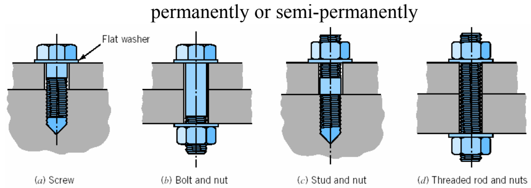
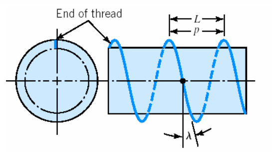
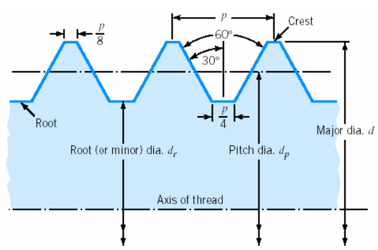
Fasteners: Join two bodies permanently or semi-permanently



Helix (Single Thread)
- Pitch angle λ
- Pitch p (threads per inch)
- Lead L = Pitch
- Diameter d_m
- $\tan\lambda = L/(\pi d_m)$



Fasteners: Helical Thread Details



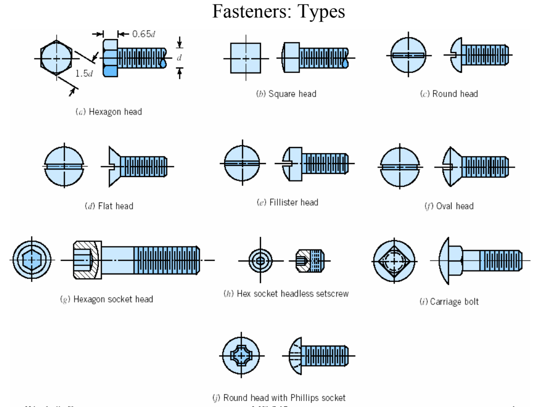
Tables 10.1 and 10.2 provide typical values

Fasteners Design/ Selection

Decisions to be made
- Type: Screw, bolt/nut, stud/nut, …
- Units: Inch (UNC/UNF), or metric (ISO)
- Head-type: hexagon, socket, flat, …
- Material: alloy steel, stainless steel, aluminum, plastic, …
- Size: diameter
- Other choices: lock washers, lock nuts, …

Factors to consider:
- Space / Access
- Cost/ availability
- Product life
- Static and fatigue analysis
- Environment

Fasteners: Types



Fasteners: UNC and UNF

Table 10.1: Screw threads (inch)
Example: 1/8- 40, implies 1/8'' diameter and 40 threads per inch

Table 10.1 Basic Dimensions of Unified Screw Threads

		Coarse Threads—UNC		
Size	Major Diameter d (in.)	Threads per Inch	Minor Diameter of External Thread d_r (in.)	Tensile Stress Area A_t (in.^{2})
0(.060)	0.0600	—	—	—
1(.073)	0.0730	64	0.0538	0.00263
2(.086)	0.0860	56	0.0641	0.00370
3(.099)	0.0990	48	0.0734	0.00487
4(.112)	0.1120	40	0.0813	0.00604
5(.125)	0.1250	40	0.0943	0.00796
6(.138)	0.1380	32	0.0997	0.00909
8(.164)	0.1640	32	0.1257	0.0140
10(.190)	0.1900	24	0.1389	0.0175
12(.216)	0.2160	24	0.1649	0.0242

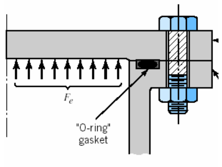
Fasteners: ISO

Table 10.2: Screw threads (ISO/ metric)
Example: M4 x 0.7, implies 4 mm diameter and 0.8 mm pitch

Table 10.2 Basic Dimensions of ISO Metric Screw Thr

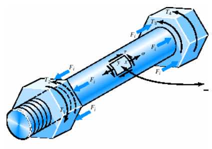
	Coarse Threads		
Nominal Diameter d (mm)	Pitch p (mm)	Minor Diameter d_r (mm)	Stress Area A_t (mm^2)
3	0.5	2.39	5.03
3.5	0.6	2.76	6.78
4	0.7	3.14	8.78
5	0.8	4.02	14.2
6	1	4.77	20.1
7	1	5.77	28.9

Fasteners: Static and Fatigue Analysis



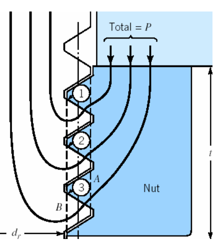
Static problem: Fixed pressure
- What size and material bolt to use?
- How much to tighten?

