Fasteners and Non-Permanent Joints – Applications to Motorcycles

CVMG - Essex-Kent Chapter Meeting

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March 2, 2017

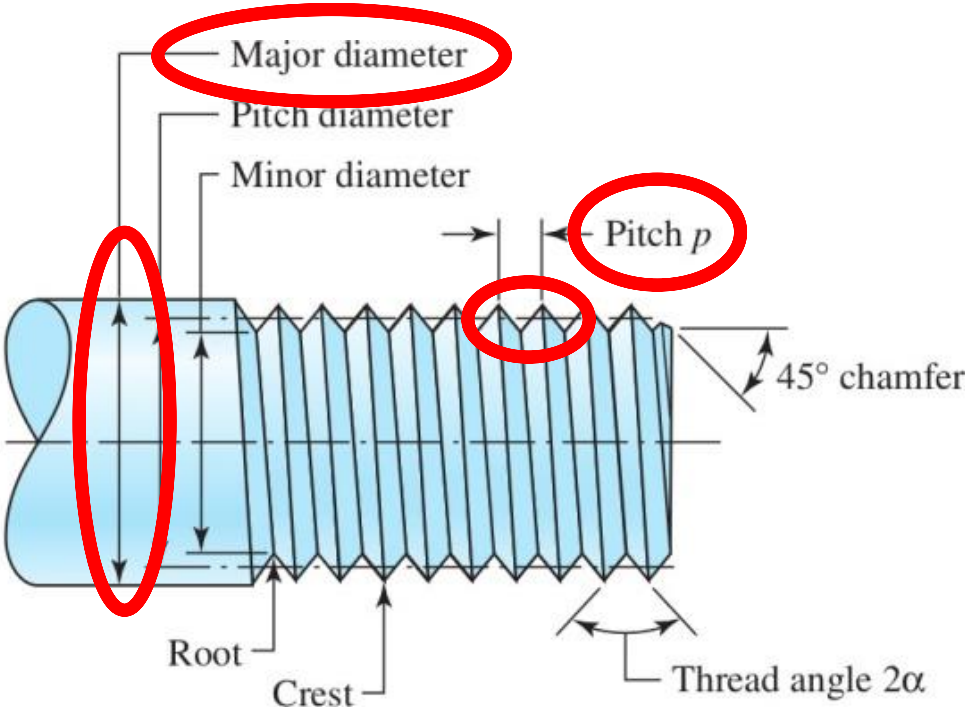
PRESENTATION OUTLINE

- **Threaded fastener terminology & geometry**
- **How threaded fasteners work**
  - ***Strength of engineering materials***
  - ***Tensile loading vs. shear loading and failure modes***
  - ***Torque variation***
  - ***Bolt stretch – torque-to-yield fasteners***
  - ***Fastener strength properties***
  - ***Fastener grades***
- **A simple sample calculation**
- **Applications to motorcycles**

THREAD GEOMETRY & NOMENCLATURE

Figure 8–1

Terminology of screw threads. Sharp vee threads shown for clarity; the crests and roots are actually flattened or rounded during the forming operation.



When specifying a thread – you need to know three things:

- System (*inch* or *metric*)
- Form *(UN, BS Cycle, Metric etc.)*
- Major Diameter
- Pitch (*aka* thread series)

Examples:

¼-20 UNC = ¼ major dia., 20 TPI Unified National Coarse Series

M6-1 = Metric 6mm major dia., 1mm pitch

DETAILS OF FASTENER THREAD GEOMETRY

Figure 8–2

Basic profile for metric M and MJ threads.

