Chapter 1

Material Specifications and Connections—Simple and Eccentric

CHAPTER HIGHLIGHTS

- ☞ *Introduction*
- ☞ *Materials and specifications*
- ☞ *Bolted connections*
- ☞ *Welded connections*
- ☞ *Eccentric connections*

Introduction

This chapter introduces different design philosophies evolved with time and materials used for the design of steel structures. Different types of connections—bolted, welded, eccentric, and their design procedures are discussed in this chapter.

Materials and Specifications

Design Philosophies

Working Stress Design Method (IS: 800–1984)

- This method is based on elastic theory.
- The failure mode of the structure cannot be visualized.

$$\boxed{\mu R \geq W \text{ (service)}}$$

Where

μ = FOS

R = Resistance to bending or shear

W = Loads

- To be on the safe side, in regard to uncertainty of strength, reduced strength of material is taken.

Ultimate (Plastic or Load Resistance Factor) Design Method

- This method is based on failure load conditions (i.e., collapse load) rather than the working load.
- To be on the safe side, in regard to uncertainty of loads, increased loads are considered.
- (Full resistance) $\boxed{R \geq \lambda W}$

Where, λ – load factor.

Limit State Method (LSM) (IS: 800–2007)

- This method considers the most critical limit states of strength and serviceability.
- It considers uncertainty in both loading and material strength, and attempts to design structures which have consistent reliability, by using partial safety factors.

$$\boxed{\mu R \geq \sum_{i=1}^{n} \lambda_i W_i}$$

Where

μ = PSF for material

λ = PSF for loads

Here,

R = Characteristic strength

W_i = Characteristic load

Partial safety factors (strength or resistance factors)

Sl. No.	Definition	Partial Safety Factor	
1.	Resistance, governed by yielding γ_{mo}	1.10	
2.	Resistance of member to buckling γ_{mo}	1.10	
3.	Resistance, governed by ultimate stress γ_{m1}	1.25	
4.	Resistance of connection γ_{ml}	**Shop Fabrications**	**Field Fabrications**
	(i) Bolts-friction type, γ_{mf}	1.25	1.25
	(ii) Bolts-bearing type, γ_{mb}	1.25	1.25
	(iii) Rivets, γ_{mr}	1.25	1.25
	(iv) Welds, γ_{mw}	1.25	1.50

Types of Limit States

1. **Limit state of strength or collapse:**

   (Primary design)
   - *Loss of equilibrium* of a structure as a whole or any of its parts.
   - *Loss of stability* (including effect of sway or overturning).
   - Failure by excessive deformation.
   - Plastic collapse
   - Fracture due to fatigue.
   - Brittle fracture.

2. **Limit state of serviceability:**

   (Secondary design)
   - Deflection
   - Cracking
   - Vibration
   - Fire resistance
   - Corrosion

Partial safety factors (load factors)

Combination	Limit State of Strength					Limit State of Serviceability			
	DL	LL		WL/EL	AL	DL	LL		WL/EL
		Leading	Accompanying (CL, SL, etc.)				Leading	Accompanying (CL, SL, etc.)	
DL + LL + CL	1.5	1.5	1.05	–	–	1.0	1.0	1.0	–
DL + LL + CL + WL/EL	1.2 1.2	1.2 1.2	1.05 0.53	0.6 1.2	–	1.0	0.8	0.8	0.8
DL + WL/EL	1.5 (0.9)	–	–	1.5	–	1.0	–	–	1.0
DL + ER	1.2 (0.9)	1.2	–	–	–	–	–	–	–
DL + LL + AL	1.0	0.35	0.35	–	1.0	–	–	–	–

Note: This value is to be considered when stability against overturning or stress reversal is critical.

Abbreviations: DL = Dead load, LL = Imposed load (live loads), WL = Wind load, SL = Snow load, CL = Crane load (vertical/horizontal), AL = Accidental load, ER = Erection load, EL = Earthquake load.

Steel structures are built up with hot-rolled steel sections which are made up of structural steel.

Types of Structural Steel

- IS 226 (Standard quality)
- IS 2062 (Fusion welding quality)
- IS 961 (High tensile steel)
- IS 1977 (Ordinary quality)
- IS 8500 (Medium and high strength qualities)

IS 226 (Standard Quality)

- Commonly used for general construction purposes, i.e., for construction of buildings, bridges, industrial structures, transmission line towers, etc.
- Riveting and bolting can be done for all thickness, but welding is permitted for thickness ≤20 mm only.
- Carbon content: 0.23–0.25%, elongation: 23%.
- Designated as: Fe410–S.

IS 2062 (Fusion Welding Type)

- It is used for general construction purpose, particularly suitable for structure subjected to dynamic loads and impact, such as bridge decking, girders and crane girders.
- Designated as Fe410 WA, Fe410 WB, and Fe410 WC.
- It is suitable for welding of all types of thickness.
- Carbon content (max) 0.21–0.25%, elongation: 23%.

IS 961 (High Tensile Steel)

- This type of steel holds greater strength and atmospheric corrosion resistant.
- Fe570–HT: For structure with fabrication using methods other than fusion welding.
- Fe540–W–HT: For structures where fusion welding is involved.
- Carbon content ≈ 0.27% for Fe570–HT, elongation = 20%.

Type of Steel	Grade/ Classification	UTS/ (MPa)	Yield Strength (MPa) Thickness (mm) <20	20–40	> 40	Elongation Gauge $5.65\sqrt{S_0}$
Standard structural steel (standard quality steel IS 226, and fusion welding quality) XIS 2062)	E250 (Fe410A)	410	250	240	230	23
	E250 (Fe410B)	410	250	240	230	23
	E250 (Fe410C)	410	250	240	230	23
			<16	16–40	41–63	
Micro alloyed high strength steel, IS 8500	Fe440	440	300	290	280	22
	Fe540	540	410	390	380	22
	Fe590	590	450	430	420	20

Physical Properties of Structural Steel

Physical Property	As per IS:800–2007
Specific gravity	7.85
Unit mass of steel	$\rho_s = 7850$ kg/m^3
Modulus of elasticity	$E = 2 \times 10^5$ N/mm^2
Modulus of rigidity	$G = 0.769 \times 10^5$ N/mm^2
Coefficient of thermal expansion	$\alpha = 12 \times 10^{-6}$/°C
Poisson's ratio	$\mu = 0.3$

Various Types of Rolled Structural Steel Section

1. Rolled steel I – sections (beam section)
2. Rolled steel channel sections
3. Rolled steel Tee sections
4. Rolled steel angle sections
5. Rolled steel bars
   (a) ISRO (round bars)
   (b) ISSQ (square bars)
6. Rolled steel tubular sections
7. Rolled steel flats
8. Rolled steel plates – ISPL
9. Rolled steel sheets – ISSH

I-sections

An I-section is designated by its depth and weight.

- ISJB—Indian standard junior beam
- ISLB—Indian standard light beam
- ISMB—Indian standard medium weight beam
- ISWB—Indian standard wide flange beam
- ISHB—Indian standard heavy beam
- ISSC—Indian column section

Example: An ISLB 500 at 735.75 N/m means, an I-section is 500 mm deep and self weight is 735.75 N per meter length.

Channel Sections

These are designated by its depth and weight.

- ISJC—Indian standard junior channel
- ISLC—Indian standard light channel
- ISMC—Indian standard medium weight channel with sloping flange
- ISMCP—Indian standard medium weight channel with parallel flange
- ISGC—Indian standard gate channel
  Example: ISLC 350 at 380.63 N/m.

T–sections

- ISNT—Indian standard rolled normal T-section.
- ISDT—Indian standard rolled deep legged T-sections.
- ISLT—Indian standard rolled silt light weight T-bars.
- ISMT—Indian standard rolled suit medium weight T-bars.
- ISHT—Indian standard rolled silt T-bars from H-section.
  Example: ISNT 125 at 274 N/m

Angle Sections

Designated along the lengths of both legs and thickness.

- Indian standard equal angles (60 × 60 × 8)
- Indian standard unequal angles (100 × 60 × 8)
- Indian standard bulb angles

Tube-sections

- HFW—Hot finished welded section.
  Example: HFW 60 (60 is inner diameter)
- HFS—Hot finished seamless section.
- ERW—Electric resistance welded.

Bolted Connections

Introduction

Various elements of a steel structure, like tension members, compression and flexural members are connected by fasteners (i.e., connectors). Forces exerted by one element on another are transferred through these fasteners, which should be adequate to transfer these forces. Different types of fasteners available for making connections are rivets, bolts, pins and welds. This chapter describes about the bolted connections, their arrangement, strength and efficiency and failure of the bolted joint.

Bolts

A bolt may be defined as a metal pin with a head at one end and a shank threaded at the other end to receive a nut. Steel washers are usually provided under bolt as well as under the nut to distribute the clamping pressure on the bolted members and to prevent the threaded portion of the bolt from bearing on the connected pieces.

Bolts can be used for making end connections in tension and compression members and in the fabrication of built-up and compound members. They can also be used to hold down column bases in position and as separators for purlins in trusses and beams in foundations.

Classification of Bolted Connections

Based on Type of Resultant Force Transferred

- *Concentric connections*—load passes through the CG of the section.
  Example: Axially loaded tension and compression members.
- *Eccentric connections*—load is away from CG of the connection.
  Example: Bracket connections, seat connections.
- *Moment resisting connections*—when joints are subjected to moments.
  Example: Beam to column connections in framed structures.

Based on the Type of Force Experienced by the Bolts

- *Shear connections*—load transfer is through shear.
  Example: Lap joint and butt joint.
- *Tension connections*—load transfer- is causd by tension on bolts.
  Example: Hanger connection.
- *Combined shear and tension connections*—when inclined member is to be connected to a column through bracket.
  Example: Connections of bracings.

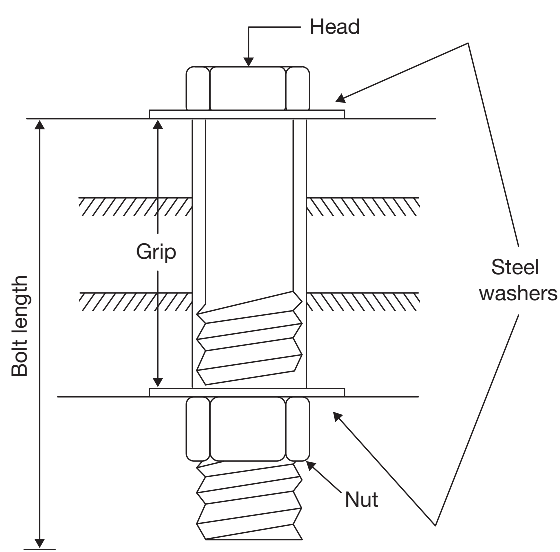
Based on Force Transfer Mechanism by Bolts

- *Bearing type*—Bolts bear against the holes to transfer the force.
  Example: Slip-type connections.
- *Friction type*—Force is transferred by friction between the plates due to tensioning of bolts.
  Example: Slip-critical connections.

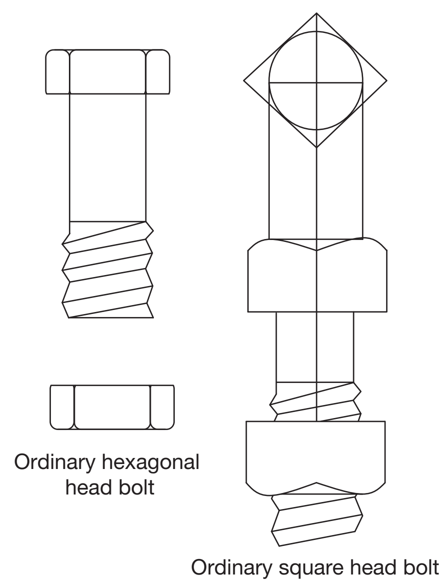
Types of Bolts

Unfinished Bolts

- These are also termed as ordinary, common, rough or black bolts.
- Used for light structures subjected to static loads and for secondary members, such as purlins, bracings, etc.



