CHAPTER 02

Rivetted, Bolted and Pinned Connections

2.1 Connections

- Connections are the weakest point of failure in a structure and thus need to be properly analyzed and designed.
- The various types of fasteners available for making connections are rivets, bolts, pins and the welds. Bolting has become so much popular that high strength bolts has almost replaced rivets now.

2.2 Rivetted Connection

- Riveted connection has become obsolete now but an idea about its behavior and its design is essential for assessing strength of the joint and also for rehabilitation of old structures.
- Analysis and design of riveted connection is almost same as that of bolted connection.
- A rivet is made up of a round ductile steel bar of mild or high tensile steel which is called as shank with a head at one of its ends. This head can be of different shapes some of them are as shown in Fig. 2.1.

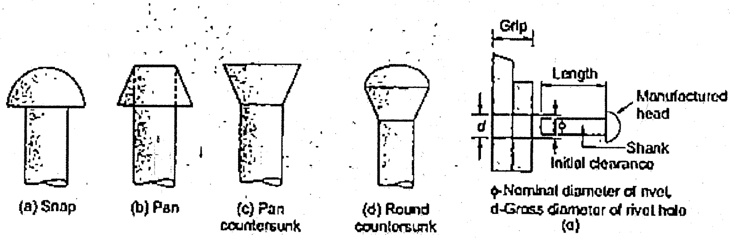


Fig. 2.1 Types of rivet, their grip and length

- Cl. 17.4.1 of IS 800:2007states that rivets should be heated uniformly and that too throughout the length without burning or excessive scaling and shall be of standard length to provide a head of standard dimension.
- When rivets are driven then these shall fill the rivet holes completely.

- **Grip:** The grip of the rivet is the distance between the undersides of the two heads i.e. shank length inside the connection as shown in Fig. 2.1(e). In case grip of the rivet becomes longer than what is required then rivet will be subjected to flexural stresses in addition to shear and bearing stresses.

NOTE

The grip length of a rivet must not be more than four times the rivet diameter. The diameter of the shank is referred to as **nominal diameter** of the rivet. A hole slightly greater than the nominal diameter is drilled through the parts to be connected, the rivet is inserted and head is formed at the other end of the shank. This whole process is called as **riveting.**

Remember

As per Cl. 17.4.2 of IS 800:2007 for connections having multiple rivets, a service bolt shall be provided in every third or the fourth rivet hole. For connections having single rivets, all connected parts must be held firmly before and after the riveting.

- Rivets when heated before driving are called as **hot driven field rivets** (when placed in field) or **hot driven shop rivets** (when placed in workshop).
- The diameter of hot rivet is equal to the rivet hole diameter and is called as gross diameter.
- Hot rivet is plastic, expands and fills the hole completely while forming head at the other end of the rivet shank. But on cooling, the rivet shrinks both in diameter and length. Due to this shrinkage in rivet length, the connected parts get stressed resulting in residual tension of unknown amount in the shank and some compression in the plates to be connected.
- Cold driven rivets i.e. rivets driven at room temperature require high pressure for head formation at room temperature and thus its use is limited.

Remember

The strength of cold driven rivet is more than hot driven rivet but their clamping force is less as the cold driven rivets do not shrink like hot driven rivets. Rivet heads for small diameter rivets can be formed manually with an ordinary hammer and are referred to as **hand driven rivets.**

2.2.1 Material of the Rivet

As per Cl. 2.3.2 of IS 800:2007, rivets should conform to IS 1929:1982 and IS 2155:1982.

Cl. 2.3.3 of IS 800:2007 states that high tensile steel rivets should be made from steel conforming to IS 1149:1982.

NOTE: As per Cl. 17.4.4 of IS 800:2007, all loose, burnt and defective rivets must be cut out and get replaced well before the structure is loaded.

2.2.2 Symbols for Rivets

Table 2.1 Rivet symbol

Description	Round head both sides	Countersunk near side	Countersunk far side	Countersunk both side
Shop rivets	○	○	⊗	⊗
Field rivets	●	◉	⊗	⊗

2.2.3 Patterns Used in Riveted Joint

The commonly used rivet patterns are chain riveting (Fig. 2.2 (a)), diamond riveting (Fig. 2.2 (b)), staggered riveting (Fig. 2.2 (c) and (d)).

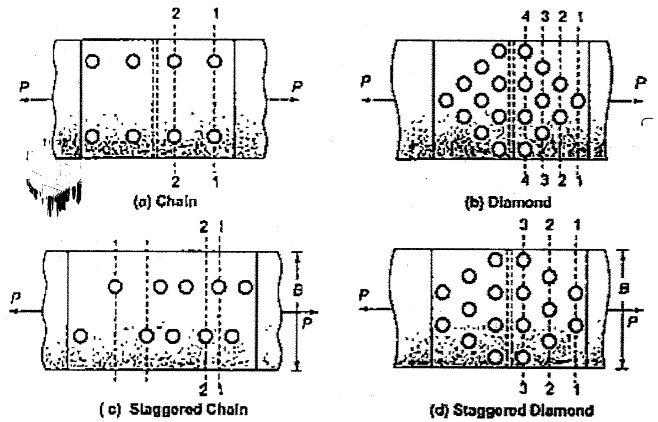


Fig. 2.2 Patterns used in riveted joint

NOTE

The design of riveted connection is almost same as that of bolted connection with the only difference that in riveted connection, the diameter to be used in calculations is the diameter of rivet hole whereas in bolted connection, it is the nominal diameter of the bolt. Apart from that, the requirements for pitch and edge distances are the same as that of bolted connections.

2.3 Bolted Connection

- A bolt is a sort of threaded pin with head at one end and threads on other end of the shank to receive nut as shown in Fig. 2.3 (a).
- **Bolt Length:** The bolt length is the distance from the bottom of bolt head to the end of bolt.
- **Grip Length:** Grip of the bolt is the distance from bottom of the bolt head to the back of the washer.
- **Steel washsers:** The steel washers are provided below the bolt head and under the nut to distribute the clamping pressure on the bolted member and to prevent threaded portion of the bolt from bearing on the connecting parts.
- The holes required for placing the bolts for making connection may either be **drilled** or **punched.** Punching is preferred by commercial fabricators since it is simple, time saving and economic but this reduces the ductility and toughness rendering the material susceptible to brittle fracture.

2.3.1 Uses of Bolts

(a) Connection of tension and compression members.

(b) Fabrication of compound and built-up sections consisting of two or more sections.

(c) As hold down bolts to hold the column bases in position, joining the column caps with shoe plates (of trusses) etc.

2.3.2 Advantages and Disadvantages of Bolted Connections over Riveted Connections

Advantages:

(a) Bolted connections facilitate faster erection of structure.

(b) Not too much skilled labours are required for making the bolted connections.

(c) Bolted connection is more economical than riveted connection because cost of skilled labour is reduced as well as equipment costs are also very less.

Disadvantages:

(a) The cost of material is high almost twice that of rivets.

(b) Because of reduced area at the root of the thread, the tensile strength of the bolt is reduced and also stress concentration occurs.

(c) Bolts are usually of low fit (except the turned bolts) and thus they have reduced strength.

(d) In case of dynamic loads where vibrations occur and also in case of shock loadings, bolts get loosened up.

2.3.3 Classification of Bolted Connections

(a) Classification based on line of action of resultant force transferred

(i) **Concentric connection:** Here the load line passes through the CG of the section. e.g. Axially loaded tension or compression member.

(ii) **Eccentric connection:** Here the load line is away from the CG of the connection. e.g. Bracket connection, moment resisting connection, seat connection etc.

(b) Classification based on the type of force

(i) **Tension connection:** Here the load gets transferred through tension on bolts. e.g. Hanger connection

(ii) **Shear connection:** Here the load gets transferred through shear. e.g. Lap joint, butt joint etc.

(iii) **Combined shear and tension connection:** This type of connection is required when an inclined member is to be connected to a column through bracket. e.g. Connection to bracings

(c) Classification based on the type of force mechanism

(i) **Bearing connection:** Here the bolts bear against the holes to transfer the load. e.g. Slip type connection.

(ii) **Friction connection:** Here the load is transferred by friction between the plates due to tensioning of bolts. e.g. Slip critical connection.

2.3.4 Types of Bolts

(a) Unfinished bolts

- These types of bolts are also called as ordinary, common, rough or black bolts. These are commonly used in light structures subjected primarily to static loads and for secondary members like purlins, bracings etc.
- They are not suitable and also not recommended for connections subjected to impact loads, vibrations and fatigue.
- These bolts are made from low carbon steel (circular rods) by forging process. The ordinary structural bolts are fabricated from mild steel rods with either a square or a hexagonal head.
- Square headed bolt costs less but hexagonal headed bolt gives better aesthetics, are easier to hold by wrenches and requires less turning space.
- These types of bolts are available in diameters ranging from 5 mm to 36 mm and are designated as M5 to M36.
- It is recommended by IS 800 that the net tensile area of bolt to be considered is the area of the root of the threads and is given in Table 2.2. Sometimes this area is also called as stress area or the **proof area.**

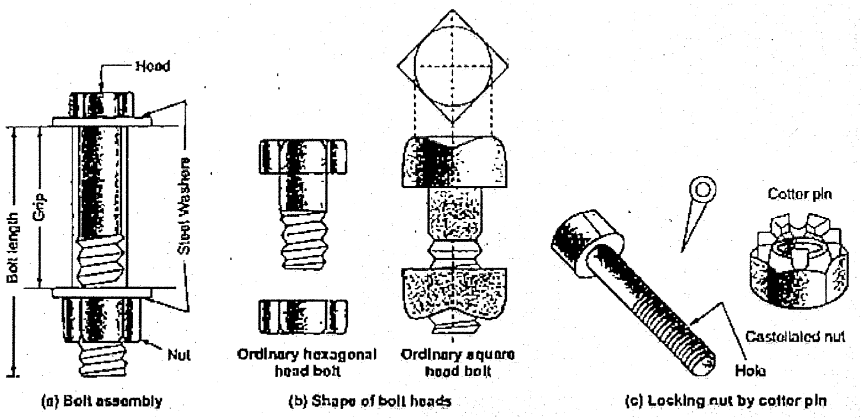


Fig. 2.3 Unfinished or ordinary bolts

Table 2.2 Tensile Stresses area of bolts

Bolt size, d (mm)	12	16	20	22	24	27	30	36
Tensile stress area (mm^2)	84.3	157	245	303	353	459	561	817

NOTE: In the absence of Table 2.2, then as per IS 1367 (Part 1) the ratio of net tensile area at root of the threads to nominal plain shank area of the bolt is taken as 0.78 i.e., tensile stress area of bolt $\simeq 0.78\frac{\pi}{4}d^2$.

- The bolts can be placed in standard size, over size, short slotted or the long slotted holes as shown in Fig. 2.4. Table 19 of IS 800:2007 gives clearances for the bolt holes.

NOTE: When wind load and earthquake loads are considered, permissible stresses in structural steel and connections (i.e., rivet/bolt or weld) are increased by 33.33% and 25% respectively.

