

**i) Calculation of longitudinal pitch ( $p$ )**

To obtain 'p', equate  $F_r$  and  $F'_\theta$

$$\begin{aligned} \text{Where, } F_r &= (1.875i_2 + i_1) \frac{\pi}{4} d^2 \tau \\ &= (1.875 \times 2 \times 1) \frac{\pi}{4} (39)^2 \times 60 \\ &= 340458.32 N \\ F'_\theta &= ph\sigma_\theta \\ 340548.32 &= (p - 39) 35 \times 90 \end{aligned}$$

$$\text{Therefore, } p = 147.082 \text{ mm}$$

**Note:** To reduce leakage of steam, adopt  $p = 147 \text{ mm}$  (slightly smaller than the calculate value of  $p$ )

**ii) Calculation of transverse pitch ( $p_t$ )**

**Note:** For a pressure vessel,  $p_t$  depends on  $\frac{p}{d}$  ratio.

For the joint being analyzed,

$$\frac{p}{d} = \frac{147}{39} = 3.77$$

When  $\frac{p}{d} < 4$ , the minimum transverse pitch  $p_t$  as per ASME boiler code is given

by

$$\begin{aligned} p_t &= 1.75d \\ &= 1.75 \times 39 \\ &= 68.25 \text{ mm} \end{aligned}$$

iii) **Thickness of cover plate ( $h_c$ )**

Thickness of outer cover plate

$$\begin{aligned} h_1 &= 0.625h \\ &= 0.625 \times 35 = 21.875 \text{ mm} \end{aligned}$$

Use,  $h_1 = 22 \text{ mm}$

Similarly, thickness of inner cover plate

$$\begin{aligned} h_2 &= 0.75h \\ &= 0.75 \times 35 = 26.25 \text{ mm} \end{aligned}$$

Use,  $h_2 = 27 \text{ mm}$

iv) **Margin  $m$**

$$\begin{aligned} m &= 1.5d \\ &= 1.5 \times 39 = 58.5 \text{ mm} \end{aligned}$$

b) **Design of circumferential Joint**

**Note:**

- 1) **The circumferential joint is a lap joint double or triple riveted (say double riveted). The size of rivets used in this joint are same as those used in longitudinal joint.**
- 2) **The number of rivets required for the joint are obtained by equating the bursting load due to steam pressure to the resistance offered by rivets for shearing.**

Now,  $\text{Bursting load} = \frac{\pi}{4} (D_i)^2 p_f$

$$\text{Resistance of rivets to shearing} = i \left( \frac{\pi d^2}{4} \right) \tau$$

Equating the above loads,

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$$\frac{\pi}{4}(D_i)^2 p_f = i \left( \frac{\pi d^2}{4} \right) \tau$$

$$\text{i.e., } D_i^2 p_f = i d^2 \tau$$

$$(2000)^2 \times 2.5 = i(39)^2 \times 60$$

$$\text{Therefore, } i = 109.6$$

$$\text{Say } i = 110 (\text{an even number})$$

These 110 rivets are arranged in *two rows* along the circumference.

Therefore, the number of rivets in each row = 55.

Taking thickness of plate used for lap joint same as that of thickness of shell, the outside diameter  $D_0 = D_i + 2h + 2h = D_i + 4h$

Therefore, *Pitch along circumference*

$$= \frac{\pi(D_0)}{55}$$

$$= \frac{\pi(D_i + 4h)}{55}$$

$$= \frac{\pi}{55}(2000 + 4 \times 35)$$

$$= 122.24 \text{ mm}$$

Transverse pitch or row pitch is

$$p_t = 2d \quad \dots \text{T(13-14)}$$

$$= 2 \times 39 = 78 \text{ mm}$$

**Example 7.12:** A triple riveted double strap butt joint for plates of 20mm thickness is to be designed with pitch in the outer row to be twice that of pitch in the inner row. The pitch in the inner row is 200mm. The plates used have an ultimate tensile strength of  $300 \text{ N/mm}^2$ , an allowable shear stress of  $60 \text{ N/mm}^2$  and ultimate crushing stress of  $400 \text{ N/mm}^2$ . What is the efficiency of the joint. Assume factor of safety 3.

**Solution:**

**Step 1: Selection of joint**

Select type – ‘m’ joint (Triple riveted butt joint with pitch in the outer row twice

than in inner row)

Therefore,  $i_1 = 0$

$$i_2 = 1 + 6\left(\frac{1}{2}\right) = 4 \text{ rivets}$$

**Figure-7.22: Triple riveted butt joint with double cover plates with pitch in the outer row twice than in inner row**

**Step II: To find diameter of rivet  $d$**

The diameter of rivet ' $d$ ' depends on plate thickness ' $d$ '

Here,  $h = 20\text{mm} > 8\text{mm}$

Therefore,  $d = 0.2\sqrt{h}$

Where ' $d$ ' and ' $h$ ' are in meter.

$$\begin{aligned} \text{Therefore } d &= 0.2\sqrt{\frac{20}{1000}} \\ &= 0.02828\text{m} = 28.28\text{mm} \end{aligned}$$

Referring table (13-2), select standard diameter  $d = 30\text{mm}$ . The corresponding hole diameter  $d_h = 31.5\text{mm}$

**Step III: To calculate  $\eta$  (Refer table (13-4))**

a) Plate efficiency  $\eta_p = \frac{p-d}{p}$

Pitch in inner row,  $p_i = 200\text{mm}$

Therefore, Pitch in outer row,  $p_o = 400\text{mm} = p$

$$\begin{aligned} \text{Therefore, } \eta_p &= \frac{400-30}{400} \\ &= 0.925 = 92.5\% \end{aligned}$$

b) Efficiency of rivets  $\eta_r = \frac{7.5\pi d^2 \tau}{4ph\sigma_\theta}$

$$= \frac{7.5\pi (30)^2 \times 60}{4 \times 400 \times 20 \times 100}$$

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$$= 0.3976 = 39.76\%$$

c) Efficiency in crushing  $\eta_c = \frac{F_c}{F_\theta}$

Where,  $F_c = (i_2 h + i_1 h_2) d \sigma_c$  ... E(13-23)

$$i_2 = 4$$

$$i_1 = 0$$

$$h = 20\text{mm}$$

$$h_2 = 0.625h$$

$$= 0.625 \times 20 = 12.5\text{mm}$$

$$\sigma_c)_{allowable} = \frac{\sigma_c)_{ut}}{\text{factor of safety}}$$

$$= \frac{400}{3} = 133.33 \text{ N/mm}^2$$

$$F_c = (4 \times 20) 30 \times 133.33$$

$$= 319992 \text{ N}$$

$$F_\theta = ph\sigma_\theta$$

$$= 400 \times 20 \times 100$$

$$= 800000 \text{ N}$$

Therefore,  $\eta_c = \frac{319992}{800000}$

$$= 0.3999 = 39.99\%$$

Therefore, efficiency of joint  $= \eta_c = 39.76\%$  (least of the three values of  $\eta$ ). The mode of failure is by crushing or plates on rivets.

**Example 7.13:** Design a triple riveted butt joint of uneven cover straps for plates of 25mm thickness. The allowable stresses may be taken as 85MPa, 60MPa and 120MPa in tension, shear and compression respectively for plates and rivets.

**Solution:**

**Step I: Selection of Joint**

Select type – 'r' joint

Figure-7.23: Triple riveted butt joint with double cover plates of equal width (chain riveting)

**Step II: Calculation of diameter 'd' of rivet**

Diameter of rivet 'd' depends on plate thickness 'h'

Here  $h = 25\text{mm} > 8\text{mm}$

Therefore,  $d = 0.2\sqrt{h}$  ... T(13-14)

Where 'd' and 'h' are in meter

$$\begin{aligned} \text{Therefore, } d &= 0.2\sqrt{\frac{25}{1000}} \\ &= 0.03162\text{m} = 31.62\text{mm} \end{aligned}$$

Adopt  $d = 33\text{mm}$  and diameter of hole,  $d_h = 34.5\text{mm}$

**Step III: Calculation of pitch (longitudinal pitch p, transverse pitch  $p_t$ ) thickness of cover plates  $h_c$  and margin 'm'.**

**a) Calculation of pitches**

**i) Longitudinal pitch 'p'**

'p' is obtained by equating  $F_r$  and  $F'_\theta$

For the selected joint

$$F_r = \frac{4.75\pi d^2}{4} \tau$$

(Obtained from  $\eta_r$  by deleting the term  $ph\sigma_\theta$  from table (13-14))

$$\begin{aligned} &= 4.75 \frac{\pi}{4} (33)^2 \times 60 \\ &= 243760.1\text{N} \\ F'_\theta &= (p - d)h\sigma_\theta \\ &= (p - 33)25 \times 85 \\ &= (p - 33)2125 \end{aligned}$$

Therefore,  $(p - 33)(2125) = 243760.1$

Therefore,  $p = 147.71\text{mm}$

ii) **Transverse pitch**  $p_t$

$$\begin{aligned} p_t &= 2d \\ &= 2 \times 33 = 66\text{mm} \end{aligned}$$

iii) **Thickness of cover plates** ( $h_c$ )

*Thickness of narrow cover plate*

$$\begin{aligned} h_1 &= 0.625h \\ &= 0.625 \times 25 \\ &= 15.625\text{mm} \end{aligned}$$

*Thickness of wider cover plate*

$$\begin{aligned} h_2 &= 0.75h \\ &= 0.75 \times 25 = 18.75\text{mm} \end{aligned}$$

iv) **Margin,  $m$**

$$\begin{aligned} m &= 1.5d \\ &= 1.5 \times 33 = 49.5\text{mm} \end{aligned}$$

**Step IV: Calculation of efficiency of joint ( $\eta$ )**

... T(13-14)

a) **Efficiency of plates**  $\eta_p = \frac{p-d}{p}$

$$\begin{aligned} &= \frac{147.71 - 44}{147.71} \\ &= 0.776589 = 77.6589\% \end{aligned}$$

b) **Efficiency of rivets**  $\eta_r = \frac{4.75\pi d^2 \tau}{4ph\sigma_\theta}$

$$\begin{aligned} &= \frac{4.75\pi (33)^2 \times 60}{4 \times 17.71 \times 25 \times 85} \\ &= 0.776593 = 77.6593\% \end{aligned}$$

c) Efficiency in crushing  $\eta_c = \frac{F_c}{F_\theta}$

Where,  $F_c = (i_2 h + i_1 h_2) d \sigma_c$  ... E(13-23)

$$i_2 = 2$$

$$i_1 = 1 \text{ rivet}$$

$$h = 25 \text{ mm}$$

$$h_2 = 18.75 \text{ mm}$$

$$d = 33 \text{ mm}$$

$$\sigma_c = 120 \text{ N/mm}^2$$

Therefore,  $F_c = (2 \times 25 + 1 \times 18.75) 33 \times 120$   
 $= 272250 \text{ N}$

$$F_\theta = ph\sigma_\theta$$

$$= 147.71 \times 25 \times 85$$

$$= 313883.75 \text{ N}$$

$$\eta_c = 0.8674$$

$$= 86.74\%$$

Therefore, efficiency of joint = 77.6589% (Least of the above three efficiencies)

**Example 7.14:** Design a double riveted butt joint with equal width cover plates to join two plates of thickness 10mm. The allowable stresses for the material of the rivet and plates are as follows:

For plate material in tension,  $\sigma_t = 80 \text{ MPa}$

For rivet material in compression,  $\sigma_c = 120 \text{ MPa}$

For rivet material in shear,  $\tau = 60 \text{ MPa}$  (VTU-July/August 2005)

**Solution:**

**Step I: Selection of joint**

Refer type 'g' joint [Double riveted butt joint with double cover plates of equal width and chain riveting.

