CHAPTER – 2

STRUCTURAL STEEL FASTNERS AND CONECTIONS

2.0: Introduction

In order to transmit the force from one part of the structure to another part or for stability purpose different members of steel of steel structures are required to be connected to each other and this is known as connection. The elements needed for a connection are called connectors or fasteners. Basically there are four types of connectors we generally used for transmission of load, and they are;
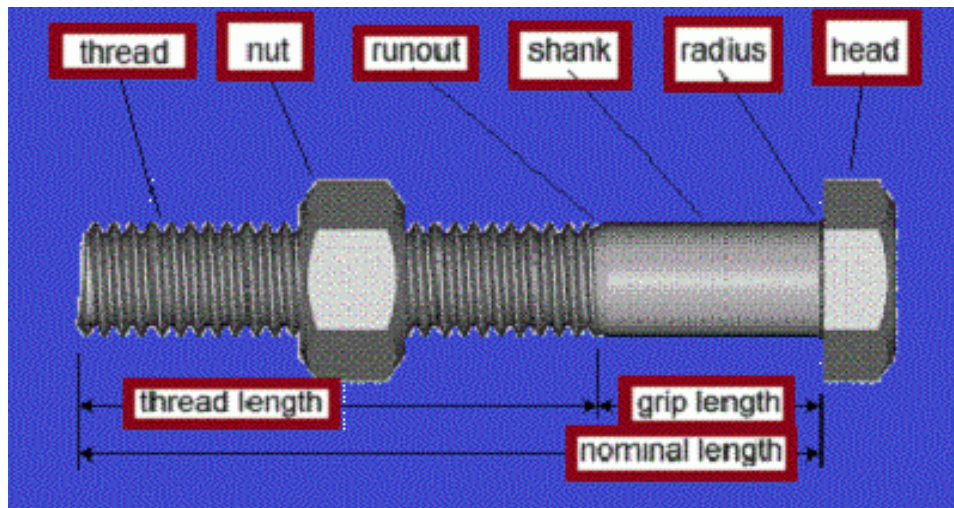
a) Bolts
b) Rivets
c) Welds
d) Pins

In most of the cases the ends of the members can not be directly connected, hence an additional member is used at the joint where ends of different members with one another and these plates are called gusset plate. Gusset plate is not provide to carry any force it just acts as a medium to transmit the force from one part to another part of the structure. The line of action of force of all the members connected are assumed to coincide at a single point to avoid the eccentricity.

Gusset plates are subjected to shear stress, direct stress and bending stress hence sufficient thickness should be provided to resist these forces at the critical sections. Usually the thickness of gusset plate is never kept less than 12mm.

2.1: Bolted Connections

Bolted connections are a type of structural joint used to connect two or more structural element in steel structure using bolts. A bolt is a metal object with a cylindrical trunk called shank with one end connected to a bolt head and threaded at the other end to receive the nut. The bolt head also comes with different shapes, hexagonal being the most common shape for the bolt head.

* The bolt has two types of area. The area of shank is called gross area where as the area of the threaded portion is called net area. The gross area gives the economical design whereas the net area gives safer design.

2.1.1: Classification of bolts, advantages and disadvantages of bolted connections

2.1.1.a: Classification of bolt

Bolted connections are of three types;

a) Unfinished or black bolts
b) Finished or turned bolts
c) High strength friction grip bolts