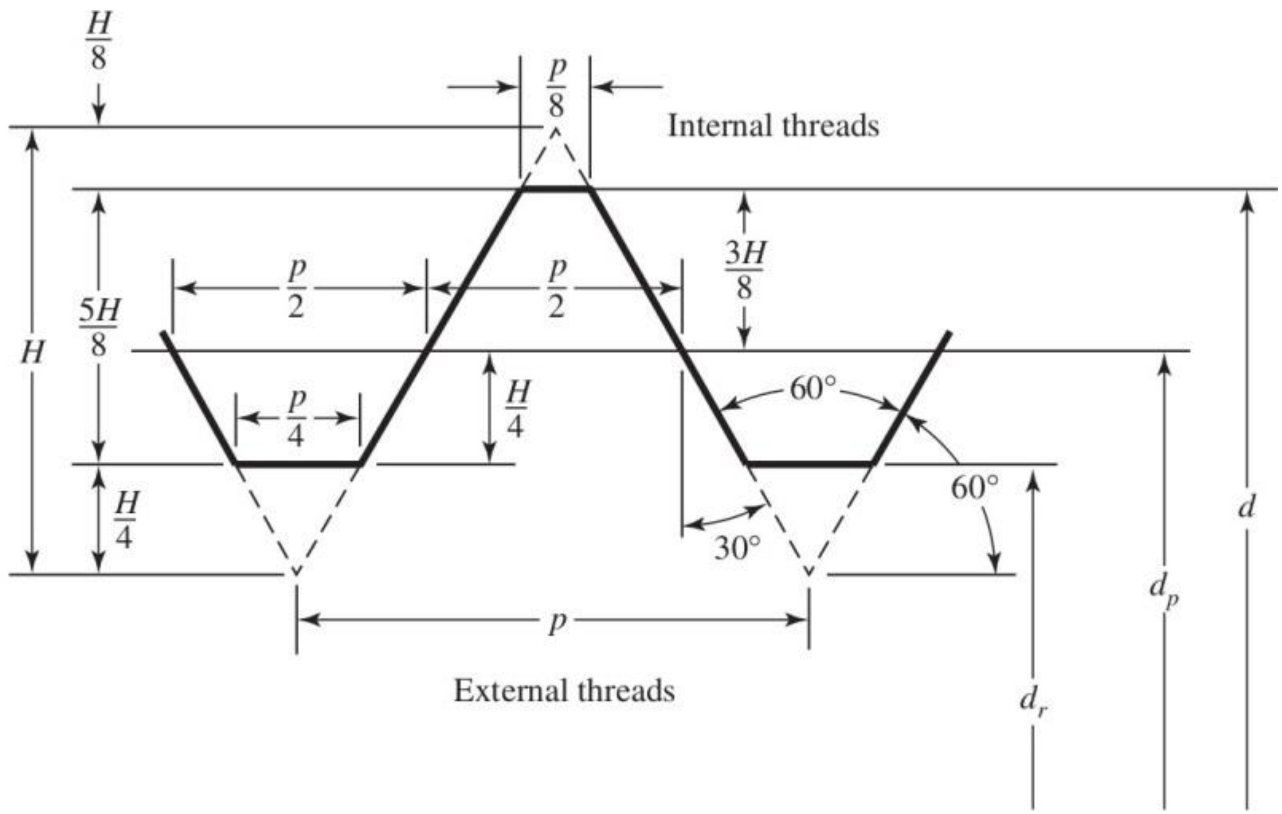
d = major diameter

d_r = minor diameter

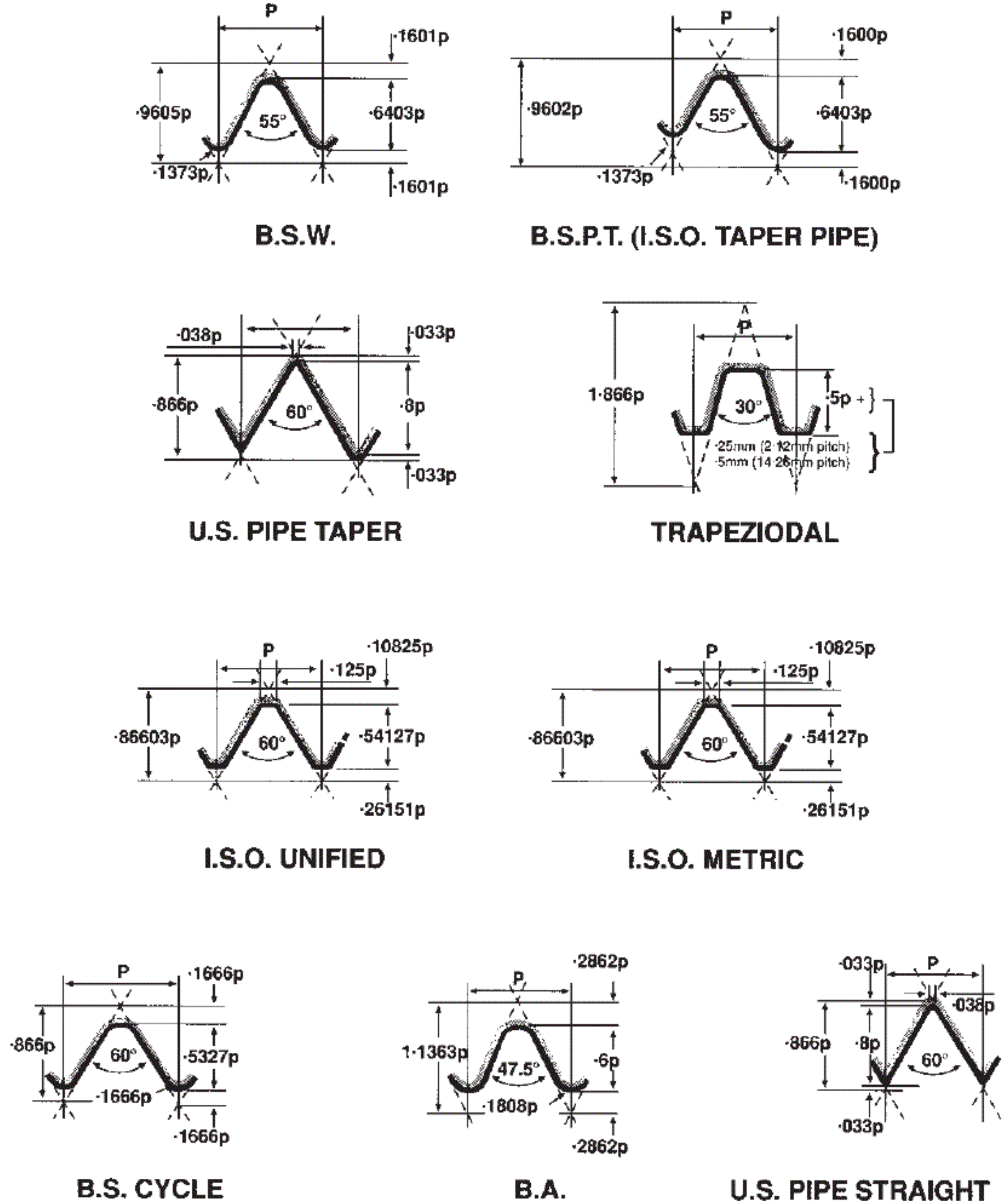
d_p = pitch diameter

p = pitch

$H = \frac{\sqrt{3}}{2} p$



THREAD GEOMETRY & NOMENCLATURE



INCH-METRIC TAP DRILL CHART

(NO HOME SHOULD BE WITHOUT ONE!)

Example:

To tap a hole for a 1/4 -20 UNC thread you would use a #7 drill which has a diameter of 0.201”.

This is approx. equal to the *minor diameter* of the thread.

INCH/METRLC TAP DRILL SIZES & DECIMAL EQUIVALENTS

Drill Size	Decimal Equivalent	Tap Size
80	.0135	
79	.0145	
1/64	.0156	
78	.0160	
77	.0180	
76	.0200	
75	.0210	
74	.0225	
73	.0240	
72	.0250	
71	.0260	
70	.0280	
69	.0292	
68	.0310	
1/32	.0312	
67	.0320	
66	.0330	
65	.0350	
64	.0360	
63	.0370	
62	.0380	
61	.0390	
60	.0400	
59	.0410	
58	.0420	
57	.0430	
56	[illegible]	
3/64	[illegible]	0 - 80
55	[illegible]	
54	[illegible]	
53	.0595	1 - 64, 72
1/16	.0625	
[illegible]	.0635	
[illegible]	.0670	
50	.0700	2 - 56, 64
49	.0730	
48	.0760	
5/64	.0781	
47	.0785	3 - 48
46	.0810	
45	.0820	3 - 56
44	.0860	
43	.0890	4 - 40
42	.0935	4 - 48
3/32	.0938	
41	.0960	
40	.0980	
39	.0995	
38	.1015	5 - 40
37	.1040	5 - 44
36	.1065	6 - 32
7/64	.1094	
35	.1100	
34	.1110	
33	.1130	6 - 40
32	.1160	
31	.1200	
1/8	.1250	
30	.1285	
29	.1360	8 - 32, 36
28	.1405	
9/64	.1406	
27	.1440	
26	.1470	
25	.1495	10 - 24
24	.1520	
23	.1540	
5/32	.1562	
22	.1570	
21	.1590	10 - 32
20	.1610	
19	.1660	
18	.1695	
11/64	.1719	
17	.1730	
16	.1770	12 - 24
15	.1800	
14	.1820	12 - 28
13	.1850	
3/16	.1875	
12	.1890	
11	.1910	

Drill Size	Decimal Equivalent	Tap Size
10	.1935	
9	[illegible]	
[illegible]	.1990	
7	.2010	1/4 - 20
13/64	.2031	
[illegible]	[illegible]	
5	.2055	
4	.2090	
3	.2130	1/4 - 28
[illegible]	.2188	
2	.2210	
1	.2280	
a	.2340	
15/64	.2344	
B	.2380	
c	.2420	
D	.2460	
1/4, e	.2500	
F	.2570	5/16 - 18
G	.2610	
17/64	.2656	
H	.2660	
i	.2720	5/16 - 24
J	.2770	
K	.2810	
9/32	.2812	
I	.2900	
m	.2950	
19/64	.2969	
n	.3020	
5/16	.3125	3/8 - 16
O	.3160	
P	.3230	
21/64	.3281	
Q	.3320	3/8 - 24
r	.3390	
11/32	.3438	
S	.3480	
t	.3580	
23/64	.3594	
U	.3680	7/16 - 14
3/8	.3750	
V	.3770	
W	.3860	
25/64	.3906	7/16 - 20
X	.3970	
Y	.4040	
13/32	.4062	
z	.4130	
27/64	.4219	1/2 - 13
7/16	.4375	
29/64	.4531	1/2 - 20
15/32	.4688	
31/64	.4844	9/16 - 12
1/2	.5000	
33/64	.5156	9/16 - 18
17/32	.5312	5/8 - 11
35/64	.5469	
9/16	.5625	
37/64	.5781	5/8 - 18
19/32	.5938	
39/64	.6094	
5/8	.6250	
41/64	.6406	
21/32	.6562	3/4 - 10
43/64	.6719	
11/16	.6875	3/4 - 16
45/64	.7031	
23/32	.7188	
47/64	.7344	
3/4	.7500	
49/64	.7656	7/8 - 9
25/32	.7812	
51/64	.7969	
13/16	.8125	7/8 - 14
53/64	.8281	
27/32	.8438	
55/64	.8594	
7/8	.8750	1 - 8
57/64	.8906	
29/32	.9062	

Drill Size	Decimal Equivalent	Tap Size
59/64	.9219	1 - 12
15/16	.9375	1 - 14
61/64	.9531	
31/32	.9688	
63/64	.9844	1 1/8 - 7
1	1.0000	
1 3/64	1.0469	1 1/8 - 12
1 7/64	1.1094	1 1/4 - 7
1 1/8	1.1250	
1 11/64	1.1719	1 1/4 - 12
1 7/32	1.2188	1 3/8 - 6
1 1/4	1.2500	
1 19/64	1.2969	1 3/8 - 12
1 11/32	1.3438	1 1/2 - 6
1 3/8	1.3750	
1 27/64	1.4219	1 1/2 - 12
1 1/2	1.5000	

metric tap Drill SizeS

metric tap	tap Drill (mm)	Decimal (inch)
m1.6 x 0.35	1.25	.0492
m1.8 x 0.35	1.45	.0571
m2 x 0.4	1.60	.0630
m2.2 x 0.45	1.75	.0689
m2.5 x 0.45	2.05	.0807
m3 x 0.5	2.50	.0984
m3.5 x 0.6	2.90	.1142
m4 x 0.7	3.30	.1299
m4.5 x 0.75	3.70	.1457
m5 x 0.8	4.20	.1654
m6 x 1	5.00	.1968
m7 x 1	6.00	.2362
m8 x 1.25	6.70	.2638
m8 x 1	7.00	.2756
m10 x 1.5	8.50	.3346
m10 x 1.25	8.70	.3425
m12 x 1.75	10.20	.4016
m12 x 1.25	10.80	.4252
m14 x 2	12.00	.4724
m14 x 1.5	12.50	.4921
m16 x 2	14.00	.5512
m16 x 1.5	14.50	.5709
m18 x 2.5	15.50	.6102
m18 x 1.5	16.50	.6496
m20 x 2.5	17.50	.6890
m20 x 1.5	18.50	.7283
m22 x 2.5	19.50	.7677
m22 x 1.5	20.50	.8071
m24 x 3	21.00	.8268
m24 x 2	22.00	.8661
m27 x 3	24.00	.9449
m27 x 2	25.00	.9843
m30 x 3.5	26.50	1.0433
m30 x 2	28.00	1.1024
m33 x 3.5	29.50	1.1614
m33 x 2	31.00	1.2205
m36 x 4	32.00	1.2598
m36 x 3	33.00	1.2992
m39 x 4	35.00	1.3780
m39 x 3	36.00	1.4173