Figure-7.24

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### Step II: To determine size of rivet 'd'

Given, plate thickness  $h = 10\text{mm} > 8\text{mm}$

$$\begin{aligned}\text{Therefore, } d &= 0.2\sqrt{h} \\ &= 0.2\sqrt{\frac{10}{1000}} = 20\text{mm}\end{aligned}$$

[As per Prof. Unwins formula]

### Step III: To calculate pitch ( $p, p_t$ ) margin 'm' and cover plate thickness $h_1$ and $h_2$

#### a) To find $p$ , the longitudinal pitch

Note: Equate  $F_\tau$  and  $F'_\theta$  to get 'p'

For the given joint,

$$F_\tau = 3.75 \frac{\pi d^2}{4} \tau \quad \dots \text{T(13-14)}$$

[Obtained by deleting  $ph\sigma_\theta$  from the denominator of  $\eta_r$  expression]

$$\begin{aligned}F_\tau &= 3.75 \frac{\pi}{4} \times 20^2 \times 60 \\ &= 70685.83\text{N} \\ F'_\theta &= (p-d)h\sigma_\theta \\ &= (p-20)10 \times 80 \\ &= 800(p-20)\end{aligned}$$

Equating the above loads, we get

$$800(p-20) = 70685.83$$

Therefore,  $p = 108.36\text{mm}$

#### b) Transverse pitch

$$\begin{aligned}p_t &= 2d \quad \dots \text{T(13-14)} \\ &= 2 \times 20 = 40\text{mm}\end{aligned}$$

#### c) Margin $m = 1.5d$

$$= 1.5 \times 20 = 30 \text{ mm}$$

d) **Thickness of butt plates (cover plates)**

$$h_1 = h_2 = 0.625h \quad \dots \text{T(13-14)}$$

$$= 0.625 \times 10 = 6.25 \text{ mm}$$

**Step IV: To find efficiency  $\eta$  [Refer table (13-14)]**

a) **Efficiency of plate**  $\eta_p = \frac{p-d}{p}$

$$= \frac{108.36 - 20}{108.36}$$

$$= 0.81543 = 81.543\%$$

b) **Efficiency of rivets**  $\eta_r = \frac{3.75\pi d^2 \tau}{4ph\sigma_\theta}$

$$= \frac{3.75\pi \times 20^2 \times 60}{4 \times 108.36 \times 10 \times 80}$$

$$= 0.815405 = 81.5405\%$$

c) **Efficiency in crushing**  $\eta_c = \frac{F_c}{F_\theta}$

$$= \frac{(i_2 h + i_1 h_2) d \sigma_c}{ph\sigma_\theta}$$

For the given joint in one pitch length, 2 rivets undergo double shear and no rivet under goes single shear

$$i_2 = 2 \quad \text{and} \quad i_1 = 0$$

Therefore,  $\eta_c = \frac{(2 \times 10) 20 \times 120}{108.36 \times 10 \times 80}$

$$= 0.5537 = 55.37\%$$

Therefore,  $\eta_{joint} = 55.37\%$  and mode of failure is by crushing of plates on rivets.

**Example 7.15: For the eccentrically loaded riveted joint shown in figure-7.25 made using 20mm diameter rivets used for riveting a 15mm thick plate to a vertical plate,**

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- i) Determine the load  $P$ , the joint will carry assuming permissible shear stress for rivets = 60MPa.
- ii) The load  $P$  the joint will carry by limiting the compressive stress for plates and rivets = 120MPa.
- iii) The safe load the joint can carry.

Figure-7.25

#### Solution:

- a) Location of CG of rivet system

Because of symmetry in the arrangement of rivets, the centre of gravity CG lies at G.

$$\text{Therefore, } \bar{x} = \frac{150}{2} = 75\text{mm}$$

$$\bar{y} = \frac{200}{2} = 100\text{mm}$$

- b) To calculate,  $F_d$  the direct load on rivets

$$\text{Direct load, } F_d = \frac{P}{i}$$

Where,  $p = \text{load applied}$

$$i = \text{Number of rivets} = 4$$

$$\text{Therefore, } F_d = \frac{P}{4}$$

**Note:** The direct load  $F_d$  acts at rivets 1, 2, 3 and 4 parallel to  $P$  and in the direction of it as shown.

- c) To calculate secondary load  $F_s$  ( $F_1, F_2, \text{ etc}$ )

The secondary load acts at centre of rivets normal to the line joining CG with centre of rivets so as to produce similar moment (clockwise moment) as that produced by  $P$  about CG, G.

$$\text{Now, } Pe = \frac{F_1}{l_1} (l_1^2 + l_2^2 + l_3^2 + l_4^2)$$

$$\text{Where, } l_1 = l_3 = \frac{150}{2} = 75\text{mm}$$

$$l_2 = l_4 = 100\text{mm}$$

$$\begin{aligned} \text{Therefore, } P \times 500 &= \frac{F_1}{75} [2(75)^2 + 2(100)^2] \\ &= 416.67 F_1 \end{aligned}$$

$$\text{Therefore, } P = 0.8333 F_1$$

$$\text{Also, } \frac{F_1}{l_1} = \frac{F_2}{l_2}$$

$$\begin{aligned} \text{Therefore, } F_2 &= F_1 \frac{l_2}{l_1} \\ &= F_1 \times \frac{100}{75} = 1.33 F_1 \end{aligned}$$

$$\frac{F_2}{l_2} = \frac{F_3}{l_3}$$

$$\begin{aligned} \text{Therefore, } F_2 &= F_3 \frac{l_2}{l_3} \\ &= F_3 \times \frac{100}{75} = 1.3333 F_3 \end{aligned}$$

$$\begin{aligned} F_R)_{rivet 2} &= \sqrt{F_d^2 + F_2^2 + 2F_d F_2 \cos \theta}; \quad \theta = 90^\circ \\ &= \sqrt{F_d^2 + F_2^2 + 2F_d F_2 \times 0} \\ &= \sqrt{F_d^2 + F_2^2} \end{aligned}$$

$$\begin{aligned} &= \sqrt{\left(\frac{P}{4}\right)^2 + (1.6P)^2} \\ &= 1.6194P \end{aligned}$$

$$\begin{aligned} F_R)_{rivet 3} &= F_d + F_3 \\ &= \frac{P}{3} + \frac{P}{0.8333} = 1.45P \end{aligned}$$

Therefore, Rivet 2 is critically loaded and the resultant load on the rivet is

$$\begin{aligned}
 F_R)_2 &= \frac{\pi d^2}{4} \tau \\
 &= \frac{\pi}{4} \times 20^2 \times 60 \\
 &= 1.6194P
 \end{aligned}$$

Therefore,  $P = 11639.84N$

ii) **Based on crushing of plates and rivets**

$$\begin{aligned}
 \text{Maximum load, } 1.6194P &= dt\sigma_c \\
 &= 20 \times 15 \times 120
 \end{aligned}$$

Therefore,  $P = 22.23046N$

iii) **The safe load the joint can carry**

It is the least of the above two values = 11639.84N

**Example 7.16:** For the eccentrically loaded riveted joint shown in figure-7.26, determine the size of rivet required by limiting the shear stress in the rivets to 60MPa.

Figure-7.26

**Solution:**

a) **Location of CG of rivets**

Because of symmetry, CG lines at rivet 2.

Therefore, Eccentricity  $e = 250mm$

b) **Calculation of direct load (shear load)  $F_d$**

$$F_d = \frac{P}{i}$$

Where,  $p = \text{Load} = 15kN = 15 \times 10^3 N$

$i = \text{Number of rivets sharing laod} = 3$

$$\text{Therefore, } F_d = \frac{15 \times 10^3}{3} = 5 \times 10^3 N$$

The load  $F_d$  acts at rivets 1, 2 and 3 in the vertical direction parallel to P and in the direction of it.

c) **Calculation of secondary load ( $F_s$ )** (i.e.,  $F_1, F_2$ , etc.,)

$$Pe = \frac{F_1}{l_1}(l_1^2 + l_2^2 + l_3^2)$$

Where,  $P = 5 \times 10^3 N$

$$e = 250mm$$

$$l_1 = l_3 = 50mm$$

$$l_2 = 0$$

Therefore,  $(5 \times 10^3) \times 250 = \frac{F_1}{50}(2 \times 50^2)$

Therefore,  $F_1 = 37500N = F_3$  (since  $l_1 = l_3$ )

$$F_2 = 0, \text{ because } l_2 = 0$$

$F_3$  acts at rivet 3 normal to  $l_3$  so as to produce clockwise moment as that produced by  $P$  about CG.

d) **Location of critically loaded rivet**

On inspection, rivet 3 is heavily loaded and the load on it is

$$\begin{aligned} F_R)_3 &= F_d + F_3 \\ &= 5000 + 37500 = 42500N \end{aligned}$$

e) **To find size of rivet ( $d$ )**

Equate  $F_R)_3$  to  $\frac{\pi d^2}{4} \tau$  to get ' $d$ ', the diameter of rivet

$$\text{i.e., } 42500 = \frac{\pi}{4} \times d^2 \times 60$$

Therefore,  $d = 30.03mm$

Use,  $d = 33mm$  (standard size) ... T(13-2)

**Lozenge Joint or Diamond Joint (Also called joint of uniform strength)**

**Example 7.17: Two steel plates 12mm thick carrying a tensile load of 400kN are to be**

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joined by means of butt joint with double cover plates (butt strap) of equal width. Assuming that the plate is not weakened by more than one rivet hole, determine

- The diameter of rivets.
- The width of plate.
- Number of rivets on each plate.
- Thickness of butt strap and margin.
- Efficiency of the joint.

The permissible stresses for the plate in tension is  $110 \text{ N/mm}^2$  and shear stress and compressive stresses for the rivet are respectively  $80$  and  $155 \text{ N/mm}^2$ .

**Solution:**

- a) To calculate the diameter of rivet 'd'

The diameter of rivet 'd' depends on plate thickness 'h'

Here,  $h = 12 \text{ mm} > 8 \text{ mm}$

Therefore,  $d = 0.2\sqrt{h}$  ... T(13-14)

$$= 0.2\sqrt{\frac{12}{1000}}$$

$$d = 0.0129 \text{ meter} = 12.9 \text{ mm}$$

Referring table (13-2), use standard diameter  $d = 22 \text{ mm}$

- b) The width of plate 'b'

The tearing strength of plate in the outer most row. i.e., first row where only one rivet is present is given by

$$F'_\theta = (b - d_h)h\sigma_\theta$$

**Note:** In case of structural joint where 'cold riveting' is done, the hole diameter  $d_h$  in the plate is to be used in place of rivet diameter d.

Here,  $F_\theta = \text{Tensile load} = 40 \text{ kN} = 40 \times 10^3 \text{ N}$

$b = \text{Width of plate}$

$$d_h = 23 \text{ mm}$$

$$h = 12 \text{ mm}$$

$$\sigma_\theta = 110 \text{ N/mm}^2$$

Therefore,  $40 \times 10^3 = (b - 23)12 \times 110$

$$b = 53.3mm$$

Use,  $b = 54mm$

Width of plate required,  $b = 54mm$

c) *Number of rivets*

a) *Shear strength of each rivet*

**Note:** *Since two cover plates of equal width are used in the joint, the rivets fail by double shear and the rivet failing by double shear is assumed to 1.875 times stronger than a rivet failing by single shear.*

$$\begin{aligned} \text{Therefore, } F_s &= 1.875 \frac{\pi d^2}{4} \tau \\ &= 1.875 \frac{\pi (22)^2}{4} \times 80 \\ &= 57019.9N \end{aligned}$$

b) *Crushing resistance of each rivet*

$$\begin{aligned} \text{Crushing resistance, } F_c &= dh\sigma_c \\ &= 22 \times 12 \times 155 \\ &= 40902N \end{aligned}$$

**Note:** *The number of rivets required to be arranged on each plate is determined by considering the least of the above loads.*

Here the least strength is  $F_c = 40920N$

$$\begin{aligned} \text{Therefore, Number of rivets} &= \frac{\text{Total load, the joint has to carry}}{\text{Least strength of joint}} \\ &= \frac{400 \times 10^3}{40920} \\ &= 9.775 \text{ rivets} \end{aligned}$$

