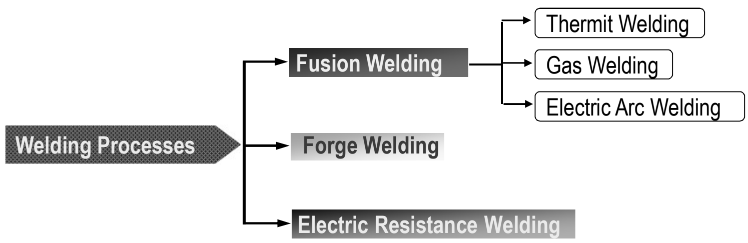
Welded Joints

Welded Joints

- A welded joint is a **permanent joint** which is obtained by fusion of the edges of the two parts to be joined together, with or without the application of pressure and a filler material

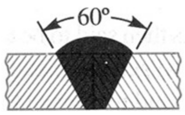
Applications of Welded Joints

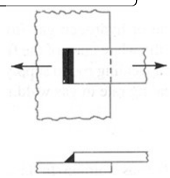
- Can be used as a substitute for a riveted joint
- Can be used as an alternative method for casting or forging
- Used as repair medium



Welded Joints

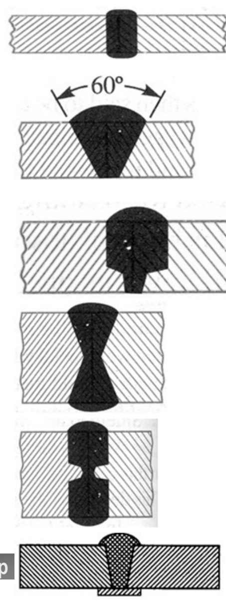
- Type of welded joints
  - Butt Joint
    - Square butt joint
    - Single V- butt joint
    - Single U- butt joint
    - Double V- butt joint
    - Double U- butt joint
    - V joint with backing strip
  - Lap or Fillet Joint
    - Single transverse fillet welded joint
    - Double transverse fillet welded joint
    - Parallel fillet welded joint
  - Other types of welded joint
    - Edge joint
    - Corner joint
    - T- joint





Welded Joints

- Butt Joint
  - Square butt joint
  - Single V- butt joint
  - Single U- butt joint
  - Double V- butt joint
  - Double U- butt joint
  - V joint with backing strip



- Joint between two components lying approximately in the same plane
- connects the end of the two plates
- The selection of the types of butt joint depends upon the plate thickness & the reliability

Butt Joint

Some guidelines

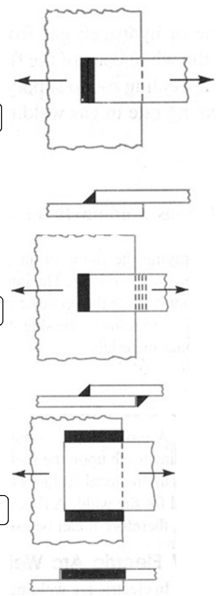
- When the thickness of the plates is less than 5 mm, it is not necessary to bevel the edges of the plates. There is no preparation of the edges of the plates before welding. The edges are square with respect to the plates <Square Butt Joint>
- When the thickness of the plates is more than 5 mm but within 20 mm, the edges are beveled before welding operation. The edges of two plates form V shape. This joint is called single V-butt joint. This joint is welded only from one side.
- When the thickness of the plates is more than 20mm but within 30 mm, the edges are machined to form U shape. This joint is called single U-butt joint. This joint is welded only from one side.
- When the thickness of the plates is more than 30 mm, a double V- joint or double U- joint are used. This joint is welded from both sides of the plate.
- When the welding is to be done only from one side, a single V-joint with backing strip is used to avoid the leakage of the molten metal on the other side.

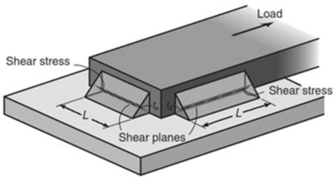
Welded Joints

Joint between two overlapping plates
- Weld consists of an approx. triangular cross-section joining two surfaces at right angles to each other