a. **Unfinished or black bolts**
   ➢ These are the ordinary bolts made from low carbon steel rods with square or hexagonal head with the shank unfinished permitting large tolerance.
   ➢ These bolts are recommended for light structures subjected to static loads and for the secondary members in a structure but not recommended for structures subjected to vibration and fatigue.
   ➢ In the joints provided with these bolts, the force is transmitted through interlocking and bearing, hence these bolts are called bearing bolts.
b. **Finished or turned bolts**
   ➢ These bolts are same as the black bolts but the shank of the bolt is turned to circular shape from mild steel hexagonal rods.
   ➢ Very small tolerance is allowed in these bolts.
   ➢ These bolts have very high shear and bearing resistance as the connection is more tight.
   ➢ Bolts from property class 3.6 to 12.9 are available but grade 4.6 are commonly used.
c. **High strength friction grip bolts**
   ➢ These bolts are made from high strength steel rods. High strength is achieved by tightening the bolts until very high tensile strength(about 90% of proof load) is developed.
   ➢ These bolts are provided with large bolt heads to provide sufficient bearing area.
   ➢ In case of these bolts loads are primarily transferred by means of friction and not by means of shear resulting into no slippage in the joint. Hence joints made with these bolts are called **slip critical connection.** When a shear load is applied to the joint no slip will occur until the shear load exceeds the frictional resistance between the elements jointed.

2.1.1.b: Classification of bolts based on load transfer mechanism

Based on load transfer mechanism, bolted connection may be divided into following two categories;

a) Bearing type or slip type connection
b) Friction grip type or slip critical connection

Bearing type or slip type connection is achieved by black bolts and turned bolts as the load transfers by relative slipping between the members and bearing of the members against bolts. Whereas slip critical is achieved by high strength friction grip bolts since the force is transmitted by means friction between the members due to tensioning of the bolts.

2.1.1.2: Advantages and dis advantages of bolted connection

Advantages:

1. Since the bolted connections are simple connections, hence less skilled labours are required for the operation.
2. It is economical due to reduced labour and reduced equipment cost.
3. The operation is less noisy and speedy.
4. Easy alterations of the joint is possible is possible in case of bolted connection.

Disadvantages

1. The effectiveness of the joint depends on tightening of the joint and the friction between nut and bolt.
2. Vibration loosens the bolts. Hence under vibration load or dynamic load the strength of the bolt reduces.
3. In a bolted connection proper lubrication is required over a period of time for smooth operations.
4. Bolted connection is susceptible to corrosion.
5. Large joint space, when heavy loads are required.

2.1.2: Important terminologies

Pitch distance: It is the distance between centres of two consecutive bolt holes in row measured along the direction of the load.
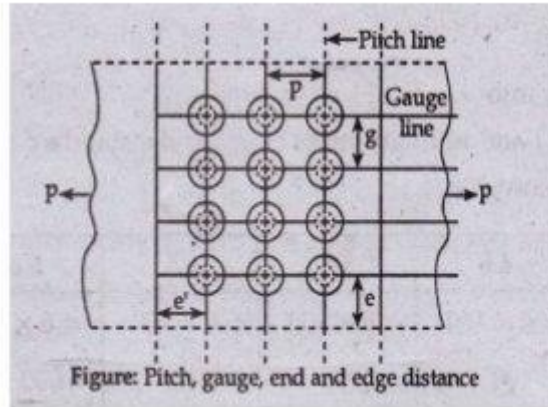
Gauge distance: It is the distance between two consecutive bolt holes in adjacent rows measured in perpendicular direction of the direction of force.

Edge distance: it is the distance between centre of bolt holes from the adjacent edge of the plate in the perpendicular direction of stress.

End distance: It is the distance between the centre of the bolt hole to the end of the element in the direction of stress.

Staggered pitch: staggered pitch is the distance between the staggered bolts measured along the direction of load.

Staggered distance: The centre to centre distance between the staggered bolts measured obliquely on the member is called staggered distance.

Figure: Pitch, gauge, end and edge distance

Nominal Diameter of Bolt (d)	Diameter of Bolt Hole (d_0)
$12 \leq d \leq 14$	$d + 1$
$16 \leq d \leq 24$	$d + 2$
$d > 24$	$d + 3$

Specifications for bolted joints:

1. The distance between centre of fasteners (both pitch and gauge) shall not be less than 2.5d (d=nominal diameter of the bolt).
2. The maximum spacing between any two adjacent fasteners shall not exceed 32t or 300mm whichever is less, where 't' is the thickness of the thinner plate.
3. Maximum pitch shall not exceed 16t or 200mm, whichever is less, in case of tension members and 12t or 200mm whichever is less in case of compression member. Here 't' is the thickness of the thinnest member in the joint.
4. When the fasteners are staggered at staggered at equal intervals and the gauge does not exceed 75mm, the spacing as mentioned above for tension and compression member may be increased by 50 percent.
5. The gauge distance should not exceed (100+4t) or 200mm whichever is less, in case of both compression and tension member.
6. The minimum edge and end distances from the centre of any hole to the nearest edge of the plate shall not be less than 1.7 times the hole diameter in case of shear or hand flamed cut edges and 1.5 times the hole diameter in case of rolled, machine flamed, sawn and planed edge.
7. Maximum edge distance should not exceed 12tϵ, where $\epsilon = \sqrt{(250/f_y)}$, t = thickness of thinner outer plate. If members are exposed to corrosive influence, it shall not exceed (40+4t), where t = thickness of thinner connected plate.
8. Spacing of tacking fasteners in a line should not exceed (i)32t or 300mm, whichever is less when not exposed to weather, where t= thickness of outside plate, (ii)16t or 200mm, whichever is less when not exposed to weather, where t= thickness of outside plate.
9. Where members are made up of two flats, angles, channels then maximum spacing between tack bolts should not be greater than 600mm for compression member and should not be greater than 1000mm for tension member.

2.1.3: Types of bolted connection

Bolted connections or joints are broadly divided into two categories;

(a) Lap joint   (b) butt joint

(a) Lap joint

➢ In this type of joint two members are lapped over one another. In this joint two members are connected face to face.

➢ If one line of bolt is there then it is called single bolted lap joint ant if two lines of bolt are there it is called double bolted lap joint.

➢ As the centre of gravity of the members joined in lap joint are not collinear there is eccentricity in the connection which can be minimised by providing at least two bolts in a line.

Lap joint (a)
Single bolted lap joint (b)
Double bolted lap joint (c)
Eccentricity in lap joint (d)
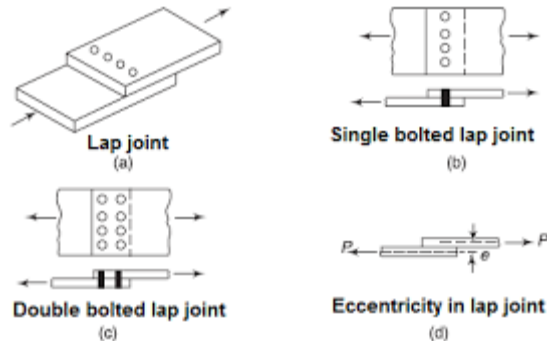
(b) Butt joint

➢ In this type of connection end to end connection is there between two members.

➢ Additional plates called cover plates are used either one side or two side of the member to make the connection.

➢ When cover plate is provided on one side of the main members it is called single cover butt joint and if it is provided on both side of the main member it is called double cover butt joint.

➢ Depending on the number of bolts provided in the connection the connection is named as single, double or triple bolted butt joint.

➢ The plane lying between cover plate and main plate is called shear plane. In single cover bolt joint one shear plane is there and in double cover butt joint two number of shear plane are there.

CHAIN ZIGZAG CONVERGENT ZIGZAG
LAP JOINTS
BUTT JOINTS
CHAIN ZIGZAG CONVERGENT ZIGZAG
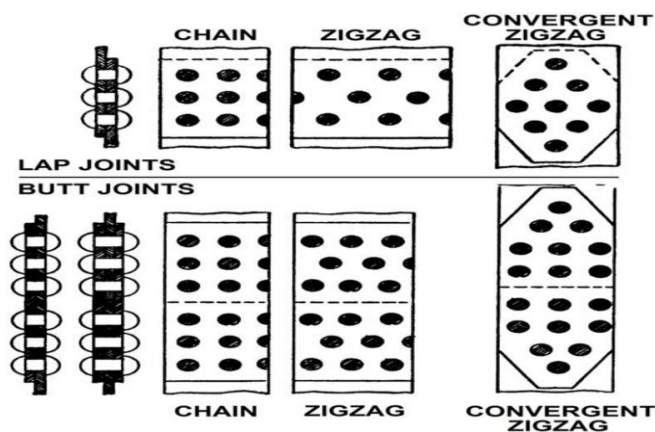
2.1.4: Principle of bolted connection

