LECTURE NOTE

ON

STRUCTURAL DESIGN-II

FOR

DIPLOMA IN CIVIL ENGINEERING

(5TH SEMESTER STUDENTS)

AS PER SCTE&VT SYLLABUS

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1.1 Common Steel Structures

In early society, human beings lived in caves and almost certainly rested in the shade of trees. Gradually, they learnt to use naturally occurring materials such as stone, timber, mud & biomass to construct houses.

The principal modern building materials are masonry, concrete (mass, reinforced, and prestressed), glass, plastic, timber and structural steel.

The main advantages of structural steel are strength, speed of erection, pre-fabrication & demountability. Structural steel is used in load-bearing frames in buildings & as members in trusses, bridges & span frames.

Common Steel Structures are :—

i) Roof trusses for factories, cinema halls, auditoriums etc.

ii) Trussed bents, crane girders, columns etc. in industrial structures.

3) Roof trusses and columns to cover platforms in railway stations and bus stands.

4) Single layer or double layer domes for auditoriums, exhibition halls, indoor stadiums etc.

5) Plate girder & truss bridges for railways & roads.

6) Transmission towers for microwave & electric power.

7) Water tanks.

8) Chimneys etc.

Advantages & Disadvantages of steel structures

The advantages of steel over other materials for construction are :-

1) It has high strength per unit mass. Hence, even for large structures, the size of steel structural element is small, saving space in construction & improving aesthetic view.

2) It has assured quality & high durability

3) Speed of construction is another important advantage of steel structure. Since standard

sections of steel are available which can be pre-fabricated in the workshop/site, they may be kept ready by the time the site is ready & the structure erected as soon as possible. Hence there is a lot of saving in construction time.

4) Steel structures can be strengthened at any later time, if necessary. It needs just welding ~~adding~~ additional sections.

5) By using bolted connections, steel structures can be easily dismantled & transported to other sites quickly.

6) If joints are taken care, it is the best water & gas resistant structure.

7) Material is reusable.

↳ The disadvantages of steel structures are:—

1) It is susceptible to corrosion.

2) Maintainance cost is high, since it needs painting to prevent corrosion.

3) Steel members are costly.

1.2 Types of Steel

(i) ~~Carbon Steel~~ :- Steels is an alloy of carbon & iron. Apart from carbon, by adding small percentage of manganese, sulphur, phosphorous, chrome nickel & copper, special properties can be imparted to iron & a variety of steels can be produced, as follows —

(i) Carbon Steel :- Increased quantity of carbon & manganese imparts higher tensile strength & yield properties but lower ductility, which is more difficult to weld. Their yield strength varies from 230 to 300 MPa.

(ii) High-Strength Carbon Steel :- Such steel has a high carbon content & hence shows reduced ductility, toughness & weldability. This steel is specified for structures such as transmission lines & microwave towers. Their yield strength varies from 350 to 400 MPa.

(iii) High-strength, quenched & tempered steel :- These steels are heat treated to develop high strength. Though they are tough & weldable, they require special welding techniques. Their yield strength varies from 550 to 700 MPa.

(iv) Weathering steels :- These are low-alloy atmospheric corrosion-resistant steels, which are often left unpainted. They have yield strength of about 350 MPa.

(v) Stainless steels :- These are essentially low-carbon steel's to which chromium & nickel are added. It improves resistance to high temperature also.

(vi) Fire resistant steel :- These are also called TMT (Thermo-mechanically treated) steels. They perform better than ordinary steel under fire.

Structural steel may be mainly classified as mild steel and high tensile steel. Structural steel is also known as standard quality steel.

Structural steel other than those specified as mild steel & high tensile steel conforming to weldable quality may also be used provided the permissible stress & other design provisions are suitably modified.

Properties of Structural Steel

The properties of steel required for engg. design may be classified as :—

(i) Physical properties.

(ii) Mechanical properties.

(i) Physical properties :-

(a) Unit mass of steel, $\rho = 7850 \ kg/m^3$.

(b) Modulus of elasticity, $E = 2.0 \times 10^5 \ N/mm^2$

(c) Poisson's ratio, $\mu = 0.3$.

(d) Modulus of rigidity, $G = 0.769 \times 10^5$ N/mm^2.

(e) Coefficient of thermal expansion, $\alpha_t = 12 \times 10^{-6}$ /°C

(ii) Mechanical properties:—

(a) Yield stress (f_y)

(b) Ultimate stress (f_u).

1.3 Rolled Steel Sections:—

The largest categories of standard shapes of structural steel include those produced by hot rolling. In this process, molten steel is taken from furnace & poured into a continuous casting system where the steel solidifies, but it never allows to ~~cco~~ cool completely.

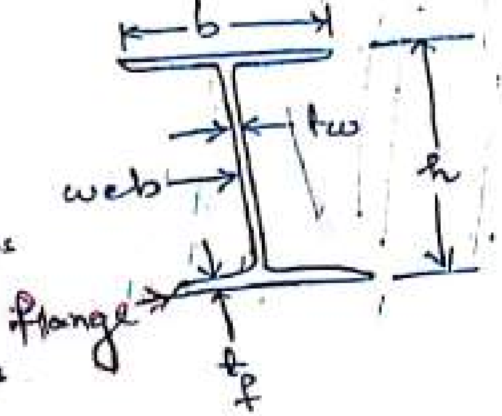
The hot steel passes through a series of rollers that squeeze the material into the desired cross-sectional shapes. Rolling the steel when it is still hot allows it to deform without any loss of ductility.

During ~~rolling~~ rolling process, the member increases in length & is cut to standard lengths, which are subsequently cut to the length required for a particular structure.