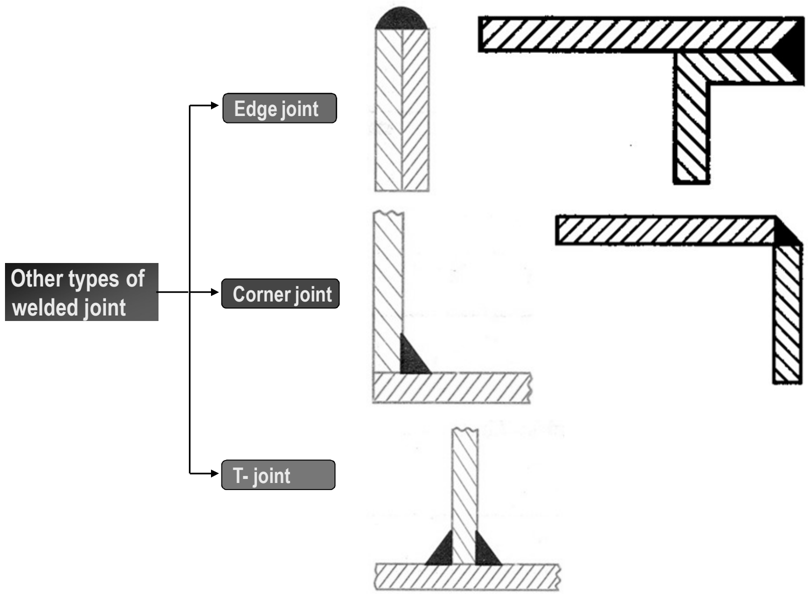
Lap or Fillet Joint

- Single transverse fillet welded joint
- Double transverse fillet welded joint
- Parallel fillet welded joint





Welded Joints



Welded Joints

Main considerations involved in the selection of weld type

- The shape of the welded component required
- The thickness of the plates to be welded
- The direction of the forces applied

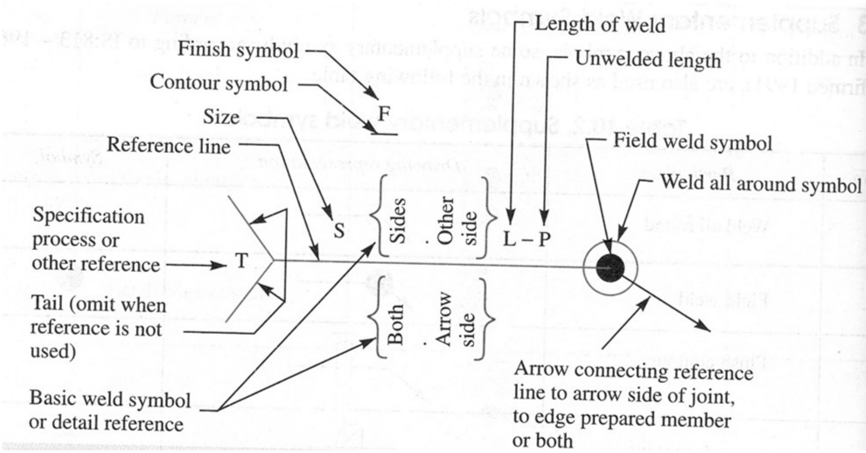
Basic Weld Symbols [*IS : 813: 1991*]

A weld symbol consists of following elements

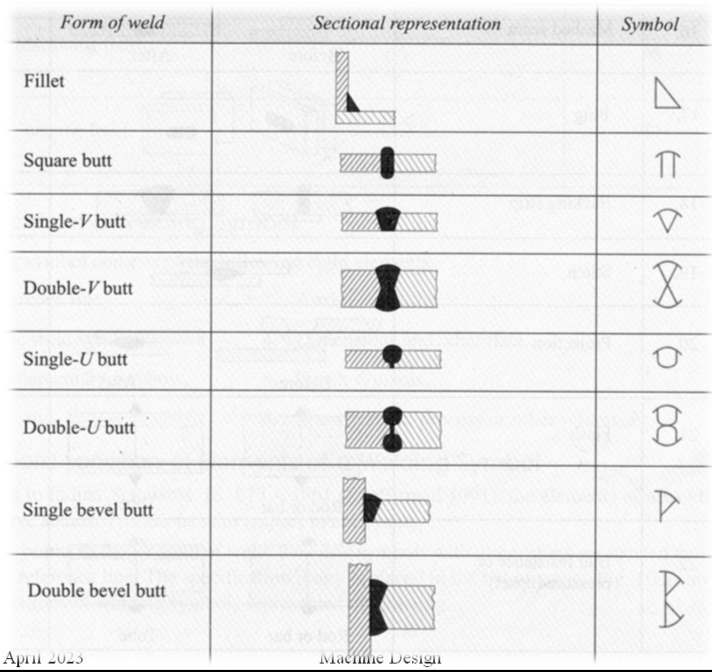
- A basic symbol to specify the type of weld
- An arrow & a reference line to indicate the location of the weld
- Dimensions of the weld (cross-section & length)
- Supplementary symbols to indicate special instructions such as weld around
- Finish symbols
- Specification, process or other reference

Welded Joints

Basic Weld Symbols [*IS : 813: 1991*]



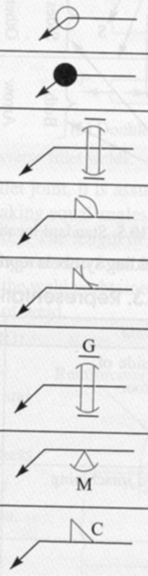
Welded Joints



Form of weld	*Sectional representation*	*Symbol*
Fillet		
Square butt		
Single-*V* butt		
Double-*V* butt		
Single-*U* butt		
Double-*U* butt		
Single bevel butt		
Double bevel butt		