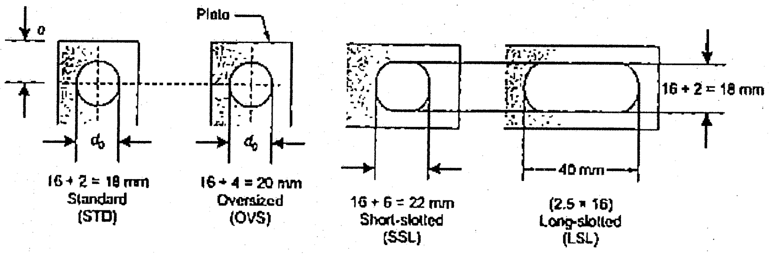


Fig. 2.4 Representation of a typical bolt hole (for 16 mm diameter bolt)

- The nuts on bolts are tightened with spud wrenches producing little tension and are referred to as **sung tight bolts**. Sometimes a hole is drilled through the bolt and a cotter pin with castellated nut is used to prevent the nut from turning out from the bolt as shown is Fig. 2.3 (c).
- Bolts of grade (or class) 3.6 to 12.9 are available and among them the most commonly used ones are the grade 4.6 and grade 8.8.

Do You Know?

What does grade (or class) of a bolt imply?
Bolts are classed as *grade x.y* where *x* represents 1/100th of the nominal tensile strength and *y* represents the ratio of yield stress to ultimate stress.
For example: A bolt of grade 4.6 implies that the ultimate tensile strength of the bolt is 400 N/mm^2 and yield strength is 0.6 x 400 = 240 N/mm^2.

Table 2.3 Tensile Properties of bolt

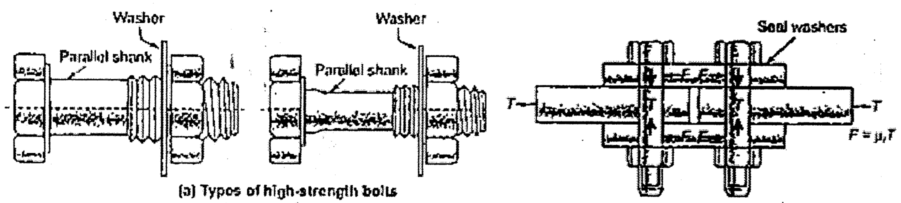
	Grade/Class	Yield stress, f_y (N/mm^2) (min)	Properties Ultimate tensile stress, f_{ub} (N/mm^2) (min)	Elongation percentage (min)
Specification IS1367 (Part 3)	3.6	180	330	25
	4.6	240	400	22
	4.8	320	420	14
	5.6	300	500	20
	5.8	400	520	10
	6.8	480	600	8
	8.8(d < 16 mm)	640	800	12
	8.8(d > 16 mm)	660	830	12
	9.8	720	900	10
	10.9	940	1040	9
	12.9	1100	1220	8

(b) High strength bolts

- High strength bolts are fabricated from bars of medium carbon heat treated steel and from the alloy steel.
- Their high strength is obtained from the quenching process followed by the tempering process or by the alloying steel.
- These types of bolts may be tightened to very high tensile stresses, about twice or more times the ordinary bolts. This allows the load to be transferred through friction and not by shear.
- The contact surfaces must be free of paint, grease, rust or the mill scales which will otherwise prevent the solid contact between the surfaces and thereby lowering the slip factor.
- Due to friction between the contact surfaces, the possible slip in the joint (which is present with ordinary bolts) is entirely eliminated. This friction is developed by applying a normal load to the joint by tightening these bolts to proof load. Thus these bolts are also referred to as **friction type bolts**.
- Joints using high strength friction grip bolts are called as **nonslip connection or slip critical connection or friction type connection.**
- Steel washers of hard carburized steel are used to uniformly distribute the clamping pressure on the bolted member and to prevent the threaded portion of the bolt from bearing on the connecting points.

Table 2.4 Typical Mean Values for Coefficient of Friction (μ_f)

Sl. No.	Treatment of Surface	Coefficient of friction (μ_f)
(i)	Surfaces not treated.	0.20
(ii)	Surfaces blasted with shot or grit with any loose rust removed, no pitting.	0.50
(iii)	Surfaces blasted with shot or grit and hot-dip galvanized.	0.10
(iv)	Surfaces blasted with shot or grit and spray metallized with zinc (thickness 50-70 μm).	025
(v)	Surfaces blasted with shot or grit and painted with ethylzinc silicate coat (thickness 30-60 μm).	0.30
(vi)	Sand blasted surface, after light rusting.	0.52
(vii)	Surfaces blasted with shot or grit and painted with ethylzinc silicate coat (thickness 60-80 μm).	0.30
(viii)	Surfaces blasted with shot or grit and painted with alcalizinc silicate coat (thickness 60-80 μm).	0.30
(ix)	Surface blasted with shot or grit and spray metallized with aluminium (thickness > 50 μm).	0.50
(x)	Clean mill scale.	0.33
(xi)	Sand blasted surface.	0.48
(xii)	Red lead painted surface.	0.1



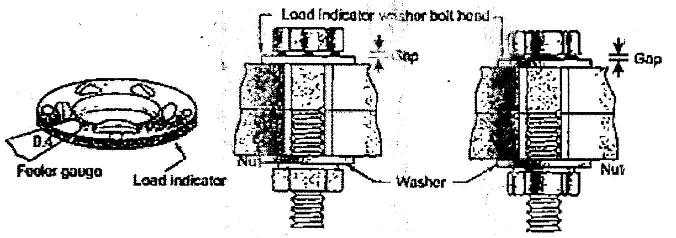
(a) Types of high-strength bolts

(b) Slip resistance

Fig. 2.5 Bolted connection of high strength bolts

Remember

In case of high strength bolts, care must be taken to tighten the bolt up to the required tension otherwise slip may occur at service loads and the joint will behave like an ordinary bolted joint. The correct shank tension is achieved either by part turning method or by torque control method or by employing load indicating washers. In case bolts are tightened by part turning method also called as turn of nut method, the nut is made snug and is tightened a half turn more by hand wrenches, then the washers are not required. This method is used for making bearing type connections where bolts are required to provide enough tension to the contact surfaces so that they bear on each other. In torque control method, a power operated or a hand wrench is used to apply a specified torque to the nut. In load indicating washer type connection, the washers are projected as shown in Fig. 2.6 (a) which crushes down as the bolt is tightened. Fig. 2.6 (b) and (c) show the bolted joint surface before and after tightening the bolt respectively.



(a) Load indicator washer (b) Before tightening (c) After tightening

Fig. 2.6 Fixing of bolts with load indicating washers

- High strength bolts are available in sizes of 16 mm to 36 mm and are designated as M16, M20, M24 and M30.
- These bolts are identified as 8S, 8.8S, 10S or 10.9S marked on the bolt head where the letter S represents 'high strength'. Most commonly used bolts are 8.8S and 10.9S.
- IS 3757:1985 and IS 4000:1992 lay down the specifications for high strength bolts.

Advantages of high strength bolts:

(a) There is no slip between the members i.e. HSFG bolts provide rigid connection.

(b) Large tensile stresses are developed in the bolt which in turn provide large clamping force to the connecting members and due to which high frictional resistance is developed thereby providing a high strength to the joint.

(c) Because of the clamping action, load is transferred through friction only and no shear or bearing stresses get developed on the bolts.

(d) As frictional resistance is effective outside the bolt hole and thus lesser load is transmitted through the net section which reduces the susceptibility of the failure at net section.

(e) There is no stress concentration in the holes and thus fatigue strength is more.

(f) There is uniform tension in the bolts and more over bolts are tensioned up to the proof load and thus this prevents the nuts from loosening.

(g) Because of the absence of hammering (like in rivets), noise nuisance is low.

(h) It offers easy alterations.

(i) For same strength, less number of bolts are required as compared to the number of rivets or ordinary bolts required thereby offering economy in construction.

(j) This cost further gets reduced as less number of persons are required for making the connection.

2.3.5 Types of Bolted Joints

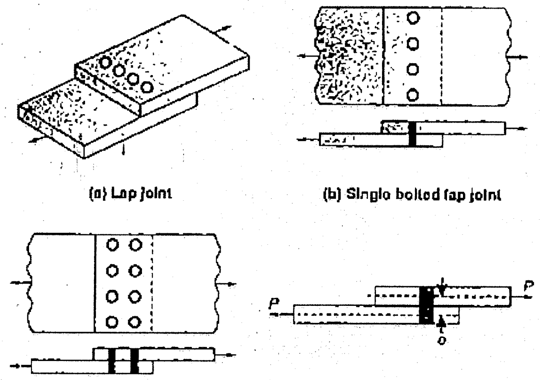
If the load line is assumed to pass through the CG of the bolt group then there are two types of bolted joints viz. lap joint and butt joint. The other case i.e. when the load line does not pass through the CG of the bolt group gives rise to eccentric connections.

(a) Lap joint

- Here the two members to be connected are overlapped and jointed as shown in Fig. 2.7 (a).
- Fig. 2.7 (b and c) shows respectively the single bolted lap joint and the double bolted lap joint. The load lines in the two members of lap joint do not coincide and hence lap joint has an eccentricity leading to the formation of an undesirable couple there by inducing tension in bolt which may lead to failure of joint as shown in Fig. 2.7 (d).
- Due to this eccentricity only, the stresses are distributed unevenly across the contact area between the bolts and members to be connected.
- Cl. 10.5.1.2 of IS 800:2007 states that minimum length of lap shall not be less than four times the thickness of thinner part being jointed or 40 mm, whichever is more.

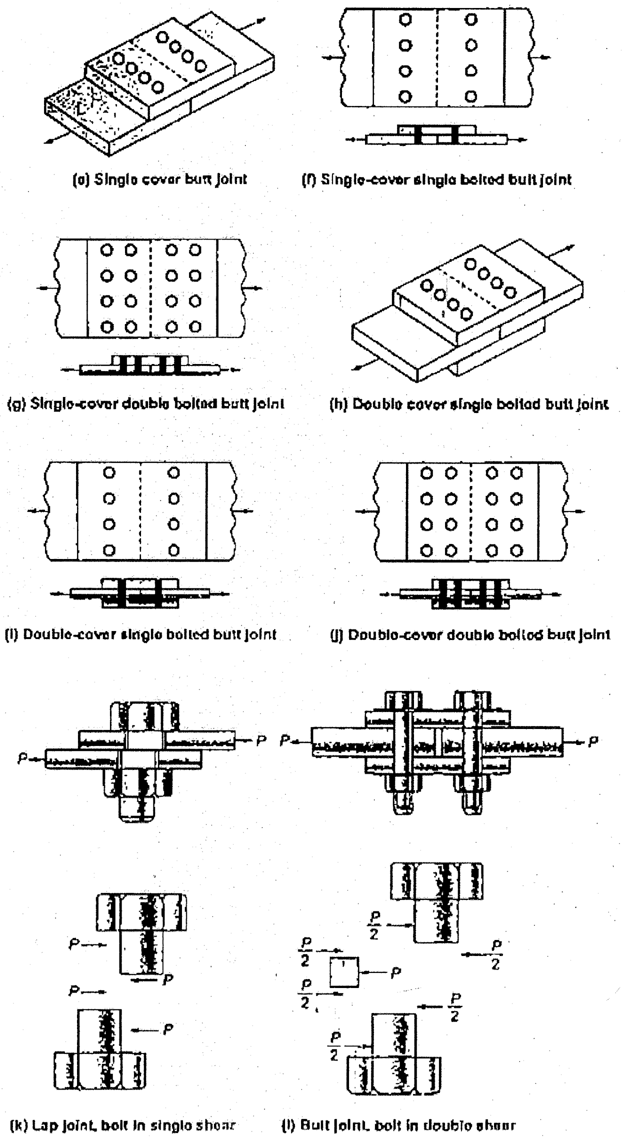
(b) Butt joint

- Here the two members to be connected are placed end to end thereby bringing the load lines in the two members in one line and reducing eccentricity to almost zero.
- Additional cover plate(s) on either side or both sides can be provided to connect the main plates as shown in Fig. 2.7 (e and h).
- The butt joint is called as **single cover butt joint** if the plate is provided only on one side of the main plate (Fig. 2.7 (e, f and g)) and is called as **double cover butt joint** if the plates are provided on both the sides of the main plate (Fig. 2.7 (h, i and j)).
- Fig. 2.7 (k and l) shows the transfer of forces in lap joint and double cover butt joint respectively.