Cross-sections of some of more commonly used hot rolled shapes are listed below:—

(i) Rolled Steel I-sections (Beam sections)

The following five series of rolled steel I-sections are manufactured in India:—



(a) Indian Standard Junior Beams (ISJB).

(b) Indian Standard Light Beams (ISLB).

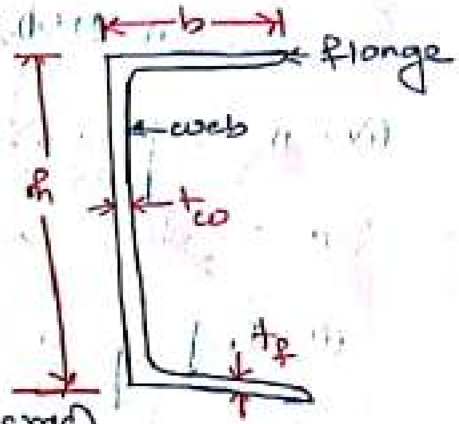
(c) Indian standard medium Beams (ISMB)

(d) Indian standard wide-flanged Beams (ISWB)

(e) Indian standard heavy beams (ISHB).

(ii) Rolled steel Channel section:

These are classified in following four series:—



(a) Indian standard Junior channel (ISJC)

(b) I.S. Light channel (ISLC)

(c) " Medium weight channel (ISMC)

(d) " Special channel (ISSC).

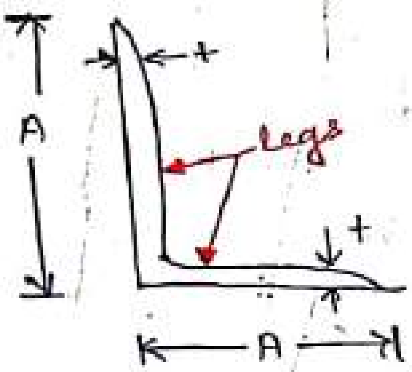
b = width
h = depth.

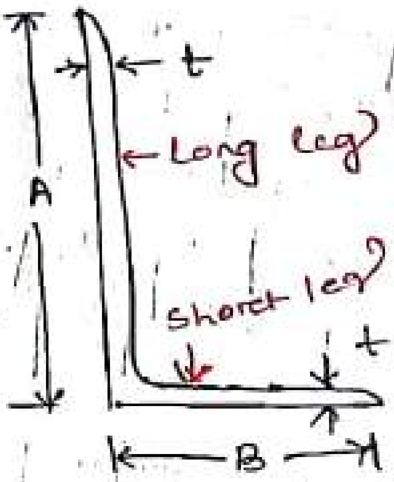
(iii) Rolled Steel Angle Sections

These are classified into following two series:—

(a) Indian Standard Equal Angle - ISA

(b) " " Unequal " - ISA.





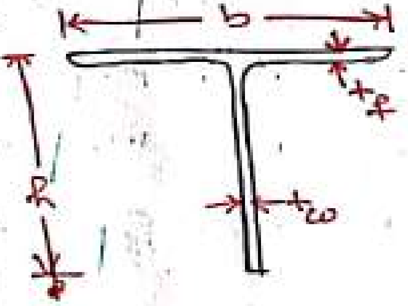
Thickness of legs of equal and unequal angles are same. They are designated by their series name ISA followed by length & thickness of legs. for eg:-

ISA 150 150 ; 12mm thick or ISA 150×150×12

ISA 150,115 , 10 mm thick or ISA 150×115×10

(iv) <u>Rolled Steel Tee Sections</u> :-

• It is available in following five series :-



(a) Indian Standard normal Tee bars (ISNT)

(b) I.S. Heavy flanged Tee ~~beam~~ bars (ISHT)

(c) I.S. Special legged Tee bars (ISLT)

(d) " Light Tee bars (ISLT)

(e) " Junior Tee bars (ISJT)

(v) <u>Rolled Steel Bars</u> :-

These are classified into following 2 series :-

(a) Indian Standard Round bars - ISRO

(b) " " Square bars - ISSQ.

Special Considerations in steel design

Following special considerations are required in steel design.

1) **Size and Shape:-** Steel is manufactured in steel mills and is available in certain shapes and sizes. Hence, the members of a steel structure should be designed to consist of any of the available sections or a combination of them.

2) **Buckling Consideration:-** The permissible load per unit area in steel is much higher as compared to permissible value in concrete. Therefore, for the same load, the cross sectional area of a steel member is smaller. As the member in a steel structure are more slender, the compression members in steel structure are liable to buckling.

3) **Minimum Thickness:-** Corrosion needs special consideration in steel design. If very thin sections are used, a small amount of corrosion may result into a large percentage reduction in effective area. Hence, design practice specify minimum thickness to be used in structural members. For the member directly exposed to weather

following minimum thickness is to be used :-

(a) If fully accessible for cleaning and painting - 6 mm.

(b) If not accessible for cleaning and painting - 8 mm.

(c) The above limitations do not apply for rolled steel sections, tubes and cold formed light gauge sections. However, IS 800-2007, has dropped the specification for minimum thickness.

4) <u>Need for design of connections</u> :- A steel design is not complete if following connections are not designed :-

(a) Connections between various standard sections selected for a member.

(b) Connection between various members like beam, column, foundations etc. of the structure.

Commonly used connections are :-

(a) Rivetted connection

(b) Bolted connection

(c) Welded connection

1.4 Loads and Load Combinations

The forces that act on a structure are called loads. For the safe design of a structure it is essential to have knowledge of various types of loads & their worst combinations to which it may be subjected during its life span.

Types of Loads

1) **Dead load** :- dead loads are examples of gravity loads. These are permanent loads & act vertically downward. For eg:- wt of structural elements like beams, columns, slabs etc.