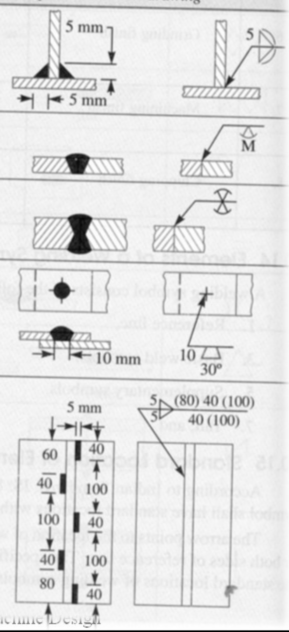
Welded Joints

Particulars	Drawing representation	Symbol
Weld all round		○
Field weld		●
Flush contour		—
Convex contour		⌒
Concave contour		◡
Grinding finish	G	G
Machining finish	M	M
Chipping finish	C	C



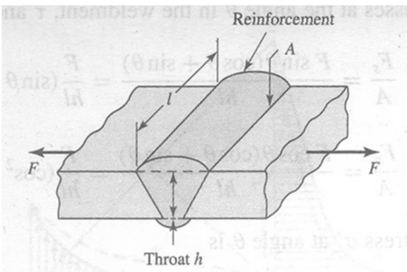
Welded Joints

Desired weld	Representation on drawing
Fillet-weld each side of Tee- convex contour	
Single V-butt weld -machining finish	
Double V- butt weld	
Plug weld - 30° Groove-angle-flush contour	
Staggered intermittent fillet welds	



Design for Static Load

Butt Welds



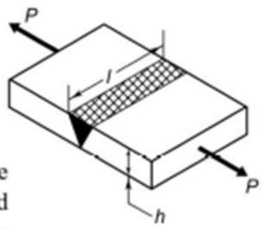
(a) Tensile loading

A butt welded joint, subjected to tensile force P, is shown in Fig. 8.5. The average tensile stress in the weld is given by,

$$\sigma_t = \frac{P}{hl} \tag{8.1}$$

where,

σ_t = tensile stress in the weld (N/mm^2)
P = tensile force on the plates (N)
h = throat of the butt weld (mm)
l = length of the weld (mm)



The throat of the weld does not include the bulge or reinforcement. The reinforcement is provided to compensate for flaws in the weld. Equating the throat of the weld h to the plate thickness t

the strength equation of butt joint can be written as,

$$P = \sigma_t t l$$

where,

P = tensile force on plates (N)

σ_t = permissible tensile stress for the weld (N/mm^2)

t = thickness of the plate (mm)

There are certain codes, like code for unfired pressure vessels, which suggest reduction in strength of a butt welded joint by a factor called *efficiency of the joint*. Where the strength is to be reduced, Eq. (8.2) is modified and rewritten in the following way,

$$P = \sigma_t t l \eta$$

where,

η = efficiency of the welded joint (in fraction)

Example 8.1 *A gas tank consists of a cylindrical shell of 2.5 m inner diameter. It is enclosed by hemispherical shells by means of butt welded joint as shown in Fig. 8.6. The thickness of the cylindrical shell as well as the hemispherical cover is 12 mm. Determine the allowable internal pressure to which the tank may be subjected, if the permissible tensile stress in the weld is 85 N/mm^2.*

Assume efficiency of the welded joint as 0.85.

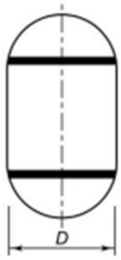


Fig. 8.6

Solution

Given For shell, $D = 2.5$ m $t = 12$ mm

For weld, $\sigma_t = 85$ N/mm^2 $\eta = 0.85$

Step I *Tensile force on plates*

The length of the welded joint is equal to the circumference of the cylindrical shell.

$l = \pi D = \pi (2.5 \times 10^3) = 7853.98$ mm

From Eq. (8.3),

$P = \sigma_t t l \eta = (85)(12)(7853.98)(0.85)$

$= (6809.4 \times 10^3)$ N

Step II *Allowable internal pressure*

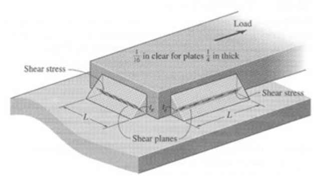
Corresponding pressure inside the tank is given by

$$p = \frac{P}{\frac{\pi}{4} D^2} = \frac{(6809.4 \times 10^3)}{\frac{\pi}{4} (2.5 \times 10^3)^2} = 1.39 \text{ N/mm}^2$$

Analysis of Fillet Welds

Loading pattern

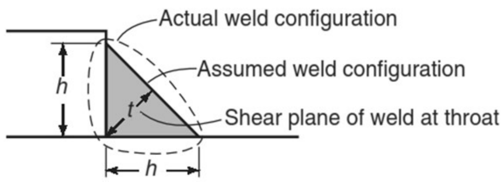
- **Axial loading**
- **Eccentric loading**



