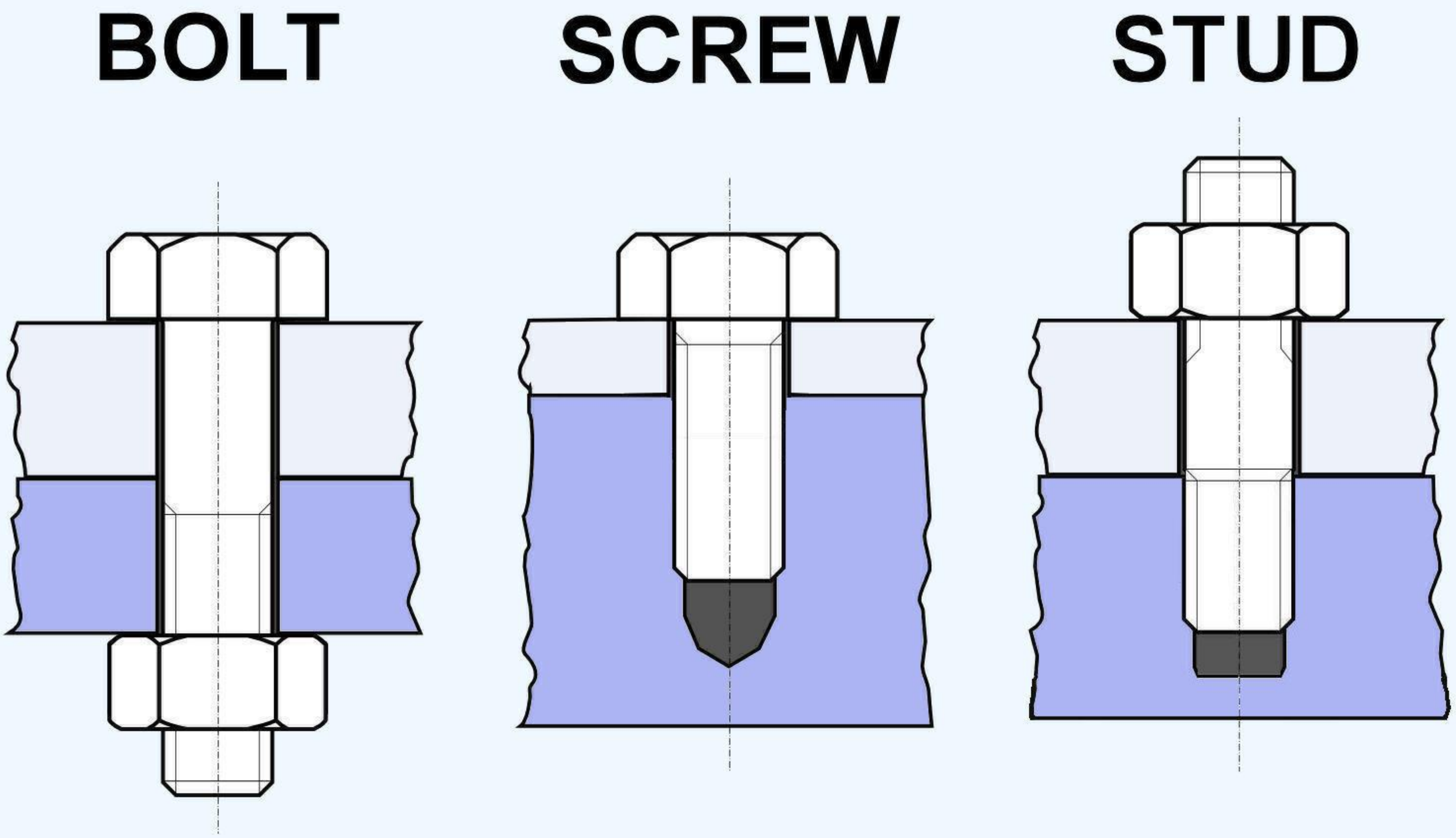
DESIGN OF MACHINE ELEMENTS

Module-III

Nivish George

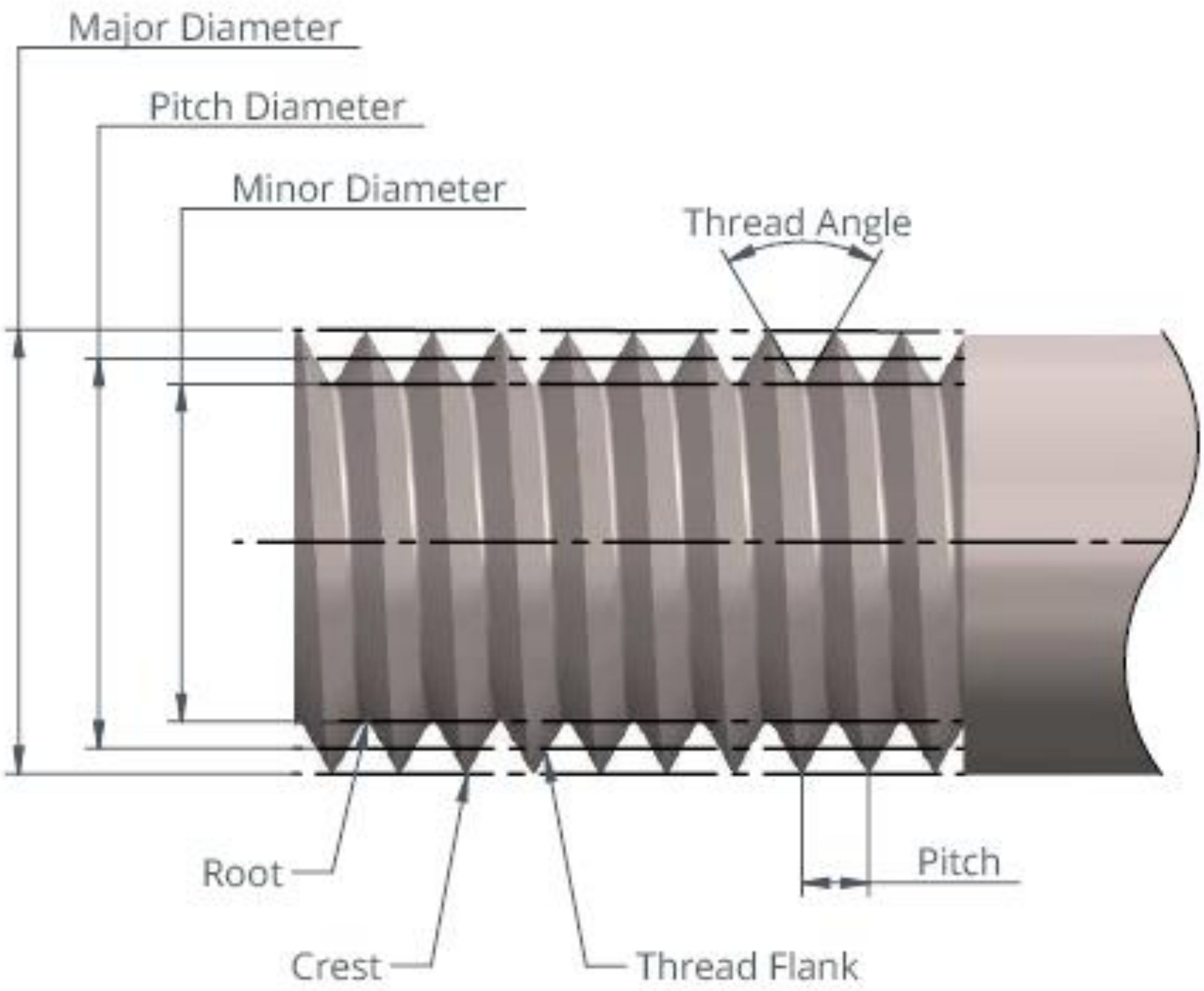
RSET
RAJAGIRI SCHOOL OF ENGINEERING & TECHNOLOGY

Threaded Joints: Types



Cap screws with different heads

Screw Threads: Terminology



Screw Threads: Terminology

Major diameter: The major diameter is the diameter of an imaginary cylinder that bounds the crest of an external thread (d) or the root of an internal thread (D) (Also called as nominal diameter)

Minor diameter: The minor diameter is the diameter of an imaginary cylinder that bounds the roots of an external thread (d_c) or the crest of an internal thread (D_c)

Pitch diameter: The pitch diameter is the diameter of an imaginary cylinder, the surface of which would pass through the threads at such points as to make the width of the threads equal to the width of spaces cut by the surface of the cylinder

Screw Threads: Terminology

Pitch, p: It is the distance between two similar points on adjacent threads measured parallel to the axis of the thread

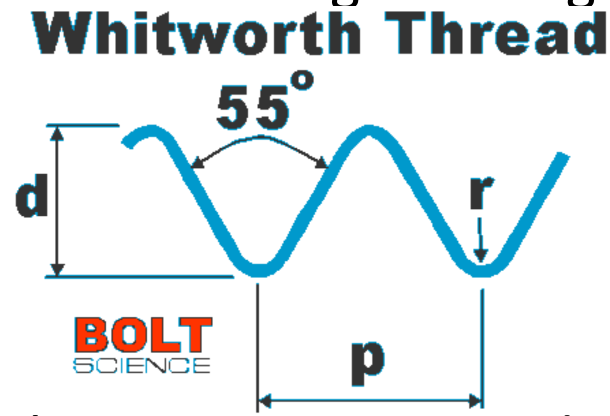
Lead: It is the distance that the nut moves parallel to the axis of the screw, when the nut is given one turn

Thread angle: It is the angle between the sides of the thread measured in an axial plane

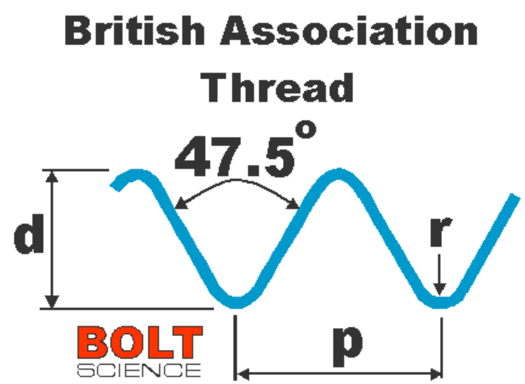
Tensile stress area: Tensile strength of the threaded rods is equal to the tensile strength of the unthreaded rod whose diameter is equal to the mean of the pitch and the minor diameter. The cross sectional area of this unthreaded rod is called as tensile stress area

Screw Threads: Standards

B.S.W thread: Symmetrical V thread with thread angle 55 deg. Used in bolts and screwed fastenings

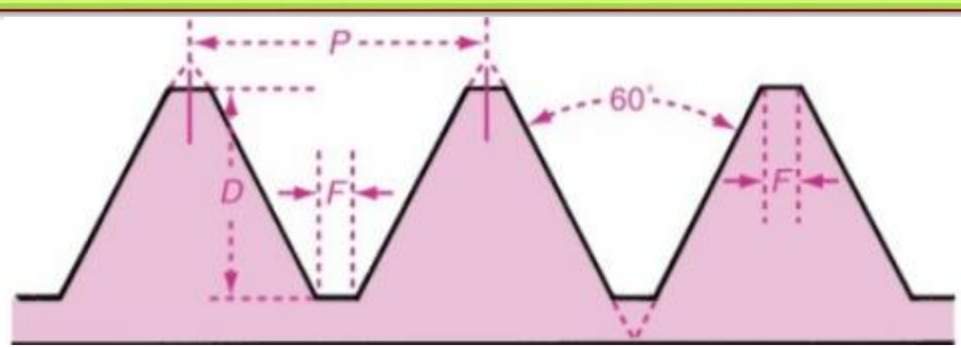


B.A thread: B.S.W threads with fine pitches. Instruments and other precision works

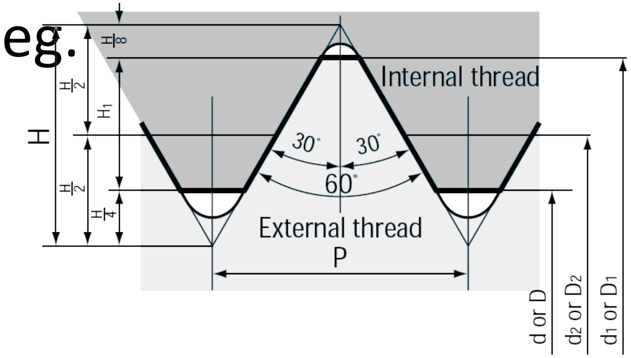


American national standard thread: Flat crest and roots. General purpose threads in bolts, nuts and tapped holes

Screw Threads: Standards

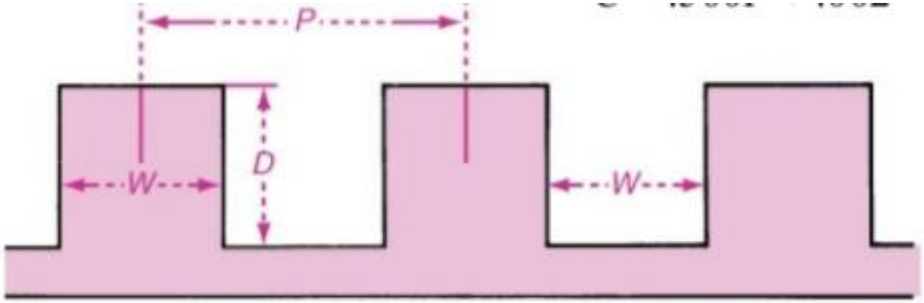


Unified standard thread: Included angle of 60 deg.



