CHAPTER 03

Welded Connections

3.1 Introduction

- In welded connections, the two structural members are joined by a weld.
- It is the compactness and greater rigidity of the welded joints that offer design assumptions to be realized more precisely in practice.

Advantages of welded joints over other joints:

(a) Welded joints offer more efficient use of materials and it is due to welding only that we are able to have one piece construction.

(b) Welding helps in speeding up the erection and construction process thereby compressing the production schedules.

(c) Welding offers light weight construction and thus cuts costs of construction. Connecting steel plates are reduced or eliminated thereby reducing the self-weight of the structure.

(d) In welding, no deductions for holes are made and thus whole of the gross section is effective in carrying the load.

(e) Welded joints perform better in case of fatigue loads, impact loads and vibrations.

(f) Welding offers complete freedom to architects and the engineers for their designs.

3.2 Types of Welded Joints

- Depending on the type of weld, welded joints can be classified as:

(a) Fillet weld	(b) Butt or groove weld	(c) Plug weld
(d) Slot weld	(e) Spot weld	

- Depending on position, welded joints can be classified as:

(a) Flat weld	(b) Horizontal weld	(c) Vertical weld
(d) Overhead weld		

- Depending on the type of joint, welded joints can be classified as:

(a) Butt or groove weld	(b) Lap weld	(c) Tee weld
(d) Corner weld		

All the above types of welds are shown in Fig. 3.1.

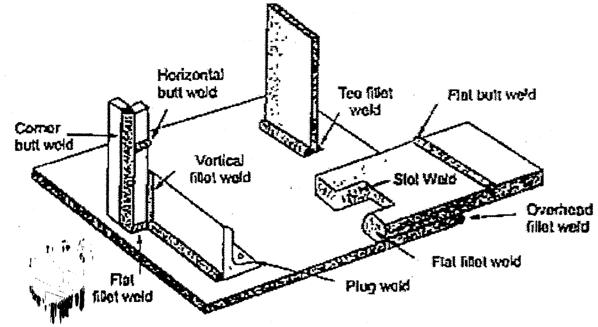


Fig. 3.1 Different types of welds

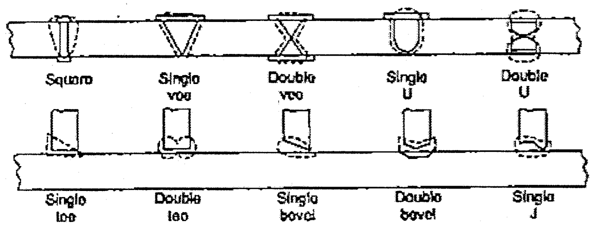


Fig. 3.2 Different types of butt (groove) welds

Groove/butt welds require edge preparation and thus are costly. Single V, U, J etc. butt welds are cheaper to form but require double the weld metal than double grooved joints.

3.2.1 Fillet Weld

- Fillet weld is provided when two metal surfaces to be joined are in different planes. Fillet welds are more common that butt welds.
- Fillet welds are easy to make, require less material preparation and are easier to fit than the butt welds.
- However, for a given amount of weld material, they are not strong and cause greater concentration of stress.
- In lightly loaded structures where stiffness rather than strength is the governing design factor and fatigue or brittle fracture is not a problem, there fillet welds are more economical.

3.2.2 Butt Weld

- Butt welds are better in highly stressed structures where smooth flow of stress is a necessity. If butt joint has the same characteristics as that of the parent metal, is flushed smooth on both sides with the parent metals and has complete penetration with no unweld zones then butt joint approaches the condition of no joint at all and for most common types of parent metals, butt joint may have impact and fatigue resistance equal to or better than that of the parent metal.

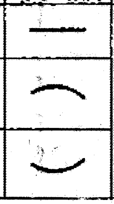
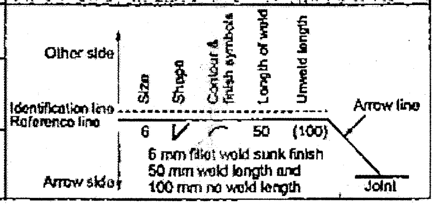
3.2.3 Slot and Plug Weld

- Slot and plug welds are used to supplement or reinforce the fillet welds when the required length of the fillet weld cannot be provided.
- The problem with these types of weld is that they are difficult to inspect and penetration of these welds cannot be ascertained.

3.3 Weld Symbols

Table 3.1 Weld symbols

Type of Weld												
Fillet	Butt								Seam	Spot	Plug	Field Weld
	Square	V	Bevel	U	J	V with broad root face	Bevel with broad root face	Weld with raised edges				

Shape of Weld Surface	Symbol	Method of representation
Flat (usually finished flush)		
Convex		
Concave		

3.4 Weld Defects

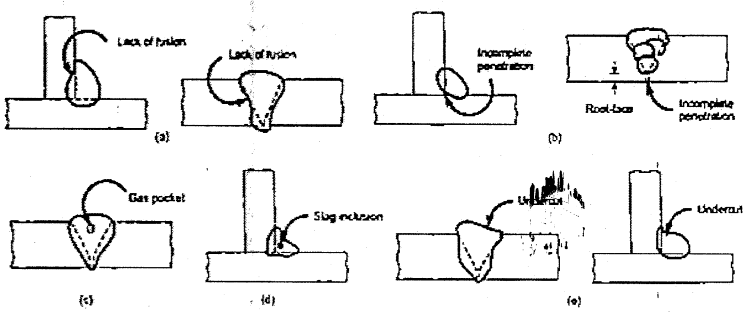


Fig. 3.3 Some common weld defects

(a) **Incomplete fusion:** It is the failure of the base (or parent) metal to get completely fused with the weld metal. This defect occurs because of rapid welding and also because of foreign materials on the surfaces to be welded.

(b) **Incomplete penetration:** It is the failure of the weld metal to penetrate completely the depth of the joint. This defect normally occurs with single V and bevel joints and also because of large sized electrodes.

(c) **Porosity:** It occurs due to gas or void packets entrapped in the weld while cooling. This results in stress concentration and reduced ductility of the metal. Normally porosity is not a problem because such voids are spherical in shape which allows a smooth flow of stress around the void without any significant loss in strength. These are caused due to the presence of moisture in the electrodes, hydrogen present in the steel and excessive amount of electric current.

(d) **Slag Inclusion:** These are metal oxides and other solid compounds which are often found as elongated or globular inclusions that are being lighter than the molten material and these float and rise to the weld surface from where these are removed after cooling of the weld. But excessive rapid cooling of the weld may cause them to get entrapped in the weld which poses a problem especially in vertical and overhead welding.

(e) **Cracks:** Cracks can be hot or cold. Hot cracks occur due to the presence of sulphur, carbon, silicon and hydrogen in the weld metal. Phosphorous and hydrogen trapped in the hollow spaces of the metal structure give rise to the formation of cold cracks. Preheating of the metals to be welded eliminates the cracks formation.

(f) **Undercutting:** It is the local decrease in the thickness of the parent metal at the weld toe. This occurs due to excessive current or very long arc. An undercut results in the loss of gross section and in fact acts like a notch.

3.5 Inspection of Welds

(a) **Magnetic particle method:** In this method of weld Inspection, iron fillings are spread over the weld and are then subjected to an electric current. The fillings form a patterns which are interpreted to locate the surface cracks.

(b) **Dye penetration method:** This method helps in estimating the depth of crack. A dye is applied over the weld surface and surplus dye is removed. A dye absorber is placed over the weld which oozes the dye thus giving an idea about the depth of crack.

(c) **Ultrasonic method:** In this method, ultrasonic sound waves are sent through the weld. Presence of defects like flaws, blow holes etc. affect the time of travel of wave transmission thereby identifying the defect.

(d) **Radiography:** In this method, X rays and gamma rays are used to locate the defects. This method is used in butt welds only and cannot be used for fillet welds because the parent material will also form part of the projected picture.

3.6 Assumptions in the Analysis of Welded Joints

(a) The welds connecting the various parts of a structure are homogeneous, isotropic and elastic elements.

(b) The parts connected with the weld are rigid and their deformations are ignored.