Following are principles those are to be observed in the design of bolted connection;

i. The arrangement of bolts should satisfy the gauge, pitch and the edge distance requirement.

ii. For economical connection in terms of cover plates, gusset plates etc. the length of the connection is kept as small as possible.
iii. The centre of gravity of the bolt group should coincide with the centre line of the connected members.
iv. The centre line of all members meeting at the joint should coincide at one point to avoid twisting of joint out of the position.
v. The number bolts should gradually increased towards the joint for uniform stress distribution in the bolts.
vi. Zigzag and diamond bolting may be adopted where ever possible to avoid strength reduction due to holes.

2.1.5.1: Strength of plates in a joint

The plates in bolted connection may fail due to rupture of plates at net cross sectional area, crushing of plate or bursting of the edges of plate. Bursting of plate at the edges may be avoided by providing minimum edge distance.

Hence majorly there are two type of strength of plate;

I. Design strength due to yielding of gross section
II. Design strength due to rupture of critical section

*(The minimum of the above two strength is considered as the strength of the plate)

I) Design strength due to yielding of gross section:

The design strength of members under axial tension, T_{dg}, as governed by yielding of gross section, is given by

$$T_{dg} = A_g f_y / Y_{m0}$$

Where,

A_g = gross area of the cross section

f_y = Yield stress of the matrial

Y_{m0} = partial safety factor for failure in tension by yielding

II) Design strength due to rupture of critical section:

The design strength in tension of a plate, T_{dn} is the strength of the thinner member against rupture which is governed by net cross sectional area A_n of the plate is given by;

$$T_{dn} = (0.9 A_n f_u) / Y_{ml}$$

f_u = ultimate stress of the material

γ_{ml} = Partial safety factor for failure at ultimate stress

A_n = net effective area of the plate at the critical section = $[b - nd_h + \sum(P^2_{si} / 4g_i)]$

b = width of the plate

t = thickness of the plate

d = diameter of the bolt hole

g = gauge distance between the bolt holes

P_s = length of the staggered pitch

n = number of bolts in the critical section

*Gross sectional area: Gross area of cross-section is the sectional area of the plate without deducting the area of holes present in the cross-section.

*Net sectional area: Net area of a cross-section is the cross sectional area of the plate after deducting the area of the hole present in the cross section.

2.1.5.2: Strength of the bearing type bolts in the joint

The bearing type bolt has two types of strength as below;

a. Shearing strength or shear capacity
b. Bearing strength or bearing capacity

*(The minimum of above two strength is considered as the strength of the bolt)

a. Shearing strength of the bolt(V_{dsb})

Shearing strength of bolt is the strength of the bolt against the shear force. The design shear strength of the bolt can be written as

$$V_{dsb} = V_{nsb} / \gamma_{mb}$$

$$V_{nsb} = \frac{fub}{\sqrt{3}}(n_n\ A_{nb} + n_s\ A_{sb}) \qquad (V_{nsb} = \text{nominal shear strength of the bolt})$$

Where

f_{ub} = uitimate tensile strength of a bolt;
n_n = number of shear planes with thread intercepting the shear plane;
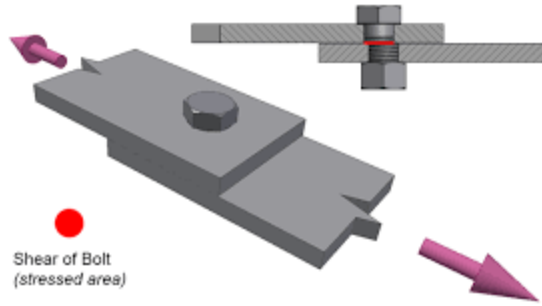n_s = number of shear planes without threadsintercepting the shear plane;
A_{sb} = nominal plain shank area of the bolt; and
A_{nb} = net shear area of the bolt at threads, may be taken as the area corresponding to root diameter at the thread.
$A_{nb} \approx 0.78\ A_{sb}$
γ_{mb} = Partial safety for bolt material

