Design of Fasteners

A) Design of Screw Fasteners

Introduction

- A screw thread is formed by cutting a continuous helical groove on cylindrical surface.
- A continuous single helical groove is known as single threaded or single start.
- If second groove is cut into the space between the groove of first then it is double threaded or double start.
- Screw joint are formed by bolt and nut used for joining machine parts or for fastening, adjustment, assembly, inspection, replacement.

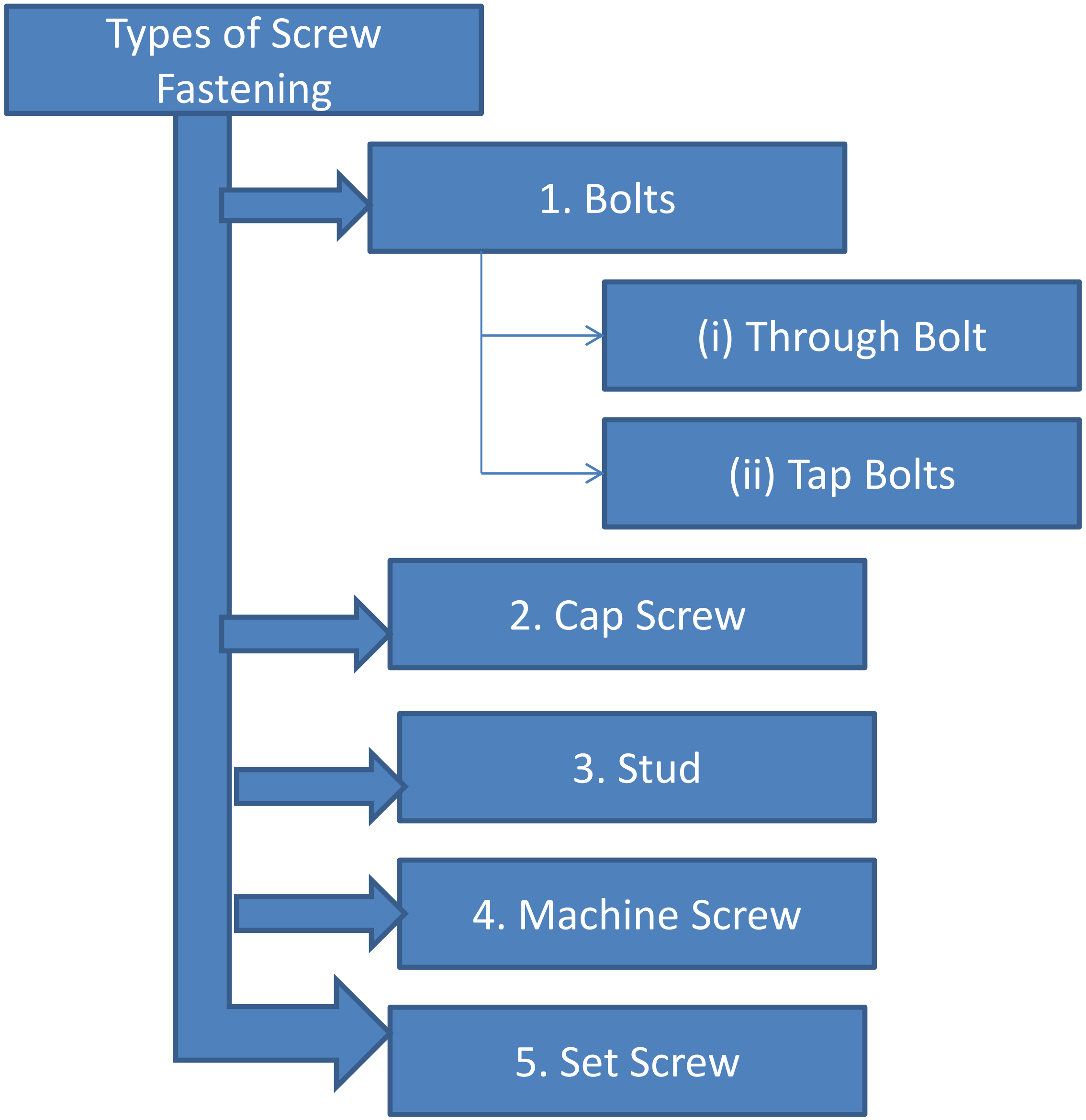
- **Advantages –**

1) These are convenient to assemble and disassemble.
2) Highly reliable in operation.
3) Screw joint are adopted in various operating conditions.
4) Screws are relatively cheap to produce due to standardization.

Disadvantages –

The main disadvantage of this joint is the stress concentration in the thread portion and strength is less than welded or riveted joint.

Types of Screw fastening



Types of Screw Fastening

- **Bolts -** They are basically threaded fasteners normally used with nuts.
- **Screws -** They engage either with a preformed or a self made internal threads.
- **Studs -**They are externally threaded headless fasteners. One end usually meets a tapped component and the other with a standard nut.
- **Tapping screws -**These are one piece fasteners which cut or form a mating thread when driven into a preformed hole. These allow rapid installation since nuts are not used.
- **Set Screws -**These are semi permanent fasteners which hold collars, pulleys, gears etc on a shaft. Different heads and point styles are available.

- Examples where screw joints are preferred over welded joint.

1) Assembly of crank shaft and connecting rod.
2) In braking system of an automobile because screw joints are convenient to assemble and disassemble and relatively cheap to produce due to standardization.