(c) Only the stresses due to external loads are considered. Effect of residual stress, stress concentration and shape of the welds are neglected.

3.7 Butt (or Groove) Welds

- A square butt weld is provided for sections up to 8 mm thickness only.
- For sections with thickness greater than 8 mm, a single U, V or double U, V etc. butt welds are provided.
- **Butt weld is mainly designed for direct compression or tension and occasionally for shear also.**
- The advantage with butt weld is that it involves no change in section at the location of joint and is thus the most preferred type of weld.

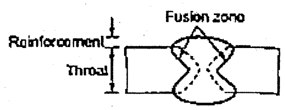


Fig. 3.4 A typical butt weld

3.7.1 Specifications for the Design of Butt Weld

(a) **Size:** The size of the butt weld is specified by the throat dimension also called as effective throat thickness. The butt welds can be of partial penetration or of full penetration.

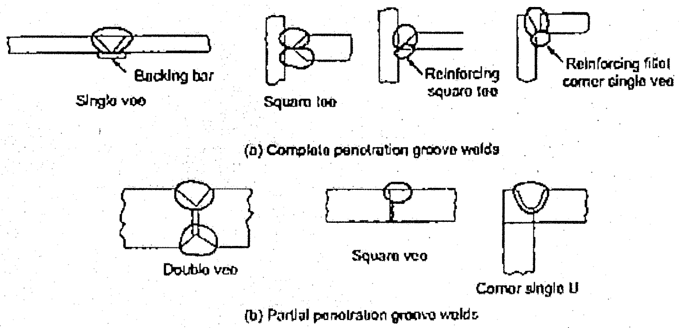


Fig. 3.5 Partial and complete penetration of butt welds

- Butt weld with partial penetration is generally not preferred.
- On the other hand, it is quite difficult to have complete penetration in case of single U, V, J or bevel welds. In fact, incomplete penetration is the failure of base metal and the weld metal to get fused at the root as shown in Fig. 3.5(b). Incomplete penetration causes stress concentration under the loads and may cause shrinkage cracks. This problem is overcome by using the backup strips as shown in Fig. 3.5 (a).
- Complete penetration is easily achieved in case of double U, V, J and bevel welds.

Remember

In case of complete penetration of butt weld, the effective throat thickness is equal to the thickness of the thinner member jointed. However, in case full penetration of butt weld cannot be ascertained, there the effective throat thickness is taken as 7/8th of the thickness of the thinner member jointed. But for strength calculation purpose, the effective throat thickness is assumed to be 5/8th of the thickness of the thinner member jointed.

(b) **Effective Area:** The effective area of a butt weld is the product of effective throat thickness and the effective length of the butt weld.

(c) **Reinforcement:** It is difficult for a welder to make a weld flush with the parent metal and thus extra metal gets deposited.

- This extra weld metal makes the throat thickness at least 10% greater than the thickness of the welded material.
- Reinforcement increases the efficiency of the butt weld and it also ensures that the weld depth is at least equal to the plate thickness.
- Any reinforcement on the weld is not taken into account for strength calculation purpose.
- Reinforcement makes the butt weld stronger for the static loads. However in case of vibrating and dynamic loads, stress concentration occurs in the reinforcement leading to early failure of the weld. Thus at such locations, reinforcement is undesirable and weld is made flush with the parent metal.
- In any case, reinforcement should not exceed 3 mm.

3.7.2 Design Strength of Butt Weld

- The design strength of butt weld either in tension or compression is governed by the smaller of the yield strength of weld or the parent metal and is given by,

$$T_{dw} = \frac{f_y l_w t_e}{\gamma_{mw}} \qquad \text{...(3.1)}$$

where f_y = Smaller of the yield strength of the weld (f_{yw}) and the parent metal (f_y) (in N/mm²)

l_w = Effective length of the weld (in mm)

t_e = Effective throat thickness of the weld (in mm)

γ_{mw} = Partial factor of safety for weld

= 1.25 for shop welding

= 1.5 for site/field welding

- The design strength of fillet weld in shear is also governed by yield and is given by,

$$V_{dw} = \frac{f_{yw1} l_w t_e}{\gamma_{mw}} \qquad \text{...(3.2)}$$

where f_{yw1} = Smaller of shear yield strength of weld $\left(\frac{f_{yw}}{\sqrt{3}}\right)$ and the parent metal $\left(\frac{f_y}{\sqrt{3}}\right)$

γ_{mw} = Partial factor of safety for weld

f_{yw} = Yield stress of the weld (in N/mm²)

3.7.3 Procedure for the Design of Butt Weld

Step-1. For the case of complete penetration of butt weld, there is no need to have design calculations as strength of the weld at the joint is equal to the strength of the member connected.

Step-2. For the case of partial penetration of butt weld, the effective throat thickness is computed as described above and required effective length is determined in order to have strength of the weld equal to the strength of the member connected.

Step-3. The design strength of the butt weld is computed as per Eq. (3.1).

3.8 Fillet Weld

- This weld is required where members overlap each other or the connecting members are in different planes. In such cases butt weld cannot be provided.
- Fillet weld is predominantly subjected to shear stresses.

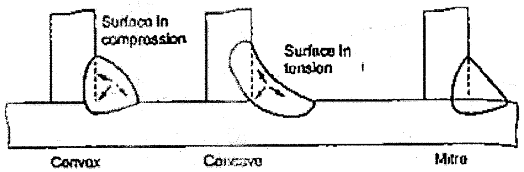


Fig. 3.6 Different types of fillet weld

- Fillet weld can either be convex or concave as per requirement (Fig. 3.6).
- From appearance point of view, concave fillet weld appears to be larger in length than convex fillet weld but actually concave fillet weld has less penetration and smaller throat thickness. Thus convex fillet weld is stronger even with less deposited metal. Convex fillet weld shrinks on cooling and thus stresses induced on outer face are compression.
- When concave fillet weld cools, the outer surface is stressed in tension. Thus, cracks get developed in concave fillet welds on cooling.
- Concave fillet welds are made in more than one pass, the first pass being slightly convex and subsequent passes are built up to form concave fillet weld. Concave fillet welds are more suitable under repetitive type of stresses.

3.8.1 Specifications for the Design of Fillet Weld

(a) **Size:** The leg length of the fillet weld specifies its size. Thus size of a fillet weld can be defined as the minimum leg length of fillet weld.

- The leg length is the distance from root to toe of the fillet weld and is measured by the largest inscribed right angle triangle within the weld. But this inscribed triangle within the weld often gives different or unequal sides of the triangle.
- Thus the above definition of size of the fillet weld is modified as the **largest inscribed isosceles triangle** within the weld. This definition gives equal legs of the fillet weld.

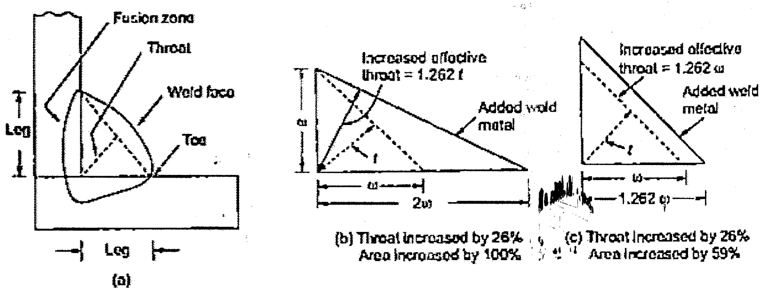


Fig. 3.7 Size of Fillet Weld

- In case where unequal lengths of the fillet weld are unavoidable, there the size of the fillet weld is specified by giving both leg lengths.
- **The maximum size of fillet weld** is a function of thickness of thinner member to be jointed (just like in butt weld). **This limit on maximum size of fillet weld avoids over-stressing the adjacent metal and also helps to examine** physically that the desired throat thickness has been attained (Fig. 3.8).