Use number of rivets = 10

These 10 rivets are arranged on each plate as shown below

*Figure-7.27*

d) **Thickness of butt strap ( $h_c$ ) and margin  $m$**

$$h = 12\text{mm} = 0.012\text{m}$$

$$h_1 = h_2 = h_c = 0.625h$$

$$= 0.625 \times 12 = 7.5\text{mm}$$

**Margin,**  $m = 1.5d$

$$= 1.5 \times 22 = 33\text{mm}$$

e) **Efficiency  $\eta$**

**Note: Shear strength of each rivet**

$$F_\tau = \frac{1.875\pi d^2 \tau}{4}$$
$$= \frac{1.875\pi (22^2) \times 80}{4}$$
$$= 570199.91\text{N}$$

Crushing strength of each rivet

$$F_\theta = dh\sigma_c$$
$$= 22 \times 12 \times 155$$
$$= 40920\text{N}$$

**Note: Since shear strength is more than crushing strength, check is made only for crushing in each row.**

i) **Tearing resistance along the first row is**

$$F'_\theta = (b - d_h)h\sigma_\theta$$
$$= (54 - 23)12 \times 110$$
$$= 40920\text{N}$$

ii) **Tearing resistance of plate along the second row and simultaneous crushing of one rivet in first row is**

$$= (b - 2d_h)h\sigma_\theta + (dh\sigma_c)1$$
$$= (54 - 2 \times 23)12 \times 110 + (22 \times 12 \times 155)1$$
$$= 10560 + 40920$$

$$= 51480N$$

- iii) *Tearing resistance of plate along third row and simultaneous crushing of 3. i.e., (1+2) rivets in first and second row is*

$$\begin{aligned} &= (b - 3d_h)h\sigma_\theta + (dh\sigma_c) \times 3 \\ &= (54 - 3 \times 23)12 \times 110 + (22 \times 12 \times 155) \times 3 \\ &= 102960N \end{aligned}$$

- iv) *Tearing resistance of plate along the fourth row with simultaneous crushing of 6. i.e., (1+2+3) rivets in first three rows is*

$$\begin{aligned} &= (b - 4d_h)h\sigma_\theta + (dh\sigma_c)6 \\ &= (54 - 4 \times 23)12 \times 110 + (22 \times 12 \times 155)6 \\ &= -50160 + 245520 \\ &= 195360N \end{aligned}$$

Therefore, Least strength (or resistance) of joint

$$= 40920N$$

$$\begin{aligned} \text{Therefore, Efficiency of joint} &= \frac{\text{Least strength}}{\text{Strength of plate without holes}} \\ &= \frac{40920}{bh\sigma_\theta} \\ &= \frac{40920}{54 \times 12 \times 110} = 57.41\% \end{aligned}$$

**Example 7.18:** *Two MS plates of 25mm thickness are to be joined by means of a butt joint with two cover plates of equal width for a tensile load of 250kN. Assuming that the plate is not weakened by more than one rivet hole, design the joint of uniform strength by using the permissible tensile stress for plates equal to 90MPa, and permissible shear and crushing stresses for plates and rivets as 60 and 120MPa respectively.*

**Solution:**

- a) *Diameter of rivet 'd'*

*The diameter of rivet depends on h, the plate thickness*

Here,  $h = 25\text{mm} > 8\text{mm}$

... T(13-14)

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$$\begin{aligned}d &= 0.2\sqrt{h} \\ \text{Where, } d \text{ and } h \text{ are in meter.} \\ &= 0.2\sqrt{\frac{25}{1000}} \\ &= 0.03162\text{m} = 31.62\text{mm} \\ \text{i.e., } d &= 31.62\text{mm}\end{aligned}$$

Referring table (13-2) use standard diameter  $d = 33\text{mm}$  and the corresponding hole diameter  $d_h = 34.5\text{mm}$

**b) To find width of plate  $b$**

The tearing strength of strength of plate in the outer most row where only one rivet is present is

$$\begin{aligned}F'_\theta &= (b - d_h)h\sigma_\theta \\ 250 \times 10^3 &= (b - 34.5)25 \times 90\end{aligned}$$

Therefore,  $b = 145.01\text{mm}$

Adopt  $b = 146\text{mm}$

**iii) To calculate the number of rivets required**

**a) The shear stress of each rivet**

$$\begin{aligned}F_\tau &= \frac{1.875\pi d^2 \tau}{4} \\ &= 1.875 \times \frac{\pi}{4} \times 33^3 \times 80 \\ &= 128294.79\text{N}\end{aligned}$$

**b) The crushing strength of each rivet is**

$$\begin{aligned}F_c &= dh\sigma_c \\ &= 33 \times 25 \times 120 \\ &= 99000\text{N}\end{aligned}$$

**Note:** The number of rivets required on each plate is based on the least of the above two resistances.

Therefore, 
$$\text{Number of rivets required} = \frac{\text{Total load the joint has to carry}}{\text{Least strength of joint}}$$

$$= \frac{250 \times 10^3}{99000} = 2.5252$$

Use number of rivets = 3.

**IV) Thickness of butt strap  $h_c$  and margin  $m$**

$$h_c = h_1 = h_2 = 0.625h$$

$$= 0.625 \times 25 = 15.625 \text{ mm}$$

**Margin**  $m = 1.5d$

$$= 1.5 \times 33 = 49.5 \text{ mm}$$

Use,  $m = 50 \text{ mm}$

Figure-7.28

**v) Efficiency of joint  $\eta$**

**Note:** Since crushing strength is lesser than shear strength, check is made only for crushing

**i) Tearing resistance of plate along the first row is**

$$F'_\theta = (b - d_h) h \sigma_\theta$$

$$= (146 - 34.5) 25 \times 90$$

$$= 250875 \text{ N}$$

Tearing resistance of plate along second row with simultaneous crushing of rivet in first row is

$$= (b - 2d_h) h \sigma_\theta + 1(dh \sigma_c)$$

$$= (146 - 2 \times 34.5) 25 \times 90 + (33 \times 25 \times 120)$$

$$= 272250 \text{ N}$$

Therefore, 
$$\text{Efficiency of joint } \eta = \frac{\text{Least strength of joint}}{\text{Strength of solid plate}}$$

$$= \frac{F'_\theta}{bh \sigma_\theta}$$

$$= \frac{250875}{146 \times 25 \times 90} = 76.37\%$$

### *Design of Eccentrically loaded riveted joint*

**Example 7.19:** A bracket is supported by four rivets of equal diameter as shown in figure-7.29 to support a load of 50kN. Determine the size of the rivet taking the permissible shear stress in the rivet equal to 80MPa.

Figure-7.29

**Solution:**

**Step I: Location of CG of the rivet system**

Because of symmetry of arrangement of rivets, the centre of gravity of rivet system lies at G, the point of intersection of lines joining the centres of diagonally opposite rivets.

Taking the first column of rivets as y-axis and bottom row as x-axis,

$$\bar{x} = \frac{200}{2} = 100mm$$

$$\bar{y} = \frac{180}{2} = 90mm$$

Therefore, eccentricity 'e' (distance between CG and load axis)

$$= 500 + \frac{200}{2} = 600mm$$

**Step II: Calculation of direct load on each rivet ( $F_d$ )**

The direct load on each rivet is given by the load shared by each rivet and is obtained by dividing the total load on the joint by the number of rivets sharing it

Therefore,  $F_d = \frac{P}{i}$

Where,  $P = \text{Total load} = 50kN = 50 \times 10^3 N$

$i = \text{Number of rivets} = 4$

$$F_d = \frac{50 \times 10^3}{4} = 12.5 \times 10^3 N$$

**Note:**  $F_d$ , irrespective of the arrangement of rivets, acts each rivet, parallel to the applied load P and in the direction of it.

Figure-7.30

**Step III: Calculation of secondary load  $F_s$  (i.e.,  $F_1, F_2, etc.$ )**

The secondary load  $F_s$  due to eccentricity of load P.

The secondary load is obtained by equating the moment due to applied load to the sum of moments of secondary loads at rivets.

$$\text{i.e., } Pe = \frac{F_1}{l_1} (l_1^2 + l_2^2 + l_3^2 + l_4^2 + \dots)$$

Where,  $l_1, l_2, l_3, \dots$  etc., are the distances of rivets 1, 2, 3 .... etc., from the centre of gravity 'G'.

$$\text{Also } \frac{F_1}{l_1} = \frac{F_2}{l_2} = \frac{F_3}{l_3} = \frac{F_n}{l_n} \text{ where } F_1, F_2, F_3, etc., \text{ are the secondary loads at rivets 1, 2, 3, etc.}$$

Figure-7.31

**Direction of secondary load  $F_s$  (i.e.,  $F_1, F_2, etc.$ )**

The secondary loads  $F_1, F_2, F_3, etc.$ , act at rivets 1, 2, 3, .... *perpendicular to  $l_1, l_2, l_3, \dots$*  etc., so as to produce similar moment (i.e., *clockwise moment in this case*) as that produced by load 'P' about C.G. 'G'.

In the above problem,

$$P = 50 \times 10^3 \text{ N}$$

$$e = 600 \text{ mm}$$

$$l_1 = \sqrt{90^2 + 100^2} = 134.54 \text{ mm}$$

$$l_1 = l_2 = l_3 = l_4 = 134.54 \text{ mm}$$

**Note:**  $l_1 = l_2 = l_3 = l_4$  because  $F_1 = F_2 = F_3 = F_4$

$$\frac{F_1}{l_1} = \frac{F_2}{l_2} = \frac{F_3}{l_3}$$

$$Pe = \frac{F_1}{l_1} [4l_1^2] = 4F_1l_1$$

$$\text{i.e., } 50 \times 10^3 \times 600 = 4F_1 \times 134.54$$

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Therefore,  $F_1 = 5574.5N = F_2 = F_3 = F_4$

- iv) **Location of critically loaded rivet (or heavily loaded rivet) and the resultant load acting on the rivet**

Figure-7.32

Let  $\theta_1, \theta_2, \theta_3$  and  $\theta_4$  be the angle between direct and secondary loads at rivets 1, 2, 3 and 4.

Here  $\theta_2 = \theta_3$  and  $\theta_1 = \theta_4$

The critically loaded rivet is one for which the angle between the direct load and secondary load is the least.

On observation, rivets 2 and 3 are critically loaded.

Therefore, resultant load on rivet 2 is

$$F_R)_2 = \sqrt{F_d^2 + F_2^2 + 2F_d F_2 \cos \theta_2}$$

From figure-7.29,

$$\begin{aligned} \cos \theta_2 &= \frac{GK}{l_2} \\ &= \frac{100}{134.54} = 0.7433 \end{aligned}$$

Therefore,

$$\begin{aligned} F_R)_2 &= \sqrt{(12.5 \times 10)^2 + (5574.5)^2 + 2(12.5 \times 10^3)(5574.5) \times 0.7433} \\ F_R)_2 &= 65572.11N = F_R)_3 \end{aligned}$$

- v) **Calculation of size of rivet (i.e., diameter of rivet 'd')**

Equate  $F_R)_2$  to the resistance offered by rivet to shearing

$$\text{Therefore, } F_R)_2 = \frac{\pi d^2}{4} \tau$$

$$\text{i.e., } 65572.11 = \frac{\pi d^2}{4} \times 80$$

$$\text{Therefore, } d = 32.31mm$$

Adopt  $d = 33\text{mm}$  (Standard size)

... T(13-2)

**Note:** The thickness of plate 'h' of the bracket can be determined by knowing the crushing stress using equation

$$F_R = dh\sigma_c$$

i.e., 
$$h = \frac{F_R}{d\sigma_c}$$

**Example 7.20:** For the eccentrically loaded riveted joint shown in figure-7.33 locate, the critically loaded rivet and determine

- i) Maximum load on the critically loaded rivet.
- ii) The diameter of the rivet required by using permissible shear stress in rivets equal to 60MPa.
- iii) The shear stress induced in the rivet if the diameter of rivets is 20mm.
- iv) The thickness of plate if the crushing stress is 120MPa.

Figure-7.33

**Solution:**

**Step I: Location of C.G. of rivet system**

The rivet arrangement is symmetrical about horizontal axis 1-1.

Therefore,  $\bar{y} = 80\text{mm}$

$$\begin{aligned} \bar{x} &= \frac{\sum Ax}{\sum A} \\ &= \frac{a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + \dots + a_nx_n}{a_1 + a_2 + a_3 + a_4 + \dots + a_n} \end{aligned}$$

Where  $a_1, a_2, a_3$  etc., are areas of rivets 1, 2, 3, etc.