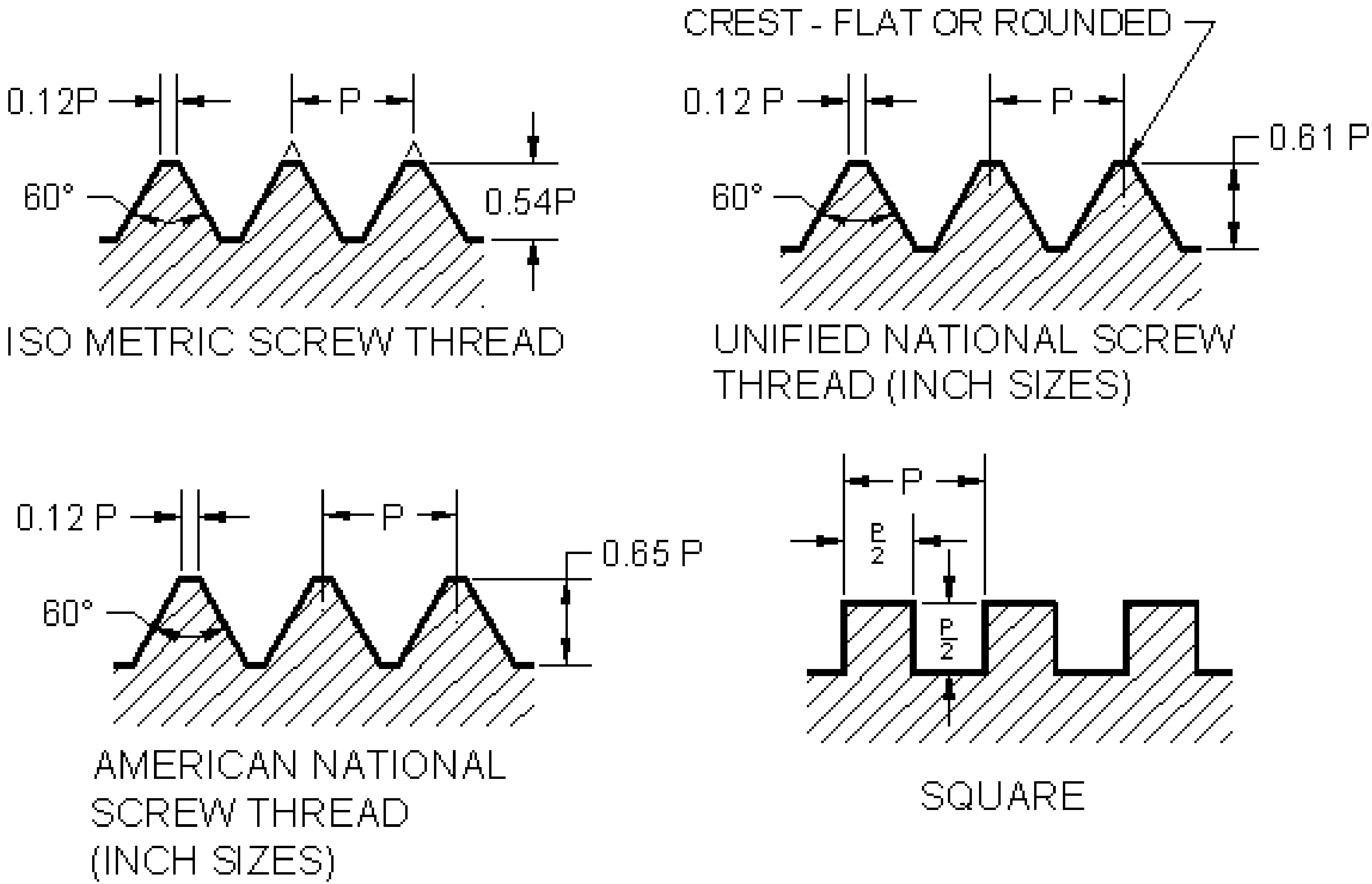
Advantages of V thread

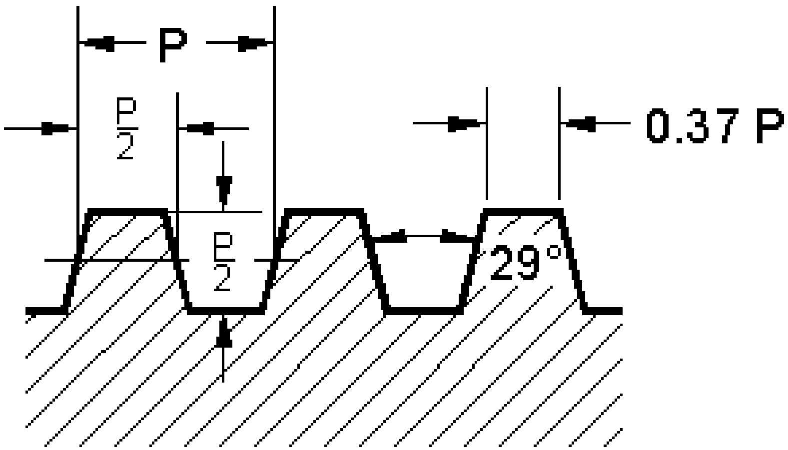
1) V threads offers greater frictional resistance of motion than square thread and are thus better suited for fastening purpose.
2) These are stronger than square thread.
3) These are cheaper because of easy to cut by die or on machine.
4) These are used to tighten the parts together in bolts, nuts, stud and nut, tap bolts etc. because they prevent the nut from slacking back due to high frictional resistance.

Disadvantages

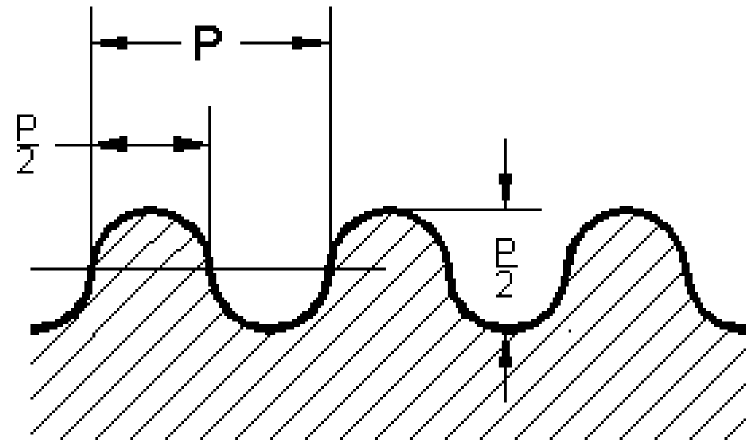
1) V threads are not suitable for power transmission.
2) They have a component of force which acts perpendicular to the axis causing bursting action on the nut and increasing friction.

Forms of Threads

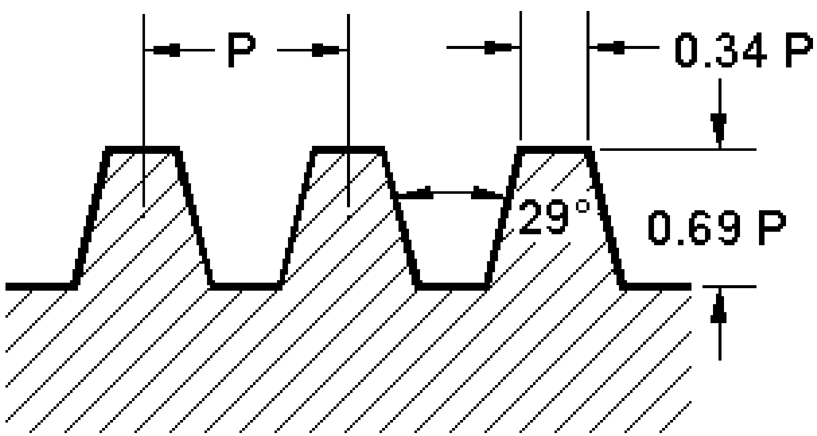




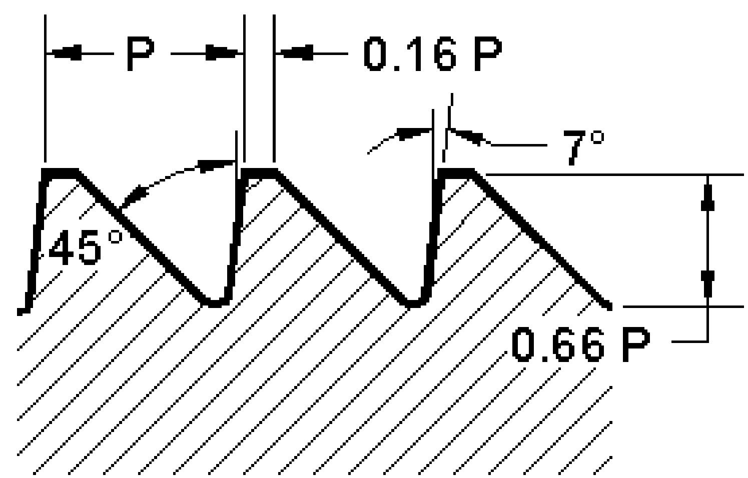
ACME



KNUCKLE

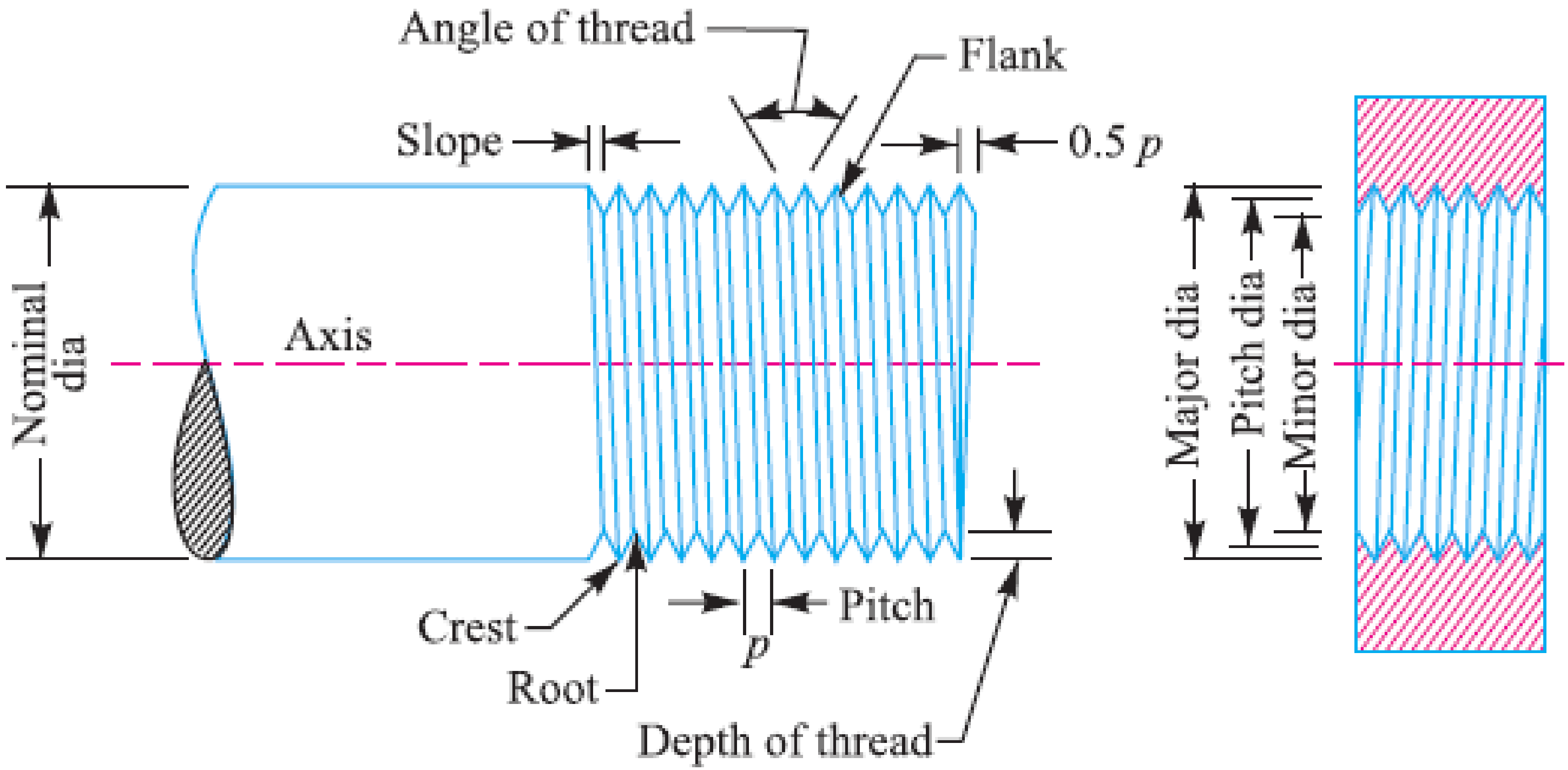


WORM



BUTTRESS

Terminology for Screw Threads



1. **Major diameter (d_o)-**

- It is the largest diameter of an external or internal screw thread.
- The screw is specified by this diameter. It is also known as outside or nominal diameter.

