Chapter 4

THREADED FASTENERS

Bolted Joint

A *bolted joint* is temporary joint made using bolts. The mechanical joint made using bolts can be dismantled by loosening the nut accompanying the bolt, a threaded rod. A bolts is a round bar which is threaded at one end and fitted with a nut while the other end has a head, square or hexagonal shaped.

The best form of screw fastening is obtained using through bolts because when the screw is tightened using nut, the shank of the bolt is subjected to only tension. A *machine bolt* having rough shank and rough or good finished nuts are available in sizes varying from 6mm to 30mm. A *coupling bolt* is well machined bolt and is fitted into a reamed hole having same diameter as the bolt. A *carriage bolt* is used when the head must rest against wood. The portion of the shank at the head is square in shape to prevent the bolt from turning when the nut is tightened. A *stud bolt* more often called *stud* is used when it is desired to fasten two parts when it is not possible or not desirable to drill a hole entirely through the second part. Stud are particular convenient for positioning the covers of a cylinder head.

Initial stress in screw

There are three types of stresses induced in bolt or screw when it is screwed up. They are

i) ***Tensile stress*** *due to extension or stretching of bolt.*

ii) ***Torsional stress,*** caused by the frictional resistance of the thread during it tightening and

iii) ***Bending stress,*** *if the surfaces under the head or nut are not perfectly normal to the axis of bolt.*

If F is the tensile load acting on the member, A_c is the core area of bolt, then the tensile stress σ_t in the bolt is obtained from

$$\sigma_t = \frac{F}{A_c}$$

The *shear stress* τ in the bolt is calculated from the equation

$$\tau = \frac{M_t}{Z_t}$$

Where, M_t is the torque transmitted and

$Z_t = Section\ modulus\ in\ torsion\ and\ is\ given\ by$

$$Z_t = \frac{\pi d_1^3}{16}$$

Where, $d_1 = Core\ diamter\ of\ bolt$

With this value of Z_t,

$$\tau = \frac{M_t}{\frac{\pi d_1^3}{16}} = \frac{16 M_t}{\pi d_1^3}$$

The magnitude of maximum shear stress can be determined from equation

$$\tau = \frac{1}{2}\sqrt{\sigma^2 + 4\tau^2}$$

Stress due to external forces

Generally the external load applied to bolts tends to separate the connected machine parts in the direction of the bolt axis. Hence tensile stress is induced in the bolts. Similarly shear stresses are induced in bolts when they are used to prevent relative motion between two parts. When the load acts normal to the axis of bolt, there will be combined *tensile* and *torsional stress.* As far as possible the bolts should preferably not subjected to *shear.* If it cannot be avoided in design, the bolt shank should be accurately fitted in the hole.

Eccentrically loaded bolted joints with rectangular base (refer figure-4.1)

Consider a bracket held by four bolts supporting load *P* at a distance of *e* from the edge *AB.* Due to *F*, the bolts are subjected to *direct shear load* given by

$$F_d = \frac{P}{i}$$

Where, $P = Load\ applied$

$i = Number\ of\ bolts\ supporting\ load = 4$

Also, the load *P* causes the bracket to rotate in the clockwise direction about the edge *AB.* The *moment due to external load P is balanced by the moment due to loads carried by bolts at 1, 2, 3 and 4 given by*

$$Pe = \frac{F_1}{l_1}\left(l_1^2 + l_2^2 + l_3^2 + l_4^2\right)$$

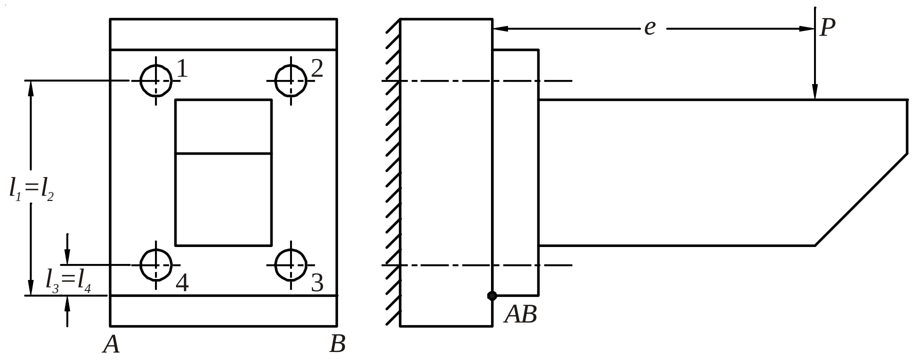


Figure-4.1

Where, l_1, l_2, l_3 *and* l_4 *are the distances of bolts 1,2,3 and 4 from edge AB*

From figure (4.1) $\quad l_1 = l_2$ *and* $l_3 = l_4$

Hence, $$P = \frac{F_1}{l_1}\left(2l_1^2 + 2l_3^2\right)$$

$$= \frac{2F_1}{l_1}\left(l_1^2 + l_3^2\right)$$

Where, $$\frac{F_1}{l_1} = \frac{F_2}{l_2} = \frac{F_3}{l_3} = \frac{F_4}{l_4}$$

Note: Since $\quad l_1 = l_2,\ F_1 = F_2$

$$l_3 = l_4,\ F_3 = F_4$$

Note: Since the stresses in the bolts are directly proportional to the distance from edge AB, the bolts away from AB are loaded more compared to those near to edge AB.

i.e., Bolts 1 and 2 are loaded more compared to bolts 3 and 4.

The maximum load on bolts 1 and 2 is

$$F_{\max} = F_d + F_1\left(or\ F_2\right)$$

Say $\quad F_{\max} = F_d + F_1$

Note: ***Knowing the maximum load on bolt and the stresses (design) for the materials of bolts, the size of bolts can be computed.***

It is very important to note that even though the bolts near the edge AB are loaded less compared to those away from AB, for convenience and economy, same size bolts are used at 1, 2, 3 and 4.

Eccentrically loaded bolted joint with circular base (Refer figure-4.2)

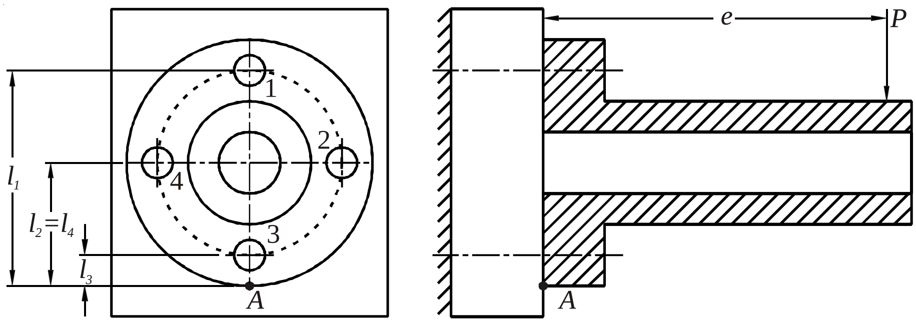


Figure-4.2

Consider a bracket with circular base supporting load *P* by four bolts 1, 2, 3 and 4 as shown in figure-4.2

The *direct shear load* F_d on each bolt is

$$F_d = \frac{P}{i}$$

Where, $P = Total\ load\ on\ bolts$

$i = Number\ of\ bolts = 4$

Therefore, $F_d = \frac{P}{4}$

The *secondary loads* due to eccentricity *e* causes the bracket to tilt about *A*. The moment due to *P* is Pe and is balanced by the moments due to loads at bolts 1, 2, 3 and 4 and is related by

$$Pe = \frac{F_1}{l_1}\left(l_1^2 + l_2^2 + l_3^2 + l_4^2\right)$$

Here, $l_2 = l_4 \quad (from\ figure\text{-}4.2)$

Therefore, $$Pe = \frac{F_1}{l_1}\left(l_1^2 + 2l_2^2 + l_3^2\right)$$

Where l_1, l_2, l_3 *and* l_4 are the distances of bolts 1, 2, 3 and 4 from *A*.