2) **Live load** :- Live loads are those which may change in position and magnitude. For eg:- furniture, equipments & occupants of the structure. Some other examples of live loads are :- (a) impact load, (b) earth pressure, (c) water current load (d) Thermal loads, (e) blast loads.

(a) Impact load :- When a live load is applied suddenly on a member, it experiences impact, like vibration of movable loads.

(b) Earth pressure :- In design of structures below ground level, eg:- basement, sheet piles, retaining walls etc., the pressure exerted by soil must be considered.

(c) Water current load :- The force exerted due to water current on the piers, abutments & other structures inside water must be taken into consideration.

(d) Thermal forces :- Due to fluctuation in temperature, the structural members expand or contract & produce some loading effects in the member, provided the ends are restrained.

(e) Blast loads :- It is caused by explosions and military weapons etc.

3) Environmental loads :- These are the loads caused by environment in which a particular structure is located. Forces due to wind, earthquake, snow, rain, temperature changes are the example of environmental loads.

(a) Wind forces :- All exposed structures irrespective of their heights are affected by wind forces. As wind blows against a structure, its surface experiences the effect of wind force. The wind pressure intensity of a structure depends upon velocity & density of air, shape & height of the structure, topography of the surrounding ground surface & the angle of wind attack.

(b) Earthquake forces or Seismic forces :- When a structure is subjected to ground motions in an earthquake, it responds in a vibratory fashion. Earthquake shocks cause movement of foundation structures. There are two methods used for computing seismic forces:—

(i) Seismic coefficient method

(ii) Response spectrum method.

(c) Snow & Rain loads :— Snow load is considered for buildings located in regions where snow is likely to fall. Snow load & rain load act the vertically downwards & it is caused on the roof of a structure due to their accumulation.

(iv) Others

(a) Crane loads :— These loads include loads from cranes & other machines acting on the structure. The loads may be taken as per manufacturers or suppliers data.

(b) Dust load :— In areas prone to settlement of dust on roof (eg:- steel plants, cement plants) provision for dust load may be made.

(c) Erection load :— Prefabricated or precast members are subjected to different types of supports & different types of loads during erection compared to the types of supports & types of loads after erection.

(d) Accidental load :— Following accidental loads may be exerted on a structure :—

(i) Collision between vehicles, dropped objects

from cranes, lifts, etc.
(ii) Explosion of gas or boilers or dynamite
(iii) Fire.

Load Combinations

A judicious combination of the loads is necessary to ensure the required safety & economy in the design keeping in view the probability of
(a) their acting together
(b) their disposition in relation to other loads and severity of stresses or deformation caused by the combination of various loads.

The recommended load combinations by IS 875 are:—

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

DL = Dead load
WL = wind load
TL = Temperature load
IL = Imposed load
EL = Earthquake load

1·5 Structural Analysis & Design Philosophy

Structural analysis is necessary to find the internal forces developed in the members of the structures. The required internal forces for design are axial forces & moments. IS code permits following methods of analysis:

(a) Elastic Analysis :- It is based on the assumption that no fibre of the member had yielded for the design load and stress is linearly proportional to strain. The analysis may be in two stages:-

stage-I :- First order analysis :- It is based on the loads acting on underformed geometry of the structure.

stage-II :- Second order analysis : It is based on the deformed shape of the structure.

(b) Plastic Analysis :- In this method it is assumed that when every fibre at a section reaches yield stress plastic hinge is formed. After hinge is formed, it is assumed that the member rotates freely at the plastic hinge without resisting any additional moment. However, it resistance to moment remains constant.

(c) **Advanced analysis :—** For a frame with full lateral restraints, an advanced structural analysis may be carried out, provided the analysis can be shown to accurately model the actual behaviour of that class of frames. The analysis shall take followings into consideration :—

(i) Relevant material properties.
(ii) Residual stresses.
(iii) Geometric imperfections.
(iv) Reduction in stiffness due to axial compressions.
(v) Second order effects.
(vi) Erection procedures.
(vii) Interaction with foundations.

(d) **Dynamic Analysis :—** It is carried out for vibration & earthquake effect. The analysis is done in accordance with IS 1893 (part I).

Design Philosophy :—

The aim of design is to decide shape, size & connection details of the members so that the structure being designed will perform satisfactorily during its intended life. With an appropriate degree of safety the structure should :—

(a) Sustain all loads expected on it.
(b) Sustain deformations during and after construction.
(c) Should have adequate durability.
(d) Should have adequate resistance to fire.
(e) Should be stable and have alternate load paths to prevent overall collapse under accidental loads.

The design philosophies used are listed below:—

(i) Working stress Method (WSM)
(ii) Ultimate load design (ULD)
(iii) Limit state Design. (LSD).

1.6 Brief Review Of Principles of Limit State design.

→ A structure may become unfit for use not only when it collapses but also when it violates the serviceability requirements of deflections, vibrations, cracks due to fatigue, corrosion and fire.

→ In LSM, various limits are fixed to consider a structure as fit.

→ This design is based on both probable load and probable strength.

→ Thus philosophy of LSM design is to see that structure remains fit for use throughout it's designed life by remaining within the acceptable limit of safety and serviceability requirements.

(1) Design Requirements :-

(a) The structure should remain fit with adequate reliability & be able to sustain all loads.

(b) Have adequate durability under normal maintance.

(c) Donot suffer overall damage or collapse under any accidental events like explosion, fire etc

Limit States

→ Limit states are the states, beyond which the structure no longer satisfies the specified performance requirements.

→ It is of two types:—

(a) Limit state of strength

(b) Limit state of serviceability.

(a) Limit State of Strength:—

↳ It prescribes to avoid collapse of the structure which may endanger safety of life and property.

↳ It includes:—

(i) Loss of equilibrium of whole or part of the structure

(ii) Loss of stability of structures as a whole or part of it.

(iii) Brittle fracture.