2. **Minor diameter (d_c)-**

- It is the smallest diameter of an external or internal screw thread.
- It is also known as core or root diameter.

3. Pitch diameter (d_p) –

- It is the diameter of an imaginary cylinder, on a cylindrical screw thread, the surface of which would pass through the thread at such points as to make equal the width of the thread and the width of the spaces between the threads.
- It is also called an **effective diameter.**

4. Pitch (p) -

- It is the distance from a point on one thread to the corresponding point on the next.
- This is measured in an axial direction between corresponding points in the same axial plane.

5. Lead -

- It is the distance between two corresponding points on the same helix.
- It may also be defined as the distance which a screw thread advances axially in one rotation of the nut.
- Lead is equal to the pitch in case of single start threads, it is twice the pitch in double start, thrice the pitch in triple start and so on.

6. Crest - It is the top surface of the thread.

7. **Root -** It is the bottom surface created by the two adjacent flanks of the thread.
8. **Depth of thread -** It is the perpendicular distance between the crest and root.
9. **Flank -** It is the surface joining the crest and root.
10. **Angle of thread -** It is the angle included by the flanks of the thread.
11. **Slope -** It is half the pitch of the thread.

Stresses in screw fastenings

- It is necessary to determine the stresses in screw fastening due to both static and dynamic loading in order to determine their dimensions. In order to design for static loading both initial tightening and external loadings need be known.

A) Initial tightening load

When a nut is tightened over a screw following stresses are induced:

(a) Tensile stresses due to stretching of the bolt

(b) Torsional shear stress due to frictional resistance at the threads.

(c) Shear stress across threads

(d) Compressive or crushing stress on the threads

(e) Bending stress if the surfaces under the bolt head or nut are not perfectly normal to the bolt axis.

a) Tensile Stress –

Since none of the above mentioned stresses can be accurately determined bolts are usually designed on the basis of direct tensile stress with a large factor of safety.

$$\sigma_t = \frac{P_i}{A} = \frac{2840\, d_o}{\frac{\pi}{4}\left(\frac{d + d_c}{2}\right)^2}$$

$$Where\, d = Mean\, diameter\ or\ pitch\ of\ screw$$

$$d_c = Core\, diameter = 0.84\, d_o$$

$$P_i = Initial\ tension\ in\ bolts$$

b) Torsional shear stress -

Due to twisting moment, the bolt is subjected to torsional shear stress.

$$\frac{T}{I_P} = \frac{\tau_s}{r} = \frac{G\theta}{l}$$

$$\tau_s = \frac{T}{I_P} \times r$$

$$\tau_s = \frac{T}{\frac{\pi}{32} \times d_c^3} \times \frac{d_c}{2} = \frac{16T}{\pi\, d_c^3}$$

$$\therefore T = \frac{\pi}{16} \times \tau_s \times d_c^3$$

$$Where\; I_P = Polar\; moment\; of\; inertia$$

$$T = Twisting\; torque$$

c) Shear stress across the threads -

$$The\,average\,shear\,stress\;for\,screw\,is$$

$$\tau_s = \frac{P}{\pi d_c b n}$$

$$The\,average\,shear\,stress\;for\,nut\,is$$

$$\tau_n = \frac{P}{\pi d_o b n}$$

$$d_o = no\min al\,diameter\;of\;nou$$

$$n = Number\,of\;thread\,in\,contact$$

$$b = width\,of\;thread\,at\,the\,root$$

d) Crushing stress on threads

The compression or crushing stress between the thread of screw nut is given by

$$\sigma_c = \sigma_{cr} = \frac{P}{\pi(d_o^2 - d_c^2)n}$$

e) Bending Stress

Let, X – difference in height between the extreme corner of the nut or head.

E – Modulus of elasticity

l – length of shank of the bolt

The bending stress induced in the shank of the bolt is given by

$$\sigma_b = \frac{XE}{2l}$$

2. Stresses due to external forces

a) Tensile stress –

$$\sigma_t = \frac{P}{\frac{\pi}{4} d_c^2} \quad d_c \; is \; found \; out$$

$$if \; n \; is \; the \; number \; of \; bolts \; then$$

$$\sigma_t = \frac{P}{\frac{\pi}{4} d_c^2 \times n}$$

$$d_o = 0.84 d_c$$

b) Shear Stress in bolt –

$$\tau_s = \frac{P}{\frac{\pi}{4} d_o^2 \times n}$$

c) Combine tension and shear stress

Maximum principal tensile sress

$$(\sigma_t)_{\max} = \frac{1}{2}[\sigma_t + \sqrt{\sigma_t^2 + 4\tau^2}]$$

Maximum shear stress

$$\tau_{\max} = \frac{1}{2}[\sqrt{\sigma_t^2 + 4\tau^2}]$$

3. Stress due to combine forces

- The resultant load on the bolt is

$$P = P_i + \left(\frac{a}{1+a}\right)P_2$$

$$\therefore P = P_i + kP_2$$

$$Where\, k = \left(\frac{a}{1+a}\right)$$

$$P_i = Initial\ tension\ due\ to\ tightening\ of\ bolts$$

$$P_2 = Extrnal\ load\ on\ the\ bolts$$

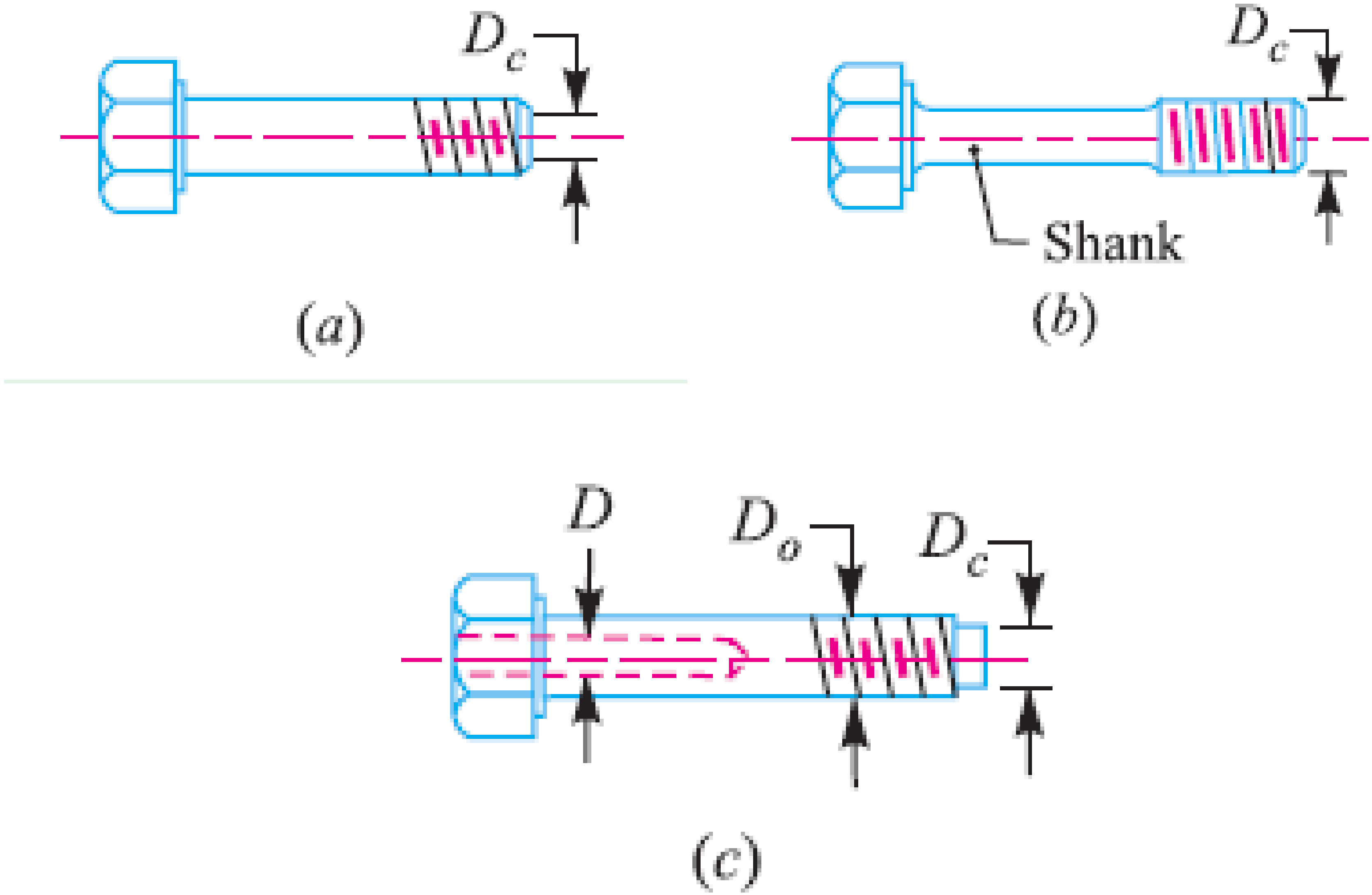
$$a = Ratio\ of\ elasticity\ of\ connected\ parts\ to\ the\ elsicity\ of\ bolt$$

Values of 'K'

Type of joint	$K = \dfrac{a}{1+a}$
Metal to metal joint with through bolts	0.00 to 0.10
Hard copper gasket with long through bolts	0.25 to 0.50
Soft copper gasket with long through bolts	0.50 to 0.75
Soft packing with through bolts	0.75 to 1.00
Soft packing with studs	1.00

Bolts with Uniform strength

- When a bolt is subjected to shock load. the In such cases the bolt is designed to absorb impact load and to resist the torque to prevent breakage of thread.
- In ordinary bolts, the effect of load concentration on the weakest part of the bolt i.e. The c/s area of the root of the thread.
- The stress in the threaded part will be more as compared to the shank hence the maximum portion of energy will be absorbed at the region of the threaded part which may fracture the threaded portion.