Maximum size of fillet weld = Thickness of thinner member to be jointed − 1.5 mm

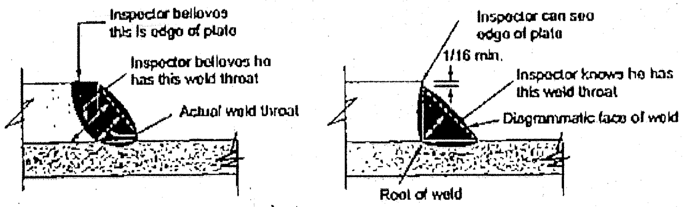


Fig. 3.8 Physical examination of fillet weld

- When fillet weld is applied to sections with rounded toes, there the maximum size of the fillet weld should not exceed 75% (or 3/4) of the thickness of the section at the toe.
- The minimum size of fillet weld is specified by IS 800 and is given in Table 3.2. These are the minimum sizes for the first run in order to avoid cracking.

Table 3.2 Minimum size of fillet weld

Thickness of thicker member		Minimum size (mm)
Over (mm)	Up to and including (mm)	
0	10	3
10	20	5
20	32	6
32	50	8 for first run, 10

The minimum size of the fillet weld is specified so as to have adequate heating to expand the thicker base metal. If a very small weld is provided on a thick base metal then heat generated in depositing the small size weld may not be sufficient enough to expand the thicker base metal. Moreover, as the weld cools, it tries to contract but is prevented from doing so by the thicker base metal resulting in induced stresses in the weld metal. **The minimum size of the weld must not exceed the thickness of the thinner member jointed and also must not be less than 3 mm (Cl. 10.5.2.3 of IS 800:2007).**

(b) **Effective throat thickness:** It is the shortest distance from the root of fillet weld to the hypotenuses of the inscribed right triangle within the weld (Fig. 3.9).

- In any case, the effective throat thickness should not be less than 3 mm and should not exceed 0.7t or 1.0t under certain situations, where 't' is the thickness of the thinner member jointed.
- Thus, Effective throat thickness = $K \times$ Size of fillet weld = KS

where S = Size of the weld.

K = Constant that depends on the angle between the joining (fusion) surfaces and is given in Table 3.3 and also in Table 22 of IS 800:2007.

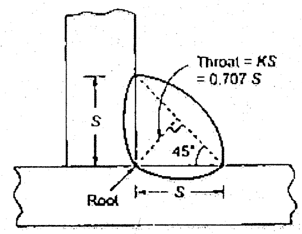


Fig. 3.9 Typical cross-sectional dimensions of a fillet weld

Table 3.3 Constant K for different joining surface angles

Angle between the joining (fusion) surfaces	60° - 90°	91° - 100°	101° - 106°	107° - 113°	114° - 120°
K	0.70	0.65	0.60	0.55	0.50

NOTE: For angles less than 60° and more than 120°, fillet weld is not recommended.

(c) Effective length

- Effective length of fillet weld = Actual length of weld − 2S

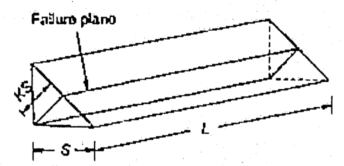


Fig. 3.10 Effective length of fillet weld

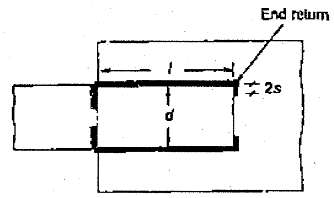


Fig. 3.11 End Returns

- Deduction of $2S$ is made to give due allowance to the formation of craters at the ends of the welded length.
- In order to relieve ends of weld length from high stress concentrations, often end returns are provided of size equal to twice the size of the weld (Fig. 3.11).

NOTE

The actual length of the weld must not be less than four times the size of the weld i.e. '4s'. This minimum length is specified because however experienced a welder is, a slight tapering often occurs at the start and end of the weld length. For longitudinal fillet weld where weld is parallel to the actual line of stress and are placed at the edges of the plate, there a high level of stress concentration occurs at the plate edges. Thus the length of longitudinal fillet weld must not be less than width of the plate. Moreover the non-uniformity in stress distribution magnifies as the width of plate increases. For this reason, the normal distance between the longitudinal fillet welds is limited to 16 times the thickness of thinner plate jointed. If plate is wider than this limit then slot or plug weld is provided. Longitudinal fillet weld in slot has the same strength as that of ordinary longitudinal fillet weld.

- In case the length of welded joint of a splice or end connection in compression or tension element exceeds 150 times the throat size of the weld then reduction in the strength of weld is done (Cl. 10.5.7.3 of IS 800:2007). But in case of flange to web connections where full length of the weld is loaded, no reduction in strength is made.
- Thus for long welded joints, the design capacity of the weld is reduced by a factor as given below:

$$\beta_{Lw} = 1.2 - \frac{0.2 l_j}{150 t_t} \leq 0.1 \qquad ...(3.3)$$

where l_j = Length of welded joint in the direction of force transfer

t_t = Size of throat of the weld

(d) Effective area:

Effective area of fillet weld = Effective length x Effective throat thickness

(e) **Overlap:** The overlap of the plates to be joined by fillet weld should not be less than four times the thickness of thinner member to be joined or 40 mm whichever is greater (Fig. 3.12).

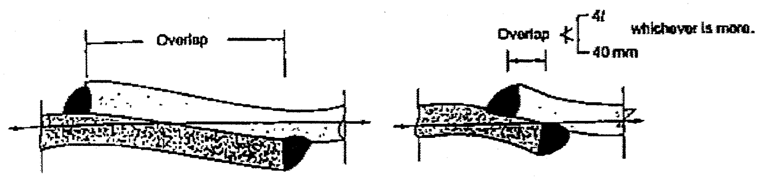


Fig. 3.12 Overlap for fillet welded joint

(f) **Transverse spacing:** In case end of an element is connected only by parallel longitudinal fillet welds, the length of the weld along either edge should not be less than the transverse spacing between the longitudinal welds.

(g) **Packing:** When a packing of thickness less than 6 mm is welded between the two members then it must be trimmed flush with the edges of the element.

- The size of the weld for such cases, is increased along the edges over the required size by an amount equal to thickness of the packing. Else the packing is extended beyond the edges and is fillet welded to the pieces between which it is fitted.

3.8.2 Design Strength of Fillet Weld

- The design stress in a fillet weld is given by,

$$f_{wd} = \frac{f_{wn}}{\gamma_{mw}} \qquad ...(3.4)$$

where f_{wn} = Nominal strength of fillet weld = $\frac{f_u}{\sqrt{3}}$

- The design strength of a fillet weld is a function of throat area and is given by,

$$P_{dw} = l_w t_t \frac{f_u}{\sqrt{3}.\gamma_{mw}} = l_w KS \frac{f_u}{\sqrt{3}.\gamma_{mw}} \qquad ...(3.5)$$

where l_w = Effective length of the fillet weld (in mm)

t_t = Throat thickness of fillet weld (in mm)

S = Size of the fillet weld (in mm)

f_u = Lesser of ultimate strength of weld or the parent metal (in N/mm²)

P_{dw} = Design strength of weld (in N)

γ_{mw} = Partial factor of safety for weld

= 1.25 for shop welding

= 1.5 for site/field welding

3.8.3 Procedure for the Design of Fillet Weld

A fillet weld may be subjected to any general type of stress i.e. axial/direct stress (tensile or compressive), flexural stress (tension or compression) and shear stresses but **the design of fillet weld is governed by shear stresses since a fillet weld always gets fail in shear.**

Step-1. The size of the fillet weld (S) is assumed to be forehand based on the thickness of the members to be jointed.

Step-2. An equal legged fillet weld gets fail at an angle of 45° through the throat. The strength of the weld is computed from Eq. (3.5).

Step-3. Force to be transmitted by the joint is either known or is estimated.

Step-4. The effective length of the weld is worked out by dividing the factored force by the strength of the weld per unit (usually mm) length. The resulting weld length is adjusted either by providing longitudinal fillet welds (parallel to the force) or transverse fillet weld (normal to the force) in combination with longitudinal fillet weld. It is assumed that both the welds are stressed equally. If required length of the weld exceeds 150 t_t then design capacity of the weld is reduced by the factor β_{lw} as defined by Eq. (3.3).