Shear of Bolt
(stressed area)

As per the code Reduction factors are used in few situations for determination of bearing capacity of bolt and they are as follows

    i.   Long joint
   ii.   Large grip length
  iii.   In case of packing plate more than 6mm thick

i. Reduction factor for long joint(β_{lj})

A joint is called as long joint if the distance between first and last bolt holes is more than 15d where, "d" is the nominal diameter of the bolt.

$\beta_{lj} = 1.075 - 0.005(l_j/d)$ where, $0.75 \leq \beta_{lj} \leq 1.0$

ii. Reduction factor for large grip length(β_{lg})

If the total thickness of the connected plates exceeds 5d it is called large grip length. In case of large grip length the design shear force shall be reduced by

$\beta_{lg} = 8d / (3d + l_g)$

iii. Reduction Factor for packing plates(β_{pk})

If packing plates of thickness more than 6mm are used in a joint then reduction factor for packing plates is used to determine the shear strength of bolt.

$\beta_{lg} = 1 - 0.0125\ t_{pk}$

b. Bearing strength of bolt(V_{dpb})

$V_{dpb} = (2.5\ K_b\ d\ t\ f_u)/\ \gamma_{mb}$

Where,

f_u = ultimate tensile strength of plate

d = nominal diameter of bolt

t = summation of thickness of the connected plates experiencing bearing stress in same direction
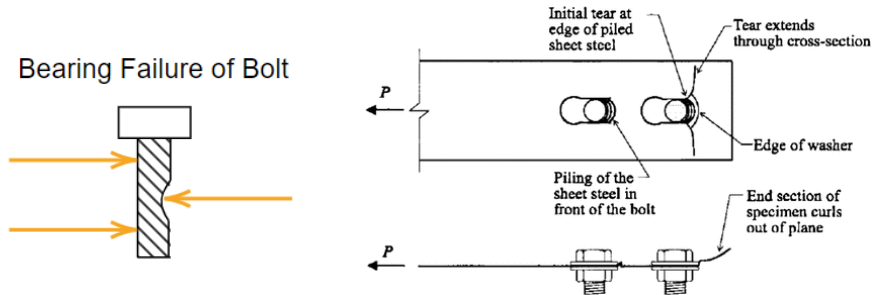
K_b can be calculated as minimum of following 4 values

$K_b = e/3d_0$

$= (p/3d_0) - 0.25$

$= f_{ub}/f_u$

$= 1$

Bearing Failure of Bolt

Initial tear at edge of piled sheet steel — Tear extends through cross-section

Edge of washer

Piling of the sheet steel in front of the bolt

End section of specimen curls out of plane

Bearing resistance of bolts in holes other than standard clearance holes may be reduced by multiplying the bearing resistance obtained as above by following factors given below,

- For over size and short slotted holes - 0.7
- For long slotted holes – 0.5

2.1.5.3: Shear Capacity of HSFG bolts

The nominal shear capacity of a bolt is given by ;

$V_{nsf} = \mu_f \, n_e \, K_h \, F_0$

μ_f = slip factor or coefficient of friction

n_e = number of effective interfaces offering frictional resistance to slip

$K_h = 1$ for fasteners in clearance holes

$= 0.85$ for fasteners in oversized and short slotted holes and for long slotted holes loaded perpendicular to the slot

$= 0.7$ for fasteners in long slotted holes loaded parallel to slot

F_0 = minimum bolt tension at installation $= A_{nb} \, f_0$

A_{nb} = Net area of bolt at heads

f_0 = proof stress $= 0.70 \, f_{ub}$

* As the shank of the HSFG bolts does not fill the hole completely hence the load is transferred by means of friction and shear. The nut of these bolts are tightened to developed a clamping force on the plates which is indicated as tensile force in the bolt. This tension is about 90% of the proof load. And when a shear force is applied to the joint, no slip will occur until the shear load exceeds the frictional resistance between the elements joined. And when the shear load exceeds the frictional resistance, slip occurs.

