

## Mechanical joints

### Screw fasteners

Helical threads screws are an extremely important mechanical invention. It is the basis of power screws (which change angular motion to linear motion) and threaded fasteners such as bolts, nuts, studs, etc. (Which is used in joining engineering components).

One of the key targets of design for manufacture is to reduce the number of fasteners, however fasteners will always be there to facilitate disassembly for many purposes.

### Thread standards and definitions

Figure (8.1) illustrates the terminology of screw threads as follows:

**The pitch:** *It is the distance between adjacent thread forms measured parallel to the thread axis*

**The major diameter  $d$ :** *It is the largest diameter of a screw thread*

**The minor diameter  $d_r$  or  $d_1$ :** *It is the smallest diameter of a screw thread*

**The lead  $l$ :** *It is the distance a nut moves when the nut is given one turn*

**Multiple thread:** *It is the one having two or more threads cut beside each other:*

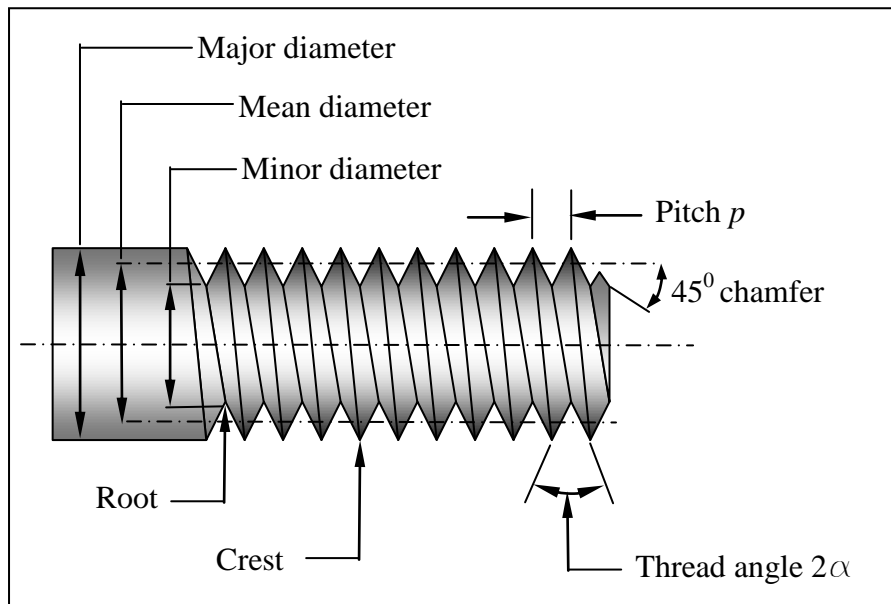


Fig.(8.1) Terminology of screw thread

***All threads are made according to the right hand rule unless otherwise stated.***

Table (8.1) and (8.2) below are very useful in specifying and designing threaded parts.

The mean diameter of the thread should be considered when calculating the strength of screw thread.

Table (8.1) diameters and areas of coarse-pitch and fine-pitch metric threads  
(All dimensions in millimeters)









Nominal major diameter d	Coarse pitch series			Coarse pitch series		
	Pitch $p$	Tensile stress area $A_t$	Minor diameter area $A_r$	Pitch $p$	Tensile stress area $A_t$	Minor diameter area $A_r$
1.6	0.35	1.27	1.07			
2	0.40	2.07	1.79			
2.5	0.45	3.39	2.98			
3	0.50	5.03	4.47			
3.5	0.60	6.78	6.00			
4	0.70	8.78	7.75			
5	0.80	14.2	12.7			
6	1	20.1	17.9			
8	1.25	36.6	32.8	1	39.2	36.0
10	1.5	58.0	52.3	1.25	61.2	56.3
12	1.75	84.3	76.3	1.25	92.1	86.0
14	2	115	104	1.5	125	116
16	2	157	144	1.5	167	157
20	2.5	245	225	1.5	272	259
24	3	353	324	2	384	365
30	3.5	561	519	2	621	596
36	4	817	759	2	915	884
42	4.5	1120	1050	2	1260	1230
48	5	1470	1380	2	1670	1630
56	5.5	2030	1910	2	2300	2250
64	6	2680	2520	2	3030	2980
72	6	3460	3280	2	3860	3800
80	6	4340	4140	1.5	4850	4800
90	6	5590	5360	2	6100	6020
100	6	6990	6740	2	7560	7470
110				2	9180	9080