Step-5. If only longitudinal fillet weld is provided then length of each longitudinal fillet weld must be more than the perpendicular distance between them.

Step-6. At each end of the longitudinal fillet weld, end returns of length 2S are provided.

NOTE

1. As shown in Fig. 3.13, it is assumed that strength of longitudinal and transverse fillet weld is the same. But in reality, transverse fillet weld is stressed more uniformly along the length than the longitudinal fillet weld and thus strength of transverse fillet weld is about 30% more than the longitudinal fillet weld.
2. In order to have uniformity in the design of longitudinal and transverse fillet welds, the additional strength of transverse fillet weld (i.e. about 30%) is ignored in design.

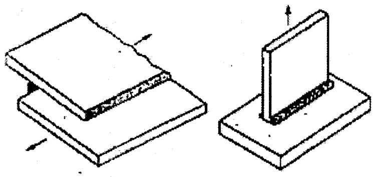


Fig. 3.13 Longitudinal and transverse fillet weld

3.9 Fillet Weld when Applied to Edge of a Section

- Fillet weld when provided at the square edges of the sections to be jointed, the specified size of the weld must be at least 1.5 mm less than the edge thickness.
- Fillet weld when applied to rounded toe of a section then the specified size of the weld should not exceed 75% (or 3/4) of the thickness of the section at the toe (Fig. 3.14).

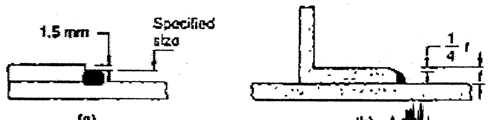


Fig. 3.14 Fillet weld on square edge and round toe of a section

- Where the specified size of the fillet weld is such that the parent metal will not project beyond the weld, then no melting of outer covers is allowed to occur to such an extent so as to reduce the throat thickness (Fig. 3.15).

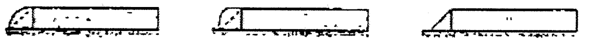


Fig. 3.15 Full size fillet weld applied to edge of section

- The end fillet weld normal to the direction of force should be of unequal size with throat thickness not less than 0.5t where 't' is thickness as shown in Fig. 3.16. The difference in thickness of the weld is profiled at a uniform slope.

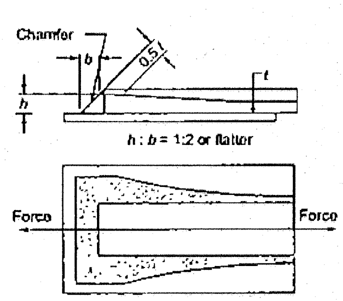


Fig. 3.16 End fillet weld normal to the direction of force

3.10 Intermittent Fillet Weld

- Intermittent fillet weld is provided to transmit the calculated stress across a joint when the strength of weld required is less than that developed by a continuous fillet weld of the smallest practical size.
- The fillet weld length required is computed as if it is a continuous fillet weld but a chain of intermittent fillet welds of total length equal to the computed length with spacing as per IS provisions is provided.
- Staggered intermittent fillet weld (Fig. 3.17 (a)) is better than chain intermittent fillet weld (Fig. 3.17 (b))

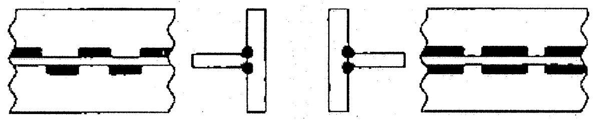


Fig. 3.17 Two different ways of providing intermittent fillet weld

3.10.1 Factors Influencing the Use of Intermittent Fillet Weld

(a) Unless the fillet weld is of small size, intermittent fillet welds are not economical. A small size fillet weld of longer length is more economical than an intermittent fillet weld of same strength because strength of fillet weld is linearly related to weld size but weight of weld varies as square of weld size.

(b) In case of automatic welding, the welding has to be continuous.

(c) In case of dynamic and repetitive type of loads, continuous fillet weld is more preferable.

3.10.2 Procedure for the Design of Intermittent Fillet Weld

Step-1. The size of the weld is assumed beforehand and effective length of weld required is computed.

Step-2. Intermittent fillet weld should have a minimum effective length of four times the weld size and in any case should not be less than 40 mm (except plate girders).

Step-3. The clear spacing between the intermittent fillet weld must not be greater than 12t for compression and 16t for tension and must not exceed 200 mm in any case, where 't' is the thickness of the thinner member being jointed.

Step-4. At the ends, longitudinal intermittent fillet weld should be of length of at least equal to width of the member or otherwise transverse welds should be provided. If transverse fillet welds are provided along with longitudinal intermittent fillet welds, then the total weld length at the ends must not be less than the twice the width of the member.

3.11 Slot and Plug Weld

- Slot and plug welds are used to tie two parts together.
- They facilitate to reduce the unsupported length of the cover plate in compression.
- They are also used for shear transmission.
- They are generally used at locations where fillet welding is not possible but slot or plug welding is possible.

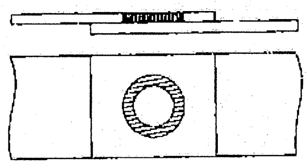


Fig. 3.18 Slot weld (Fillet weld around hole circumference)

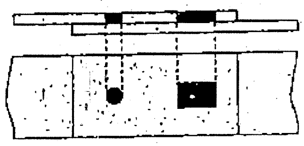


Fig. 3.19 Plug weld (Entire hole is filled with weld material)

NOTE

Slot and plug weld must not be used where tension is to be transmitted since tensile resistance depends mainly on degree of penetration of weld which is quite not certain in slot or plug weld.

Slot and plug weld pose difficulty in inspection and thus many designers do not prefer slot or plug weld. These welds appear quite finished from the surface but often contains voids.

3.11.1 Specifications for the Design of Slot and Plug Weld

(a) Width or diameter of slot/plug weld must not be less than 3t and also 25 mm where t is the thickness of plate containing the hole or the slot.

(b) Clear distance between the holes should be ≥ 2t and also ≥ 25 mm.

(c) Corner radius in slotted hole should be ≥ 1.5t and also ≥ 12 mm.

3.12 Combination of Stresses

- **Combination of stresses in fillet weld:** Fillet weld when subjected to axial stress (f_a) (due to compression, tension, and flexure) and shear stress (q), then the equivalent stress (f_e) is given by,

$$f_e = \sqrt{f_a^2 + 3q^2} \le \frac{f_u}{\sqrt{3}\,\gamma_{mw}} \qquad ...(3.6)$$

- **Combination of stresses in butt weld:** In case of butt weld, the check for combination of stresses is not required if:
  (a) butt welds are axially loaded
  (b) in single and double bevel butt weld, the summation of normal and shear stresses does not exceed the design normal stress and also the shear stress does not exceed 50% of the design shear stress.

- **Combined bearing, flexure and shear stress:** Under the most unfavourable condition of loading wherein the bearing stress (f_{br}) is required to be combined with flexure stress, (f_b) (tension or compression) and shear stress (q), the equivalent stress (f_e) is given by,

$$f_e = \sqrt{f_b^2 + f_{br}^2 + f_b f_{br} + 3q^2} \le \text{Strength values of the parent metal} \qquad ...(3.7)$$

3.13 Weld Failure

Failure of butt weld: In situations where butt weld is reinforced on both the sides of the plate then the section passing through the weld gets enhanced so much that failure does not occur at the weld section but at some distance away from the weld section as shown in Fig. 3.20.

- This increased section acts as a supporting rib which checks the necking formation in the immediate vicinity of the butt weld.
- When the butt weld is made flush with the surface of the joining plate then the location of the fracture depends on the relative strength of the parent metal and the weld metal. In case the tensile strength or the yield strength of the weld metal is lower than that of parent metal, then fracture (i.e. failure plane) passes through the center of the weld as shown in Fig. 3.21.
- In case the tensile strength and the yield strength of the weld metal are greater than the parent metal then failure plane is located away from the weld in the plate.