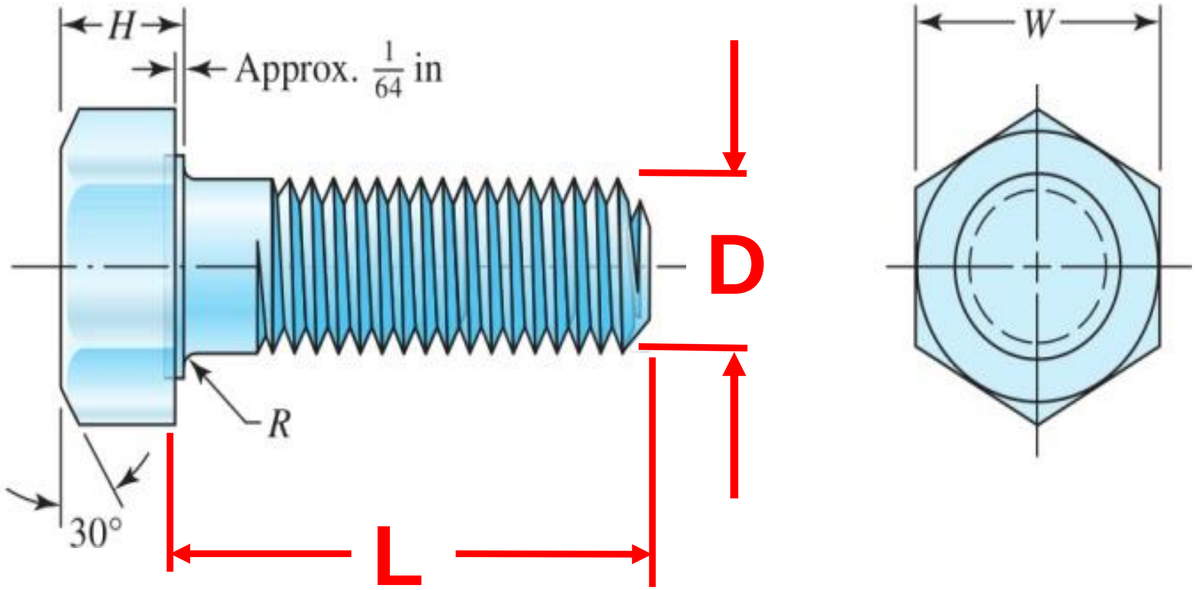
pipe tHreaD SizeS (npSc)

tHreaD	Drill	tHreaD	Drill
1/8 – 27	11/32	1 1/2 – 11 1/2	1 3/4
1/4 – 18	7/16	2 – 11 1/2	2 7/32
3/8 – 18	37/64	2 1/2 – 8	2 21/32
1/2 – 14	23/32	3 – 8	3 1/4
3/4 – 14	59/64	3 1/2 – 8	3 3/4
1 – 11 1/2	1 5/32	4 – 8	4 1/4
1 1/4 – 11 1/2	1 1/2		

HEX HEAD BOLT GEOMETRY & NOMENCLATURE

Figure 8–9

Hexagon-head bolt; note the washer face, the fillet under the head, the start of threads, and the chamfer on both ends. Bolt lengths are always measured from below the head.



Examples:

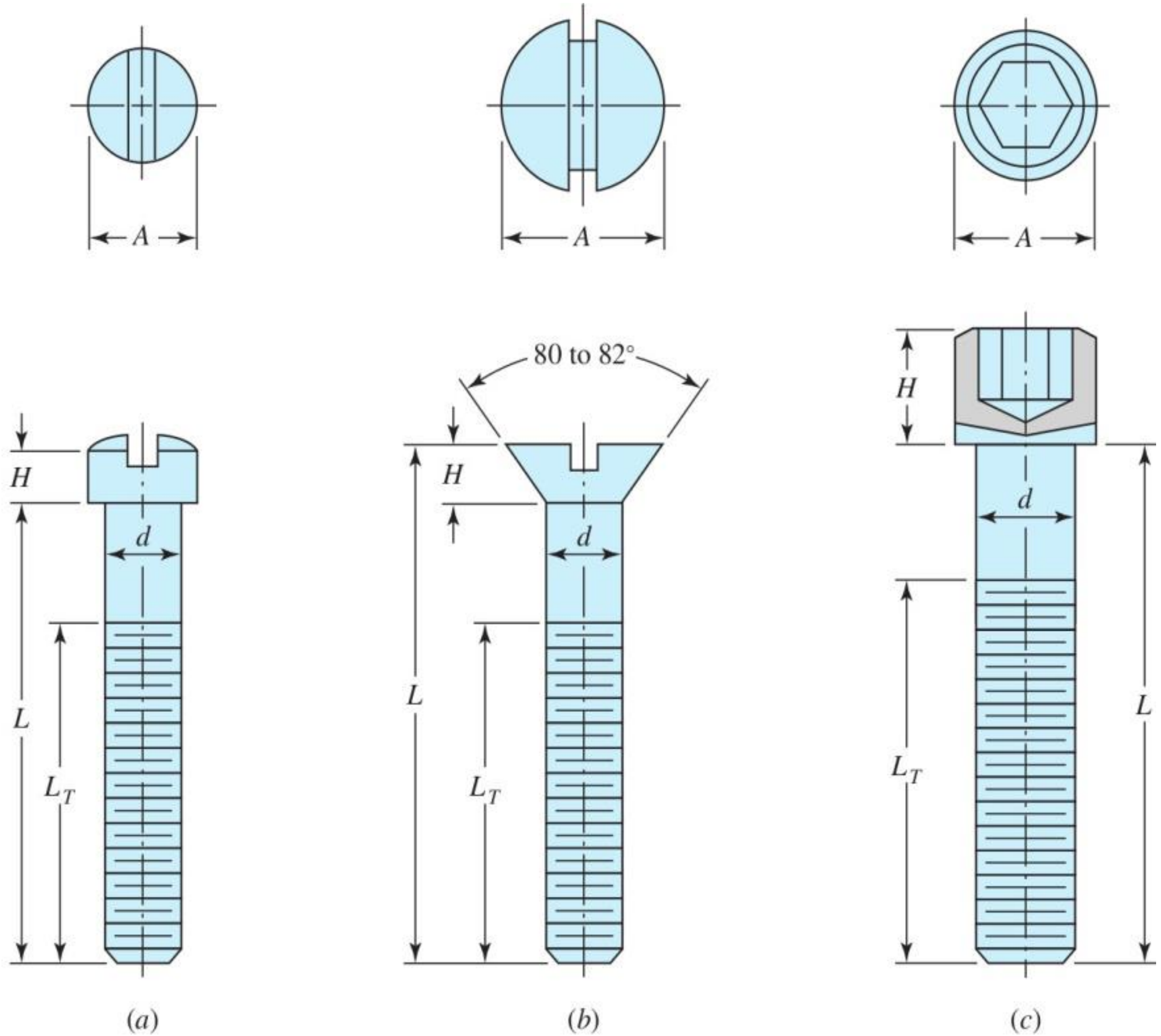
¼-20UNC x 1 ➔ ¼” dia., 20 thread/inch UNC bolt, 1” long

M6-1 x 25 ➔ Metric 6mm dia., 1mm pitch bolt, 25 mm long

TYPICAL CAPSCREWS

Figure 8–10

Typical cap-screw heads: (*a*) fillister head; (*b*) flat head; (*c*) hexagonal socket head. Cap screws are also manufactured with hexagonal heads similar to the one shown in Fig. 8–9, as well as a variety of other head styles. This illustration uses one of the conventional methods of representing threads.



STRENGTH PROPERTIES OF ENGINEERING MATERIALS

Material Used	Poisson Ratio	Elastic GPa	Modulus Mpsi	A	B
Steel	0.291	207	30.0	0.787 15	0.628 73
Aluminum	0.334	71	10.3	0.796 70	0.638 16
Copper	0.326	119	17.3	0.795 68	0.635 53
Gray cast iron	0.211	100	14.5	0.778 71	0.616 16
General expression				0.789 52	0.629 14

Table 8–8

Stiffness Parameters of Various Member Materials†

†*Source:* J. Wileman, M. Choudury, and I. Green, "Computation of Member Stiffness in Bolted Connections," *Trans. ASME, J. Mech. Design,* vol. 113, December 1991, pp. 432–437.

The elastic modulus of a material is basically a measure of its stiffness and is related to the atomic structure of the material.