D_c
(a)
D_c
Shank
(b)
D
D_o
D_c
(c)

- If the diameter of shank of the bolt is turned to the core diameter of the thread, then the shank of the bolt will undergo a higher stress. This means that shank will absorb large portion of energy thus relieving the material at the threaded portion.
- The bolt in this way become stronger and lighter and it increases the impact load carrying capacity. This gives us bolts of uniform strength.

- Another method, an axial hole is drilled through the head of the bolt as far as threaded portion, such area of the shank become equal to the root area of the thread.

$$\frac{\pi}{4} D^2 = \frac{\pi}{4} (d_o^2 - d_c^2)$$

$$\therefore D = \sqrt{(d_o^2 - d_c^2)}$$

$$where, D = diameter\ of\ hole$$

$$d_o = outer\ diameter\ of\ thread$$

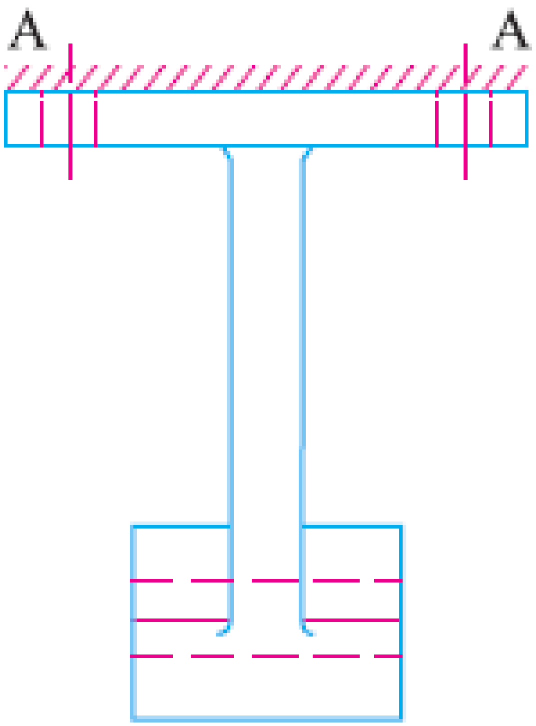
$$d_c = core\ diameter\ of\ thread$$

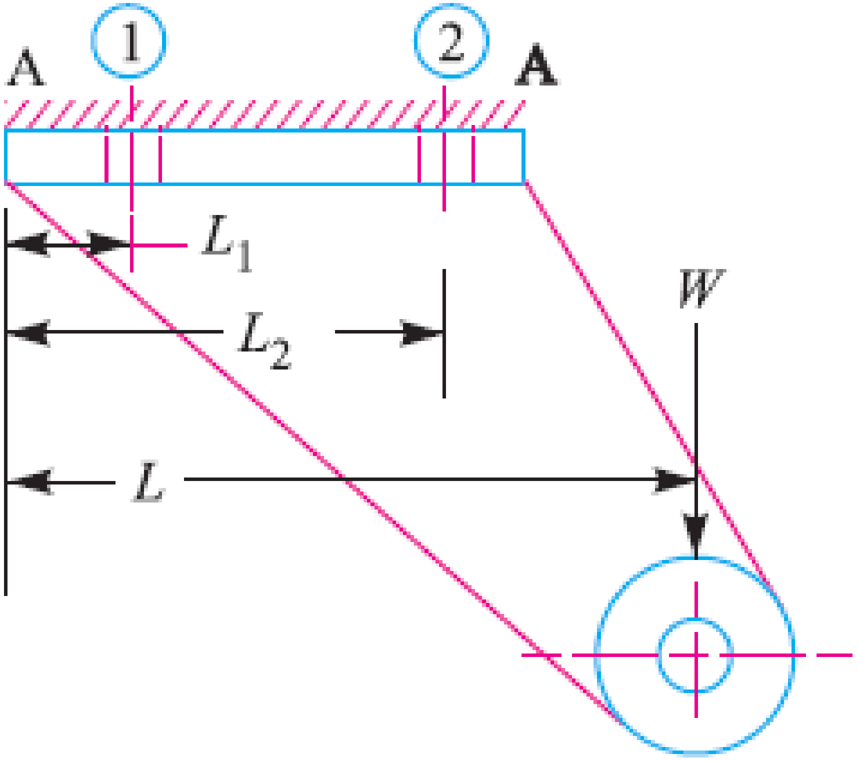
Design of bolted joint subjected to Eccentric Loading

- There are many application of the bolted joints which are subjected to eccentric loading such as machine foundation bolt, wall brackets, pillar crane, etc.

1) Parallel to the axis of bolts.
2) Perpendicular to the axis of bolts.
3) In the plane containing the bolts.

Eccentric load parallel to the axis of bolt





a) Each bolt is subjected to direct tensile load.

$$W_{td} = \frac{W}{n}$$

$$W_{td} = Direct\ tensile\ load$$

$$W = load\ acting\ on\ bracket$$

$$n = Number\ of\ bolts$$

b) Due to load W the bracket tends to rotate about edge A-A

Let w – load in a bolt per unit distance due to turning effect of the bracket

- W_1 & W_2 – load on bolt at a distance L_1 & L_2 from tilting edge.

Load on each bolt at distance L_1

$W_1 = w\ L_1$

Similarly, load on each bolt at distance L2

$W_2 = w\ L_2$

The moment of load W_1 about tilting edge

$$M_1 = W_1 L_1 = wL_1 \times L_1 = wL_1^2$$

- Similarly, the moment of load W_2 about tilting edge

$$M_2 = W_2 L_2 = wL_2 \times L_2 = wL_2^2$$

$$\therefore Total\ moment\ of\ load\ about\ tilting\ edge$$

$$M = M_1 + M_2 = 2[wL_1^2 + wL_2^2] - -(1)$$

$$The\ moment\ of\ the\ load\ W\ at\ a\ distance\ L,\ about\ tilting\ edge$$

$$M = WL - -(2)$$

Equating equation (1) and (2)

$$WL = 2[wL_1^2 + wL_2^2]$$

$$= 2w[L_1^2 + L_2^2]$$

$$\therefore w = \frac{WL}{2[L_1^2 + L_2^2]}$$

The bolts at distance L_2 *are most heavily loaded*

$\therefore$ *Tensile load on each bolt at distance* L_2

$$W_{t2} = W_2 = wL_2 = \frac{W\,L\,L_2}{2[L_1^2 + L_2^2]}$$

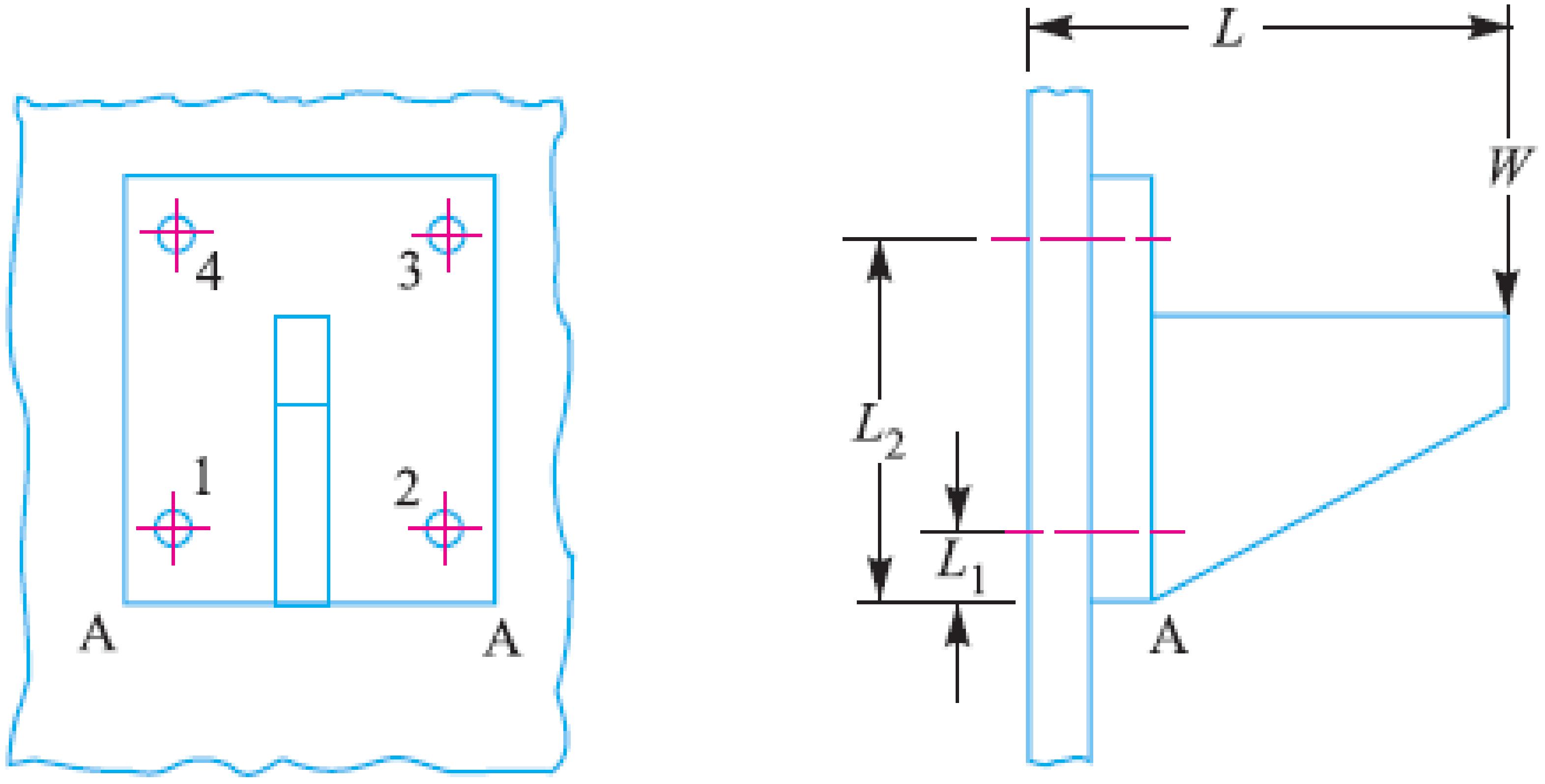
$\therefore$ *Total load on most heavily loaded bolts*