Table (8.2) Diameters and areas of Unified Screw Threads UNC and UNF

Size designation	Nominal major diameter in	Coarse series - UNC			Fine series - UNF		
		Threads per inch N	Tensile stress area $A_t$	Minor diameter area $A_r$	Threads per inch N	Tensile stress area $A_t$	Minor diameter area $A_r$
0	0.0600				80	0.00180	0.00151
1	0.0730	64	0.00263	0.00218	72	0.00278	0.00237
2	0.0860	56	0.00370	0.00310	64	0.00394	0.00339
3	0.0990	48	0.00487	0.00406	56	0.00523	0.00451
4	0.1120	40	0.00604	0.00496	48	0.00661	0.00566
5	0.1250	40	0.00796	0.00672	44	0.00880	0.00716
6	0.1380	32	0.00909	0.00745	40	0.01015	0.00874
8	0.1640	32	0.0140	0.01196	36	0.01474	0.01285
10	0.1900	24	0.0175	0.01450	32	0.0200	0.0175

12	0.2160	24	0.0242	0.0206	28	0.0258	0.00226
¼	0.2500	20	0.0318	0.0269	28	0.0364	0.0326
5/16	0.3125	18	0.0524	0.0454	24	0.0580	0.0524
3/8	0.3750	16	0.0775	0.0678	24	0.0878	0.0809
7/16	0.4375	14	0.1063	0.0933	20	0.1187	0.1090
½	0.5000	13	0.1419	0.1257	20	0.1599	0.1486
9/16	0.5625	12	0.182	0.162	18	0.203	0.189
5/8	0.6250	11	0.226	0.202	18	0.256	0.240
¾	0.7500	10	0.334	0.302	16	0.373	0.351
7/8	0.8750	9	0.462	0.419	14	0.509	0.480
1	1.0000	8	0.606	0.551	12	0.663	0.625
1¼	1.25	7	0.969	0.890	12	1.074	1.024
1½	1.500	6	1.405	1.294	12	1.581	1.521

Table (8.4) SAE specifications for steel bolts

SAE Grade No.	Size range inclusive, in	Minimum proof strength, kpsi	Minimum tensile strength, kpsi	Minimum yield strength, kpsi	Material	Head marking
1	$\frac{1}{4}$ ..... $1 \frac{1}{2}$	33	60	36	Low or medium carbon	
2	$\frac{1}{4}$ ..... $\frac{3}{4}$ $\frac{7}{8}$ ..... $1 \frac{1}{2}$	55	74	57	Low or medium carbon	
		33	60	36		
4	$\frac{1}{4}$ ..... $1 \frac{1}{2}$	65	115	100	Medium carbon, cold drawn	
5	$\frac{1}{4}$ ..... $1$ $1 \frac{1}{8}$ ..... $1 \frac{1}{2}$	85	120	92	Medium carbon, Q&T	
		74	105	81		
5.2	$\frac{1}{4}$ ..... $1$	85	120	92	Low carbon martensite, Q&T	
7	$\frac{1}{4}$ ..... $1 \frac{1}{2}$	102	133	115	Medium carbon alloy, Q&T	
8	$\frac{1}{4}$ ..... $1 \frac{1}{2}$	120	150	130	Medium carbon alloy, Q&T	
8.2	$\frac{1}{4}$ ..... $1 \frac{1}{2}$	120	150	130	Low carbon martensite, Q&T	

The purpose of a bolt is to clamp two or more parts together. The clamping load stretches or elongates the bolt; the load is obtained by turning the nut until the bolt has elongated to the elastic limit. If the nut does not loosen, the bolt tension remains as a *preload* or *clamping force*.