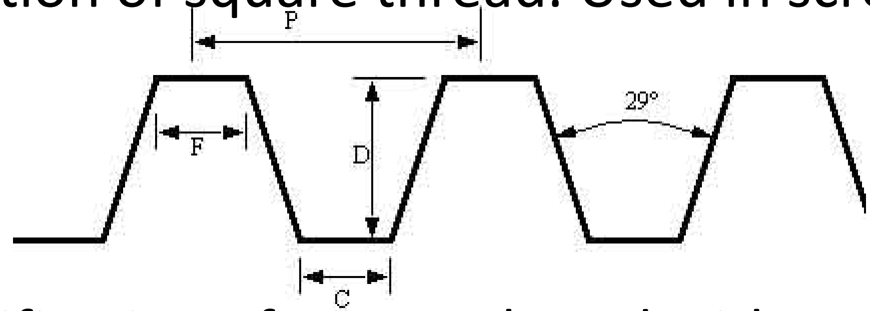
Square thread : High efficiency and are used for power transmission.

Not strong as V threads but offers lesser frictional resistance

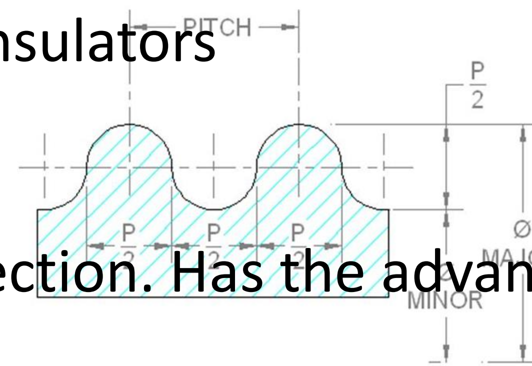


Screw Threads: Standards

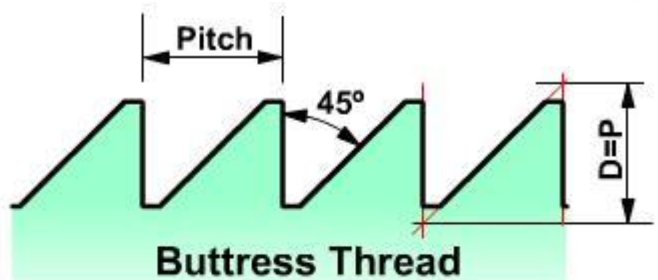
Acme thread: Modification of square thread. Used in screw cutting lathes, bench vices



Knuckle thread: A modification of square thread with rounded top and bottom. Necks of glass bottles, large moulded insulators



Buttress thread: Power transmission in one direction. Has the advantage of square and V thread



Metric thread: Same as B.S.W with an included angle of 55 deg

Bolted Joint: Design Procedure

1. Initial stresses due to screwing up forces (Tensile)

$$F_i = 2805d \quad \text{(Eqn. 9.1c)}$$

2. Tensile stress due to external forces

$$F = \frac{\pi}{4} d_1^2 \sigma_T \times n$$

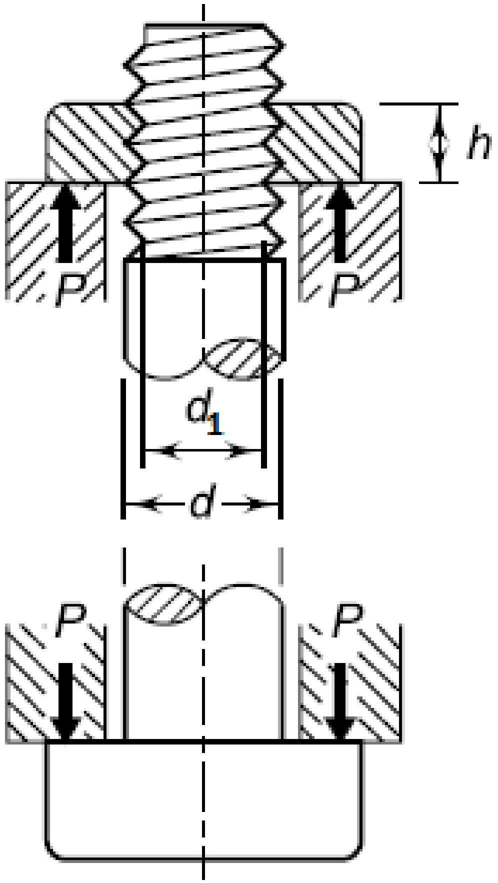
3. Shear stress

$$F_s = \pi d_1 h \tau \times n$$

4. Combined tension and shear stress

$$\tau_{max} = \frac{1}{2}\sqrt{\sigma_T^2 + 4\tau^2}$$

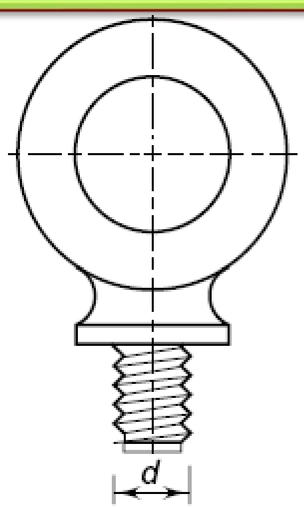
$$\sigma_{Tmax} = \frac{\sigma_T}{2} + \frac{1}{2}\sqrt{\sigma_T^2 + 4\tau^2}$$



Bolt in Tension

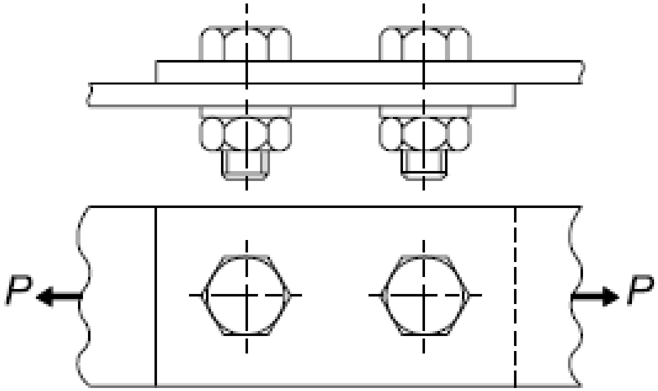
Problem 3.1

An eye bolt is to be used for lifting a load of 10 kN. The eye bolt is screwed into the frame of the motor. The eye bolt has coarse threads. It is made of plain carbon steel 30C8 (S_{yt} = 400N/mm^2) and factor of safety is 6. Determine the size of the bolt

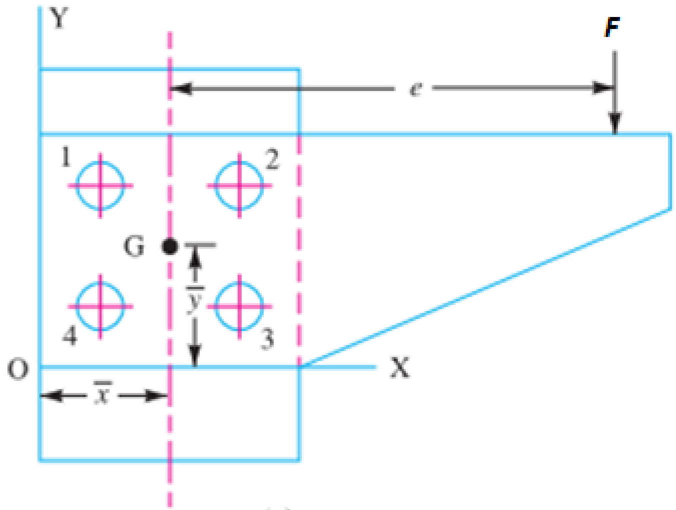


Problem 3.2

Two plates are fastened by means of two bolts as shown in Figure. The bolts are made of plain carbon steel 30C8 (S_{yt} = 400N/mm^2) and the factor of safety is 5. Determine the size of the bolts, if P = 5kN



Eccentric load acting in the plane containing the bolts



(a)

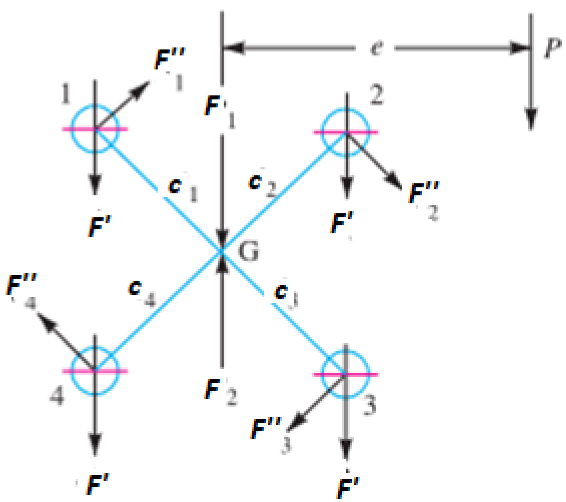
$$\bar{x} = \frac{A_1x_1 + A_2x_2 + A_3x_3 + \ldots.}{A_1 + A_2 + A_3 + \ \ldots}$$

$$\bar{y} = \frac{y_1 + y_2 + y_3 + ..}{n}$$

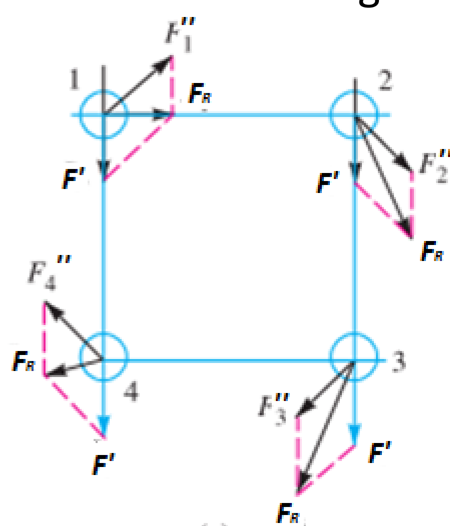
Direct shear, $F' = \frac{F}{n}$ Eqn 9.9(a)

Secondary shear proportional to the radial distance from the centre of gravity (assumption)

$$\frac{F_1}{c_1} = \frac{F_2}{c_2} = \frac{F_3}{c_3} = \cdots$$



(b)



(c)

Eqn 9.9(d)

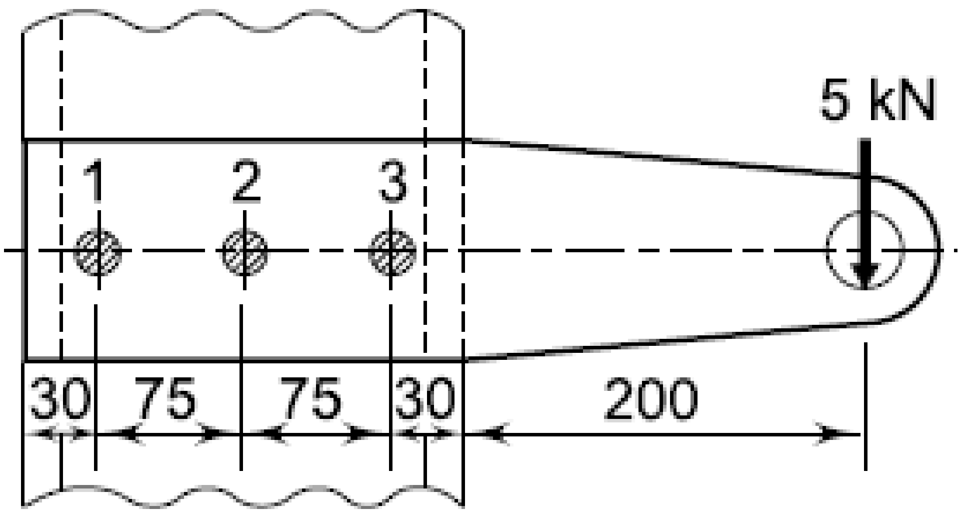
$$F_1'' = \frac{Fec_1}{(c_1^2 + c_2^2 + c_3^2 + c_4^2)}$$

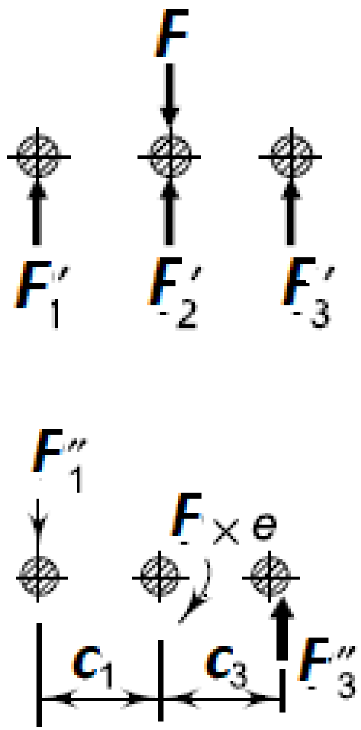
Eqn 9.9(g)