(a) Bolt assembly



(b) Shape of bolt heads

This type of bolts is also used in roof trusses. These are not recommended for connections subjected to impact load, vibration and fatigue.

- These bolts are made of low carbon steels (i.e., mild steels) with square or hexagonal head with 5–36 mm diameter and designated as M5 to M36 and the diameter of the hole is 1.5–2.0 mm larger than the bolt diameter for ease in fitting.
- Commonly used bolts are of property class 4.6 and 8.8. For 4.6 grade bolt, ultimate tensile strength is 400 N/mm^2 and yield strength is 0.6(400) = 240 N/mm^2.
- In ordinary bolted joints, the force is transferred through the interlocking and bearing of bolts and the joint is called 'bearing-type joint'.

High Strength Friction Grip (HSFG) Bolts

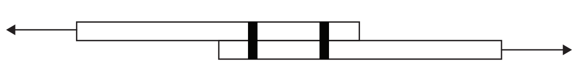
- These bolts are made from bars of medium carbon heat treated steel and from alloying steel. This high strength is achieved through quenching and tempering processes.
- These bolts are tightened until they have very high tensile stresses, so that the connected parts are clamped tightly together between the bolts and nut heads, which permit loads to be transferred mainly by friction and not by shear.
- Friction is developed by applying a load normal to the joint by tightening these bolts to proof load. For this reason, it is named as friction–type bolts.
- These bolts are available in sizes from 16–36 mm and are designated as M16, M20, M24 and M30 and are identified as 8S, 8.8S, 10S and 10.9S property class. Most commonly used bolt types are 8.8S and 10.9S.
- High strength bolts have replaced rivets and ordinary (black) bolts and used for in structures, such as high-rise buildings, bridges, machines, etc.

Types of Bolted Joints

There are two types of bolted joints subjected to axial forces (loads are assumed to pass through CG of the group of bolts).

Lap Joint

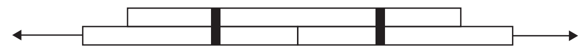
- The two members to be connected are overlapped and connected together. Such a joint is called 'lap joint'.
- The load in the lap joint has eccentricity, as the center of gravity of the load in one member and the center of gravity of load in the second member are not in the same line. Therefore, a couple is formed which causes undesirable bending in the connection and the bolts may fail due to tension.



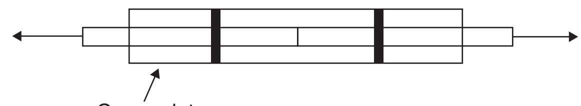
Lap joint

Butt Joint

- The two members to be connected are placed end-to-end.



Single cover butt joint



Double cover butt Joint

- If the cover plate is provided on one side, it is called 'single cover butt joint'. If cover plate is provided on both sides of the main plate, it is called 'double cover butt joint'.
- In double cover butt joint, the total shear force to be transmitted by the members is split into two parts. But in lap joint, there is only one plane on which force acts. Therefore, the shear carrying capacity of a bolt in a double cover butt joint is double that if a bolt in a lap joint.
- In case of a double cover butt joint, eccentricity of forces does not exist and, hence, bending is eliminated, whereas it exists in case of a lap joint.

Specifications of Bolted Joints

Diameter of Bolt Holes (d_0)

$$d_o = \begin{cases} \text{Nominal diameter of bolt } (d) + 1 \text{ mm (for 12 mm to 14 mm)} \\ \text{Nominal diameter of bolt } (d) + 2 \text{ mm (for 16 mm to 24 mm)} \\ \text{Nominal diameter of bolt } (d) + 3 \text{ mm (for } d \geq 24 \text{ mm)} \end{cases}$$

Pitch (p)

It is the distance between centres of two consecutive bolts measured along parallel to the direction of force or stress in a member. For wide plates, pitch may also be defined as the centre-to-centre distance of bolts measured along the length of member or the connection. When bolts are placed staggered, the pitch is called 'staggered pitch'.

1. **Minimum pitch (p_{min})**

   2.5 × Nominal diameter of bolt

2. **Maximum pitch (p_{min})**

   $$\begin{cases} 12t \text{ or 200 mm (For compression member)} \\ 16t \text{ or 200 mm (For tension member) } p \ngtr 4.5d \text{ (For compression member, when forces are transferred through betting faces, and it is for a distance of } 1.5b \text{ from the end)} \end{cases}$$

   Where

   t = Thickness of thinner plate

   d = Nominal diameter of fastener (bolt)

Gauge Distance (g)

It is the centre-to-centre distance between two consecutive bolts measured along the width of the member of connection. Gauge lines are also termed as the lines.

$$g \nless 2.5d$$
$$g \ngtr 100\text{ mm} + 4t \text{ or } 200\text{ mm}$$

(For compression and tension members)

Where

d = Nominal diameter of bolt

t = Thickness of thinner outside plate

End and Edge Distance

- The edge distance (e_o) is the distance at right angles to the direction of stress from the centre of a bolt hole to the adjacent edge.
- The end distance (e) is the distance in the direction of stress from the centre of a hole to the end of the element.

Where

$e, e_0 \nless 1.7d_0$ (Hand-flame cut edges)

$1.5d_0$ (Machine-flame cut edges)

d_0 = Diameter of bolt hole.

$e, e_0 \ngtr 12t\,\varepsilon$

$\varepsilon = (250/f_y)^{1/2}$ 40 mm + 4t

(Under corrosive influences).

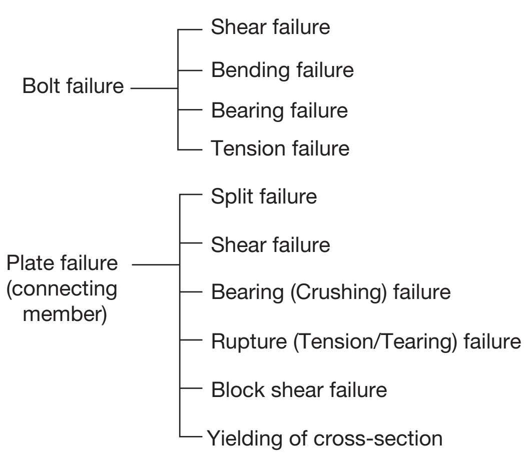
t = Thickness of thinner outside plate.

Tacking Bolts

Tacking or stitch bolts are used to make the sections act in union and to prevent buckling in compression members, when two or more sections are in contact. These bolts are just to hold plates in position and are not subjected to calculate stresses.

- Spacing between c/c of bolts (pitch) $\ngtr$ 32t or 300 mm (not exposed to aggressive environment) 16t or 200 mm (exposed to aggressive environment) 600 mm (compression members) 1000 mm (tension members)
- Lines of bolts should not be apart at a distance greater than above pitches.

Failure of Bolted Joints



Design Strength of Bolts (V_{db})

Design Shear Strength of Bolts (V_{dsb})

A bolt is subjected to a factored shear force.

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

Where

V_{nsb} = Nominal shear capacity of a bolt.

γ_{mb} = 1.25 (partial safety factor, bolts-bearing type).

$$V_{nsb} = \frac{f_{ub}}{\sqrt{3}}(n_n A_{nb} + n_s A_{sb})$$

Where

f_{ub} = Ultimate tensile stress of the bolt.

n_n = Number of shear planes with threads intercepting the shear plane.

n_s = Number of shear planes without threads intercepting the shear plane.

A_{sb} = Nominal plain shank area of the bolt.

A_{nb} = Net tensile area at root of threads $= 0.78\,A_{sb}$.

- For bolts in single shear, $n_n = 1$; $n_s = 0$
- For bolts in double shear, $n_n = n_s = 1$

Corrections

Long Joint (β_{lj})

Length of joint is the distance between the first and last row of bolts in direction of loads. This correction is done to avoid excessive stresses in extreme bolts of the joint.

If length of the joint $l_J \leq 15d \Rightarrow$ No joint correction is required.

If length of the joint $l_J > 15d \Rightarrow$ Correction is required.

$$\beta_{lj} = 1.075 - 0.005\left(\frac{l_j}{d}\right)$$

$$\text{if } \frac{l_J}{d} > 15d \Rightarrow V_{db} = \frac{V_{nb}}{\gamma_{mb}} \times \beta_{lj}$$

Large Grip Lengths (β_{lg})

When grip length of a bolt increases, the bolt is subjected to a greater bending, reducing the shear capacity of the joint.

If total thickness of connected members $l_g > 5d \Rightarrow$ correction is required.

$$\beta_{lg} = \frac{8}{\left(3 + \frac{l_g}{d}\right)}$$

Where, l_g is the grip length (mm).

Packing Plates (β_{pkg})

If $t_{pkg} > 6$ mm $\Rightarrow$ correction is required as the shank of the bolt is subjected to bending.

$$B_{pkg} = 1 - 0.0125\, t_{pkg}$$

t_{pkg} = Thickness of thicker packing plate (mm).

- Nominal shear capacity of a bolt after corrections is:

$$V_{nsb} = \frac{f_{ub}}{\sqrt{3}}(n_n A_{nb} + n_s A_{sb})\, \beta_{lj}\, \beta_{\lambda g}\, \beta_{pkg}$$

Design Bearing Strength of Bolt (V_{dpb})

To prevent excessive elongation of the bolt-hole, an upper limit is placed on the nominal bearing strength of the bolt.

$$V_{dbp} = \frac{V_{npb}}{\gamma_{mb}} = \frac{1}{\gamma_{mb}}[2.5\, k_b\, dt f_u]$$

Where

V_{npb} = Nominal bearing strength of bolt.

$$k_b = \text{Smaller of} \begin{cases} \dfrac{e}{3d_0} \\ \dfrac{p}{3d_0} - 0.25 \\ \dfrac{f_{ub}}{f_u} \\ 1 \end{cases}$$

d_0 = Diameter of bolt hole.
e = End distance
d = Nominal diameter of bolt (mm)
p = Pitch distance
f_{ub} = Ultimate tensile stress of the bolt
f_u = Ultimate tensile stress of the plate
γ_{mb} = 1.25

Design Tensile Strength of Bolts (T_{db})

$$T_{db} = \frac{T_{nb}}{\gamma_{mb}} = \frac{0.9 f_{ub} A_n}{\gamma_{mb}} \le \frac{f_{yb} A_{sb}}{\gamma_{mo}}$$

f_{ub} = Ultimate tensile stress of the bolt.
f_{yb} = Yield stress of the bolt.
γ_{mb} = 1.25 (partial safety factor for bolts, i.e., bearing type)
γ_{mo} = 1.1 (partial safety factor for material in yielding)

- Design bolt strength or design bolt value (V_{db}) is the least value of design strength of bolt in shear, bearing and in tension (if exists).

Number of Bolts (n)

If the connection is subjected to concentric design axial load (P), the number of bolts (n) required to support design load is:

$$n = \frac{\text{Design load}}{\text{Design strength of one bolt}}$$

Design tensile strength (Rupture/Tearing) of plate:

$$T_{dn} = \frac{0.9 f_u A_n}{\gamma_{ml}}$$

Effective net area of plate, mm^2 : $A_n = (b - nd_o)t\ldots$, for chain bolting, $\left[b - nd_0 + \sum_{i=1}^{n} \frac{p^2{}_{si}}{4g_i}\right] x\, t\ldots$, for staggered bolting.

- Path which gives least load should be considered and Σ to be carried out for number of inclined lines.