### Joints – fastener stiffness

Fig. (8.2) shows two joints one uses a bolt and a nut and the other uses a cap screw. An alternative approach is to use studs, a rod threaded on both ends. Notice the clearance provided by the bolt holes and how the bolt thread extend into the body of the connection.

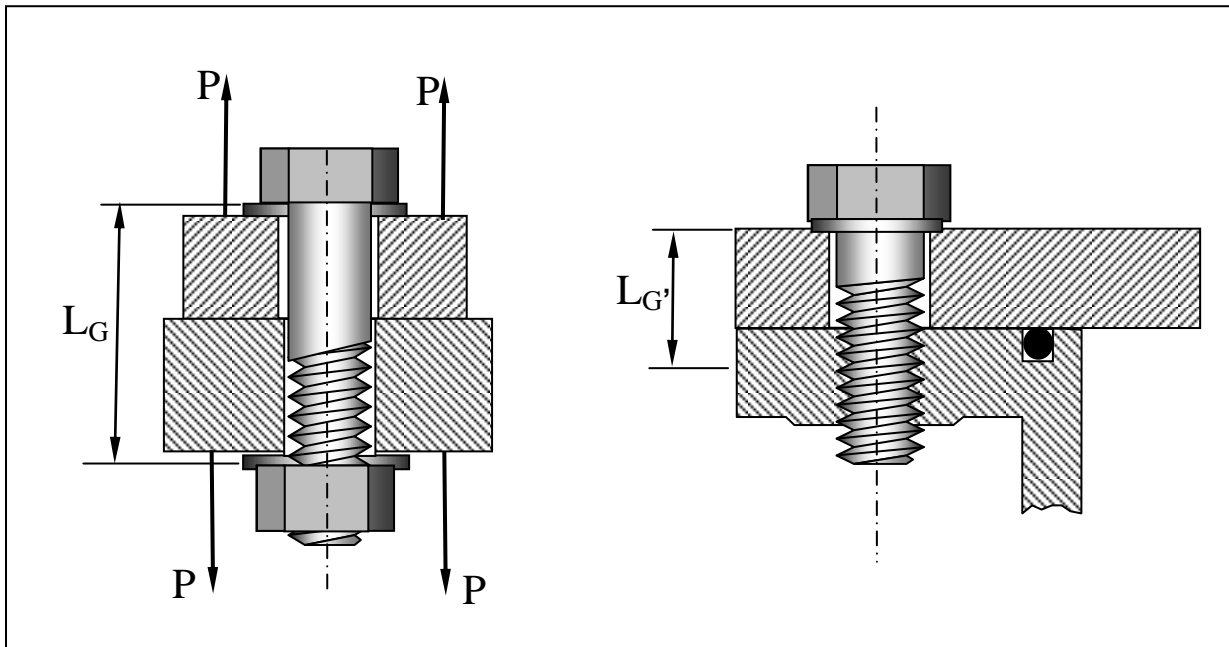


Fig. (8.2) Bolted Connection

The bolt clamps two or more parts together, and by twisting the nut it produces the clamping force which is called the *pretension* or bolt *preload*. The clamping force produces a compression force on the joint members.  $L_G$  is called the grip of the connection and it is the total thickness of the clamped material.