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

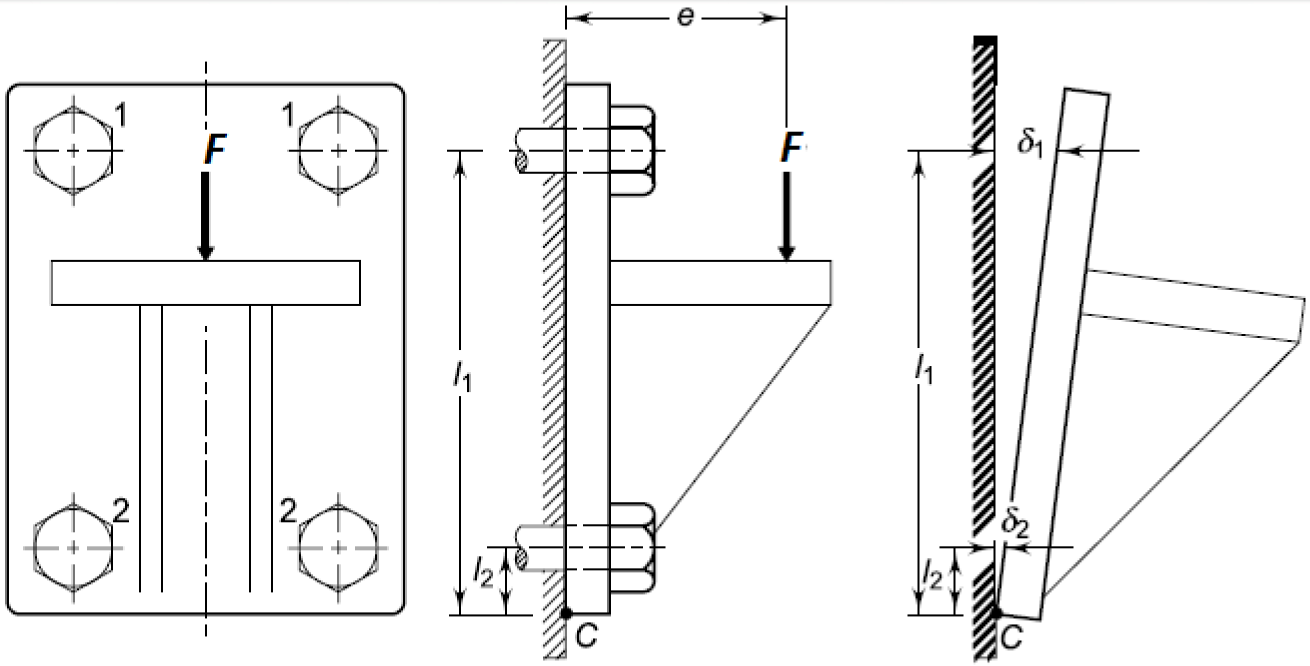
Problem 3.3

A steel plate subjected to a force of 5 kN and fixed to a channel by means of three identical bolts is shown in Figure. The bolts are made from plain carbon steel 45C8 (S_{yt} = 380 N/mm^2) and the factor of safety is 3. Specify the size of bolts





Eccentric load acting perpendicular to the axis of the bolt



Direct shear, $F' = \frac{F}{n}$ (Eqn 9.7a)

Secondary tensile, $F_1'' = \frac{Fel_1}{2(l_1^2 + l_2^2)}$ (Eqn 9.7b)

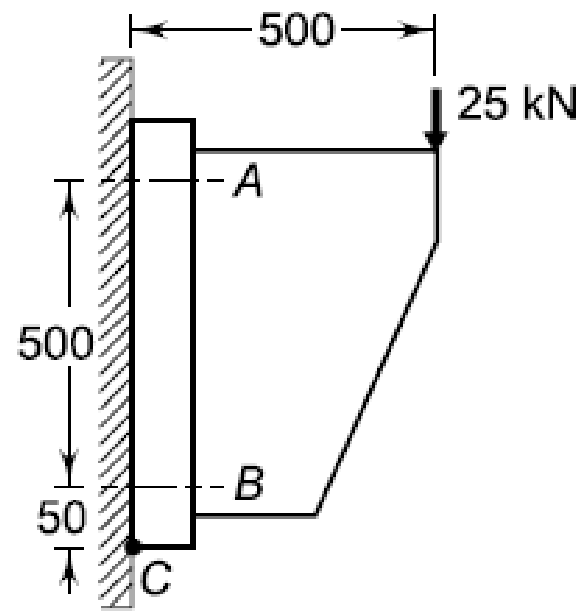
Equivalent tensile load, $F_R = \frac{1}{2}\left[F_1'' + \sqrt{F_1''^2 + 4F'^2}\right]$ (Eqn 9.7c)

Equivalent shear load, $F_R = \frac{1}{2}\left[\sqrt{F_1''^2 + F'^2}\right]$ (Eqn 9.7d)

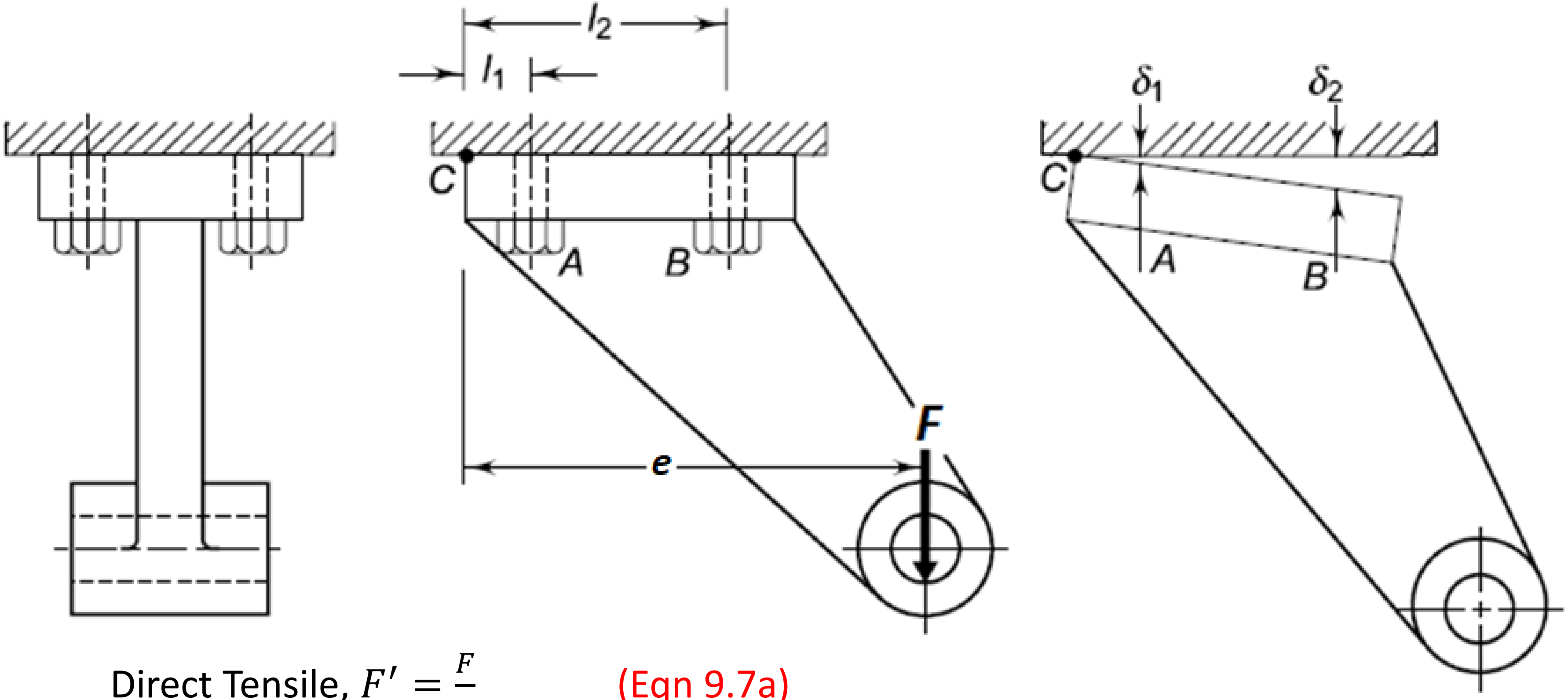
Design bolt for the total load

Problem 3.4

A wall bracket is attached to the wall by means of four identical bolts, two at A and two at B as shown in Figure. Assuming the bracket is held against the wall and prevented from tipping about the point C by all four bolts and using an allowable tensile stress = 35 N/mm^2 , determine the size of the bolts on the basis of maximum principal stress theory.



Eccentric load acting parallel to the axis of the bolt



Direct Tensile, $F' = \frac{F}{n}$ (Eqn 9.7a)

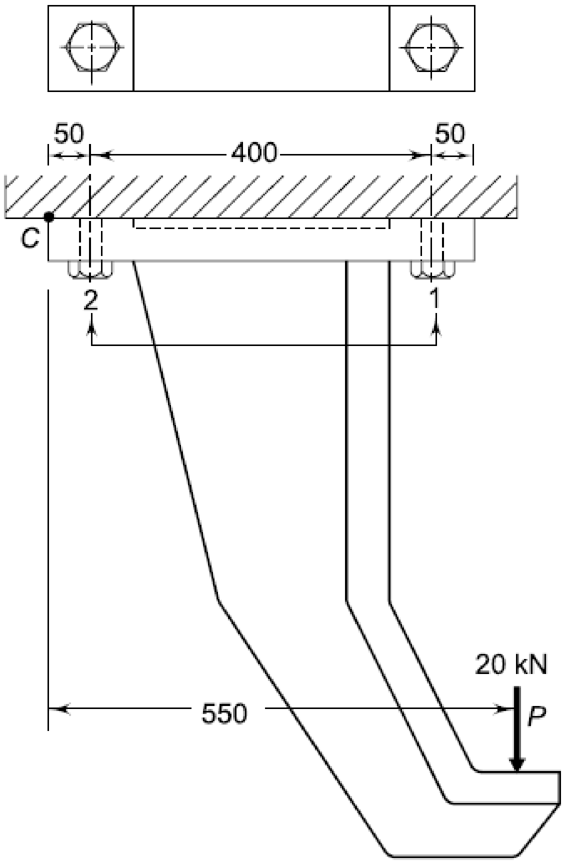
Secondary tensile, $F_1'' = \frac{Fel_2}{2(l_1^2 + l_2^2)}$ (Eqn 9.7b)

Total load, $F_R = F' + F_1''$

Design bolt for the total load F_R

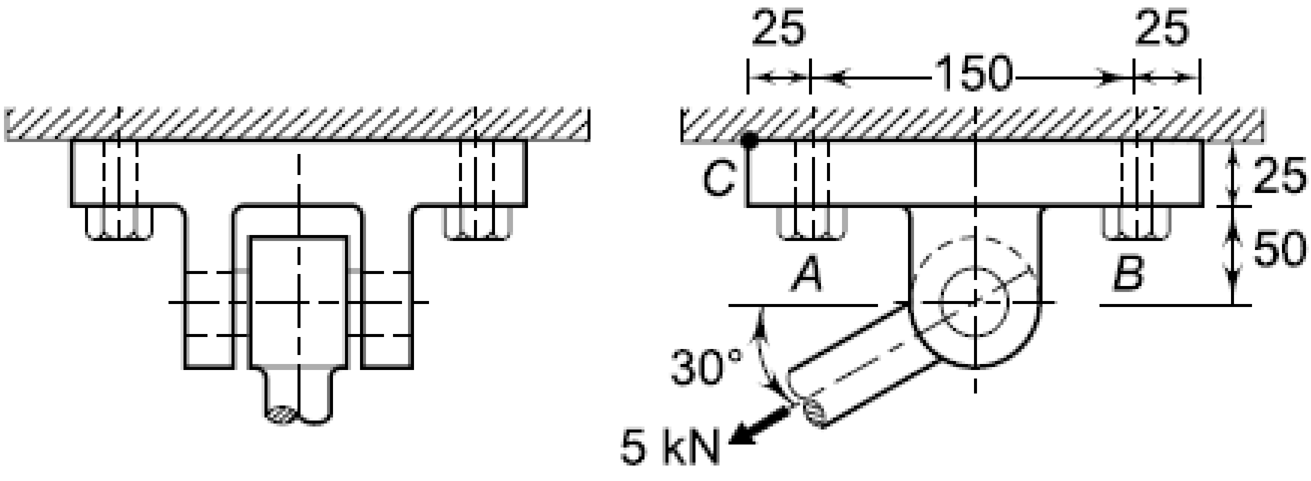
Problem 3.5

A crane runway bracket is fastened to the roof truss by means of two identical bolts as shown in Figure. Determine the size of the bolts, if the permissible tensile stress in the bolts is limited to 75 N/mm^2