Here  $a_1 = a_2 = a_3 = a_4 = a_n = a$

Where  $x_1, x_4, x_5 = 0$

$$x_2 = x_6 = 100\text{mm}$$

$$x_3 = x_7 = 200\text{mm}$$

Therefore, 
$$\bar{x} = \frac{a(x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7)}{7a}$$

$$= \frac{x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7}{7}$$

$$= \frac{2x_2 + 2x_3}{7}$$

$$= \frac{2(100 + 200)}{7} = 85.71mm$$

$$\begin{aligned} e &= 600 - \bar{x} \\ &= 600 - 85.71 \\ &= 514.29mm \end{aligned}$$

**Step II: Calculation of direct load  $F_d$**

Direct load  $F_d = \frac{P}{i}$

Where,  $P = 10.5kN = 10.5 \times 10^3 N$   
 $i = \text{Total number of rivets sharing load} = 7$

$$F_d = \frac{10.5 \times 10^3}{7}$$

**Note:**  $F_d$  acts at the centre of each rivet parallel to  $P$  and in the direction of  $P$  as shown in figure-7.34

**Step III: Calculation of secondary load  $F_s$  ( $F_1, F_2, \text{etc.}$ )**

Secondary load due to eccentricity is obtained from equation

$$Pe = \frac{F_1}{l_1} (l_1^2 + l_2^2 + l_3^2 + l_4^2 + l_5^2 + l_6^2 + l_7^2)$$

**Figure-7.34**

From figure-7.32

$$l_1 = l_5 = \sqrt{80^2 + 85.72^2} = 117.24mm$$

$$l_2 = l_6 = \sqrt{(100 - 85.71)^2 + 80^2} = 81.27mm$$

$$l_3 = l_7 = \sqrt{(200 - 85.71)^2 + 80^2} = 139.51 \text{ mm}$$

$$l_4 = \bar{x} = 85.71 \text{ mm}$$

Therefore, 
$$Pe = \frac{F_1}{l_1} [2(l_1^2 + l_2^2 + l_3^2) + l_4^2]$$

$$(10.5 \times 10^3) 514.29 = \frac{F_1}{117.24} [2(117.24^2 + 81.27^2 + 139.51^2) + 85.71^2]$$

Therefore, 
$$F_1 = 7279.34 \text{ N} = F_5$$

**Step IV: Location of critically loaded rivet**

$$F_1 = 7279.34 \text{ N}$$

From 
$$\frac{F_1}{l_1} = \frac{F_3}{l_3} = \frac{F_7}{l_7},$$

$$F_3 = \frac{F_1 l_3}{l_1}$$

$$= \frac{7279.34 \times 139.51}{117.24} = 8662.1 = F_7 \quad \text{because } l_3 = l_7$$

$$\frac{F_2}{l_2} = \frac{F_6}{l_6} = \frac{F_1}{l_1}$$

Therefore, 
$$F_2 = \frac{F_1}{l_1} l_2$$

$$= \frac{7279.34}{117.24} \times 81.27$$

$$= 5045.99 \text{ N} = F_6, \quad \text{because } l_2 = l_6$$

On inspection, we see that the secondary loads at rivets 3 and 7, i.e.,  $F_3$  and  $F_7$  are maximum and also the angle between  $F_d$  and  $F_3$ ,  $F_d$  and  $F_7$  is least. Hence rivets 3 and 7 are critically loaded.

Therefore, Resultant load on heavily loaded rivets is

$$F_R)_3 = F_R)_7 = \sqrt{F_d^2 + F_3^2 + 2F_d F_3 \cos \theta_3}$$

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$$\begin{aligned}\text{Where, } \cos \theta_3 &= \frac{GK}{l_3} \quad [\text{From triangle, } GKL] \\ &= \frac{200 - 85.71}{139.51} = 0.8192\end{aligned}$$

$$\begin{aligned}\text{Therefore, } F_R)_3 &= \sqrt{(1500)^2 + (8662.1)^2 + 2(1500)(8662.1)(0.8192)} \\ &= 9928.24N\end{aligned}$$

### Step V: Calculation of size of rivet, 'd'

Equate  $F_R)_3$  to  $F_\tau$ , i.e., the resistance offered by rivets to shearing

$$\begin{aligned}F_R)_3 &= F_\tau \\ 9928.24 &= \frac{\pi d^2}{4} \tau \\ 9928.24 &= \frac{\pi d^2}{4} \times 60\end{aligned}$$

Therefore,  $d = 14.51mm$

Adopt  $d = 16mm$  (Standard size) ... T(13-2)

When  $d = 20mm$ , shear stress induced in rivet is obtained from equation,

$$9928.24 = \frac{\pi (20)^2}{4} \tau_{ind}$$

Therefore,  $\tau_{ind} = 31.6MPa$

### Step IV: To determine the thickness of bracket

Considering crushing of plate,

$$\begin{aligned}F_R)_3 &= dh\sigma_c \\ h &= \frac{F_R)_3}{d\sigma_c} \\ &= \frac{9928.24}{16 \times 120} = 5.17mm\end{aligned}$$

Use,  $h = 5.2\text{mm}$

**Example 7.21:** Four rivets of diameter ‘d’ are used in an eccentrically loaded riveted joint shown in figure-7.35. Determine the size of the rivet required using the permissible shear stress in the rivets equal to 60MPa

Figure-7.35

**Solution:**

**Step I: Location of centre of gravity ‘G’**

Because of symmetry of arrangement of rivets along X-X, the centre of gravity lines at G at a distance of 175mm from rivet 1.

Figure-7.36

$$\begin{aligned} \text{Eccentricity } e &= 500 + l_4 \\ &= 500 + 175 = 675\text{mm} \end{aligned}$$

**Step II: Calculation of direct load  $F_d$**

$$\text{Direct load } F_d = \frac{P}{i}$$

$$\begin{aligned} \text{Where, } P &= 20\text{kN} = 20 \times 10^3 \text{ N} \\ i &= \text{Number of rivets sharing load} = 4 \end{aligned}$$

$$\begin{aligned} \text{Therefore, } F_d &= \frac{P}{i} \\ &= \frac{20 \times 10^3}{4} = 5000\text{N} \end{aligned}$$

**Note:** This  $F_d$  acts at rivets 1, 2, 3 and 4 parallel to the applied load P and in the direction of P as shown in figure-7.36

**Step II: Calculation of secondary load  $F_s$  ( $F_1, F_2, \text{etc.}$ )**

Secondary load  $F_s$  due to P is given by

$$Pe = \frac{F_1}{l_1} (l_1^2 + l_2^2 + l_3^2 + l_4^2)$$

Where  $l_1, l_2, l_3$  and  $l_4$  are the distances of rivets 1, 2, 3 and 4 from centre of gravity ‘G’.

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From figure-7.36,

$$l_1 = l_4 = 175\text{mm}$$

$$l_2 = l_3 = 75\text{mm}$$

Therefore, 
$$Pe = \frac{F_1}{l_1} [2(l_1^2 + l_2^2)]$$

$$(20 \times 10^3) 675 = \frac{F_1}{175} [2(175^2 + 75^2)]$$

i.e., 
$$F_1 = F_4 = 32586.21\text{N}$$

But, 
$$\frac{F_1}{l_1} = \frac{F_2}{l_2}$$

Therefore, 
$$F_2 = \frac{F_1}{l_1} l_2$$

$$= \frac{32586.21}{175} \times 75$$

$$F_2 = F_3 = 13965.52\text{N} \quad \text{because } l_2 = l_3$$

### **Step IV: Location of critically loaded rivet and the load on it**

*Figure-7.37*

The secondary load  $F_1, F_2, F_3$  and  $F_4$  act at rivets 1, 2, 3 and 4 as shown in figure-7.37

**Note:**  $F_1, F_2, F_3$  and  $F_4$  act normal to  $l_1, l_2, l_3$  and  $l_4$  so as to produce clockwise moment as that produced by  $P$  about centre of gravity 'G'.

*Resultant load on rivet 1*

$$\begin{aligned} &= F_1 - F_d \\ &= 32586.21 - 5000 \\ &= 27586.21\text{N} \end{aligned}$$

*Resultant load on rivet 2*

$$= F_2 - F_d$$

$$= 13965.52 - 5000$$

$$= 8965.52N \text{ (Minimum load)}$$

Resultant load on rivet 3

$$= F_d + F_3$$

$$= 5000 + 13965.52$$

$$= 18965.52N$$

Resultant load on rivet 4

$$= F_d + F_4$$

$$= 5000 + 32586.21$$

$$= 37586.21N \text{ (Maximum load)}$$

Therefore, Rivet 4 is heavily loaded and the load on this rivet is

$$F_R)_4 = 37586.21N$$

**Step V: Calculation of size of rivet (d)**

Equate  $F_R)_4 = F_\tau$  to obtain 'd'

$$\text{i.e., } 37586.21 = \frac{\pi d^2}{d} \tau$$

$$37586.21 = \frac{\pi d^2}{d} \times 60$$

Therefore,  $d = 28.24mm$

Adopt  $d = 30mm$  (Standard size) ... T(13-2)

**Example 7.22: For the riveted joint shown in figure-7.38, determine the size of rivet required taking the permissible shear stress in rivet equal to 60MPa.**

Figure-7.38

**Solution:**

**Step I: Location of centre of gravity 'G'**

The centre of gravity of rivets lies at 'G' as shown in figure-7.39

Eccentricity  $e = 400mm$

Direct load  $F_d = \frac{P}{i}$

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Where  $P = \text{Total load on rivets} = 20\text{kN} = 20 \times 10^3 \text{ N}$   
 $i = \text{Number of rivets sharing load} = 4$

Therefore,  $F_d = \frac{20 \times 10^3}{4} = 5000 \text{ N}$

$F_d$  acts at rivets 1, 2, 3 and 4 parallel to  $P$  and in the direction of it (Refer figure-7.39)

#### Step III: Calculation of secondary load $F_s$ ( $F_1, F_2, \text{etc.}$ )

The secondary load due to  $P$  is given by

$$Pe = \frac{F_1}{l_1} (l_1^2 + l_2^2 + l_3^2 + l_4^2)$$

Where  $l_1, l_2, l_3$  and  $l_4$  are the distances of rivets 1, 2, 3 and 4 from the centre of gravity 'G'

Here  $l_1 = l_4 = 150\text{mm}$  and  $l_2 = l_3 = 50\text{mm}$

Figure-7.40

Therefore,  $Pe = \frac{F_1}{l_1} [2(l_1^2 + l_2^2)]$

$$(20 \times 10^3) 400 = \frac{F_1}{100} [2(150^2 + 50^2)]$$

Therefore,  $F_1 = F_4 = 16000$ , because  $l_1 = l_4$

From  $\frac{F_2}{l_2} = \frac{F_1}{l_1}$

Therefore,  $F_2 = \frac{F_1}{l_1} l_2$   
 $= 16000 \times \frac{50}{150} = 533.33 \text{ N}$

The secondary loads  $F_1, F_2, F_3$  and  $F_4$  act as shown in figure-7.41

#### Step IV: Location of critically loaded rivet

Figure-7.41

$$F_R)_1 = \sqrt{F_d^2 + F_1^2 + 2F_d F_1 \cos \theta_1}$$

$$\text{Here, } \theta_1 = \theta_2 = \theta_3 = \theta_4 = 90^\circ$$

$$\begin{aligned} \text{Therefore, } F_R)_1 &= \sqrt{F_d^2 + F_1^2} \\ &= \sqrt{(5000)^2 + (16000)^2} \\ &= 16763.05 N = F_R)_4, \text{ because } l_1 = l_4 \end{aligned}$$

$$\begin{aligned} F_R)_2 &= \sqrt{F_d^2 + F_2^2} \\ &= \sqrt{(5000)^2 + (53333.33)^2} \\ &= 7310.57 N = F_R)_3, \text{ because } l_2 = l_3 \end{aligned}$$