Also $$\frac{F_1}{l_1} = \frac{F_2}{l_2} = \frac{F_3}{l_3} = \frac{F_4}{l_4}$$

Since $$l_2 = l_4, \ \ F_2 = F_4$$

Note: The bolt farthest from A i.e., bolt 1 is loaded maximum and the maximum load on bolt at 1 is

$$F = F_d + F_1$$

As explained earlier, even though bolts 2, 3 and 4 are loaded less compared to bolt 1, for convenience and economy, bolts of same size are used at 1, 2, 3 and 4.

Example 4.1: An eye bolt is used to lift a load of 25kN. Using permissible tensile stress of 80MPa, determine the size of bolts required.

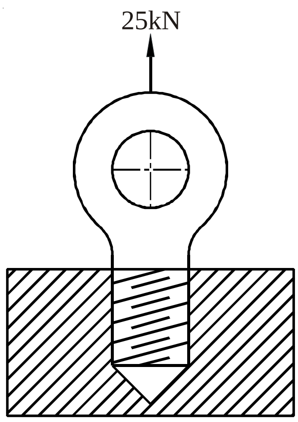


Figure-4.3

Solution:

$$F = Total\ tensile\ load\ on\ bolt = 25kN = 25 \times 10^3 N$$

$$\sigma_t = Permissible\ tensile\ stress = 80 MPa$$

Therefore, Core area of bolt required

$$A_c = \frac{F}{\sigma_t}$$

$$= \frac{25\times10^3}{80} = 312.5mm^2$$

Referring to table (18.7), for $A_c = 312.5mm^2$,

Select M22 × 2.0 bolt (ISO-metric screw threads)

Example 4.2: A bracket is fixed to the wall by means of four bolts and loaded as shown in figure-4.4. Calculate the size of the bolts if the load is 10kN and the allowable shear stress for bolt material is 40MPa.

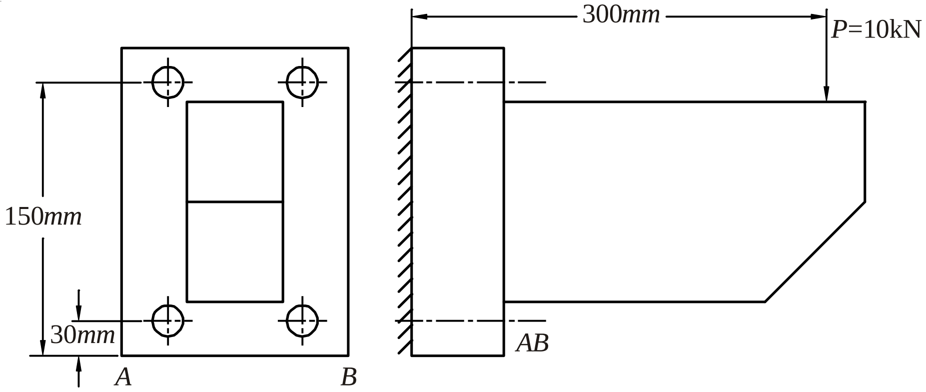


Figure-4.4

Solution:

The bolts are subjected to *direct shear load* given by

$$F_d = \frac{P}{i} = \frac{Total\ load}{Number\ of\ bolts}$$

$$= \frac{10\times10^3}{4} = 2.5\times10^3 N$$

The bending moment due to eccentricity is related by

$$Pe = \frac{F_1}{l_1}\left(l_1^2 + l_2^2 + l_3^2 + l_4^2\right)$$

Where, $l_1, l_2, l_3\ and\ l_4$ are the distances of bolts 1, 2, 3 and 4 from edge *AB*.

Also, $$\frac{F_1}{l_1} = \frac{F_2}{l_2} = \frac{F_3}{l_3} = \frac{F_n}{l_n}$$

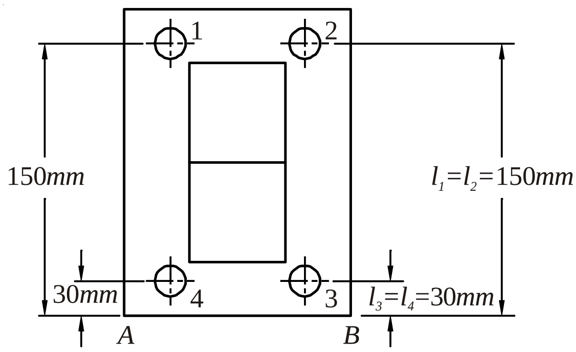


Figure-4.5

Therefore, $$Pe = \frac{F_1}{L_1}\left[2l_1^2 + 2l_3^2\right]$$

$$= \frac{2F_1}{l_1}\left[l_1^2 + l_3^2\right]$$

Where, $l_1 = 150mm,\quad l_3 = 30mm,\quad e = 300mm$

$$10\times10^3\times300 = \frac{2F_1}{150}\left(150^2 + 30^2\right)$$

i.e., $F_1 = 9615.39N = F_2$

Also, $$\frac{F_1}{l_1} = \frac{F_3}{l_3}$$

Therefore, $$F_3 = \frac{F_1}{l_1}\times l_3$$

$$= \frac{9615.39}{150}\times30N$$

$$= 1923N = F_4$$

Maximum load on bolts 1 and 2

$$= F_d + F_1$$

$$= 2.5\times10^3 + 9615.39$$

$$= 12115.4N$$

Load on bolts 3 and 4

$$= F_d + F_3$$
$$= 2.5 \times 10^3 + 1923$$
$$= 4423N$$

Note: From the above analysis, we find that bolts which are neared to edge AB are loaded less compared to those bolts which are away from AB.

Hence bolts 1 and bolt 2 are heavily loaded.
Now, equivalent shear load on bolts

$$F_\tau = \frac{1}{2}\sqrt{F_1^2 + 4(F_d)^2}$$
$$= \frac{1}{2}\sqrt{(12115.4)^2 + 4(2500)^2} = 6553.3N$$

Therefore, Shear stress

$$\tau = \frac{Maximum\ load, F_t}{Core\ area\ of\ bolts}$$

Therefore, Core area of bolts

$$A_c = \frac{Maximum\ load, F_t}{\tau}$$

Therefore, $Core\ area = \frac{6553.3}{40} = 163.8325mm^2$

Referring to table (18.7), corresponding to $A_c = 167mm^2$*, adopt M16 × 1.5 bolts (ISO-metric screw threads)*

Example 4.3: A bracket is fixed to a wall by means of 6bolts as shown in figure-4.6. Determine the size of bolts required by taking the permissible tensile stress in the bolts = 90MPa.