Strength of Parallel Fillet Welds

Dimension of Fillet Weld

- Leg length of the weld (h)
- Length of the weld (l)



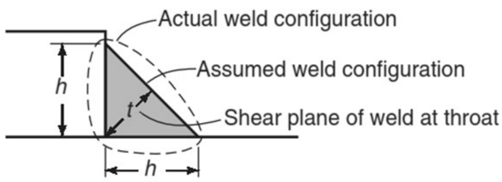
The size of the weld is specified by the Leg length of the weld (h)

The *throat* is the minimum cross-section of the weld located at 45° to the leg dimension. Therefore,

$$t = h \cos(45°)$$

or

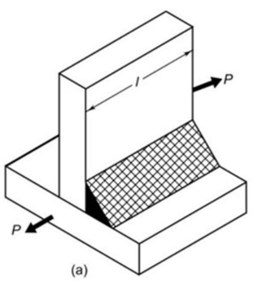
$$t = 0.707\, h$$

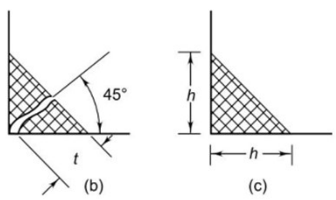


Fillet Weld:

- Leg length of the weld (h)
- Throat of the weld (t)

Strength of Parallel Fillet Welds



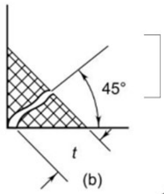


(a)

Failure of the fillet weld occurs due to shear along the minimum cross-section at the throat.

for parallel fillet weld, the inclination of the plane where maximum shear stress is induced, is 45° to the leg dimension. The shear failure of the weld is shown in Fig. 8.7(b). The cross-sectional area at the throat is (tl) or ($0.707\ hl$). The shear stress in the fillet weld is given by,

$$\tau = \frac{P}{0.707\,hl}$$



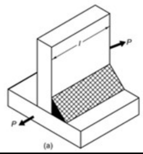
where,

P = tensile force on plates (N)

h = leg of the weld (mm)

l = length of the weld (mm)

τ = permissible shear stress for the weld (N/mm^2)



Strength of Parallel Fillet Welds

Rearranging the terms of Eq. (8.5), the strength equation of the parallel fillet weld is written in the following form:

$$P = 0.707\ hl\tau \qquad (8.6)$$

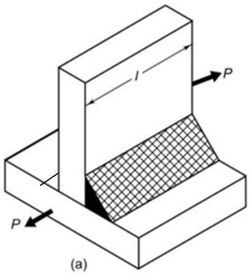
the permissible shear stress for the fillet welds is taken as 94 N/mm^2 as per the code of American Welding Society (AWS).

Usually, there are two welds of equal length on two sides of the vertical plate. In that case,

$$P = 2\ (0.707\ hl\tau)$$

or

$$P = 1.414\ hl\tau \qquad (8.7)$$



Example 8.2 *A steel plate, 100 mm wide and 10 mm thick, is welded to another steel plate by means of double parallel fillet welds as shown in Fig. 8.9. The plates are subjected to a static tensile force of 50 kN. Determine the required length of the welds if the permissible shear stress in the weld is 94 N/mm².*

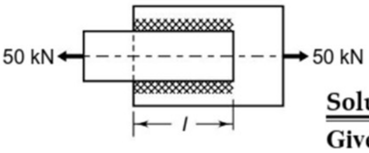
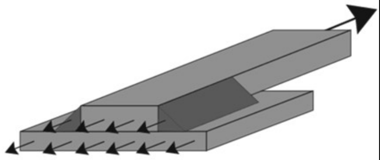


Fig. 8.9



Solution

Given $P = 50$ kN $\quad \tau = 94$ N/mm² $\quad h = 10$ mm

Step I *Length of weld*

From Eq. (8.7),

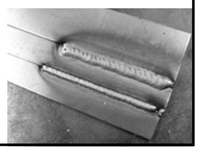
$$P = 1.414\, hl\tau$$

or $50 \times 10^3 = 1.414\,(10)\, l\,(94)$

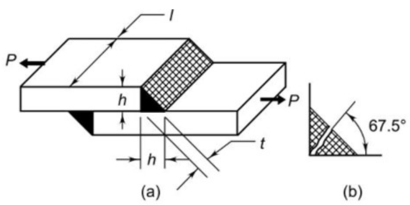
$\therefore \quad l = 37.62$ mm

Adding 15 mm of length for starting and stopping of the weld run, the length of the weld is given by,