From the above analysis, we find that rivets 1 and 4 are heavily loaded and the load on rivet 1 or rivet 4 is given by,

$$F_R)_1 = F_R)_4 = 16763.05 N$$

**Step V: To determine the size of rivet 'd'**

Equate  $F_R)_1 = F_\tau$  to obtain 'd'

$$\text{Where, } F_c = \frac{\pi d^2}{4} \tau$$

$$\text{i.e., } 16763.05 = \frac{\pi d^2}{4} \times 60$$

$$\text{Therefore, } d = 18.86 \text{ mm}$$

Adopt  $d = 20 \text{ mm}$  (Standard size)

**Example 7.23: For the eccentrically loaded riveted joint shown in figure-7.42, determine the size of rivet required taking permissible shear stress in rivet equal to 60MPa.**

**Solution:**

**Step I: Location of centre of gravity G**

Because of symmetry of arrangement of rivets, about both horizontal and vertical axes

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$$\bar{x} = 100\text{mm} \text{ and } \bar{y} = 50\text{mm}$$

### Step II: Calculation of direct load $F_d$

The direct load  $F_d$  on each rivet is given by,

$$F_d = \frac{P}{i}$$

Where,  $P = \text{Load applied} = 30\text{kN} = 30 \times 10^3 \text{ N}$   
 $i = \text{Number of rivets} = 6$

Therefore, 
$$F_d = \frac{30 \times 10^3}{6} = 5000 \text{ N}$$

Figure-7.42

$F_d$  acts at the centre of rivets 1, 2, 3, etc., parallel to the applied  $P$  and in the direction of it. Refer figure-7.43

Figure-7.43

### Step III: Calculation of secondary load $F_s$ (i.e., $F_1, F_2$ , etc.,)

Figure-7.44

The secondary load is calculated using equation,

$$\begin{aligned} Pe &= \frac{F_1}{l_1} (l_1^2 + l_2^2 + l_3^2 + l_4^2 + l_5^2 + l_6^2) \\ &= \frac{F_1}{l_1} [2(l_1^2 + l_2^2 + l_3^2)] \\ &= \frac{F_1}{l_1} [4l_1^2 + 2l_2^2] \quad \text{because } l_1 = l_4 = l_3 = l_6; \quad l_2 = l_5 \end{aligned}$$

$$\begin{aligned} l_1 &= \sqrt{50^2 + 100^2} \\ &= 111.8\text{mm} \\ l_2 &= l_5 = 50\text{mm} \end{aligned}$$

Therefore,  $30 \times 10^3 \times 300 = \frac{F_1}{111.8} [4(111.8)^2 + 2(50)^2]$

$$F_1 = 18295.56N$$

$$F_1 = F_3 = F_4 = F_6 = 18295.56N$$

Since  $l_1 = l_3 = l_4 = l_6$

$$\frac{F_1}{l_1} = \frac{F_2}{l_2}$$

$$F_2 = \frac{F_1}{l_1} l_2$$

$$= \frac{18295.56}{111.8} \times 50$$

$$= 8182.27N = F_5$$

**Step IV: Location of critically loaded rivet and the load on the rivet**

*Resultant load on rivet 3*

$$F_R)_3 = \sqrt{F_d^2 + F_3^2 + 2F_d F_3 \cos \theta_3}$$

Where  $F_d = 5000N$

$$F_3 = 18295.56N$$

$$\cos \theta_3 = \frac{100}{l_3} = \frac{100}{111.8} = 0.8945$$

$$F_R)_3 = \sqrt{(5000)^2 + (18295.56)^2 + 2 \times 5000 \times 18295.56 \times 0.8945}$$

$$= 22877.52N$$

*Resultant load on rivet 2*

$$F_R)_2 = \sqrt{F_d^2 + F_2^2 + 2F_d F_2 \cos \theta_2}$$

$$= \sqrt{(5000)^2 + (8182.27)^2 + 2(5000)(8182.27) \cos 40}$$

$$= 12435N$$

*Resultant load on rivet 1*

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$$\begin{aligned} F_R)_1 &= \sqrt{F_d^2 + F_1^2 + 2F_d F_1 \cos \theta_1} \\ &= \sqrt{(5000)^2 + (18295.56)^2 + 2 \times 5000 \times 18295.56 \cos(90 + \phi)} \end{aligned}$$

**Note:** Since  $\cos(90 + \phi)$  is negative,

$$F_R)_1 < F_R)_3$$

Resultant load on rivet 5

$$F_R)_5 = \sqrt{F_d^2 + F_5^2 + 2F_d F_5 \cos \theta_5}$$

Where  $\theta_5 = 50 + 90 = 140^\circ$

$$\begin{aligned} F_R)_5 &= \sqrt{(5000)^2 + (8182.27)^2 + 2(5000)(8182.27)\cos(140)} \\ &= 5410.1N \end{aligned}$$

Since  $\theta_6 > \theta_3$ ,  $F_6 = F_3$

$$\cos \theta_6 < \cos \theta_3$$

Hence,  $F_R)_6 < F_R)_3$

Therefore, rivet 3 is heavily loaded among the six rivets used in the joint and the load on this rivet is 22877.52N.

### Step V: Calculation of size of rivet 'd'

Equate  $F_R)_3$  to  $F_t$  to get 'd'

$$\text{i.e., } F_R)_3 = F_t$$

$$22877.52 = \frac{\pi d^2}{4} \tau$$

$$22877.52 = \frac{\pi d^2}{4} \times 60$$

Therefore,  $d = 22.033mm$

Adopt  $d = 24mm$  (Standard size)

## Welded Joint

**Definition**

Welding is defined as the localized union of metal parts in the plastic and molten states with the application of mechanical pressure or the union of parts in the molten state without any pressure.

**Methods of welding**

*There are three main methods of welding namely*

- a) *Forge welding.*
- b) *Pressure welding.*
- c) *Fusion welding.*

*Forge welding* is the oldest process known and is accomplished by either hand hammering (practiced by blacksmiths) or by machines (as in the case of manufacturing of wrought-Iron pipes and pressure vessels). This type of welding can be applied to only wrought Iron and low carbon steels.

*Pressure welding* (also known as *Resistance welding*) utilizes the heat produced by an electric current which passes through the two parts to be welded. The current raises the temperature of metal parts to a molten state and the pressure applied unites them. Pressure welding if properly done results in a joint which is practically as strong as the materials joined.

*Spot welding* is another form of resistance welding and is used sometimes instead of riveting. It is usually done on plates of thickness less than 20mm.

*Seam welding* is development of spot welding and in this process, the electrodes are in the form of two rollers between which the overlapping edge of thin plates are pressed thereby producing a continuous strip of welded surfaces.

In *Fusion welding* no pressure is applied to form the weld. The place of contact of the two metal parts to be joined are heated to the fusion temperature of metal; addition metal is usually applied to the corner of joint by melting a filler rod the joint is allowed to cool. The heating of metal is produced in one of the following ways; by a *burning gas*, by an *electric arc* or by *thermit*.

*Gas welding* uses a blue flame produced by the combustion of oxygen and hydrogen. It is used for welding non-ferrous metals of low fusibility. Here the temperature obtained is above 2200°C.

The *oxy-acetylene* process of gas welding produced by the combustion of oxygen and acetylene and temperature of about 3500°C is attained. This process is used for welding steel, steel castings, wrought iron, cast iron, aluminum, copper and its alloys. It is also used to weld a metal to a dissimilar metal such as *steel to cast iron*, *copper to steel*.

In *Arc welding*, the necessary temperature is produced by an electric arc formed between the pieces to be welded and an electrode. The electrode may be either a carbon rod with a separate filler rod or a metal rod which acts as a filler rod.

**Types of welded joints**

Welded joints are broadly classified into two types namely

- a) *Butt welds*
- b) *Fillet welds*

**a) Butt welds**

*Figure-7.45*

Figure-7.45 shows a single V-groove weld laded with tensile load  $P$ . The average normal stress due to  $P$  is given by

$$\sigma_t = \frac{P}{hl}$$

Where ' $h$ ' is the *weld throat* and ' $l$ ' is the *length of weld*. It is obvious from figure-7.45 that the value of ' $h$ ' does not include the *reinforcement* which is very important to compensate for flaws. There is stress concentration at A. If the joint is subjected to fatigue loads, it is better to grind or machine off the reinforcement.

*Figure-7.46*

The average shear stress in a butt weld due to shear load is

$$\tau = \frac{P}{hl}$$

For the purpose of design, it is a practice to base the shear stress on *throat area*. Hence the equation of shear stress is

$$\tau = \frac{P}{0.707hl} \quad \dots \text{E(12.5a)}$$

Similarly the equation of tensile stress based on throat area is

$$\sigma_t = \frac{P}{0.707hl} \quad \dots \text{E(12-10)}$$

*Figure-7.47*

**Fillet welds**

Fillet welds are classified according to the direction of load as

- i) *Parallel fillet welds.*
- ii) *Normal fillet welds.*

iii) *Combined parallel and transverse welds.*

*Figure-7.48*

In parallel fillet welds shown in figure-7.48, welding is done along the fillet parallel to the load axis

*Figure-7.49*

In transverse weld shown in figure-7.49, welding (single transverse weld or double transverse weld) is done normal to the load axis.

Usually parallel fillet welds fail by shearing and transverse fillet welds fail by tearing.

*Figure-7.50*

In fillet welded joint (figure-7.50) with combined parallel and transverse welds, two parallel welds and single transverse weld are used. In special cases, to increase load carrying capacity or where the width of plate is limited, double transverse welds is suggested.

### ***Design procedure for welded joints***

- a) ***Design procedure for transverse fillet welds***  
 i) ***Determine the length of weld required using the formula***

$$l = \frac{P}{0.707h\sigma_t}$$

Where,

*P = Load in Newton*

*h = Size of weld in mm and*

*$\sigma_t$  is tensile stress for the weld material in  $N/mm^2$*

***Note:***

- i) ***If length obtained from the above equation is equal to or less than plate width 'b' used in the joint, then use only single transverse fillet weld.***

*Figure-7.51*

- ii) ***If length of weld 'l' exceeds the width of plate 'b', use double transverse welds in which case the length of weld on each side =  $\frac{l}{2}$***

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- iii) *The length of weld obtained from the above equation holds good for static loads. For dynamic or fatigue loads, the allowable tensile stress for the welding is obtained by dividing  $\sigma_t$  by the fatigue stress concentration factor  $K_{-\sigma}$  (Table-12.7).*
- iv) *A length of 10mm is to be added to the final length of weld for starting and stopping of beads.*

**b) Design procedure for parallel fillet welds**

The welds in parallel fillet welds are subjected to *shear loading* and the length of weld 'l' is obtained from the equation

$$l = \frac{P}{0.707h\tau}$$

- Where
- $\tau =$  Permissible shear stress in  $N/mm^2$
  - $h =$  Size of weld in mm
  - $l = l_1 + l_1 = 2l_1$

**Note:**

- i) *Here the width of plate 'b' has no effect on the load carrying capacity.*

Figure-7.52

*The length of weld 'l' required is equally distributed along the two edges of plate. i.e.,  $l_1 = \frac{l}{2}$*

- ii) *For fatigue of dynamic loads, shear stress  $\tau$  is to be divided by fatigue stress concentration factor  $K_{-\sigma}$  for parallel welds obtained from table (12-7).*
  - iii) *A length of 10mm is to be added for length of weld on each side for starting and stopping of beads.*
- c) Design procedure for joints with combined transverse and parallel welds**

Figure-7.53

For single transverse and double parallel welds, the length of welding required is obtained from the relation,

*Total load  $P =$  Load carried by transverse weld + Load carried by parallel welds*

$$\begin{aligned} \text{i.e., } P &= P_{\text{transverse}} + P_{\text{parallel}} \\ &= 0.707hl_2\sigma_t + 0.707h(2l_1)\tau \end{aligned} \quad \dots (1)$$

**Note:**

- i) *The length of weld for transverse welding  $l_2$  is generally equal to the width of plate 'b' and hence  $l_1$ , the length of each parallel weld can be obtained from equation-1.*
- ii) *The load 'P' the joint can withstand is obtained from equation  $P = bh\sigma_t$   
Where  $h =$  Plate thickness, mm  
 $b =$  Width of plate, mm  
 $\sigma_t =$  Tensile stress of material of plate welded,  $N/mm^2$*
- iii) *For dynamic or fatigue loads, the values of  $\sigma_t$  and  $\tau$  are to be divided by the corresponding fatigue stress concentration factors obtained from Table (12.7)*