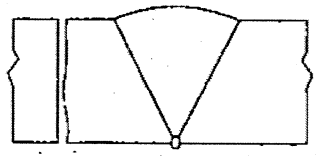


Fig. 3.20 Failure of reinforced butt weld

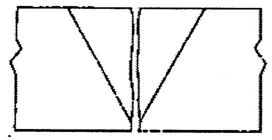


Fig. 3.21 Failure of unreinforced (flushed) butt weld

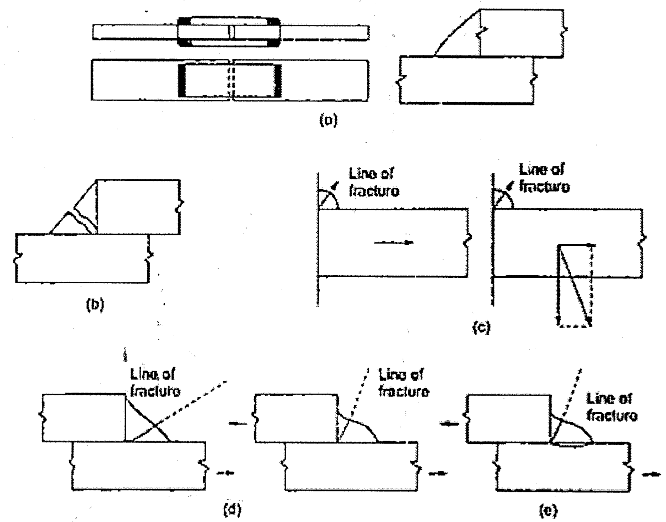


Fig. 3.22 Fracture position in end fillet weld

Failure of end fillet weld

- When the fillet weld is subjected to shear also in addition to tension then the failure position of the fracture plane will depend on the relative magnitudes of shear and tensile forces as shown in Fig. 3.22(c).
- When the two legs of the fillet weld are unequal then the failure plane passes nearer to the shorter leg as shown in Fig. 3.22(d).
- When tensile strength of the weld metal is much greater than the parent metal then in such cases fillet weld remains intact as a rigid body and gets pulled out of the parent metal as shown in Fig. 3.22(e). After a small amount of deformation, failure of fillet weld occurs suddenly.

Failure of side fillet weld

- In case of side fillet weld subjected to shear forces along the weld, failure occurs through the throat of the weld.
- This failure plane takes off from the toe of the fillet weld at one or both the ends of the weld and proceeds further.
- Unlike failure of end fillet weld, failure of side fillet weld is gradual and an appreciable amount of deformation of fillet and often of the parent metal takes place before the final fracture.

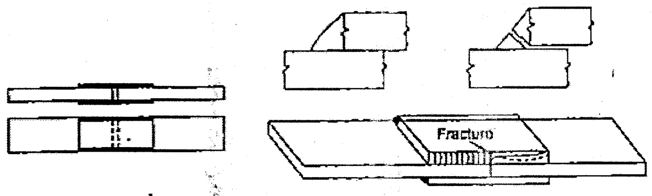


Fig. 3.23 Fracture position in side fillet weld

3.14 Advantages of Fillet Weld over Butt Weld

(a) Veeing and finishing operations are not required in case of fillet weld.

(b) Butt welds possess higher residual stresses.

(c) While joining the members with butt weld, the joining members are fabricated slightly longer than required and then cut exactly to have a proper fit of the member. Obviously this is quite uneconomical.

3.15 Comparison between Welded Joints and Bolted/Riveted Joints

S.No.	Item	Welded Joint	Bolted/Riveted Joint
1.	Economy	More economical since splice plates and rivet/bolt materials are eliminated. Less labour is required	Due to additional rivet/bolt materials, splice plates, it is not so much economical. More labour is required for making the connection.
2.	Strength	More rigid due to continuity of the section at the joint.	Less rigid due to discontinuity of the section at the joint. Thus additional cover plates, connecting angles are required
3.	Ease	Very easy even to join tubular sections.	Joining of tubular sections is difficult.
4.	Continuity	Due to fusion of the metal pieces, a continuous structure is obtained.	This is not so here in this connection.
5.	Alteration	Alterations can be done with ease.	Alterations are difficult
6.	Time	Less time is required for making the connection	More time is required for making the connection.
7.	Noise	Silent process.	A large noise is produced.
8.	Join detailing	Less detailing of joints in drawings are required.	More detailing of joints in drawings are required.
9.	Efficiency	More efficient.	Less efficient.
10.	After effect	Due to heat generated in welding process, joining members may distort.	Possibility of distortion of members is not there.
11.	Failure	Possibility of brittle failure is more in welded joints.	Usually brittle failure does not occur.
12.	Inspection	Difficult to inspect the welded joint.	Easy to inspect the bolted/rivet joint.
13.	Skill	A skill personnel is required.	Not so much skilled personnel required.

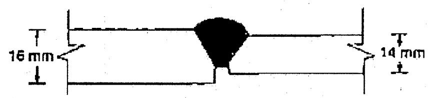
Illustrative Examples

Example 3.1 Two plates of thickness 16 mm and 14mm are required to be joined by a butt (groove) weld. The plates are subjected to a factored tensile force of 400 kN. The effective weld length is limited to 180 mm. Check whether the joint is safe if in following cases? (Assume f_y= 250 N/mm²)

(a) Single *V* butt weld is provided (b) Double *V* butt weld is provided

Solution:

(a) Single V butt weld



For the case of single *V* butt weld, complete penetration of weld cannot be ensured and thus incomplete penetration of weld takes place.

∴ Effective throat thickness,

$$t_e = \frac{5}{8} \times \text{Thickness of thinner member}$$

$$= \frac{5}{8} \times 14 = 8.75 \text{ mm}$$

For shop weld, partial factor of safety γ_{mw} = 1.25

Effective length of weld,

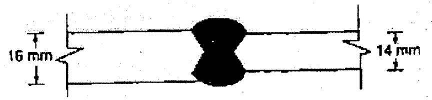
$$l_w = 180 \text{ mm}$$

$$\therefore \quad \text{Strength of weld, } T_{dw} = l_w t_e \cdot \frac{f_y}{\gamma_{mw}} = 180 \times 8.75 \times \frac{250}{1.25} \text{ N} = 315 \text{ kN} < 400 \text{ kN}$$

Thus strength of weld < factored tensile force

⇒ Single *V* butt weld provided is not adequate and is unsafe.

(b) Double V butt weld



For the case of double V butt weld, complete penetration of weld can be ensured.

$\therefore$ Effective throat thickness, t_e = Thickness of thinner member being jointed = 14 mm

Effective length of weld, l_w = 180 mm

$$\therefore \quad \text{Strength of weld, } T_{dw} = l_w t_e \cdot \frac{f_y}{\gamma_{mw}} = 180 \times 14 \times \frac{250}{1.25} \text{ N}$$
$$= 504 \text{ kN}$$
$$> 400 \text{ kN}$$

Thus strength of weld > factored tensile force

$\Rightarrow$ Double V butt weld provided is adequate and is safe.

Example 3.2 A channel section is required to be welded to a 10 mm thick gusset plate. The channel is required to carry a factored tensile load of 750 kN. The overlap of channel section on gusset plate is limited to 280 mm. Welding is to be done at site. Using Fe410 steel, design the weld. The channel section used is ISMC 250 @ 298 N/m.