(iv) Fracture due to fatigue.

(b) Limit State of Serviceability:—

It includes:—

(i) Deformation and deflections adversely affecting appearance or effective use of structure.

(ii) Vibrations in structures or any part of its component limiting its functional effectiveness.

(iii) Repairable damages or crack due to fatigue.

(iv) Corrosion

(v) Fire.

Q-10) Define ISA, ISMC, ISWB & ISMB (04)

Q-1) What do you mean by rolled steel sections - - - - - - - - - (02)

Q-2) What are the types of rolled steel sections available in the market - - - (02)

Q-3) Write down the advantages and disadvantages of steel structures - - - (05)

Q-4) Why load combination is necessary in design - - - - - - - - - (02)

Q-5) What are the types of loads considered in design - - - - - - (02)

Q-6) Write the difference between LSM & WSM (05)

Q-7) Define characteristic strength of & design strength of material - - - (02)

Q-8) Define structural steel - - - - - - (02)

Q-9) What are the limit states available? (05)

STRUCTURAL STEEL FASTENERS & CONNECTIONS

→ The various elements of a steel structure like beams, columns etc. are connected by fasteners or connectors.

→ The force exerted by one element on the other are transferred through these fasteners, which should therefore be adequate to transmit the forces safely.

→ (1) Different types of fasteners available in the design are :-

(a) Rivets
(b) Bolts
(c) welds
(d) Pins.

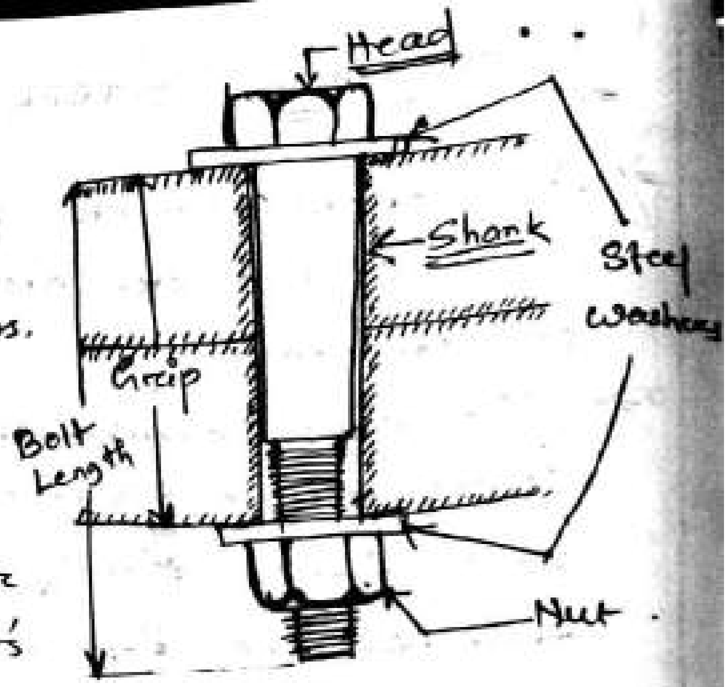
BOLTED CONNECTION

→ A bolt may be defined as a metal pin with a head at one end and a shank at the other end to threaded portion to receive a nut.

→ Steel washers are usually provided under the bolts as well as under the nut to distribute the clamping pressure on the bolted member.

→ The washer also prevents ~~foom~~ the threading to give large bearing pressure on the connecting members.

Advantages :-



(1) Making of joints using bolt is noiseless.

(2) Don't need skilled labourer.

(3) Needs less number of labourers for it's installation.

(4) These connections can be made quickly.

(5) Structure can be put to use immediately after connection.

(6) Alterations or changes in connection can be made easily if required.

(7) Area required for bolting is less.

Disadvantages :-

(1) Due to vibration, nuts are likely to loosen, endangering the safety of the structure.

(2) Gross area is reduced due to presence of bolt holes.

(3) Tensile strength is reduced considerably due to stress concentrations at the holes & due to reduction of area at the root of thread.

Classification of Bolt.

⇒ There are several types of bolts used to connect the structural elements like :-

(a) Unfinished bolts

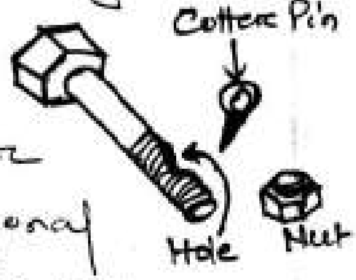
(b) Turned bolts

(c) Ribbed bolts

(d) High Strength bolts

(a) Unfinished Bolts :-

↳ These bolts are also called as ordinary, common, rough or black bolts. These are used for light structures & are not recommended for connection subjected to impact load, vibrations and fatigue.



↳ These bolts are made from low carbon, rolled steel, circular rod with square or hexagonal head, whereas ordinary bolts are made from mild steel.

↳ The bolt hole is punched 1.6 mm more than bolt diameter.

↳ Some times a hole is drilled in the bolt & a cotter pin is used to prevent the nut from turning on the bolt.

↳ As bolt hole is more than bolt dia. & as the shank is unfinished, they may not establish contact with connecting members.

(b) Turned Bolts

→ These are similar to unfinished bolts with the difference that the shank of these bolts are formed from a hexagonal rod.

⇒ These bolts have high shear and bearing resistance as compared to unfinished bolts.

(∗) They are also called as Finished bolts.

(c) Ribbed Bolts.

→ The heads of these bolts are round as like rivets and the other end is provided with threads and nut.

→ From the shank core, longitudinal ribs project making the diameter of the shank more than the diameter of the hole.

→ These ribs ~~cut~~ cut grooves into the connected members while tightening and ensures a tight fit.

→ Hence these bolts have more resistance to vibrations as compared to ordinary bolts.