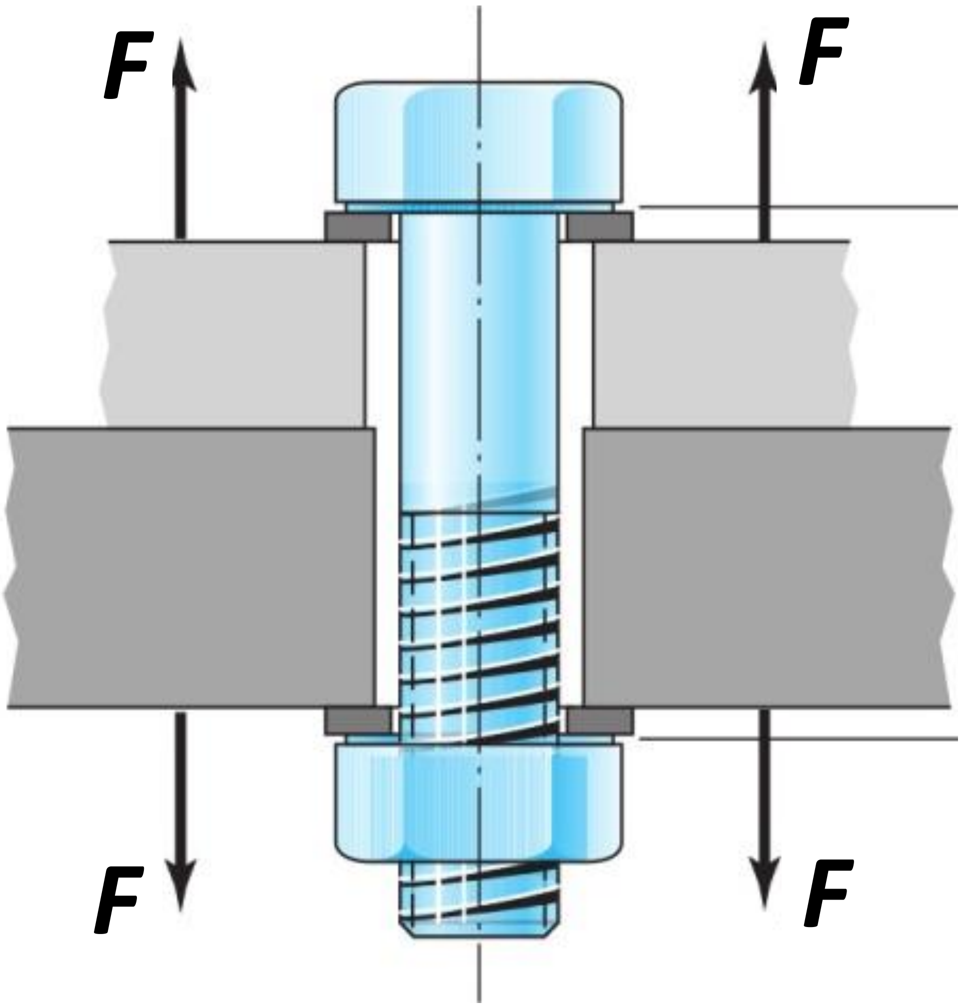
Note the much higher value for steel than aluminium – this is one of several reasons why fasteners are ***not*** made of aluminium.

TENSION LOADED FASTENER

The forces "***F***" are trying to pull the two components apart – and are being resisted by ***tension*** in the bolt.

This is called *tensile loading.*

The cylinder head bolts or studs on a motorcycle engine are loaded in tension.

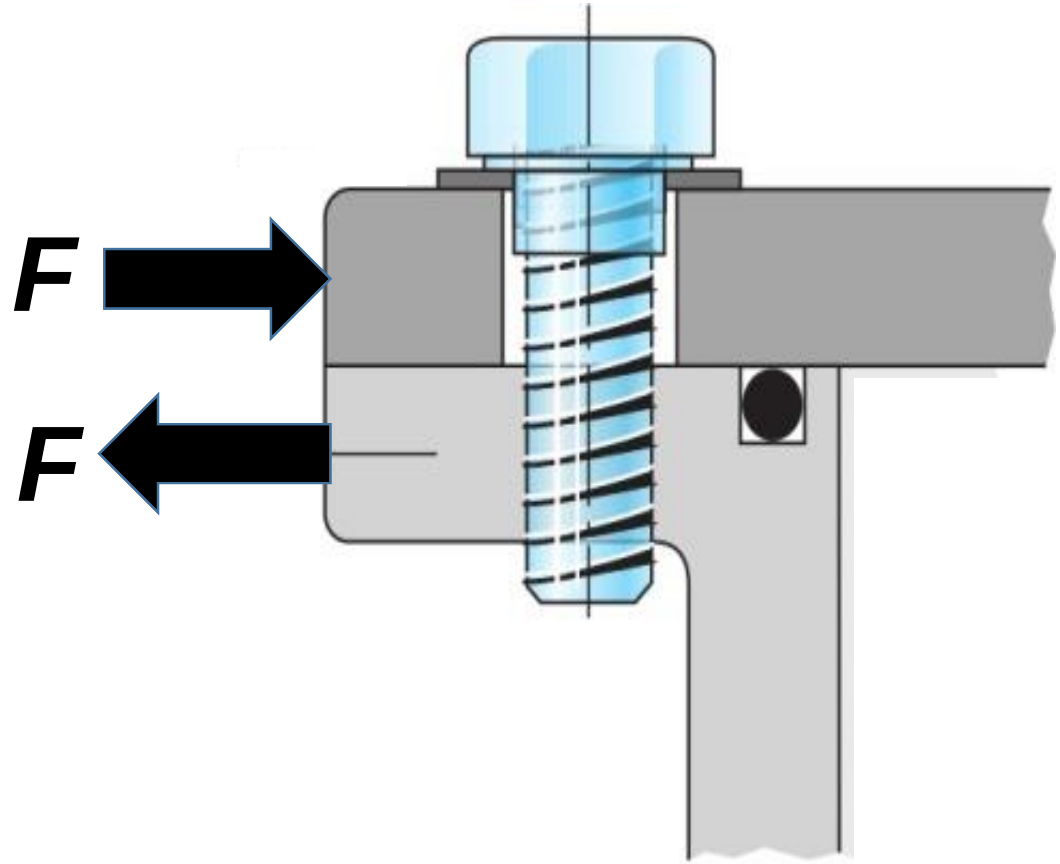


SHEAR LOADED FASTENER

The forces "***F***" are acting to make the two parts *slide* over each other.

This is called *shear loading*.

A motorcycle brake disc mounting bolt *could* be loaded in *shear* relative to the wheel hub, when you apply the brake.



