UNIT - I

1 General Considerations and Introduction to Limit State Design

1.1 : Introduction

Q.1 Define steel structures and Explain in short.

Ans. : A steel structure is **group of elements** which is used to sustained there share of applied forces and various load combinations and to transfer them safely to the ground.

1) Structural steel is alloy of Iron containing carbon [C] and manganese [Mg], various other metals in small quantities.
2) Various grades of steel are : Fe 250, Fe 415 and Fe 500 etc. where, Fe stands for ferrous metal and numerical value stands for the characteristics ultimate tensile stress in MPa.

1.2 : Advantages and Disadvantages of Steel as Structural Material

Q.2 What are the advantages and disadvantages of steel as structural material ?

Ans. :

Advantages :

1) Steel has high strength to weight ratio.
2) It has very good mechanical properties like ductility, tensile and compressible strength.
3) It can be recycled i.e. its scrap value is more.
4) Steel has a very long life span.
5) It can be handled conveniently so it is easy in transportation.

Disadvantages :

1) Steel is susceptible to corrosion.
2) It is a very costly material.
3) When there is high temperature, steel loose its strength rapidly.
4) Susceptible to buckling, fatigue and loose its strength.
5) It requires periodic maintainance (i.e. painting)

1.3 : Materials

Q.3 Give the chemical composition of structural steel and discuss the amount of carbon in it ?

Ans. : • Structural steel is made by combining the Carbon (C), Manganese (Mn), Silicon (Si), Sulphur (S), Phosphorous (P) along with Iron (Fe).

- The strength, ductility and durability of steel is depends on the chemical composition of such material.
- On the basis of percentage of Carbon, Steel is classified as follows :

Sr.No.	Type of Steel	Carbon (%)
1.	Dead Mild Steel	< 0.15
2.	Mild Steel (MS)	0.15 - 0.3
3.	Medium Carbon Steel	0.3 - 0.8
4.	High Carbon Steel	0.8 - 1.5

- The various combinations of strength and ductility can be obtained by controlling carbon content and other alloying elements.

1.4 : Types of Structural Steel and It's Mechanical Properties

Q.4 What are the various types of structural steel ? Discuss their mechanical properties.

☞ **[JNTU : April-18, Marks 5]**

Ans. : • Metals which are used for engineering purposes are mostly ferrous metals, with iron as main constituent.

- Iron is most widely used and important structural material.
- The major ores of iron with percentage of iron are :

1) Haematite (Fe_2O_3) - 70 %

2) Magnetite (Fe_3O_4) - 75 %
3) Limonite ($2\,Fe_2O_3\ \ 3H_2O$) - 60 %
4) Iron Pyrite (FeS_3) - 47 %
5) Siderite ($FeCO_3$) - 40 %

- The types of structural steel or iron are :

Pig Iron, Cast Iron, Wrought Iron, Steel, and Alloy Steel

Properties of Structural Steel :

1) Physical Properties :

a) Unit mass ( ) = 7850 kg/m^3
b) Modulus of elasticity (E) = 2.0 10^5 N/mm^2
c) Poisson's ratio ( ) = 0.3
d) Modulus of rigidity : (G) = 0.769 10^5 N/mm^2

Mechanical Properties of Steel :

a) Yield stress, f_y
b) The tensile or ultimate stress, f_u
c) The coefficient of thermal expansion ( ) = 12 10^{-6} C^{-1}

1.5 : Concepts of Plasticity and Yield Strength

Q.5 What is plasticity ? Explain stress - strain curve for mild steel and discuss salient point on it ?

Ans. : • Plasticity : Plasticity is the deformation of material undergoing non - reversible changes of shapes in response to applied forces.

Stress - strain curve for mild steel :

- Curve OABC'CDEF represents stress - strain curve for mild steel i.e. tensile material :

where, A - Represents the limit of proportionality.

B - Represents the elastic limit i.e. The maximum stress upto which a specimen regains its original length on removal of the applied load.

OAB - Represent straight line curve, i.e. it obey's Hook's law.

C'   C - Represents plastic yielding

The strain occurs before yield point is called **elastic strain** and which occurs after yield point is called **plastic strain**.

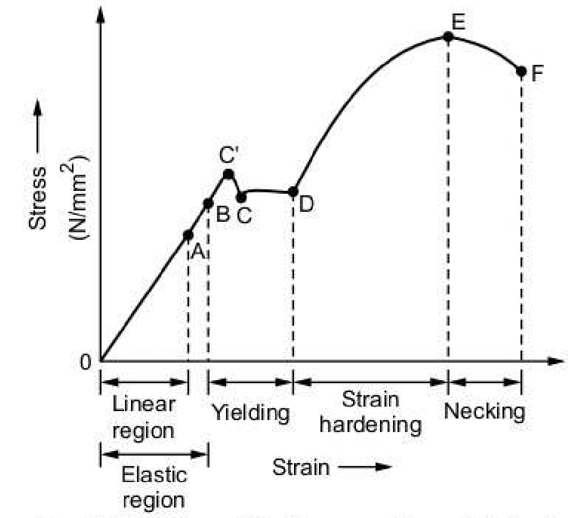


Fig. Q.5.1 Stress-Strain curve for mild steel

C   D - Represents total yielding.

D   E - Represents strain hardening, where continuous additional stress produces additional strain.

E - Represents ultimate point, normally it is 20 %.

EF - The portion where necking is done i.e. specimen breaks.

F - Breaking stress i.e. stress corresponding to the breaking load.

1.6 : Loads and Combinations

Q.6 What are the loads, combinations for design purpose ? ☞ **[JNTU : May-16, Marks 2]**

Ans. : Following are the various loads which affects the design consideration :

a) Dead load :

- Weight of permanent constructions consider under it.
- For e.g. Weight of Beams, Columns, Slabs, Flooring etc.

b) Impose load :

- It also termed as live load, impact load.
- It include movable and temporary loads.
- For e.g. weight of snow, furniture, persons etc.

c) Environmental loads :

- Environmental loads are loads which are due to directly or indirectly to environmental actions.

i) **Direct actions :** Earthquake load, snow and rain load etc.

ii) **Indirect actions :** Temperature change create shrinkage and swelling in structure which produce loads.

d) Erection loads :

- Erection loads are due to storage of material and impact of hanging equipments.
- Temporary bracings are provided to sustained from it.