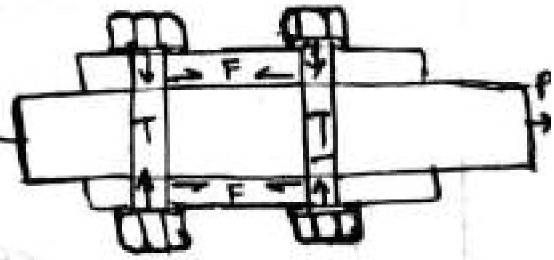
(d) **High Strength Bolts / High Strength Friction Grip bolts (HSFG Bolts):-**

→ In normal bolts, the force is transferred through the interlocking and bearing of bolts.

→ However, for HSFG bolts, this force is accompanied with friction between the interface of ~~bolt~~ washer and connecting members. Hence these are also known as friction type bolts.

→ The shank of the bolt don't allow slippage in the joint and hence such bolts can be used to connect members subjected to dynamic loads also.

→ These bolts are made from bars of medium carbon steel.



→ In HSFG bolts, the nut is tightened to develop a clamping force on the plates which is indicated as the tensile force T.

→ Horizontal frictional force F, is induced in the joints which is equal to tensile force T multiplied with coefficient of

7
2.1.

Friction μ i.e. $F = \mu T$

Advantages of HSFG bolts :-

(i) These provide a rigid joint & hence no slip takes place in the joint.

(ii) As load transfer is mainly by friction, the bolts are not subjected to shearing and bearing stresses.

(iii) Since nuts are prevented from loosening and stress concentration is avoided due to friction grip, they have high fatigue strength.

(iv) Smaller number of bolts are required.

Disadvantages of HSFG bolts :-

(i) Material cost is high

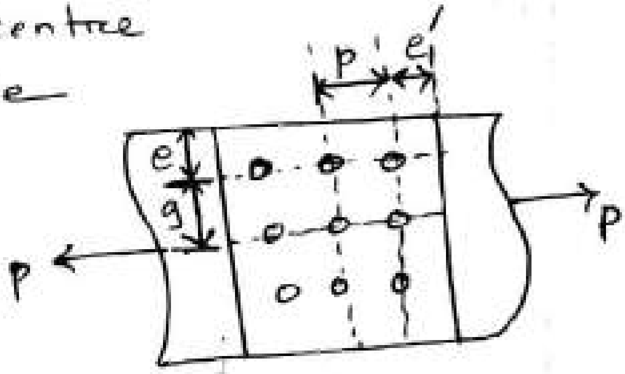
(ii) Special attention is given to workmanship especially to give them right amount of tension.

BOLTS

- Bearing Type (Unfinished / black bolts, Finished / Turned bolts & Ribbed bolts.
- Friction Type (HSFG bolts)

2.1.2 TERMINOLOGY

Pitch (P) :- It is the centre to centre spacing of the bolts in a row, are measured along the direction of load.

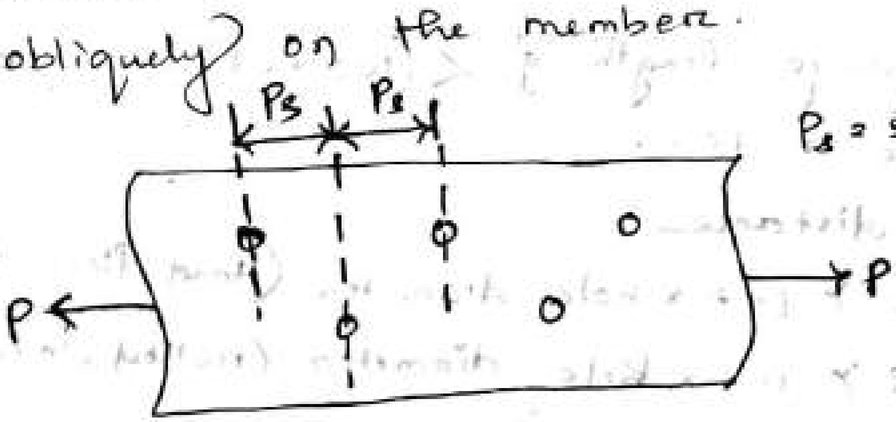


Gauge Distance (g) :- It is the distance between two consecutive bolts of adjacent rows and is measured at right angles to the direction of load.

Edge Distance (e) :- It is the distance of centre of bolt hole from adjacent edge of the plate measured at right angle to the direction of load.

End Distance (e') :- It is the distance of nearest bolt hole from end of the plate measured along the direction of load.

Staggered Distance :- It is the centre to centre distance of staggered bolts measured obliquely on the member.



P_s = staggered pitch

IS Specifications a/c to IS 800-2007

1) Pitch shall not be less than 2.5d, where d is the nominal diameter of bolts

2) Pitch shall not be more than
   (a) 16t or 200 mm whichever is less in case of tension member
   (b) 12t or 200mm, whichever is less in case of compression member.

   t = thickness of thinnest member.

3) In case of staggered pitch, pitch may be increased by 50% ~~spe~~ values as specified above, provided gauge distance is less than 75mm.

4) In case of butt joints maximum pitch is to be restricted to 4.5d for a distance of 1.5 times width of plate from butting surface.

5) The gauge length 'g' < (100+4t) or 200 whichever is less.

6) Edge distance
   e > 1.7 × hole diameter (Hand flame cut)
   e > 1.5 × hole diameter (rolled, machine flame cut).

(7) $e < 12t\varepsilon$, where $\varepsilon = \sqrt{\frac{250}{f_y}}$

t = thickness of thinner outer plate.

$e < (40+4t)$; t = thickness of thinner connecting plate, if exposed to corrosive influence.