**Design procedure for welded joint with eccentric loading**

The following steps are to be followed in designing a welded joint subjected to eccentric loading

**Step I: Location of G, the centre of gravity of weld (Table 12.3)**

Considering the left edge of plate welded as y-axis and bottom edge as x-axis, obtain G, the centre of gravity of weld by using equations as given in Table (12.3)

Figure-7.54

**Note:** *For the welded joint shown, the welding is symmetrical about horizontal axis (i.e., x-x) and hence*

$$\bar{y} = \frac{d}{2}$$

And  $\bar{x} = c_y = \frac{b^2}{2b+d}$

Where,  $b =$  Length of parallel weld  
 $d =$  Length of transverse weld

**Step II: Calculation of direct load  $P_d$  on welding**

$P_d$  is obtained by dividing the *total load* on the welding by the *total length of weld*. In the example considered

$$d_d = \frac{P}{b+b+d}$$

$$= \frac{P}{2b+d} \text{ N-mm}$$

**Note:** The load  $P_d$  acts at the farthest corner of welding i.e., at ‘A’ or ‘B’ in the joint, parallel to the applied load  $P$  and in the direction of  $P$  (similar to the eccentrically loaded riveted joint)

Figure-7.55

**Step III: Calculation of secondary load  $P_n$**

The secondary load (due to eccentricity in loading) is obtained using the formula

$$P_n = \frac{Per}{J} \quad \dots \text{ E(12.20)}$$

Where,

$P$  = Load applied in N

$e$  = Eccentricity = Distance of load line from CG of weld

$r$  = Distance of farthest end A or B or weld from CG ‘G’

i.e., 
$$r = AG = BG = \sqrt{\left(\frac{d}{2}\right)^2 + (b - c_y)^2}$$

$J$  = Polar moment of inertial of weld ... (Refer Table 12.3)

For the joint being analyzed,

$$J = \frac{(2b+d)^3}{12} - \frac{b^2(b+d)^2}{2b+d} \quad \dots \text{ T(12.3)}$$

**Note:**  $P_n$  acts normal to ‘ $r$ ’ at A so as to produce clockwise moment as that produced by ‘ $P$ ’ about ‘ $G$ ’.

For the joint considered, load  $P$  produces *clockwise moment*  $P_e$  about  $G$  and hence

$P_n$  should produce clockwise moment  $P_n r$  about  $G$ .

**Step IV: Calculation of resultant load  $P_R$  at point A**

$$P_R = \sqrt{P_d^2 + P_n^2 + 2P_d P_n \cos \theta} \quad \dots \text{E(12.21)}$$

Where  $\theta$  is the angle between  $P_d$  and  $P_n$

From figure-7.55,

$$\begin{aligned} \cos \theta &= \frac{GK}{OA} \\ &= \frac{b - \bar{x}}{r} = \frac{b - c_y}{r} \end{aligned}$$

**Step V: Calculation of size of weld ‘h’**

The size of weld is obtained from formula

$$\tau = \frac{P_R}{0.707h}$$

Where  $\tau = \text{Shear stress in weld, } N/mm^2$

$P_R = \text{Resultant load in, } N/mm$

$h = \text{Size of weld in mm}$

**Note:** Generally, the size of weld is 0.8 times the plate thickness (thumb rule) for fillet welds.

**Example 7.24:** A steel plate 15mm thick and 50mm wide is welded to another plate by transverse weld to sustain a tensile load of 25kN. Determine the length of weld required by taking the permissible stress equal to 110MPa. When

- i) The load is static
- ii) The load is dynamic.

**Solution:**

Figure-7.56

**i) Static Load**

The welding is subjected to tensile load  $P$ . Since the welding is normal to load  $P$ , the

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tensile stress in the weld is given by

$$\sigma_t = \frac{P}{0.707hl}$$

Where,  $\sigma_t = 110\text{MPa}$

$$P = \text{Load} = 25\text{kN} = 25 \times 10^3 \text{ N}$$

$$h = \text{Size of weld / Thickness of plate} = 15\text{mm}$$

$$l = \text{Length of weld, mm}$$

Therefore,  $l = \frac{P}{0.707h\sigma_t}$

$$= \frac{25 \times 10^3}{0.707 \times 15 \times 110} = 21.4\text{mm}$$

Therefore, Length of weld = 21.4mm < Width of plate  $b = 50\text{mm}$

#### ii) Dynamic Load

$$\text{Permissible tensile stress} = \frac{\sigma_t}{\text{Fatigue stress concentration factor}}$$

Fatigue stress concentration factor,  $K_{-\sigma} = 1.5$  for transverse welds ... T(12.7)

Therefore,  $\sigma_t)_{\text{allowable}} = \frac{110}{1.5} = 73.33 \text{ N/mm}^2$

Therefore, Length of weld required is

$$l = \frac{P}{0.707h\sigma_t)_{\text{allowable}}}$$
$$= \frac{25 \times 10^3}{0.707 \times 15 \times 73.33} = 38.147\text{mm}$$

Since Length of weld < Width of plate, a single transverse fillet weld is sufficient for load P.

**Note:** Add 10mm to the lengths calculated for starting and stopping of beads.

Therefore, Length of weld = 31.45mm when load is static.  
= 48.147mm when the load is dynamic.

**Example 7.25:** A M.S. plate 10mm thick and 55mm wide welded to another plate by normal fillet welds is subjected to a tensile load of 40kN. Determine the length of weld required taking permissible tensile stress as 100MPa. When

- i) The load is static
- ii) The load is dynamic.

Figure-7.57

**Solution:**

**Case I: Static weld**

**Note:** Normal welds (transverse welds) are subjected to tearing and hence the tensile stress in welds is given by

$$\sigma_t = \frac{P}{0.707hl}$$

Where,  $\sigma_t = \text{Tensile stress} = 100\text{MPa}$

$P = \text{Tensile load} = 40\text{kN} = 40 \times 10^3 \text{ N}$

$h = \text{Thickness of plate} = 10\text{mm}$

$l = \text{Length of weld, mm}$

Therefore,

$$100 = \frac{40 \times 10^3}{0.707 \times 10 \times l}$$

$$l = 56.577\text{mm} = 56.58\text{mm}$$

**Note:** Here, the length of weld required is more than width of plate. Hence a single transverse weld is not sufficient to withstand load and a double transverse weld is to be used.

Therefore, The length of weld on each side

$$= \frac{56.58}{2} = 28.29\text{mm}$$

Adding 10mm for starting and stopping of beads

$$l = 28.29 + 10 = 38.29\text{mm}$$

**Case II: Dynamic load**

When the load is dynamic, the joint fails at a lower value of stress compared to static load. The design tensile stress is obtained by dividing the tensile stress by *fatigue stress concen-*

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traction factor  $K_{-\sigma}$

For normal welds, stress concentration factor  $K_{-\sigma} = 1.5$  (Refer Table (12.7))

Therefore, Allowable tensile stress

$$= \frac{100}{1.5} = 66.67 \text{ N/mm}^2$$

From, 
$$\sigma_t = \frac{P}{0.707hl}$$

$$66.67 = \frac{40 \times 10^3}{0.707 \times 10 \times l}$$

$$l = 84.86 \text{ mm}$$

The length of weld  $l >$  Width of plate  $b = 55 \text{ mm}$

Hence a single transverse weld is not sufficient and double transverse weld is to be used.

The length of weld on each side

$$= \frac{84.86}{2} = 42.43 \text{ mm}$$

Adding 10mm on each side for starting and stopping of beads,

$$\text{Length of weld } l = 42.43 + 10 = 53.43 \text{ mm}$$

**Example 7.26:** A mild steel plate 15mm thickness is welded to another plate by two parallel welds to carry a load of 50kN. Determine the length of weld required. When

i) Load is static.

ii) Load is dynamic.

(VTU-Dec 08/Jan 09)

**Solution:**

Figure-7.58

**Note:** Parallel welds are subjected to shear and the shear stress in the welds is given by

$$\tau = \frac{P}{0.707hl} \quad \dots \text{E(12.5a)}$$

**Case I: Static Load**

Referring table (12.8) the permissible shear stress for static load is 75.8MPa

i.e., 
$$\tau = 75.8 \text{ MPa}$$

$$h = \text{Size of weld} = \text{Plate thickness} = 15\text{mm}$$

$$p = \text{Load} = 15\text{kN} = 50 \times 10^3 \text{ N}$$

$$l = \text{Total length of weld} = l_1 + l_1 = 2l_1$$

Substituting in E(12.5a),

$$75.8 = \frac{50 \times 10^3}{0.707 \times 15 \times l}$$

Therefore, Total length of weld  $l = 43.98\text{mm}$

Length of weld on each side

$$l_1 = \frac{43.98}{2} = 21.99\text{mm}$$

Adding 10mm for starting and stopping of beads,

$$l_1 = 21.99 + 10 = 31.99\text{mm}$$

$$\text{Say, } l_1 = 32\text{mm}$$

### Case II: Dynamic load

For dynamic load, use

$$\tau)_{\text{permissible}} = \frac{75.8}{K_{-\sigma}} = 20.07\text{MPa}$$

Where  $K_{-\sigma} = 2.7$  for parallel welds.

$$\text{Now, } 20.07 = \frac{P}{0.707hl}$$

$$20.07 = \frac{50 \times 10^3}{0.707 \times 15 \times l}$$

Therefore,  $l = 167.96\text{mm}$

Therefore Length of weld on each side

$$= \frac{167.96}{2} = 83.95\text{mm}$$

Adding 10mm for starting and stopping of beads

$$l = 83.98 + 10 = 93.98\text{mm} \approx 94\text{mm}$$

**Example 7.27:** A M.S. plate 50mm wide and 15mm thick is welded to another plate by a single transverse and double parallel fillet welds as shown in figure-7.59. Determine

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*the length of parallel weld when*

- i) *The load is static.*
- ii) *The load is dynamic.*

**Solution:**

*Figure-7.59*

If  $P_{Transverse}$  and  $P_{Parallel}$  are the loads carried by *transverse* and *parallel welds* respectively, then

$$P = P_{Transverse} + P_{Parallel}$$

Where  $P = (\text{Area of cross section of plate})\sigma_t$   
 $= (bh)\sigma_t$

$$b = \text{Width of plate} = 50\text{mm}$$

$$h = \text{Thickness of plate} = 15\text{mm}$$

$$\sigma_t = 110.3\text{MPa} \quad \dots \text{T(12.8)}$$

$$\tau = 75.8\text{MPa for static loading} \quad \dots \text{T(12.8)}$$

Therefore,  $P = 50 \times 15 \times 110.3\text{N}$   
 $= 82725\text{N}$

**Case I: Static load**

$$P = P_{Transverse} + P_{Parallel}$$

Where  $P_{Transverse} = 0.707h_2l_2\sigma_t$   
 $= 0.707 \times 15 \times l_2 \times 110.3$   
 $= 0.707 \times 15 \times b \times 110.3 \quad (\text{since } l_2 = b)$   
 $= 0.707 \times 15 \times 50 \times 110.3$   
 $= 54486.575\text{N}$

$$P_{Parallel} = 0.707h(l_1 \times 2)\tau$$
$$= 0.707h(l_1 \times 2) \times 75.8$$
$$= 1607.72l_1$$

i.e.,  $p = 82725 = 54486.575 + 1607.72l_1$

$$l_1 = 15.08\text{mm} = \text{Length of each parallel weld}$$

**Case II: Dynamic load (fatigue load)**

**Note:** For fatigue loading, the values of tensile and shear stresses are divided by fatigue stress concentration factors obtained from Table (12-7)

$$\begin{aligned} \text{Therefore, } \sigma_t)_{\text{allowable}} &= \frac{110.3}{K_{-\sigma}} \\ &= \frac{110.3}{1.5} = 73.53\text{MPa} \end{aligned}$$

$$\begin{aligned} \tau_{\text{allowable}} &= \frac{75.8}{K_{-\sigma}} \\ &= \frac{75.8}{2.7} = 28.07\text{MPa} \end{aligned}$$

$$\begin{aligned} \text{Therefore, } P &= P_{\text{Transverse}} + P_{\text{Parallel}} \\ 82725 &= 0.707 \times 15 \times l_2 \times 73.53 + 0.707 \times 15 \times (2l_1) \times 28.07 \\ &= 0.707 \times 15 \times 50 \times 73.53 + 0.707 \times 15 \times (2l_1) \times 28.07 \\ &= 38989.3 + 595.37l_1 \end{aligned}$$

$$\text{Therefore, } l_1 = \text{Length of each parallel weld} = 73.46\text{mm}$$