$$W_{Total} = W_t = W_{td} + W_{t2}$$

As the bolt subjected to tensile stress

$$\sigma_t = \frac{W_t}{\frac{\pi}{4} d_c^2}$$

Eccentric Load Acting Perpendicular to the Axis of Bolts



The bolts are subjected to two types of loads

1. Bolts are subjected to direct shearing load which are equally sheared by the bolts.

$$W_s = \frac{W}{n}$$

Where, W = load acting at a distance 'L'

n = number of bolts

2. The eccentric load (W) will try to tilt the bracket in clockwise direction about the tilting edge B-B.

Therefore maximum tensile load will be act on bolt at position 3 and 4 which are at a greater distance from the tilting edge.

Let, w = load in the bolt per unit distance due to turning effect of the bracket.

W_t= Tensile load each bolt at a distance L_1 from the tilting edge B-B.

$$\therefore W_{t1} = w L_1$$

$$Moment\ of\ this\ load\ about\ tilting\ edge$$

$$M_1 = W_{t1} \times L_1 = w L_1^2 \ ---(2)$$

$$As\ two\ bolts\ at\ a\ dist.\ L_1,\ hence$$

$$M_1 = 2 w L_1^2 ---(3)$$

- Similarly W_t will be the tensile load each bolt at a distance L_2 from the tilting edge B-B.

$$W_{t2} = w L_2$$

Moment of the load W_{t2} about tilting edge

$$M_2 = W_{t2} \times L_2 = w L_2^2$$

As the two bolts are at a dist. L_2, hence

$$M_2 = 2 w L_2^2 ----(4)$$

Total moment about tilting edge is

$$M = M_1 + M_2$$

$$M = 2 w L_1^2 + 2 w L_2^2$$

$$M = 2 w[L_1^2 + L_2^2]--(5)$$

The moment of bracket due to load (W)

at a dist. L is

$$M = W\,L \quad --(6)$$

Equating equation 5 & 6

$$W\,L = 2\,w[L_1^2 + L_2^2]$$

$$\therefore w = \frac{W\,L}{2[L_1^2 + L_2^2]}$$

$\therefore$ The maximum tensile load will be in a bolt 3 & 4

which are situated at a dist. L_2 from tilting edge.

$$\therefore W_{t2} = w\,L_2 = \frac{W\,L}{2[L_1^2 + L_2^2]} \times L_2$$

$$\therefore W_{t2} = \frac{W\,L\,L_2}{2[L_1^2 + L_2^2]} \quad ---(7)$$

$As\ the\ bolts\ are\ subjected\ to\ combile\ tensile$

$as\ well\ as\ shear\ load.$

$\therefore Equivalent\ tensile\ load\ (W_{te})$

$$W_{te} = \frac{1}{2}[W_{t2} + \sqrt{W_{t2}^2 + 4W_s^2}]$$

And

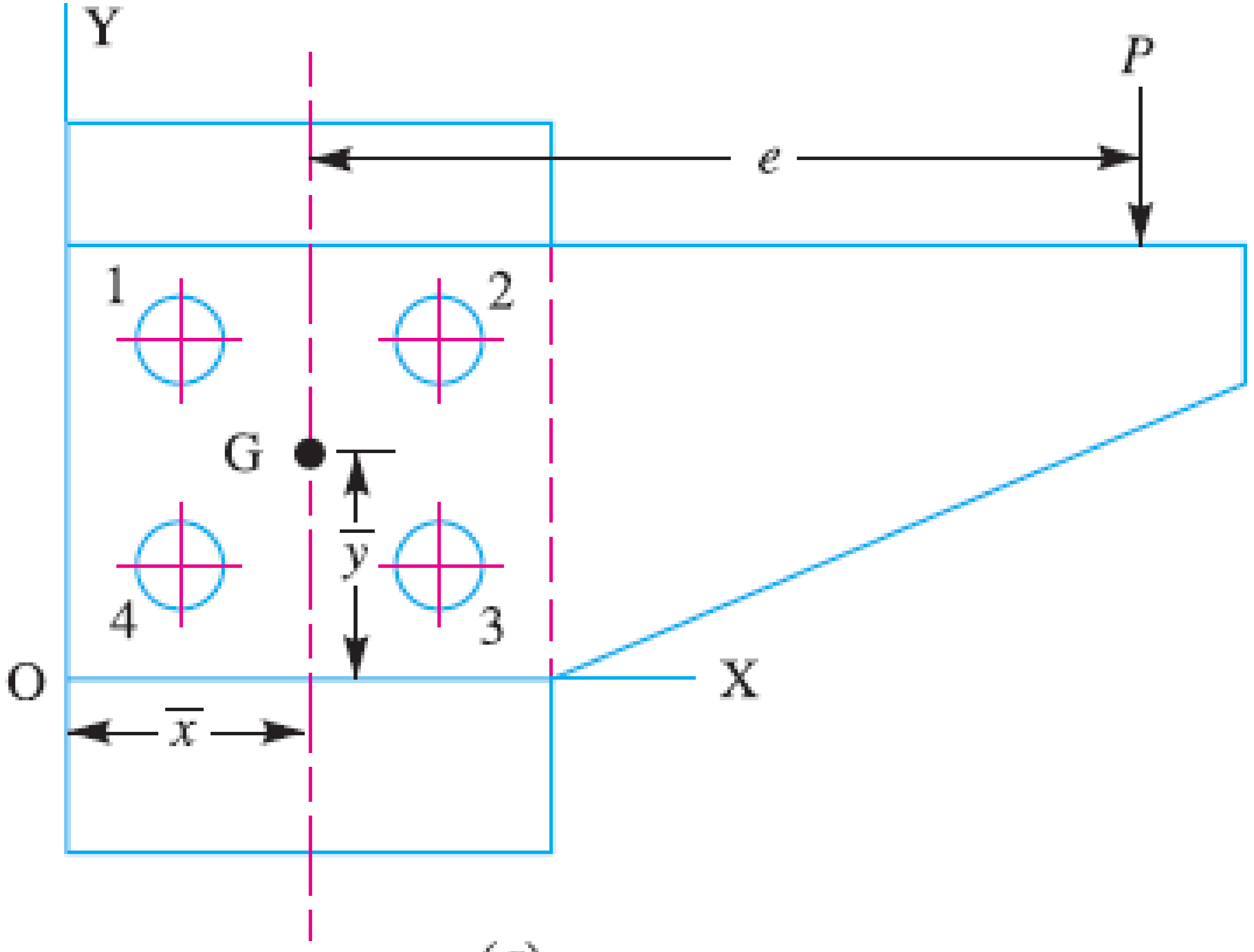
$Equivalent\ shear\ load\ (W_{se})$

$$W_{se} = \frac{1}{2}[\sqrt{W_{t2}^2 + 4W_s^2}]$$

- By knowing the equivalent load, the core diameter of the bolt is obtained.

$$\sigma_t = \frac{W_{te}}{\frac{\pi}{4} \times d_c^2}$$

Eccentric Load acting in the plane containing the Bolts



(a)