A judicious combination of loads is necessary to insure the required safety and economy in the design keeping in view the probability of :

a) Their acting together

b) Their desposition in relation to other loads and severity of stresses or deformation causes by combination of various load.

The recommended load combinations by IS code are,

1) DL	7) DL + IL + EL
2) DL + IL	8) DL + IL + TL
3) DL + WL	9) DL + WL + TL
4) DL + EL	10) DL + EL + TL
5) DL + TL	11) DL + IL + WL + TL
6) DL + IL + WL	12) DL + IL + EL + TL

Where,

DL = Dead Load

IL = Imposed Load

WL = Wind Load

EL = Earthquake Load

TL = Temperature Load

1.7 : Local Buckling Behavior of Steel

Q.7 What is local buckling of beam member ?

Ans. :

1) Local buckling involves distortion of cross section which effects the reduction in overall load carrying capacity as well as rotation capacity of column and beams.

2) This is mainly due to reduction in stiffness of locally buckled section.

3) IS 800 : 2007 provides the limiting width to thickness ratio to prevent local buckling.

4) These limiting values depends on,

   i) The way in which the outstanding flanges of sections are provided.

   ii) The bending stress distribution.

   iii) The type of section.

   iv) Residual stress distribution.

1.8 : Concept of Limit State Design

Q.8 Discuss various limit states which are considered in design.

Ans. :

1) Limit state method is latest method of design of structure which eliminate all the limitations which remains in working stress method and Ultimate Load Design.

2) In Limit State Method (LSM), structure is design as **safety at ultimate loads and serviceability at service loads.**

3) These multiple safety factors are based on probabilistic approach separated for each type of failure, type of material and types of loads.

4) In LSM, two types of limit states are defined which are :

a) Limit State of Collapse :

- Various limit states of collapse are :

I) Flexure II) Compression

III) Shear IV) Torsion

b) Limit State of Serviceability :

- Various limit states of serviceability are :

I) Deflection II) Excessive vibration

III) Corrosion IV) Cracking

5) If structure has attained limit state of serviceability and then loads are removed, then structure will return to its original shape.

6) But, when it attained the limit state of collapse, then the structure will not return to its original shape.

Advantages :

1) This method recognizes that design parameters are variant.

2) All the limitations of WSM and ULD are removed.

3) This method gives different weightages to different loads and materials.

Disadvantages :

1) There are possibilities of errors because this method is complex than WSM.

2) More calculations are needed.

1.9 : Basis for Design

Q.9 What are the partial safety factors for material adopted by IS 800:2007 code ?

Ans. :

$$\text{Design Strength} = \frac{\text{Ultimate Strength}}{\text{Partial Safety Factor}}$$

- The table below gives partial safety factors for various conditions :

Sr. No.	Definition	Partial safety factor	
1.	Resistance, governed by yielding, $_{m0}$	1.10	
2.	Resistance of member to buckling, $_{m0}$	1.10	
3.	Resistance, governed by ultimate stress, $_{m1}$	1.25	
4.	Resistance of connection :	Shop fabrications	Field fabrications
	a) Bolts - friction type, $_{mf}$	1.25	1.25
	b) Bolts - bearing type, $_{mb}$	1.25	1.25
	c) Rivets, $_{mf}$	1.25	1.25
	d) Welds, $_{mw}$	1.25	1.50

1.10 : Riveted Connections

Q.10 Explain riveted connection in short, give its advantages and disadvantages ?

Ans. :

1) A piece of steel forged in place to connect two or more than two steel members together is known as **rivet.**

2) A rivet is made up of a round ductile steel bar of mild or high tensile steel which is called **shank** with the head at one of its ends.

3) IS 800 : 2007 states that rivets should be heated uniformly and that too throughout the length without burning or excessive scaling.

4) Shank shall be of standard length to provide a head of standard dimension.

5) When rivets are driven then these shall fill the rivets hole completely.

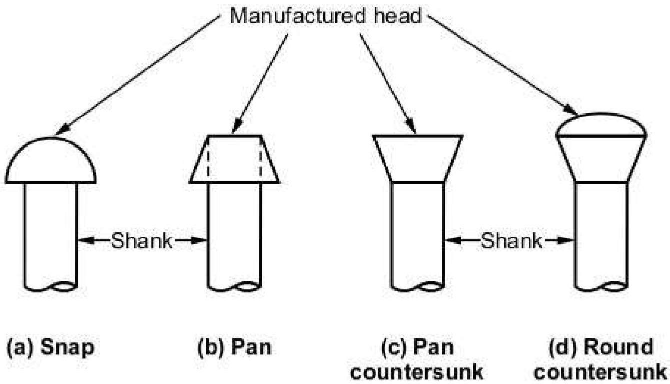


Fig. Q.10.1 Types of rivets

Advantages of riveted joints :

1) Its fabrication is simple.

2) Cheaper and low maintenance cost required.

3) It can join material or plat of different properties.

Disadvantages of riveted joints :

1) Its labour cost is high

2) Inspection of it requires skilled workmen.

3) During fabrication it creates high level noise pollution.

Q.11 Enlist different types of riveted connections and explain it with its patterns ?

Ans. :

A) Following are the types of **riveted joints,**

i) **Lap joint :** two members are overlapped.

ii) **Butt joint :** two members are connected end to end.