**Note:** Add 10mm to  $l_1$  in both the above cases for starting and stopping of beads.

**Example 7.28:** A plate 80mm wide and 15mm thick is joined with another plate by a single transverse weld and a double parallel weld. Determine the length of parallel fillet weld if the joint is subjected to both static and fatigue loading (separately). Taking  $\sigma_t = 90\text{MPa}$ ,  $\tau = 55\text{MPa}$  as allowable stresses and stress concentration factor as 1.5 for transverse weld and 2.7 for parallel weld. (VTU-July/August 2003)

**Solution:**

Figure-7.60

**Case I: Static loading**

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$$\text{Load } P = P_{\text{Transverse weld}} + P_{\text{Parallel weld}}$$

$$\begin{aligned}\text{Where, } P &= bh\sigma_t \\ &= 80 \times 15 \times 90 = 108000N\end{aligned}$$

$$P_{\text{Transverse}} = 0.707hl_2\sigma_t$$

$$P_{\text{Parallel}} = 0.707h(2l_1)\tau; \quad (\text{Here } l_2 = b = 80\text{mm})$$

$$\text{Therefore } 108000 = 0.707 \times 15 \times 90 + 0.707 \times 15 \times (2l_1) \times 55$$

$$\text{Therefore, Length of parallel weld } l_1 = 27.13\text{mm}$$

### Case II: Fatigue loading

$$\begin{aligned}\sigma_t)_{\text{permissible}} &= \frac{\sigma_t}{\text{Fatigue stress concentration factor for transverse welding}} \\ &= \frac{90}{1.5} = 60\text{MPa}\end{aligned}$$

$$\begin{aligned}\tau)_{\text{permissible}} &= \frac{\tau}{\text{Fatigue stress concentration factor for parallel welding}} \\ &= \frac{55}{2.5} = 20.37\text{MPa}\end{aligned}$$

Therefore, Load  $P = P_{\text{Transverse}} + P_{\text{Parallel}}$  becomes

$$108000 = 0.707h \times l_2 \times (\sigma_t)_{\text{permissible}} + 0.707h(2l_1)(\tau)_{\text{permissible}}$$

$$108000 = 0.707 \times 15 \times 80 \times 60 + 0.707 \times 15 \times (2l_1) \times 20.37$$

$$\text{Therefore, } l_1 = 132.15\text{mm}$$

Adding 10mm for starting and stopping of beads,

$$l_1 = 132.15 + 10 = 142.15\text{mm}$$

**Example 7.29:** An unequal leg angle section designated by  $125\text{mm} \times 100\text{mm} \times 10\text{mm}$  is to be welded to a steel plate by fillet welds along the 125mm long edges. The angle is subjected to a tensile load of 100kN passing through the C.G. of angle. Determine the length of welds taking the size of weld 8mm and allowable shear stress 80MPa. Also calculate the total length of weld and the individual length of welds if welding is done along 100mm edge.

**Solution:**

*Figure-7.61*

**Step I: Location of C.G. of angle (refer figure-7.62)**

*Figure-7.62*

The given  $L$  section is split into two rectangles (1) and (2).

$$\text{Then, } \bar{x} = \frac{a_1 x_1 + a_2 x_2}{a_1 + a_2}$$

$$\text{Where, } a_1 = (100 - 10)10 = 900\text{mm}^2$$

$$a_2 = 125 \times 10 = 1250\text{mm}^2$$

$$x_1 = 5\text{mm}$$

$$x_2 = \frac{125}{2} = 62.5\text{mm}$$

$$\text{Therefore, } \bar{x} = \frac{900 \times 5 + 1250 \times 62.5}{900 + 1250} = 38.43\text{mm}$$

Therefore, the load axis is 38.43mm from the extreme end of vertical edge having 100mm height.

**Note: Welding is done parallel to the load axis passing through CG. The total length of weld required is obtained from equation**

$$\tau = \frac{P}{0.707hl}$$

$$\text{Where, } \tau = \text{Allowable shear stress} = 80\text{MPa}$$

$$P = \text{Load (tensile)} = 100\text{kN} = 100 \times 10^3 \text{N}$$

$$h = \text{Size of weld} = 8\text{mm}$$

Therefore, substituting the values we get

$$80 = \frac{100 \times 10^3}{0.707 \times 8 \times l}$$

$$\text{Therefore, } l = 221\text{mm}$$

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To obtain individual weld lengths  $l_1$  and  $l_2$

$$l = l_1 + l_2$$

$$\text{i.e., } l_1 + l_2 = 221 \quad \dots (i)$$

**Note:** *The lengths of weld are inversely proportional to the distance of load axis from welds.*

$$\text{i.e., } \frac{l_1}{l_2} = \frac{86.57}{38.43}$$

$$\text{i.e., } l_1 \times 38.43 = l_2 \times 86.57$$

$$l_1 = 2.253l_2$$

From (i) and (ii)

$$l_1 = 153.06\text{mm}$$

$$l_2 = 67.94\text{mm}$$

**Case II: Welding is done along 100mm edge**

*Figure-7.63*

**a) Location of centre gravity through which the load  $P$  acts (Figure-8.79)**

*Figure-7.64*

$$a_1 = (125 - 10)10 = 1150\text{mm}^2$$

$$a_2 = 100 \times 10 = 1000\text{mm}^2$$

$$x_1 = 5\text{mm}$$

$$x_2 = \frac{100}{2} = 50\text{mm}$$

$$\begin{aligned} \text{Therefore, } \bar{x} &= \frac{a_1x_1 + a_2x_2}{a_1 + a_2} \\ &= \frac{1150 \times 5 + 1000 \times 50}{1150 + 1000} \\ &= 25.93\text{mm} \end{aligned}$$

**b) Calculation of length of weld**

$$\text{Shear stress } \tau = \frac{P}{0.707hl'}$$

$$\text{i.e., } 80 = \frac{100 \times (10)^3}{0.707 \times 8 \times l'}$$

$$\text{Therefore, } l' = 221\text{mm}$$

**Note:** The total length of weld remains same whether welding is done along 100mm leg or 125mm leg.

$$\text{i.e., } l = l' = 221\text{mm}$$

**c) To find the length of individual welds ( $l'_1, l'_2$ )**

$$\text{We have, } l' = l'_1 + l'_2 = 221$$

$$\text{Also } \frac{l'_1}{l'_2} = \frac{74.07}{25.93} \quad \dots (1)$$

$$25.93l'_1 = 74.07l'_2$$

$$l'_1 = 2.8565l'_2 \quad \dots (2)$$

From (1) and (2), the length of individual welds are,

$$l'_2 = 57.31\text{mm}$$

$$l'_1 = 163.69\text{mm}$$

**Note:** The length of weld  $l'_1$  and  $l'_2$  may also be obtained by using equation from Table (12-1)

Figure-7.65

$$l'_1 = \frac{1.414Pe_2}{\sigma hb}$$

$$\text{Where, } P = 100\text{kN} = 100 \times 10^3 \text{ N}$$

$$e_2 = 100 - \bar{x}$$

$$= 100 - 25.93 = 74.07\text{mm}$$

$$\sigma = 80 \text{ N/mm}^2$$

## Riveted and Welded Joints

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$h = \text{Size of weld} = 8\text{mm}$

$b = \text{Length of leg of angle welded} = 100\text{mm}$

Therefore, 
$$l'_1 = \frac{1.414 \times 100 \times 10^3 \times 74.07}{80 \times 8 \times 100}$$
$$= 163.65\text{mm}$$

And 
$$l'_2 = \frac{1.414 P e_1}{\sigma h b}$$
$$= \frac{1.414 (100 \times 10^3) (25.93)}{80 \times 8 \times 100} = 57.35\text{mm}$$

### *Eccentrically loaded welded joint*

**Example 7.30:** A steel plate welded by fillet welds to a structure is loaded as shown in figure-7.66. Calculate the size of the weld if the load is 35kN and allowable shear stress for the weld material is 90MPa. (VTU-Feb 2002)

Figure-7.66

**Solution:**

**Step I:** Location of centre of gravity 'G' of welding (Figure-7.77)

Figure-7.77

The welding is symmetrical about horizontal axis

Therefore, 
$$\bar{y} = \frac{240}{2} = 120\text{mm}$$

$$\bar{x} = c_y = \frac{b^2}{2b + d} \quad \dots \text{T(12-3)}$$

Where  $b = 120\text{mm}$  and  $d = 240\text{mm}$

Therefore, 
$$c_y = \frac{(120)^2}{2 \times 120 + 240} = 30\text{mm}$$

Therefore, Eccentricity  $e = 480 + 120 - c_y$

$$= 600 - 30 = 570\text{mm}$$

The point A or B of weld is farthest from G. Hence its distance from G is

$$r = \sqrt{(b - c_y)^2 + \left(\frac{d}{2}\right)^2}$$

$$= \sqrt{(120 - 30)^2 + \left(\frac{240}{2}\right)^2} = 150 \text{ mm}$$

**Step II: To calculate direct load  $P_d$**

$$P_d = \frac{\text{Total load}}{l} = \frac{P}{l}$$

Where,  $l = \text{Total length of weld} = 2b + d$

$$P_d = \frac{35 \times 10^3}{(2 \times 120) + 240} = 72.92 \text{ N/mm}$$

**Note:**  $P_d$  acts parallel to applied load  $P$  and in the direction of  $P$ .

Figure-7.78

**Step III: To calculate secondary load  $p_n$**

$$p_n = \frac{Per}{J} \quad \dots \text{E(12-20)}$$

**Note:** 'J' is obtained from table (12-3)

For the joint under consideration,

$$J_w = \frac{(2b + d)^3}{12} = \frac{b^2(b + d)}{(2b + d)} \quad \dots \text{T(12-3)}$$

$$= \frac{(2 \times 120 + 240)^3}{12} - \frac{(120)^2(120 + 240)}{(2 \times 120) + 240}$$

$$= 9216 \times 10^3 - 3888 \times 10^3$$

$$J = 6328 \times 10^3 \text{ mm}^3$$

Therefore,  $P_n = \frac{35 \times 10^3 \times 570 \times 150}{5328 \times 10^3} = 561.66 \text{ N/mm}$

*Note:  $P_n$  acts at A perpendicular to r so as to produce clockwise moment about 'G' similar to that produced by P about G.*

*Step IV: To calculate the resultant load  $P_R$*

$$P_R = \sqrt{P_d^2 + P_n^2 + 2P_dP_n \cos \theta}$$

Where  $\theta$  is the angle between  $P_d$  and  $P_n$

From figure-7.78, from triangle AGK

$$\begin{aligned} \cos \theta &= \frac{GK}{GA} \\ &= \frac{(b - c_y)}{r} \\ &= \frac{120 - 30}{150} = 0.6 \end{aligned}$$

$$\begin{aligned} P_R &= \sqrt{(72.92)^2 + (561.66)^2 + 2(79.92)(561.66) \times 0.6} \\ &= 608.22 \text{ N/mm} \end{aligned}$$

*Step V: To calculate the size of weld 'h'*

$$\begin{aligned} \text{Shear stress } \tau &= \frac{P_R}{0.707h} \\ 90 &= \frac{608.29}{0.707 \times h} \end{aligned}$$

Therefore, Adopt  $h = 10\text{mm}$

**Example 7.31:** A 16mm thick steel plate is welded to a vertical support by two fillet welds as shown in figure-7.79. Determine the size of weld if the permissible shear stress for the weld material is 75MPa.