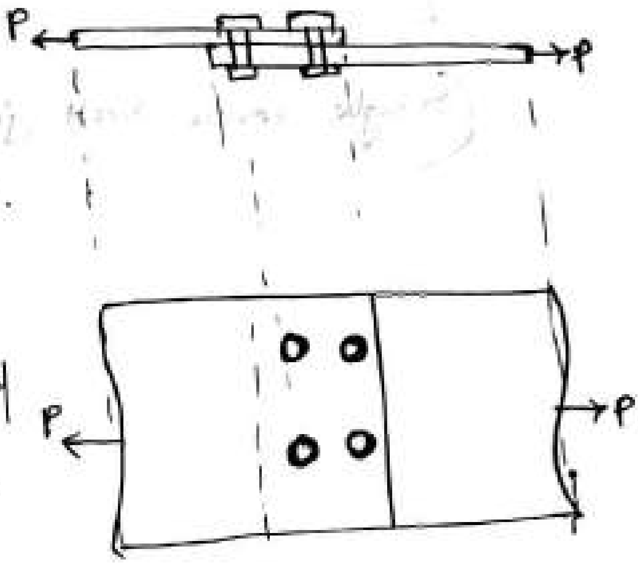
2.1.3 Types Of Bolted Connections

Bolted joints may be grouped into following types: —

(a) Lap joint

(b) Butt joint.

(a) Lap joint



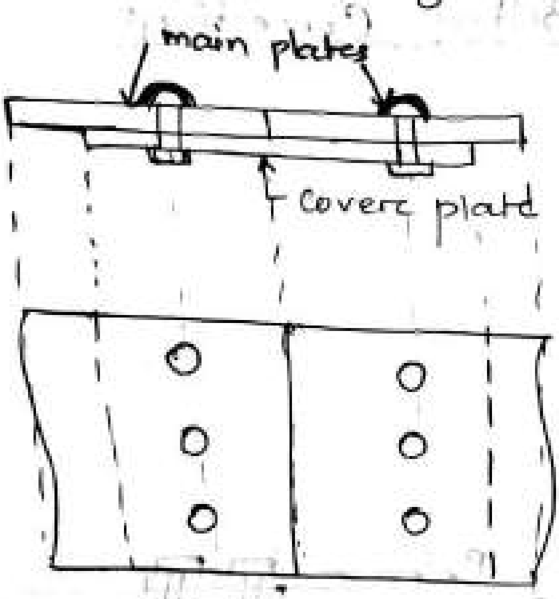
⇒ "It is the simplest type of joint."

⇒ In this, the plates to be connected are overlapped with one another.

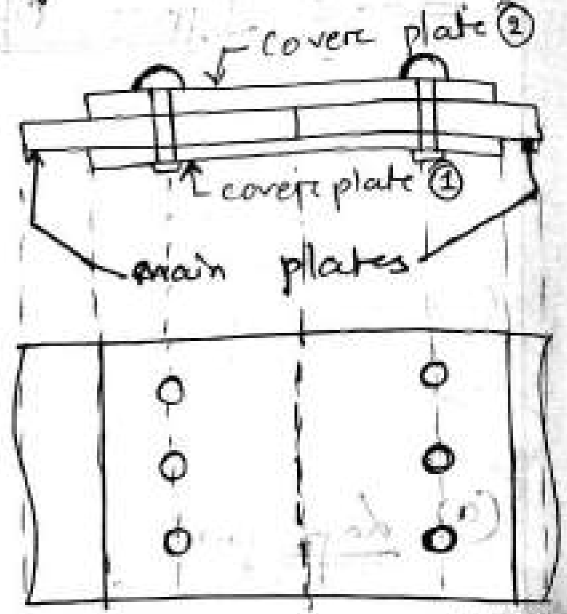
(b) Butt joint

⇒ In this type of connection, the two main plates to be connected are placed side by side & butting against each other..

→ The connection is made by providing a cover plate one one side or may be on both sides and connected to the main plate by bolting.



(Single cover butt joint)



(Double Cover butt joint).

2.1.4 Types of actions on fasteners

Depending upon the types of connections and loads, bolts are subjected to following types of actions :-

(a) Only one plane subjected to shear (single shear)