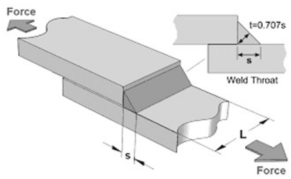
$l = 37.62 + 15 = 52.62$ or 55 mm



Strength of Transverse Fillet Welds



A transverse fillet weld subjected to a tensile force P is shown in Fig. 8.8(a). The transverse fillet welds are subjected to tensile stress. The minimum cross-section of the weld is at the throat. Therefore, the failure due to tensile stress will occur at the throat section. The cross-sectional area at the throat is (tl). The tensile stress in the transverse fillet weld is given by,



$$\sigma_t = \frac{P}{tl}$$

$t = h \cos(45°)$

$t = 0.707\, h$

Substituting Eq. (8.4) in the above equation,

$$\sigma_t = \frac{P}{0.707\, hl} \qquad (8.8)$$

Rearranging the terms of Eq. (8.8), the strength equation of the transverse fillet weld is written in the following form,

$$P = 0.707\ hl\sigma_t \qquad (8.9)$$

where,

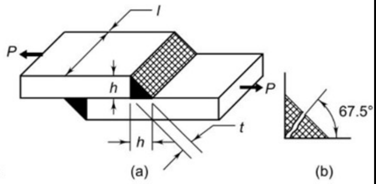
σ_t = permissible tensile stress for the weld (N/mm^2)

Usually, there are two welds of equal length on two sides of the plate as shown in Fig. 8.8(a). In such cases,

$$P = 2\ (0.707\ hl\sigma_t)$$

or

$$P = 1.414hl\sigma_t \qquad (8.10)$$



Example 8.3 *Two steel plates, 120 mm wide and 12.5 mm thick, are joined together by means of double transverse fillet welds as shown in Fig. 8.10. The maximum tensile stress for the plates and the welding material should not exceed 110 N/mm^2. Find the required length of the weld, if the strength of weld is equal to the strength of the plates.*

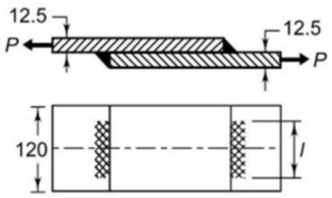


Fig. 8.10

Solution

Given For plates w = 120 mm t = 12.5 mm
For welds h = 12.5 mm σ_t = 110 N/mm^2

Step I *Tensile force on plates*

The plates are subjected to tensile stress. The maximum tensile force acting on the plates is given by,

$$P = (wt)\ \sigma_t = (120 \times 12.5)\ (110) = 165\ 000 \text{ N}$$

Step II *Length of the weld*

From Eq. (8.10),

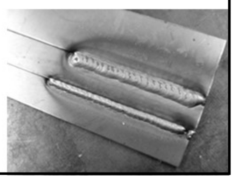
$P = 1.414\ h\ l\ \sigma_t$ or

$165\ 000 = 1.414\ (12.5)\ l\ (110)$

$\therefore\ l = 84.87$ mm

Adding 15 mm for starting and stopping of the weld run, the required length of the weld is given by,

$$l = 84.87 + 15 = 99.87 \text{ or } 100 \text{ mm}$$



Example 8.5 *A steel plate, 100 mm wide and 10 mm thick, is joined with another steel plate by means of single transverse and double parallel fillet welds, as shown in Fig. 8.12. The strength of the welded joint should be equal to the strength of the plates to be joined. The permissible tensile and shear stresses for the weld material and the plates are 70 and 50 N/mm² respectively. Find the length of each parallel fillet weld. Assume the tensile force acting on the plates as static.*

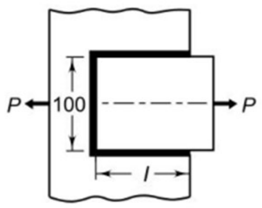


Fig. 8.12

Solution

Given For plates $w = 100$ mm $t = 10$ mm

For welds $h = 10$ mm $\sigma_t = 70$ N/mm^2

$\tau = 50$ N/mm^2

Step I *Tensile strength of plate*

The tensile strength of the plate is given by,

$$P = (w \times t)\ \sigma_t = (100 \times 10)\ (70) = 70\ 000 \text{ N} \qquad \text{(i)}$$

Step II *Strength of transverse and parallel fillet welds*

The strength of the transverse fillet weld is denoted by P_1. From Eq. (8.9),

$$P_1 = 0.707hl\sigma_t = 0.707\ (10)\ (100)\ (70)$$
$$= 49\ 490 \text{ N} \qquad \text{(ii)}$$

The strength of the double parallel fillet weld is denoted by P_2. From Eq. (8.7),

$$P_2 = 1.414hl\tau = 1.414\ (10)\ l\ (50) = 707 \times l \qquad \text{(iii)}$$

Step III *Length of parallel fillet weld*

The strength of the welded joint is equal to the strength of the plate.