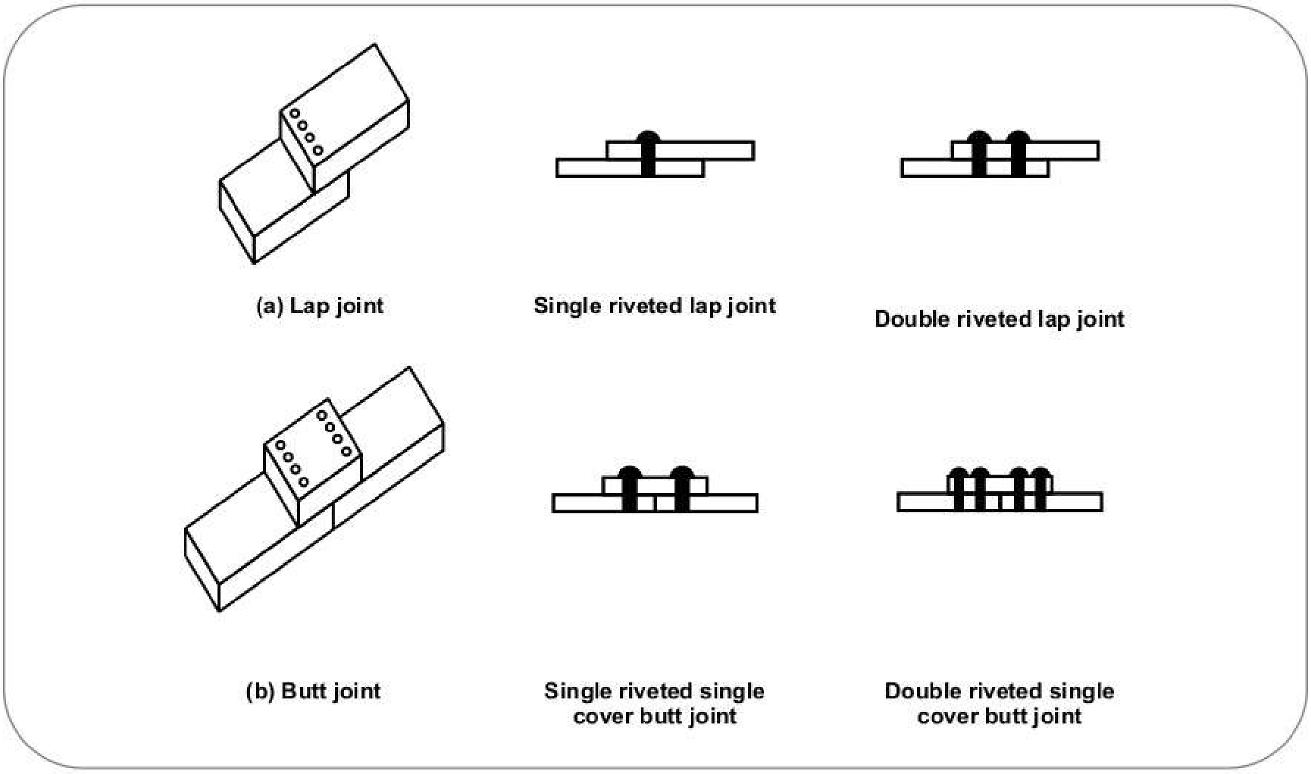
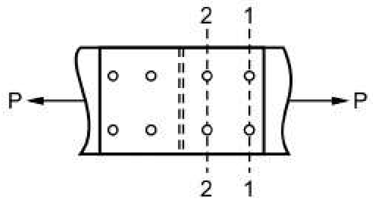


Fig. Q.11.1 Types of riveted joints

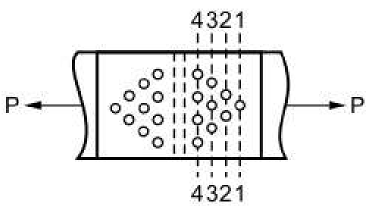
B) The commonly used **rivet patterns are,**

i) Chain riveting **ii) Diamond riveting**

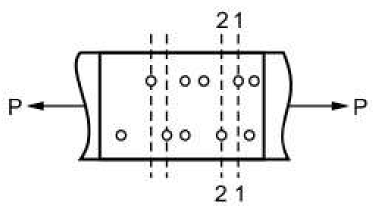
iii) Staggered riveting



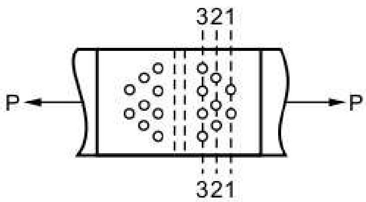
(a) Chain



(b) Diamond



(c) Staggered chain



(d) Staggered diamond

Fig. Q.11.2 Patterns used in riveted joint

1.11 : Bolted Connections

Q.12 Explain bolted connections, give advantages and disadvantages of it.

Ans. :

1) A bolt is a sort of threaded pin with head at one end and threads on other of the shank to receive nut as shown in Fig. Q.12.1

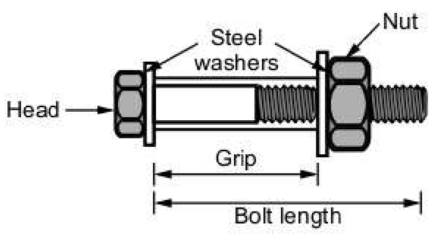


Fig. Q.12.1 Bolted assembly

2) **Bold length :** The bolt length is the distance from bottom of bolt head to the end of bolt.

3) **Grip length :** Grip of bolt is the distance from bottom of bolt head to the back of washer.

Advantages and disadvantages of bolted connection over riveted connections :

Advantages :

i) Bolted connections facilate faster erection of structure.

ii) Skilled persons not required.

iii) Overall construction of bolted connections is less than riveted connections.

Disadvantages :

i) Cost is almost double than rivets.

ii) Bolts usually have minimum strength since they can loose fit.

iii) When they are used in dynamic loading where vibrations occurs, they get loosened up.

iv) Tensile strength of bolts is reduced, because of reduced area at the root of thread.

Types of Bolts

Q.13 What are the different types of bolts ? Also enlists its types of joint ?

Ans. : Following are the types of bolts : (as per IS 800 : 2007)

a) **Unfinished bolts :** Also known as ordinary, common rough or black bolts.
  - They are commonly used in light structures.

b) **High strength bolts :** High strength bolts are fabricated from bars of medium carbon heat treated steel and from alloy of steel.
  - Due to friction between contact surfaces, the slip of joints is entirely eliminated. So, they are also called nonslip bolts.

Following are the different types of bolted joint :

a) Lap joint :

i) Single bolted lap joint

ii) Double bolted lap joint

b) Butt joint :

i) Single-cover single bolted butt joint

ii) Single-cover double bolted butt joint

iii) Double cover single bolted butt joint

iv) Double cover double bolted butt joint

Load Transfer Mechanism

Q.14 Explain mechanism of load transfer through bolts.

Ans. :

1) The transfer of force from one member to another depends on the type of bolt being used.

2) This transfer of force mechanism,

Bearing type : Where load transfer occurs by shearing and bearing.

- **Slip resistance type :** Where load transfer occurs by friction.