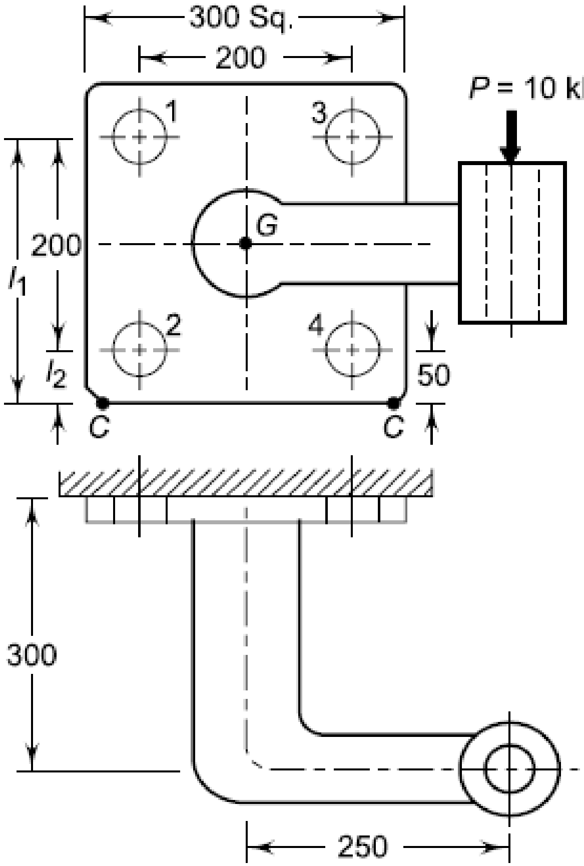


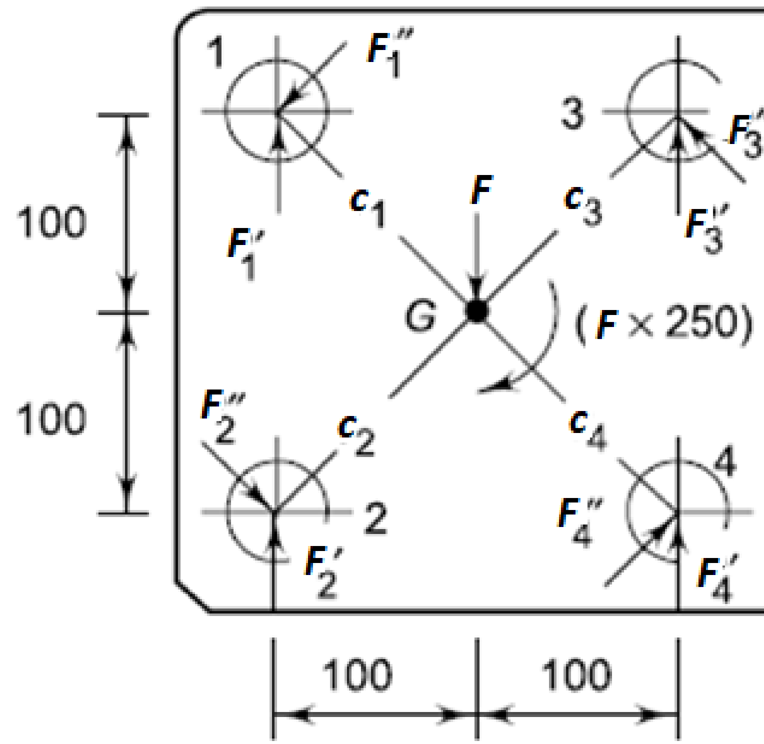
Problem 3.6

Figure shows the bracket used in a jib crane to connect the tie rod. The maximum force in the tie rod is 5 kN, which is inclined at an angle 30^0 with horizontal. The bracket is fastened by means of four identical bolts, two at A and two at B. The bolts are made of plain carbon steel 30C8 (S_{yt} = 400 N/mm^2) and the factor of safety is 5. Assume maximum shear stress theory and determine the size of the bolts.



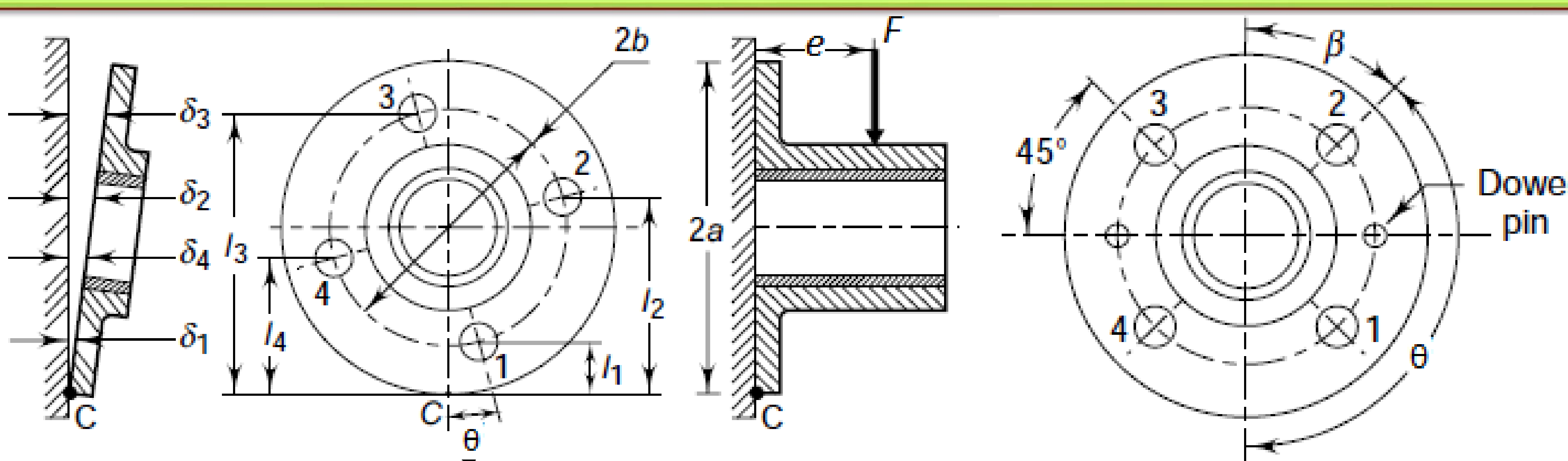
Problem 3.7





A rigid bracket subjected to a vertical force of 10 kN is shown in Figure. It is fastened to a vertical stanchion by means of four identical bolts. Determine the size of the bolts by maximum shear stress theory. The maximum permissible shear stress in any bolt is limited to 50 N/mm^2

Eccentric load acting perpendicular to the axis of the bolt



Direct shear load, $F' = \frac{F}{N}$ (Eqn 9.8a)

Secondary tensile, $F_1'' = \frac{Fel_1}{(l_1^2 + l_2^2 + l_3^2 + l_4^2)}$ (Eqn 9.8b)

$$l_1 = a - b\cos\theta \qquad l_2 = a + b\sin\theta$$

$$l_3 = a + b\cos\theta \qquad l_4 = a - b\sin\theta$$

$$F_{1-n} = \frac{2Fe(a - b\cos\theta)}{(2a^2 + b^2)N}$$ (Eqn 9.8c)

$$F_{max} = \frac{2Fe(a + b)}{(2a^2 + b^2)N}$$ (Eqn 9.8d)

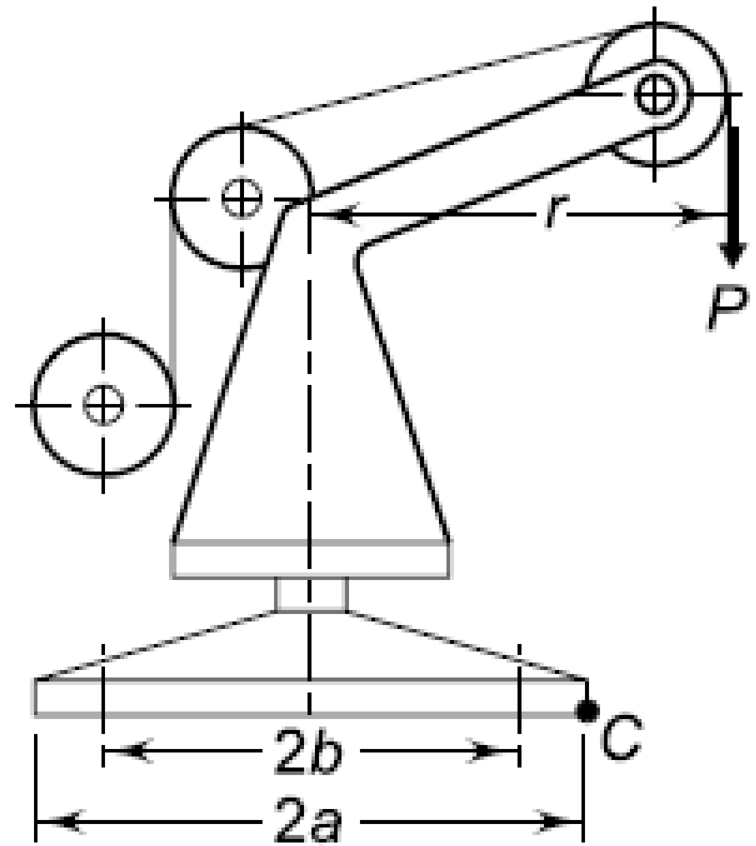
Design bolt for the total load

$$F_{max} = 2Fe\left(\frac{a + b\cos(\frac{180}{N})}{(2a^2 + b^2)N}\right)$$

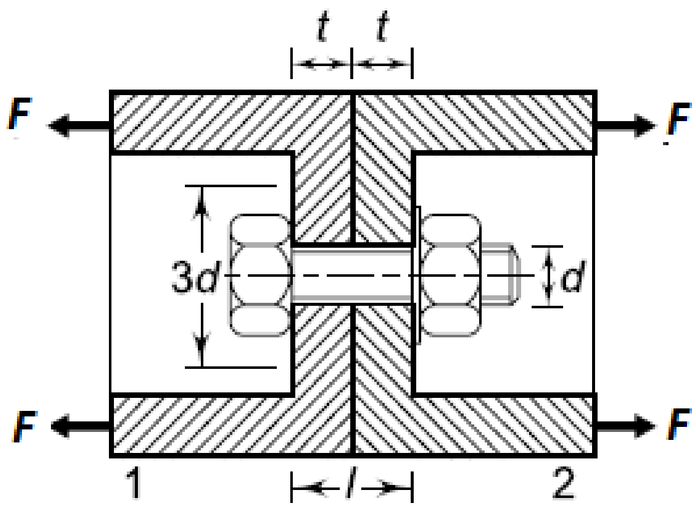
(Eqn 9.8e)

Problem 3.8

A pillar crane, shown in Figure is fastened to the foundation by means of 16 identical bolts spaced equally on 2 m pitch circle diameter. The diameter of the pillar flange is 2.25 m. Determine the size of the bolts if a load of 50 kN acts at a radius of 7.5 m from the axis of the crane. The maximum permissible tensile stress in the bolt is limited to 75 N/mm^2

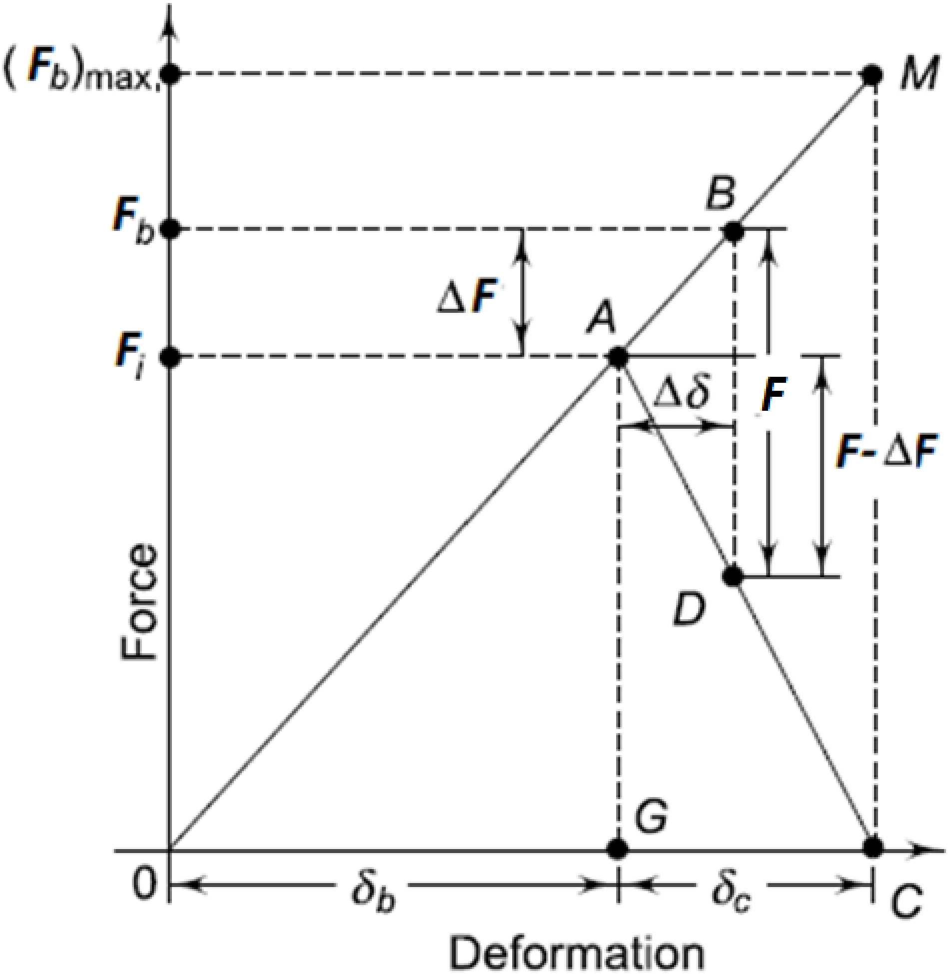


Elastic analysis of bolted joints



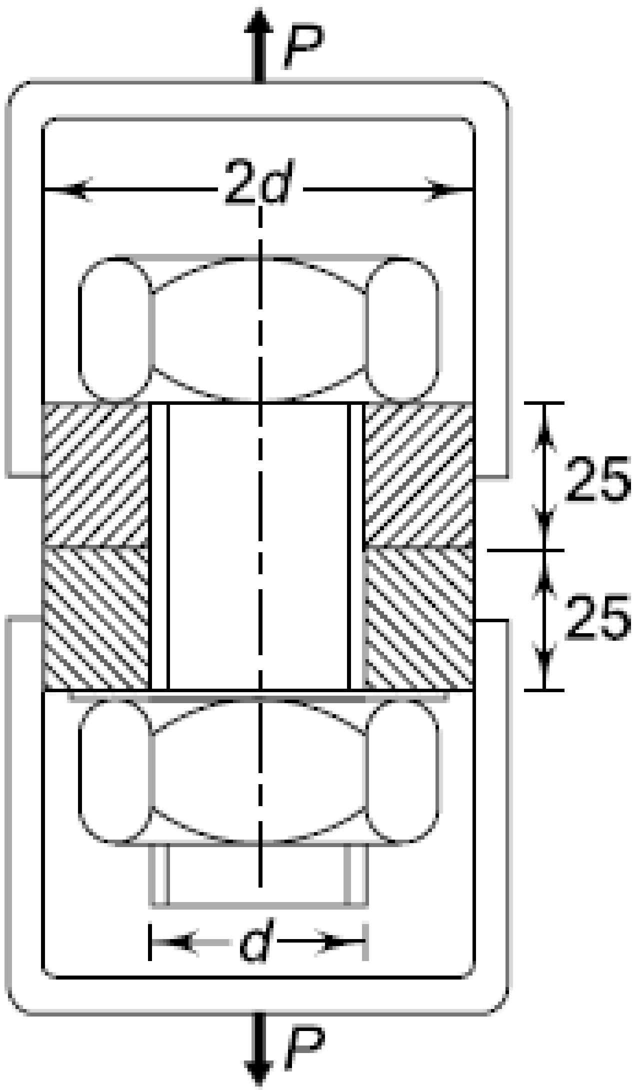
Final load on the bolt $F_b = KF_a + F_i$ (Eqn. 9.2a)