SHEAR LOADED FASTENERS

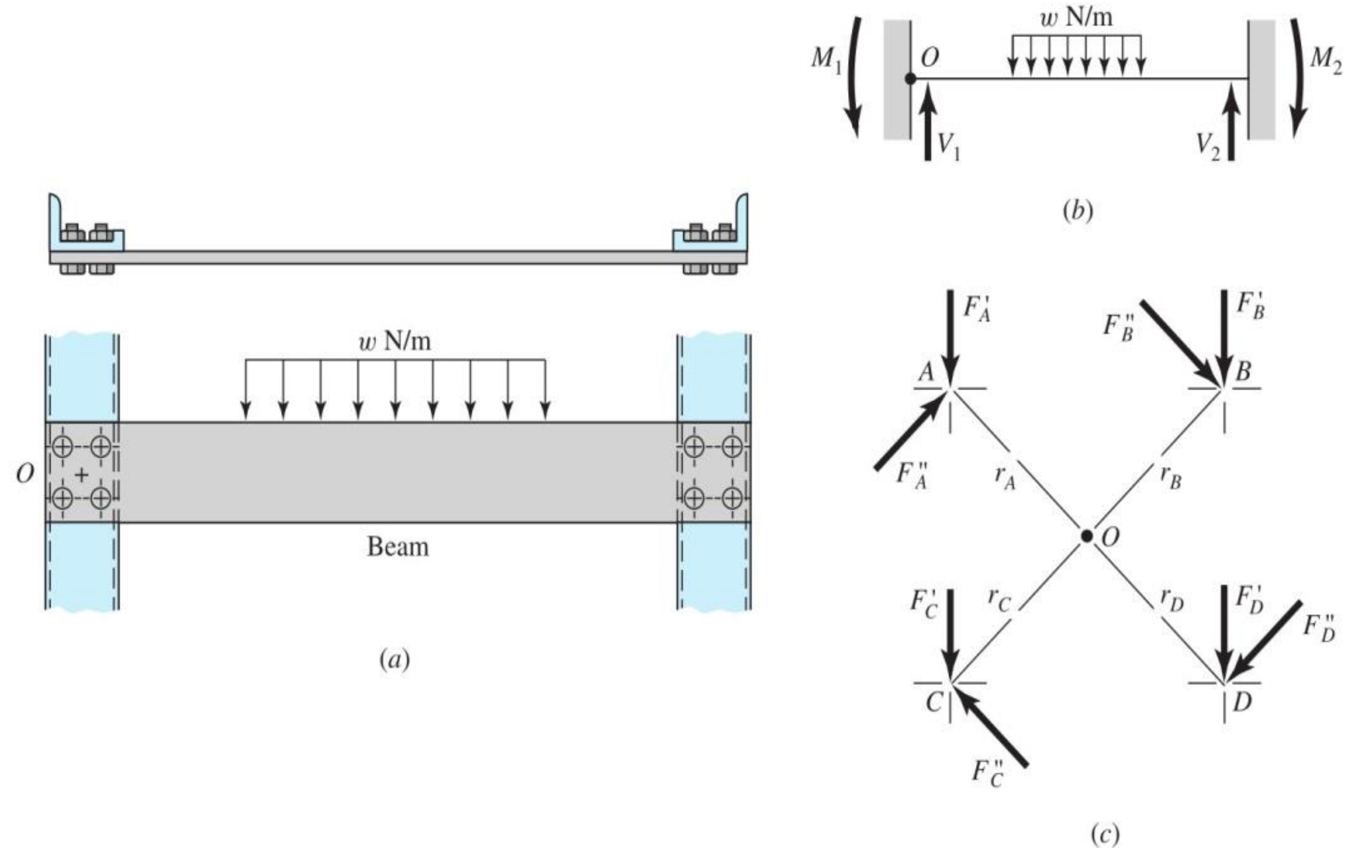


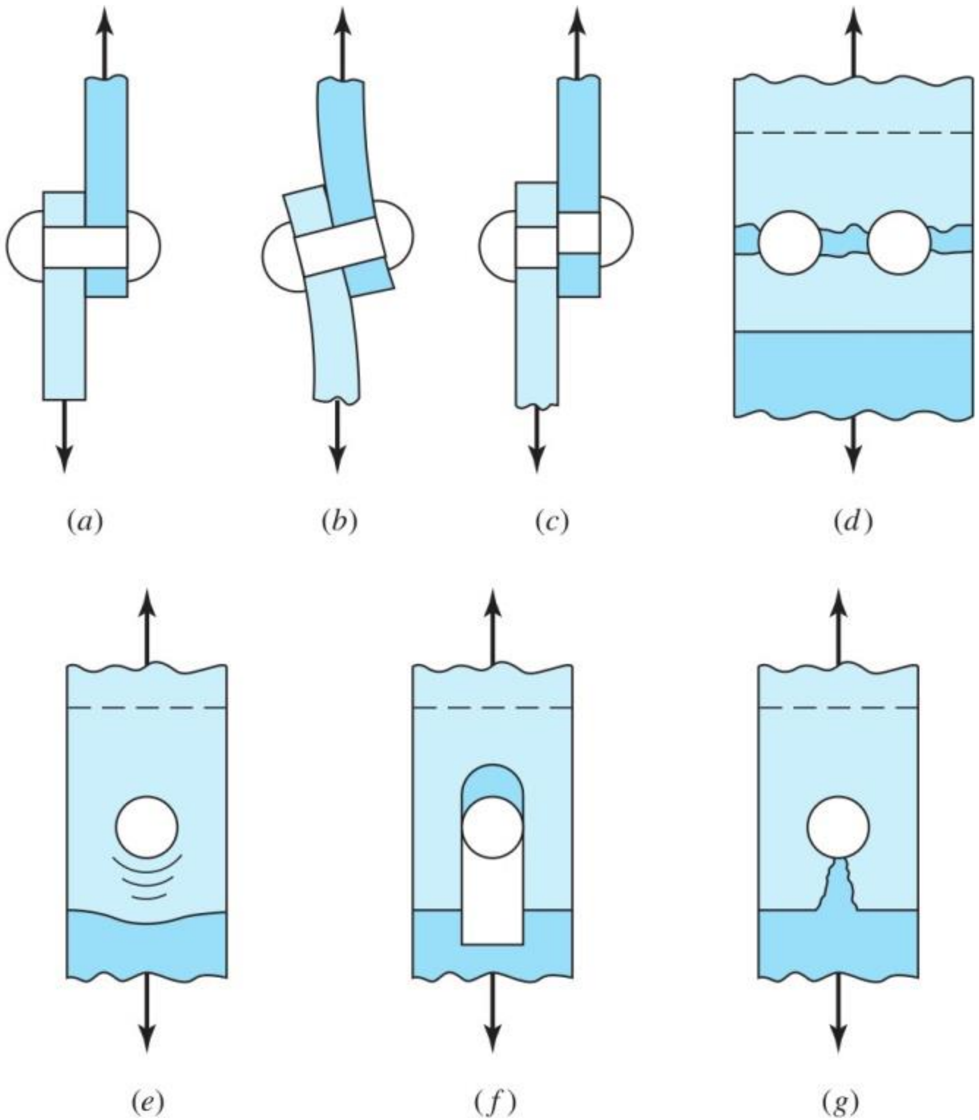
Figure 8–26

(*a*) Beam bolted at both ends with distributed load; (*b*) free-body diagram of beam; (*c*) enlarged view of bolt group centered at *O* showing primary and secondary resultant shear forces.

FASTENER FAILURE MODES

Figure 8–23

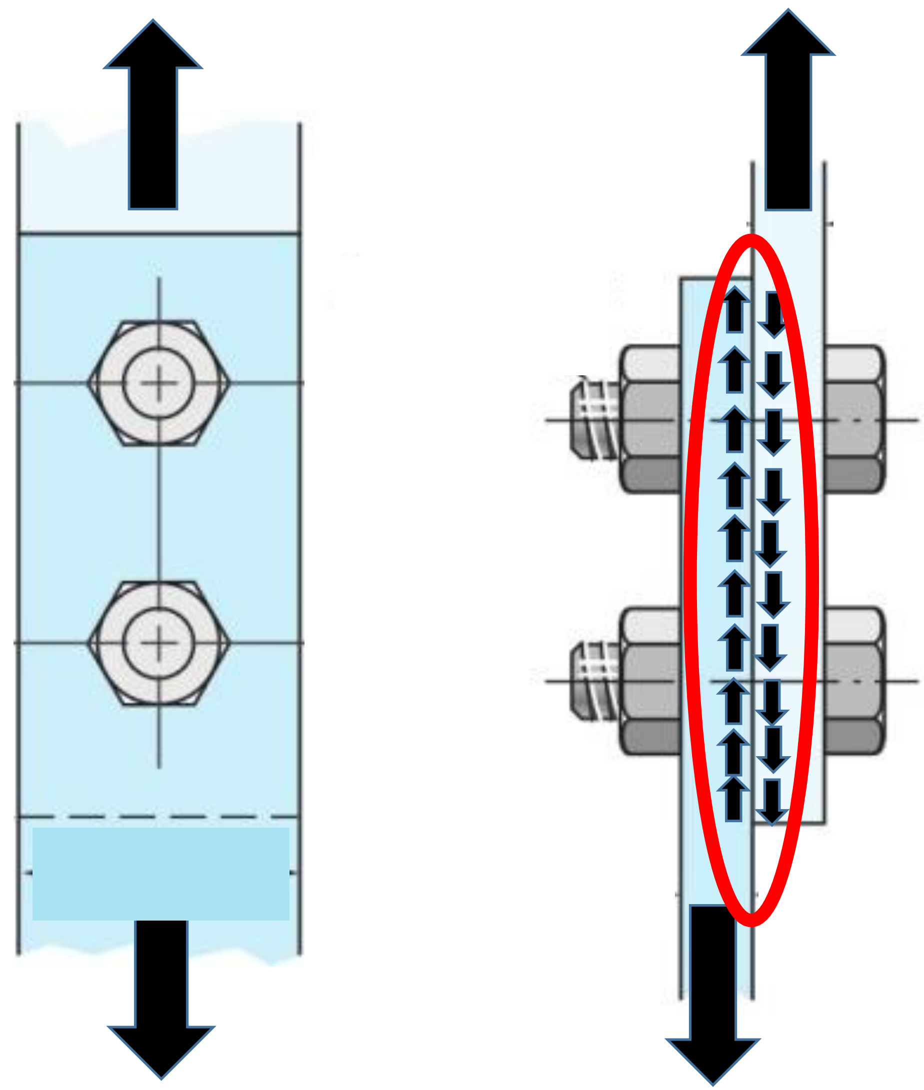
Modes of failure in shear loading of a bolted or riveted connection: (*a*) shear loading; (*b*) bending of rivet; (*c*) shear of rivet; (*d*) tensile failure of members; (*e*) bearing of rivet on members or bearing of members on rivet; (*f*) shear tear-out; (*g*) tensile tear-out.



SHEAR LOADED FASTENERS

Shear loads must be resisted by *friction* between the bolted components and *NOT* by shear loads in the fasteners themselves.

So – the bolts in a shear loaded joint are *only* there to squeeze the two parts together tightly enough to generate enough friction to stop them from sliding.



TORQUE VARIATION – UN-LUBRICATED BOLTS

Table 8–13

Distribution of Preload F_i for 20 Tests of Unlubricated Bolts Torqued to 90 N · m

23.6,	27.6,	28.0,	29.4,	30.3,	30.7,	32.9,	33.8,	33.8,	33.8,
34.7,	35.6,	35.6,	37.4,	37.8,	37.8,	39.2,	40.0,	40.5,	42.7

Mean value $\bar{F}_i$ = 34.3 kN. Standard deviation, $\hat{\sigma}$ = 4.91 kN.