Fatigue problem: Varying pressure
- What size and material bolt to use?
- How much to tighten?
- Predict life in cycles



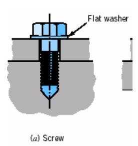
Possible failure locations:
- Threads
- Body
- Neck

Fasteners



Thread failure depends on length of nut
Longer the nut, less likely to fail at thread.
Thread failure (stripping) is undesirable.

Roughly t = 7/8 d will ensure that the fastener will not fail at thread first if nut and bolt have the same strength.
If half strength nut, then twice thickness…



Use of washers will prevent premature failure of fasteners at neck.

Fastener: Failure at some cross-section

Stresses: Axial (and torsion if friction is present … neglect)

Static problem: How much tension can a bolt withstand?
Typically $\sigma > S_y$ is considered failure in static
But S_y will cause strain of 0.2% (acceptable for most applications)
0.2% strain is not acceptable for fastener applications since the parts will separate.
Fasteners axial stress $\sigma <$ Proof Strength $S_p < S_y$

Proof strength depends on material (SAE grade).
Table 10.4 and Table 10.5

Fastener: Proof Strength

Table 10.4 Specifications for Steel Used in Inch Series Sc

SAE Grade	Diameter d (in.)	Proof Load (Strength)[a] S_p (ksi)	Yield Strength[b] S_y (ksi)	Tensile Strength S_u (ksi)
1	$\frac{1}{4}$ thru $1\frac{1}{2}$	33	36	60
2	$\frac{1}{4}$ thru $\frac{3}{4}$	55	57	74
2	Over $\frac{3}{4}$ to $1\frac{1}{2}$	33	36	60
5	$\frac{1}{4}$ thru 1	85	92	120
5	Over 1 to $1\frac{1}{2}$	74	81	105

Table 10.5 Specifications for Steel Used in Millimeter

SAE Class	Diameter d (mm)	Proof Load (Strength)[a] S_p (MPa)	Yield Strength[b] S_y (MPa)	Tensile Strength S_u (MPa)
4.6	5 thru 36	225	240	400
4.8	1.6 thru 16	310	—	420
5.8	5 thru 24	380	—	520

Fasteners are designed based on Proof Strength and stress area

Maximum tension
$F_i = 0.9 A_t S_P$

0.9 provides an additional factor of safety

Fastener: Static force

How much tensile force can M6 X 1 bolt (SAE 4.6) be subject to?

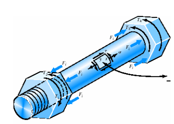
$F_i = 0.9 A_t S_P$

$S_p = 225 MPa = 225x10^6 Pa$

$A_t = 20.1 mm^2 = 20.1x10^{-6} m^2$

$F_i = 452.25 N$

How much torque is needed (approx) to achieve this tensile load?
Analysis similar to a power screw



$$T = W\left(\frac{d_m}{2}\right)\left[\frac{f + \tan\lambda}{1 - f\tan\lambda}\right] + \frac{W f_c d_c}{2}$$

$W = F_i; d_m = d_c = d \text{(major dia)}$

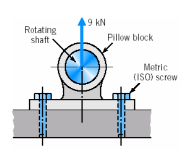
$f = f_c = 0.15; \lambda = 4^0$

$$\boxed{T = 0.2 F_i d}$$

$T = 0.2 * 452 * .006 = 0.54 Nm$

Fastener: Application

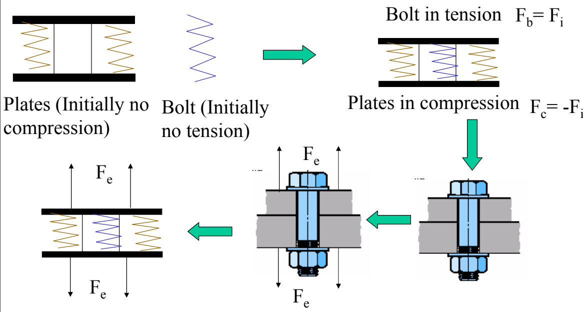
How much tensile force is needed for a particular application?
What bolt would you use for a particular application?