From (i) , (ii) and (iii),

$$70\ 000 = 49\ 490 + 707 \times l$$

$$\therefore \qquad l = 29.01 \text{ mm}$$

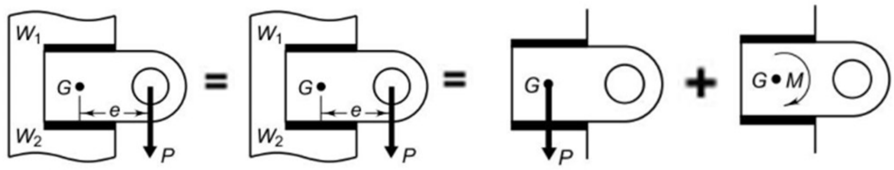
Adding 15 mm for starting and stopping of the weld run,

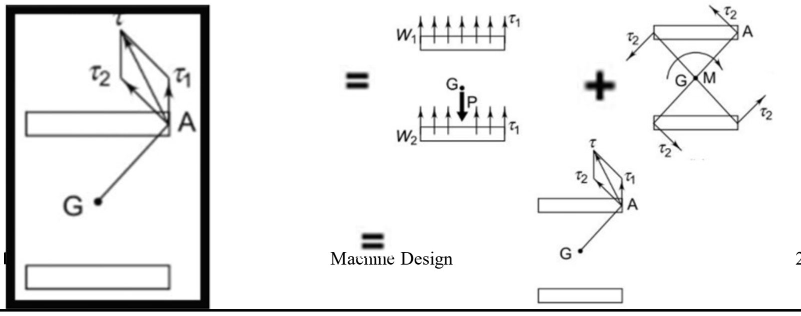
$$l = 29.01 + 15 = 44.01 \text{ or } 45 \text{ mm}$$

Loading pattern • **Eccentric loading**

Analysis of Eccentrically Loaded Welded Joint

ECCENTRIC LOAD IN THE PLANE OF WELDS





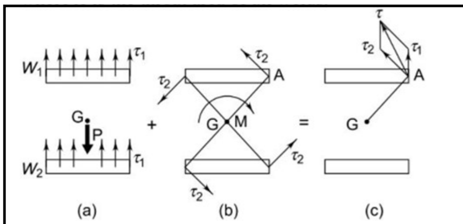


Fig. 8.20 *Primary and Secondary Shear Stresses*

The stresses in this welded joint are shown in Fig. 8.20. The force P acting through the centre of gravity causes direct shear stress in the welds [Fig. 8.20(a)]. It is called the *primary shear stress*. It is assumed that the primary shear stress is uniformly distributed over the throat area of all welds. Therefore,

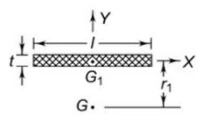
$$\tau_1 = \frac{P}{A_1} \qquad (8.21)$$

where A_1 is the throat area of all welds.

In this case, A_1=2.t.l

The couple M causes torsional shear stresses in the throat area of welds [Fig. 8.20(b)]. They are called *secondary shear stresses* and given by

$$\tau_2 = \frac{Mr}{J} \qquad (8.22)$$



where

r = distance of a point in the weld from G

J = polar moment of inertia of all welds about G

Figure 8.21 shows a weld of length l and throat t. G_1 is the centre of gravity of the weld, while G

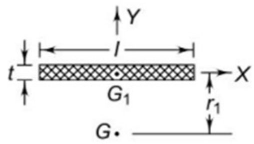


Fig. 8.21

is the centre of gravity of a group of welds. The moment of inertia of this weld about its centre of gravity G_1 is given by,

$$I_{xx} = \frac{lt^3}{12} \quad \text{and} \quad I_{yy} = \frac{tl^3}{12}$$

Since t is very small compared with l, I_{xx} is negligible compared with I_{yy}.

$$\therefore \quad J_{G_1} = I_{xx} + I_{yy} \cong I_{yy}$$

$$\text{or} \quad J_{G_1} = \frac{tl^3}{12} = \frac{tl(l^2)}{12} = \frac{Al^2}{12}$$

Therefore,

$$J_{G_1} = \frac{Al^2}{12} \tag{8.23}$$

where A is the throat area of the weld and J_{G_1} is the polar moment of inertia of the weld about its centre of gravity. The polar moment of inertia about an axis passing through G is determined by the parallel axis theorem. Thus,

$$J_G = J_{G_1} + Ar_1^2 \tag{8.24}$$

where r_1 is the distance between G and G_1. From Eqs (8.23) and (8.24),

$$J_G = A\left[\frac{l^2}{12} + r_1^2\right] \tag{8.25}$$

Where there are a number of welds, with polar moment of inertias J_1, J_2, J_3,…, etc., about the centre of gravity G, the resultant polar moment of inertia is given by,

$$J = J_1 + J_2 + J_3 + \cdots \tag{8.26}$$

The above value of J is to be used in Eq. (8.22) to determine secondary shear stresses.