$$K = \frac{1}{1+\frac{k_g}{k_b}}$$ (Eqn 9.2b)



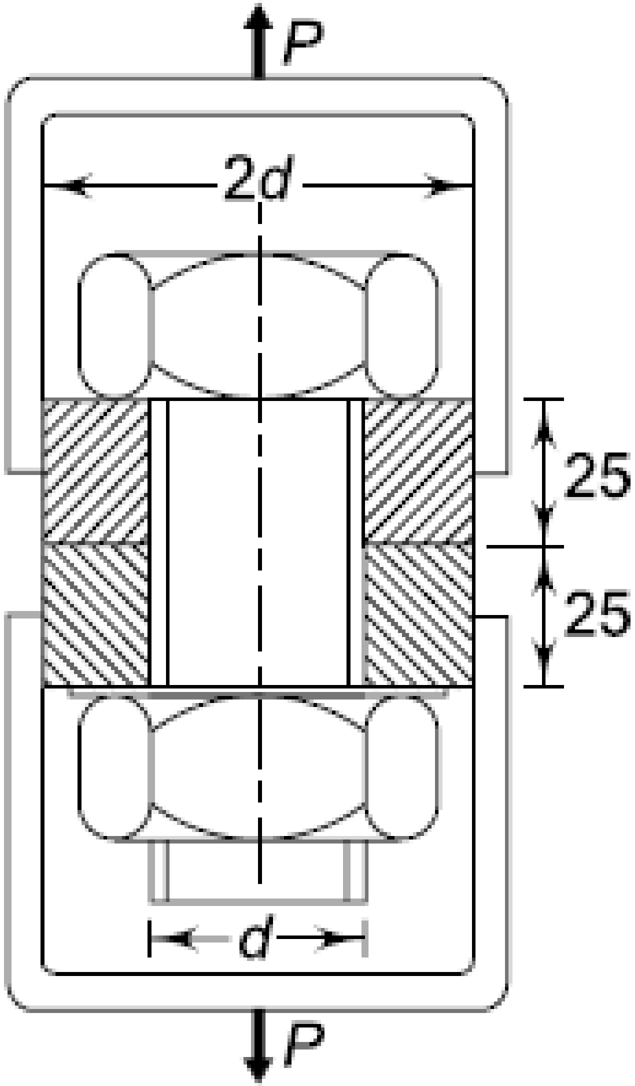
Problem 3.9

Two circular plates with 2d and d as outer and inner diameters respectively, are clamped together by means of a bolt as shown in Figure. The bolts is made of plain carbon steel 45C8 (S_{yt} = 380 N/mm^2 and E = 207000 N/mm^2), while the plates are made of aluminium (E = 71000 N/mm^2). The initial pre load in the bolt is 5 kN and the external force acting on the bolted joint is 10 kN. Determine the size of the bolt, if the factor of safety is 2.5

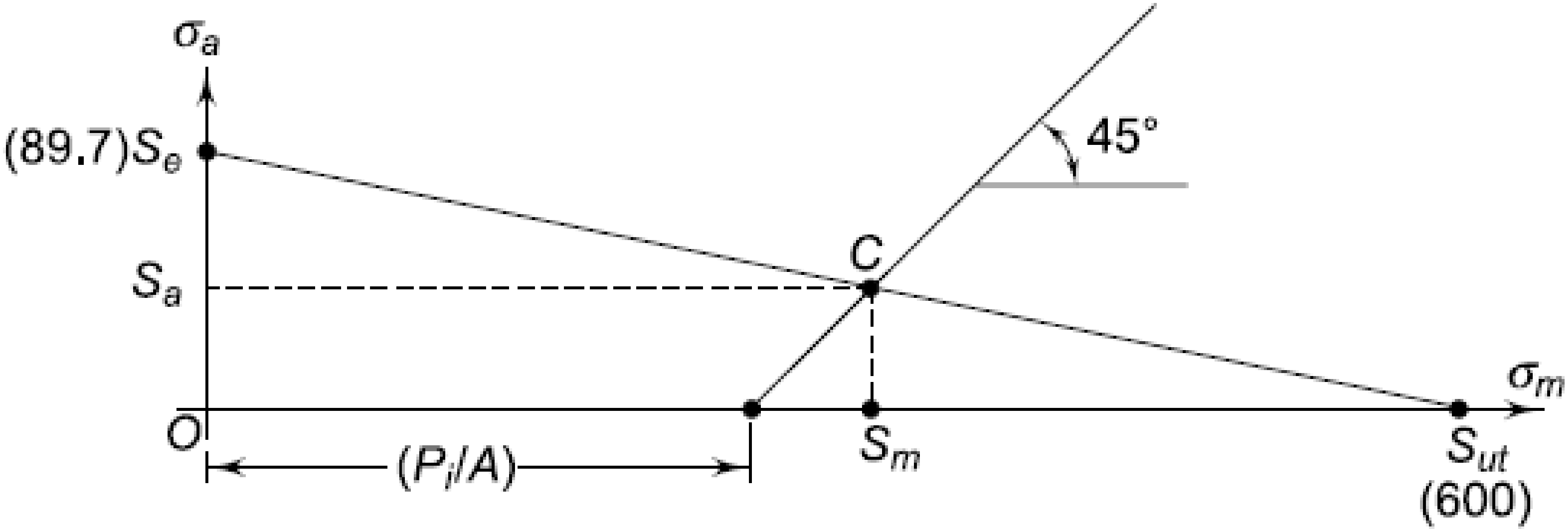


Problem 3.10

The assembly of two circular plates clamped together by means of a bolt which is shown in Figure is subjected to a variable force P varying from 0 to 10 kN. The bolts is made of plain carbon steel 45C8 (S_{ut} = 630 N/mm^2, S_{yt} = 380 N/mm^2 and E = 207000 N/mm^2). The two circular plates are made of aluminium (E = 71000 N/mm^2). The fatigue stress concentration factor is 2.2 and the expected reliability is 90 %. The initial pre load in the bolt is 5 kN. Determine the size of the bolt if the factor of safety is 2.



Problem 3.10



Problem 3.11

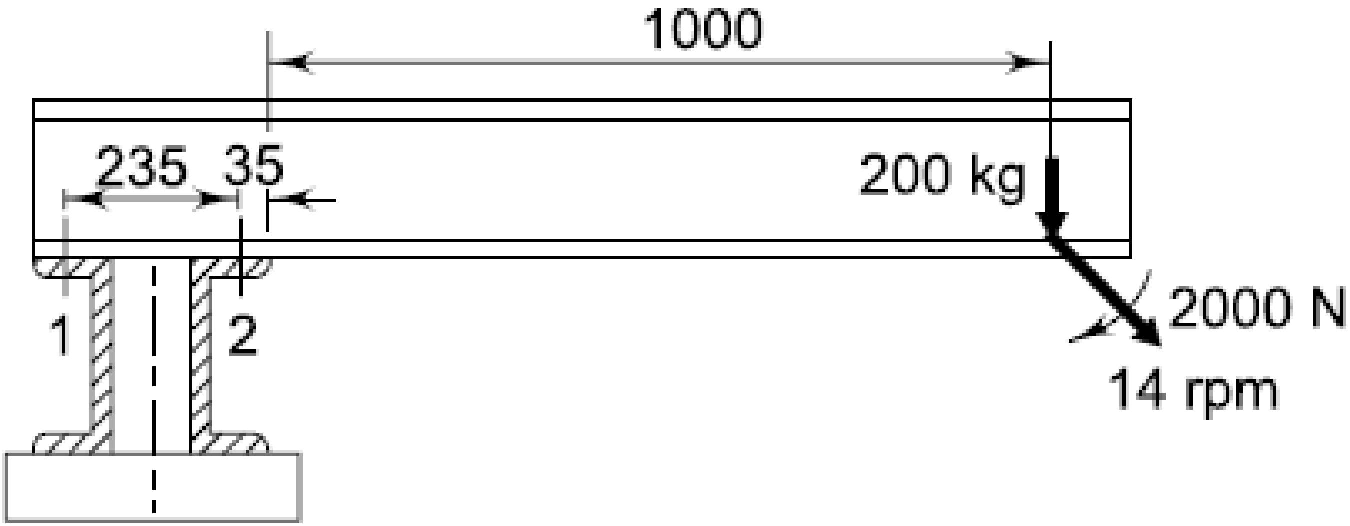
Figure shows the arrangement of a supporting machine weighing 200 kg at a distance of 1 m from the nearest point of support. The operation of the machine creates a rotating unbalanced force of 2000 N in the plane of the figure and at the position of the machine. The speed of rotation is 14 rpm. The weight of the channel is 20 kg/m. Two bolts, denoted by 1 and 2, hold the channel to the main frame. The bolts are located at 35 and 270 mm from the nearest point of support. The following data is given for the bolts.

- Ultimate tensile strength = 960 MPa
- Yield point strength = 850 MPa
- Endurance limit in bending = 500 MPa
- Fatigue stress concentration factor = 3.0
- Factor of safety = 2

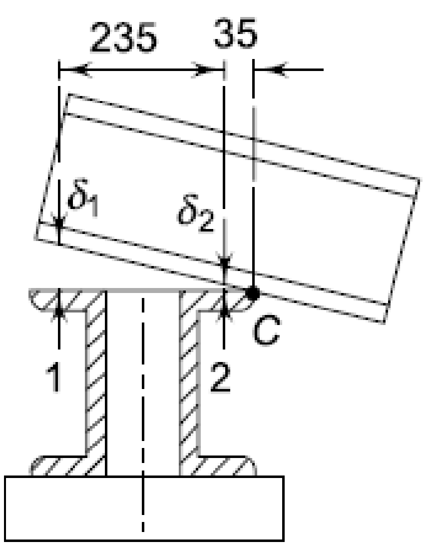
The initial preload in each bolt is 55 kN. The ratio of stiffness of the parts held together by the bolts to the stiffness of the bolts is 3. Assume Goodman line as the criterion of failure.

Determine the size of the bolts.