Depends on the separating force expected.
If fastener is not sufficiently tightened, the parts will separate (undesirable).

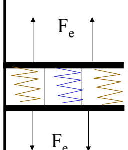
Need a mathematical model of a bolted joint.

Fastener: Bolted Joint



Compression in plates decreases
Tension in bolt increases

Fastener: Bolted Joint



$F_b = F_i + \Delta F_b$

$F_c = -F_i + \Delta F_c$

$\Delta F_b + \Delta F_c = F_e$ 2 unknowns, 1 equation!!

Need to consider displacement to solve!!

Bolt and plates have displacement δ when external force is applied.

k_c : stiffness of plate $\Delta F_c = k_c \delta$

k_b : stiffness of bolt $\Delta F_b = k_b \delta$

$$\frac{\Delta F_c}{\Delta F_b} = \frac{k_c}{k_b}$$

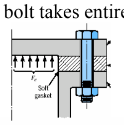
$$\Delta F_c = \left[\frac{k_c}{k_c + k_b}\right] F_e$$

$$\Delta F_b = \left[\frac{k_b}{k_c + k_b}\right] F_e$$

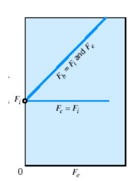
Fastener: Bolted Joint

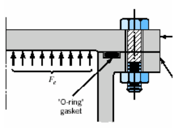
$$F_c = -F_i + \left[\frac{k_c}{k_c + k_b}\right] F_e \qquad F_b = F_i + \left[\frac{k_b}{k_c + k_b}\right] F_e$$

Above load sharing is valid provided $F_c < 0$, else the parts will separate and bolt takes entire load

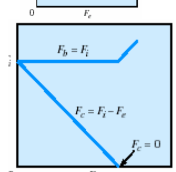


$k_c = 0$



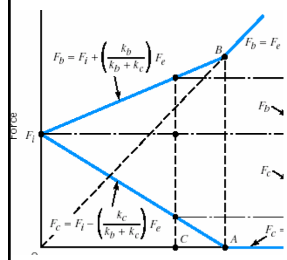


$k_b = 0$



Fastener: Bolted Joints

In general

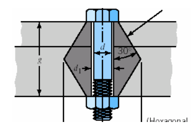


How to find k_b and k_c?

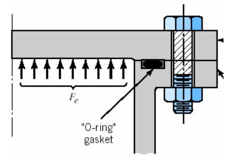
$k_b = \frac{AE}{l}$; A = based on major dia

k_c = based on fulcrum analysis

Else k_c must be assumed



Fasteners: Static and Fatigue Analysis



Static problem: Fixed F_e = 1.2KN /bolt

- What metric bolt to use?
- Use a safety factor of 4 for F_i
- How much torque?
- Assume $k_c = 5*k_b$

$$F_c = -F_i + \left[\frac{5}{6}\right]1200$$

F_i must be sufficiently high that the parts don't separate, ie. $F_c < 0$

$-F_i + (5/6)1200 < 0$

$F_i > 1000N$

Bolt to be tightened to F_i =4*1000 = 4kN

Assume SAE grade 4.6; S_p = 225 Mpa

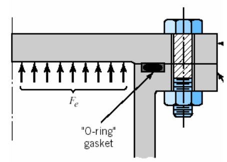
$4000 = 0.9 * S_p A_t$

$A_t = 19mm^2$

$M6x1$ ($A_t = 20.1mm^2$)

Torque = $0.2F_i d$ = 48Nm

Fasteners: Static and Fatigue Analysis



Static problem:

- M4x0.7(SAE 4.8) to proof strength
- Find load F_e before separation
- Assume $k_c = 3*k_b$
- Find F_b and F_c for F_e = 1kN
- Find F_b and F_c for F_e = 10kN

$F_i = 0.9 * S_p A_t$

$A_t = 8.78mm^2$

$S_p = 310MPa$

$F_i = 2.45kN$

$F_c = -F_i + \left[\frac{3}{4}\right] F_e < 0$

$F_e < 3.27kN$

Since $1kN < 3.27kN$

$F_b = F_i + (1/4)1000 = 2.7kN$

$F_c = -F_i + (3/4)1000 = -1.7kN$

$Note: F_b + F_c = 1kN$

Since $10kN > 3.27kN$

$F_b = 10kN$

$F_c = 0 (separation)$

$Note: F_b + F_c = 10kN$