Example 8.9 *A welded connection, as shown in Fig. 8.22 is subjected to an eccentric force of 7.5 kN. Determine the size of welds if the permissible shear stress for the weld is 100 N/mm^2. Assume static conditions.*

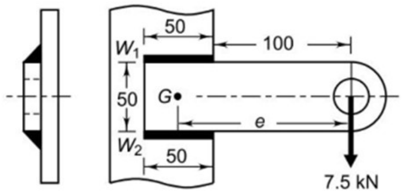


Fig. 8.22

Solution

Given $P = 7.5$ kN $\quad \tau = 100$ N/mm^2

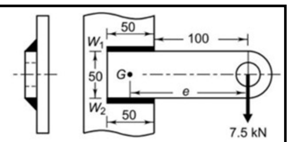
Step I *Primary shear stress*

Suppose t is the throat of each weld. There are two welds W_1 and W_2 and their throat area is given by,

$$A_1 = 2(50t) = (100t) \text{ mm}^2$$

From Eq. (8.21), the primary shear stress is given by,

$$\tau_1 = \frac{P}{A_1} = \frac{7500}{(100t)} = \left(\frac{75}{t}\right) \text{N/mm}^2 \qquad \text{(a)}$$



Step II *Secondary shear stress*

The two welds are symmetrical and G is the centre of gravity of the two welds.

$$e = 25 + 100 = 125 \text{ mm}$$

$$M = P \times e = (7500)(125) = 937\,500 \text{ N-mm} \qquad \text{(i)}$$

The distance r of the farthest point in the weld from the centre of gravity is given by (Fig. 8.23),

$$r = \sqrt{(25)^2 + (25)^2} = 35.36 \text{ mm} \qquad \text{(ii)}$$

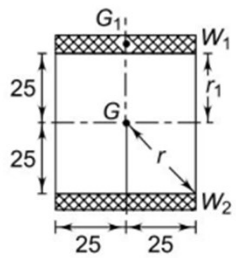


Fig. 8.23

From Eq. (8.25), the polar moment of inertia J_1 of the weld W_1 about G is given by

$$J_1 = A\left[\frac{l^2}{12} + r_1^2\right] = (50t) \times \left[\frac{50^2}{12} + 25^2\right]$$

$$= (41\ 667t)\ \text{mm}^4$$

Due to symmetry, the polar moment of inertia of the two welds (J) is given by

$$J = J_1 + J_2 = 2J_1 = 2(41\ 667t) = (83\ 334t)\ \text{mm}^4$$

From Eq. (8.22), the secondary shear stress is given by

$$\tau_2 = \frac{Mr}{J} = \frac{(937\ 500)(35.36)}{(83\ 334t)} = \left(\frac{397.8}{t}\right)\ \text{N/mm}^2$$

Step III *Resultant shear stress*

Figure 8.24 shows the primary and secondary shear stresses. The vertical and horizontal components of these shear stresses are added and the resultant shear stress is determined. Therefore, from the figure,

$$\tau = \left(\frac{454}{t}\right)\ \text{N/mm}^2$$

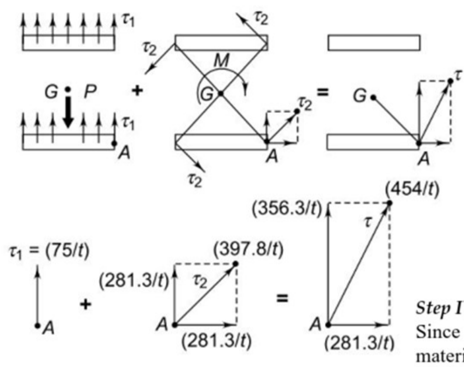


Fig. 8.24

Step IV *Size of weld*

Since the permissible shear stress for the weld material is 100 N/mm^2,

$$\left(\frac{454}{t}\right) = 100 \quad \text{or} \quad t = 4.54$$

$t = h \cos(45°)$

$t = 0.707\ h$

Example 8.10 *A welded connection, as shown in Fig. 8.25, is subjected to an eccentric force of 60 kN in the plane of the welds. Determine the size of the welds, if the permissible shear stress for the weld is 100 N/mm². Assume static conditions.*

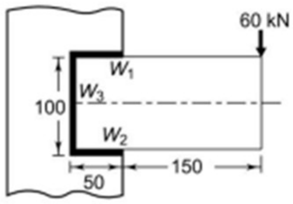


Fig. 8.25

Solution

Given $P = 60$ kN $\tau = 100$ N/mm²

Step I *Primary shear stress*

There are two horizontal welds W_1 and W_2 and one vertical weld W_3. Refer to Fig. 8.26. By symmetry, the centre of gravity G of the three welds is midway between the two horizontal welds. Therefore,

$$\bar{y} = 50 \text{ mm}$$

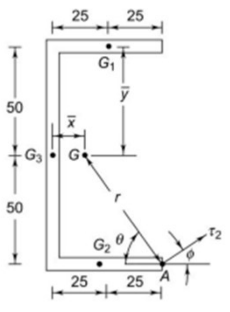


Fig. 8.26

Taking moment about the vertical weld and treating the weld as a line,

$$(50 + 100 + 50)\ \bar{x} = 50 \times 25 + 50 \times 25 + 100 \times 0$$

$$\bar{x} = 12.5 \text{ mm}$$

The areas of three welds are as follows:

$A_1 = (50\ t)$ mm²

$A_2 = (50\ t)$ mm²

$A_3 = (100\ t)$ mm²

$A = A_1 + A_2 + A_3 = (200\ t)$ mm²

The primary shear stress in the weld is given by,

$$\tau_1 = \frac{P}{A} = \frac{60000}{200t} = \frac{300}{t} \text{ N/mm}^2 \qquad \text{(i)}$$

Step II *Secondary shear stress*

As seen in Fig. 8.26, A is the farthest point from the centre of gravity G and its distance r is given by,

$$r = \sqrt{(50 - 12.5)^2 + (50)^2} = 62.5 \text{ mm}$$

Also,

$$\tan\theta = \frac{50}{(50 - 12.5)} \quad \text{or} \quad \theta = 53.13°$$

$$\phi = 90 - \theta = 90 - 53.13 = 36.87°$$

Therefore, the secondary shear stress is inclined at 36.87° with horizontal.

$e = (50 - \bar{x}) + 150 = (50 - 12.5) + 150 = 187.5$ mm

$M = P \times e = (60 \times 10^3)(187.5) = (11\,250 \times 10^3)$ N-mm

G_1, G_2 and G_3 are the centres of gravity of the three welds and their distances from the common centre of gravity G are as follows,

$$\overline{G_1G} = \overline{G_2G} = \sqrt{(25 - 12.5)^2 + (50)^2} = 51.54 \text{ mm}$$

or

$$r_1 = r_2 = 51.54 \text{ mm}$$

$$r_3 = \overline{G_3G} = \bar{x} = 12.5 \text{ mm}$$

From Eq. (8.25),

$$J_1 = J_2 = A_1\left[\frac{l_1^2}{12} + r_1^2\right]$$

$$= (50\,t)\left[\frac{(50)^2}{12} + (51.54)^2\right]$$

$$= (143\,235.25\,t) \text{ mm}^4$$

$$J_3 = A_3\left[\frac{l_3^2}{12} + r_3^2\right] = (100\,t)\left[\frac{100^2}{12} + (12.5)^2\right]$$

$$= (98\,958.33\,t) \text{ mm}^4$$

$$J = 2\,J_1 + J_3 = 2(143\,235.25\,t) + (98\,958.33\,t)$$

$$= (385\,428.83\,t) \text{ mm}^4$$

The secondary shear stress at the point A is given by,

$$\tau_2 = \frac{Mr}{J} = \frac{(11\,250 \times 10^3)(62.5)}{(385\,4\,28.83t)}$$

$$= \frac{1824.27}{t} \text{ N/mm}^2 \qquad \text{(ii)}$$

Step III *Resultant shear stress*

The secondary shear stress is inclined at 36.87° with the horizontal. It is resolved into vertical and horizontal components as shown in Fig. 8.27.

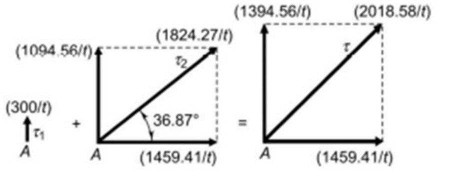
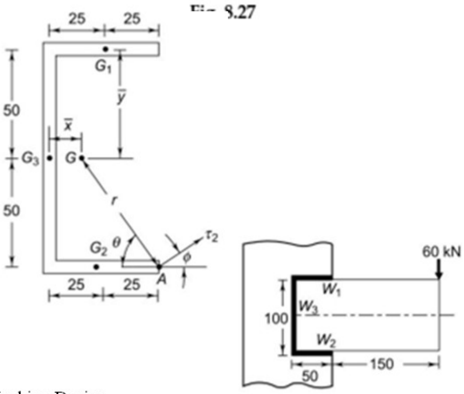


Fig. 8.27



Vertical component = $\tau_2 \sin\phi$

$$= \frac{1824.27}{t}\sin(36.87) = \frac{1094.56}{t} \text{ N/mm}^2$$

Horizontal component = $\tau_2 \cos\phi$

$$= \frac{1824.27}{t}\cos(36.87) = \frac{1459.41}{t} \text{ N/mm}^2$$

The primary shear stress $\left(\frac{300}{t}\right)$ is vertically upward. Therefore, the total vertical component is given by,

$$\left(\frac{1094.56}{t} + \frac{300}{t}\right) \text{ or } \left(\frac{1394.56}{t}\right) \text{N/mm}^2$$

The resultant shear stress is given by,

$$\tau = \sqrt{\left(\frac{1394.56}{t}\right)^2 + \left(\frac{1459.41}{t}\right)^2}$$

$$= \frac{2018.58}{t} \text{ N/mm}^2$$

Step IV *Size of weld*

The permissible shear stress for the weld material is 100 N/mm². Therefore,

$$100 = \frac{2018.58}{t} \text{ or } t = 20.19 \text{ mm}$$

and $$h = \frac{t}{0.707} = \frac{20.19}{0.707} = 28.56 \text{ mm}$$