3) When load exceeds the frictional resistance then slippage occurs.

4) When high strength bolts are not tightened sufficiently squeeze the plated together, there will be negligible friction between plates.

Failure of Bolted Joints

Q.15 Write about failure of bolted joints.

Ans. : Failure of bolted joints are as follows,

a) **Shear failure of bolts :** It occurs when the maximum factored shear force exceeds the shear capacity of the bolt. Shear failure of bolts takes place at bolt shear plane.

b) **Bearing failure of bolts :** Here the bolt gets crush around a semi-circumference. In general bearing failure of bolts do not occurs in practice except when the plates are made of high strength steel and corresponding bolts are of low grade steel.

c) **Tensile failure of bolts :** Bolts subjected to tension may fail at the stress area.

d) **Tension or tearing failure of plates :** Tension failure of plates occurs when bolts are stronger than the plates. Tension on both the gross area (i.e. yielding) and the net effective are (i.e. rupture) must be considered.

e) **Block shear failure :** Many times bolt may have been placed at a lesser end distance than required which may lead to plates to shear out and this failure occurs.

1.12 : Specification for Bolted Joints

Q.16 Give specifications for the bolted joints.

Ans. : Following are important-specification of bolted joints :

1) **Gross cross sectional area** $[A_g] = \frac{\;}{4}(d)^2 \text{ mm}^2$.

2) **Net cross sectional area** $[A_n] = 0.78 \; A_g$

3) **Pitch,** (P) [As per clause 10.2.2]

- Pitch is the distance between the centres of two consecutive bolts in the direction of load.
  - **Minimum pitch** should not be less than **2.5 times the nominal diameter of bolt.**
  - **Maximum pitch** = 16t or 200 mm whichever is less in tension members.

4) **Gauge (g) :** It is centre to centre distance between two consecutive bolts in the perpendicular direction to load.

5) **Edge distance :** It is the distance from centre of bolt hole to the adjacent edge in the direction normal to the direction of load.

6) **Staggered pitch (P_s) :** It is distance between two consecutive bolts in zigzag bolting measured parallel to the direction of load.

7) **End distance :** It is distance from the centre of the fastener hole to the edge of an element measured parallel to direction of load.

1.13 : Prying Action

Q.17 Explain the prying force.

Ans. :

1) High strength bolts are non-deforming and are subjected to tensile forces when tighted.

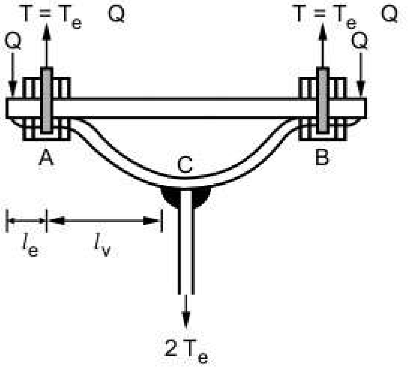


Fig. Q.17.1 Prying action in T-section

2) In most of the connections subjected to tension in general, due to the flexibility of connected parts, can lead to deformation that increase the tension applied to bolts. This additional tension force is called as prying force.

The prying force Q is given by,

$$Q = \frac{l_v}{2\,l_e}\,T_e - \frac{f_o \; b_e \; t^4}{27\,l_e\,l_v^2}$$

where,

l_v = Distance from the bolt centre line to the toe of the fillet weld or to half the root radius for rolled section.

l_e = Distance between prying force and bolt centre line and is minimum of either the end distance or the value given by,

$$\boldsymbol{l_e = 1\;1t\sqrt{\frac{f_o}{f_y}}}$$

= 1 for pre-tensioned bolt

= 2 for non-pre-tensioned bolt

= 1.5 for limit state design.

b_e = Effective width of the flange per pair of bolts

f_o = Proof stress

t = Thickness of end plate

1.14 : Tensile Strength of Plate

Q.18 Explain tensile strength of plate.

Ans. :

1) If tensile load acting on the plate exceeds tensile strength of the plate then failure of joint in the form of tension failure or rupture takes place.

2) Diamond pattern of bolting is the most efficient an economical as cover plates can be proportional to load transferred from main plates through bolts.

The tensile strength of plate is given by,

$$T_{nd} = 0.9\;A_n\,\frac{f_u}{m1}$$

where,

f_u = Ultimate stress of material (in N/mm^2)

A_n = Effective area of the plate (in mm^2)

$_{m1}$ = Partial factor of safety for material strength governed by ultimate strength

= 1.25

1.15 : Strength and Efficiency of Bolted Joints

Q.19 Explain strength and efficiency of bolted joint.

Ans. : The strength of joint is the minimum of strength of bolts in shear and bearing and strength of main connected member at the net section.

The efficiency of a bolted joint ( ) is defined as the ratio of strength of a joint to the strength of main connected member. i.e. (Solid plate)

$$= \frac{\text{Strength of bolted joint}}{\text{Strength of solid plate}} \quad 100$$

1.16 : Combined Tension and Shear

Q.20 Explain effect of combine tension and shear ?

Ans. : Generally in eccentrically loaded connection, the bolt is subjected to tension and shear both.

The combined effect of tension and shear is assessed by the interaction formula to check the safety of connection as,

$$\frac{V_{sb}}{V_{dsb}}^{2} \quad \frac{T_b}{T_{db}}^{2} \quad 1.0$$

where, V_{sb} = Factored shear force on the bolt

V_{dsb} = Design shear capacity of the bolt

T_b = Factored tensile force on bolt

T_{db} = Design tension capacity of the bolt

1.17 : Welded Connections

Q.21 What is welded connection ? Give different types of it.

Ans. : • When various members of metals are connected to each other by weld, then it is called as welded connection.

- A metallurgical bond is formed between them by process of heat and pressure.
- IS816, IS9595 and IS800 are refer for welding.