- In this case, the bolts are subjected to two types of load –

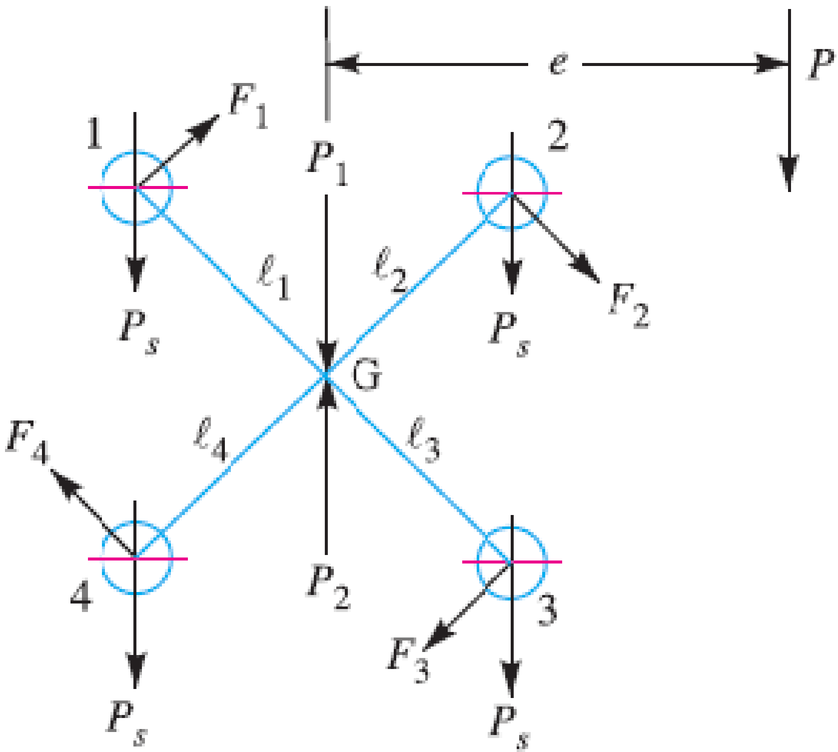
1. The Direct shear load (W_{sd}) –

$$W_{sd} = (W/n) \text{ ----- (a)}$$

2. The secondary shear load (W_{s2})

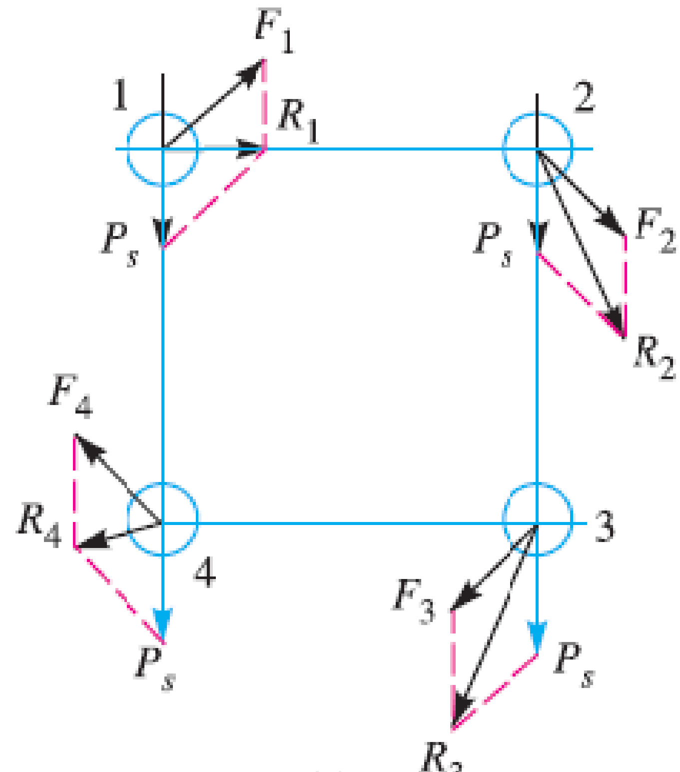
   a) This secondary load is perpendicular to line joining the centre of the bolt.

   b) This secondary load is perpendicular to the radial distance.



e
P
P_1
P_2
F_1
F_2
F_3
F_4
P_s
ℓ_1
ℓ_2
ℓ_3
ℓ_4
G
1
2
3
4

(b)



F_1
F_2
F_3
F_4
R_1
R_2
R_3
R_4
P_s
1
2
3
4

(c)

W_1, W_2, W_3, W_4 *are the* secondary *shear loads*

at a dist. l_1, l_2, l_3, l_4 *of bolt* 1,2,3,4 *from C.G.*

*As force is directly proportional to radial dis*tan*ce*

$$\frac{W_1}{l_1} = \frac{W_2}{l_2} = \frac{W_3}{l_3} = \frac{W_4}{l_4}$$

$$\therefore W_2 = W_1 \times \frac{l_2}{l_1}$$

$$W_3 = W_1 \times \frac{l_3}{l_1}$$

$$W_4 = W_1 \times \frac{l_4}{l_1}$$

- Sum of turning moment due to eccentric load and internal resisting moment of the bolt must be zero.

$$\therefore W \times e = W_1 l_1 + W_2 l_2 + W_3 l_3 + W_4 l_4$$

$$= W_1 l_1 + W_1 (\frac{l_2}{l_1}) l_2 + W_1 (\frac{l_3}{l_1}) l_3 + W_1 (\frac{l_4}{l_1}) l_4$$

$$= \frac{W_1}{l_1} [l_1^2 + l_2^2 + l_3^2 + l_4^2] \; ---(b)$$

$$From\, equation\, 'b' W_1\, is\, calculated$$

Calculate the resultant shear load

$$W_{SR} = \sqrt{W_{sd}^{2} + W_{s}^{2} + 2W_{sd}W_{s}\cos\theta}$$

Where, $\theta =$ *Angle between primary and secondary shear load*

$$Then, shear\ stress = \tau = \frac{W_{SR}}{\frac{\pi}{4} \times d_c^{2}}$$

find d_c *and*

$$d_o = \frac{0.84}{d_c}$$

Problems

B) Design of Welded Joints

Welded Joints

- Welding is a process of joining two similar metal by heating with or without application of pressure and filler materials.
- Welded joint can be used an alternatively to riveted joint.

Advantages

1) The welded structure are usually lighter than riveted structure because in welding, gussets and other connecting component are not used.
2) Weld joint provide maximum efficiency which is not possible by riveted joint.
3) Alteration and addition can be easily made in the exiting structure.
4) It is smooth in appearance therefore looks pleasing.
5) In welded connection, the tension member are not weakened as in case of riveted joint.

6) A weld joint has greater strength often a welded joint has the strength of the parent metal itself.

7) Circular shape member are difficult to rivet but they can easily welded.

8) The welding provide very rigid joints

9) Welding is possible at any point, any place.

10) Welding required less time than the riveting.

Disadvantages

1) Due to uneven heating and cooling during fabrication, the members get distorted or addition stresses may developed.
2) Highly skilled worker and supervision is required.
3) Due to uneven contraction and expansion in the frame, there is possibilities of cracks.
4) The inspection of weld is difficult than riveted joint.

Types of welded joint

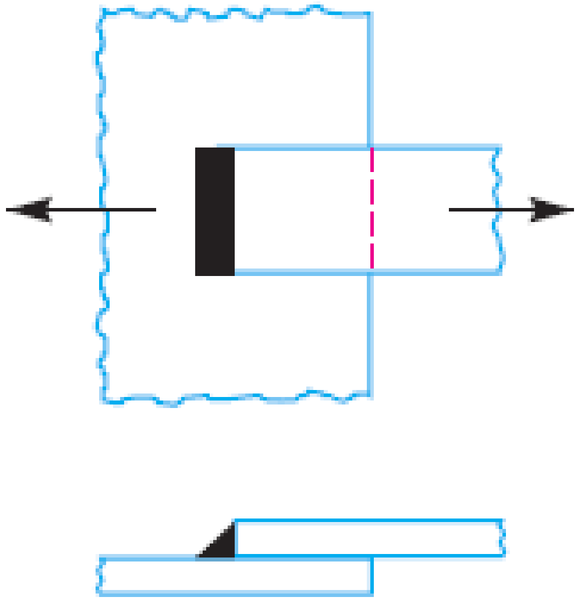
1) Lap Joint:

- The Lap Joint is obtained by over lapping the plates and then welding the edge of plates.

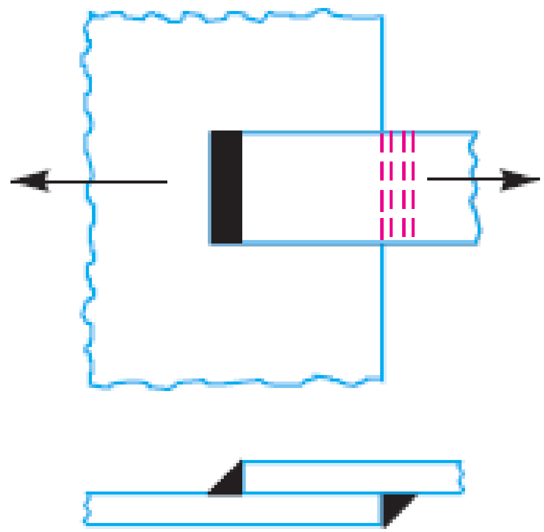
a) Single transverse

b) Double transverse

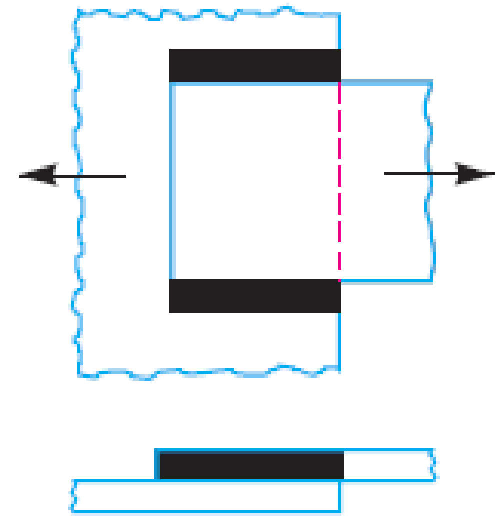
c) Parallel fillet joints.