The stiffness constant of the bolt is equivalent to the stiffness of the threaded portion and the unthreaded shank portion. It is equivalent to two spring in series. Hence the total stiffness of the bolt can be obtained from:

$$\frac{1}{k} = \frac{1}{k_d} + \frac{1}{k_t} \text{ or } k = \frac{k_d k_t}{k_d + k_t}$$

Where:

$$k_d = \frac{A_d E}{l_d} \text{ and } k_t = \frac{A_t E}{l_t}$$

$A_d$  = tensile-stress area

$l_d$  = length of threaded portion of grip

$A_t$  = major diameter area of fastener  
 $l_t$  = length of unthreaded portion in grip

Substituting equation (8.2) into equation (8.1) gives:

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l d} \quad (8.1)$$

### Joints – member stiffness

There may be more than two members included in the grip of the fastener, all together they act like compressive springs in series and hence the total stiffness of the members is:

$$\frac{1}{k_s} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \dots + \frac{1}{k_i} \quad (8.2)$$

If one of the members is a soft gasket, its stiffness relative to the other members is so small that for practical purposes the others can be neglected and only the gasket stiffness used.

For the stiffness of the flange or the frustum the stiffness can be obtained using the equation:

$$k = \frac{0.5774 \pi E d}{\ln \frac{(1.155t + D - d)(D + d)}{(1.155t + D + d)(D - d)}} \quad (8.3)$$

If member of the joint have the same young modulus with symmetrical frustum back to back, then stiffness can be obtained from the equation:

$$k_m = \frac{0.5774 \pi E d}{2 \ln \left( 5 \frac{0.5774l + 0.5d}{0.5774l + 2.5d} \right)} \quad (8.4)$$

Where,

$l$  = thickness of grip

$d$  = diameter of bolt

### Tension joints – The external load

If an external tensile load  $P$  is applied to a bolted connection with a preload  $F_i$ , the load  $P$  will cause connection to stretch through some distance  $\delta$ . then we can say:

$F_i$  = preload

$P$  = external load

$P_b$  = portion of  $P$  taken by bolt

$P_m$  = portion of  $P$  taken by members

$F_b = P_b + F_i$  = resultant load on bolt

$F_m = P_m - F_i$  = resultant load on members

$C$  = fraction of external load  $P$  carried by bolt

$1 - C$  = fraction of external load  $P$  carried by members

We can relate the elongation to the stiffness as follows:

$$\delta = \frac{P_b}{k_b} \quad \text{and} \quad \delta = \frac{P_m}{k_m} \quad (8.5)$$

Or

$$P_m = P_b \frac{k_m}{k_b} \quad (8.6)$$

Since  $P = P_b + P_m$  we have

$$P_b = \frac{k_b P}{k_b + k_m} = CP \quad (8.7)$$

And

$$P_m = P - P_b = (1 - C)P \quad (8.8)$$

Where

$$C = \frac{k_b}{k_b + k_m} \quad (8.9)$$

***C is called the stiffness constant of the joint***

The resultant bolt load is

$$F_b = P_b + F_i = CP + F_i \quad F_m < 0 \quad (8.10)$$

And the resultant load on the connected members is

$$F_m = P_m - F_i = (1 - C)P - F_i \quad F_m < 0 \quad (8.11)$$

### **Relating bolt torque to bolt tension**

A torque wrench with built in dial or an impact wrench where the air pressure is adjusted are used to provide the adequate tension on the bolt can be obtained. The required torque can be calculated from the equation:

$$T = KF_i d \quad (8.12)$$

Where K is called the torque coefficient and can be estimated from table (8.3)

Table (8.3) Torque factors K

Bolt condition	K
Nonplated, black finish	0.30
Zink plated	0.20
Lubricated	0.18
Cadmium plated	0.16
With Bowman anti-seize	0.12
With Bowman-grip nuts	0.09

### **Recommended preload**

Bowman recommend a preload of 75% of the proof load for reused bolts, so it is recommended for static and fatigue loading that the following be used for preload:







$$\bar{y} = \frac{A_1 y_1 + A_2 y_2 + A_3 y_3 + A_4 y_4}{A_1 + A_2 + A_3 + A_4} = \frac{\sum_1^n A_i y_i}{\sum_1^n A_i} \quad (8.20)$$