(a) Lap joint (b) Single bolted lap joint

(c) Double bolted lap joint (d) Eccentricity in lap joint



(e) Single cover butt joint (f) Single-cover single bolted butt joint

(g) Single-cover double bolted butt joint (h) Double cover single bolted butt joint

(i) Double-cover single bolted butt joint (j) Double-cover double bolted butt joint

(k) Lap joint, bolt in single shear (l) Butt joint, bolt in double shear

Fig. 2.7 Bolted joints

Advantages of butt joint over lap-joint:

(a) As shown in Fig. 2.7 (l), the total shear that gets transferred through double cover butt joint is almost half of that of lap joint (Fig. 2.7 (k)).

(b) In case of double cover butt joint, there does not exist the eccentricity of load line and hence bending is eliminated. But this bending exists in lap joint.

Do You Know?

Why washers are provided in bolted connections?

The bolts are provided with washers where full bearing area of the bolt is to be developed. The washer provided under the nut must be of sufficient thickness so that no portion of threaded bolt comes within the thickness or the parts bolted together unless the same has been accounted for in design (Cl. 17.5.1 of IS 800:2007).

2.4 Mechanism of Load Transfer Through Bolts

- The transfer of force from one member to another depends on the type of bolt being used.
- This transfer of force mechanism may be either **bearing type** where load transfer occurs by shearing and bearing or **slip-critical/slip-resistant** where load transfer occurs by friction.
- In slip resistant connections, the entire force is transmitted through friction and the joints are not really subjected to shear or bearing. The bolts are first brought to sung tight condition and then tightened further. Joints with so tightened bolts are referred to as **pre-tensioned joints**. But when the load exceeds the frictional resistance then slippage occurs and consequently the bolts will be subjected to shear and bearing and will behave like a bearing type joint.
- When high strength bolts are not tightened sufficiently so as to significantly squeeze the plates together, there will be a negligible friction between the plates. On load application, the plates slip a little and the load will tend to shear off the bolts on the interface and press or bear against the side of the bolts. Now the load transfer will be like bearing type connection.

2.5 Failure of Bolted Joints

(a) **Shear failure of bolts :** When plates slip due to the applied forces, shear stresses are generated. It may be possible that maximum factored shear force exceeds the shear capacity of the bolt. Shear failure of bolt takes place at bolt shear plane. However the bolt may fail in single shear or double shear as shown in Fig. 2.8 (a).

(b) **Bearing failure of bolts :** Here the bolt gets crushed around a semi-circumference. The plate may be strong in bearing and it may happen that the heaviest stressed plate may press the bolt shank as shown in Fig. 2.8 (b). In general bearing failure of bolts do not occur in practice except when the plates are made of high strength steel and the corresponding bolts are of low grade steel.

(c) **Tension failure of bolts :** Bolts subjected to tension may fail at the stress area. In case any of the connecting plates are flexible enough then in that case additional forces due to prying action has also to be considered.

(d) **Tension/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 area (i.e. rupture) must be considered. Fig. 2.8 (d) shows the tension failure of plate in rupture.

(e) **Bearing failure of plates :** When ordinary bolts are subjected to shear forces then slip takes place and bolts come in contact with the plates. It may be quite possible that plate may get crushed if the plate material is weaker than the bolt material as shown in Fig. 2.8 (b). This bearing failure gets complicated further due to the presence of nearby bolt or nearness of an edge in the load direction. The bearing strength gets affected by bolt spacing and the edge distance. One of the possible mode of failure resulting from too much bearing is the shear tear-out at the end of the connected member as shown in Fig. 2.8 (c).

(f) **Block shear failure :** Many a times bolts may have been placed at a lesser end-distance than required which may lead to plates to shear out which can in fact be avoided by adherence to edge distance. Fig. 2.8 (e) shows the failure of joint in block shear failure which may occur when a block of a material within the bolted area breaks away from the remaining of the area. This possibility of failure increases if bolts used are of high strength and fewer bolts are used for making the connection. In this type of failure, shear on one plane and tension on perpendicular plane occurs leading to fall of a portion of plate.

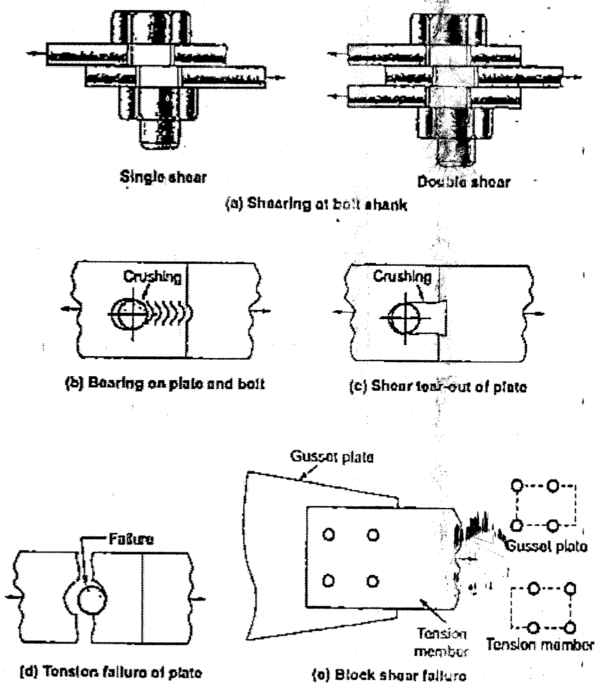


Fig. 2.8 Various types of failure in bolted joints

2.6 Specifications for the Bolted Joints

2.6.1 Diameter of the Bolt

- Fewer the number of bolts lesser will the holes required for bolts and less installation work.
- It is more economical to have less number of large diameter bolts than more number of small diameter bolts.
- The large diameter bolts are particularly favorable where shear governs the design because the bolt capacity in shear varies in proportion to the square of the bolt diameter.

2.6.2 Spacing of Bolt Holes

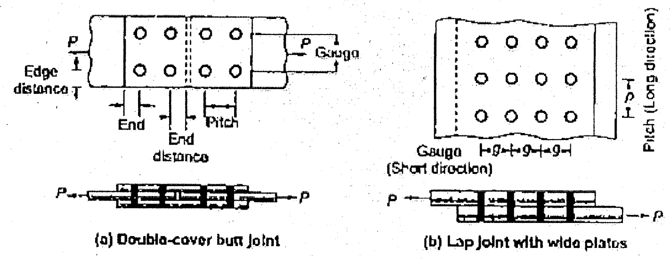


Fig. 2.9 Spacing of holes in bolted joint

Pitch

- Pitch (p) is the distance between the centers of two consecutive bolts in the direction of load i.e. along the line parallel to the stress in the member. When bolts are placed in a staggered fashion then it is referred as staggered pitch.

(a) Minimum pitch

- A minimum pitch must be ensured between the bolts because of the following reasons.
  (i) To prevent bearing failure of members between the two bolts.
  (ii) To ease in installation of bolts i.e. sufficient space must be ensured to tighten the bolts, prevent overlapping of the washers and provide adequate resistance to tear-out of the bolts.
- The center to center distance between the holes should not be less than 2.5 times the nominal diameter of bolt. When bolts are placed at a distance lesser than this then very little clearance is left between the bolts and installation of bolts become difficult.

(b) Maximum pitch

- Maximum pitch is ensured for the following reasons:
  (i) To reduce the length of joint and of gusset plate.
  (ii) To have uniform stress in the bolts. It is assumed that load on the joint is equally distributed among all the bolts. In case of short length joints, a redistribution of forces in the bolts occurs due to plastic action and thus the bolts will share the load equally. However this is true when there are only a few bolts in a line.

- In case of long joints (> 15 times the bolt diameter), the shear stress distribution is not uniform and bolts at the ends are stressed more as shown in Fig. 2.10.

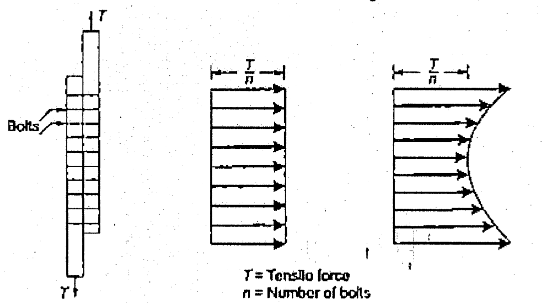


Fig. 2.10 Distribution of shear stress in long bolted joints

(c) Limits on Maximum Pitch:

(i) The center to center distance between the two consecutive bolts in the direction of pitch should not exceed **16 *t* or 200 mm** whichever is less, in tension and **12 *t* or 200 mm** whichever is less, in compression. In case of compression member where forces are transmitted through butting face, this distance must not exceed 4.5 times the bolt diameter and for a distance from the butting face, equal to 1.5 times the width of the member, where *t* is the thickness of thinner outside plate (in mm).

(ii) The center to center distance between the two adjacent bolts should not exceed **32 *t* or 300 mm** whichever is less.

(iii) The center to center distance between any two adjacent bolts in a line adjacent and parallel to an edge of the outside plate should not exceed **(4 *t* + 100 mm)** or **200 mm** whichever is less.

(iv) In case of staggered bolts at equal intervals and gauge does not exceed **75 mm**, the distance as given in (i) and (iii) above should be increased by 50% subject to a maximum as given in (ii) above.

Gauge

The gauge (g) is the distance between the adjacent bolt lines or distance between the back of rolled section and the first line of bolts, or the center to center distance between the two consecutive bolts measured along the width of the member. The terms **bolt lines** and **gauge lines** are used synonymously.

2.6.3 Edge Distance

- It is the distance from the center of bolt to the adjacent edge in a direction normal to the direction of stress.
- Bolt holes must not be placed too close to the edge because of the following reasons:
  (a) Tension failure of plates may take place.
  (b) The steel of the plate opposite to the hole may bulge out and leading to crack.

Table 2.5 Bolt hole diameter and minimum edge distance of bolts

Nominal diameter of bolt (d) (mm)	Hole diameter (d_h or d_o) (mm)	Distance to sheared or hand flame cut edge (mm)	Distance to rolled, machine flame cut, sawn or planed edge (e), (mm)
12	13	20	19
14	15	26	23
16	18	30	27
18	20	34	30
20	22	37	33
22	24	40	36
24	26	44	39
27	30	51	45
30	33	56	50
Over 33 mm	Bolt diameter + 3 mm	1.7 × hole diameter	1.5 × hole diameter

- The maximum edge distance to the nearest line of bolts from an edge of any unstiffened part should not exceed $12t\varepsilon$ where $\varepsilon = \sqrt{250/f_y}$ where *t* is the thickness of thinner outer plate. This is proposed so as to reduce the chances of moisture getting between the parts.
- When fasteners are too far apart from the edges of the parts being connected, in that case, the edges may sometimes separate thus allowing the entry of moisture thereby leading to corrosion causing enhanced separation of parts.