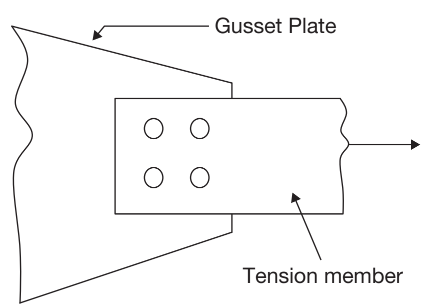
Yield strength of gross cross-section of solid plate (T_{dg}):

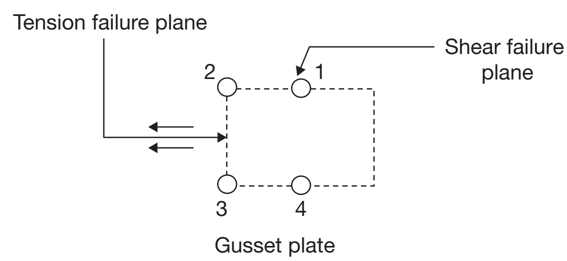
$$T_{dg} = \frac{A_g f_y}{\gamma_{mo}}$$

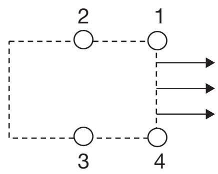
γ_{mo} = 1.1 (partial safety factor for material in yielding)

Block shear failure (T_{db}): Bolts may have been placed at a lesser end-distance than the required, hence causing the plates to shear out. This failure occurs when a block of material, within the bolted area, breaks away from the remainder area, even if the bolts are intact. The possibility of failure increase when high strength bolts are used.

- This type of failure occurs with shear on one plane and tension on perpendicular plane leading to fall of the hatched portion of the plate.







Tension member

- Block shear strength = Shear + tensile (i.e., area × stresses)

$$= \frac{A_{vg}}{\gamma_{mo}} \times \left(\frac{f_y}{\sqrt{3}}\right) + \frac{0.9\, A_{tn}\, f_u}{\gamma_{ml}} \quad \text{(OR)}$$

$$= \frac{0.9\, A_{vn}}{\gamma_{ml}} \left(\frac{f_u}{\sqrt{3}}\right) + \frac{A_{tg}\, f_y}{\gamma_{mo}}$$

A_{vg}, A_{vn} = Minimum gross and net area in shear along bolt line parallel to external force (i.e., 1 – 2 and 3 – 4).

A_{tg}, A_{tn} = Minimum gross and net area in tension from the bolt hole to the toe of the angle, end bolt line, perpendicular to the line of force (i.e., 2 – 3).

f_u, f_y = Ultimate and yield stress of the material.

- Block shear failure is considered in calculating strength and efficiency of joint. (Usually, it is ignored in exam point as it is always more than other strength values).

Strength and efficiency of the joint: Strength of a bolted joint is the minimum strength based on the strength of the bolts in shear in bearing and in tension in the joint, and the minimum design strength of connected members against the gross cross-section yielding or tearing of the net section.

$V_{dsb} \times N$, $V_{dpb} \times N$, $T_{db} \times N$ } Bolt

T_{dn}, T_{dg}, T_{db} } Plate

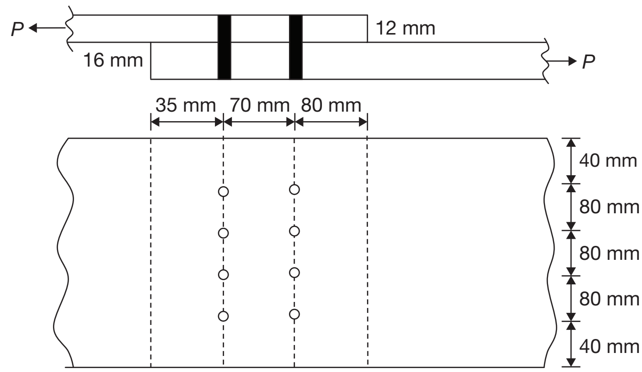
} Least value of all these is the strength of the joint.

$$\text{Efficiency} \quad \boxed{\eta = \frac{\text{Strength of the joint}}{\text{Yield strength of solid plate}} \times 100}$$

SOLVED EXAMPLES

Example 1

Determine the strength and efficiency of the lap joint shown in the following figure. Bolts are of 20 mm diameter and of grade 4.6. The two plates to be joined are 10 mm and 12 mm thick (steel is of grade Fe410).



Solution

Given data:

Bolt:

$d = 20$ mm

$d_o = 20 + 2 = 22$ mm

Shank area: $A_{sb} = \frac{\pi}{4} \times 20^2 = 314\text{ mm}^2$

Thread area: $A_{nb} = 0.78\, A_{sb} = 245\text{ mm}^2$

$f_{ub} = 400$ MPa

$f_{yb} = 0.6 \times 400 = 240$ MPa

Single shear $\Rightarrow n_n = 1;\ n_s = 0$

Plates:

$t_1 = 12$ mm

$t_2 = 16$ mm

E250 (A) Grade plates and $t < 20$ mm

$f_y = 250$ MPa

$f_u = 410$ MPa.

Design Strength of Bolt

1. Shear strength:

$$V_{dsb} = \frac{1}{\gamma_{mb}}\left[\frac{f_{ub}}{\sqrt{3}}(n_n\, A_{nb} + n_s\, A_{sb})\right]$$

$$= \frac{1}{1.25}\left[\frac{400}{\sqrt{3}}(245 \times 1 + (0 \times 314))\right]$$

$$= 45.27\text{ kN} \qquad (1)$$

2. Bearing strength:

$$V_{db} = \frac{1}{\gamma_{mb}}[2.5\, k_b\, dt\, f_u]$$

$$k_b = \text{(Least valve)} \begin{cases} \dfrac{e}{3d_0} = \dfrac{35}{3 \times 22} = 0.53 \\ \dfrac{p}{3d_0} - 0.25 = \dfrac{70}{3 \times 22} - 0.25 = 0.81 \\ \dfrac{f_{ub}}{f_u} = \dfrac{400}{410} = 0.975 \\ 1 \end{cases}$$

$k_b = 0.53$

$$V_{dbp} = \frac{1}{1.25}[2.5 \times 0.53 \times 20 \times 12 \times 410] = 104.3 \text{ kN}$$

Bolt value is least of Eqs. (1) and (2).

∴ Bolt value = 45.27 kN

Yield of gross c/s of plate:

$$T_{dg} = \frac{A_g f_y}{\gamma_{mo}} = \frac{(320 \times 12) \times 250}{1.1} = 872.7 \text{ kN}$$

Tearing/rupture strength of plate:

$$T_{dn} = \frac{0.9 A_n f_u}{\gamma_{ml}}$$

Along (1) – (2),

$$A_n = [320 - 4(22)]12 = 2784 \text{ mm}^2$$

$$T_{dn} = \frac{0.9 \times 2784 \times 410}{1.25} = 821.8 \text{ kN}$$

Result:

Strength of the bolt in shear = 45.2 × 8 = 362 kN

Strength of the bolt in bearing = 104 × 8 = 832 kN

Strength of the joint in yielding = 872 kN

Strength of the joint in rupture = 821 kN

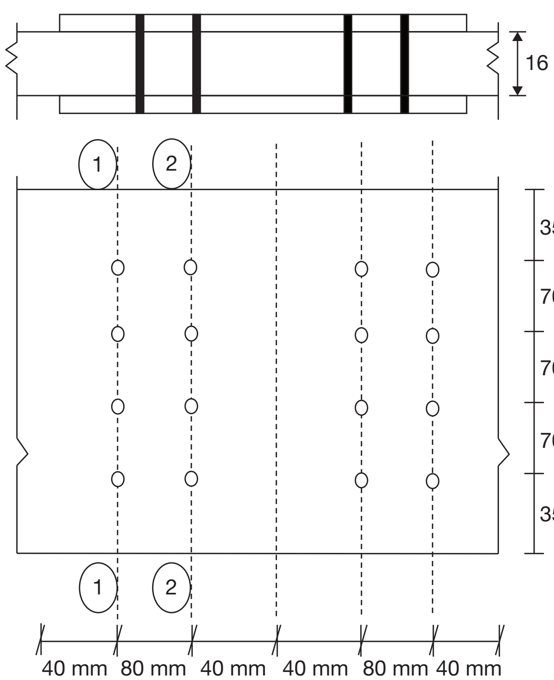
Strength of the joint = 362 kN

Efficiency

$$\eta = \frac{\text{Strength of the joint}}{\text{Yield strength of solid plate}} = \frac{362}{872} \times 100 = 41\%.$$

Example 2

Calculate the design strength and efficiency of a bearing type connection for a bolt joint as shown in the following figure. Two plates of 16 mm thick joined using 20 mm bolts of 5.6 grade and 2 cover plates of each 10 mm thick.



Solution

Bolts:

$$d = 20 \text{ mm}$$
$$d_0 = 22 \text{ mm}$$
$$A_{sb} = \frac{\pi}{4} \times 20^2 = 314 \text{ mm}^2$$
$$A_{nb} = 0.78\, A_{sb} = 245 \text{ mm}^2$$
$$f_{ub} = 500 \text{ MPa}$$

Plates:

$$t = 16 \text{ mm}$$
$$t_c = 10 \text{ mm}$$

E 250 A grade and $t < 20$ mm

$$\therefore f_u = 410 \text{ MPa}$$
$$f_y = 250 \text{ MPa}$$

Double shear:

$$n_n = n_s = 1$$
$$p = \text{pitch} = 80 \text{ mm}$$
$$g = \text{gauge} = 70 \text{ mm}$$
$$e = \text{end distance} = 40 \text{ mm}$$
$$e_0 = \text{edge distance} = 35 \text{ mm}$$

1. Shear strength:

$$V_{dsb} = \frac{1}{\gamma_{mb}}\left[\frac{f_{ub}}{\sqrt{3}}(n_n A_{nb} + n_s A_{sb})\right]$$

$$= \frac{1}{1.25}\left[\frac{500}{\sqrt{3}}(1 \times 245) + (1 \times 314)\right]$$

$$= 129 \text{ kN} \quad (1)$$

2. Bearing:

$$V_{dpb} = \frac{1}{\gamma_{mb}}[2.5\, k_b\, d\, t\, f_u]$$

$$k_b = \begin{cases} \dfrac{e}{3d_0} = 0.61 \\ \dfrac{p}{3d_0} - 0.25 = 0.96 \\ \dfrac{f_{ub}}{f_u} = 1.21 \\ 1 \end{cases}$$

$$\therefore k_b = 0.61$$

$$V_{dpb} = \frac{1}{1.25}[2.5 \times 0.61 \times 20 \times 16 \times 410]$$

$$= 160 \text{ kN} \quad (2)$$

Bolt value = 129 kN (least of Eqs. (1) and (2))

Plate:

1. **Yield strength:**

$$T_{dg} = \frac{A_g f_y}{\gamma_{mo}} = \frac{[280 \times 16] \times 250}{1.1}$$

$$= 1018.18 \text{ kN}$$

2. **Tearing/rupture:**

Let tearing along (1) – (1).

$$T_{dn} = \frac{0.9 A_n f_u}{\gamma_{ml}}$$

$$A_{n\,(1)-(1)} = (b - nd_0)t = (280 - 4 \times 22) \times 16 = 3072$$

$$T_{dn} = \frac{0.9 \times 410 \times 3072}{1.25} = 906 \text{ kN}$$

Strength of joint:

Strength of bolt in shear = 8 × 129 = 1032 kN

Strength of bolt in bearing = 8 × 160 = 1280 kN

Strength of plate in yielding = 1018 kN

Strength of plate in tearing/rupture = 906 kN

$$\text{Efficiency } \eta = \frac{906}{1018} \times 100 = 88.99\%$$

NOTES

1. If tearing at (2)–(2), there is an alternative load path at (1)–(1) for transfer. Therefore, tearing at outer end of plate is always critical, i.e., at (1)–(1). For failure at inner bolt lines:
   $T_{dn(2)-(2)} = T_{dn(1)-(1)} + n[\text{bolt value}]$
   n = number of bolts in outer lines
2. Butt joints are more efficient than lap joint.

Welded Connections

Introduction

Welding is the process of joining two pieces of metal by creating a strong metallurgical bond between them by heating (fusion) or pressure or both. The most commonly used process is arc welding which is a fusion process. The bond between the metals is produced by reducing the surfaces to the joined to a molten state and, then allowing the molten metal to solidify.