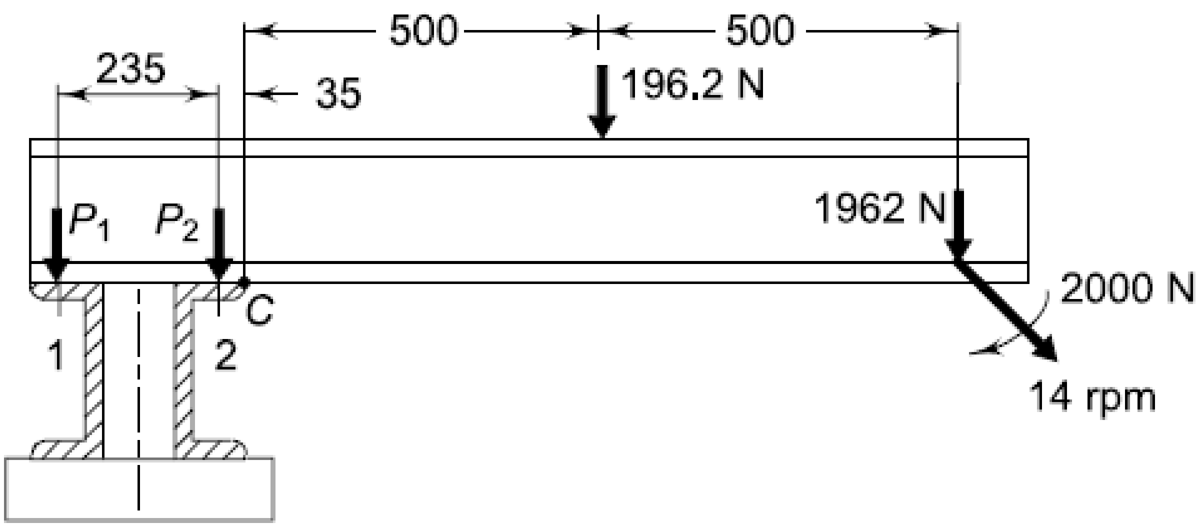
Problem 3.11



1000
235
35
200 kg
2000 N
14 rpm
1
2

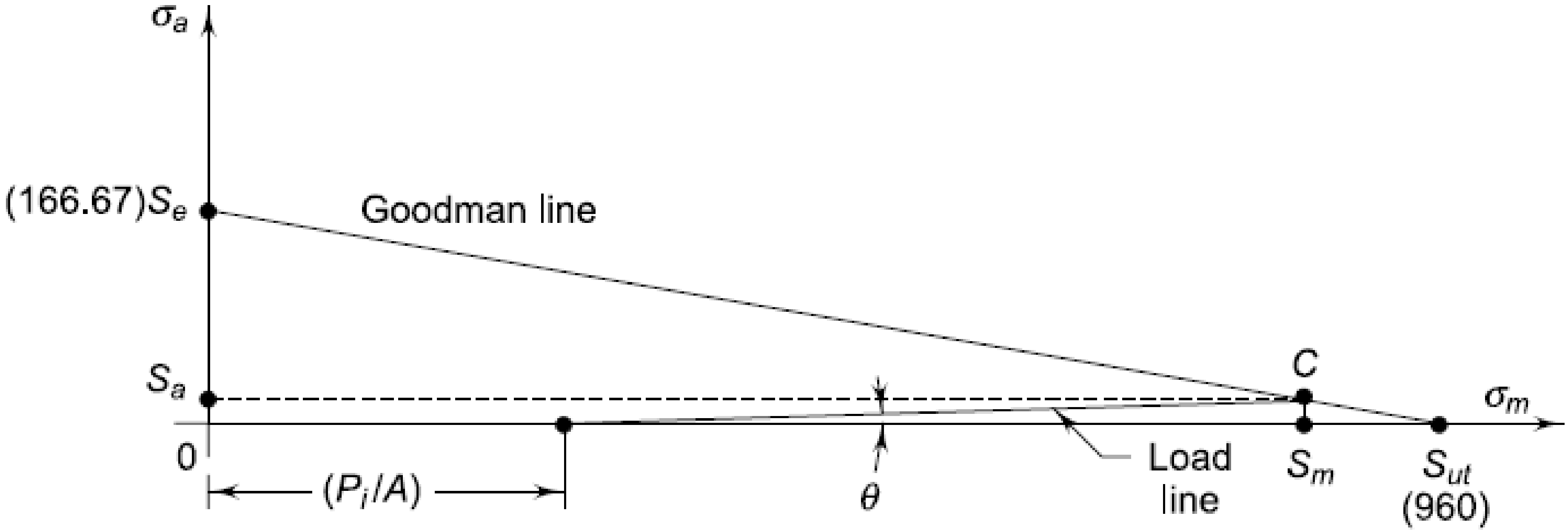


235
35
δ_1
δ_2
C
1
2



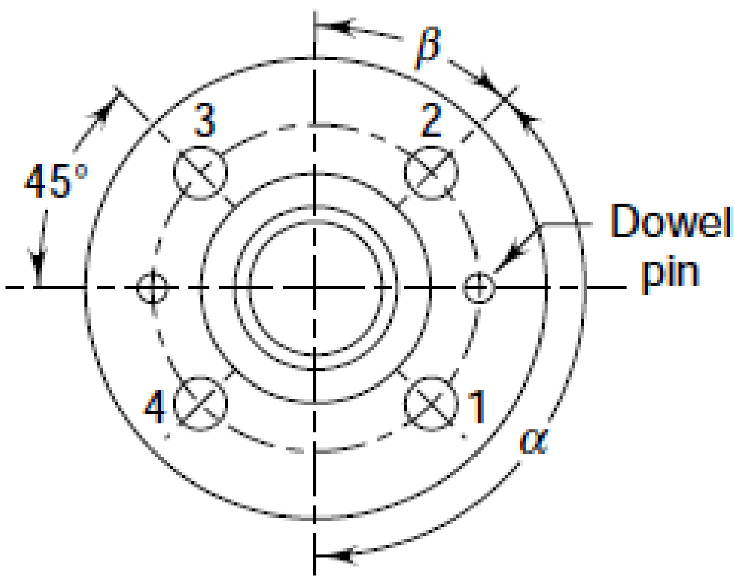
500
500
235
35
196.2 N
P_1
P_2
1962 N
2000 N
14 rpm
C
1
2

Problem 3.11



Problem 3.12

A round flange bearing as shown in Figure is fastened by means of four cap screws spaced equally on 300 mm pitch circle diameter. The diameter of the flange is 400 mm. The external force is 25 kN, which is located at a distance of 150 mm from the machine frame. There are two dowel pins to take shear load. The cap screws are relieved of all shear force. Determine the size of the cap screws, if the maximum permissible tensile stress in the cap screw is limited to 50 N/mm^2.



Power Screws

Power screw is a mechanical device used for converting rotary motion into linear motion and transmitting power.

Applications

- To raise the load
- To obtain accurate motion in machining
- To clamp a workpiece
- To load a specimen

Advantages

- Large load carrying capacity
- Compact construction
- Simple design
- Controlled and highly accurate linear motion
- Smooth and noiseless service
- Reduced cost and reliable
- Self locking property

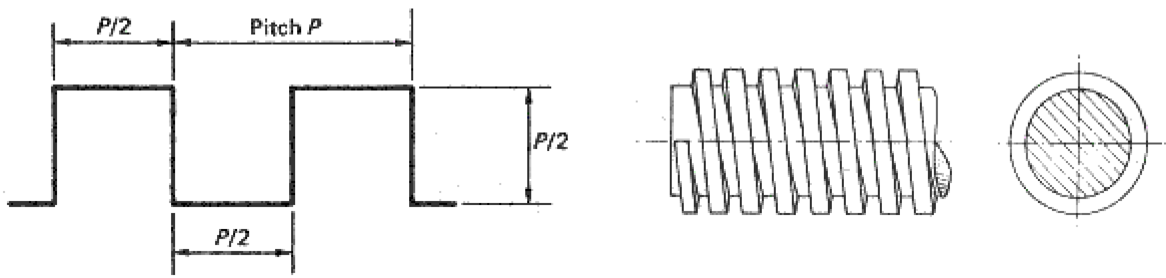
Power Screws

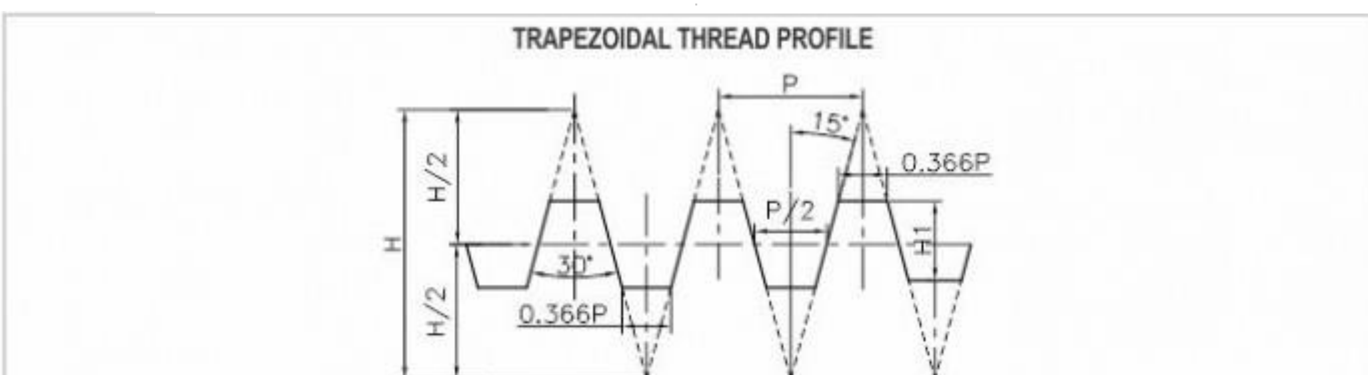
Disadvantages

- Low efficiency
- High friction in threads

Forms of threads

- Square
- ISO metric trapezoidal





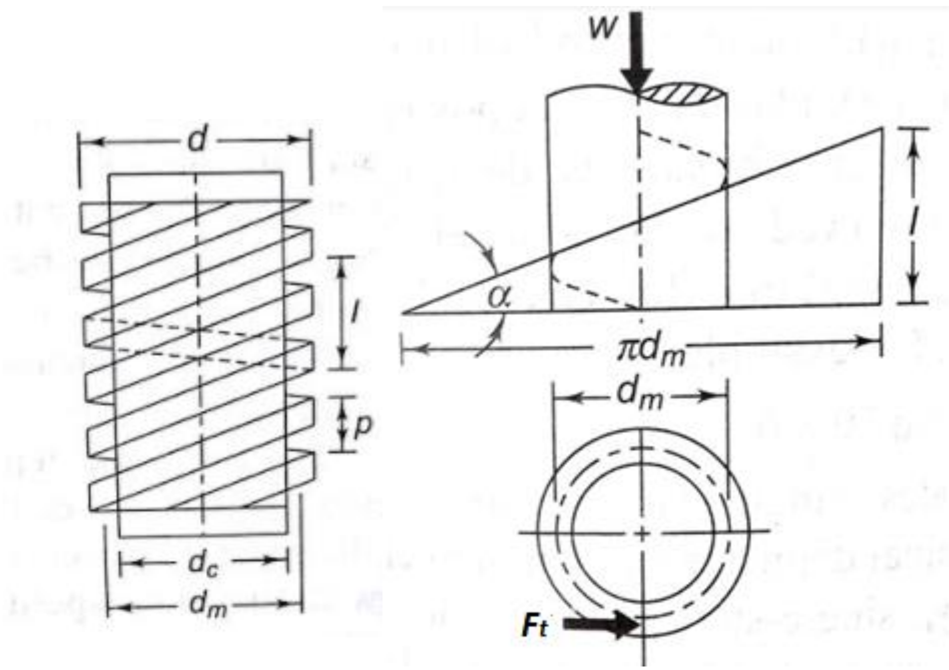
Threads: Comparison

Square Thread	
Advantages	**Disadvantages**
Efficiency is more	Difficult to manufacture
No radial pressure or side thrust	Less thread thickness at core diameter
	Screw or nut replacement due to wear

Trapezoidal Thread	
Advantages	**Disadvantages**
Manufactured on thread milling machine	Efficiency is less
More thickness at the core diameter	Side thrust or radial pressure on nut

Terminology in power screw

Definitions of pitch, lead, nominal diameter, core diameter follows the same definition as seen in normal threaded joints



Helix angle (α)

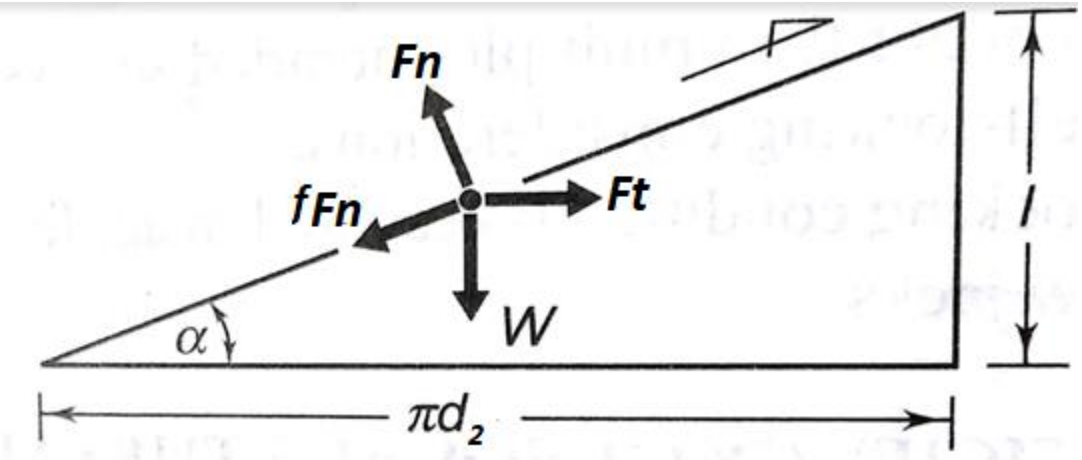
Angle made by the helix of the thread with a plane perpendicular to the axis of the screw

$$d_c = d_1 = (d - p)$$

$$d_m = d_2 = (d - 0.5p)$$

$$\tan\alpha = \frac{l}{\pi d_m} = \frac{l}{\pi d_2} \quad \textit{Eqn } 9.10\ b$$