(a) Single transverse.



(b) Double transverse.

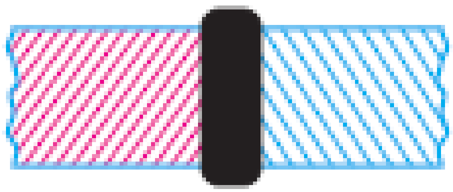


(c) Parallel fillet.

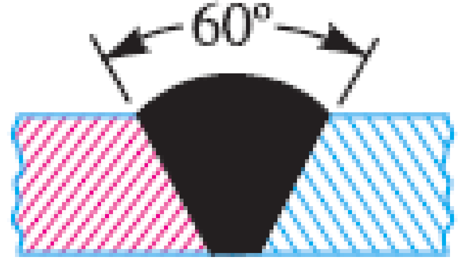
2) Butt Joints:

- The butt joint is obtained by welding the ends and edge of the two plates which approximately in the same plane.
- The Butt Joint may

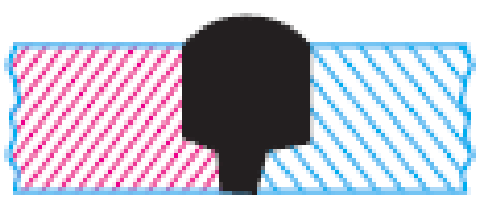
1. **Square butt joint,**
2. **Single V-butt joint**
3. **Single U-butt joint,**
4. **Double V-butt joint, and**
5. **Double U-butt joint.**



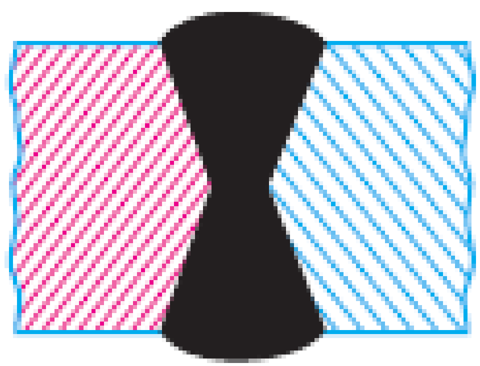
(*a*) Square butt joint.



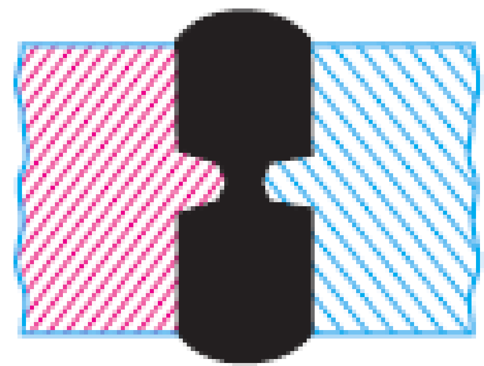
(*b*) Single *V*-butt joint.



(*c*) Single *U*-butt joint.

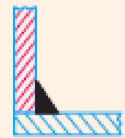
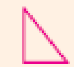
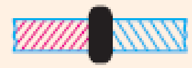
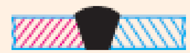
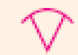
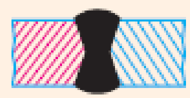
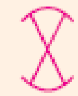
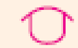
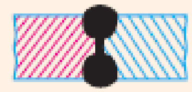
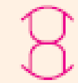
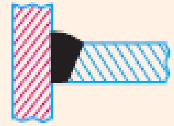
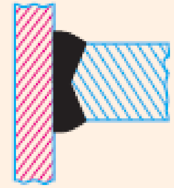
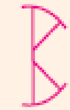


(*d*) Double *V*-butt joint.

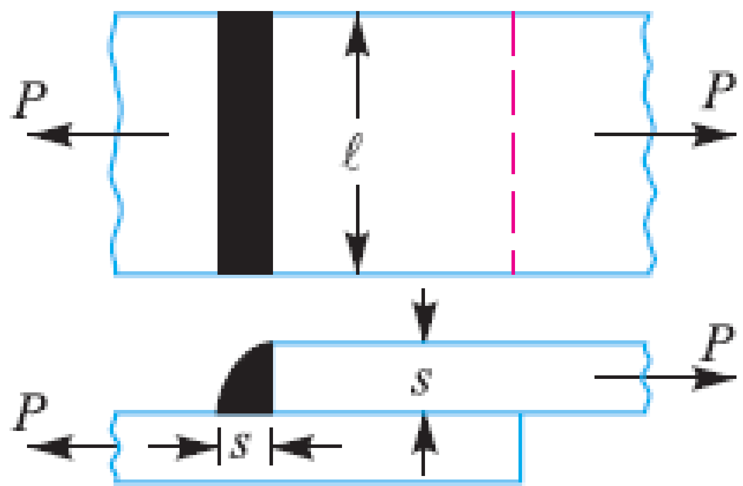


(*e*) Double *U*-butt joint.

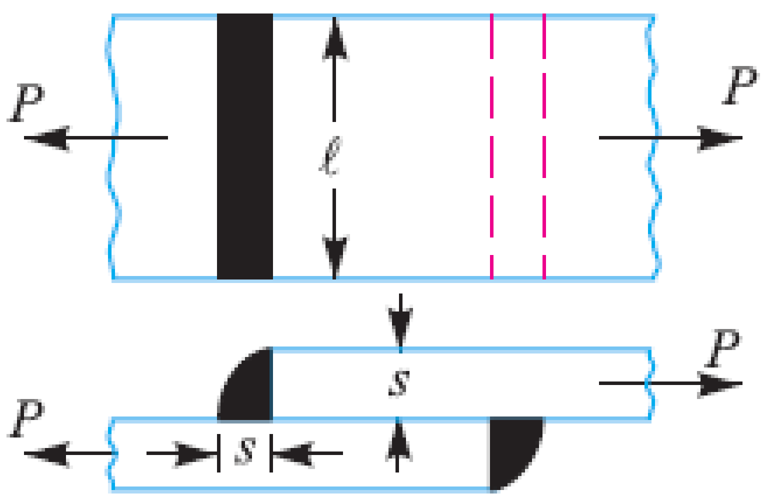
Basic Weld Symbols

S. No.	*Form of weld*	*Sectional representation*	*Symbol*
1.	Fillet		
2.	Square butt		
3.	Single-*V* butt		
4.	Double-*V* butt		
5.	Single-*U* butt		
6.	Double-*U* butt		
7.	Single bevel butt		
8.	Double bevel butt		

Strength of Transverse Fillet Welded Joints



(*a*) Single transverse fillet weld.



(*b*) Double transverse fillet weld.

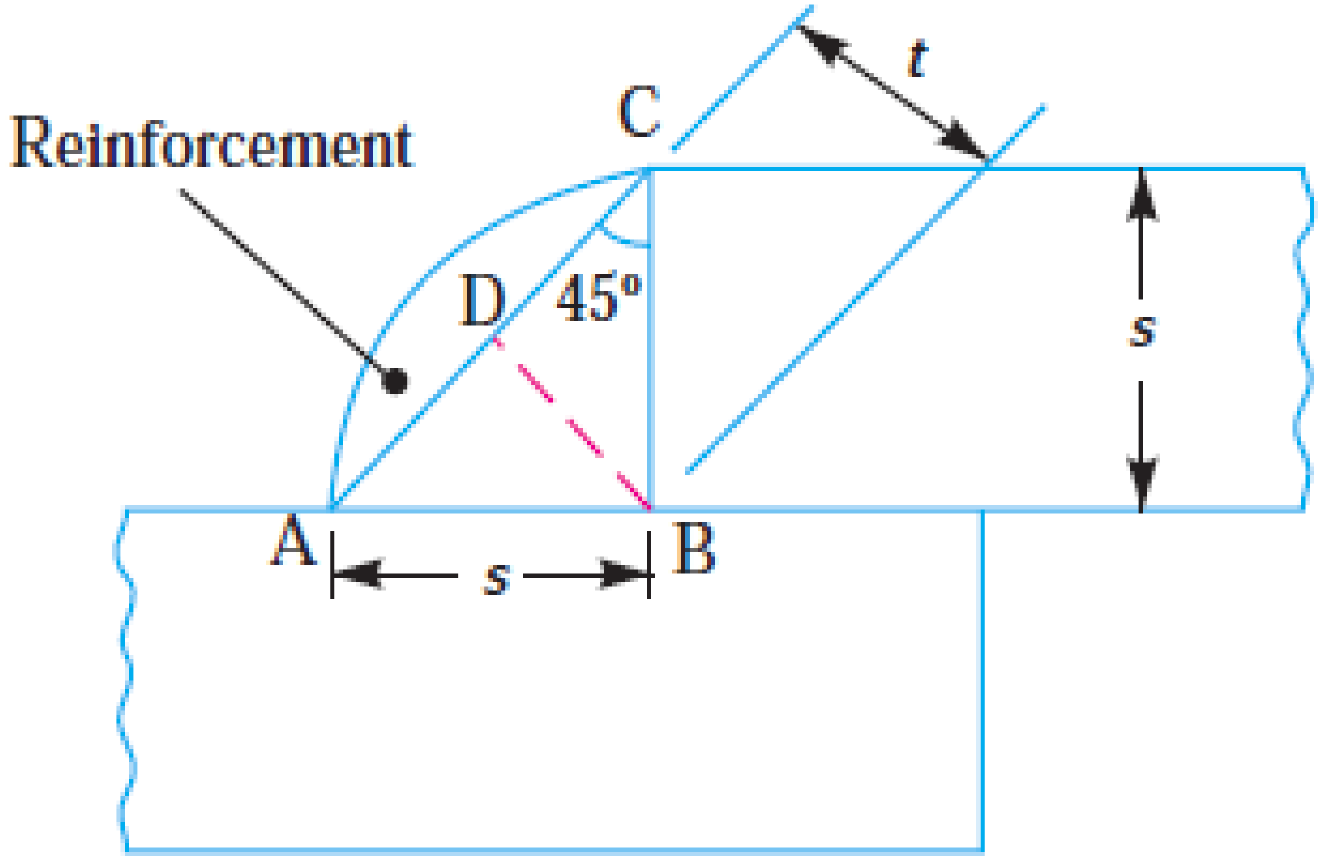


Fig. 10.7. Enlarged view of a fillet weld.