Advantages and Disadvantages of Welded Connections Compared to Bolted Connections

1. Welded joints are economical and reduce weight of the structures as spice plates and bolt materials are eliminated. Gusset plates required are of smaller size because of reduced connection length and they enable direct transfer of stress elimination of operations, like drilling, punching, etc., and consequently less labour.
2. Weld structures are more rigid.
3. Absence of holes improves the strength and efficiency of the section.
4. A continuous structure is obtained by welding which gives a better architectural appearance.
5. Welding is quicker and is a silent process.
6. Alterations can be done with less expense in welding.
7. Efficiency of a welded joint is higher. A properly weld joint may have 100% efficiency.
8. Welding offers air-tight and water-tight joining and, hence, is ideal for oil storage tanks, ships, etc.
9. Members to be joined may distort due to heat during welding process.
10. Welded joints have more possibility of brittle fracture.
11. Large residual stresses and distortion are developed in welded connections, but stress concentration effect is less.
12. More skilled persons are required for welding.
13. Details and drawing are easier in welded structures.
14. Inspection of welded joints is difficult and expensive.

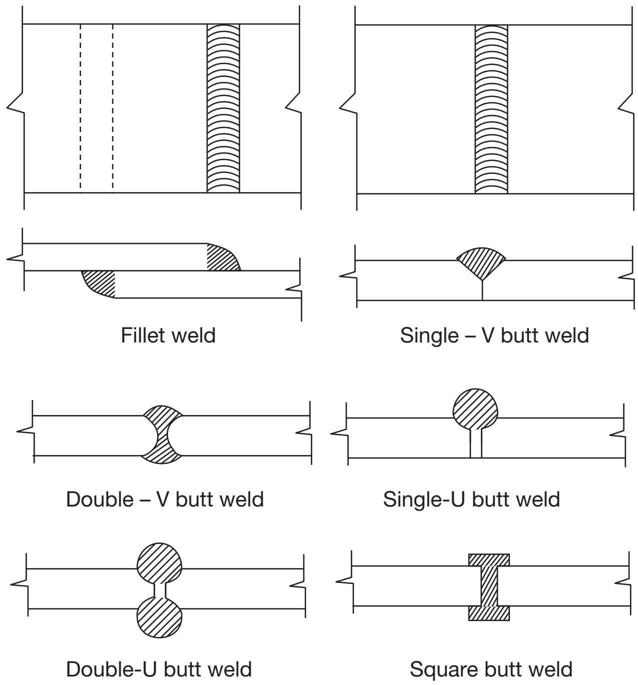
Types of Welds

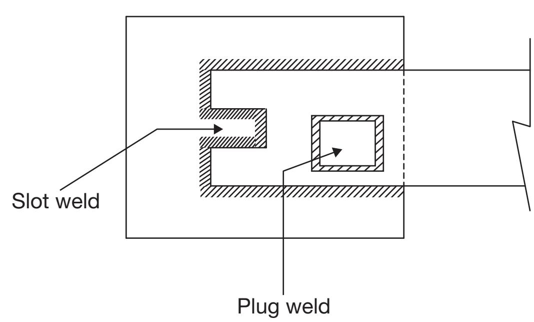
1. Fillet or lap weld.
2. Butt or groove weld. It includes the following types:

   Square butt weld, single-V butt weld, double-V butt weld, single level butt weld, double level weld, single-U butt weld, double-U butt weld, single-J butt weld and double-J butt weld, etc.
3. Slot weld
4. Plug weld

NOTES

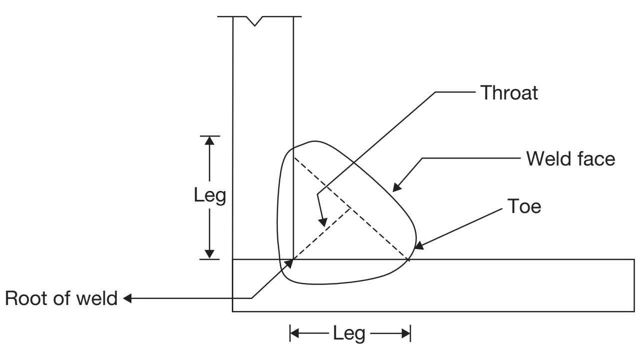
1. Fillet welds are provided when two members to be joined are in different planes.
2. Groove welds are provided when the members to be joined are lined up (in same plane).
3. In lightly stressed structures where stiffness rather than strength controls design and fatigue or brittle fracture is not a problem, fillet welds are adequate and economical.
4. Groove welds are better in highly-stressed structures where smooth flow of stress is necessary.
5. Slot and plug welds are used to supplement the filled welds when required length of fillet weld cannot be provided.





Slot and plug weld

Design of Fillet Weld



Typical fillet weld

Specifications

Size of Weld (S)

It is the minimum leg length (distance from the root to the toe of the fillet weld) of the weld.

1. **Minimum size (S_{min}):**
   - The size of the fillet weld should not exceed the thickness of thinner part joined or should not be less than 3 mm.

Thickness of Thicker Part		
Over (mm)	Upto and Including (mm)	Minimum Size of Fillet Weld (mm)
–	10	3
10	20	5
20	32	6
32	50	8 (first run) and 10

2. **Maximum size (S_{max}):**
   - $S_{max} \ngtr (t - 1.5)$ mm
     Where, t = thickness of thinner number.
   - For the rounded toe of a rolled section, $S_{max} \ngtr \frac{3}{4}$ (thickness of section at toe).

Effective Throat Thickness (t_t)

- It is the perpendicular distance from root of the fillet weld to the hypotenuse.
- It should not be less than 3 mm, and should not exceed 0.7 t or 1.0 t under special circumstances where t is the thickness of the thinner plate of the elements being welded.

$$\text{Effective throat thickness } t_t = K \times S$$

Where, S is the size of weld in mm and K is a constant. (It depends on the angle between the fusion faces.)

Angle between Fusion Faces	*K*
60° to 90°	0.70
91° to 100°	0.65
101° to 106°	0.60
107° to 113°	0.55
114° to 120°	0.50

NOTE

Fillet weld is not recommended if the angle between the fusions is less than 60° and more than 120°.

Effective Length of Weld (L_w)

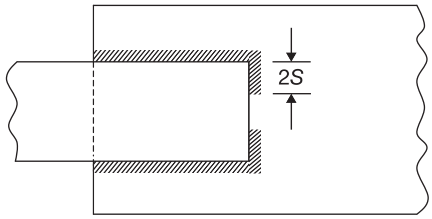
- It is the length of fillet weld for which the specified size and throat thickness of weld exist.

$$L_w = \text{Actual length provided} - 2(\text{size of fillet weld})$$

Actual length of weld should not be less than 4S.

End Return

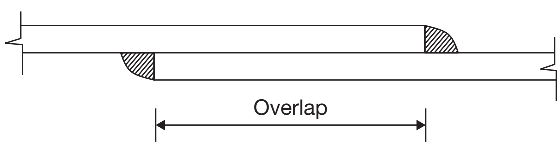
- The fillet weld terminating at the end or side of the member should be returned around the corner whenever practicable for a distance not less than 2S.



- End returns are made twice the size of the weld to relieve the high-stress concentration at the ends.
- End returns must be provided for welded joints, which are subjected to eccentricity, stress reversals or impact loads. This is particularly important on the tension-end of parts carrying bending loads.

Overlap

- The overlap of plates to be filler welded in a lap joint should not be less than four times the thickness of the thinner part (4*t*) joined (or) 40 mm, whichever is more.



Design Strength of Fillet Weld (P_{dw})

The design stress of a fillet weld

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

$$f_{wn} = \text{Nominal strength of a fillet weld}$$

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

The design strength of a fillet weld based on its throat area,

$$P_{dw} = \frac{L_w\, t_t\, f_u}{\sqrt{3}\,\gamma_{mw}} = \frac{L_w \cdot (K(S)) f_u}{\sqrt{3}\,\gamma_{mw}}$$

L_w = Effective length of the weld in mm.
t_t = Throat thickness in mm.
LC = Size of weld in mm.
f_u = Smaller of ultimate strength of the weld and the parent material (N/mm^2).
P_{dw} = Design strength of weld in Newtons.
γ_{mw} = Partial safety factor
= 1.25 (for shop welding)
= 1.5 (for site welding)

Reduction Factor for Long Joint (β_{lw})

- When the length of the welded joint, l_j, of a splice or end-connection in a compression or tension element is greater than 150 t_t, the design capacity of the weld shall be reduced by the factor:

$$\beta_{lw} = 1.2 - \frac{0.2\, l_j}{150\, t_t} \leq 1.0$$

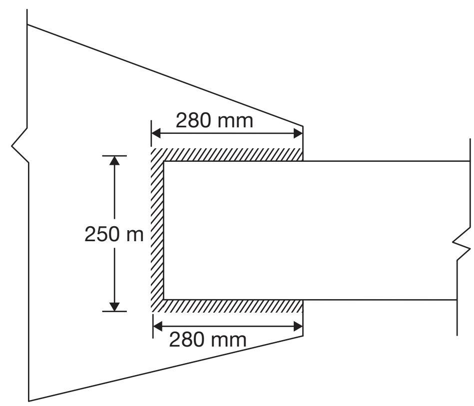
l_j = Length of the joint in the direction of the force transfer.
t_t = Throat size of the weld.

Intermittent Fillet Weld

- These are provided when the length of the fillet weld required transmitting a force less than the continuous weld. It shall have an effective length of not less than four times the weld size, with a minimum length of 40 mm.
- Clear spacing between intermittent fillet weld.
  $\not>$ 12 *t* or 200 mm (For compression member).
  $\not>$ 16 *t* or 200 mm (For tension member)
  Where t is the thickness of thinner plate.

Example 3

Determine the service load permitted on connection in which an ISF 250 mm × 12 mm in size is welded to a 10 mm thick gusset plate by a fillet weld. Use weld size as 6 mm and overlap of members is 280 mm. Use steel of Fe410 grade and shop welding.



(A) 644 kN (B) 429 kN
(C) 966 kN (D) 515 kN

Solution

For Fe410 grade steel, $f_u = 410$ MPa $f_y = 250$ MPa.
For shop weld, partial safety factor for material $\gamma_{mw} = 1.25$.
Effective length of weld,

$$L_w = 250 + 2(280) = 810 \text{ mm.}$$

Effective throat thickness,

$$t_t = K_s = 0.7 \times 6 = 4.2 \text{ mm.}$$

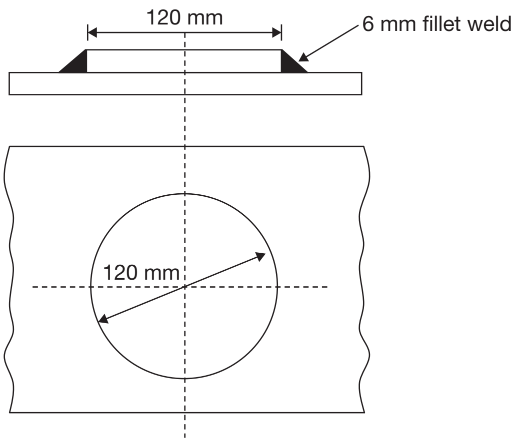
Design strength of the weld, $P_{dw} = \dfrac{L_w\, t_t\, f_u}{\sqrt{3} \times \gamma_{mw}}$

$$= \frac{810 \times 4.2 \times 410}{\sqrt{3} \times 1.25} = 644.24 \times 10^3 \text{ N}$$

= 644 kN.
Service load carrying capacity = 644/1.5
= 429 kN
Hence, the correct answer is option (B).

Example 4

A circular plate, 120 mm in diameter is welded to another plate by means of 6 mm fillet weld as shown in the following figure. Calculate the ultimate twisting moment (kN-m) that can be resisted by the weld. Use steel of grade Fe410 and shop weld.