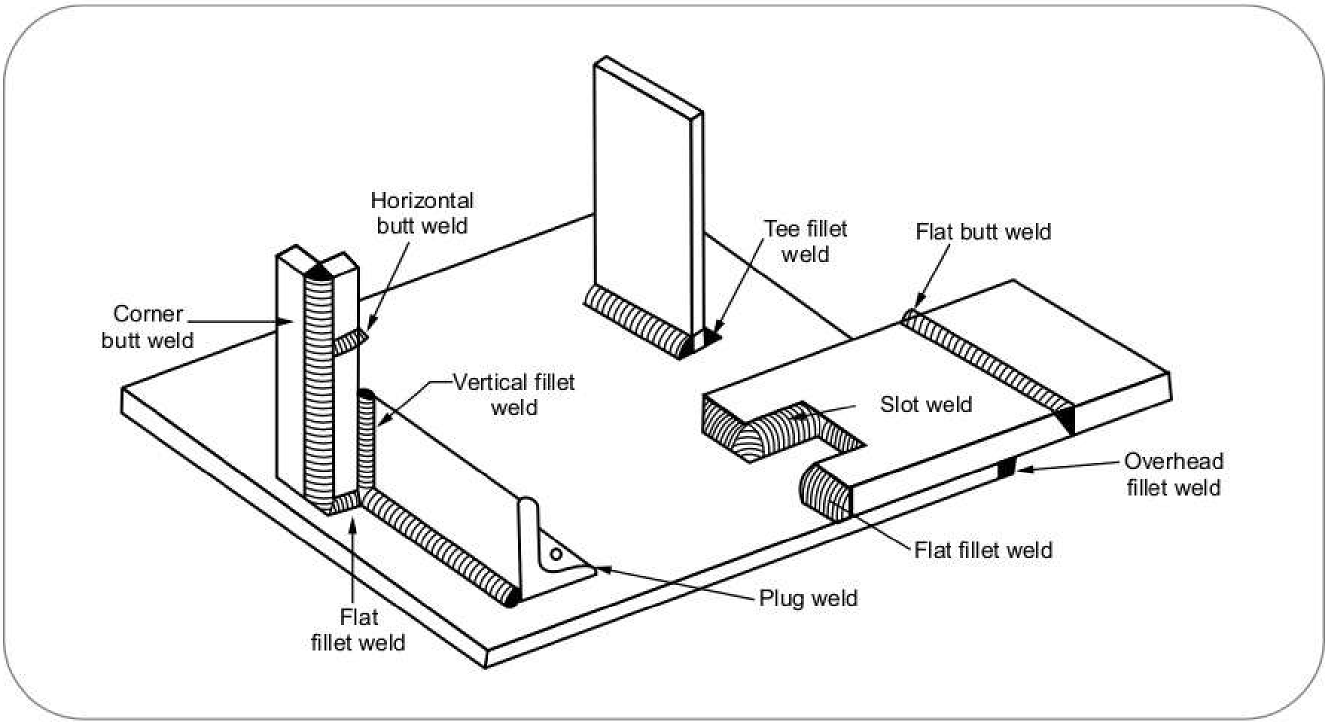


Fig. Q.1.1 Different types of welds

Types of Welded Connections :

- **Depending on the type of weld,**

I) Fillet weld II) Butt or groove weld

III) Plug weld IV)Slot weld

V) Spot weld

- **Depending on position,**

I) Flat weld II) Horizontal weld

III) Vertical weld IV)Overhead weld

- **Depending upon type of joint,**

I) Butt or groove weld II) Lap weld

III) Tee weld IV)Corner weld

- The Fig. Q.21.1 shows different types of welded connections, (See Fig. Q.21.1 on previous page)

Q.22 Give comparison between Fillet and Butt weld.

Ans. :

I) Fillet Weld : (IS 800 : 2007, Clause 10.5)

- Fillet weld is provided when two metal surfaces to be joined are in different planes.
- Fillet welds are more common than butt welds.
- Fillet welds are easy to make, required 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.
- Fillet welds are more economical than butt welds.
- Different types of fillet welds are shown in Fig. Q.22.1.

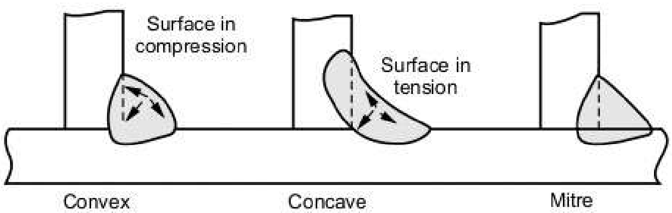


Fig. Q.2.1 Different types of fillet weld

II) Butt Welds : (IS 800 : 2007, clause 10.5)

- Butt joint is used to join flat plates of heavy equal sizes. When parts to be jointed are un-equal width or where the difference in thickness of parts to be jointed.
- It is also known as groove weld.
- Butt welds may have impact and fatigue resistance equal to or better than that of parent metal.
- Following and different types of butt (groove) welds, shown in Fig. Q.22.2,

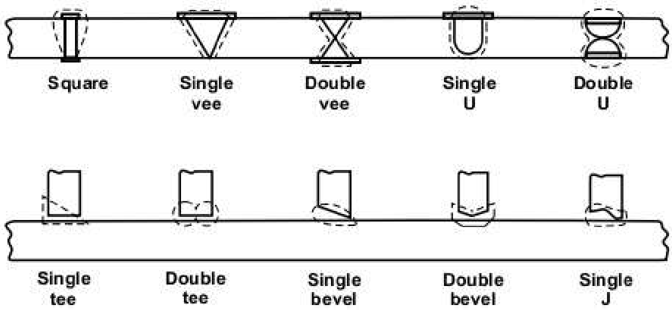


Fig. Q.22.2 Different types of butt (groove) welds

III) Slot and Plug Weld :

- Slot and plug weld are used to 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 weld cannot be ascertained.

1.18 : Design Requirements of Welds

A : Design of Butt Welds

Q.23 Explain design of groove welds ?

Ans. : utt (or Groove) welds :

- A square butt weld is provided for sections upto 8 mm thickness only.
- Butt weld is mainly designed for direct compression or tension and occasionally for shear also.

Specifications for the design of butt welds :

a) **Size :** The size of butt weld is specified by throat dimension also called as effective throat thickness.

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

Effective area = Effective throat thickness Effective length of butt weld

c) **Reinforcement :** Reinforcement increases the efficiency of the butt weld and it also ensures that the weld depth is at least equal to the plot thickness.

- Any reinforcement on the weld is not taken into account for strength calculation purpose.