2.1.6: Analysis and design of joint using bearing type and HSFG bolts

The object of design of bolted connection is to arrange the bolts in such a manner that the load can be transmitted safely and economically. If the thickness of the plate and force to be transmitted is known to us then the following procedure can be followed to design the bolt.

- If the size of the bolt hole is not given in question then it is calculated using Unwin's formula as d = 6.04√t , where "d" is the nominal diameter of the bolt "t" is the thickness of the thinner member.
- If the values of pitch distance and gauge distance are not given then they are calculated as per the code. Then both the bearing strength and shearing strength of the bolt are calculated and the minimum of these two values is called bolt value.
- Then the number of bolts are obtained by dividing the applied force by bolt value. This value is rounded of to the nearest whole number to get the desired value of bolt.
- Then the bolts are arranged suitably for an efficient joint.
- At last the joint is checked against rupture.

2.1.7: Efficiency of a joint

Due to the presence of bolt holes the strength of the section is reduced to a certain extent in case of bolted connection. Efficiency is a parameter to show the actual strength of joint as compared to the strength of the solid plate. It can be expressed as the ratio of strength of the joint to the strength of the solid plate expressed in terms of percentage.

η = (strength of the joint)/(strength of the solid plate) x 100

* The minimum of the strength of the plate and strength of the bolt is called strength of the joint.

Welded Connection

2.2: Welded connection

Welding is a process of connecting two metal pieces by establishing a metallurgical bond between them by application of pressure and / or by fusion.

2.2.1: Advantages and dis-advantages of welded connection

2.2.1.1: Advantages of welded connection

➢ Due to the absence of gusset plate the welded structure are lighter than the bolted structures.
➢ The absence of making holes for the fasteners, makes the welding process easier.
➢ Welding is more adaptable than bolting or riveting for almost all type of sections
➢ It is possible to achieve 100 percent efficiency in case of welded conection
➢ Welded connection has good aesthetic appearance.
➢ Air tight and water tight connection is possible in case of welded connection. Hence these connection are less susceptible to corrosion.
➢ It provides better resistance against fatigue, impact and vibration loads.

2.2.1.2: Disadvantages of welded connection

➢ Skilled manpower is required for the welding process.
➢ Due to uneven heating and cooling, internal stresses and warping develops.
➢ It is difficult to detect defects like internal air pockets, slag inclusion and incomplete penetration in case of welded connection.
➢ Welded joints are over rigid
➢ Proper welding in field conditions are difficult
➢ Welded joints are more brittle and their fatigue strength is less.

## 2.2.2: Types of welded joints and specifications for welding

2.2.2.1: Types of welded joints

Depending upon the types of weld the welded joints are classified into three types