2.6.4 Tacking Bolts

- These are also called as stitch bolts and are provided so that the connected sections (when two or more sections are in contact) act as single unit i.e. in unison.
- These are provided when the center to center distance between the two consecutive bolts exceed **12 *t*** or **200 mm** whichever is less in compression and **16 *t*** or **200 mm** whichever is less in tension.
- These bolts are not subjected to the calculated stresses.
- Tacking or stitch bolts should comply with the following requirements:
  (a) Tacking bolts should have a pitch in line not exceeding **32 *t*** or **300 mm** whichever is less. When it is exposed to weather then pitch in line should not exceed **16 *t*** or **200 mm** whichever is less. In both of these cases, the line of bolts should not be apart at a distance greater than these pitches.
  (b) When T-section, angle sections or channel sections are used:
    (i) Maximum pitch of tacking bolts should not exceed **600 mm** for compression members.
    (ii) Maximum pitch of tacking bolts should not exceed **1000 mm** for tension members.

2.6.5 Combination of Fasteners

- When different types of fasteners are used to carry the shear stresses or when a combination of welding and fasteners is used then one type of fastener should normally be designed to carry the total load.
- Cl .10.1.5 of IS 800:2007 gives an exception to this wherein it is stated that fully tensioned friction grip bolts may be designed to share the load with welding provided the bolts are fully tightened to develop the necessary pretension before welding.

2.7 Bearing Type Connection

- In case of bearing type connections, it is assumed that load to be transferred is greater than the frictional resistance developed due to tightening of bolts and thus members slip over each other a little thereby placing the bolts in shear and bearing.
- In the bearing type connection, the threads of the bolt may be included or excluded from the plane of shear. The bolts can be inserted from either side of the connection.

NOTE Strength of bolt is the minimum of strength in shear, bearing and tension (if present). Thus strength of one bolt when multiplied with the number of bolts will give the strength of joint on the basis of bolts but a joint failure can occur either in bolt or in plate. Thus the strength of a joint is the minimum of strength of bolt and tensile strength of plate (point *a*, *b* and *d* respectivley of section 2.5). The remaining types of failure as specified in Section 2.5 can be avoided by adhering to specifications of edge distance, end distance etc.

2.7.1 Shear Strength of Bolts

- The shank of the bolt shears along the plane of slip i.e. at interface.
- The number of planes along which a bolt can get sheared indicates the number of shear i.e. single shear or the double shear.
- The resistance of bolt in shear is referred to as shear capacity of bolt denoted as V_{nsb}. It depends on the ultimate tensile strength of the bolt f_{ub}, the number of shear planes n, the nominal area of shank A_{sb} and the net tensile stress area A_{nb} of bolt in each shear plane.
- The nominal shear capacity of a bolt is given by,

$$V_{nsb} = \frac{f_{ub}}{\sqrt{3}}(n_n A_{nb} + n_s A_{sb}) \qquad \text{...(2.1)}$$

- The nominal shear capacity of bolts for long joints, long grip length and with packing plates (if provided) will be less and is modified as

$$V_{nsb} = \frac{f_{ub}}{\sqrt{3}}(n_n A_{nb} + n_s A_{sb})\beta_{lj}\beta_{lg}\beta_{pkg} \qquad \text{...(2.2)}$$

where f_{ub} = Ultimate tensile strength of the bolt

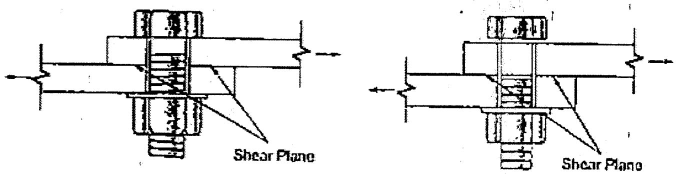
n_n = Number of shear planes with threads intercepting the shear plane,

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

β_{lj} = Reduction factor to allow for the overloading of the end bolts occurring in long connections

β_{lg} = Reduction factor to allow for the effect of large grip length

β_{pkg} = Reduction factor to account for packing plates in excess of 6 mm



(a) Threads included in the Shear Plane (b) Threads excluded in the Shear Plane

Fig. 2.11 Bolt in shear

Do You Know? What is shear plane?
The shear plane is the plane between two or more connected plates under load where the plates are having the tendency to move parallel from each other but in opposite direction. The threads of the bolt may either fall in shear plane or may not fall in shear plane. The capacity of the bolt in shear is greater with threads excluded from the shear plane.

- For bolt to be safe in shear, the strength of bolt V_{nsb} i.e. the maximum factored shear force the bolt can carry should be greater than the design shear strength of the bolt V_{dsb} i.e.,

$$V_{nsb} \geq V_{dsb}$$

- The design shear strength of bolt is given by,

$$V_{dsb} = \frac{V_{nsb}}{\gamma_{mb}} \qquad \text{...(2.3)}$$

where γ_{mb} = Partial factor of safety for the bolt material = 1.25

Thus design shear strength of the bolt can be expressed as,

$$V_{dsb} = \frac{V_{nsb}}{\gamma_{mb}} = \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}}(n_n A_{nb} + n_s A_{sb})\beta_{lj}\beta_{lg}\beta_{pkg} \qquad \text{...(2.4)}$$

NOTE
- For WSM, permissible shearing stress = 100 MPa.
- The thread of the bolt may occur in shear plane and thus effective area for resisting shear is taken as net tensile stress area of the bolt A_{nb}. For bolts whose net tensile stress area is not defined, A_{nb} is taken as area at the root of the threads. In case threads do not fall in shear plane, then effective area is taken as cross sectional area of the shank A_{sb}.

Remember: For normal bolts and member sizes, threads will always be excluded from the shear plane. Assuming the threads to be in shear plane will be too much conservative approach.

2.7.2 Reduction Factor for Long Joints (β_{lj})

- Cl. 10.3.3.1 of IS 800:2007 states that in case length of the joint exceeds 15 times the bolt diameter in the load direction then shear capacity of the bolt gets reduced to avoid too much stresses in the extreme bolts of the joint.
- This reduction factor for long joints is given by,

$$\beta_{lj} = 1.075 - \frac{l_j}{200d} \quad \forall\, 0.75 \leq \beta_{lj} \leq 1.0 \qquad \text{...(2.5)}$$

where l_j = length of the joint which is equal to distance between the first and last row of bolts in a joint measured in the direction of load transfer

Remember: Reduction factor for long joints (β_{lj}) is taken as unity i.e. 1.0 for joints having uniform shear over the entire length just like connection of web and flange in a plate girder.

2.7.3 Reduction Factor for Large Grip Length (β_{lg})

- As per Cl. 10.3.3.2 of IS 800:2007, as the grip length of the bolt increases, the bolt is subjected to flexural moments due to shear forces being acting on its shank.
- If the total thickness of the connected plates exceeds five times the nominal diameter of bolt then the shear capacity of the bolt gets reduced by a factor β_{lg} which is given by,

$$\beta_{lg} = \frac{8d}{3d + l_g} \qquad ...(2.6)$$

where l_g = Grip length

Remember: β_{lg} should not be more than β_{lj} and $l_g \leq 8d$

2.7.4 Reduction Factor for Packing Plates (β_{pkg})

- Cl. 10.3.3.3 of IS 800:2007 provides a provision when the thickness of the packing plate exceeds 6 mm then shank of the bolt is subjected to flexure which in fact affects the nominal shear capacity of the bolt.
- The nominal shear capacity of such bolts is reduced by a factor which is given by,

$$\beta_{pkg} = 1 - 0.0125\, t_{pkg} \qquad ...(2.7)$$

where t_{pkg} = Thickness of thicker packing plate in mm

2.7.5 Bearing Strength of Bolt

- In bearing neither the bolt nor the metal in contact with the bolt fails in bearing. But the magnitudes of bearing stress do affect the efficiency of the connected parts. So IS specifications put a limit on the nominal bearing strength above which it is considered that the strength of the connected parts gets impaired.
- Bolt fails in bearing only if the bolts used are of very low grade. Thus bearing strength of bolted connection is a function of strength of the connected parts and the arrangement of bolts irrespective of the grade of bolt.

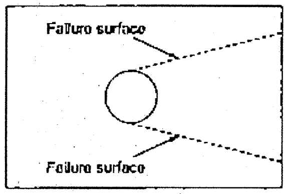


Fig. 2.12 Excessive bearing failure: Shear tear-out

- One of the possible failure modes in bearing is the shear tear-out at the end of the connected member as shown in Fig. 2.12. This tear out can take place either at the end of connected part or between two holes in the direction of bearing load.
- In order to prevent too much elongation of bolt hole, an upper limit is placed on the nominal bearing strength of the bolt. This upper limit is the projected area times the ultimate tensile strength of the connected parts.
- Except for bearing of bolts on slotted holes, the nominal bearing strength of bolt is given as per Cl. 10.3.4 of IS 800:2007 by,

$$V_{npb} = 2.5 k_b d t f_u \qquad ...(2.8)$$

where, e, p = End distance and pitch distance respectively of the fastener along the direction of bearing

f_{ub} = Ultimate tensile strength of bolt

f_u = Ultimate tensile strength of the plate

d = Nominal diameter of the bolt

t = Aggregate thickness of the connected plates having bearing stress in the same direction. For countersunk bolts, this thickness is taken as thickness of the plate minus half the depth of countersunking.

NOTE

1. The factor 2.5 in Eq. (2.8) corresponds to hole elongation of about 6 mm which may be considered to be excessive deformation in order to cause the bearing failure.
2. The end distance (e) and the distance of bolt holes parallel to the load (p) may serve to limit the bearing strength which is accounted for in the factor k_b.
3. Bearing failure of low strength bolts is taken care of by IS 800:2007 through the coefficient k_b which includes the factor f_u/f_{ub}.

$$k_b = \text{Minimum of}\left(\frac{e}{3d_o},\ \frac{p}{3d_o} - 0.25,\ \frac{f_{ub}}{f_u},\ 1.0\right)$$

- For joint to be safe in bearing, the bearing strength of the bolt (V_{npb}) should be greater than the design strength of the bolt (V_{dpb}) i.e.

$$V_{npb} \geq V_{dpb}$$

- The design strength of the bolt in bearing is given by,

$$V_{dpb} = \frac{V_{npb}}{\gamma_{mb}} = 2.5 k_b d t \frac{f_u}{\gamma_{mb}} \qquad ...(2.9)$$

where γ_{mb} = Partial factor of safety for the bolt material = 1.25

NOTE

- Permissible bearing stress for WSM = $1.2 f_y$
- Bearing strength is also a function of type of bolt hole. Bearing strength as given by Eq. (2.8) is for standard type of bolt holes. However, bolt holes may be oversized, Short Slotted (SSL) or Long Slotted (LSL).

2.7.6 Tensile Strength of Bolt

- The nominal tensile capacity of the bolt is given by,

$$T_{nb} = 0.9 f_{ub} A_{nb} \qquad ...(2.10)$$

where f_{ub} = Ultimate tensile stress of bolt, f_{yb} = Yield stress of bolt

A_{nb} = Net tensile stress area of bolt as given in Table 2.2.

NOTE: The factor 0.9 accounts for safety at ultimate load.

- For bolt to be safe in tension, the factored tension force (T_b) on the bolt should be less than the design tensile strength of the bolt i.e.

$$T_b \leq T_{db}$$

where T_{db} is given by,

$$T_{db} = \min.\left\{\frac{0.9 f_{ub} A_{nb}}{\gamma_{mb}},\ \frac{f_{yb} A_{sb}}{\gamma_{m0}}\right\} \qquad ...(2.11)$$

γ_{mb} = Partial factor of safety for the bolt material = 1.25

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

A_{sb} = Shank area of bolt

2.8 Tensile Strength of Plate

- 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.