(A) 17.99 (B) 29.99
(C) 39.99 (D) 49.99

Solution

For Fe410 grade steel, $f_u = 410$ MPa

For shop welding, $g_{mw} = 1.25$

Size of weld, $S = 6$ mm

Effective throat thickness, $t_t = K \times S$

$= 0.7 \times 6 = 4.2$ mm

Strength of weld per mm length

$$= \frac{1 \times t_t \times f_u}{\sqrt{3}\,\gamma_{mw}} = \frac{1 \times 4.2 \times 410}{\sqrt{3} \times 1.25}$$

$= 795.36$ N/mm

Total length of weld provided $= \pi d = \pi \times 120 = 377$ mm

Greatest twisting moment

$$= 795.36 \times 377 \times \frac{120}{2}$$

$= 17.99 \times 10^6$ Nmm $= 17.99$ kN-m

Hence, the correct answer is option (A).

Design of Butt (Groove) Weld

As a groove weld involves no abrupt change in section at the joint, it is the most suitable form of weld for transmitting alternating stresses.

Specifications

Size of Groove Weld

The size of the groove weld used as specified by the throat dimension also called 'effective throat thickness (t_e)'.

$t_e =$ { Thickness of thinner number (for full penetration of groove weld).
$\frac{5}{8}$ (Thickness of thinner member (For partial penetration of groove. Weld.)

Effective Area

It is the product of effective thickness and the effective length of the groove weld.

Design Strength of Groove Weld

- Design strength of the groove weld in tension or compression is governed by yield.

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

f_y = Smaller of yield stress of the weld (f_{yw}) and the parent metal (f_y) in MPa.

L_w = Effective length of the weld in mm.

t_e = Effective throat thickness of the weld in mm.

γ_{mw} = Partial safety factor

= 1.25 (for shop welding)

= 1.5 (for site welding)

- Design strength of the groove weld in shear is also governed by yield,

$$V_{dw} = \frac{f_{yw1}\, L_w\, t_e}{\gamma_{mw}}$$

Where

f_{yw1} = Smaller of shear stress of weld $(f_{yw}/\sqrt{3})$ and the parent metal $(f_y/\sqrt{3})$.

f_{yw} = Yield stress of the weld (MPa).

γ_{mw} = 1.25 (for shop welding)

= 1.5 (for site welding)

Example 5

Two 12 mm thick plates are joined in the workshop by a single 'U' groove weld. The effective length of weld is 250 mm. Determine the design strength of the welded joint which is in tension. The yield and ultimate tensile strength of the weld and steel are 250 MPa and 410 MPa.

(A) 260 kN (B) 380 kN
(C) 450 kN (D) 520 kN

Solution

For workshop welding, $\gamma_{mw} = 1.25$

$f_u = 410$ MPa and $f_{uw} = 410$ MPa.

$f_y = 250$ MPa and $f_{yw} = 250$ MPa.

For single 'U' groove weld (partially penetrated groove weld),

Effective throat thickness, $t_e = \frac{5t}{8}$

$$= 5 \times \frac{12}{8} = 7.5 \text{ mm}$$

Effective length of weld, $L_w = 250$ mm

Strength of groove weld,

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

$$= \frac{380 \times 7.5 \times 250}{1.25} = 450 \times 10^3 \text{ N}$$

$$= 450 \text{ kN}$$

Hence, the correct answer is option (C).

Design of Plug and Slot Welds

- Plug and slot welds are used to tie two parts together and in particular to reduce the unsupported dimensions of cover plates in compression. They may also be used for shear transmission, but should not be used for transmitting tension.
- They are used in addition to fillet welds when sufficient welding length is not available along the edges of the members.
- A slot is cut in one of the overlapping members and the welding metal is filled in the slot. If the slot is small and completely filled with weld metal, it is known as a plug weld. If only the periphery of the slot is fillet welded, then it is known as a slot weld.
- The following specifications are for the design of plug or slot weld as per IS:816–1969.
  (a) Width or diameter of the slot ≥3 t or 25 mm. (t = thickness of part in which slot is formed)
  (b) Corners at the enclosed ends should be rounded to a radius ≥1.5 t (or) 12 mm. (t = thickness of upper plate.
  (c) The distance between the edges of the plates and the slot or between the edges of adjacent slots should be ≥ 2 t or 25 mm. (t = thickness of plate with slot).
  (d) Plug and slot welds are designed for shear stress acting at throat.
  Strength of plug or slot weld = Permissible stress × Cross-section area at throat.
  (e) Plug welds are not designed to carry loads.

Eccentric Connections

Introduction

The simple bolted connections and welded connections are used for the load passing through the CG of the joint. However, in practice the load may be applied at an eccentricity from the joint inducing moments as well. Also for beam to column connections in buildings, for most of the situations, bending moment will always be there. This topic describes the details of the connections subjected to eccentric loads, axial load and bending moment or twisting moment.

Beam-to-Column Connections

Flexible Connections

The beam-to-column connections expected to resist and transfer end reactions only are termed as 'shear connections' or 'flexible connections'. These allow free rotation of the end, and do not have any moment restrain, and are used to transfer only shear at some nominal eccentricity. Therefore, such connections can be used only in non-sway frames where the lateral loads are resisted by some alternative arrangement, such as bracings or shear walls.

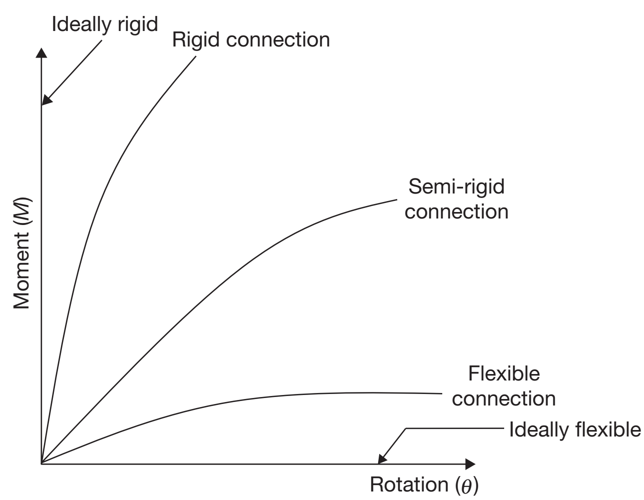
Rigid Connections

This connection does not permit any relative rotation between the beam and column end, and are expected to resist moments in addition to end reactions. These are necessary in sway frames for stability, and also contribute in resisting lateral loads. They are also used in tall buildings in which wind resistance is developed by providing continuity between the members of the building frame.

Semi-rigid Connections

This connection resists end moments as well as permits relative rotation between the beam and column.

- The moment rotation relationship between different types of connections is shown in the figure.



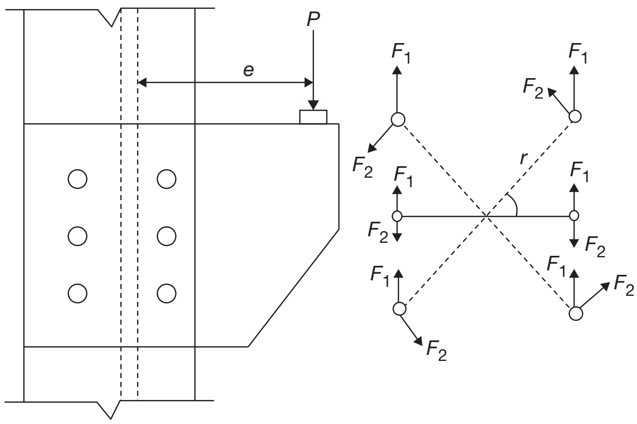
Theoretical connection characteristics

M = Moment transmitted by the connection.
Q = Relative rotation of the elastic lines of connected members at the point of intersection.

Bolted Bracket Connections

- Bracket type of connections is made whenever two members to be secured together do not intersect.
- These types of joints are subjected to direct shear and torque/bending moment due to eccentric shear.
- When connections are subjected to direct shear and shear due to torque those are called 'bracket connection-type I'.
- In case shear is accompanied with tension (due to bending moment), these are called 'bracket connection-type II'.

Bracket Connection—Type-I (Elastic Analysis)



Load or moment is lying in the plane of bolt group

The eccentric load 'P' can be made concentric along with a torque 'M' ($M = P \cdot e$). The forces in bolts, due to direct shear and torque, are F_1 and F_2, respectively.

- Load over the joint is shared equally by all the bolts. Force in any bolt, due to direct load, is:

$$F_1 = \frac{P}{n}$$

Force in each bolt due to moment ($M = P \cdot e$):

$$F_2 = \frac{P \cdot e \cdot r}{\Sigma r^2}$$

n = Number of bolts in a connection
P = Factored load
e = Eccentricity of a load.
r = Radial distance of bolt from CG of bolt group.

$$\Sigma r^2 = \Sigma x^2 + \Sigma y^2$$

The resultant force on the bolt,

$$F_R = \sqrt{F_1^2 + F_2^2 + 2F_1 F_2 \cos\theta}$$

Where, θ = Angle between F_1 and F_2.

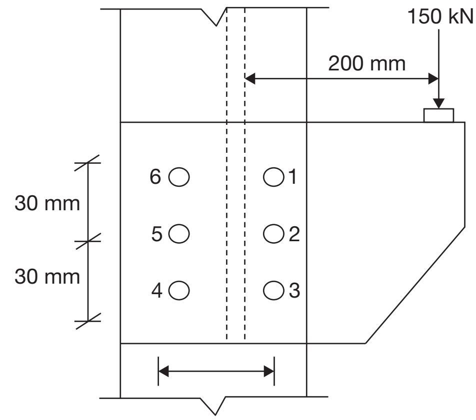
- For safety of the connection, $F_R \leq$ Design strength of the bolt (V_{db}).
- A critical bolt is that which is subjected to the maximum resultant force. A bolt which is farthest from the centre of gravity of the bolt group and nearest to the applied load line is the most critical one.
- The number of bolts required in one vertical row.

$$n' = \sqrt{\frac{6M}{mpV_{db}}}$$

m = Number of bolt lines in vertical
p = Pitch of the bolt
V_{db} = Design strength of the bolt

Example 6

A bracket connection is made with four bolts of 20 mm diameter of grade 4.6 supports a factored load of P = 150 kN with an eccentricity of 200 mm as shown in following figure. The maximum force taken up by any bolt is:



All dimensions are in 'mm'

(A) 25 kN (B) 113.64 kN
(C) 145.3 kN (D) 201.5 kN

Solution

$$e = 200 \text{ mm}$$
$$P = 150 \text{ kN}$$
$$M = Pe = (150)(200) = 3 \times 10^4 \text{ kN/mm.}$$

Bolts 1, 3, 4, 6 are at maximum radial distance. But bolts 1 and 3 are nearer to applied load line and subjected to maximum resultant force.

Force in each bolt due to direct load:

$$F_1 = \frac{P}{n} = \frac{150}{6} = 25 \text{ kN}$$

Force in critical bolt due to moment:

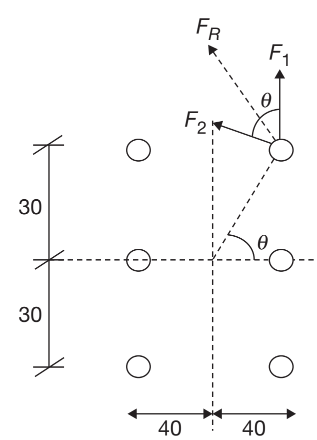
$$F_2 = \frac{Mr}{\Sigma r^2}$$

Distance of bolt 1 and 3 CG of bolt group:

$$r = \sqrt{30^2 + (80/2)^2} = 50 \text{ mm}$$

$$\Sigma r^2 = 4(50)^2 + (40)^2 = 13200 \text{ mm}^2$$

$$F_2 = \frac{3 \times 10^4 \times 50}{13200} = 113.64 \text{ kN}$$



Maximum resultant force in critical bolt 1 and 3 is:

$$F_R = \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos\theta}$$

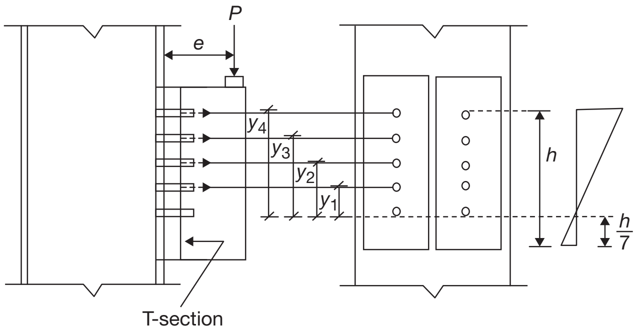
$$= \sqrt{25^2 + (113.64)^2 + 2(25)(113.64)\left(\frac{4}{3}\right)}$$

$$= 145.3 \text{ kN}$$

The maximum force taken up by any bolt = 145.3 kN

Hence, the correct answer is option (C).