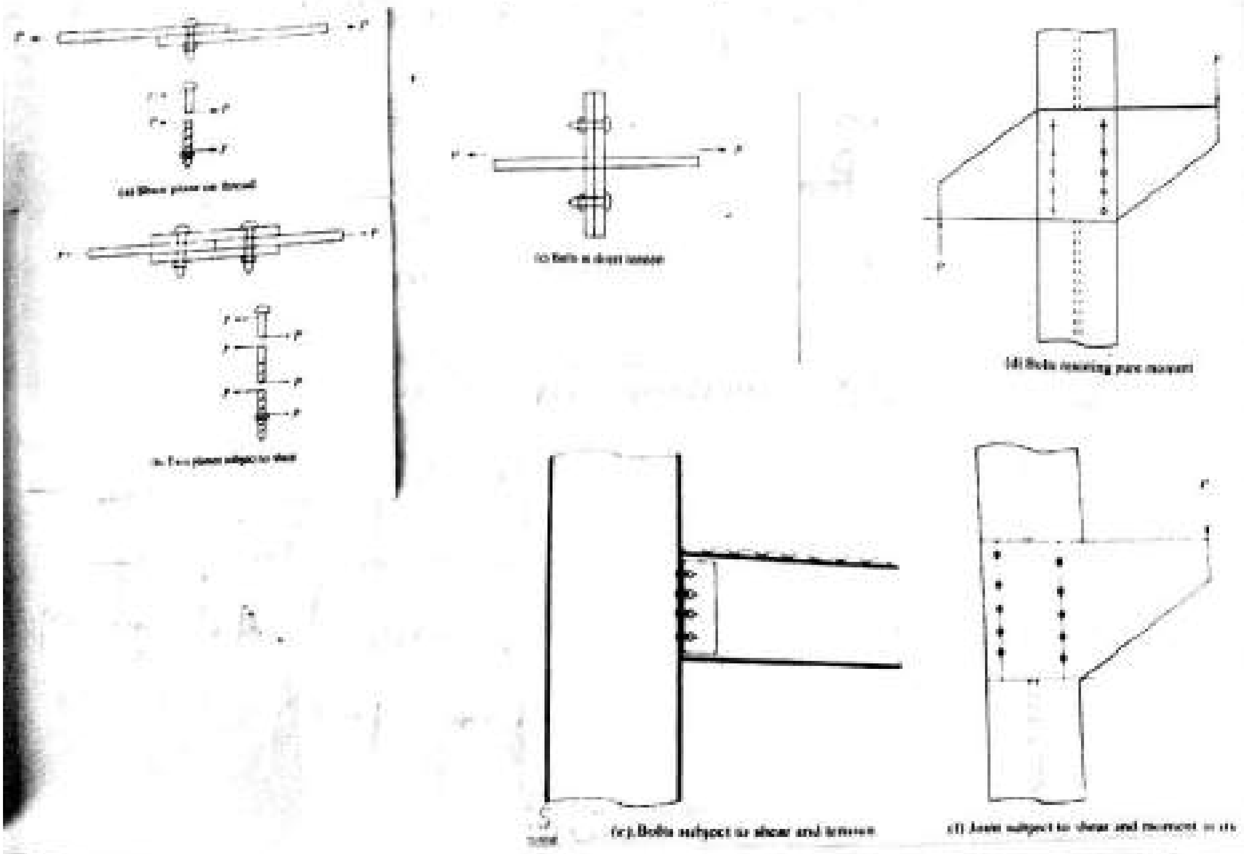
(b) Two planes subjected to shear (double shear)

(c) Pure tension

(d) Pure moment

(e) Shear & moments in the plane of connection

(f) Shear and tension.



2.1.4(b) ASSUMPTIONS IN DESIGN OF BEARING BOLTS

(1) Friction between the plates is negligible.
(2) The shear is uniform over the cross-section of the bolt.
(3) The distribution of stress on the plates between the bolt holes is uniform.
(4) Bolts in a group subjected to direct loads share the load equally.
(5) Bending stresses developed in the bolts are neglected.

Limitations :-

(1) Assumption-(1) is not correct, because the friction exists between the plates as they are held tightly by the bolts.

(2) Actual stress distribution in the plates are not uniform in working conditions. Stresses are very high near the bolt holes.

With the increase in load, the fibres near the holes start yielding & hence stresses ~~at are~~ start transferring to the whole member. At failure, stress distribution is uniform and all ~~members~~ part reaches to yield.

(3) The fourth assumption is questionable. Because the bolts far away from centre of gravity of bolt groups are subjected to more loads. But in a ultimate stage, when all bolts are about to fail, then bolts are found to be share load equally. Hence assumption-4 is not completely wrong.

2.1.4 (c) Principles of Designing bolted Connection

(1) The centre of gravity of bolts should coincide with the centre of gravity of the connected members.

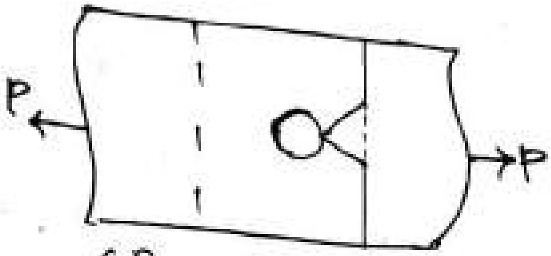
(2) The length of connection should be kept as small as possible.

2.1.5 (a) STRENGTH OF PLATES IN A JOINT

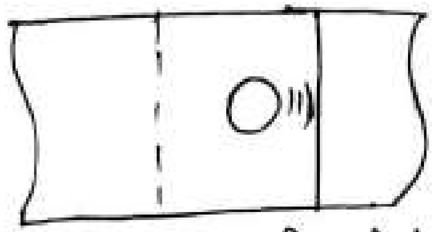
Plates in a joint made with bearing type bolts may fail under tensile force due to any of the following :—

1) Bursting or Shearing of edge
2) Crushing of Plates
3) Rupture of Plates.

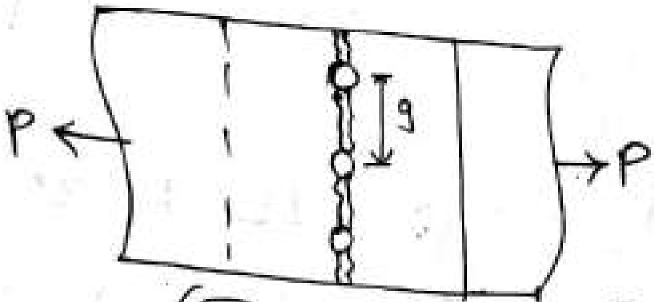
The ~~about~~ above failures are due to the disobeying of specifications like edge distance, end distance pitch & gauge.



(Bursting of plate)



(Crushing of plate)



(Rupture of Plate)

⇒ Hence to avoid these failure minimum distances are provided.

⇒ If minimum distances are ensured in a joint, then the design tensile strength of plate is ~~the~~ taken as the strength of thinnest member :—

i.e. $T_{dn} = \dfrac{0.9 A_n f_u}{\gamma_{m1}}$

T_{dn} : Strength of plate

γ_{m1} = Partial safety factor for failure at ultimate stress = 1.25

f_u = ultimate stress of material.