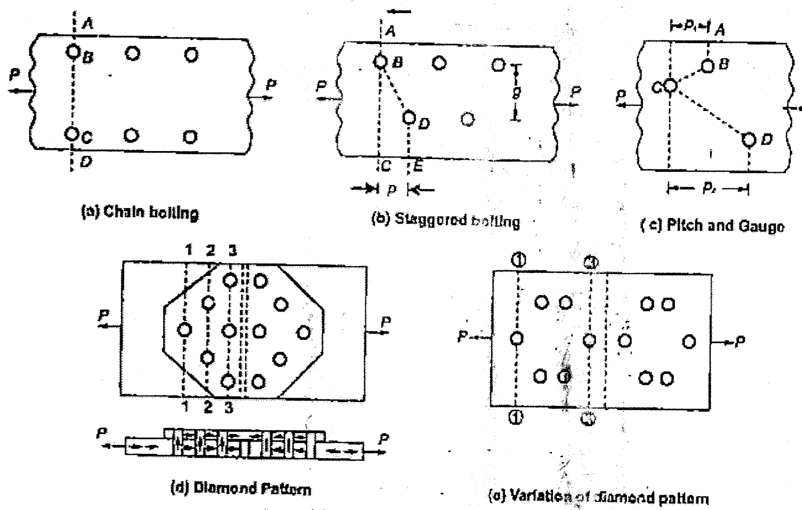


Fig. 2.13 Net section in bolted plate connection

NOTE: For main plate critical section is at (1)-(1), while for cover plates critical section is at (3)-(3).

- Diamond rivetting (d) is better than other (a, b, c) arrangements as only one rivet hole is deducted at section (1)-(1) but three holes are deducted at (3)-(3) which makes cover plate weak.
- To eliminate above problem a variation of diamond arrangement may be provided as shown in (e). In this arrangement both main plate and cover plate are relatively strong than other arrangements. Hence it is best arrangement.
- The net area of plates and that of flats is given by,

$$A_n = \left[B - nd + \sum_{i=1}^{m} \frac{p_i^2}{4g_i}\right] \cdot t \quad \text{(for staggered bolting)} \quad ...(2.12)$$

$$= (B - nd_0)\, t \quad \text{(for chain bolting)} \quad ...(2.13)$$

- The tensile strength of a plate is given by,

$$T_{nd_1} = 0.9\, A_n \frac{f_u}{\gamma_{m1}}, \qquad T_{nd_2} = \frac{A_g f_y}{\gamma_{m0}} \quad ...(2.14)$$

where, f_u = Ultimate stress of the material (in N/mm²)
A_n = Effective area of the plate (in mm²)
γ_{m1} = Partial factor of safety for material strength governed by ultimate strength = 1.25
γ_{m0} = 1.1

Tensile strength of plate is taken as $\min.\{T_{nd_1}, T_{nd_2}\}$

2.9 Strength and Efficiency of a Bolted Joint

- The strength of a 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 (η) is defined as the ratio of strength of a joint to the strength of the main connected member i.e.

$$\eta = \frac{\text{Strength of bolted joint}}{\text{Strength of solid plate}} \times 100 \quad ...(2.15)$$

NOTE: In design of rivetted/bolted connection we have to ensure that shearing and bearing strength of rivets are more than tearing strength of plate.

2.10 Combined Tension and Shear

- Generally in eccentrically loaded connection, the bolt is subjected to tension and shear both. One of such case is shown in Fig. 2.14 where T section is connected to the column flange for attaching a bracing member.

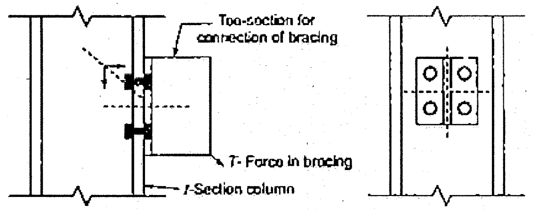


Fig. 2.14 Bolted connection subjected to tension and shear

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

$$\left(\frac{V_{sb}}{V_{dsb}}\right)^2 + \left(\frac{T_b}{T_{db}}\right)^2 \le 1.0 \quad ...(2.16)$$

where, V_{sb} = Factored shear force on the bolt, V_{dsb} = Design shear capacity of the bolt
T_b = Factored tensile force on the bolt, T_{db} = Design tension capacity of the bolt

2.11 Slip Critical Connection

- Where the member forces are too large and/or where the connection length is limited, there high strength friction grip (HSFG) bolts are the most suitable choice since at serviceability load; they do not slip and are also referred to as slip resistant connections.
- However at ultimate loads, they do slip and after that the joint behaves like a bearing type connection. This situation occurs when load exceeds the frictional resistance between the plates being connected.

NOTE Theoretically slip-critical connections are not subjected to shear and bearing but they must have enough shear strength and bearing strength in case over loading occurs that may lead to slipping of plates. In most of the structures, slipping occurs and there bearing type connections can be used.

Remember: Slip critical connections can be designed using factored loads or the service loads.

2.11.1 Underlying Principle of HSFG Bolts

- The shank of high strength bolts does not fill the bolt hole completely.
- Thus, shear and bearing are not the deciding criteria unlike in bearing type connection.
- The nut is tighten to develop the clamping force on the plates which is designated as tensile force T in the bolt. This tension should be about 90% of the proof load.
- When shear load is also applied to a joint, no slipping will occur until shear load exceeds the frictional resistance between the surfaces of the members being jointed.
- Slip occurs when shear load exceeds the frictional resistance of the joint. With further increase in shear load, gradual slipping brings the bolt in contact with the plate edge, shear and bearing will then exist and ultimately affects the capacity of the joint.
- For slip resistant connections, the horizontal frictional force F gets induced in the joint which is equal to the tensile force T in the bolts multiplied by coefficient of friction μ_f i.e.

$$F = \mu_f T \qquad ...(2.16)$$

Here μ_f is the coefficient which is called as slip factor which is defined as ratio of load per effective interface required to produce slip in a pure shear joint to the proof load induced in bolt.

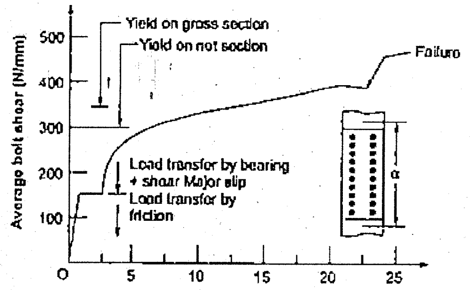


Fig. 2.15 Load deformation behavior of friction type connection

Remember

For determination of strength capacity of a general grade bolt, the capacity of the bolt is defined as minimum of the slip resistance and the bearing capacity. While the slip resistance is based on service load conditions, a design check is made for factored loads. It is quite possible that joint may slip and go into bearing at loads exceeding service loads and hence bearing capacity must be checked.

2.11.2 Shear Strength of HSFG Bolts

- The resistance to slip is a function of product of coefficient of static friction and normal force between the connected parts.
- Slip can be considered either at serviceability limit state or at collapse/strength limit state.
- The design slip resistance or the nominal shear capacity of HSFG bolt is given by,

$$V_{nsf} = \mu_f n_e K_h F_o \qquad ...(2.17)$$

- The design shear strength of HSFG bolt is given by,

$$V_{dsf} = \frac{V_{nsf}}{\gamma_{mf}} \qquad ...(2.18)$$

where μ_f = Slip factor as given in Table 2.4

n_e = Number of interfaces providing frictional resistance to the slip

K_h = 1.0 for fasteners in clearance holes

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

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

F_o = Minimum bolt tension (proof load) at installation as given in **Table 2.6** = $A_{nb} \cdot f_o$

A_{nb} = Net area of bolt at the root of the threads as given in **Table 2.6**

f_o = Proof stress = $0.7 f_{ub}$

f_{ub} = Ultimate tensile stress of bolt

- For safe joint, the factored shear force should be less than the design shear strength of the bolt i.e.

$$V_{sf} \le V_{dsf}$$

where γ_{mf} = 1.1 for slip resistance designed at service load

= 1.25 for slip resistance designed at ultimate load

Table 2.6 Stress area and proof load of HSFG bolts in clearance holes

Bolt diameter (mm)			12	16	20	22	24	27	30	36
Stress area of bolt (mm^2)	Thread		84.3	157	245	303	353	459	561	817
	Shank		113	201	314	380	452	572	706	1017
Proof load of bolt (kN) $F_o = 0.7 f_{ub} \cdot A_{nb}$	Property class	8.8 S	47.2	87	137	169	197	257	314	457
		10.9 S	61.3	114	178	220	256	334	408	595

For long joints, the nominal shear capacity V_{nsf} of the bolt is reduced by a factor β_{lj} which is given by Eq. (2.5)

2.11.3 Bearing Strength of HSFG Bolts

- HSFG bolts come under bearing action only after slipping takes place.
- In case slip cannot be allowed i.e. for **slip-critical connections**, the slip resistance is computed as described in Section 2.11.2.
- Where slip is allowed i.e. slip is not critical, there a need to check the bolt in bearing arises provided limit state method is used. At ultimate limit state, HSFG bolts slip into bearing and there is a possibility that bolt may deform due to very high localized bearing stresses between the bolt and the plate.
- The design bearing capacity of the bolt (V_{npb}) can be determined as per Eq. (2.9).

2.11.4 Tensile Strength of HSFG Bolts

- The nominal tensile strength of HSFG bolts subjected to factored tensile load is assessed in a similar way as for ordinary bolts as,

$$T_{nf} = 0.9 f_{ub} A_{nb} \le f_{yb} A_{sb} \frac{\gamma_{m1}}{\gamma_{m0}} \qquad ...(2.19)$$

- The design tensile strength of the bolt is given by,

$$T_{df} = \frac{T_{nf}}{\gamma_{m0}} \qquad ...(2.20)$$

where, γ_{m0} = Partial factor of safety for material resistance governed by yield = 1.10

γ_{mf} = Partial factor of safety for bolt material = 1.25

A_{nb} = Net tensile area of bolt as given in **Table 2.6**

A_{sb} = Shank area of the bolt

f_{ub} = Tensile stress of the bolt as per **Table 2.2**

2.12 Prying Action

It is assumed that high strength bolts are non-deforming and are subjected to tensile forces when tightened. The tension force is close to yield strength of the bolts. As shown in Fig. 2.16 (a), a T hanger is subjected to a concentric tensile load T_1. Thus for a tensile load that is applied to sung type of bolt (i.e. bolts with no initial tension), the tensile force in the bolt will be equal to the applied tensile load.

In case of high strength bolts that are fully tensioned, pre-stress in the joints get introduced (tensile force in the bolts due to full tightening) and the connected member plates get squeezed. The bolts are under initial tension T_i. For static equilibrium, the connected parts are subjected to compression C_i and are thus prestressed as shown in Fig. 2.16 (b). Due to prestressing of the plates, the thickness of the plates gets reduced which consequently reduces the tension in the connectors and subsequently the compressive stress in the plate. This increases the plate thickness. The whole sole effect is that neither the plate thickness nor the connector tension is changed. Thus the connection subjected to tensile load T_i equals the total tension $2T_i$ in the connectors. Thus the tensile force in high strength bolts should be computed without considering any initial tension. Application of any additional tensile load to the connection cannot exert any additional load on the bolts unless the connected members are pulled apart thereby creating additional strain in the bolts. But this increase in bolt strain is accompanied by expansion of plates. In fact the increase in bolt tension is very small due to the additional load which is shared between the plate and the connectors roughly in proportion to their stiffness and the plates being stiffer take the most of load.