Solution:

For steel of grade Fe410, f_u = 410 N/mm^2, f_y = 250 N/mm^2

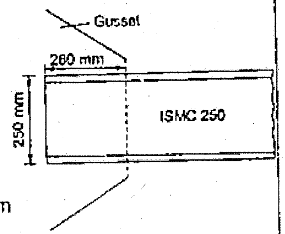
Partial factor of safety for material for site welding, γ_{mw} = 1.5

For ISMC 250 @ 298 N/m,

Cross-section area,	A = 3867 mm^2	Overall depth,	h = 250 mm
Width of flange,	b_f = 80 mm	Thickness of flange,	t_f = 14.1 mm
Thickness of web,	t_w = 7.1 mm		

Let provide side of weld = 5 mm

$\therefore$ Effective throat thickness of weld $(t_e) = kS$
$= 0.7 \times 5 = 3.5$ mm



The design strength of weld is given by,

$$P_{dw} = \frac{l_w t_t f_u}{\sqrt{3}\gamma_{mw}}$$

$\therefore$ Strength of weld per mm length

$$= \frac{1 \times 3.5 \times 410}{\sqrt{3} \times 1.5} \text{ N/mm} = 552.33 \text{ N/mm}$$

Thus for a factored tensile load of 750 kN, length of weld required

$$= \frac{750 \times 1000}{552.33} = 1357.88 \text{ mm}$$

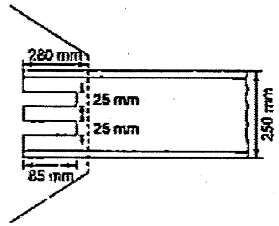
But overalap limited on gusset = 280 mm

Here, length available for weld = 250 + 2 × 280 = 810 mm
< 1357.88 mm

$\therefore$ Shortage of weld length = 1357.88 − 810 = 547.88 mm

Thus slot welding has to be provided

$$\text{Width of slot} = \text{Max. of} \begin{cases} 3t_w = 3 \times 7.1 = 21.3 \text{ mm} \\ 25 \text{ mm} \end{cases} = 25 \text{ mm}$$



$\therefore$ Provide two slots of width 25 mm

Let l = length of slot weld required

$\therefore \quad 4l + 2 \times 280 + 250 \geq 1357.88$

$\Rightarrow \quad l \geq 80.39$ mm = 85 mm (say)

$\therefore$ Provide a slot length of 85 mm

Example 3.3 There is a steel circular pipe of diameter 110 mm and 8 mm thickness which is required to be shop welded to a 14 mm thick plate. The pipe carries a vertical factored load of 4.2 kN at a distance of 1.2 m from the welded joint and a factored twist of 1.4 kNm. Using steel of grade Fe410, design the weld.

Solution:

For steel of grade Fe410, f_u = 410 N/mm^2

f_y = 250 N/mm^2

Partial factor of safety for material for shop welding,

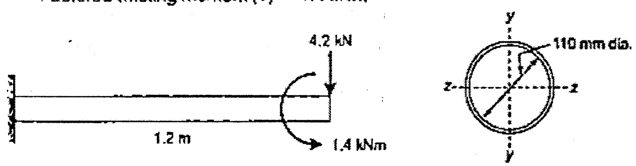
γ_{mw} = 1.25

Factored load (P) = 4.2 kN

Bending moment due to factored load (M)

= 4.2 × 1.2 = 5.04 kNm

Factored twisting moment (T) = 1.4 kNm



Polar moment of inertia of weld, $I_p = 2\pi r^3 t = 2\pi (55)^3 t$ mm^4

Now $I_z = I_y$

$\therefore \quad I_z + I_y = I_p$

$$\Rightarrow \quad I_z = \frac{I_p}{2} = \pi(55)^3 t \text{ mm}^4$$

$$\text{Shear stress due to direct load } (q_1) = \frac{P}{2\pi r t} = \frac{4.2 \times 1000}{2\pi(55)t} \text{ N/mm}^2 = \frac{2100}{55\pi t} \text{N/mm}^2.$$

$$\text{Shear stress due to twisting moment } (q_2) = \frac{M}{I_P}\left(\frac{D}{2}\right) = \frac{1.4 \times 10^6 \times 55}{2\pi(55)^3 t} \text{ N/mm}^2$$

$$\text{Normal stress due to bending moment } (f_b) = \frac{M}{I_z}\left(\frac{D}{2}\right) = \frac{5.04 \times 10^6}{\pi(55)^3 t} \times 55 \text{ N/mm}^2$$

Resultant shear stress (q) = $\sqrt{q_1^2+q_2^2} = \sqrt{\left(\frac{2100}{55\pi t}\right)^2+\left(\frac{1.4\times10^6\times55}{2\pi(55)^3 t}\right)^2}$

$$= \frac{1}{\pi t}\sqrt{38.1818^2+(231.405)^2} = \frac{234.53}{\pi t}$$

Now combined stress due to normal stress (f_b) and shear stress (q) is given by

$$f_e = \sqrt{f_b^2+3q^2} \le \frac{f_u}{\sqrt{3}\gamma_{mw}}$$

$$\Rightarrow \quad = \sqrt{\left(\frac{5.04\times10^6\times55}{\pi(55)^3 t}\right)^2+3\left(\frac{234.53}{\pi t}\right)^2}$$

$$\le \frac{410}{\sqrt{3}\times1.25} = 189.37 \text{ N/mm}^2$$

$$\Rightarrow \quad \frac{1}{\pi t}\sqrt{(1666.12)^2+3(234.53)^2} \le 189.37$$

$$\Rightarrow \quad t \ge 2.88 \text{ mm}$$

∴ Size of weld (S) = $\frac{t}{0.7} = \frac{2.88}{0.7}$ = 4.11 mm ≈ 6 mm (say)

∴ Provide 6 mm fillet weld all around the tube.

Example 3.4 **An ISA 90 × 60 × 8 mm of steel of grade Fe410 is connected to a 12 mm gusset plate and is used as a tension member. Design the weld if weld is to be provided on upper and lower edges of connected leg only.**

Solution:

For steel of grade Fe410, f_u = 410 N/mm², f_y = 250 N/mm²

∵ Factored load is not given

∴ Welded connection can transmit a maximum force equal to design strength of weld.

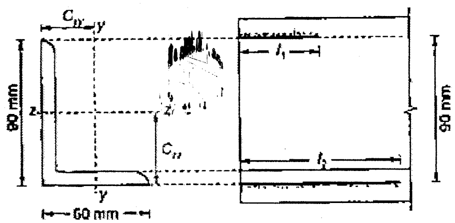
Partial factor of safety for material resistance governed by yield, γ_{m0} = 1.1

For ISA 90 × 60 × 8,

Gross area, A_g = 1137 mm²

C_{zz} = 29.6 mm

C_{yy} = 14.8 mm



Design tensile strength of member governed by gross-section yielding,

$$T_{dg} = \frac{A_g f_y}{\gamma_{m0}}$$

$$= \frac{1137\times250}{1.1} \text{ N} =$$

258.41 kN

Let force resisted by upper portion $l_1 = P_1$

$$= \frac{258.41 C_{zz}}{90} = 258.41\times\frac{29.6}{90} = 84.99 \text{ kN}$$

Force resisted by lower portion, $l_2 = P_2$

$$= \frac{258.41(90-C_{zz})}{90} = \frac{258.41(90-29.6)}{90} \text{ kN} = 173.42 \text{ kN}$$

Alternatively P_2 can also be determined as

P_2 = 258.41 − P_1 = 258.41 − 84.99 = 173.42 kN

Let size of weld, S = 6 mm

∴ Throat thickness, t = 0.7 S = 0.7 × 6 = 4.2 mm

Length of weld l_1 has to resist a force of P_1

$$\therefore \quad P_1 = l_1 t\frac{f_u}{\sqrt{3}\gamma_{mw}}$$

$$\Rightarrow \quad 84.99\times1000 = \frac{l_1(4.2)410}{\sqrt{3}\times1.25}$$ (Assuming shop weld so that γ_{mw} = 1.25)

⇒ l_1 = 106.85 mm ≃ 110 mm (say)

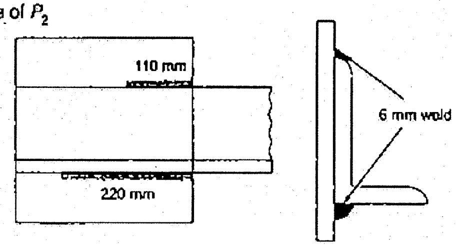
Similarly length of weld l_2 has to resist a force of P_2

$$\therefore \quad P_2 = \frac{l_2 t f_u}{\sqrt{3}\gamma_{mw}}$$

$$\Rightarrow \quad 173.42\times1000 = \frac{l_2(4.2)410}{\sqrt{3}\times1.25}$$

⇒ l_2 = 218.04 mm

≃ 220 mm (say)



Example 3.5 In example 3.4, if welding can be done on three sides of the angle then design the weld as shown in figure below.