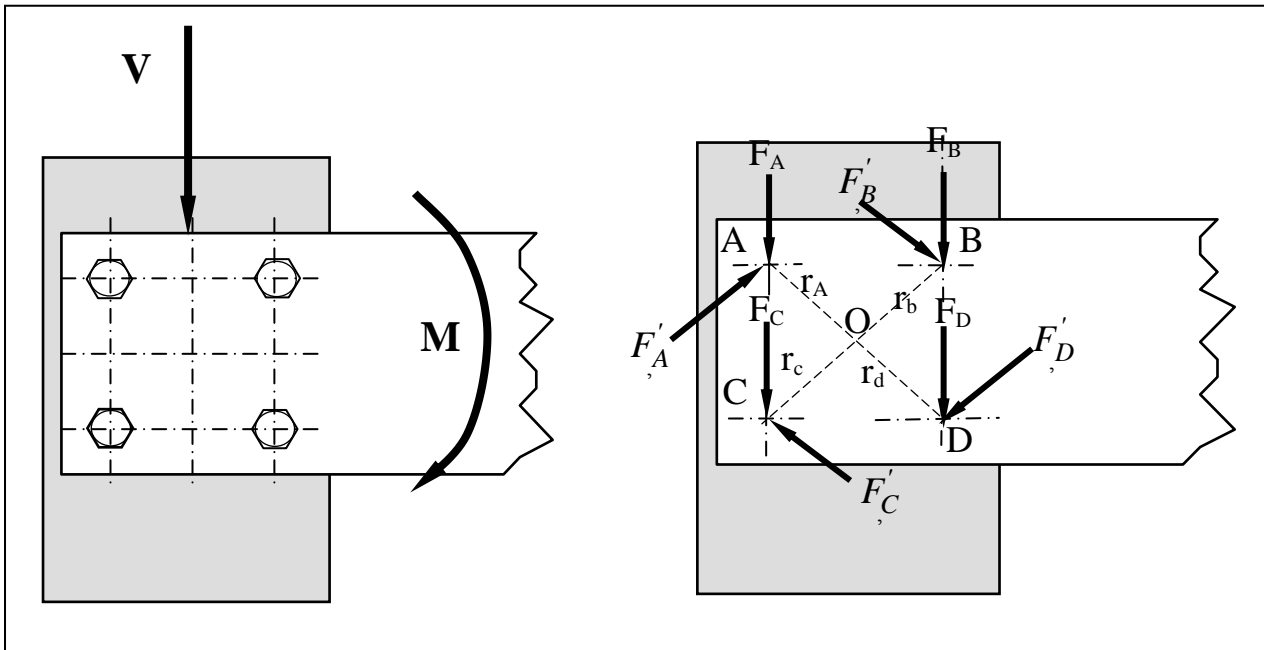


Fig. (8.4)

The total load taken by each bolt is calculated in three steps:

The shear  $V$  is divided equally among the bolts, and this is called the *direct shear* or the *primary shear*.

The moment load or secondary shear is due to the moment  $M$  and are related with the following relations:

$$M = F'_A r_A + F'_B r_B + F'_C r_C + F'_D r_D \quad (8.21)$$

and,

$$\frac{F'_A}{r_A} = \frac{F'_B}{r_B} = \frac{F'_C}{r_C} = \frac{F'_D}{r_D} \quad (8.22)$$

Solving equations (8.21) and (8.22) we obtain:

$$F'_n = \frac{M r_n}{r_A^2 + r_B^2 + r_C^2 + \dots} \quad (8.23)$$

### Example

A rectangular steel bar cantilevered to a 250 mm steel channel is shown in fig. (8.5). The bar which is 15 by 200 mm is cantilevered to the channel using two pins, located at E and F and four bolts located at A, B, C and D.

- On the basis of steady external load of 16kN, find the shear loads in the pins should the clamping action fail.
- Investigate increasing the area of pin F to obtain equal shear stresses.

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