Solution:

The direct shear load F_d on each bolt is give by

$$F_d = \frac{P}{i}$$

Where, $P = load = 60kN = 60 \times 10^3 N$

$i = Number\ of\ bolts = 6$

Therefore, $F_d = \frac{60 \times 10^3}{6} = 10^4 N$

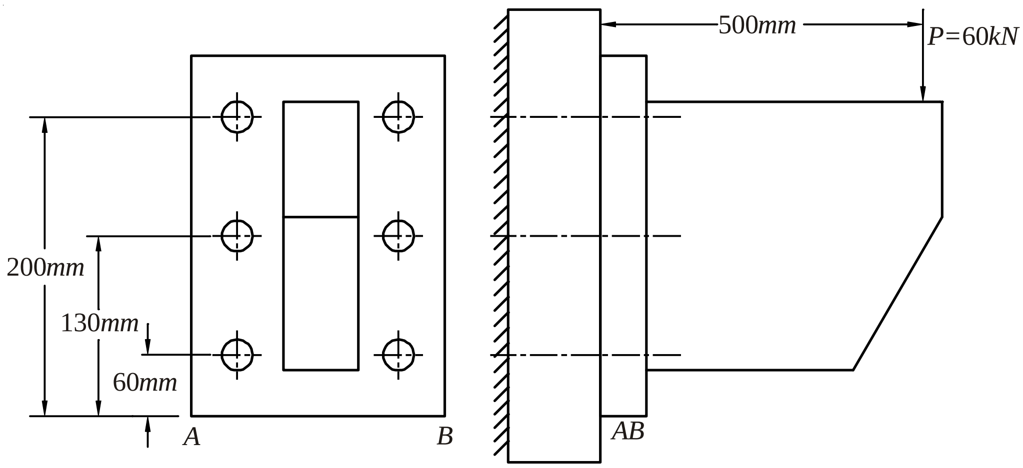


Figure-4.6

Due to bending , let F_1, F_2, F_3 etc., be the secondary loads at bolts 1, 2, 3, etc.

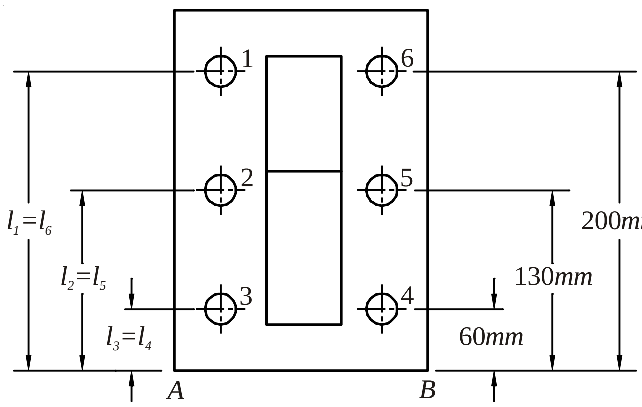


Figure-4.7

Taking moments of loads at bolts 1 to 6 about edge AB, and equating it to the moment due to external load i.e., Pe

$$Pe = \frac{F_1}{l_1}\left(l_1^2 + l_2^2 + l_3^2 + l_4^2 + l_5^2 + l_6^2\right)$$

Where, $e = eccentricity = 500mm$

From figure-4.7,

$$l_1 = l_6 = 200mm$$

$$l_2 = l_5 = 130mm$$

$$l_3 = l_4 = 60mm$$

Therefore, $Pe = \frac{F_1}{l_1}\left[2\left(l_1^2 + l_2^2 + l_3^2\right)\right]$

$$60 \times 10^3 \times 500 = \frac{F_1}{200}\left[2\left(200^2 + 130^2 + 60^2\right)\right]$$

$$F_1 = 49586.78N = F_6$$

But, $\frac{F_1}{l_1} = \frac{F_2}{l_2}$

Therefore, $F_2 = \frac{F_1}{l_1} \times l_2$

$$= \frac{49586.78}{200} \times 130 = 322314N = F_5$$

Finally, $\frac{F_1}{l_1} = \frac{F_3}{l_3}$

Therefore, $F_3 = \frac{F_1}{l_1} \times l_3$

$$= \frac{49586.78}{200} \times 60 = 14876N = F_4$$

It is obvious from the above analysis that the load on bolts 1 and 6 is maximum and is least on bolts 3 and 4. i.e., bolts farthest from the edge AB are loaded maximum.

Equivalent tensile load on bolts at 1 and 2 is

$$F_\tau = \frac{1}{2}\sqrt{F_1^2 + 4\left(F_d\right)^2}$$

$$= \frac{1}{2}\left(49586.78 + \sqrt{49586.74^2 + 4\left(10^4\right)^2}\right)$$

$= 51527.5N$

Therefore, Tensile stress σ_t in bolt is

$$\sigma_t = \frac{F_t}{A_c}, \text{ from which}$$

Therefore, $$A_c = \frac{51527.5}{\sigma_t}$$

$$= \frac{51527.5}{90} = 572.53mm^2$$

Referring table (18.7), for $A_c = 581mm^2$, *Select M30 × 3 bolts (ISO-metric screw threads)*

Example 4.4: A steel bracket weighing 1.5kN is fastened to a vertical support by four bolts, 2 at 1-1 and 2 at 2-2. The total tension in the vertical direction is 10kN. Taking the permissible shear stress for the bolt materials as 60MPa, determine the standard size of bolts required.

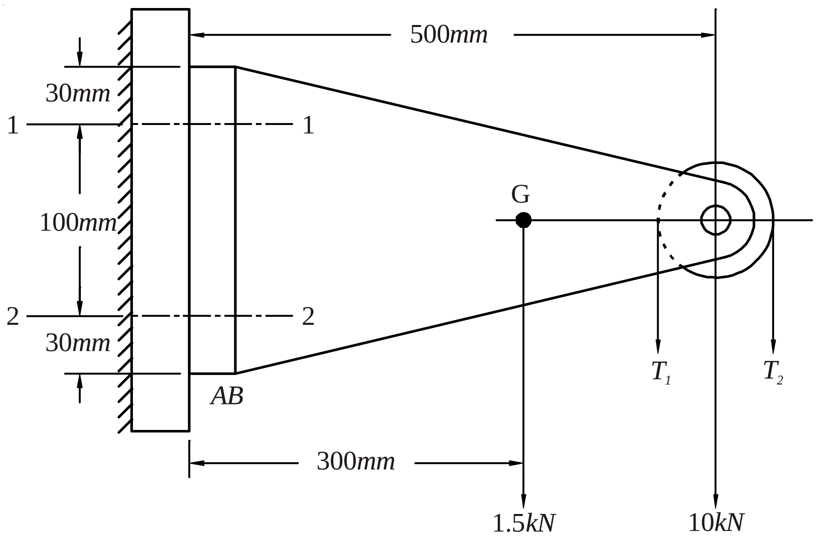


Figure-4.8

Solution:

The total load P ob bolts $= 10 + 1.5$

$$= 11.5kN = 11.5 \times 10^3 N$$

Number of bolts sharing load $i = 4$

Therefore Shear load on each bolt is given by

$$F_d = \frac{P}{i}$$

$$= \frac{11.5\times10^3}{4} N$$

$$= 2.875\times10^3 N$$

Due to eccentricity, $e = 500mm,$

$$Pe = \frac{F_1}{l_1}\left(l_1^2 + l_2^2 + l_3^2 + l_4^2\right)$$

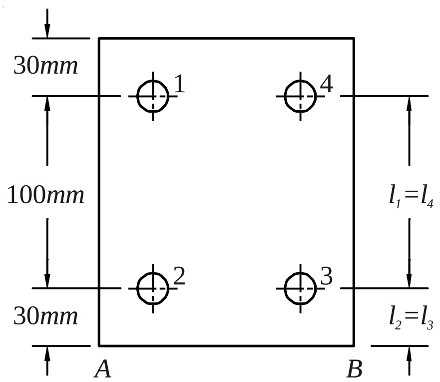


Figure-4.9

Also, $$\frac{F_1}{l_1} = \frac{F_2}{l_2} = \frac{F_3}{l_3} = \frac{F_4}{l_4}$$

And $$l_1 = l_4 = 130mm$$

$$l_2 = l_3 = 30mm \text{ with respect to } AB$$

$$M_b = \frac{F_1}{l_1}\left[2\left(l_1^2 + l_2^2\right)\right] = Pe$$

Here, $$M_b = \left(10\times10^3\right)\times500 + \left(1.5\times10^3\right)\times300$$

$$= 92\times10^5 \text{ N-mm}$$

Therefore, $$92\times10^5 = \frac{F_1}{130}\left[2\left(130^2 + 30^2\right)\right]$$

$$F_1 = 33595.51N = F_4 \quad because \; l_1 = l_4$$

Also $$\frac{F_1}{l_1} = \frac{F_2}{l_2}$$

Therefore, $$F_2 = \frac{F_1}{l_1} \times l_2$$

$$= \frac{3359.51}{130} \times 30$$

$$= 7752.81N = F_3 \quad because \; l_2 = l_3$$

Therefore, bolts 1 and 4 are heavily loaded.
The equivalent shear load on bolts at 1 and 3 is given by

$$F_\tau = \frac{1}{2}\sqrt{F_1^2 + 4\left(F_d\right)^2}$$

$$= \frac{1}{2}\sqrt{33595.51^2 + 4\left(2875\right)^2}$$

$$= 17042.01N$$

From shear stress $\tau = \dfrac{F_t}{A_c}$

Therefore, $$A_c = \frac{17042.01}{\tau}$$

$$= \frac{17042.01}{60} = 284.03mm^2$$

Referring table (18.7), for $A_c = 303mm^2$ (nearest higher value of A_c), select M22 $\times$ 2.5 bolts (ISO - metric screw threads)

Example 4.5: A flanged bearing shown in figure-6.10 is fastened to a frame by six bolts equally spaced on a bolt circle of 300mm diameter. The diameter of the flange is 400mm and a load of 40kN is applied at a distance of 250mm from the frame. Taking the safe tensile stress as 60MPa for material of bolt, determine the size of bolts required.

(VTU-July/August 2002)

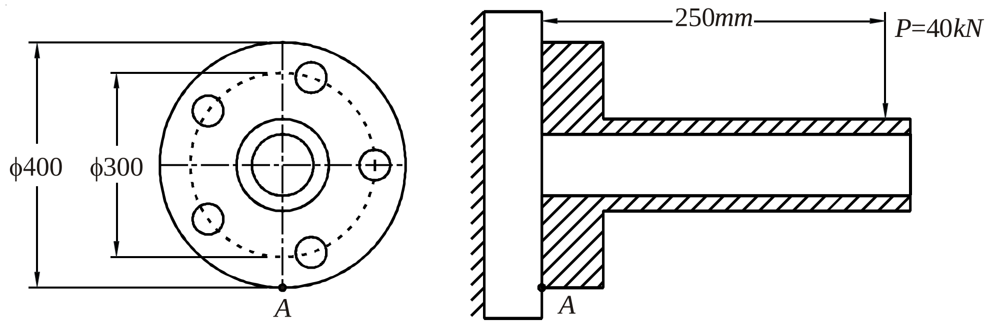


Figure-4.10

Solution:

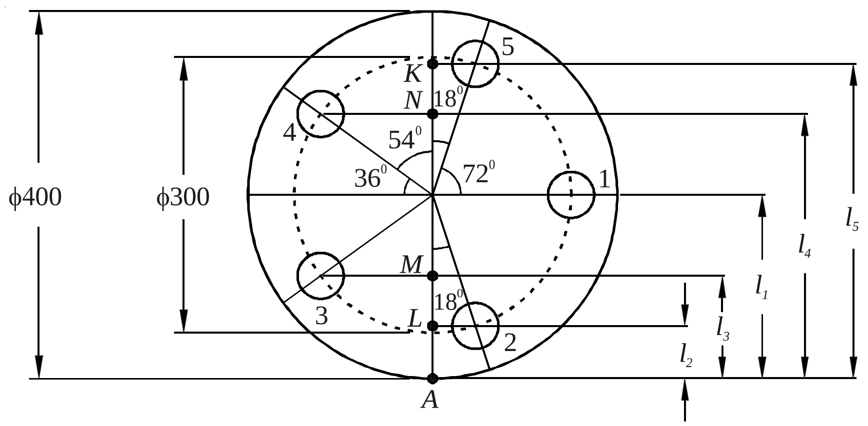


Figure-4.11

$l_1 = 200mm = OA$

$l_2 = OA - OL = AL$

$= 200 - 150\cos 18^0 = 57.34mm$

$l_3 = OA - OM$

$= 200 - 150\cos 54^0 = 111.83mm$

Where, $ON = OM$

$l_4 = 200 + 150\cos 54^0 = 288.17mm$

$l_5 = AK = OA + OK$

$= 200 + 150\cos 18^0 = 342.66mm$

Direct shear load F_d on each bolt is given by

$$F_d = \frac{P}{i}$$

Where, $P = Total\ load = 40kN = 40 \times 10^3 N$

$i = Number\ of\ bolts\ sharing\ load = 5$

Therefore, $F_d = \frac{40 \times 10^3}{5} = 8000N$

Due to eccentricity,

$$Pe = \frac{F_1}{l_1}\left(l_1^2 + l_2^2 + l_3^2 + l_4^2\right)$$

Where, $e = 250mm$

Therefore,

$$\left(40 \times 10^3\right) \times 250 = \frac{F_1}{200}\left[200^2 + 57.34^2 + 111.83^2 + 288.17^2 + 342.66^2\right]$$

i.e., $F_1 = 7804.83N$

and $F_5 = \frac{F_1}{l_1} \times l_5$

$$= 7804.83 \times \frac{342.66}{200} = 13372.01N$$

Note:* *Since bolt 5 is farthest from end A, bolt 5 is heavily loaded compared to the remaining four bolts.

Therefore, Equivalent shear load on bolt 5 is

$$F_\tau = \frac{1}{2}\sqrt{F_5^2 + 4\left(F_d\right)^2}$$

$$= \frac{1}{2}\sqrt{\left(13372.01\right)^2 + 4\left(8000\right)^2}$$

$$= 17340.78N$$

Therefore, from shear stress

$$\tau = \frac{F_t}{A_c}$$

$$A_c = \frac{176340.78}{60} = 298mm^2$$

Referring table (18.7) for $A_c = 303mm^2$, *select* $M\,22 \times 2.5\,bolts$

Example 6.6: The cylinder head of a stem engine is held in position by 10 bolts. The diameter of the cylinder is 400mm and the maximum pressure of stem in cylinders is 1MPa. A copper gasket is used to make the joint leak proof. Determine the standard size of bolts required by taking the design tensile stress for bolt material equal to 90MPa.