The stiffness (or flexibility) of the T hanger flange plays a prominent role in the determination of resultant tension in bolts. In case of very flexible flange, if load is increased, the contact stress in the vicinity of bolts decrease and will reduce to zero as the flange separates from the support. Moreover, since the flange will bend, the outer portion of the flange will be forced against the support and develop contact stresses in different locations as shown in Fig. 2.16 (c). This is called as prying stress. In most of the connections subjected to tension in general, due to the flexibility of connected parts, can lead to deformations that increase the tension applied to bolts. This additional tension force is called as prying force. For static equilibrium, the total force in the bolts must be equal to the applied force plus the prying forces. Thus the useful capacity of the bolt gets decreased by prying force. The maximum value of prying force will be reached only when the corners of the hanger flange remain in contact with the other connected part. Depending on their relative stiffness of the connected part and the bolt, the prying action may be negligible or it may be quite significant in proportion to total tension in the bolts.

On the other hand, for very stiff flange, the picture is quite different. Its flexural deformations will be negligible relative to the bolt elongation. Bending will cause the compressed zones of the connected parts to loose their symmetry but this compression remains localized in their bolt regions as shown in Fig. 2.16 (d). This system is identical to an indeterminate condition. At this stage a very little pressure gets exerted by the support on the rest of the flange. With further increase of load, the contact stress will reduce to zero and the system becomes statically determinate and no additional tension will be developed on the fasteners.

The hanger connection as shown in Fig. 2.16 (c) and Fig. 2.17 is an instance of connection subjected to prying action. In this type of connection, bending due to the prying action will usually control the design. The additional force Q in the bolts due to prying action should be added to tensile force T_e resulting directly from the applied forces.

It is quite cumbersome to determine the exact magnitude of prying force, and thus approximate formulae are developed

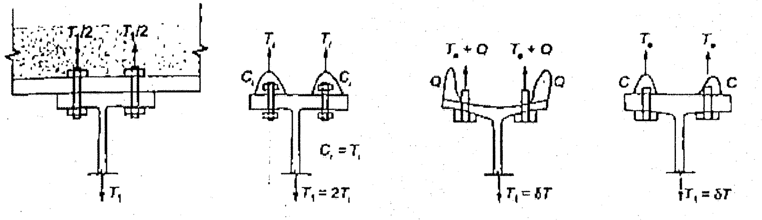


Fig. 2.16 Explanation of prying action with T-section hanger

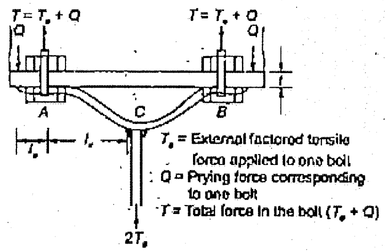


Fig. 2.17 Prying action in fabricated T-section

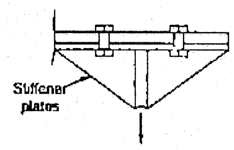


Fig. 2.18 Stiffened hanger connection

Fig. 2.18 shows flanges of the hanger which are thick and stiff (or are stiffened). In this case the prying action will be negligible. Thus in order to prevent significant deformations in the hanger and other similar connections, the use of rigid flanges is recommended.

2.12.1 Analysis and Design for Prying Action

Consider a hanger connection as shown in Fig. 2.17 where a T section is being jointed to an end plate with high strength bolts and acted upon by a tensile force $2T_e$. Prior to the application of tensile load, the balancing compressive force will be equal to the pore-tension in the bolts. With further increase of load, if the flange is flexible enough to deform as shown in Fig. 2.17, the CG of the compressive force will move towards the edges of the flange. This redistribution will alter the relationship between all forces and bolt tension will get increase.

But if the connected parts are sufficiently rigid, the shifting of forces will not occur and thus there will be no prying action. The maximum value of the prying force will be reached only when the corners of the flange remain in contact with the other connected part and in this case the prying force will shift to the tip of the flange. Now since the correct distribution of prying forces is not known, they are assumed to act as line load Q at the end of spans l_e.

The prying force Q is given by,

$$Q = \frac{l_v}{2l_e}\left[T_e - \frac{\beta \eta f_o b_e t^4}{27 l_e l_v^2}\right] \approx \frac{T_e l_v}{2l_e} \qquad \text{...(2.21)}$$

where l_v = Distance from the bolt center line to the toe of the fillet weld (Fig. 2.17) or to half the root radius for a rolled section

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

$$= 1.1t\sqrt{\beta\frac{f_o}{f_y}}$$

β = 1 for pre-tensioned bolt

= 2 for non-pre-tensioned bolt

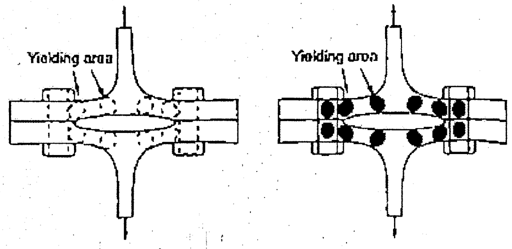
η = 1.5 for limit state design

b_e = Effective width of the flange per pair of bolts

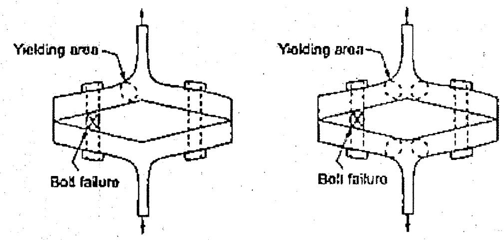
f_o = Proof stress

t = Thickness of end plate

The connection design subjected to prying action is a trial and error procedure. While selecting the diameter and number of bolts, an allowance for prying action must be made. The selection of T flange thickness is even more difficult since it is a function of both bolt selection and T dimensions.



(a) Bending failure of hanger tee flange



(b) Failure mechanism and hanger Tee

Fig. 2.19 Shows two possible limit states viz.

It is assumed that T section gets failed after the formation of plastic hinges at the face of stem and the bolt line as shown in Fig. 2.19 (a) thereby creating a beam mechanism. The moment at each of these locations is equal to the plastic moment M_p. When the moment at bolt line is less than the moment at the face of stem, it infers that beam mechanism has not formed and the deciding limit state will be tensile failure of bolt as shown in Fig. 2.19 (b). The thickness of T flange is determined so that it does not yield.

2.13 Pin Connections

- Here, the members are connected through a cylindrical shaped pin passing through the members. This connection is required where hinged joint is needed.
- Hinge connections simplify the analysis by reducing the degree of indeterminacy.
- The pin in pinned connection serves as a shank of a bolt but because only one pin is present and thus forces acting on a pin are much larger than forces acting on a single bolt.
- Pins are made from mild steel. The usual diameters of pin vary from 9 mm to 330 mm.

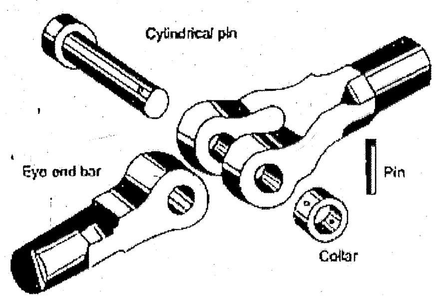


Fig. 2.20 Pinned connection

- Different types of pins used for making pinned connections are forged steel pins, drilled pins and the undrilled pins.
- A pin may be subjected to flexure, shear and/or bearing. Among these, flexure is the most critical. The following limit states are considered for the design of a pinned connection:

(a) **Shear capacity:** The shear capacity of a pin is defined as follows:

(i) When rotation is not required and also the pin is not to be removed then,

$$\text{Shear capacity of pin} = 0.6 f_{yp}A \quad ...(2.22)$$

(ii) When rotation is required or the pin is required to be removed then,

$$\text{Shear capacity of pin} = 0.5 f_{yp}A \quad ...(2.23)$$

where f_{yp} = Design strength of the pin

A = Gross sectional area of the pin

(b) **Bearing capacity:** The bearing capacity of the pin is defined as follows:

(i) When rotation is not required and also the pin is not to be removed then,

$$\text{Bearing capacity} = 1.5 f_{yp}dt \quad ...(2.24)$$

(ii) When rotation is required or the pin is required to be removed then,

$$\text{Bearing capacity} = 0.8 f_{yp}dt \quad ...(2.25)$$

where f_{yp} = Minimum of design strength of pin and the connected member

(c) **Flexural capacity:** In pinned connections, flexure is most important. Here the connected members are separated by some distance because we need to prevent the friction.

Because of this, large flexural moments get developed and thus the pin diameter is decided by flexure.

The moment (or flexural) capacity of a pin is given by,

(i) When rotation is not required and also the pin is not to be removed then,

$$\text{Moment capacity} = 1.5 f_{yp}Z \quad ...(2.26)$$

(ii) When rotation is required or the pin is required to be removed then,

$$\text{Moment capacity} = f_{yp}Z \quad ...(2.27)$$

where f_{yp} = Design strength of the pin

Z = Section modulus of the pin

Let d = Diameter of the pin to be designed

M_u = Factored moment on pin

and the pin is not required to be removed then,

$$M_u = 1.5 f_{yp}Z$$

$$M_u = 1.5 f_{yp}\frac{\pi d^3}{32} \quad ...(2.28)$$

$$d = \left(21.33\frac{M_u}{\pi f_{yp}}\right)^{1/3} \quad ...(2.29)$$

2.13.1 Procedure for the Design of Pinned Connection

Step-1: It should be known that if pin is to be removed or not and if rotation is required or not.

Step-2: Determine the ultimate pull to be transferred through the pinned connection and moment capacity of the ply to be connected.

Step-3: Determine the diameter of the pin from Eq. (2.31)

Step-4: The diameter of pin so arrived at must be checked for its shear capacity and bearing capacity.

Illustrative Examples

Example 2.1 **Determine the strength of 20 mm diameter bolt of grade 4.6 for the following cases.**

(a) Lap joint.
(b) Single cover butt joint with 10 mm thick cover plate.
(c) Double cover butt joint with 8 mm thick cover plates.
The main plates to be joined are 14 mm thick. Use Fe410 grade steel.