Bracket Connection—Type-II (Elastic Analysis)



Load or moment is not lying in the plane of bolt group

- The bolts are subjected to direct shear along with tension due to moment.
- To estimate the amount of tension in the bolts, the position of NA (line of rotation) is assumed (by trial and error) at a distance of 1/7th of the depth of the bracket, from the base of the bracket. The depth is measured from bottom of bracket to the top most bolts in the connection.
- The bolts above the line of rotation are in tension and direct shear. The moment tries to pull out the bolts, so they are in tension. The compression necessary to balance this tension will be provided by the bracket below the line of rotation.
- Shear Force in each bolt:

$$V_b = \frac{P}{n}$$

n = Number of bolts in the connection.

- Tensile force in any bolt due to moment:

$$T_b = \frac{M'y}{\Sigma y^2}$$

y = Distance of bolt from line of rotation.

M' = Moment of resistance provided by bolts in tension.

$$= \frac{M}{\left[1 + \frac{2h}{21}\left(\frac{\Sigma y}{\Sigma y^2}\right)\right]}$$

$M = Pe$,

where e = Eccentricity of loading, h = Height of bracket

- Usually, the entrance bolt, which is at larger distance from line of rotation, will be the critical bolt.

NOTE

If bolts are loose, more number of bolts comes into tension, i.e., the neutral axis moves downward which is practical and safe as the force to be resisted in tension reduced on each bolt.

- The safety of connection is checked in combined shear and tension by using the interaction formula.

$$\left[\left(\frac{V_b}{V_{dsb}}\right)^2 + \left(\frac{T_b}{T_{db}}\right)^2 \le 1.0\right]$$

V_b, T_b = Shear and tension force in each bolt.

V_{dsb} = Design shear strength of bolt.

T_{db} = Design tensile strength of bolt.

- For design of connection, approximate number of bolts in each vertical line:

$$n = \sqrt{\frac{6M}{mpV_{db}}}$$

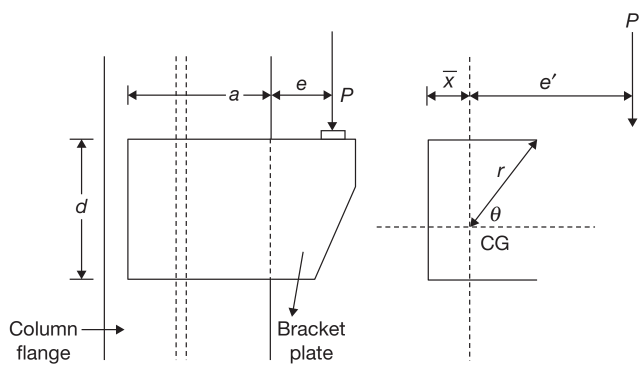
m = Number of bolt lines in vertical

P = Pitch of bolt

V_{db} = Design strength of bolt

Welded Bracket Connections

Bracket Connection–Type-I



Load or moment is in the plane of fillet weld group

Direct shear stress:

$$q_1 = \frac{\text{Load}}{\text{Effective area of weld}}$$

$$q_1 = \frac{P}{(2a+d)t_t}$$

t_t = Throat thickness

Shear stress due to twisting (torsional) moment can be computed from the torsion equation.

$$\frac{T}{J} = \frac{\tau}{r}; \quad \tau = \frac{Tr}{J}$$

Let, $q_2 = \tau$ and Twisting moment $T = P \cdot e'$.

$$q_2 = \frac{P \cdot e'r}{J}$$

e' = Horizontal distance from load point to CG of weld group $(a + e - \bar{x})$

r = Distance of the extreme weld from the centre of gravity of the weld group.

J = Polar moment Inertia of the weld group $(I_{xx} + I_{yy})$.

- Resultant shear stress,

$$q_R = \sqrt{q_1^2 + q_2^2 + 2q_1q_2\cos\theta}$$

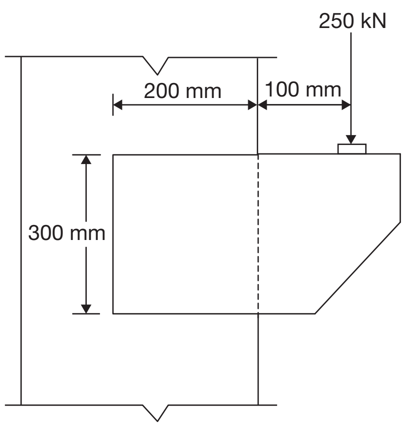
- For safety of connection, $q_R \le f_{wd}$.

f_{wd} = Design shear strength of the weld

$$= \frac{f_u}{\sqrt{3}\gamma_{mw}}$$

Example 7

Determine the maximum resultant stress (in N/mm^2) and its safety in the fillet weld *ABCD* as shown in the following figure. Bracket plate of 10 mm thick is connected to flange of ISHB 400 and 6 mm fillet weld is used (Assume shop weld).



Solution

Size of weld, $s = 6$ mm

Throat thickness, $t_t = 0.7 \times 6 = 4.2$ mm

$$\bar{x} = \frac{(300\times4.2)\left(\frac{4.2}{2}\right) + 2\left[(200\times4.2)\times\left(\frac{200}{2}\right)\right]}{(300\times4.2)+(200\times4.2)}$$

$= 58.04$ mm

$e' = e + a - \bar{x} = 100 + 200 - 58.04$

$e' = 241.96$ mm

$T = P \cdot e' = 250 \times 241.96$

$= 60.49 \times 10^3$ kN mm

$= 60.49$ kNm

$$I_{xx} = \frac{4.24\times300^3}{12} + 2\left[200\times4.24\times\left(\frac{800}{2}\right)^2\right]$$

$= 47.7 \times 10^6$ mm^4 (t^3 terms are neglected)

$I_{yy} = 7.27 \times 10^6$ mm^4

$J = I_{xx} + I_{yy} = 54.97 \times 10^6$ mm^4

$$I_{xx} = \frac{4.2\times300^3}{12} + 2\left[\frac{(200\times4.2^3)}{12} + (200\times4.2)(150)^2\right]$$

$= 47.25 \times 10^6$ mm^4

$$I_{yy} = \frac{300\times4.2^3}{12} + (300\times4.2)(58.04)^2$$

$$2\left[\left(\frac{4.2\times200^3}{12}\right) + (200\times4.2)(100-58.04)^2\right]$$

$= 12.8 \times 10^6$ mm^4

$J = I_{xx} + I_{yy} = 60.05 \times 10^6$ mm^4

$r = \sqrt{(a-\bar{x})^2 + (d/2)^2} = 206.53$ mm

$$f_1 = \frac{250\times10^3}{(2\times200+300)4.2} = 85.03 \text{ N/mm}^2$$

$$f_2 = \frac{P\cdot e'\times r}{J} = \frac{250\times10^3\times241.96\times206.53}{60.05\times10^6}$$

$= 208.04$ N/mm^2

$$\tan\theta = \left(\frac{150}{200-58.04}\right) = 46.57$$

$\cos\theta = 0.687$

$$f_R = \sqrt{f_1^2 + f_2^2 + 2f_1f_2\cos\theta}$$

$$= \sqrt{(85.03)^2 + (208.04)^2 + 2(85.03)(208.04)(0.687)}$$

$f_R = 273.52$ N/mm^2

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

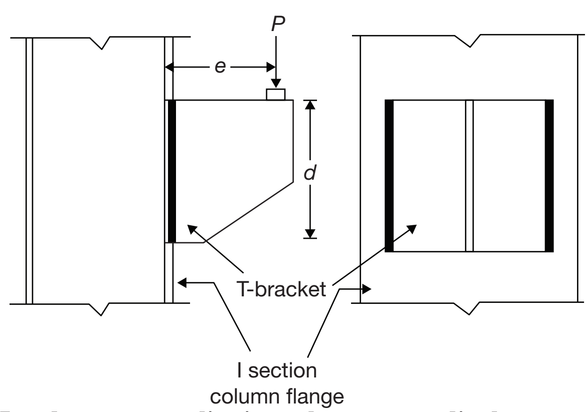
$\gamma_{mw} = 1.25$ (As shop weld is used)

$f_R \le f_{wd}$

∴ The welded connection is unsafe.

Hence, the answer is 273.52

Bracket Connection—Type-II



Load or moment lies in a plane perpendicular to weld group

1. **Fillet weld:**
   Direct shear stress in the weld

$$q_{cal} = \frac{\text{Load}}{\text{Effective area of weld}}$$

$$q_{cal} = \frac{P}{2d\,t_t}$$

d = Effective length of fillet weld.
t_t = Effective throat thickness of fillet weld (K_s).

2. **Groove weld:**

$$q_{cal} = \frac{P}{d\,t_e}$$

d = Depth of bracket plate in groove weld.
t_e = Effective throat of groove weld.

Stress in the weld due to bending moment:

1. **Fillet weld:**
   Bending stress, f_a

$$= \frac{(P \times e) \times \left(\frac{d}{2}\right)}{2 \times \left(\frac{t_t \times d^3}{12}\right)} \quad \left[\because f = \frac{M \times y}{I}\right]$$

e = Eccentricity of the load
d = Depth of the bracket

- Combined stress in fillet weld:

$$f_e = \sqrt{f_a^2 + 3q_{cal}^2}$$

- For safety, $f_e \le \dfrac{f_u}{\sqrt{3}\,\gamma_{mw}}$

2. **Groove weld:**

$$f_a = \frac{Pe\left(\frac{d}{2}\right)}{t_e\left(\frac{d^3}{12}\right)}$$

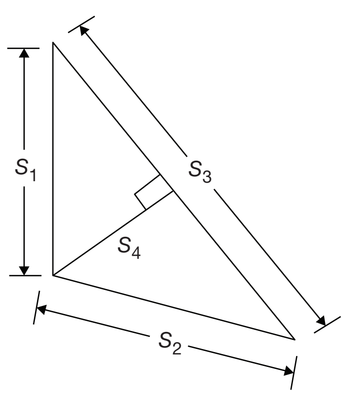
Combined stress $f_e = \sqrt{f_a + 3q_{cal}^2}$

- For safety, $f_e \le \dfrac{f_y}{\gamma_{mo}}$

  γ_{mo} = Partial safety factor for resistance governed in yielding. (1.1)

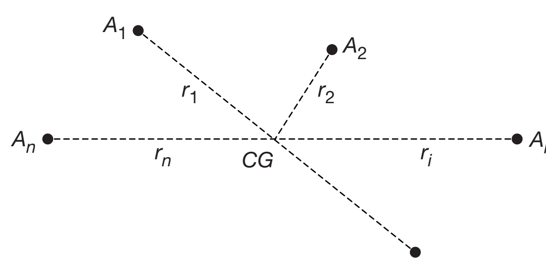
Exercises

1. The effective section of a fillet weld is represented by a triangle ABC with sides S_1, S_2 and S_3 such that $S_3 > S_2 > S_1$. If the allowable shear stress in weld material is τ, the resistance of weld per unit length is



(A) $S_1\tau$ (B) $S_2\,\tau$
(C) $S_3\tau$ (D) $S_4\tau$

2. A group of rivets of a joint is subjected to in plane torsion moment M. The rivets have finished areas of cross-section $A_i(i = 1, 2\ldots, n)$ and distance $r_i(i = 1, 2,\ldots n)$ from CG of the rivet group as shown in figure. The shear force developed in ith rivet is proportional to



(A) area of cross-section, A_i only.
(B) distance from CG of group, r_i only.
(C) both A_i and r_i.
(D) polar moment of inertia of group of area A_i.