Torque requirement: Lifting load



Equilibrium of vertical and horizontal components

$$F_t = fF_n cos\alpha + F_n sin\alpha$$

$$W = F_n cos\alpha - fF_n sin\alpha$$

Dividing the above equations and further arithmetic substitutions

$$F_t = \frac{W(f + tan\alpha)}{(1 - f tan\alpha)}$$ Eqn 9.11a

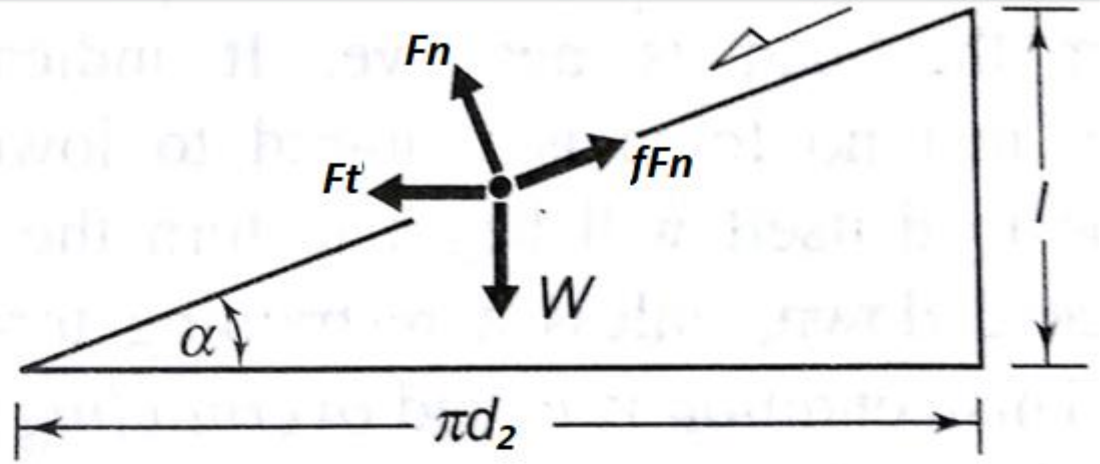
The effort Eqn 9.11a

$$F_t = W tan(\emptyset + \alpha)$$

The torque

$$T = \frac{F_t d_2}{2}$$ Eqn 9.11b

Torque requirement: Lowering load



Equilibrium of vertical and horizontal components

$$F_t = fF_n cos\alpha - F_n sin\alpha$$

$$W = F_n cos\alpha + fF_n sin\alpha$$

Dividing the above equations and further arithmetic substitutions

$$F_t = \frac{W(f - tan\alpha)}{(1 + ftan\alpha)}$$ Eqn 9.11d

The effort

$$F_t = Wtan(\emptyset - \alpha)$$ Eqn 9.11d

The torque

$$T = \frac{F_t d_2}{2}$$ Eqn 9.11e

Self locking screw

The torque

$$T = \frac{F_t d_2}{2} = \frac{W d_2 tan(\emptyset - \alpha)}{2}$$

If $\emptyset < \alpha$

Torque required to lower the load is negative

If $\emptyset \geq \alpha$

Torque required to lower the load is positive (**SELF LOCKING**)

A screw will be self locking if the coefficient of friction is equal to or greater than the tangent of the helix angle

$$f > \frac{l}{\pi d_2}$$

Causes of reduction in self locking property

- Lubrication
- High lead

Efficiency of square threaded screw

Work output=force X distance travelled in the direction of force= Wl

Work input = $F_t \pi d_2$

$$\eta = \frac{Work\ output}{Work\ input} = \frac{Wl}{F_t \pi d_2} = \frac{W}{F_t} tan\alpha$$

$$\eta = \frac{tan\alpha}{tan(\emptyset + \alpha)} = \frac{sin\alpha / cos\alpha}{sin(\alpha + \emptyset)/cos(\alpha + \emptyset)}$$

$$\eta = \frac{sin(2\alpha + \emptyset) - sin\emptyset}{sin(2\alpha + \emptyset) + sin\emptyset}$$

For η to be maximum $sin(2\alpha + \emptyset)$ should be maximum

$sin(2\alpha + \emptyset)$=1 $\qquad (2\alpha + \emptyset) = 90^o$

$$\eta = \frac{1 - sin\emptyset}{1 + sin\emptyset}$$

Efficiency of Self locking screw

$$\eta = \frac{tan\alpha}{tan(\emptyset + \alpha)}$$ Eqn 9.11f

For a self locking screw

$$\emptyset \geq \alpha$$

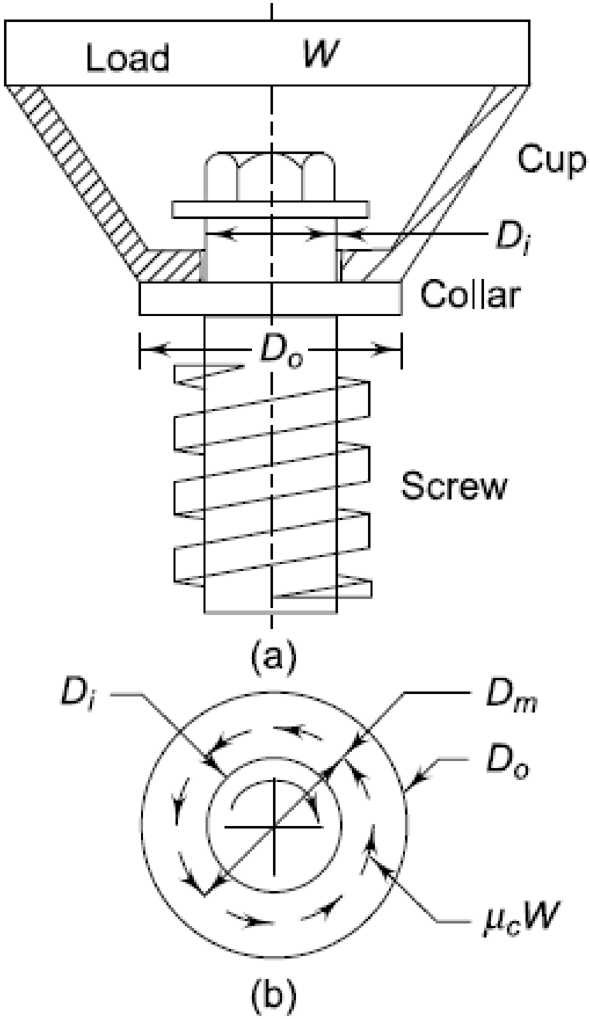
Substituting limiting value

$$\eta \leq \frac{tan\emptyset}{tan(2\emptyset)}$$

$$\eta \leq \left[\frac{1}{2} - \frac{tan^2\emptyset}{2}\right]$$

Maximum efficiency is less than ½ or 50%

Collar friction torque



- Relative motion between cup and collar induces Collar friction
- Torque required to overcome this collar friction is obtained using uniform pressure or uniform wear theory
- Normal force acting on collar: W
- Frictional force acting on collar: $f_c W$
- Zone of frictional force: D_m
- $T_c = \frac{f_c W}{2}(D_m)$ Eqn 9.11g

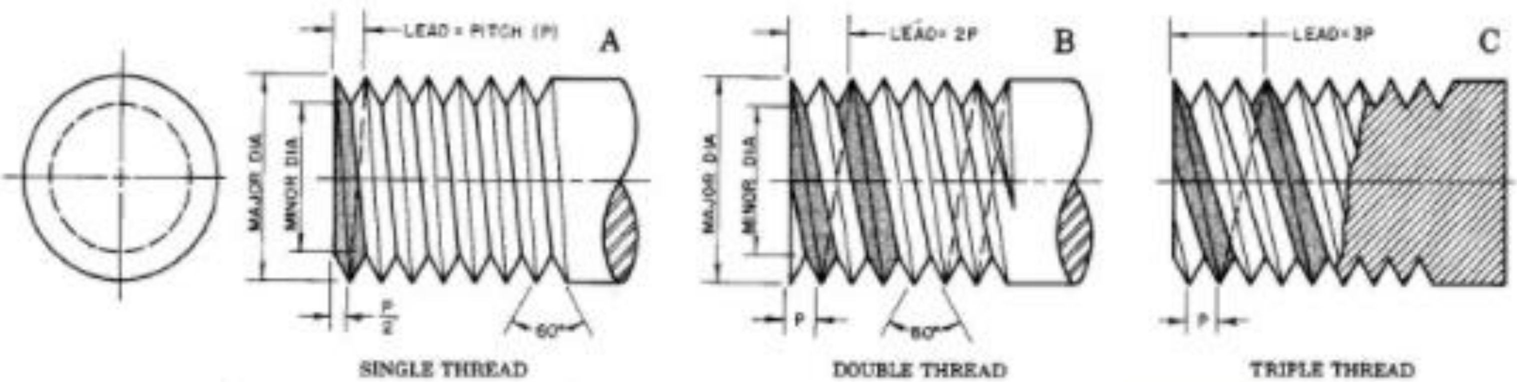
Overall Efficiency

- The total external torque

$$T_t = T + T_c$$

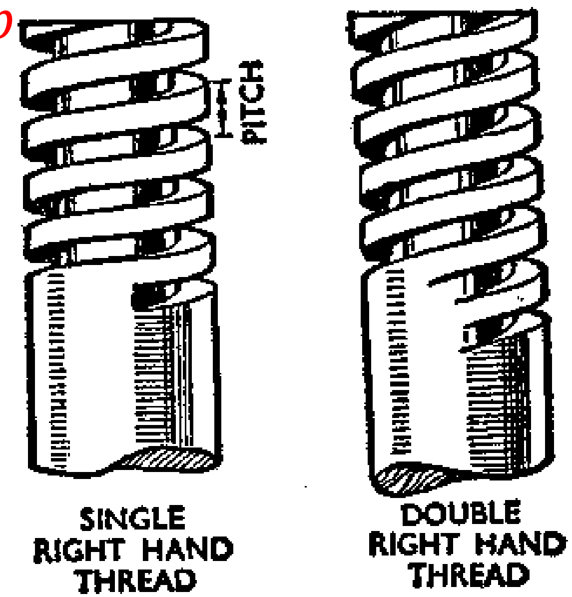
- Work output = Wl
- Work input: Torque X angle turned = $T_t 2\pi$
- Overall efficiency, $\eta_o = \frac{Wl}{2\pi(T)_t}$

Multiple threaded screw



$l = p$ $l = 2p$ $l = 3p$

- Double start or triple start screws
- Two or more threads cut side by side
- Large axial motion
- Efficiency high due to large helix angle
- Less mechanical advantage
- Self locking property may be lost



Problem 3.13

The nominal diameter of a triple threaded square screw is 50 mm, while the pitch is 8 mm. It is used with a collar having an outer diameter of 100 mm and inner diameter as 65 mm. The coefficient of friction at the thread surface as well as at the collar surface can be taken as 0.15. The screw is used to raise a load of 15 kN. Using the uniform wear theory for collar friction. Calculate

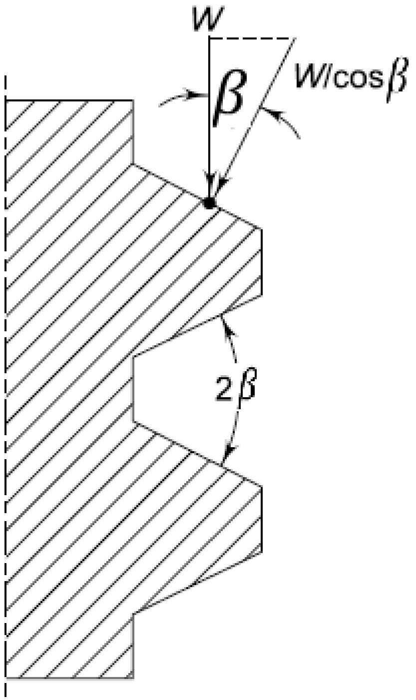
- Torque required to raise the load
- Torque required to lower the load
- The force required to raise the load, if applied at a radius of 500 mm

Efficiency of Trapezoidal and ACME threads

Normal force on thread surface = $W sec\ \beta$

Effect of thread angle: To increase frictional force

Coefficient of friction : f sec β



Lifting load

$$F_t = \frac{W(f sec\beta + tan\alpha)}{(1 - f\ \sec\beta\ tan\alpha)}$$ Eqn 9.10f

Lowering load

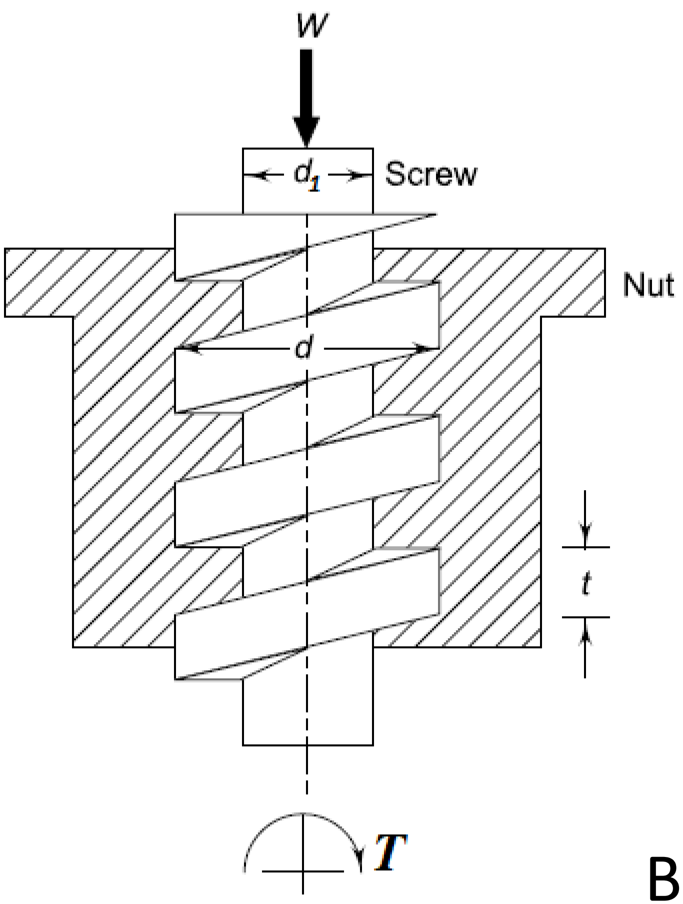
$$F_t = \frac{W(f sec\beta - tan\alpha)}{(1 + f\ \sec\beta\ tan\alpha)}$$

$$T = \frac{F_t d_2}{2}$$

Efficiency

$$\eta = \frac{tan\alpha(1 - f\ \sec\beta\ \tan\alpha)}{(f\ \sec\beta + \tan\alpha)}$$ Eqn 9.10g