Solution:

The maximum tensile load F_f is given by

$$F_f = KF_a + F_i \qquad \text{... E(18.4)}$$

Where, $F_a = External\ load\ on\ each\ bolt\ in\ kN$

$D_i = Inside\ diameter\ of\ cylinder\ in\ mm.$

$P_f = Steam\ pressure\ in\ N/mm^2$

Therefore, $$F_a = \frac{Steam\ load}{Number\ of\ bolts}$$

$$= \frac{\frac{\pi}{4}(D_i)^2 P_f}{10}$$

$$= \frac{\frac{\pi}{4}(400)^2 \times 1}{10}$$

$$= 12566.37N = 12.5664kN$$

$F_i = Initial\ tightening\ load$

$$= 2804.69d \qquad \text{... E(18.5a)}$$

Where, $F_i\ is\ in\ kN$

d, *the outside diameter of bolt in meter*

$$K = Gasket\ factor \qquad \text{... T(18.1)}$$

For copper Gasket, $K = 0.4$

Therefore, $F_f = 0.4 \times 12.5664 + 2804.69d$

$$= 5.02656 + 2804.69d$$

Equating $F_f \ to \ \frac{\pi}{4} d_c^2 \sigma_t$

Where, $\sigma_t \ is \ in \ kN/m^2$

i.e., $\left(5.02656 + 2804.69d\right) = \frac{\pi}{4} d_c^2 \left(90000\right)$

Assuming, $d_c = 0.8d \ and \ using$

$$\sigma_t = 90 \ N/mm^2 = 90000 \ kN/m^2 \left(given\right)$$

$$\left(5.02656 + 2804.69d\right) = \frac{\pi}{4}\left(0.8d\right)^2 \times \left(90000\right)$$

$$20.106 + 11218.76d = 180955.75d^2$$

i.e., $d^2 - 0.062d - 0.001 = 0$

$$d = \frac{0.062 \pm \sqrt{\left(0.062\right)^2 + 4 \times 0.0001}}{2}$$

$$= 0.6357 \ meter$$

$$= 63.57mm = 64mm$$

Therefore, core area

$$A_c = \frac{\pi}{4}\left(0.8d\right)^2$$

$$= \frac{\pi}{4}\left(0.8 \times 64\right)^2$$

$$= 2058.9mm^2$$

Refer table (18.7) to obtain the standard size of bolts as $M\,60 \times 5.5$

Example 6.7: The cylinder of a stationary engine is 120mm in diameter and is held to the crank case by M12 × 1.75 Cr-Ni steel bolts. The maximum gas pressure in the cylinder is 3.5MPa. Assume the ultimate strength of steel as 800MPa and yield stress as 600MPa. Determine the number of bolts required. Take gasket factor = 0.75.

(VTU-July/August 2003)

Solution:

The bolts are subjected to *fluctuating axial loads* and the *Soderberg's equation* for fluctuating axial load is

$$\frac{\sigma_a}{\sigma_{-1d}} + \frac{\sigma_m}{\sigma_{yd}} = 1 \qquad \text{... E(5.40)}$$

To find σ_a, the stress amplitude

$$\sigma_a = Stress\ amplitude = \frac{F_a}{A}$$

Where, $$F_a = Load\ amplitude = \frac{F_{\max} - F_{\min}}{2}$$

To find $F_{\max}$ and $F_{\min}$

$$F_{\max} = F_f = KF_a + F_1 \qquad \text{... E(18.4)}$$

Where, $K = Gasket\ \ factor = 0.75$

$F_a = External\ load\ on\ each\ bolt$

$$= \frac{Gas\ load}{Number\ of\ bolts} = \frac{\frac{\pi}{4}(D_i)^2 \times p_f}{i}$$

$$= \frac{\frac{\pi}{4}(120)^2 \times 3.5}{i} = \frac{39584.1}{i}$$

$$F_a = \frac{39.5841}{i} kN$$

$$F_i = Initial\ tightening\ load = 2804.69d \qquad \text{... E(18.5a)}$$

Where, $d = Outside\ diameter\ of\ bolt\ in\ meter$

$$F_i = 2804.69 \times \frac{12}{1000} kN$$

$$= 33.656 kN$$

Note: M12 × 1.75 bolts have $d = 12mm = \frac{12}{1000} meter$

Therefore, $F_{\max} = 0.75\left(\dfrac{39.5841}{i}\right) + 33.656$

$$= \frac{29.69}{i} + 33.656kN$$

$$F_{\min} = F_i = 33.656kN$$

Therefore, $F_a = \dfrac{F_{\max} - F_{\min}}{2}$

$$= \frac{\left(\dfrac{26.69}{i} + 33.656\right) - 33.656}{2}$$

$$F_a = \frac{14.845}{i}$$

Therefore, $\sigma_a = \dfrac{F_a}{A}$

$$= \frac{14.845}{Ai}$$

$$A = A_c = \frac{\pi}{4} d_c^2$$

For, $d = 12mm,\ A_c = A = 84.3mm^2$ ... T(18.7)

Therefore, $\sigma_a = \dfrac{14.845}{84.3i}$

$$= \frac{0.1761}{i}$$

To find F_m, the mean load

$$F_m = \frac{F_{\max} + F_{\min}}{2}$$

$$= \frac{\left(\dfrac{2969}{i} + 33.656\right) + 33.656}{2}$$

$$= \frac{14.845}{i} + 33.656$$

Therefore, $$\sigma_m = \frac{\frac{14.845}{i} + 33.656}{A}$$

$$= \frac{\frac{14.845}{i} + 33.656}{84.3}$$

$$= \frac{0.1761}{i} + 0.3992$$

To find σ_{-1d}, the design endurance stress

$$\sigma_{-1d} = \frac{\sigma_{-1}}{n_{-1d}}$$

Where, $$\sigma_{-1} = 0.5\sigma_u$$

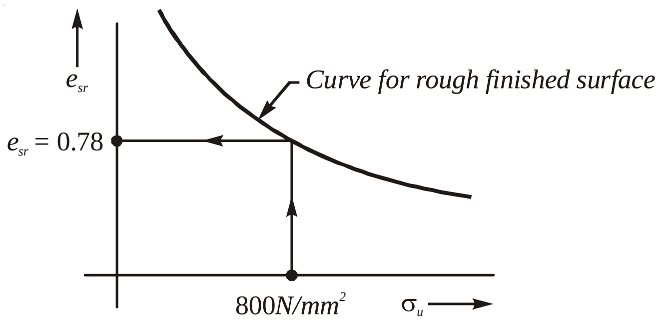
$$= 0.5 \times 800 = 400 MPa$$

$$= 400 \times 10^3\ kN/m^2$$

$$n_{-1d} = K_{sz}\ K_{sr}\ K_l\ n_{-1a}$$

$$K_{sz} = Size\ \ factor = 0.85$$

$$K_{sr} = Surface\ \ factor = \frac{1}{e_{sr}}$$



$$K_l = Load\ \ factor = 0.7\ for\ axial\ loading$$

$$n_{-1a} = \text{factor of safety} = 2$$

$$n_{-1d} = 0.85 \times \frac{1}{e_{sr}} \times 0.7 \times 2$$

Therefore, $$n_{-1d} = 0.85 \times \frac{1}{0.78} \times 0.7 \times 2$$

$$= 1.5256$$

$$\sigma_{-1d} = \frac{400 \times 10^3}{1.5256}$$

$$= 263291.9245\, kN/m^2$$

To find σ_{yd}, the design yield stress

$$\sigma_{yd} = \frac{\sigma_y}{n_{yd}}$$

Where, $$\sigma_y = 600 MPa = 600 \times 10^3\, kN/m^2$$

$$n_{yd} = K_{sz}\ K_{\sigma a}\ n_{ya}$$

$$= 0.85 \times 1 \times 2 = 1.7$$

Therefore, $$\sigma_{yd} = \frac{600 \times 10^3}{1.7}$$

$$= 352941.18\, kN/m^2$$

Substituting in *Soderberg's equation* we get,

$$\frac{\frac{0.1761}{i}}{262191.9245} + \frac{\left(\frac{0.1761}{i} + 0.3992\right)}{352941.18} = 1$$

$$\frac{6.7165 \times 10^{-7}}{i} + \frac{4.9895 \times 10^{-7}}{i} + 1.1311 \times 10^{-6} = 1$$

$$\frac{11.706}{i} = 1 - 1.311 \times 10^{-6}$$

$$\frac{11.706}{i} = 0.99999$$

Therefore, $i = 12\ bolts$

Example 4.8: A steel bracket weighing 2kN is fastened to a support by six steel bolts as shown in figure-4.12. The total belt tension assumed to be acting at the centre of pulley is 15kN. Using M18 × 15 bolts and permissible shear stress as 60MPa for the bolt material, determine x, the distance of the centre of gravity of pulley and bracket from AB, the bottom edge of bracket.