Figure-7.79

**Solution:**

**Step I: Location of CG**

Figure-7.80

For the give welding, from MDH, T (12-3)

$$c_y = \frac{b^2}{2(b+d)}$$

And  $c_x = \frac{d^2}{2(b+d)}$

Where,  $b = 100mm$   
 $d = 150mm$

Therefore,  $c_y = \frac{(100)^2}{2(100+150)} = 20mm$

$$c_x = \frac{(150)^2}{2(100+150)} = 45mm$$

Therefore, Eccentricity  $e = 350 - c_y$   
 $= 350 - 20 = 330mm$

**To locate the farthest end of weld from CG (i.e., distance  $r$ )**

From figure-7.80

$$r_1 = \sqrt{c_x^2 + (b - c_y)^2} \quad [\text{From triangle GKA}]$$

$$= \sqrt{(45)^2 + (100 - 20)^2} = 91.79mm$$

From triangle  $GLB$ ,

$$r_2 = \sqrt{c_y^2 + (b - c_x)^2}$$

$$= \sqrt{(20)^2 + (150 - 45)^2} = 106.89mm$$

From the values of  $r_1$  and  $r_2$ , we find that end  $B$  is far from  $G$  compared to  $A$ .

Therefore,  $r_2 = r = 106.89mm$

**Step II: Calculation of direct load  $P_d$**

$$P_d = \frac{P}{l}$$
$$= \frac{20 \times 10^3}{b+d}$$

Where,  $p = 20kN = 20 \times 10^3 N$   
 $l = b + d = 100 + 150 = 250mm$

Therefore,  $P_d = \frac{20 \times 10^3}{100 + 150} = 80 N/mm$

**Note:** This load  $P_d$  acts at  $B$  parallel to  $P$  and in the direction of it.

Figure-7.81

**Step III: Calculation of normal load (secondary load  $P_n$ )**

The secondary load  $P_n$  acts normal to 'r' at  $B$  (farthest end) and is given by,

$$P_n = \frac{Per}{J}$$
$$= \frac{(20 \times 10^3) \times 330 \times 106.89}{J}$$

For the given weld,

$$J = \frac{(b+d)^4 - 6b^2d^2}{12(b+d)} \quad \dots T(12-3)$$

Where,  $b = 100mm$  and  $d = 150mm$

Therefore,  $J = \frac{(100+150)^4 - 6(100)^2(150)^2}{12(100+150)} = 852083.33mm^3$

$$P_n = \frac{20 \times 10^3 \times 330 \times 106.89}{852083.33} = 827.94 N/mm$$

**Step V: Calculation of resultant load on rivet ( $P_R$ )**

$$P_R = \sqrt{P_d^2 + P_n^2 + 2P_dP_n \cos \theta}$$

Where,  $P_d = 80 \text{ N/mm}$   
 $P_n = 827.94 \text{ N/mm}$   
 $\theta = \text{Angle between } P_d \text{ and } P_n$

From figure-7.81,  $\theta = (90 + \beta)$

Also,  $\sin \alpha = \frac{c_y}{r_2} = \frac{20}{106.89}$  (From triangle BKG)

$$\sigma = 10.78^\circ = \beta$$

$$\theta = 90 + \beta$$

$$= 90 + 10.78 = 100.78^\circ$$

$$P_R = \sqrt{(80)^2 + (827.94)^2 + 2(80)(827.94)\cos 100.78^\circ}$$

$$= 846.77 \text{ N/mm}$$

Step IV: Calculation of size of weld 'h'

Now,  $\tau = \frac{P_R}{0.707h} = \frac{846.77}{0.707h}$

Therefore, size of weld  $h = 15.96 \text{ mm}$

Adopt  $h = 16 \text{ mm}$

**Example 7.32:** For the eccentrically loaded welded joint shown in figure-7.82, determine the size of weld required if the permissible shear stress is  $80 \text{ N/mm}^2$ .

Figure-7.82

**Solution:**

**Step I: Location of centre of gravity 'G'**

Because of symmetry, the CG lies at G as shown in figure-7.83

Figure-7.83

$$\text{Eccentricity } e = 500 + 50 = 550 \text{ mm}$$

**Step II: Calculation of direct load  $P_d$**

$$P_d = \frac{P}{\text{Total length of weld}}$$

$$= \frac{P}{2b} = \frac{40 \times 10^3}{200} = 200 \text{ N/mm}$$

**Note:**  $P_d$  acts at A (or B) parallel to  $P$  and in the direction of  $P$  as shown.

**Step III: Calculation of secondary load  $P_n$**

$$P_n = \frac{Per}{J} \quad \dots \text{E(12-20)}$$

Where  $J = \frac{b^3 + 3bd^2}{6} \quad \dots \text{T(12-13)}$

Where  $b = 100\text{mm}$  and  $d = 100\text{mm}$

$$J = \frac{(100)^3 + 3 \times 100 \times 100^2}{6}$$

$$= 666666.67 \text{ mm}^3$$

$$e = 550\text{mm}$$

$r =$  Distance of farthes corner of weld  
from G = Distance of A from G

$$= \sqrt{50^2 + 50^2} = 70.71\text{mm}$$

**Figure-7.84**

**Note:**  $P_n$  acts at A normal to 'r' so as to produce clockwise moment as that produced by  $P$  about G

**Step IV: Calculation of resultant load  $P_R$**

$$P_R = \sqrt{P_d^2 + P_n^2 + 2P_dP_n \cos \theta}$$

Where  $\theta =$  Angle between  $P_d$  and  $P_n = 45^\circ$

$$P_R = 2478.89 \text{ N/mm}$$

**Step V: To calculate size of weld 'h'**

$$\text{Shear stress } \tau = \frac{P_R}{0.707h}$$

$$\text{i.e., } 80 = \frac{P_R}{0.707h} = \frac{2478.89}{0.707h}$$

$$\text{Therefore, } h = 43.83\text{mm}$$

$$\text{Adopt } h = 44\text{mm}$$

**Example 7.33:** An M.S. plate of width 50mm is welded to another vertical plate by two parallel welds as shown in figure-7.85 to sustain a load of 20kN. Determine the size of weld by taking shear stress in weld as  $80 \text{ N/mm}^2$ .

Figure-7.85

**Solution:**

**Step I: Location of centre of gravity G**

Because of symmetry, CG lies at G at a distance of  $(300 + 50)\text{mm}$  from O. Refer figure-7.86.

$$\text{Therefore, Eccentricity } e = 300 + 50 = 350\text{mm}$$

Figure-7.86

**Step II: To calculate direct load  $P_d$**

$$P_d = \frac{P}{\text{Total length of weld}}$$

$$= \frac{P}{2d} = \frac{20 \times 10^3}{2 \times 50} = 200 \text{ N/mm}$$

**Note:**  $P_d$  acts as A (or B), the farthest end of welding parallel to load P and in the direction of it. Here all the four corners of weld A, B, C and D are equidistant from G.

**Step III: To calculate secondary load**

The secondary load due to eccentricity is given by,

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$$P_n = \frac{Per}{J}$$

Where,

$$P = 20 \times 10^3 \text{ N}$$

$$e = 350 \text{ mm}$$

$$r = \text{Distance of } A \text{ from } G$$

$$= \sqrt{50^2 + 25^2} = 55.9 \text{ mm}$$

For the given weld,

$$J = \frac{d(3b^2 + d^2)}{6} \quad \dots \text{T(12-3)}$$

$$= \frac{50[3 \times (100)^2 + 50^2]}{6}$$

$$= 270.83 \text{ mm}^3$$

$$P_n = \frac{20 \times 10^3 \times 350 \times 55.9}{270.83}$$

$$= 1444.8 \text{ N/mm}$$

$P_n$  acts normal to 'r' so as to produce clockwise moment about G (similar to that produced by P about G).

**Step IV: To calculate the resultant load  $P_R$**

$$P_R = \sqrt{P_d^2 + P_n^2 + 2P_dP_n \cos \theta}$$

Where

$$P_d = 200 \text{ N/mm}$$

$$P_n = 1444.8 \text{ N/mm}$$

From figure 7.86,

$$\cos \theta = \frac{GK}{OA}$$

$$= \frac{50}{r} = \frac{50}{55.9} = 0.8945$$

$$P_R = \sqrt{(200)^2 + (1444.8)^2 + 2 \times 200 \times 1444.8 \times 0.8945}$$

**Step V: To calculate the size of weld  $h$**

$$\text{Shear stress, } \tau = \frac{P_R}{0.707h}$$

$$\text{Therefore, } 80 = \frac{1626.16}{0.707h}$$

$$h = 28.75\text{mm}$$

Therefore, Size of weld  $h = 29\text{mm}$

### ***Exercise***

- 1) *Design a triple riveted lap joint with zig-zag riveting for steel plates 15mm thick. Use allowable values of stresses 60, 90 and 120MPa in shear, tension and crushing respectively.*
- 2) *Design a triple riveted lap joint with pitch in the outer row to be twice that in the inner row of steel plates 7mm thick. Use  $\sigma_t = 90\text{MPa}$ ,  $\tau = 60\text{MPa}$  and  $\sigma_c = 120\text{MPa}$ . Make a neat freehand sketch of joint.*
- 3) *Design a double riveted butt joint with chain riveting with single cover plate for steel plates 20mm thick. The permissible values of shear, tension and crushing stresses are 60, 90 and 120MPa respectively.*
- 4) *Design completely the longitudinal and circumferential joint for a boiler of 2 meter diameter to withstand steam pressure of 2.5MPa. The rivets in double shear may be assumed to be 87.5% more stronger than rivets failing by single shear. The allowable values of shear, tension and compressive stresses for plates and rivets may be taken as 60, 90 and 120MPa respectively.*
- 5) *Design a double riveted butt joint with double cover plates of equal width for steel plates 15mm thick using a tensile stress of 90MPa for plates. The allowable values in shear and compression may be taken as 60 and 120MPa respectively.*
- 6) *Design a triple riveted butt joint with double butt straps of unequal width for steel plates 20mm thick. The allowable value of tensile stress for plates may be taken as 95MPa. The design values of shear and crushing stresses for rivets may be taken*

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as 60 and 120MPa respectively. Use zig-zag riveting. The rivets in double shear may be assumed to be 1.875 times stronger than rivets in single shear.

- 7) For the eccentrically loaded riveted shown in figure-7.87, determine the standard size of rivet required by taking the permissible values of stresses in shear 60MPa. Determine
- Locate, the critically loaded rivet.
  - Distance between the centre of gravity of rivets and the load.
  - The standard size of rivet required by taking design shear stress = 60MPa.
  - The shear stress induced in the rivet taking the size of rivet equal to 30mm.

**Figure-7.87**

- 8) A riveted joint with eccentric loading shown in figure-7.88 is to carry a load of 30kN. Determine the size of rivet required taking the permissible shear stress for rivet materials as 60MPa.

**Figure-7.88**

- 9) A steel plate 10mm thick and 50mm wide is to be welded to another plate by transverse filled welds to carry tensile load of 30kN. Determine the length of weld required by taking the design tensile stress for weld material as 110MPa. When (i) the load is static and (ii) Dynamic load.
- 10) A M.S. plate is welded to another plate by two parallel welds to carry a tensile load of 25kN. Determine the length of weld required for (i) Static load and (ii) Dynamic load.
- 11) An angle 100mm × 100mm × 10mm thick is to be welded to a steel plate along one of the edges to carry a tensile load of 80kN passing thorough the CG of weld. Determine the length of welds required by taking size of weld equal to 8mm. Also determine the length of individual parallel welds.
- 12) A steel plate is welded to a vertical column to carry a load of 50kN. Refer figure-7.89. Determine the size of the weld required by using an allowable shear stress of 110MPa for the weld material.

**Figure-7.89**

- 13) A 20mm thick plate is welded to a vertical support by two fillet welds as shown in

*figure-7.90. Determine the size of the weld required by taking the permissible shear stress for weld material equal to 80MPa.*

**Figure-7.90**

- 14) *For the eccentrically loaded welded joint shown in figure-7.91. Calculate the shear stress in the weld if the size of the weld is 30mm.*

**Figure-7.91**