Solution:

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

For 4.6 grade bolt, $f_{ub} = 400\ N/mm^2$, $f_y = 240\ N/mm^2$

Partial factor of safety for bolt material (γ_{mb}) = 1.25

Net tensile stress area for 20 mm diameter bolt (A_{nb}) = 245 mm² $\left(\simeq 0.78 \times \frac{\pi}{4} \times 20^2\right)$

(a) Lap joint

In lap joint, the bolts are in single shear

∴ Shear strength of bolt in single shear (V_{dsb})

$$= \frac{f_{ub} A_{nb}}{\sqrt{3}\,\gamma_{mb}} = \frac{400 \times 245}{\sqrt{3} \times 1.25} N = 45.26\ kN$$

Strength of bolt in bearing (V_{dpb}) = $2.5\, k_b dt \frac{f_u}{\gamma_{mb}}$

For 20 mm diameter bolt, diameter of bolt hole (d_0) = 22 mm

End distance (e) = 33 mm

Let pitch (p) = 50 mm

$$\therefore \quad k_b = \text{minimum of} \begin{bmatrix} \frac{e}{3d_0} = \frac{33}{3 \times 22} = 0.5 \\ \frac{p}{3d_0} - 0.25 = \frac{50}{3 \times 22} - 0.25 = 0.508 \\ \frac{f_{ub}}{f_u} = \frac{400}{410} = 0.976 \\ 1.0 \end{bmatrix}$$

$= 0.5$

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

$$= 2.5 \times 0.5 \times 20 \times 14 \times \frac{410}{1.25} N = 114.8\ kN$$

Thus strength of bolt = Minimum of V_{dsb} and V_{dpb} = 45.26 kN

(b) Single cover butt joint with 10 mm thick cover plate

Here also the bolt will be in single shear and bearing. The considered thickness for bearing will be the minimum of aggregate thickness of cover plate and minimum thickness of main plates to be jointed i.e. t = 10 mm

As computed in part (a) above, strength of bolt in single shear (V_{dsb}) = 45.26 kN

Strength of the bolt in bearing (V_{dpb}) = $2.5 k_b \frac{dt f_u}{g_{mb}}$

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

$= 82$ kN

Thus strength of bolt = Minimum of V_{dsb} and V_{dpb}

= 45.26 kN

(c) Double cover butt joint with 8 mm thick cover plates

Here the bolt will be in double shear and bearing. The considered thickness for bearing will be the minimum of aggregate thickness of cover plates and minimum thickness of main plates to be jointed i.e.

t = Minimum of (8 + 8, 14) mm = 14 mm

Strength of bolt in double shear (V_{dsb})

$$= 2 \times \frac{f_{ub} A_{nb}}{\sqrt{3}\,\gamma_{mb}} = 90.53\ kN$$

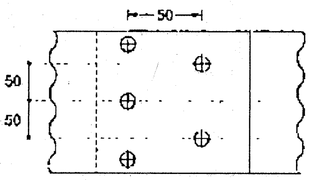
Strength of bolt in bearing (V_{dpb})

$$= 2.5 k_b \frac{dt f_u}{\sqrt{3}\,\gamma_{mb}} = 2.5 \times 0.5 \times 20 \times 14 \times \frac{410}{1.25} N = 114.8\ kN$$

Thus strength of bolt = Minimum of V_{dsb} and V_{dpb} = 90.53 kN

Example 2.2 **Find the strength and efficiency of lap joint as shown in figure. Bolts of grade 4.6 and diameter 20 mm are used for making the connection. The plates to be joined are 12 mm and 14 mm thick. Use Fe410 steel.**

Solution:



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

For bolt of grade 4.6, $f_{ub} = 400\ N/mm^2$, $f_y = 240\ N/mm^2$

For 20 mm diameter bolt, diameter of bolt hole (d_0) = 22 mm

Tensile stress area of bolt (A_{nb}) = 245 mm²

Partial factor of safety for bolt material (γ_{mb}) = 1.25

Partial factor of safety for resistance governed by ultimate stress (γ_{m1}) = 1.25

In lap joint, bolts are in single shear and bearing where bearing strength is governed by thickness of thinner plate i.e. t = 12 mm

Strength of bolt in single shear (V_{dsb}) = $\frac{A_{nb} \cdot f_{ub}}{\sqrt{3}\gamma_{mb}} = \frac{245 \times 400}{\sqrt{3} \times 1.25} N = 45.26\ kN$

Strength of bolt in bearing (V_{dpb}) = $2.5\, k_b \dfrac{dt f_u}{\gamma_{mb}}$

where, k_b = minimum of
$$\begin{cases} \dfrac{e}{3d_0} = \dfrac{33}{3\times 22} = 0.5 \\ \dfrac{p}{3d_0} - 0.25 = \dfrac{50}{3\times 22} - 0.25 = 0.50 \\ \dfrac{f_{ub}}{f_u} = \dfrac{400}{410} = 0.976 \\ 1.0 \end{cases}$$

= 0.5

∴ $V_{dpb} = 2.5\times 0.50\times 20\times 12\times \dfrac{410}{1.25}\,\text{N} = 98.4\ \text{kN}$

∴ Strength of joint per pitch in shear = 2 × 45.26 = 90.52 kN

Strength of joint per pitch in bearing = 2 × 98.4 = 196.8 kN

Tensile strength of plate per pitch (T_{dn}) = $\dfrac{0.9 f_u}{\gamma_{m1}} A_n = 0.9\times \dfrac{f_u}{\gamma_{m1}}(p - d_0)t$

$= 0.9\times \dfrac{410}{1.25}(50-22)\times 12 = 99.187\ \text{kN}$

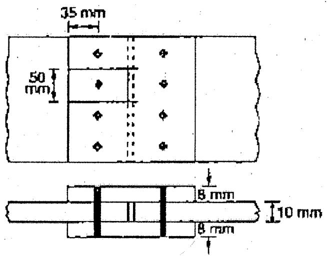
∴ Strength of joint per pitch = 99.187 kN

Strength of solid plate per pitch = $A_g \times \dfrac{f_y}{1.1} = 50\times 12\times \dfrac{250}{1.1} = 136.36\ \text{kN}$

∴ Efficiency of joint = $\dfrac{99.187}{136.36}\times 100 = 72.73\%$

Notice that per pitch length efficiency may be difference from total width efficiency.

Example 2.3 A double cover butt joint which is single bolted is used to connect two plates each 10 mm thick. The cover plates are 8 mm thick and bolts of grade 4.6 and diameter 16 mm are used. The gauge of joints is 50 mm as shown in figure. Determine the strength and efficiency of joint if form bolts are provided in a line. Use steel of grade Fe410.



Solution:

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

For bolt of grade 4.6, f_{ub} = 400 N/mm², f_y = 240 N/mm²

Tensile stress area of bolt for 16 mm diameter, A_{nb} = 157 mm² $\left(\simeq 0.78\times \dfrac{\pi}{4}\times 16^2\right)$

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

Partial factor of safety for resistance governed by ultimate stress γ_{m1} = 1.25

Partial factor of safety for bolt material, γ_{mb} = 1.25

Here the bolts are subjected to double shear and bearing.

For assessing the bearing strength of bolt, the thickness to be used for bearing is

Minimum of $\begin{cases}\text{Main plate thickness} = 10\ \text{mm} \\ \text{Aggregate thickness of} = (8+8)\text{mm} = 16\ \text{mm cover plate}\end{cases}$

Thus for bearing, t = 10 mm

Dia. of 16 mm diameter bolt hole

d_0 = 18 mm

Per gauge shear strength of bolt

$V_{dsb} = 2\times \dfrac{f_{ub}A_{nb}}{\sqrt{3}\gamma_{mb}} = \dfrac{2\times 400\times 157}{\sqrt{3}\times 1.25}\,\text{N} = 58.01\ \text{kN}$ ...(i)

Per gauge, bearing strength of bolt,

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

where k_b = minimum of
$$\begin{cases} \dfrac{e}{3d_0} = \dfrac{35}{3\times 18} = 0.648 \\ \dfrac{p}{3d_0} - 0.25 = \dfrac{50}{3\times 18} - 0.25 = 0.676 \\ \dfrac{f_{ub}}{f_u} = \dfrac{400}{410} = 0.976 \\ 1.0 \end{cases}$$

= 0.648

Thus k_b = 0.648

∴ $V_{dpb} = \dfrac{2.5 k_b dt f_u}{\gamma_{mb}} = 2.5\times 0.648\times 16\times 10\times \dfrac{410}{1.25}\,\text{N} = 85.02\ \text{kN}$ ...(ii)

Per pitch, tensile strength of plate,

$T_{dn} = \dfrac{0.9 f_u A_n}{\gamma_{m1}} = \dfrac{0.9 f_u}{\gamma_{m1}}(p - d_0)t$

$= \dfrac{0.9\times 410}{1.25}(50-18)10\ \text{N} = 94.46\text{kN}$ ...(iii)

Per pitch strength of solid plate = $A_g \times \dfrac{f_y}{1.1} = 50\times 10\times \dfrac{250}{1.1} = 113.64\ \text{kN}$

Thus strength of joint per pitch = Minimum of (i), (ii) and (iii) = 58.01 kN

∴ Efficiency of joint = $\dfrac{58.01}{113.64}\times 100 = 51.05\%$

Example 2.4 Two steel plates (each of Fe410 grade steel) of size 300 × 8 mm are required to be connected through a lap joint. 20 mm diameter bolts of grade 4.6 are available. Design the joint if the joint is required to trasnmit a working load of 160 kN.

Solution:

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

For bolt of grade 4.6, $f_{ub} = 400$ N/mm², $f_y = 240$ N/mm²

Tensile stress area of 20 mm diameter bolts,

$$A_{nb} = 245 \text{ mm}^2 \left(\simeq 0.78 \times \frac{\pi}{4} \times 20^2\right)$$

Working tensile load = 160 kN

∴ Factored tensile load (P) = 1.5 × 160 kN = 240 kN

Partial factor of safety for resistance governed by yield,

$$\gamma_{m0} = 1.1$$

Partial factor of safety for resistance governed by ultimate stress,

$$\gamma_{m1} = 1.25$$

Partial factor of safety for bolt material,

$$\gamma_{mb} = 1.25$$

Here bearing strength of bolt also needs to be determined which involves the factor k_b which infact depends on pitch. But pitch at this stage is not known. Thus assume $k_b = 1$

In general bearing strength of bolt is greater than shear strength of bolt and thus shear strength of bolt decides the strength of joint.

In lap joint, bolts are in single shear.

∴ Shear strength of bolt in single shear

$$V_{dsb} = \frac{A_{nb} f_{ub}}{\sqrt{3}\,\gamma_{mb}} = \frac{245 \times 400}{\sqrt{3} \times 1.25} \text{N} = 45.26 \text{ kN}$$

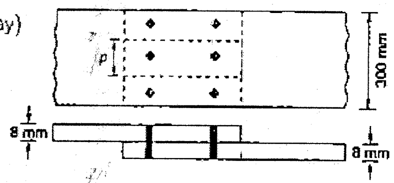
∴ No. of bolts required $= \frac{240}{45.26} = 5.3 \approx 6$(say)

These six bolts are arranged as shown in figure.

In this arrangement, per pitch there are two bolts.

∴ Per pitch shear strength of joint = 2 × 45.26 kN

= 90.52 kN



Per pitch tensile strength of plate, $T_{dn} = \frac{0.9 A_{nb} f_u}{\gamma_{m1}} = \frac{0.9 f_u}{\gamma_{m1}}(p - d_0)t$

Equating tensile strenght of plate per pitch with shear strength of joint give the required pitch. This pitch is needed to compute the bearing strength of bolt.

$$\therefore \quad \frac{0.9 f_u}{\gamma_{m1}}(p - d_0)t = 90.52 \times 10^3$$

$$\Rightarrow \quad \frac{0.9 \times 410}{1.25}(p - 22)8 = 90.52 \times 10^3$$

⇒ $p = 60.33$ mm

But $p > 2.5d = 2.5 \times 20 = 50$ mm

Thus adopt $p = 65$ mm

Thus available edge distance (e)

$$= \frac{300 - 2p}{2} = \frac{300 - 2 \times 65}{2} = 85 \text{ mm}$$

$$\therefore \quad k_b = \text{minimum of} \begin{cases} \dfrac{e}{3d_0} = \dfrac{85}{3 \times 22} = 1.288 \\ \dfrac{p}{3d_0} - 0.25 = \dfrac{65}{3 \times 22} - 0.25 = 0.735 \\ \dfrac{f_{ub}}{f_u} = \dfrac{400}{410} = 0.976 \\ 1.0 \end{cases}$$

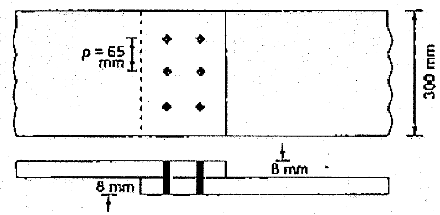
∴ Bearing strength of bolt,

$$V_{dpb} = 2.5 k_b \frac{dt f_u}{\gamma_{mb}} = 2.5 \times 0.735 \times 20 \times 8 \times \frac{410}{1.25} \text{ N}$$

$= 96.43$ kN

> 45.26 kN ($= V_{dsb}$)

Now since strength of joint is minimum of shear strength of bolt, bearing strength of bolt and tensile strength of plate. But pitch is detemined by equating shear strength of bolt with tensile strength of plate and bearing strength of bolt comes out to be greater than shear strength of bolt and thus bearing strength of bolt in this case will not affect the design.