Design strength of butt weld :

- The design strength of butt weld either in tension or compression is given by,

$$T_{dw} = \frac{f_y \;\; L_w \;\; t_e}{mw}$$

where, f_y = Smaller of yield strength of the weld (f_{yw}) and the parent metal (f_y) [in N/mm^2].

L_w = Effective length of the weld (in mm).

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

$_{mw}$ = Partial safety factor for weld.

= 1.25 for shop welding.

= 1.5 for site / field welding.

B : Design of Fillet Welds

Q.24 Explain design of fillet weld ?

Ans. : Fillet weld :

- This weld is required where member overlap each other or connecting members are in different planes. In such cases butt weld cannot be provided.
- Fillet weld is predominantly subjected to shear stresses.
- Fillet weld can either be convex or concave as per requirement.

Specifications for design of fillet weld :

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

- The minimum size of fillet weld is specified by IS800. These are the minimum sizes for the first run in order to avoid cracking.

b) Effective throat thickness :

- It is the shortest distance from the root of fillet weld to the hypotenuse of inscribed right triangle within the weld.
- The value of K (constant) is given in Table 22 of IS 800 : 2007.

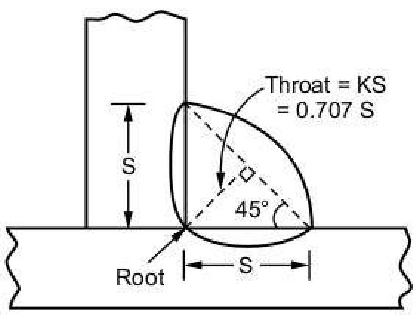


Fig. Q.24.1 Typical cross - sectional dimensions of a fillet weld

c) Effective length :

Effective length of fillet weld = Actual length of weld 25

d) Effective area :

Effective area of fillet weld = Effective lenght Effective throat thickness

e) Overlap :

- The overlap of the plates to be jointed by fillet weld should not be less than four times thickness of thinner member to be joined or 40 mm whichever is greater.

Design strenght of fillet weld :

- Design stress in a fillet weld is given by,

$$\boxed{f_{wd} = \frac{f_{wn}}{{}_{mw}}}$$

where, f_{wn} = Nominal strength of fillet weld

$= \frac{f_u}{\sqrt{3}}.$

f_u = Smaller of the ultimate stress of the weld or of the parent metal.

${}_{mw}$ = Partial safety factor for weld

= 1.25 for shop welding

= 1.5 for site / field welding.

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

$$\boxed{P_{dw} = L_w t_t \frac{f_u}{\sqrt{3}\ {}_{mw}}}$$

where, L_w = Effective length of fillet weld (in mm)

t_t = (K.S) Throat thickness (in mm)

S = Size of the fillet weld (in mm)

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

Symbols

Q.25 What are the symbols of weld ? Enlist and Draw neat sketches.

Ans. : • The basic weld symbols are shown in Table Q.25.1 :

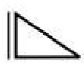
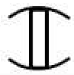
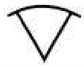
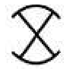
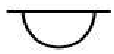
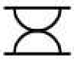
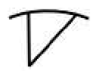
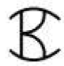
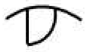
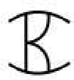
Sr. No.	Form of weld	Symbol
I	Fillet	
II	Square butt	
III	Single V butt	
IV	Double - V - butt	
V	Single U - butt	
VI	Double U - butt	
VII	Single bevel butt	
VIII	Double bevel butt	
IX	Single J butt	
X	Double J butt	

Table Q.25.1

- The supplementary weld symbols are shown in Table Q.25.2,

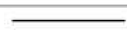
Sr. No.	Particulars	Weld Symbol
1.	Flush contour	
2.	Convex contour	
3.	Concave contour	
4.	Grinding finish	G
5.	Machining finish	M
6.	Chipping finish	C

Table Q.25.2

1.19 : Combination of Stresses and Failure of Welds

Q.26 Explain combination of stresses.

Ans. : • 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,

$$\boxed{F_e = \sqrt{f_a^2 \quad 3q^2}} \qquad \frac{f_u}{\sqrt{3}\ _{mw}}$$

Combination of stresses in butt weld :

In case of butt weld, the neck for combination of stresses is not required if :

a) Butt weld 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 where in 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,

$$\boxed{F_e = \sqrt{f_b^2 \quad f_{br}^2 \quad f_b f_{br} \quad 3_q^2}} \qquad \text{Strength values of the parent metal.}$$

Q.27 Explain failure of welds ?

Ans. :

Ans. : Failure of reinforced butt weld :

- In situation where butt weld is reinforced on both the sides of the plate the failure occurs at some distance away from the weld section as shown in Fig. Q.27.1 below.

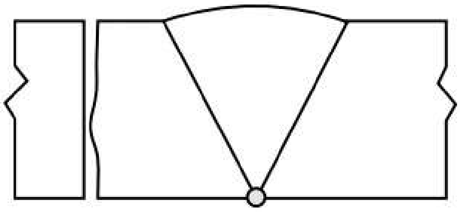


Fig. Q.27.1 Failure of reinforced butt weld

Failure of unreinforced (flushed) butt weld :

- When the butt weld is made flush with the surface of the joining plate then the location of the fracture depends on relative strength of the parent metal and weld metal.

I) When strength of weld metal < strength of parent metal, then fracture passes through the centre of weld.

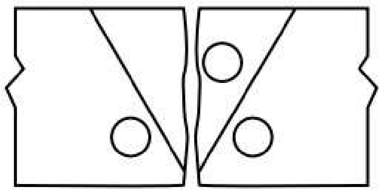


Fig. Q.27.2 Failure of unreinforced (flushed) butt weld

II) When strength of weld metal > strength of parent metal then failure plane located away from the weld in the plate.