1. Butt weld
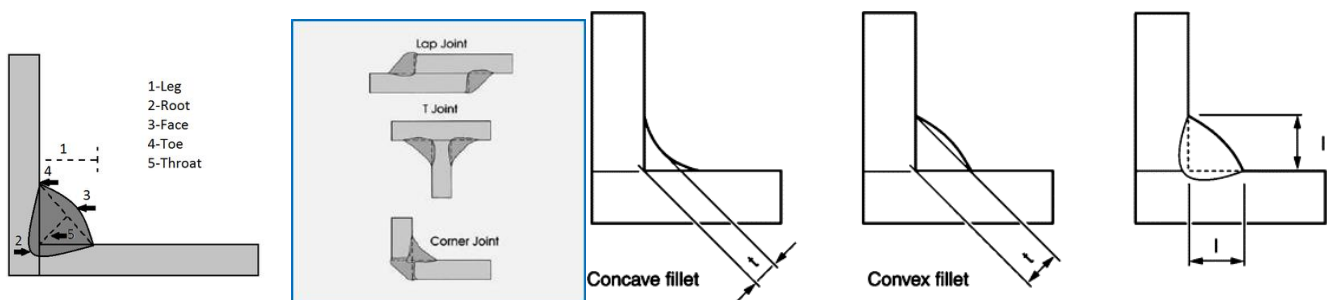2. Fillet weld
3. Slot weld and plug weld

1.Butt weld

When ends of the plates are connected with each other it is called as butt weld. It is otherwise called as groove weld. Butt weld is done when two member to be connected lies in same plane. Depending on the shape of the grooves different types of groove welds are there as follows.
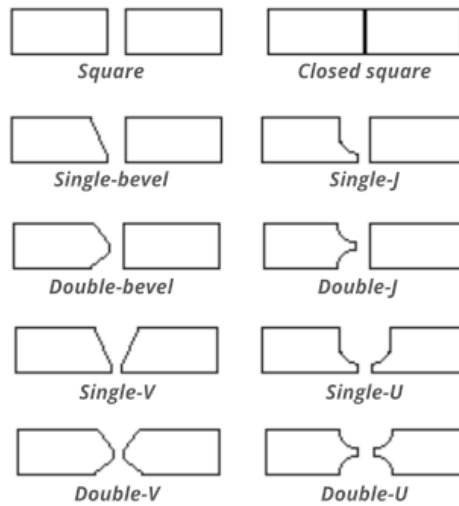
2. Fillet weld

This type of welds are provided when two members to be joined are in two different planes. Fillet weld is a weld of approximately triangular cross-section joining two surfaces nearly at right angle to each other in lap joint, tee joint and corner joint. When cross-section of fillet weld is isosceles triangle it is called a standard fillet weld. The angle between fusion faces of the connected members in case of fillet weld lies within 60-120 degree. Depending on the shape of the weld face a fillet weld is known as concave fillet weld, convex fillet weld or metre fillet weld.

3. Slot weld and Plug weld

Slot weld and Plug weld are used as a supplement to the fillet weld, when required length of fillet weld can not be provided. In case of slot weld slots are made on one of the plate and fillet weld is done along the periphery of the slot. Some time the slots are partially or completely filled with weld material.

In case of slot weld a small hole is made on one plate and it is placed over another plate to be connected and he hole is filled with filler material.
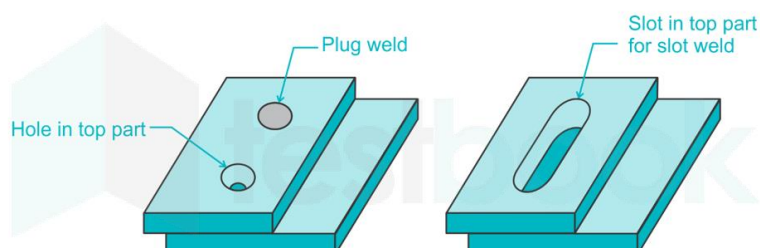
2.2.2.2: Specifications for welding

2.2.2.2a: Butt weld

i. To increase the efficiency of butt weld and to make the weld stronger against static load extra weld material is deposited above the surface level of the parent material to be connected.

ii. The size of the butt weld is specified by the effective throat thickness. There may be complete or partial penetration in case of butt weld. In case of complete penetration of butt weld the effective throat thickness may be considered as the thickness of the thinner member. For partial penetration the effective throat thickness may be taken as $5/8^{th}$ of thickness of the thinner member to be joined.

iii. Effective length of butt weld shall be taken as the length of the full size weld. And the effective area may be calculated by multiplying effective length with the effective throat thickness.

iv. The minimum length of butt weld should not be less than four times the size of the weld.

v. Unless specified, the intermittent butt weld shall have an effective length not less than 4 times the size of the weld and the longitudinal spacing between the welds should not be more than 16times the thickness of the thinner part. The intermittent weld shall not be used in the positions subjected to dynamic, repetitive and alternating forces.