TORQUE VARIATION - LUBRICATED BOLTS

Table 8–14

Distribution of Preload F_i for 10 Tests of Lubricated Bolts Torqued to 90 N · m

30.3,	32.5,	32.5,	32.9,	32.9,	33.8,	34.3,	34.7,	37.4,	40.5

Mean value, $\bar{F}_i$ = 34.18 kN. Standard deviation, $\hat{\sigma}$ = 2.88 kN.

CONCLUSION: ***Lubricated fasteners provided more consistent torque values and that ensures better joint strength and gasket sealing.***

TORQUE-TO-YIELD FASTENERS

- All fastener materials have some degree of elasticity or *"stretch"* before they permanently deform (*and eventually break*);
- It can be shown that the highest level of force a bolt can achieve occurs when it is stretched to its *yield point* where it is *permanently deformed*;

- So, to achieve the maximum bolted joint strength, engineers design the joint so that the fasteners *just* reach their yield point;
- This means that the fastener *cannot* be used *twice* – it must be discarded after it has been torqued;
- The graph on the next slide shows this effect and it also shows how important it is to clean and lubricate fasteners before torqueing them down.

TORQUE-TO-YIELD FASTENERS

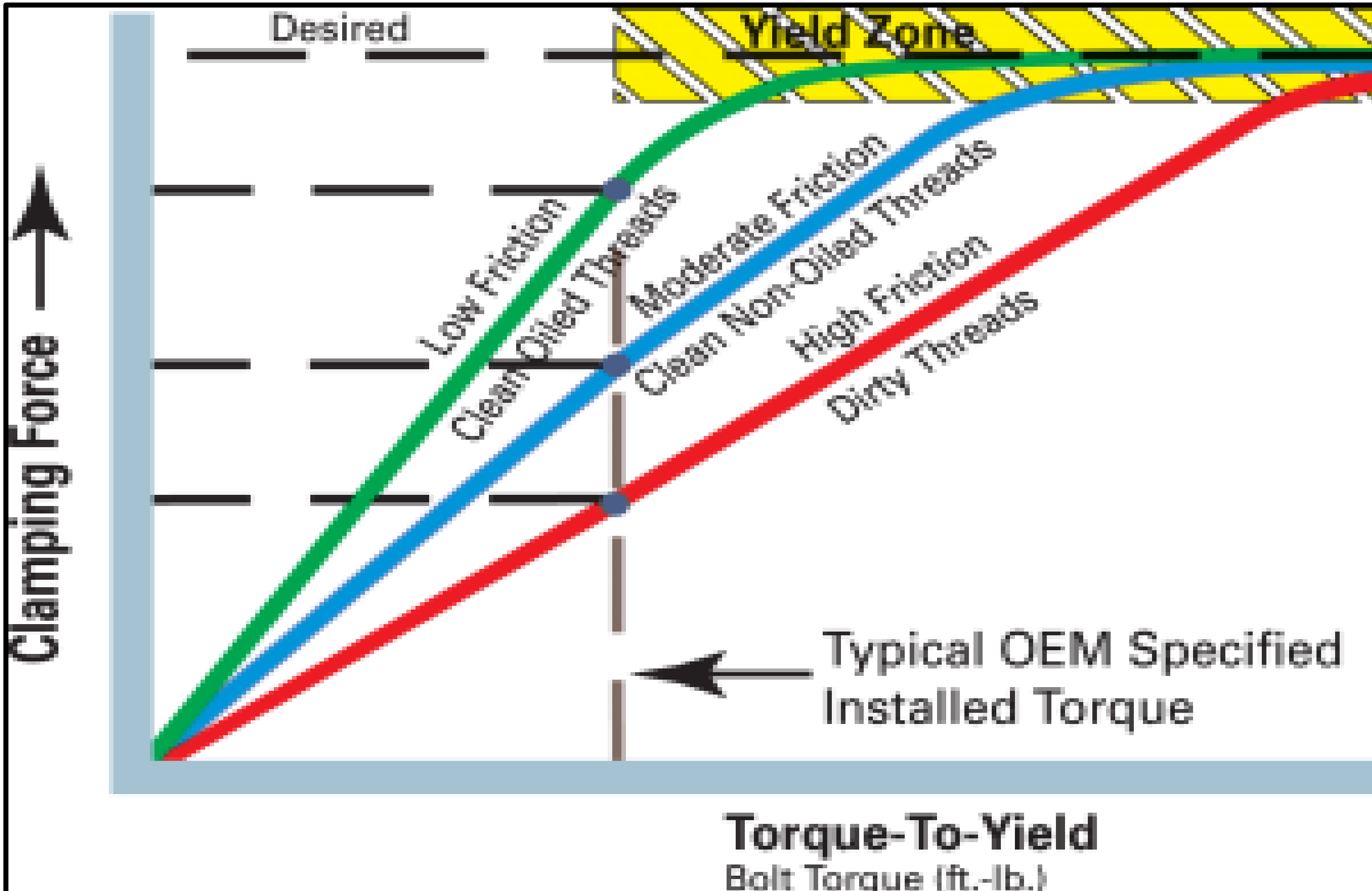
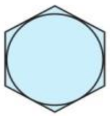
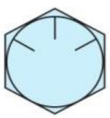


Table 8–9

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	$\frac{1}{4}$–$\frac{3}{4}$	55	74	57	Low or medium carbon	
	$\frac{7}{8}$–$1\frac{1}{2}$	33	60	36		
4	$\frac{1}{4}$–$1\frac{1}{2}$	65	115	100	Medium carbon, cold-drawn	
5	$\frac{1}{4}$–1	85	120	92	Medium carbon, Q&T	
	$1\frac{1}{8}$–$1\frac{1}{2}$	74	105	81		
5.2	$\frac{1}{4}$–1	85	120	92	Low-carbon martensite, Q&T	
7	$\frac{1}{4}$–$1\frac{1}{2}$	105	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	120	150	130	Low-carbon martensite, Q&T	

*Minimum strengths are strengths exceeded by 99 percent of fasteners.

Table 8–11

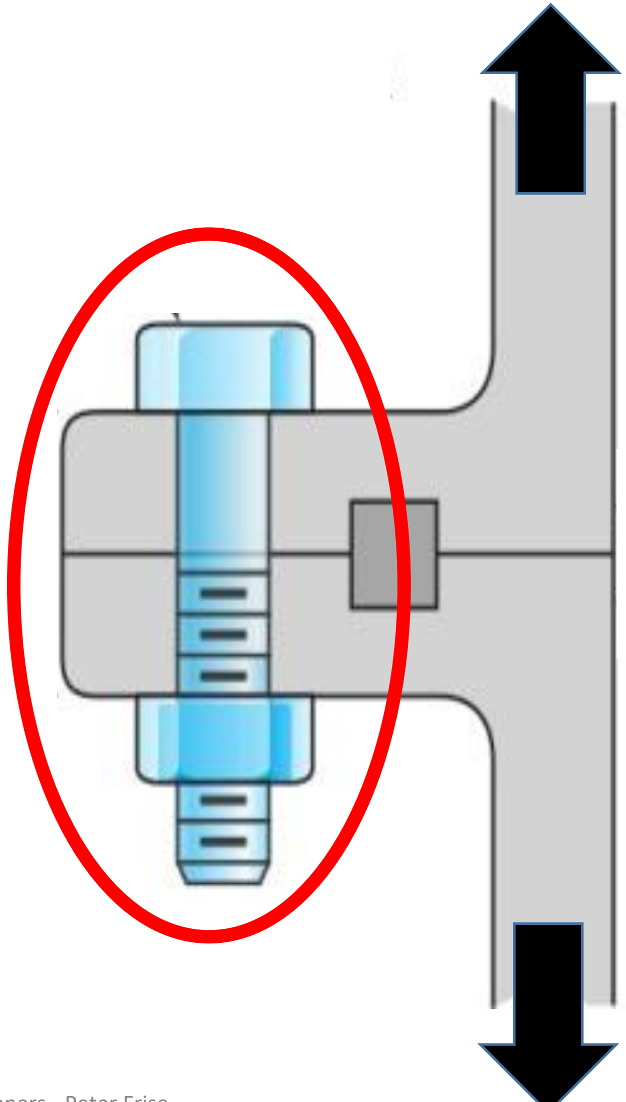
Metric Mechanical-Property Classes for Steel Bolts, Screws, and Studs

Property Class	Size Range, Inclusive	Minimum Proof Strength,* MPa	Minimum Tensile Strength,* MPa	Minimum Yield Strength,* MPa	Material	Head Marking
4.6	M5–M36	225	400	240	Low or medium carbon	4.6
4.8	M1.6–M16	310	420	340	Low or medium carbon	4.8
5.8	M5–M24	380	520	420	Low or medium carbon	5.8
8.8	M16–M36	600	830	660	Medium carbon, Q&T	8.8
9.8	M1.6–M16	650	900	720	Medium carbon, Q&T	9.8
10.9	M5–M36	830	1040	940	Low-carbon martensite, Q&T	10.9
12.9	M1.6–M36	970	1220	1100	Alloy, Q&T	12.9

*Minimum strengths are strengths exceeded by 99 percent of fasteners.