Design of Screw and nut in Power Screw



Direct compressive stress and torsional shear stress

$$\sigma_c = \frac{W}{\frac{\pi}{4} d_1^2} \qquad \tau = \frac{16T}{\pi d_1^3}$$

Maximum principal shear stress

$$\tau_{max} = \sqrt{\left(\frac{\sigma_c}{2}\right)^2 + \tau^2}$$

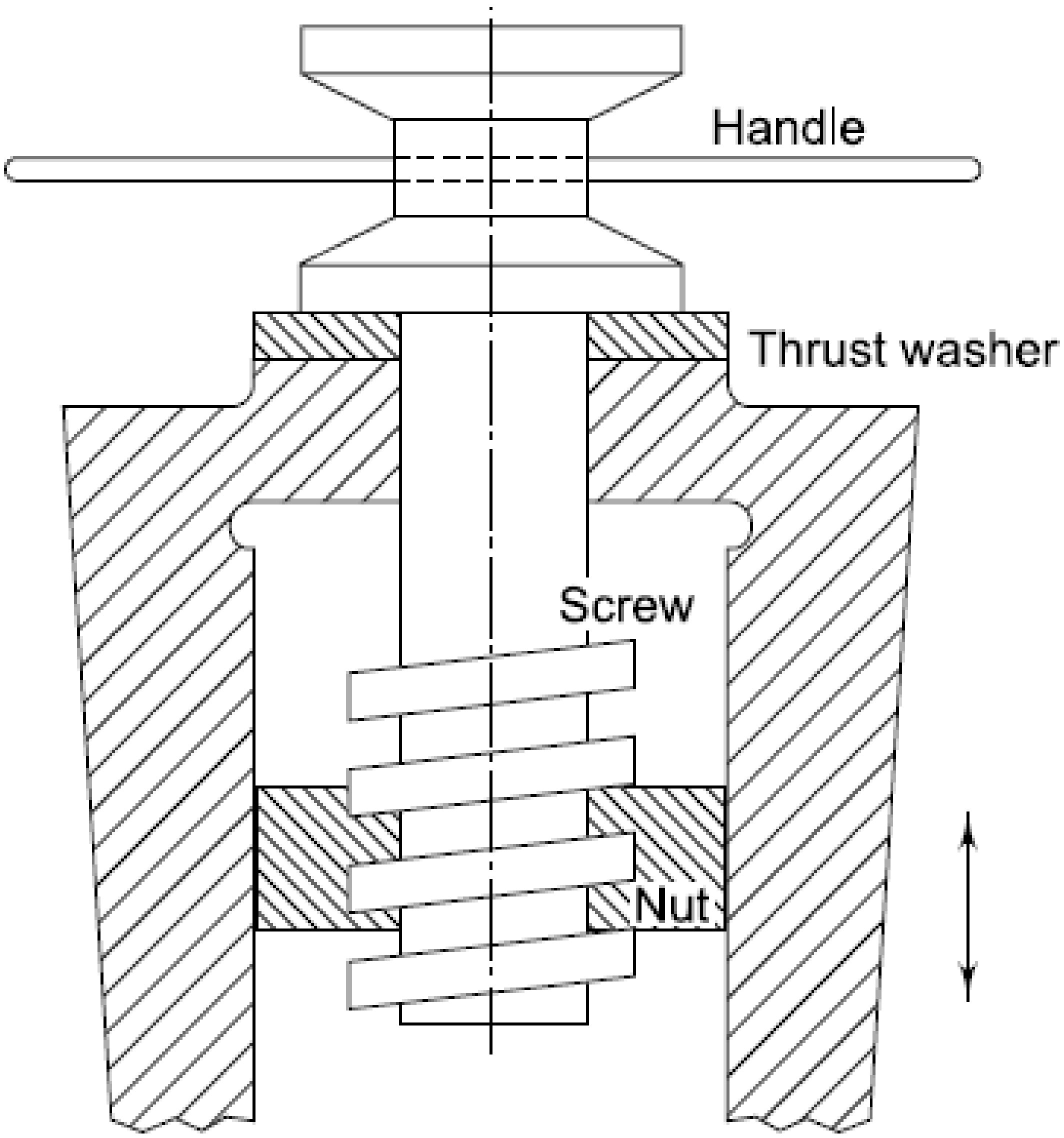
Transverse shear stress in the screw and nut

$$\tau_s = \frac{W}{\pi d_1 t n} \qquad \tau_n = \frac{W}{\pi d t n}$$

Bearing pressure between screw and nut

$$p_b = \frac{4W}{n\pi(d^2 - d_1^2)}$$ Eqn 9.13a

Problem 3.14



Problem 3.14

The construction of a gate valve used in high pressure pipeline is shown in Figure. The screw is rotated in its place by means of the handle. The nut is fixed to the gate. When the screw rotates, the nut along with the gate moves downward or upward depending upon the direction of rotation of the screw. The screw has single start square threads of 40 mm outer diameter and 7 mm pitch. The weight of the gate is 5kN. The water pressure in the pipeline induces frictional resistance between the gate and its seat. The resultant frictional resistance in the axial direction is 2 kN. The inner and outer diameters of thrust washer are 40 and 80 mm respectively. The values of coefficient of friction at the threads and at the washer are 0.15 and 0.12, respectively. The handle is rotated by the two arms, each exerting equal force at a radius of 500 mm from the axis of the screw. Calculate

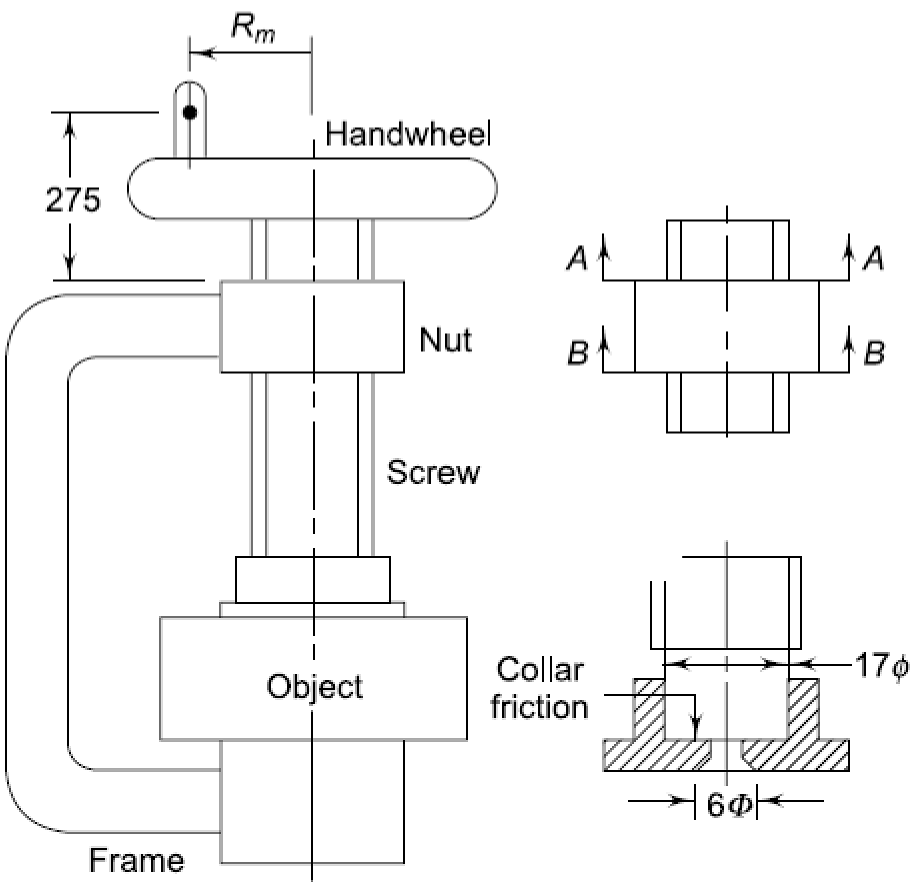
- The maximum force exerted by each arm when the gate is being raised
- The maximum force exerted by each arm when the gate is being lowered
- The efficiency of the gate mechanism
- The length of the nut, if the permissible bearing pressure is $5 N/mm^2$

Problem 3.15

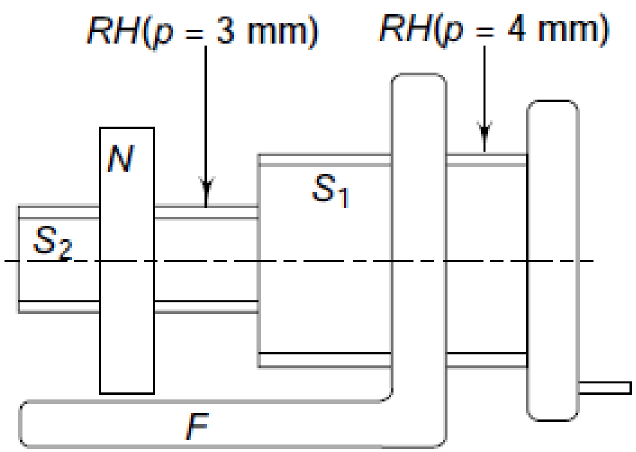
A single-start square threaded screw is used in a screw press to exert a force of 50 kN. The screw is made of plain carbon steel 10C4 (S_{ut} = 340 N/mm^2) and the factor of safety is 4. The permissible compressive stress is equal to permissible tensile stress and permissible shear stress is 50% of permissible tensile stress. The nut is made of grey cast iron FG200 and the permissible bearing pressure between contacting surface of screw and nut is 17 MPa. A low friction thrust ball bearing is used in the mechanism and collar friction can be neglected. The coefficient of friction at the thread surface between steel screw and cast iron nut can be taken as 0.15. Determine the size of screw and nut. Check the transverse shear in screw and nut. Axial length of thread in the nut. The axial length of threads in the nut should be between 1 to 1.5 times of the nominal diameter of screw.

Problem 3.16

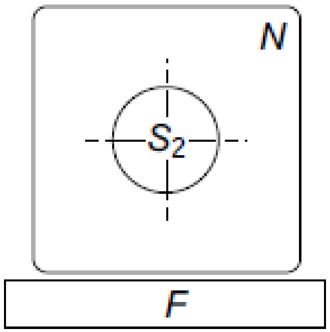
It is required to design a double start screw with square threads for the C clamp shown in Figure. The maximum force exerted by the clamp is 5kN. It is assumed that the operator will exert a force of 250 N at the ball handle of the hand wheel. The screw is made of plain carbon steel 45C8 (S_{yt}= 330N/mm^2), while the nut is made of grey cast iron FG200. The dimensions of the collar are given in Figure. The factor of safety is 2. Determine the dimensions of the screw and the nut also calculate the radius Rm of the ball handle. Assume permissible bearing pressure =15 N/mm^2



Differential and Compound Screws



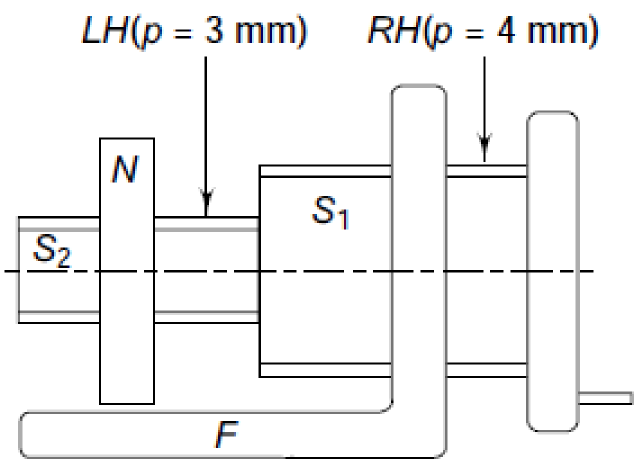
(a) Differential screw



(c)

A **differential screw** is defined as a mechanical device consisting of two screws in series, which are arranged in such a way that the resultant motion is the difference of individual motions of two screws

$$Resultant\ motion = p_1 - p_2$$



(b) Compound screw

A **compound screw** is defined as a mechanical device consisting of two screws in series, which are arranged in such a way that the resultant motion is the sum of individual motions of two screws

$$Resultant\ motion = p_1 + p_2$$

Differential and Compound Screws

Problem 3.17

A differential type of screw jack is shown in Figure. In the construction, the two screws do not rotate and the nut is rotated by the operator by applying a force of 100 N at a mean radius of 500 mm. The coefficient of friction at the threads is 0.15. Calculate

- The load that can be raised
- The efficiency of the screw jack