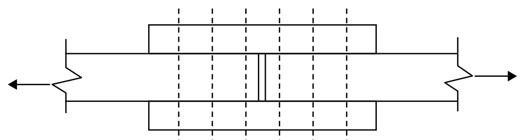
3. Generally, fatigue life of welded steel structure to fatigue life of riveted steel structure ratio is
(A) smaller than 1. (B) equal to 1.
(C) greater than 1. (D) greater than 2.1.

4. Permissible bending tensile stress in high yield strength deformed bars of grade 415 in a beam is
(A) 190 N/mm^2 (B) 230 N/mm^2
(C) 140 N/mm^2 (D) None of these

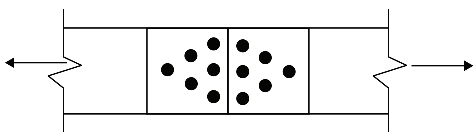
5. Two steel plates each of width 150 mm and thickness 10 mm are connected with three 20 mm diameter rivets placed in a zig-zag pattern. The pitch of rivets is 75 mm and gauge is 60 mm. If the allowable tensile stress is 150 MPa, the maximum tensile force that the joint can withstand is

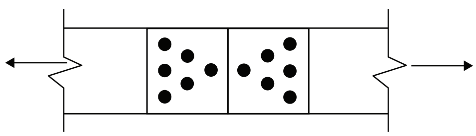
(A) 195.66 kN (B) 195.00 kN
(C) 192.75 kN (D) 225.00 kN

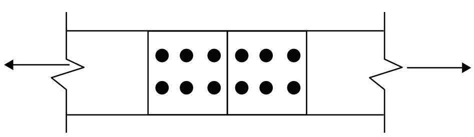
6. Identify the most effective but joint (with double cover plates) for a plate in tension from the patterns (plan view) shown in the following figure, each comprising 6 identical bolts with the same pitch and gauge:

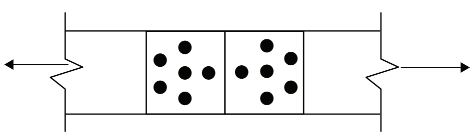


Common elevation
(all plates have same thickness)

(A)


(B)


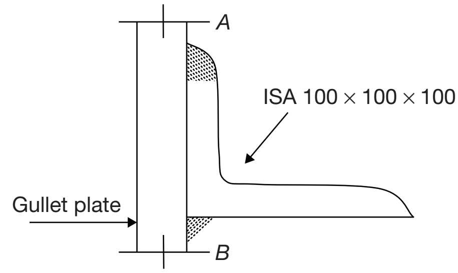
(C)


(D)


7. When designing steel structures, one must ensure that local buckling in webs does not take place. This check may not be very critical when using rolled steel sections because
(A) quality control at the time of manufacture of rolled sections is very good.
(B) web depths available are small.
(C) web stiffeners are in built in rolled sections.
(D) depth to thickness ratio (of the web) are appropriately adjusted.

8. An ISMB 500 is used as a beam in a multi-storey construction. From the viewpoint of structural design, it can be considered to be 'laterally restrained' when
(A) the tension flange is 'laterally restrained'.
(B) the compression flange is 'laterally restrained'.
(C) the web is adequately stiffened.
(D) the conditions in (A) and (C) are met.

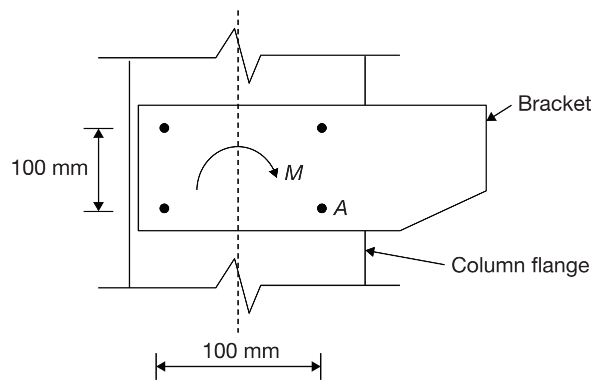
9. ISA 100 × 100 × 10 mm (cross-sectional area = 1908 mm^2) is welded along A and B as shown in the following figure, such that the length of the weld along A and B are I_1 and I_2, respectively. Which of the following is a possibly acceptable combination of I_1 and I_2?



(A) $I_1 = 60$ mm and $I_2 = 150$ mm
(B) $I_1 = 150$ mm and $I_2 = 60$ mm
(C) $I_1 = 150$ mm and $I_2 = 150$ mm
(D) Any of the above depending on the size of the weld

10. Rivet value is defined as
(A) lesser of the bearing strength of rivet and the shearing strength of the rivet.
(B) lesser of the bearing strength of rivet and the tearing strength of thinner plate.
(C) greater of the bearing strength of rivet and the shearing of the rivet.
(D) lesser of the shearing strength of the rivet and the tearing strength of thinner plate.

11. A moment M of magnitude 50 kN-m is transmitted to a column through a bracket by using four 20 mm diameter rivets as shown in the figure.



The shear force induced in the rivet A is
(A) 250 kN (B) 175.8 kN
(C) 125 kN (D) 88.4 kN

12. In the design of welded tension members, consider the following statements:
I. The entire cross-sectional area of the connected leg is assumed to contribute to the effective area in case of angles.
II. Two angles back-to-back and tack welded as per the codal requirements may be assumed to behave as a tee section.
III. A check on slenderness ratio may be necessary in some cases.

The TRUE statements are
(A) only I and II (B) only II and III
(C) only I and III (D) I, II and III

13. The common assumption that, 'all rivets share equally a non-eccentric load' is valid at a load
(A) below the working load.
(B) equal to the working load.
(C) above the working load.
(D) equal to the failure load.

14. In a fillet weld the weakest section is the
(A) smaller side of the fillet.
(B) throat of the fillet.
(C) side perpendicular to force.
(D) side parallel to force.

15. The effective length of the fillet weld is
(A) Total length $-2 \times$ Throat size
(B) Total length $-2 \times$ Weld size
(C) $0.7 \times$ Total length
(D) Total length – (Weld size/ $\sqrt{2}$)

16. In a diamond riveting, for a plate of width 'b' and rivet diameter 'd', the efficiency of the joint is given by

(A) $\frac{(b-d)}{b}$ (B) $\frac{(b-2d)}{b}$

(C) $\frac{(b-d)}{d}$ (D) $\frac{(b-2d)}{d}$

17. Minimum edge distance of bolted joint for hand flame cut edges is not less than
(A) $1.5 \times$ diameter of bolt hole
(B) $1.5 \times$ diameter of bolt
(C) $1.7 \times$ diameter of bolt hole
(D) $1.7 \times$ diameter of bolt

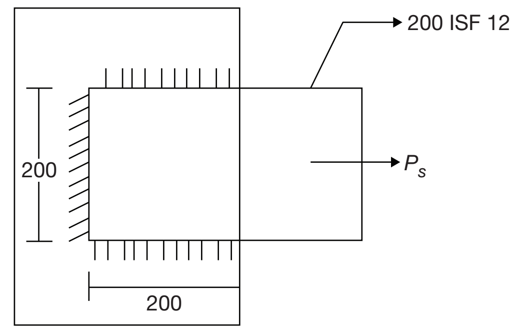
18. The type of weld used for joining two surfaces in two different planes is
(A) fillet weld
(B) single V butt weld
(C) double groove weld
(D) None of these

19. Two plates 12 mm and 20 mm thick are to be joined by a double cover butt joint with 8 mm thick packing plate. What will be the effect of packing on the design shear strength of bolt?
(A) Decreases by 10% (B) Increases by 10%
(C) Decreases by 15% (D) Increases by 15%

20. Calculate the design tensile capacity of M20 bolt of grade 4.6 is
(A) 50 kN (B) 68 kN
(C) 75 kN (D) 35 kN

21. Calculate the number of bolts required for a lap joint between two plates of 12 mm and 24 mm thick to transmit a factored load of 100 kN using M16 bolts of grade 4.6 and Fe410 plates. (assume minimum end distance = 27 mm; minimum pitch = 40 mm and thread intercept shear plane)
(A) 2 (B) 6
(C) 4 (D) 8

22. Determined the service load which can be applied to the fillet weld for the figure shown with a weld size of 5 mm. Use plates of grade 410 steel and workshop welding.

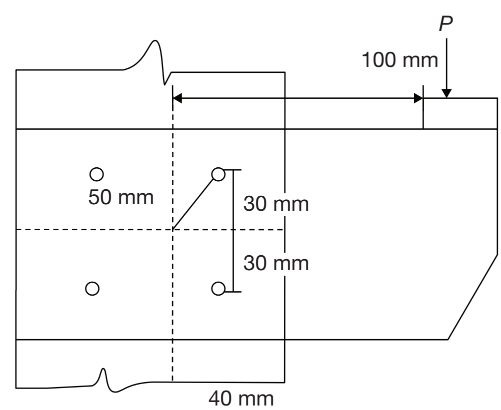


(A) 450 kN (B) 500 kN
(C) 350 kN (D) 265 kN

23. When length of side fillet weld is 400 times the effective throat thickness. Then the design shear capacity of fillet weld is
(A) decreased by 33% (B) increased by 33%
(C) decreased by 20% (D) decreased by 66%

24. Two 12 mm thick plates are joined in the field by a single 'V' bolt weld. The effective length of weld is 250 mm. Determine the design strength of welded joint. The yield and ultimate tensile strength of weld and steel are 250 MPa and 410 MPa respectively.
(A) 330.50 kN (B) 437.50 kN
(C) 530.50 kN (D) 357.50 kN

25. Four bolt systems are shown in the figure, the bolts are at a distance of 50 mm from center of gravity of bolt group. The resultant force in the critical bolt is



(A) $P/4$ (B) $0.50P$
(C) $0.70P$ (D) $1.0P$

26. The most suited bolt in case of reversal of stress is
(A) black (B) turned
(C) ordinary (D) friction grip

27. The shear capacity of bolt is affected in case of
(A) long joints (B) long grip length
(C) thicker packing plate (D) all the above

28. Which of the following bolted pattern has the highest efficiency with same number of bolts at the joint?
(A) Staggered (B) Chain
(C) Diamond (D) Can't be say

29. For an angle of 90° between the fusion faces, the effective throat thickeness is given by $K \times S$, where K is
(A) 0.65 (B) 0.70
(C) 0.60 (D) 0.55

30. Which one of the following is the mode of failure in a fillet weld material?
(A) Shear (B) Tension
(C) Crushing (D) Bearing

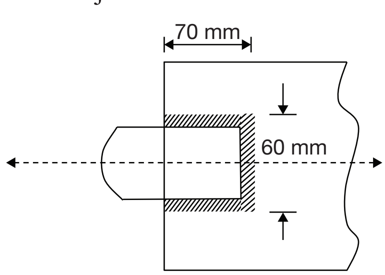
31. The best tension member will be
(A) bolted single-angle section.
(B) channel section.
(C) welded-single angle section.
(D) double angle section on opposite of gusset plate.

32. The slenderness ratio of a tension member which is always under tension (other than pre-tensioned member) is
(A) 180 (B) 350
(C) 400 (D) 225

33. Pick up the correct statements.
I. Maximum pitch for a tension whose thickness 't' is 16t or 200 mm.
II. Maximum edge distance of the bolt from an edge should not exceed 12$t\varepsilon$.
III. Minimum end distance for a bolt in case of hand flame cut edges is 1.5 × d_h(d_h: diameter of bolt hole).
(A) I and II are correct (B) I and III are correct
(C) II and III are correct (D) I, II and III are correct

34. A single bolted lap joint is used to connect 6 mm thick plates using 20 mm diameter bolts at a pitch of 50 mm. Assume the design shear strength of bolt is smaller than the design bearing and tensile strength of bolt. The efficiency of joint or connection is _______. (Assume k_b = 0.5 and thread intercept plane and Take f_u of plate as 410 MPa and 4.6 grade bolts)
(A) 50% (B) 60%
(C) 45% (D) 70%

35. A fillet-welded joint is shown in the figure. The size of weld is 7 mm. Safe stress in the weld is 100 MPa. What is the safe force (to the nearest) magnitude to which the weld can be subjected?