Failure of end fillet weld :

- The Fig. Q.27.3 shows various types of failure in end fillet weld,

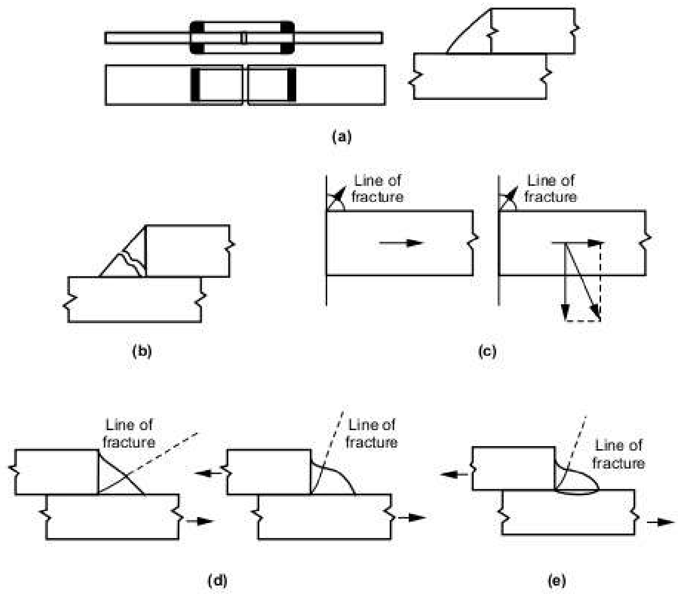


Fig. Q.27.3 Fracture position in end fillet weld

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 as shown in Fig. Q.27.4,

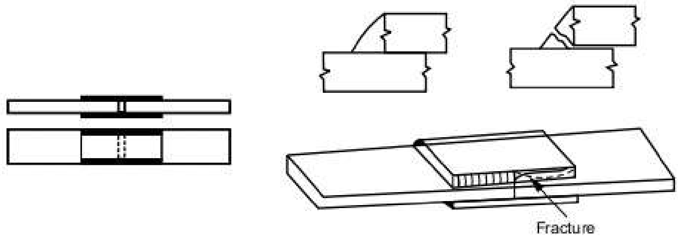


Fig. Q.27.4 Fracture position in side fillet weld

1.20 : Weld Defects

Q.28 Explain some of the common defects in the welds. ☞ **[JNTU : April-18, Marks 2]**

Ans. :

1) Incomplete fusion :

- It is the failure of base or parent metal to get completely fused with the weld metal.
- Occurs because of rapid welding and foreign materials on the surfaces to be weld.

2) Incomplete penetration :

- It is the failure of the weld metal to penetrate completely the depth of the joint.

3) 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.

4) Slag inclusion :

- These are metal oxides and other solid components which are often found as elongated inclusion that are being lighter than the molten material and rise to the weld surface from where these are removed after cooling the weld.

5) Cracks :

- Cracks can be hot or cool, Hot cracks occur due to present of sulphur, carbon, silicon and hydrogen in the weld metal.

6) Undercutting :

- It is the local decrease in the thickness of parent metal at the weld toe. This occurs due to excessive current or very long arc.

Illustrative Examples

Q.29 Two plates 10 mm and 18 mm thick are to be joined by a double cover butt joint. Assuming cover plates of 8 mm thickness, design the joint to transmit a factored load of 500 kN. Assume Fe 410 plate and grade 4.6 bolt. Assume the thickness of packing plate as 8 mm. ☞ **[JNTU : May-16, Marks 10]**

Ans. : Given data :

1) Thickness of plates = 10 mm and 18 mm
2) Thickness of cover plates = 8 mm
3) Factored load = 500 kN
4) Fe410 and Grade of bolt = 4.6, F_{ub} = 400

Assume 20 mm diameter bolts.

1) V_{dsb} = Bolt strength in double shear per pitch length,

$$A_{nb} = 0.78 \ \frac{}{4} \ d^2$$

$$= 0.78 \ \frac{}{4} \ 20^2$$

$$\boxed{A_{nb} = 245 \text{ mm}^2}$$

- The thickness of packing plate 8 mm > 6 mm then, the correction factor of packaging is considered.

$$_{pkg} = 1 - 0.0125 \ t_{pkg}$$

$$= 1 - 0.0125 \times 8 = 0.9$$

$$\mathbf{V_{dsb}} = 2 \ A_{nb} \frac{f_{ub}}{\sqrt{3} \ \ _{mb}} \ _{pkg}$$

$$= 2 \ 245 \ \frac{400}{\sqrt{3} \ 1.25} \ 0.9$$

$$= 81500 \text{ N} = \mathbf{81.5 \text{ kN}}$$

2) Bolt strength in bearing (assuming k_b = 0.5),

$$V_{dpb} = 2.5 \ k_b \ d \ t \ \frac{f_{ub}}{_{mb}}$$

$$= 2.5 \ 0.5 \ 20 \ 10 \ \frac{410}{1.25}$$

$$= 82000 \text{ N} = \mathbf{82 \text{ kN}}$$

Note : Strength of the joint is governed by the strength of the inner plate at the weakest section.

Hence, **Bolt strength = 81.5 kN**

$$\text{Required No. of bolts} = \frac{\text{Factored load}}{\text{Bolt strength}}$$

$$= \frac{500}{81.5}$$

$$= \mathbf{6.13}$$

Provide eight bolts, four bolts in two rows,

3) Strength of bolt per pitch length

$$= 2 \times 81.54 = \mathbf{163.08\ kN}$$

Equating it to the strength per pitch length of plat in tearing.

i.e. $$T_{dn} = 0.9 \ \frac{f_u}{mb}(p \quad nd_h)t$$

$$= 163.08 \quad 10^3$$

$$0.9 \ \frac{410}{(1.25 \quad 1000)} \ (p \quad 22) \quad 10$$

$$p = 77.24 \text{ mm} > 2.5 \times 20 = 50 \text{ mm}$$

- Minimum spacing of bolts = 2.5 × 20 = 50 mm
- Minimum edge distance = 1.5 × 22 = 33 mm
- Provide edge distance of **35 mm**

Hence provide **P = 75 mm**

- Provide additional two bolts of 20 mm diameter on the packing plate as shown in Fig. Q.29.1.
- Design strength of plate,

$$= \frac{0.9 \ A_n \ f_u}{m}$$

$$= \frac{0.9 \quad (295 \quad 4.22) \quad 10 \quad 410}{1.25 \quad 1000}$$

$$= \mathbf{611\ kN > 500\ kN}$$

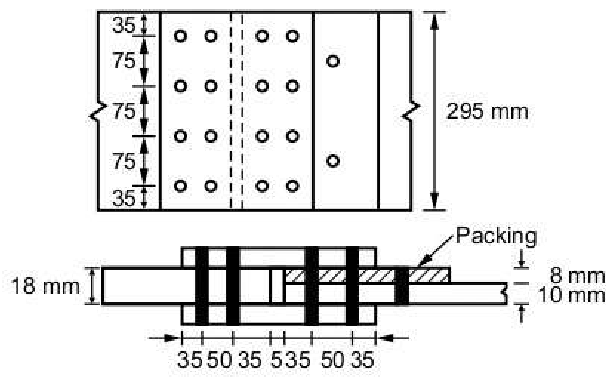


Fig. Q.29.1

Q.30 Calculate the strength of a 20 mm diameter bolt of grade 4.6 for the following cases. The main plates to be jointed are 12 mm thick
a) Lap joint
b) Single cover butt joint, cover plate being 10 mm thick. ☞ **[JNTU : May-17, Marks 10]**