A_n = net effective area of plates at

critical sections & is given by :-

$$A_n = \left[b - nd_0 + \Sigma \frac{P_{si}^2}{4 g_i} \right] t$$

b = width of plate

t = thickness of thinner plate

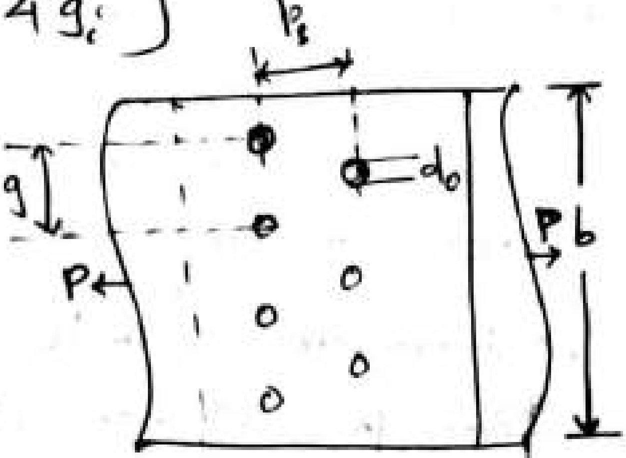
d_0 = diameter of bolt hole

g = gauge distance

P_s = staggered pitch
= 0 if staggering is not done.

n = number of bolt holes in critical section.

i = no. of legs connecting bolts obliquely.



when $P_{si} = 0$, $A_n = (b - nd_0) t$.

2.1.5 (b) Strength of Bearing type bolts

The design strength of bearing type of bolts are taken as the least of following :-

(i) Shear Capacity

(ii) Bearing Capacity.

(i) Shear Capacity :-

The failure of connections with bearing bolts in shear involves either bolt failure or the failure of connected plates.

⇒ The shearing of bolts can take place in the threaded portion of the bolts and so at the root area of threads. This area is taken as A_s i.e. shear area.

→ However, if it is ensured that the threads will not lie in the shear plane, then full area can be taken as shear area.

If V_{nsb} = nominal shear capacity of a bolt

then, $V_{nsb} = \frac{f_u}{\sqrt{3}}(n_n A_{nb} + n_s A_{sb})$

f_u = ultimate tensile strength of a bolt

n_n = no. of shear planes intersected by threads.

n_s = no. of shear plane without intersected by threads.

A_{sb} = nominal plain shank area of bolt $= \frac{\pi}{4}d^2$.

A_{nb} = net tensile area at threads & it may be taken as area corresponding to root diameter. $= 0.78 A_{sb}$

If V_{sb} = factored Shear force (external), then it should be $V_{sb} \leq \frac{V_{nsb}}{\gamma_{mb}}$

γ_{mb} = partial safety factor for bolt.

6 (ii) Bearing Capacity :-

- If the strength of connected plates are more than that of bolts, then the failure of bolt can take place by bearing of plates on the bolts.
- If plate material is weaker than that of bolt, then failure will occur by bearing of bolt on the plate & the hole will elongate.

If V_{npb} = bearing strength of bolt,

$$V_{npb} = 2.5\, d t f_u \cdot K_b \quad \left[K_b = \text{smaller of } \frac{e}{3d_0}, \frac{p}{3d_0} - 0.25, \frac{f_{ub}}{f_u}, \ldots\right]$$

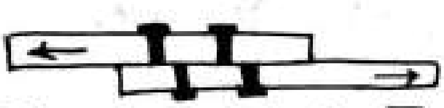
f_u = ultimate tensile stress of bolt

or " " " " plate

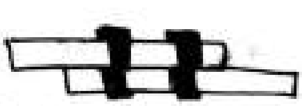
whichever is smaller

d = nominal diameter of the bolt.

t = summation of thicknesses of connected plates experiencing bearing stress.



[Shearing failure of bolts]

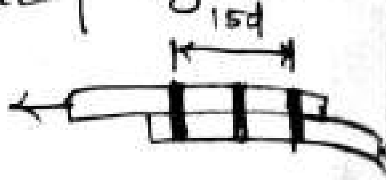


[Bearing failure of plate].

(Reduction factors for shear capacity) of Bolts :-

(i) Reduction factor for long joints (β_{lj})

↳ If the distance between first & last bolt in the joint measured in the direction of the load exceeds 15d, then the shear capacity & V_{db} shall be reduced by a factor β_{lj} i.e.



$$\beta_{lj} = 1.075 - 0.005 \frac{l_j}{d}.$$

$$0.75 \leq \beta_{lj} \leq 1.0.$$

d = nominal diameter of bolt.

(ii) Reduction factor if Grip length is large (β_{lg}).

↳ If the total thickness of the connected plates exceeds 5d (d = nominal diameter of bolts), then the design shear capacity V_{db}, shall be reduced by β_{lg} i.e.

$$\beta_{lg} = \frac{8d}{3d + l_g}.$$

l_g = grip length.
= total thickness of connected plate.

$l_g < 8d$.

(iii) Reduction factor if packing plates are used (β_{pk})

If packing plates of thickness more than 6mm are used in the joint, then the shear capacity shall be reduced by β_{pk} i.e.

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

t_{pk} = thickness of thicker packing plates.

So now, shear capacity of bolts can be written as :-

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

2.17 Efficiency of a joint

It is defined as the ratio of strength of joint to the strength of solid plate.

$$\eta = \frac{\text{Strength of joint}}{\text{Strength of Solid Plate}} \times 100$$

Bolt Grade

4.6 → 400 N/mm² ultimate & 60% of 400 N/mm² is yield strength

8.8 → 800 N/mm² " & 80% of 800 N/mm² " " "

12.9 → 1200 N/mm² " & 90% of 1200 N/mm² " " "

Other grades are 4.8, 5.6, 5.8, 6.8, 8.8, 9.8, 10.9 & 12.9.

& HSFG.