Solution:

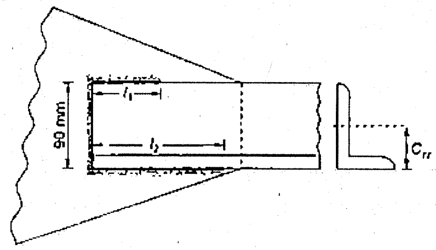
From above question,

T_{dg} = 258.41 kN

Let weld size (S) = 6 mm

∴ Throat size (t) = 0.7S

= 0.7 × 6 = 4.2 mm



Per mm strength of weld T_{dw} = $(1\times t)\frac{f_u}{\sqrt{3}\gamma_{mw}}$

$$= \frac{1\times4.2\times410}{\sqrt{3}\times1.25} \text{ N/mm} = 795.36 \text{ N/mm}$$

Equating strength of weld to factored load,

$$(l_1 + l_2 + 90)795.36 = 258.41 \times 1000 \quad ...(i)$$

$$\Rightarrow \quad l_1 + l_2 = 234.89 \text{ mm}$$

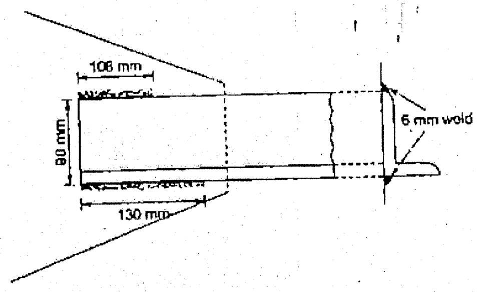
Taking moment about lower edge of weld length l_2,

$$T_{dg} C_{zz} = T_{dw} l_1 (90)$$

$$\Rightarrow \quad 258.41 \times 1000 \times 29.6 = 795.36 \times l_1 \times 90$$

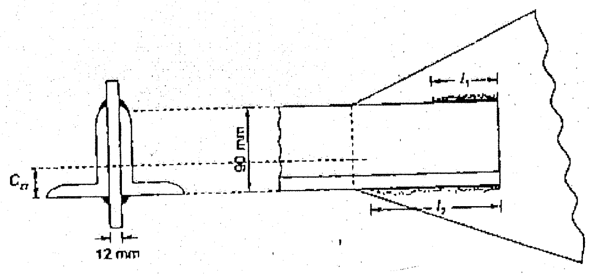
$$l_1 = 106.85 \text{ mm} \simeq 108 \text{ mm (say)}$$

$$\therefore \quad l_2 = 234.89 - l_1 = 234.89 - 106.85 = 128.04 \text{ mm} \simeq 130 \text{ mm (say)}$$



Example 3.6 A double angle section ISA 90 × 60 × 8 mm is welded on opposite side of a 12 mm thick gusset plate. If the member is required to carry a factored tensile load of 280 kN with long side of angle welded to gusset, design the site welded fillet weld. Use steel of grade Fe410.

Solution:



For steel of grade Fe410, $f_u = 410$ N/mm^2, $f_y = 250$ N/mm^2

Partial factor of safety for site welding $\gamma_{mw} = 1.5$

$\therefore$ Total length of weld $= 2(l_1 + l_2)$

Let size of weld (S) = 6 mm

$\therefore$ Throat thickness of weld $(t) = 0.7 \times 6 = 4.2$ mm

$$\text{Per mm strength of weld } (T_{dw}) = (1 \times t)\frac{f_u}{\sqrt{3}\gamma_{mw}} = (1 \times 4.2) \times \frac{410}{\sqrt{3} \times 1.5} \text{ N/mm} = 662.8 \text{ N/mm}$$

Factored tensile load $(P) = 280$ kN

Thus equating strength of weld to factored tensile load

$$662.8\,(l_1 + l_2) \times 2 = 280 \times 1000$$

$$\Rightarrow \quad l_1 + l_2 = 211.22 \text{ mm}$$

For ISA 90 × 60 × 8

$$C_{zz} = 29.6 \text{ mm}$$

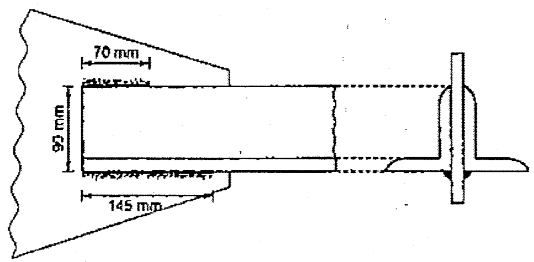
Taking moment about bottom weld length,

$$P.C_{zz} = T_{dw}(l_1)90 \times 2$$

$$\Rightarrow \quad l_1 = \frac{280 \times 1000 \times 29.6}{662.8 \times 90 \times 2} = 69.47 \text{ mm}$$

$$\therefore \quad l_2 = 211.22 - l_1 = 141.75 \text{ mm}$$

Thus provide $l_1 = 70$ mm and $l_2 = 145$ mm



Example 3.7 The tie member of a roof truss is having the section 2 ISA100 × 100 × 8. The angles are connected on either side of a 10 mm thick gusset plate. The tie member carries a tension of 320 kN under working conditions. Assuming shop welding, design the welded joint. (Take Fe410 steel).

Solution:

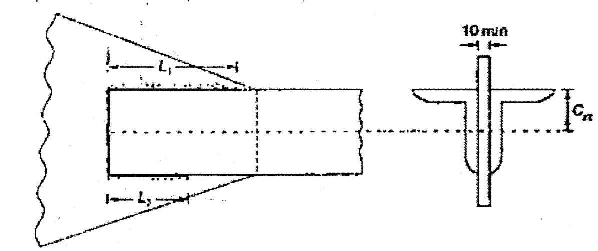
Factored load $(P) = 1.5 \times 320 = 480$ kN

Weld thickness

(i) At the rounded toe of angle section, the weld thickness $\not> \frac{3}{4} \times$ Thickness

$$= \frac{3}{4} \times 8 = 6 \text{ mm}$$

(ii) Also at top, weld thickness $\not> t - 1.5 = 8 - 1.5 = 6.5$ mm



Thus provide weld size (S) = 6 mm

Factored load carried by each angle $(P_1) = \frac{P}{2} = \frac{480}{2} = 240$ kN

Throat thickness of weld $(t_e) = 0.7S = 0.7 \times 6 = 4.2$ mm

Design strength of weld $(T_{dw}) = l_w t_e \frac{f_y}{\gamma_{mw}}$ where, $f_y = \frac{f_u}{\sqrt{3}}$

$$= l_w (4.2)\frac{410}{1.25} \qquad \gamma_{mw} = 1.25 \text{ for shop weld}$$

$\therefore \quad P_1 = T_{dw}$

$\Rightarrow \quad 240 \times 1000 = l_w (4.2)\frac{410}{1.25}$

$\Rightarrow \quad l_w = 174.2$ mm

For ISA 100 × 100 × 8, $\quad C_{xx} = C_{yy} = 27.6$ mm

Let, $\quad L_1$ = Length of top weld

$\quad L_2$ = Length of bottom weld

$\therefore \quad L_1 + L_2 = 174.2$ mm ...(i)

Equating moments about the centre of gravity of the section

$L_1(27.6) = L_2(100 - 27.6)$ ...(ii)

$\Rightarrow \quad (174.2 - L_2)27.6 = L_2(72.4)$

$\Rightarrow \quad 4807.92 - 27.6\,L_2 = 72.4\,L_2$

$\Rightarrow \quad L_2 = 48.0792$ mm

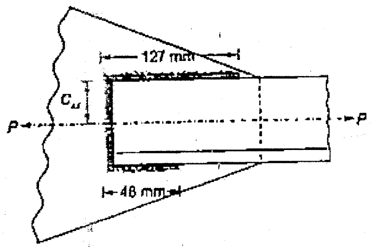
$\therefore \quad L_1 = 174.2 - L_2$

$= 174.2 - 48.0792$

$= 126.1208$ mm

$\therefore \quad$ Provide $L_1 = 127$ mm

and $\quad L_2 = 48$ mm



Example 3.8 **Design a fillet welded joint to join two plates each of thickness 10 mm and 250 mm width for 100% efficiency. (Take f_y = 250 MPa)**

Solution:

Strength of plate $= \frac{A_g f_y}{\gamma_{m0}} = \frac{250 \times 10 \times 250}{1.1} = 568.18$ kN

Minimum weld size = 5 mm

Maximum weld size = 10 − 1.5 = 8.5 mm

∴ Let 8 mm fillet weld is provided.