Ans. : Diameter of bolt d = 20 mm

For Fe410 grade of steel

$$f_u = 410 \text{ MPa}$$

For bolts of grade 4.6

$$f_{ub} = 4 \times 100 = 400 \text{ MPa}$$

The partial safety factor for the material of bolt,

$$r_{mb} = 1.25$$

for d = 20 mm, net tensile stress area is given by,

$$A_{nb} = 245 \text{ mm}^2 \text{ (from table 5.1)}$$

a) Lap joint :

The bolts will be in single shear and bearing.

Strength of bolt in single shear,

$$V_{dsb} = \frac{A_{nb} f_{ub}}{\sqrt{3} \ _{mb}} = \frac{245 \quad 400}{\sqrt{3} \quad 1.25}$$

$$= 45.26 \quad 10^3 \text{ N}$$

$$\mathbf{V_{dsb} = 45.26\ kN}$$

Strength of bolt in bearing

$$V_{dpb} = 2.5 \, k_b d t \frac{f_u}{mb}$$

$$k_d = \frac{e}{3d_o} = \frac{P}{3d_o} \quad 0.25$$

$$= \frac{f_{ub}}{f_u} = 1$$

Consider minimum value among these values

$$d_o = \text{Diameter of hole provided for bolt}$$

$$= 20 + 2 = 22 \text{ mm}$$

[for 20 mm, cover = 2 mm, from table : 5.3]

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

Assume pitch, p = 50 mm

$$k_d = \frac{e}{3d_o} = \frac{33}{3 \quad 22} = 0.5$$

$$= \frac{P}{3d_o} \quad 0.25 = \frac{50}{3 \quad 22} \quad 0.25 = 0.5$$

$$= \frac{f_{ub}}{f_u} = \frac{400}{410} = 0.975 = 1.0$$

$$k_d = 0.5 \text{ (minimum value of all above values)}$$

$$V_{dpb} = 2.5 \;\; 0.5 \;\; 20 \;\; 12 \;\; \frac{410}{1.25}$$

$$= 98.4 \;\; 10^3 \text{ N}$$

$$\mathbf{V_{dpb} = 98.4 \text{ kN}}$$

The strength of the bolt is takes as the minimum of V_{dsb} and V_{dpb}

Strength of bolt = 45.26 kN

b) Single cover butt joint,

Thickness of main plate = 10 mm

Cover plate thickness = 12 mm (given)

The thickness of bearing is taken as the minimum of above values,

$$t = 10 \text{ mm}$$

Strength of bolt in single shear

$$\mathbf{V_{dsb} = 45.26 \text{ kN}}$$

Strength of bolt in bearing,

$$V_{dpb} = 2.5 k_b dt \frac{f_u}{mb}$$

$$= 2.5 \;\; 0.5 \;\; 20 \;\; 10 \;\; \frac{410}{1.25} = 82 \;\; 10^3 \text{ N}$$

$$\mathbf{V_{dpb} = 82 \text{ kN}}$$

Strength of bolt is taken as minimum value of V_{dsb} and V_{dpb}

Strength of bolt = 45.26 kN

Q.31 A 120 mm diameter and 6 mm thick pipe is fillet welded to a 14 mm plate. It is subjected to a vertical factored load of 4.5 kN at 1 m from the welded end and a factored twisting moment of 1.8 kN-m. Design the joint assuming shop welding and steel grade Fe410. ☞ **[JNTU : May-17, Marks 10]**

Ans. : Given :

$$d = 120 \text{ mm}, r = d/2 = 60 \text{ mm}$$

Thickness of plate = 6 mm

Direct load = 4.5 kN

Bending moment,

$$M_b = 4.5 \;\; 10^3 \;\; 1000$$

$$= 4.5 \;\; 10^6 \text{ Nmm}$$

Twisting moment,

$$M_t = 1.8 \;\; 10^6 \text{ Nmm}$$

Let t = Effective throat thickness of the weld

Polar moment of inertia,

$$I_{zz} = 2 \;\; r^3 t$$

$$= 2 \;\;\;\; (60)^3 \;\; t$$

$$= 1357168 \text{ t mm}^4$$

Moment of inertia,

$$I_{XX} = \frac{I_{ZZ}}{2} = \frac{1357168}{2}$$

$$= 678584.01 \text{ t mm}^4$$

Shear stress due to direct load,

$$= \frac{4.5 \;\; 10^3}{2 \;\; 60 \;\; t} = \frac{11.94}{t} \text{ N/mm}^2$$

Bending stress due to bending moment,

$$= \frac{4.5 \;\; 10^6 \;\; 60}{67.85 \;\; 10^4 \;\; t}$$

$$= \frac{397.94}{t} \text{ N/mm}^2$$

This bending stress shall be treated as shear since, the actual failure will be along the throat of the weld.

Shear stress due to twisting moment

$$= \frac{1.8 \;\; 10^6 \;\; 60}{135.7168 \;\; 10^4 \;\; t}$$

$$= \frac{79.58}{t} \text{ N/mm}^2$$

Combined stress

$$= \;\; \frac{11.94}{t}{}^{2} \;\;\;\; \frac{379.94}{t}{}^{2} \;\;\;\; \frac{79.58}{t}{}^{2} \;\; {}^{1/2}$$

$$_{vf} = \frac{388.37}{t}$$

$$_{vf} = \text{Allowable shear stress in weld}$$

$$= 108 \text{ N/mm}^2$$

$$108 = \frac{388.37}{t}$$

$$t = 3.60 = 4 \text{ mm}$$

Provide 4 mm fillet weld.