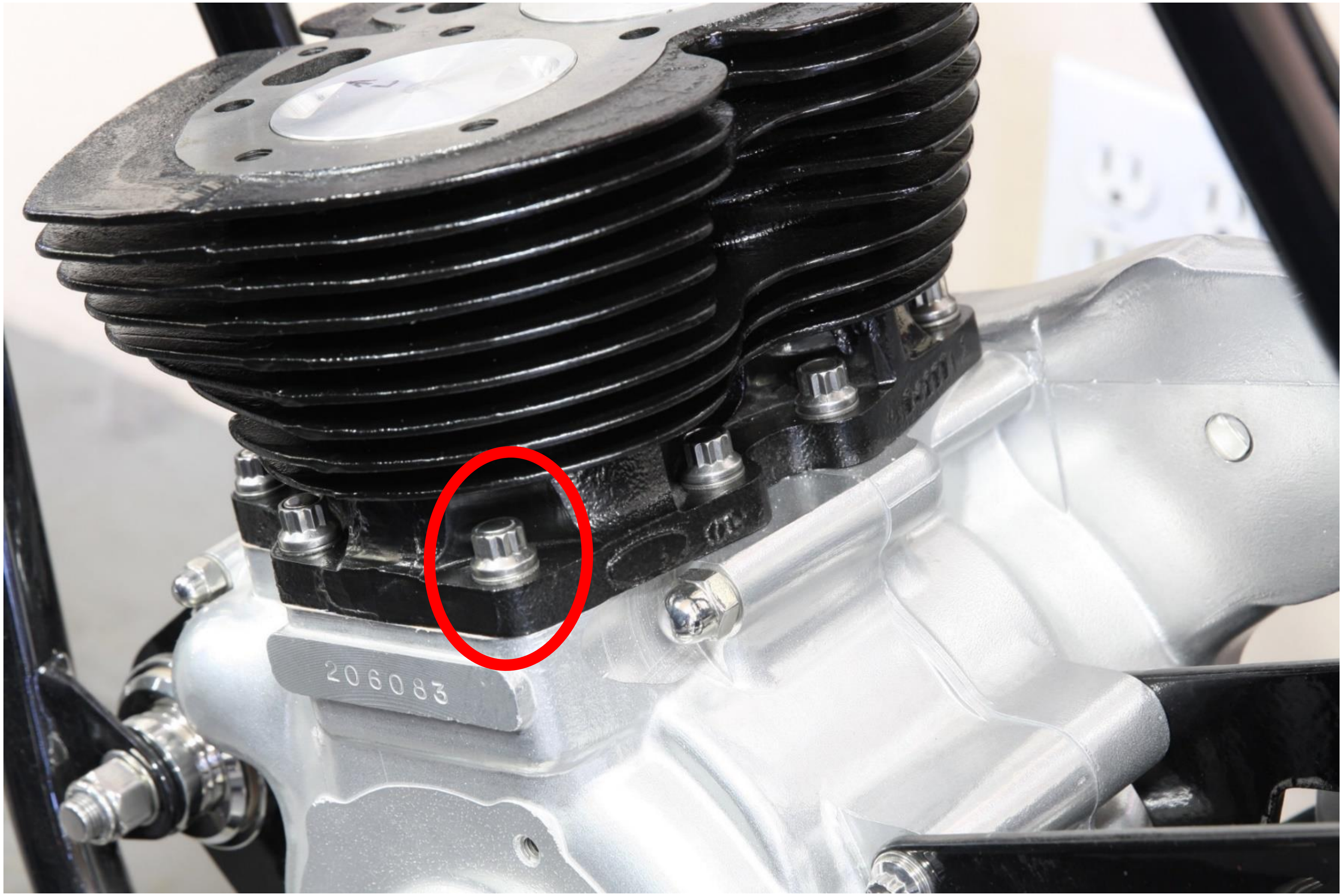
SHORT FASTENERS – *NOT MUCH STRETCH AVAILABLE*

This type of joint design is simple and inexpensive but it is not able to resist applied loads as well as a design with a longer fastener because the short fastener cannot stretch and develop a high pre-load.