- In order to determine the strength of the fillet joint, it is assumed that the section of fillet is a right angled triangle *ABC with hypotenuse AC making equal angles with other two sides AB and BC.*
- The enlarged view of the fillet is shown in Fig. 10.7.
- The length of each side is known as ***leg or size of the weld and the perpendicular distance of the hypotenuse from the intersection of legs (i.e. BD) is*** known as ***throat thickness.***
- ***The minimum area of the weld is obtained at the throat BD, which is given*** by the product of the throat thickness and length of weld.

$$\Delta\, ABC \text{ is right angle isosceles triangle.}$$

$$Let,\, t = BD = Throat\, thickness\, in\, mm$$

$$S_W = AB = BC = Leg\, or\, size\, of\;\, weld$$

$$= Thickness\, of\;\, weld\;\, in\, mm$$

$$l_w = Length\, of\;\, weld\;\, in\, mm$$

$$\angle BAC = \angle BCA = 45^0$$

$$From\;\, figure$$

$$\sin 45^0 = \frac{BD}{AB}$$

$$0.707 = \frac{t}{S_w}$$

$$\therefore Thickness\, of\;\, weld = t = 0.707\, S_w - - - (1)$$

$\therefore$ *The minimum area of the throat or weld area*

$$A = Throat\, thickness \times Length\, of\ weld$$

$$A = t \times l_w$$

$$A = 0.707\, S_w\, l_w --- (2)$$

The failure of fillet weld is due to tensile force

$$\therefore \sigma_t = \frac{P}{Area\, of\ throat}$$

$$\sigma_t = \frac{P}{0.707 \times S_w \times l_w}$$

$$\therefore P = 0.707 \times S_w \times l_w \times \sigma_t$$

This equation for single transverse fillet weld.

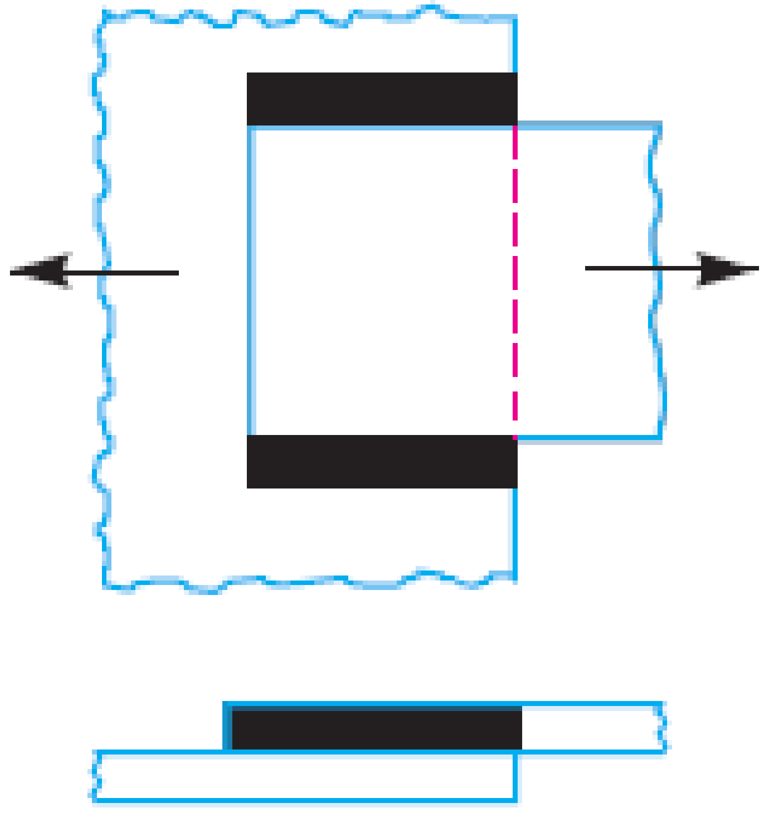
For double transverse fillet weld

$$\sigma_t = \frac{P}{2A} = \frac{P}{2 \times 0.707 \times S_w \, l_w}$$

$$P = 2 \times 0.707 \times S_W \, l_w \times \sigma_t$$

During welding, the slag and blow holes are occur, so the weld is weaker than plate, therefore the weld is provided with some reinforcement which may be taken as 10% of the plate thickness.

Strength of Parallel Fillet Weld



(c) Parallel fillet.

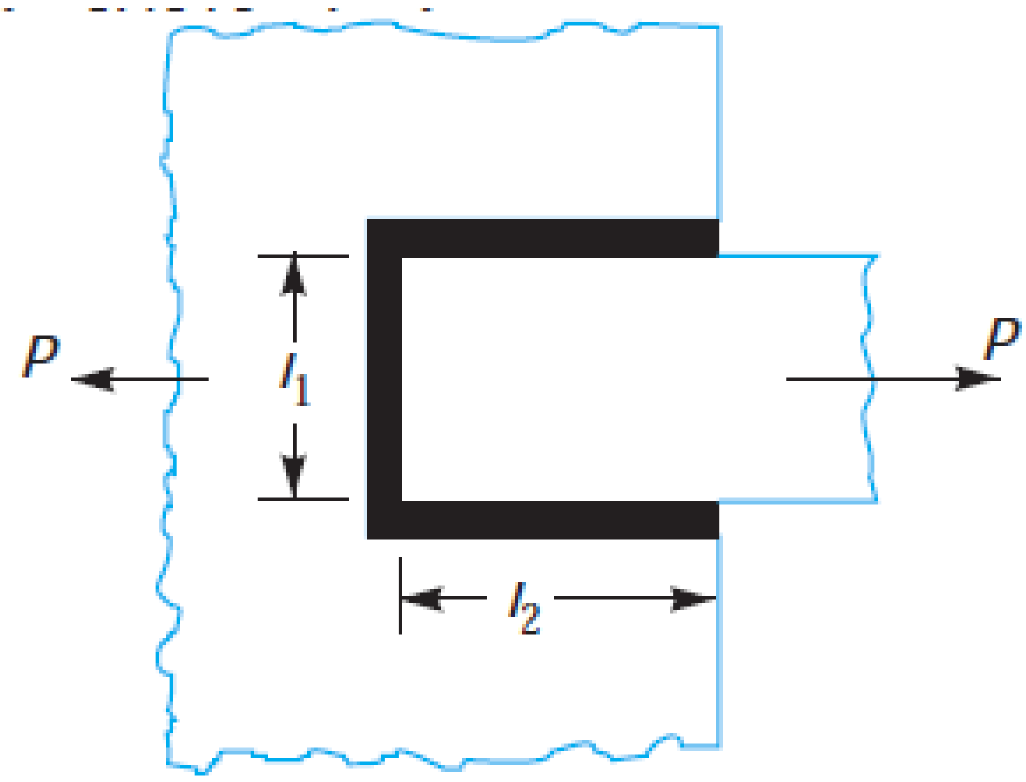
$$\therefore The\ stress\ indced\ in\ the\ fillet\ weld\ is$$
$$shear\ stress\ due\ to\ axial\ force$$

$$\tau_s = \frac{P}{2 \times Throat\ area}$$

$$\tau_s = \frac{P}{2 \times 0.707 \times S_w l_w}$$

$$\therefore P = 2 \times 0.707 \times S_w\, l_w \times \tau_s$$

Combine Transverse & Parallel Fillet weld



(*b*) Combination of transverse
and parallel fillet weld.

- In combination of parallel and transverse fillet weld, the weld is subjected to tensile stress and shear stress due to axial force.

$$For\ transverse\ fillet\ weld$$

$$P = 0.707\, S_w\, l_{w1}\, \sigma_t \quad ---(1)$$

$$For\ parallel\ fillet\ weld$$

$$P = 2 \times 0.707\, S_w\, l_{w2}\, \tau_s \quad ---(2)$$

$$Total\ strength\ of\ weld\ is$$

$$P_t = [0.707\, S_w\, l_{w1}\, \sigma_t] + [2 \times 0.707\, S_w\, l_{w2}\, \tau_s]$$

- **Note –**

1. Stress concentration factor for transverse fillet weld Under dynamic (fatigue) loading = 1.5
2. Stress concentration factor for parallel fillet weld Under dynamic (fatigue) loading = 2.7

PROBLEMS

THE END