∴ Effective length of (transverse) fillet weld $(l_w) = (250 - 2 \times 8) = 234$ mm

∴ Effective throat thickness of weld $(t_e) = 0.7 \times 8 = 5.6$ mm

∴ Design strength of (transverse) fillet weld $= l_w t_e \left(\frac{f_u}{\sqrt{3}}\right)\frac{1}{\gamma_{mw}} = 234(5.6)\frac{410}{\sqrt{3}} \times \frac{1}{1.25} \times 2 = 496.30$ kN

Thus design strength of (transverse) fillet weld < Strength of plate

⇒ Slot welds are required.

Slot welds are required to resist a force = (568.18 − 496.30) = 71.88 kN

$$\text{Strength of slot weld} = \frac{f_u}{\sqrt{3}\gamma_{mw}} = \frac{410}{\sqrt{3} \times 1.25} = 189.37 \text{ N/mm}^2$$

$$\therefore \quad \text{Area of slot weld required} = \frac{71.88 \times 1000}{189.37} = 379.57 \text{ mm}^2 = 380 \text{ mm}^2$$

Thus provide 2 slot welds of size 15 mm × 15 mm each

∴ Total area of slot weld provided = 2 × (15 × 15) = 450 mm² > 380 mm² (OK)

Objective Brain Teasers

Q.1 In slot welding, the two plates are
(a) required to be butt against each other
(b) required to be on one another
(c) required to be next to each other
(d) required to be at 60° to each other

Q.2 The equivalent stress in fillet weld subjected to normal stress (f_a) and shear stress (q) is given by,
(a) $\sqrt{f_a^2 + q^2}$ (b) $\sqrt{f_a^2 + 4q^2}$
(c) $\sqrt{f_a^2 + 3q^2}$ (d) $\sqrt{3f_a^2 + q^2}$

Q.3 The design nominal strength of fillet weld is given by,
(a) $\frac{f_y}{\sqrt{3}}$ (b) f_u
(c) $\frac{f_y}{3}$ (d) $\frac{f_u}{2}$

Q.4 If the length of the weld is ________ then design capacity of weld is ________.
(a) less than 60t, reduced
(b) more than 150t, increased
(c) less than 16t, increased
(d) more than 150t, reduced

Q.5 For which of the following types of weld, the design shear stress is same as that of fillet weld?
(i) Butt weld
(ii) Slot weld
(iii) Plug weld

Of the above, the correct ones are:
(a) (i) and (iii) (b) (ii) and (iii)
(c) (i) and (ii) (d) (i), (ii) and (iii)

Q.6 In the cross section of a fillet weld, the throat thickness is the:
(a) Maximum dimension
(b) Average dimension
(c) Minimum dimension
(d) Minimum of the two leg lengths

Q.7 Which of the following weld is specified by penetration depth?
(a) Butt weld (b) Fillet weld
(c) Slot weld (d) Plug weld

Q.8 The effective length of the fillet weld is given by:
(a) total weld length
(b) total weld length less twice the throat size
(c) total weld length less weld size
(d) total weld length less twice the weld size

Q.9 The prominent mode of failure in fillet weld is:
(a) Compression (b) Shear
(c) Tension (d) Flexure

Q.10 As far as reinforcement in butt weld is concerned then which of the following statement(s) is (are) correct?
(a) It is not taken into account in design calculations.
(b) It enhances the joint efficiency.
(c) It should not exceed 3 mm.
(d) All of the above

Q.11 End returns in fillet weld are provided to avoid
(a) Failure of weld due to non uniform stress distribution in the weld
(b) Cost of weld reinforcement
(c) Loose grip of connecting members
(d) All of the above

Q.12 Small sized fillet welds are preferred over large sized fillet weld since
(a) Small sized fillet welds look better
(b) Small sized filled welds are easy to fabricate
(c) Small sized fillet welds are more fatigue resistant
(d) For the same strength, volume of material required for small sized weld is much less than the large sized weld

Q.13 Which of the following types of weld offer more gradual flow of stress?
(a) Concave wave (b) Convex weld
(c) Both (a) and (b) (d) Neither (a) nor (b)

Q.14 Which of the following statement is correct?
(a) Longitudinal fillet weld is more efficient than transverse fillet weld due to more uniform stress distribution in longitudinal fillet weld
(b) Transverse fillet weld is easy to mode at satc
(c) Longitudinal fillet weld can be made faster then transverse fillet weld
(d) Transverse fillet weld has more efficiency than longitudinal fillet weld due to more uniform stress distribution in transverse fillet weld

Q.15 If 's' is the size of fillet weld then size of end return should be
(a) s (b) 2s
(c) 3s (d) 4s

Q.16 End returns are provided
(a) to relieve ends of the weld from high stress concentration
(b) to distribute the stress uniformly
(c) to make the joint efficient
(d) All of the above

Q.17 The minimum length of weld must not be less than
(a) 4s (b) 2s
(c) 6s (d) 8s
where s = size of weld.

Q.18 The minimum length of weld is specified
(a) to account for heat evolution during welding process
(b) to make the joint rigid
(c) to make the joint semi rigid
(d) to account for slight tapering at start and end of weld length

Q.19 Minimum size of fillet weld is taken as
(a) 5 mm (b) 3 mm
(c) 6 mm (d) 10 mm

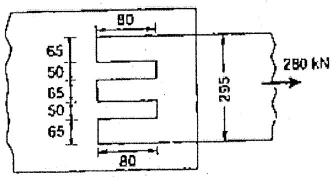
Q.20 Strength of transverse fillet weld is about ______ than longitudinal fillet weld.
(a) 30% less (b) 40% less
(c) 20% more (d) 30% more

Answers

1. (b)	2. (c)	3. (a)	4. (d)	5. (b)
6. (c)	7. (a)	8. (d)	9. (b)	10. (d)
11. (a)	12. (d)	13. (a)	14. (d)	15. (b)
16. (a)	17. (a)	18. (d)	19. (b)	20. (d)

Conventional Practice Questions

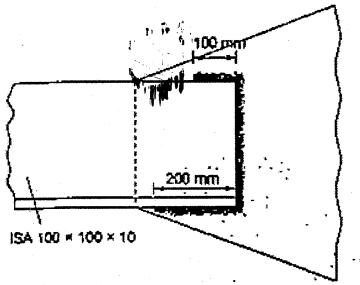
Q.1 A 295 mm wide plate 12 mm thick is connected with 8 mm fillet weld. Determine the length (L) of the plate required to transmit a tensile force of 280 kN as shown in prob. fig. 3.1



(All dimension in mm)

Q.2 An ISA 80 × 50 × 10 is required to be connected to 12 mm thick gusset plate. Design the fillet weld to carry a force equal to strength of the member.

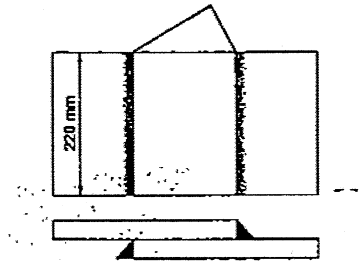
Q.3 In prob. fig. 3.2, the size of the weld is 5 mm. Determine the maximum service load that can be applied on this member.



Q.4 Two 12 mm thick MS plate are joined in workshop through (i) single V-butt weld, (ii) double V-butt weld. The effective length of the weld is 255 mm. Determine the design strength of the welded joint.

Q.5 Design a fillet weld to joint 2ISA 110 × 110 × 10 to 14 mm thick gusset plate to carry a factored tensile load of 395 kN.

Q.6 Determine the maximum force that can be transmitted through the joint as shown in prob. fig. 3.3.



Q.7 Determine the strength (per mm) of 8 mm fillet weld when done in (i) shop and (ii) site.

■■■■