2.2.2.2b: Fillet weld

i. The size of the fillet weld is taken as the minimum weld leg size. For deep penetration welds, where the depth of the penetration beyond the root run is a minimum of 2.4mm, the size of the fillet weld should be taken as the minimum leg size plus 2.4mm.

ii. To avoid the risk of cracking in the absence of pre heating, the minimum size of the fillet weld should be as per the table given below;

Thickness of the thicker member	Minimum size of the weld
Up to and including 10mm	3 mm
Over 10 mm up to and including 20 mm	5 mm
Over 20 mm up to and including 32 mm	6 mm
Over 32 mm up to and including 50 mm	8 mm in first run and minimum 10 mm

iii. The maximum size of the fillet weld for any square edge of a member should be 1.5 mm less than the nominal thickness of the edge. The fillet weld used for the toe of an angle or rounded edge of a flange should not exceed ¾ th the thickness of the flange or leg of the angle. In case of members subjected to dynamic loading the fillet weld shall be of full size with its leg length equal to the thickness of the plate.

iv. The throat thickness of the fillet weld is the length of the perpendicular from the right angle of the corner to the hypotenuse. The effective throat thickness can be calculate as;

t = K x size of the fillet weld (where the value of K depends on the angle between the fusion faces)

Angle between fusion faces	60-90°	9-100°	101-106°	107-113°	114-120°
K	0.70	.65	.60	.55	.50

v. The effective length of the fillet weld is equal to overall length minus twice the size of the weld. The effective length of the fillet weld designed to transmit the load should not be less than 4 times the size of the weld.

vi. The end return provided in the joint should not be less than two times the size of the weld.

vii. The minimum overlap in case of lap joint should not be less than four times the thickness of thinner parts joined or 40 mm whichever is more.

viii. When end of element is connected only by longitudinal fillet weld, the length of the weld along either edge should not be less than the transverse spacing between longitudinal welds.

ix. Any section of an intermittent fillet weld should have an effective length of not less than four times the size of the weld or 40 mm, whichever is greater.

x. The clear spacing between the effective length of intermittent fillet welds carrying stresses should not exceed 12t for compression and 16t for tension and in no case be more than 200 mm, where "t" is the thickness of the thinner part joined.

2.2.2.2c: Plug and Slot Welds

i. The width or diameter should not be less than 3t or 25 mm whichever is more.

ii. Clear distance between the holes should not be less than 2t or 25 mm which is more, where "t" is the thickness of the plate having a hole or slot.

2.2.3: Design Stresses in Weld

Like bolts, welds could also be classified as shop weld and site weld. Since shop welding is done under controlled conditions, its strength is more than site welds. This factor is taken into account in partial safety factor for load material.

2.2.3.1: design stress for fillet weld, plug weld and slot weld

Such welds resists the external loads by shearing action only. The tensile stress in the member is transferred as shearing stress in the welds. The design strength in the welds is calculated on the basis of throat area of the weld.

$$f_{wd} = f_{wn} / \gamma_{mw}$$

$$f_{wn} = f_u / \sqrt{3}$$

where,

f_u = smaller of the ultimate stress of the parent metal or weld

γ_{mw} = partial safety factor for the weld material

In case of long joint reduction factor will be applied to the design stress of the weld. When the length of the welded joint, l_j of a splice or end connection in a compression or tension element is greater than $150t_t$, the design capacity of the weld should be reduced by the following factor;

$$\beta_{tw} = 1.2 - (0.2\, l_j \,/150t) \leq 1.0$$

2.2.3.2: Design stress for Butt welds

Butt weld shall be treated as parent metal with a thickness equal to the throat thickness and the stress shall not exceed those permitted in the parent metal. Butt weld can resist the load by tension, compression and shear action.

Design stress of butt weld in tension and compression may be defined as

$$f_{wd} = f_u / \gamma_{mw}$$

2.2.4: Strength of the welded joints:

Strength of a welded joint can be defined as the maximum force that can be carried by the joint. Strength of the welded joint depends on the strength of the plate and strength of the weld. The minimum of the strength of the weld and strength of the plate is defined as strength of the joint.

Important Questions

Short Question