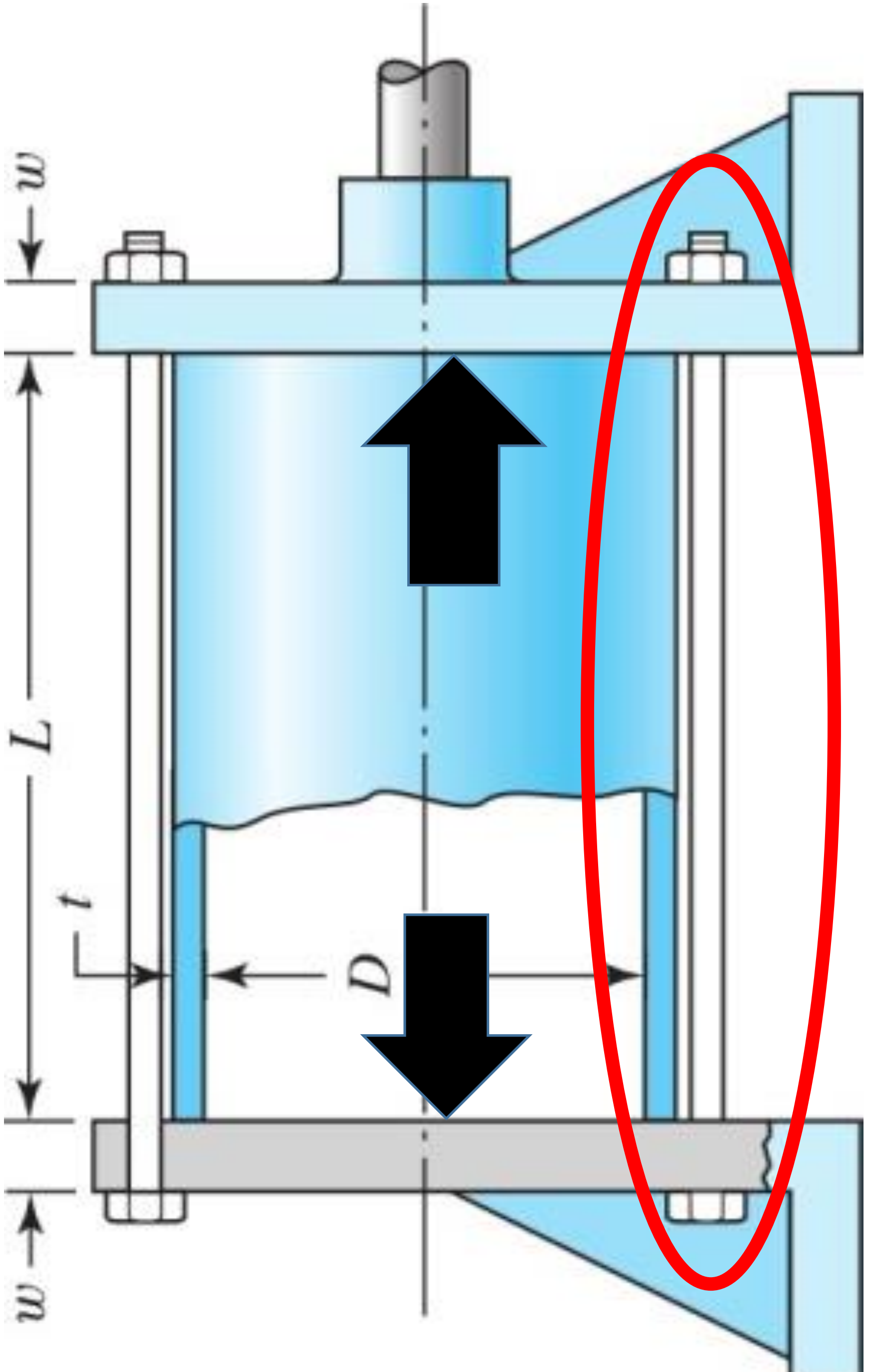


Air Cooled Engine Cylinders

Short Fastener / Bolt Variant *(small amount of fastener stretch available)*

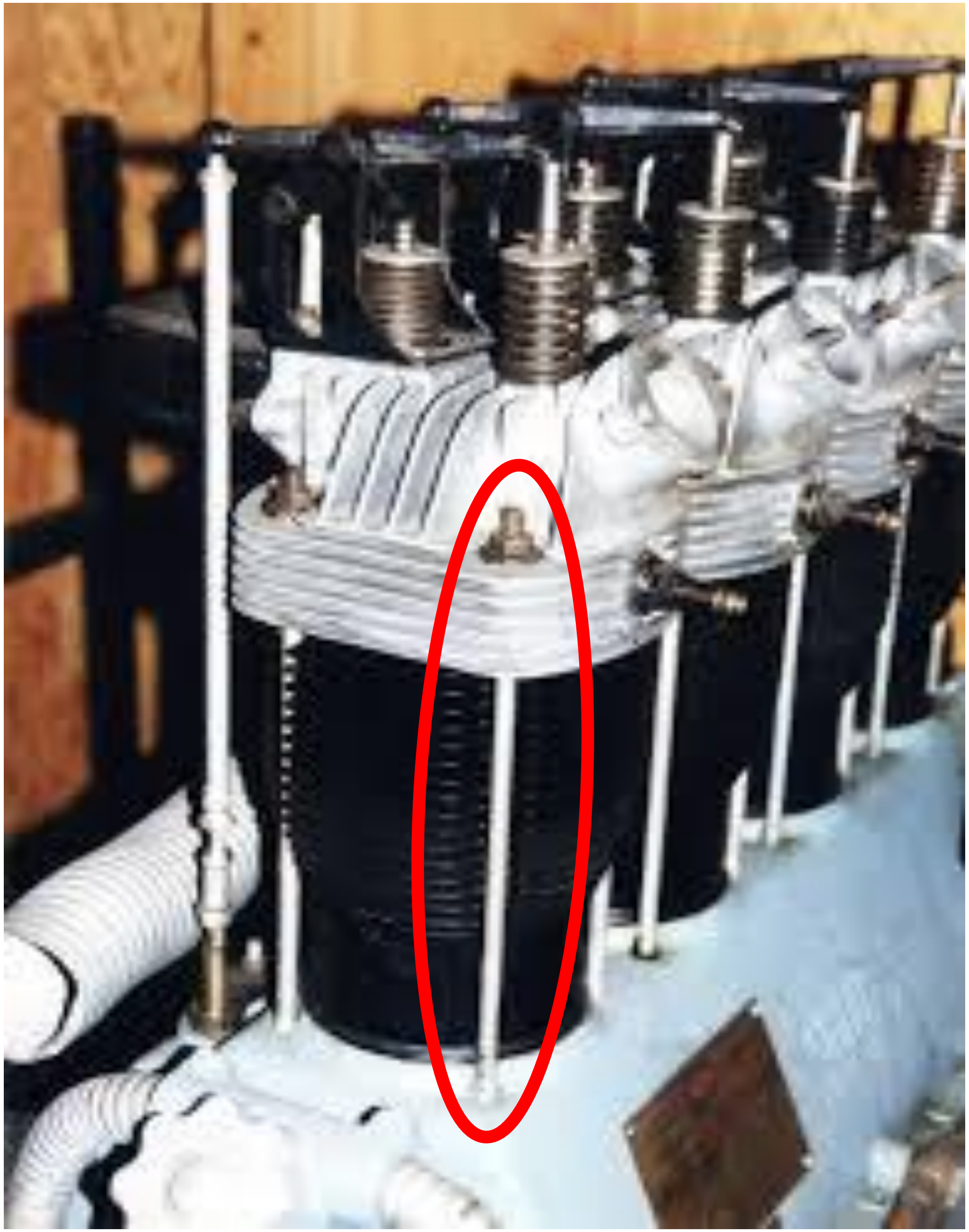


CYLINDER STUDS
- MORE STRETCH AVAILABLE



Air Cooled Engine Cylinders

Long Fastener / Stud Variant
(lots of stretch)



Sample Calculation: *the importance of bolt stretch*

- **General approximation (GA) for the clamp load to reliably seal a gasket is *<u>3 times</u> the lift-off force which is trying to separate the head from the block*.**
- **The lift-off force for a 4.250" bore engine with 1,400 psi combustion firing pressure is *<u>19,861 lbs</u>*.**
- **Clamping Force is 19,861 x *<u>3</u>* = <u>59,583 lbs</u>. *per cylinder* *(that is about 30 tons)*.**
- **5-bolt pattern requires (59,583 ÷ 5) = *<u>11,917 lbs</u>*. of clamping force per bolt;**
- **6-bolt pattern requires *<u>9,930 lbs</u>*. of clamping force *<u>per bolt</u>***

….to reliably seal the engine and prevent head gasket leaks.

If the bolts do not clamp the gasket with at least that much force, the head and block may separate enough to allow the gasket to blow out.

Sample Calculation: *the importance of bolt stretch*

So, let's select a 6-bolt pattern and look at different diameter fasteners and how much they stretch when properly torqued:

- **7/16"Ø bolt stretches .070" = 11,900 lbs. clamp force;**
- **9/16"Ø bolt stretches .030" = 11,900 lbs. clamp force;**

NOTE: the two bolts develop equal clamping force even though the smaller bolt stretches *<u>7X as much</u>*.

A typical head gasket *<u>as installed</u>* is .045" thick *<u>but</u>* it relaxes by about 25% or .011" *<u>when clamped</u>*.

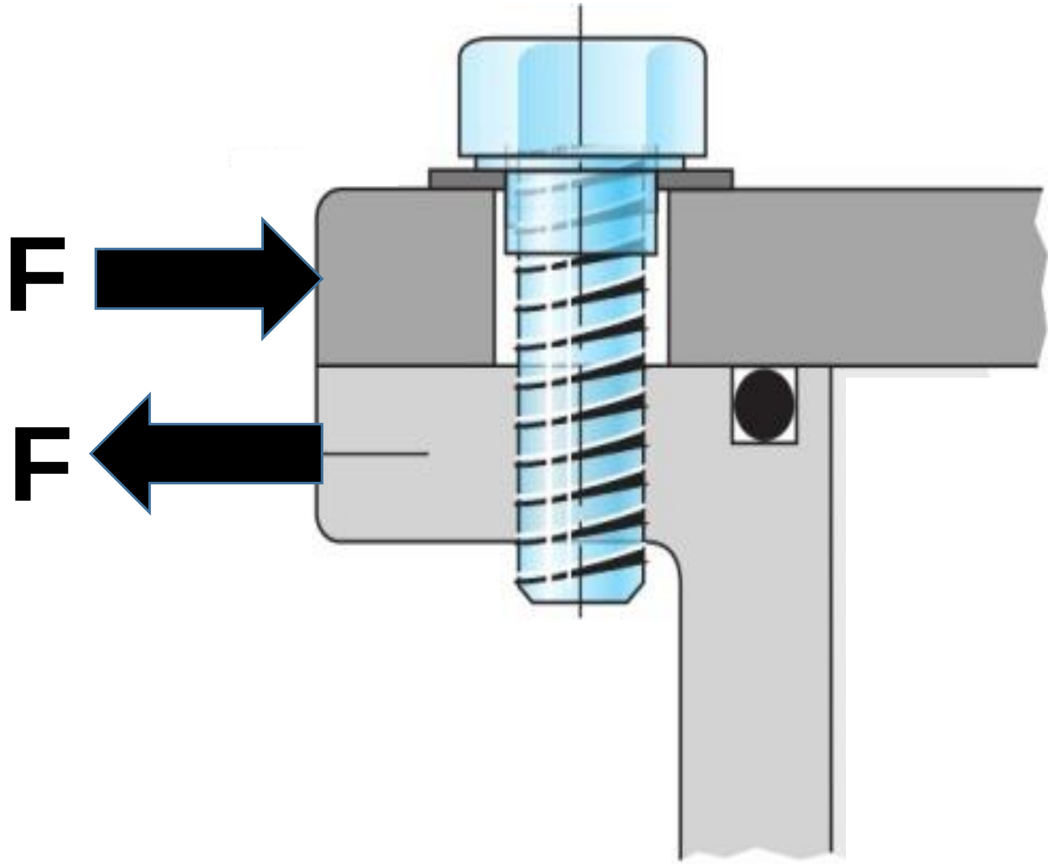
This loss in thickness of .011" also *<u>reduces</u>* the stretch in the bolt, effectively "*<u>loosening</u>*" the bolts;

So, the 7/16"Ø bolt loses 1/7 of its load (.011"/.070"), leaving (11,900 x 6/7) = 10,200 lbs. for clamping, but a 9/16"Ø bolt loses 1/3 of its load (.011"/.030"), leaving only <u>7,933 lb.</u> for clamping (a drop of 1/3 of the original clamping force in the bolts of 11,900 lb.).

BUT – this is *<u>NOT ENOUGH</u>* *to reliably seal the engine (recall that we needed about 9,930 lb. for a good seal)*.

SHEAR LOADED FASTENER

The forces "F" are acting to make the two parts *slide* over each other.



Brake Disc Mounting

(shear loaded joint – requires fasteners to create friction between the disc and the wheel hub)

Thanks very much for your attention

Any questions?