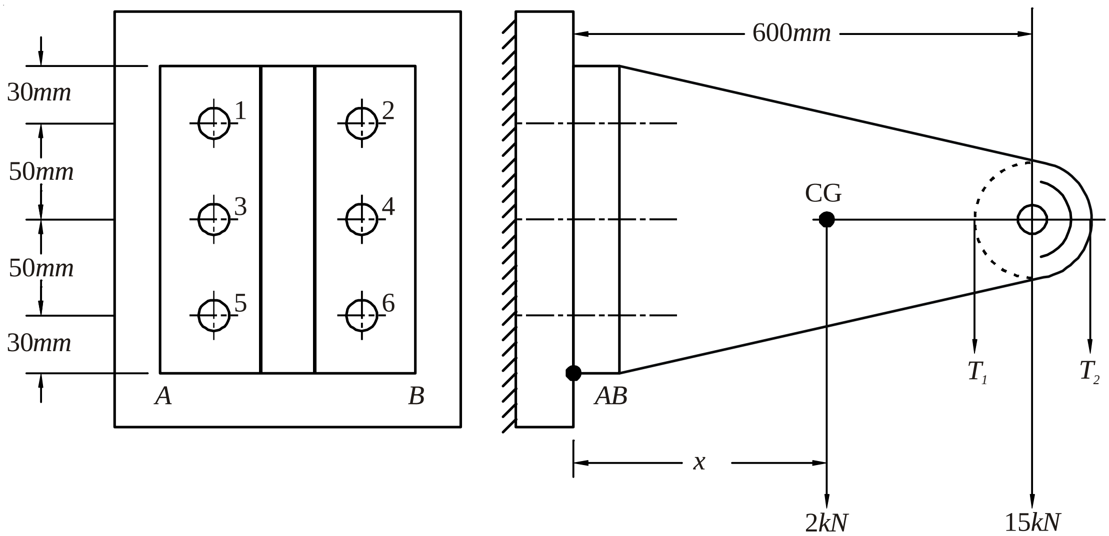


Figure-4.12

Solution:

The total shear load P on bolts $= 2 + 15 = 17kN = 17 \times 10^3\ N$

Number of bolts, $i = 6$

The direct shear load on each bolt is given by

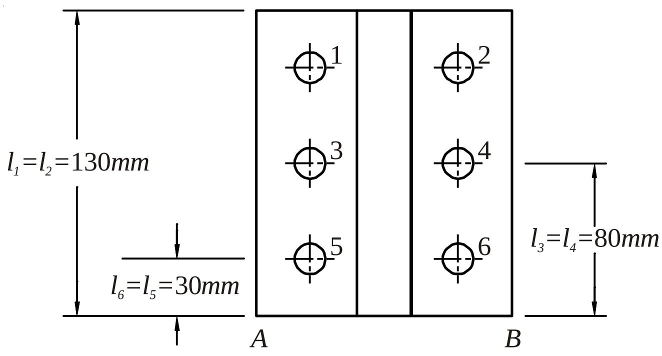
$$F_d = \frac{P}{i}$$

i.e., $$F_d = \frac{17 \times 10^3}{6} N$$

$$= 2.833 \times 10^3\ N$$

The bending moment due to eccentricity is obtained by equating the moment due to external loads resisting moment of bolts. i.e.,

$$Pe = \frac{F_1}{l_1}\left(l_1^2 + l_2^2 + l_3^2 + l_4^2 + l_5^2 + l_6^2\right)$$



Since, $l_1 = l_2,\; l_3 = l_4,\; l_5 = l_6$

$$Pe = 2\frac{F_1}{l_1}\left(l_1^2 + l_3^2 + l_4^2\right)$$

Where, $l_1 = Distance\ of\ bolt\ 1\ from\ AB$

$= 130mm = l_2$

$l_3 = 80mm = l_4$

$l_5 = 30mm = l_6$

Therefore, $\left(2\times10^3\right)\times x + \left(15\times10^3\right)\times 600 = \frac{2F_1}{130}\left[130^2 + 80^2 + 30^2\right]$

$x + 4500 = 0.18615F_1$

i.e., $x = 0.18615F_1 - 4500$

To find F_1

Note: The bolts 1 and 2 are farthest from bottom edge AB of bracket and hence are heavily loaded. The equivalent shear load on bolts 1 and 2 is

$$F_\tau = \frac{1}{2}\sqrt{F_1^2 + 4\left(F_d\right)^2}$$

Where, $F_\tau = \tau A_c$

$A_c = Core\ area\ of\ bolts$

$For\ M18\times1.5\ ISO\text{-}metric\ screw\ threads$, Referring to table (18.7), A_c is $216mm^2$

Therefore, $F_\tau = 60\times216 = 12960N$

i.e., $12960 = \frac{1}{2}\sqrt{F_1^2 + 4\left(2.833\times10^3\right)^2}$

From which, $F_1 = 25293.14F$

Now, from $x = 0.18615F_1 - 4500$

$x = 25293.14\times0.18615 - 4500$

$= 208.32mm$

Therefore, Distance of centre of gravity 'G' from AB is 208.32*mm*.

Example 4.9: A flanged bearing shown in figure-4.13 is fastened to a frame by four bolts equally spaced on a pitch circle diameter of 400mm. The diameter of the flange is 500mm. Taking the permissible shear and tensile stresses as 60 and 90MPa respectively, determine the size of bolts required for a load of 40kN acting at a distance of 600mm as shown.

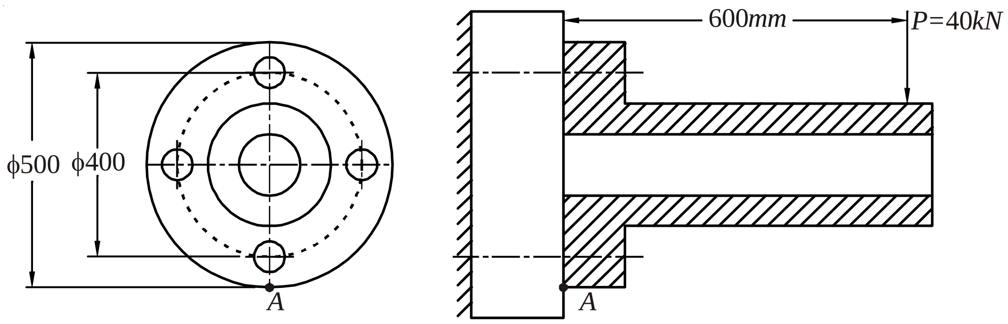


Figure-4.13

Solution:

The total load P on bolts $= 40kN = 40\times10^3\,N$

Number of bolts sharing the load $i = 4$

Therefore, direct shear load on each bolt is given by,

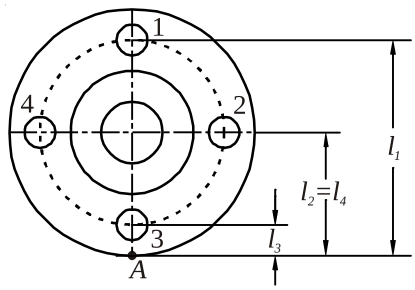
$$F_d = \frac{P}{i}$$

$$= \frac{40\times10^3}{4}N$$

$$= 10 \times 10^3 = 10^4 N$$

Bending moment due to eccentricity '*e*' is given by

$$Pe = \frac{F_1}{l_1}\left(l_1^2 + l_2^2 + l_3^2 + l_4^2\right)$$



With reference to *A*,

$$l_1 = 400 + 50 = 450mm$$

$$l_2 = l_4 = 250mm$$

$$l_3 = 50mm$$

$$40 \times 10^3 \times 600 = \frac{F_1}{450}\left[450^2 + 2\left(250^2\right) + 50^2\right]$$

$$F_1 = 32727.27N$$

Now from, $\frac{F_1}{l_1} = \frac{F_3}{l_3}$

Therefore, $F_3 = \frac{F_1}{l_1} \times l_3$

$$= \frac{32727.27}{450} \times 50 = 3636.36N$$

Note: Since bolt 1 farthest from A, it is heavily loaded

The equivalent shear load on bolt 1 is given by

$$F_\tau = \frac{1}{2}\sqrt{F_1^2 + 4\left(F_d\right)^2}$$

$$= \frac{1}{2}\sqrt{32727.27^2 + 4\left(10^4\right)^2}$$

$$= 17177.3N$$

$$\tau = \frac{F_t}{A_c}$$

i.e. $$A_c = \frac{F_t}{\tau}$$

$$= \frac{19177.3}{60} = 319.62mm^2$$

The equivalent tensile load on bolt 1 is

$$F_t = \frac{1}{2}\left[F_1 \pm \sqrt{F_1^2 + 4F_d^2}\right]$$

$$= \frac{1}{2}\left[(32727.27) \pm \sqrt{32727.27^2 + 4(10^4)^2}\right]$$

$$= 35540.93N$$

From, $$\sigma_t = \frac{F_t}{A_c}$$

$$A_c = \frac{F_1}{\sigma_1}$$

$$= \frac{35540.93}{90} = 394.9mm^2$$

Adopt $A_c = 394.9mm^2$ (higher of the two values of A_c)

Referring table (18.7), for $A_c = 401mm^2$, *select* $M\,24 \times 1.5$ *bolts (ISO-metric screw threads)*

Example 4.10: A bracket is fastened to a vertical plate by 4 bolts as shown in figure-4.14. Determine the size of bolts so that the maximum shear stress is not exceed 60MPa.

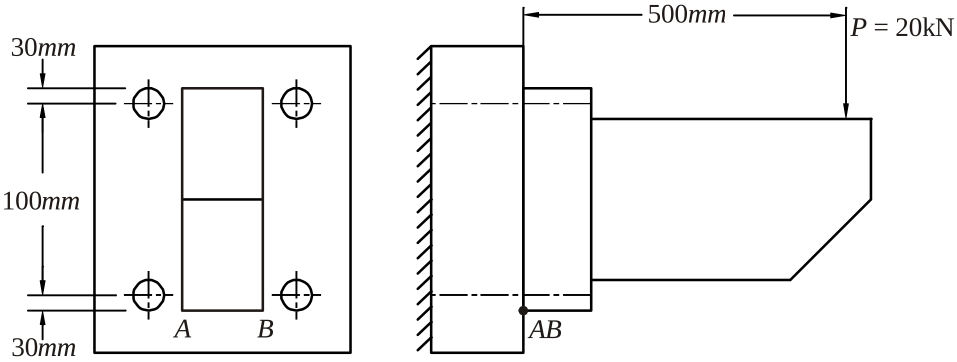


Figure-4.14

Solution:

The total load on bolts, $P = 20kN = 20 \times 10^3 N$

The number of bolts sharing the load, $i = 4$

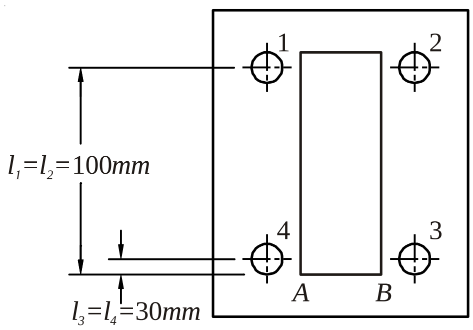
Therefore, direct shear F_d on each bolts is

$$F_d = \frac{P}{i}$$

$$= \frac{20 \times 10^3}{4} = 5 \times 10^3 = 5000N$$

Due to eccentricity in loading, the moment due to external load = Moment offered by loads at bolts 1, 2, 4 and 4 about edge *AB*

$$i.e., \quad Pe = \frac{F_1}{l_1}\left(l_1^2 + l_2^2 + l_3^2 + l_4^2\right)$$



Here, $l_1 = l_2 = 130mm, \quad l_3 = l_4 = 30mm$

Therefore, $$Pe = \frac{F_1}{l_1}\left[2\left(l_1^2 + l_4^2\right)\right]$$

$$= \frac{2F_1}{l_1}\left[\left(l_1^2 + l_4^2\right)\right]$$

$$20 \times 10^3 \times 5000 = \frac{2F_1}{130}\left(130^2 + 30^2\right)$$

$$F_1 = 365168.54N = F_2, \qquad \textit{because } l_1 = l_2$$

From, $$\frac{F_1}{l_1} = \frac{F_3}{l_3}$$

Therefore, $$F_3 = \frac{F_1}{l_1} \times l_3$$

$$= \frac{365168.54}{130} \times 30N$$

$$= 84269.66N = F_4, \qquad \textit{because } l_3 = l_4$$

Equivalent shear load at bolts 1 and 2 is

$$F_{\tau_1} = \frac{1}{2}\sqrt{F_1^2 + 4\left(F_d\right)^2}$$

$$= \frac{1}{2}\sqrt{\left(365168.54\right)^2 + 4\left(5000\right)^2}$$

$$= 182652.72N$$

Core area, $$A_{c_1} = \frac{F_{\tau_1}}{\tau}$$

$$= \frac{182652.72}{60} = 3044.21mm^2$$

Referring table (18.7), for $A_{c_1} = 3460mm^2$, select $M72 \times 6$ *ISO-metric screw threads* for bolts 1 and 2.