Example 2.5 Design a diamond pattern double cover butt joint to join two plates of size 210 × 10 mm each with 20 mm diameter bolts of grade 4.6. The plates are required to carry a factored tensile load of 435 kN. Use steel of grade Fe 410.

Solution:

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

For bolt of grade 4.6, $f_{ub} = 400$ N/mm², $f_y = 240$ N/mm²

Net tensile area of 20 mm dia. bolts

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

Dia. of bolt hole for 20 mm dia. bolt

$$d_0 = 22 \text{ mm}$$

∵ Double cover bolt joint is required

∴ Bolt will be in double shear

∴ Shear strength of bolt in double shear

$$V_{dsb} = \frac{2 \times f_{ub} A_{nb}}{\sqrt{3}\gamma_{mb}} = \frac{2 \times 400 \times 245}{\sqrt{3} \times 1.25} \text{ N} = 90.53 \text{ kN}$$

Bearing strength of bolt, $V_{dpb} = 2.5 k_b \dfrac{dt f_u}{\gamma_{mb}}$

Minimum edge distance for 20 mm dia. bolt (e) = 33 mm

Minimum pitch = 2.5d = 2.5 × 20 = 50 mm

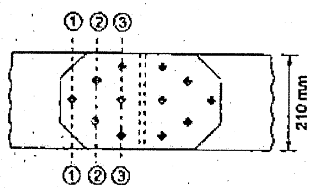
Let pitch (p) = 55 mm

$$\therefore \quad k_b = \text{Minimum of} \begin{cases} \dfrac{e}{3d_0} = \dfrac{33}{3\times 22} = 0.5 \\ \dfrac{p}{3d_0} - 0.25 = \dfrac{55}{3\times 22} - 0.25 = 0.833 \\ \dfrac{f_{ub}}{f_u} = \dfrac{400}{410} = 0.976 \\ 1.0 \end{cases} = 0.5$$

$$\therefore \quad V_{dpb} = 2.5 k_b \frac{dtf_u}{\gamma_{mb}} = 2.5\times 0.5\times 20\times 10\times \frac{410}{1.25}\ \text{N} = 82\text{kN}$$

Thus strength of bolt = Minimum of V_{dsb} and V_{dpb}
= 82 kN

$\therefore$ No. of bolts required = $\dfrac{435}{82} = 5.3 \simeq 6$ (say)



Arrange bolts in diamond pattern as shown.

Assume the thickness of cover plate = 10 mm

Provide 10 mm thick cover plates for double cover butt joint.

At section (1)-(1), maximum force is there in main plate but at section (3)-(3), maximum force is there in the cover plates.

Thus section (3)-(3) is critical for cover plates and section (1)-(1) is critical for main plate

$\therefore$ Tensile strength of main plate,

$$T_{dn_1} = \frac{0.9A_nf_u}{\gamma_{m1}} = \frac{0.9f_u}{\gamma_{m1}}(b - 1\times d_0)t = \frac{0.9\times 410}{1.25}(210 - 1\times 22)10\ \text{N}$$

$= 554.98$ kN > 435 kN (OK)

Tensile strength of cover plate

$$T_{dn_2} = \frac{0.9A_nf_u}{\gamma_{m1}} = \frac{0.9\times 410}{1.25}\times(210 - 3\times 22)10\ \text{N}$$

$= 425.09$ kN < 435 kN (Unsafe)

$\therefore$ Revise thickness of cover plate to 12 mm

$$\therefore \quad T_{dn_2} = \frac{0.9A_nf_u}{\gamma_{m1}} = \frac{0.9\times 410(210 - 3\times 22)}{1.25}\times 12\ \text{N}$$

$= 510.11$ kN > 435 kN (OK)

Example 2.6 Two plates of thickness 20 mm and 12 mm are to be joined by a butt joint. The joint is required to transmit a factored load of 600 kN. Design the joint using 8 mm thick cover plates provided on both the sides of the plates. Use steel of grade Fe410 and 20 mm dia. bolts of grade 4.6.

Solution:

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

For bolt of grade 4.6, $f_{ub} = 400$ N/mm², $f_y = 240$ N/mm²

Partial factor of safety for resistance governed by yield

$\gamma_{m0} = 1.1$

Partial factor of safety for resistance governed by ultimate stress

$\gamma_{m1} = 1.25$

Partial factor of safety for bolt material,

$\gamma_{mb} = 1.25$

For 20 mm dia. bolt, dia of hole,

$d_0 = 22$ mm

For bearing, plate thickness

t = Minimum of 20 mm, 12 mm and (8 + 8) mm = 16 mm
= 12 mm

Since plates to be connected are of different thickness and thus packing plates will be required and double cover butt joint is provide.

Thickness of packing plate required,

$t_{pkg} = 20 - 12 = 8$ mm > 6 mm

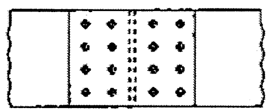
Now since thickness of packing plate exceeds 6 mm and thus shear strength of bolt has to be reduced by a factor β_{pkg} given by

$\beta_{pkg} = 1 - 0.0125\, t_{pkg}$
$= 1 - 0.0125 \times 8 = 0.9$

Shear strength of bolt in double shear

$$V_{dsb} = \frac{2A_{nb}f_{ub}}{\sqrt{3}\gamma_{mb}}\beta_{pkg} = \frac{2\times 245\times 400}{\sqrt{3}\times 1.25}\times 0.9\ \text{N} = 81.48\ \text{kN}$$

$\therefore$ No. of bolts required = $\dfrac{600}{81.48} = 7.4 \simeq 8$ bolts (say)



Provide these 8 bolts in two rows.

Thus per pitch, there will be two bolts.

$\therefore$ Per pitch shear strength of joint = 2 × 81.48 = 162.96 kN

Now since pitch is not known at this stage and thus equate per pitch shear strength of joint with net tensile strength of plate to obtain the pitch (p)

$$\therefore \text{ Tensile strength of plate } T_{dn} = \frac{0.9A_nf_u}{\gamma_{m1}} = \frac{0.9\times 410}{1.25}(p - 22)\times 12\ \text{N}$$

$$\text{Thus} \quad \frac{0.9\times 410}{1.25}(p - 22)12 = 162.96\times 10^3$$

$\Rightarrow$ $p = 68$ mm
$\not< 2.5d = 2.5 \times 20 = 50$ mm (OK)

$\therefore$ Provide pitch (p) = 70 mm

$$\therefore \quad k_b = \text{Minimum of} \begin{cases} \dfrac{e}{3d_0} = \dfrac{33}{3\times 22} = 0.5 \\ \dfrac{p}{3d_0} - 0.25 = \dfrac{70}{3\times 22} - 0.25 = 0.811 \\ \dfrac{f_{ub}}{f_u} = \dfrac{400}{410} = 0.976 \\ 1.0 \end{cases} = 0.5$$

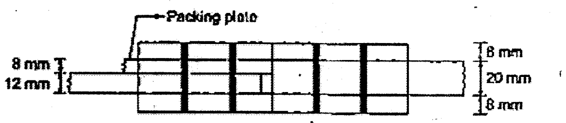
$\therefore$ Per pitch bearing strength of bolt

$$V_{dpb} = 2.5 k_b dt \frac{f_u}{\gamma_{mb}} = 2.5 \times 0.5 \times 20 \times 12 \times \frac{410}{1.25} \text{ N}$$

$$= 98.4 \text{ kN}$$

$$> 81.48 \text{ kN } (= V_{dsb})$$

Thus design need not to be revised since bearing strength of bolt is greater than the shear strength of bolt.



Objective Brain Teasers

Q.1 The value of γ_{mb} for bolt material is
(a) 1.1 (b) 1.0
(c) 1.5 (d) 1.25

Q.2 Slip resistant connections at ultimate loads may behave as
(a) slip critical connection
(b) pin connection
(c) bearing type connection
(d) cannot be said with certainty

Q.3 Slip critical connections are designed for
(a) Bearing between the connecting member and bolt
(b) Friction between the connecting members
(c) Compression in bolts
(d) Shear in bolts

Q.4 When a bolt is subjected to combined tension and shear then

(a) $\left(\dfrac{V_{sb}}{V_{db}}\right)^2 + \left(\dfrac{T_b}{T_{db}}\right)^2 \le 1$

(b) $\left(\dfrac{U_{sb}}{V_{db}}\right)^{1.4} + \left(\dfrac{T_b}{T_{db}}\right)^{1.4} \le 1$

(c) $\left(\dfrac{V_{sb}}{V_{db}}\right) + \left(\dfrac{T_b}{T_{db}}\right) \le 1.4$

(d) $\left(\dfrac{V_{sb}}{V_{dsb}}\right)^2 + \left(\dfrac{T_b}{T_{db}}\right)^2 \le 1.4$

Q.5 Which of the following is primarily designed for flexure?
(a) Rivet (b) Bolt
(c) Pin (d) All of these

Q.6 Diamond pattern of bolting is beneficial over chain and staggered bolting because
(a) It transmits maximum force
(b) It has maximum efficiency
(c) It is easy to fabricate
(d) None of the above

Q.7 Which of the following has zero eccentricity with respect to load line?
(a) Single cover butt joint
(b) Double cover butt joint
(c) Lap joint
(d) Insufficient data

Q.8 Prying action is associated with
(a) additional compressive force on bolts due to flexibility of connecting members
(b) reduction in flexure force on bolts
(c) additional shear force on rivets
(d) additional tensile force on bolts due to flexibility of connecting members

Q.9 Which type of bolt hole is more preferable?
(a) Punched hole
(b) Drilled hole
(c) Both (a) and (b)
(d) It depends on nature of force to be transferred and bolt material

Q.10 HSFG bolts are better than ordinary black bolts because
(a) HSFG bolts have high fatigue strength
(b) HSFG bolts are easy to be used for fabrication
(c) HSFG bolts are cheaper than ordinary black bolts
(d) All of the above

Q.11 HSFG bolts can be used for
(a) slip resistant connection
(b) bearing type connection
(c) shear connection
(d) both (a) and (b)

Q.12 Hanger connection is a type of
(a) Compression connection
(b) Tension connection
(c) Shear connection
(d) None of these

Q.13 In which of the following connection, lesser load is transmitted through net section of the bolt?
(a) HSFG bolt (b) Ordinary bolt
(c) Pin (d) All of the above

Answers

1. (d)	2. (c)	3. (b)	4. (a)	5. (c)
6. (b)	7. (b)	8. (d)	9. (b)	10. (a)
11. (d)	12. (b)	13. (a)		

Conventional Practice Questions

Q.1 A column ISHB 300 @ 577 N/m carries an axial compressive load of 3260 kN under working conditions. Design the connection of column section with gusset plates. Use Fe410 Steel.

Q.2 Design a lap joint to connect two plates 310 mm × 8 mm thick using 16 mm diameter bolts of grade 4.6. The load to be transferred through the plates is 350 kN at service conditions.

Q.3 Design a double cover butt joint to connect two plates one 10 mm thick and other 18 mm thick. Both the plates are 280 mm wide. The load to be transferred through the plates is 250 kN under working conditions.

Q.4 A portion of an industrial roof truss is shown in figure. The gusset plate to be used in 120 mm thick. Using 20 mm diameter bolts of grade 4.6, design the connection.