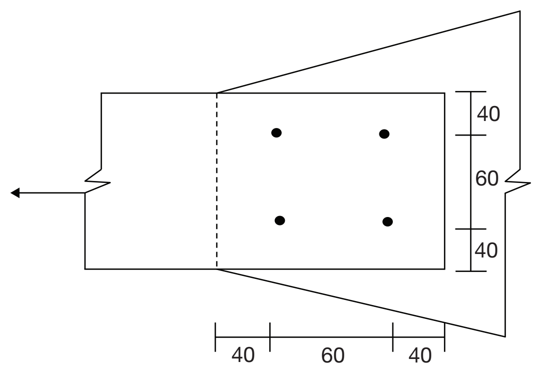


(A) 120 kN (B) 100 kN
(C) 98 kN (D) 50 kN

36. A mild steel flat plate subjected to a tensile force of 750 kN is connected to a gusset plate using bolts. If the permissible forces required per pitch length (i) to shear a single bolt, (ii) to crush the bolt and (iii) to tear the plate are 60 kN, 90 kN and 70 kN respectively, then the number of bolts required is
(A) 10 (B) 15
(C) 13 (D) 6

37. An angle ISA 60 × 60 × 5 is connected to a gusset plate of 5 mm thick, with 20 mm diameter bolts of 4.6 grade. What is the design bearing strength of bolt, if k_b = 0.5?
(A) 30 kN (B) 40 kN
(C) 45 kN (D) 50 kN

38. Determine the design tensile strength (based on net section rupture) of flat of 140 ISF 10 with 16 mm diameter bolt holes as shown in figure. Use Fe410 grade plates.

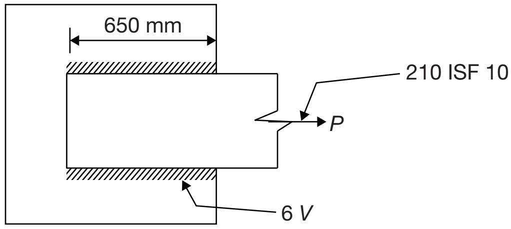


Dimensions in mm

(A) 150 kN (B) 260 kN
(C) 200 kN (D) 320 kN

39. Which of the following statements are correct?
I. Effective length of fillet weld is given by total length minus two times weld size.
II. Load on connection is eccentric for double cover butt joint.
III. For bracket type connection II, load or moment will lie in the plane of bolt or weld group.
IV. The design compressive stress in a axially loaded member in IS:800–2007 is given by perry robertson formula.
(A) I and IV are correct
(B) I and III are correct
(C) I, II and IV are correct
(D) I, II, III and IV are correct

40. Determine factored load that can be applied on fillet welded joint of weld size 6 mm as shown in the figure. The yield and ultimate tensile strength of steel and weld are 250 MPa and 410 MPa. The welding is done at workshop, γ_{mw} = 1.25.

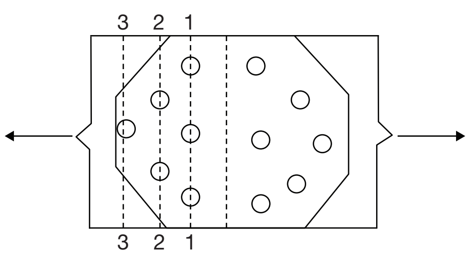


(A) 1035 kN (B) 1025 kN
(C) 950 kN (D) 550 kN

41. When the load line coincides with the centroid of the rivet group, the rivets are subjected to
(A) shear only.
(B) tension only.
(C) bending only.
(D) shear as well as tension.

42. Two steel plates, each of 12 mm thick, are connected by a double cover butt joint by bolts as shown in the figure. If the bolt diameter is 20 mm and steel is of grade Fe410, which one of the following sections is the most critical section for a cover plate?

(A) Section 1–1 (B) Section 2–2
(C) Section 3–3 (D) Both 1–1 and 2–2



43. A structural member carrying a pull of 700 kN is connected to a gusset plate using rivets. If the pull required to shear the rivet, to crush the rivet and to tear the plate per pitch length are respectively 60 kN, 35 kN and 70 kN; then the number of rivets required will be _______.
(A) 22
(B) 20
(C) 18
(D) 12

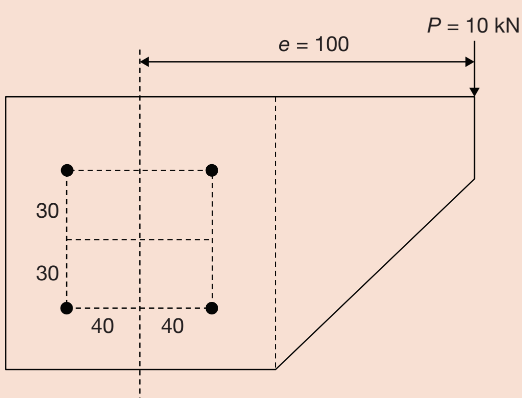
44. A steel plate is 300 mm wide and 10 mm thick. A rivet of nominal diameter of 16 mm is driven into it. What is the net sectional area of plate?
(A) 2600 mm^2
(B) 2765 mm^2
(C) 2825 mm^2
(D) 2845 mm^2

45. A 6 mm thick mild steel plate is connected to an 8 mm thick plate by 16 mm diameter shop rivets. What is the number of rivets required to carry an 120 kN load?

(Permissible stresses for shop rivets in shearing and bearing are given as 100 MPa and 300 MPa respectively)
(A) 3
(B) 4
(C) 5
(D) 6

Previous Years' Questions

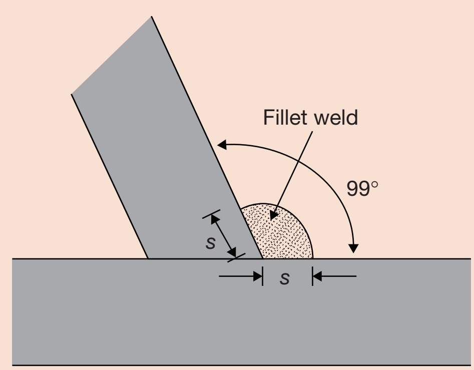
1. A bracket connection is made with four bolts of 10 mm diameter and supports a load of 10 kN at an eccentricity of 100 mm. The maximum force to be resisted by any bolt will be **[GATE, 2007]**



(all distance in mm)

(A) 5 kN (B) 6.5 kN
(C) 6.8 kN (D) 7.16 kN

2. For the fillet weld of size '*s*' shown in the adjoining figure the effective throat thickness is **[GATE, 2011]**

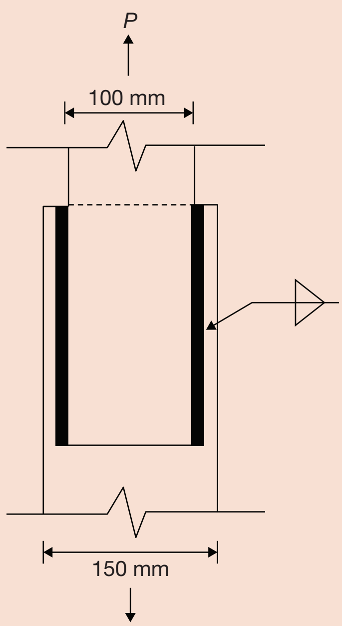


(A) 0.61*s* (B) 0.65*s*
(C) 0.70*s* (D) 0.75*s*

3. In a steel plate with bolted connection, the rupture of the net section is a mode of failure under **[GATE, 2012]**

(A) tension (B) compression
(C) flexure (D) shear

4. Two plates are connected by fillet welds of size 10 mm and subjected to tension, as shown in the figure. The thickness of each plate is 12 mm. The yield stress and the ultimate tensile stress of steel are 250 MPa and 410 MPa respectively. The welding is done in the workshop ($\gamma_{mw} = 1.25$). As per the Limit State Method of IS:800–2007, the minimum length (rounded off to the nearest higher multiple of 5 mm) of each weld to transmit a force P equal to **[GATE, 2012]**

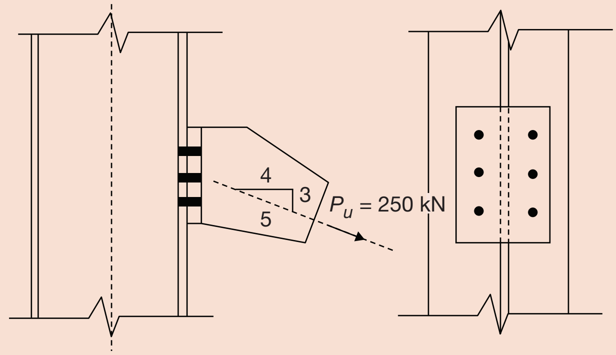


(A) 100 mm (B) 105 mm
(C) 110 mm (D) 115 mm

5. A steel section is subjected to a combination of shear and bending actions. The applied shear force is V and the shear capacity of the section is V_s. For such a section, high shear force (as per IS:800–2007) is defined as **[GATE, 2014]**

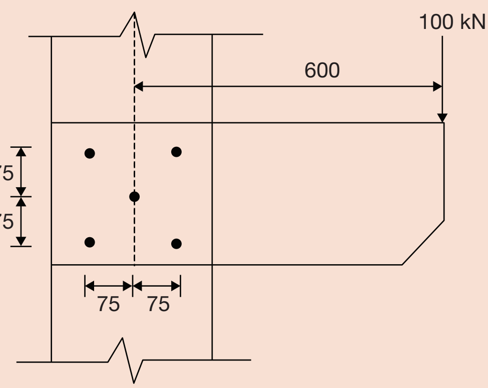
(A) $V > 0.6V_s$ (B) $V > 0.7V_s$
(C) $V > 0.8V_s$ (D) $V > 0.9V_s$

6. The tension and shear force (both in kN) in each bolt of the joint, as shown in the figure, respectively are **[GATE, 2014]**



(A) 30.33 and 20.00 (B) 30.33 and 25.00
(C) 33.33 and 20.00 (D) 33.33 and 25.00

7. A bracket plate connected to a column flange transmits a load of 100 kN as shown in the following figure. The maximum force for which the bolts should be designed is ________ kN. **[GATE, 2015]**



All dimensions are in mm

8. Prying forces are **[GATE, 2015]**

(A) shearing forces on the bolts because of the joints.
(B) tensile forces due to the flexibility of connected parts.
(C) bending forces on the bolts because of the joints.
(D) forces due to the friction between connected parts.

9. A steel member ‘M’ has reversal of stress due to live loads, whereas member ‘N’ has reversal of stress due to wind load. As per IS:800–2007, the maximum slenderness ratio permitted is **[GATE, 2015]**

(A) less for member ‘*M*’ than that of member ‘*N*’.
(B) more for member ‘*M*’ than for member ‘*N*’.
(C) same for both the members
(D) not specified in the code

Answer Keys

Exercises

1. D	**2.** D	**3.** A	**4.** B	**5.** C	**6.** A	**7.** D	**8.** B	**9.** D	**10.** A
11. B	**12.** D	**13.** D	**14.** B	**15.** B	**16.** A	**17.** C	**18.** A	**19.** A	**20.** B
21. C	**22.** D	**23.** A	**24.** B	**25.** C	**26.** D	**27.** D	**28.** C	**29.** B	**30.** A
31. D	**32.** C	**33.** A	**34.** A	**35.** C	**36.** C	**37.** B	**38.** D	**39.** A	**40.** B
41. A	**42.** A	**43.** B	**44.** C	**45.** C					

Previous Years' Questions

1. D	**2.** B	**3.** A	**4.** B	**5.** A	**6.** D	**7.** 196.2	**8.** B	**9.** A