Similarly equivalent shear load at bolts 3 and 4 is

$$F_{\tau_2} = \frac{1}{2}\sqrt{F_3^2 + 4\left(F_d\right)^2}$$

$$= \frac{1}{2}\sqrt{(84269.66)^2 + 4(5000)^2} = 42137.8N$$

Core area, $A_{c_2} = \frac{F_{\tau_2}}{\tau}$

$$= \frac{42137.8}{600} = 707.2966mm^2$$

Referring table (18.7), for $A_{c_2} = 860mm^2$, *select M35 × 1.5 ISO-metric screw threads for bolts 3 and 4.*

Note: ***For convenience and economy, same size bolts i.e., M72 × 6 (ISO-metric screw threads) are used at 1, 2, 3 and 4.***

Exercises

1) *An eye bolt is used to lift a machine weighing 50kN. Limiting the tensile stress for the bolt material as 80MPa, determine the standard size of ISO-metric screw threaded bolts required.*

2) *A bracket is fixed to a column by means of five bolts shown in figure-4.15 to carry a load of 15kN. Calculate the same size of the bolts required it the permissible shear stress for bolt material is 60MPa.*

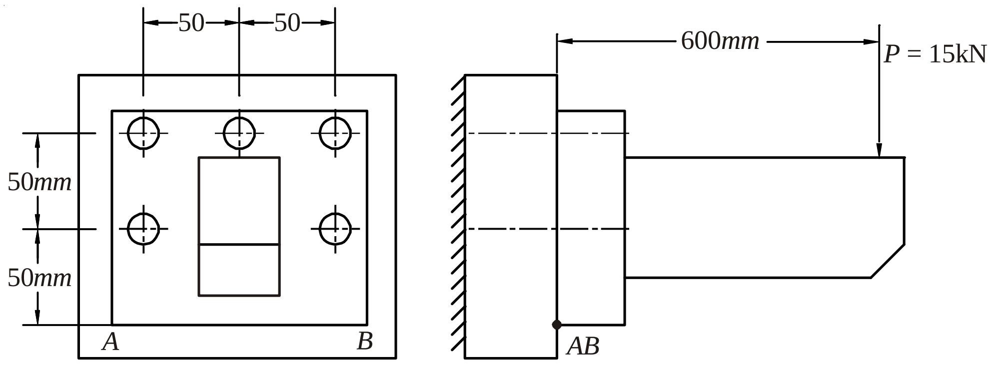


Figure-4.15

3) *A bracket is bolted to a column by six bolts as shown in figure-4.16. Determine the standard size of bolts required if the permissible tensile stress in the bolt material is 90MPa.*

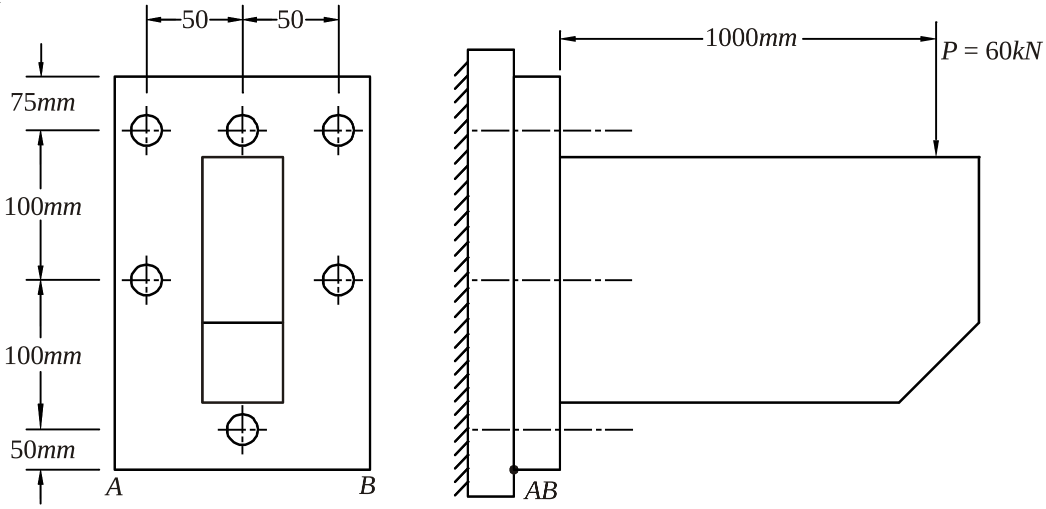


Figure-4.16

4) *A pulley bracket weighing 1800N is bolted to a vertical support by six bolts, 2 at AA, 2 at BB and 2 at CC as shown in figure-4.17. The tensions on slack and tight side are 3kN and 7kN respectively. Using a permissible tensile stress of 90MPa for the material of bolt, determine the standard size of ISO-metric screw bolts required.*

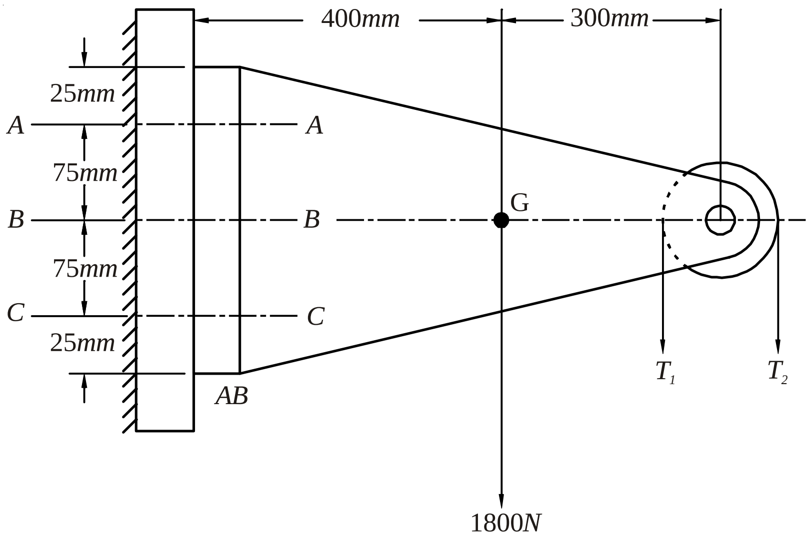


Figure-4.17

5) *A flanged bearing is fastened to a support by six steel bolts equally spaced on a pitch circle of 400mm diameter to carry a load of 40kN at a distance of 500mm*

from the support as shown in figure-4.15. The outside diameter of flange is 650mm. Determine the standard size of the bolts required by taking the permissible shear stress for the bolt material equal to 80MPa.

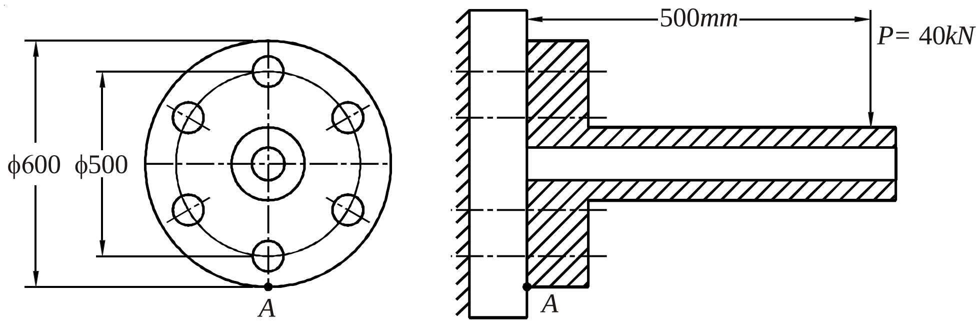


Figure-6.18

6) *The cylinder head of a steam engine is held in position by six steel bolts to withstand steam pressure of 2MPa. The diameter of cylinder is 400mm. A copper gasket is used to make the joint leak proof. Determine the standard size of ISO-metric thread bolts for the purpose.*

7) *The cylinder head of stationary engine is held in position by M35 $\times$ 1.5 ISO-metric screw threaded steel bolts. The diameter of the cylinder is 500mm and the maximum stream pressure is 4MPa. The material of bolt has an ultimate strength of 800MPa and yield stress of 600MPa. A copper gasket is used to make the joint leak proof. Determine the number of bolts required.*