WORCESTER POLYTECHNIC INSTITUTE
MECHANICAL ENGINEERING DEPARTMENT

DESIGN OF MACHINE ELEMENTS
ME-3320, A'2014

Lecture 28

October 2014



Screws and fasteners

Fastener design

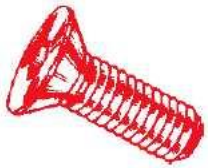
Bolts and nuts



Bolts



(a) Socket head

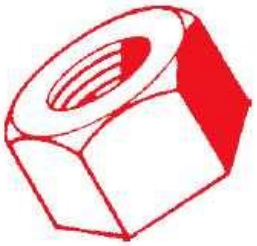


(b) Socket flat head



(c) Socket button head

Nuts



(a) Standard hex nut



(b) Hex jam nut

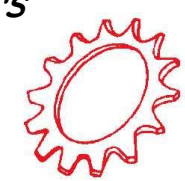


(c) Hex castle nut

Washers



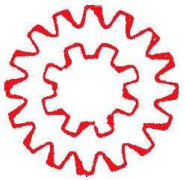
(a) Split lock washer



(c) External-tooth washer



(b) Internal-tooth washer



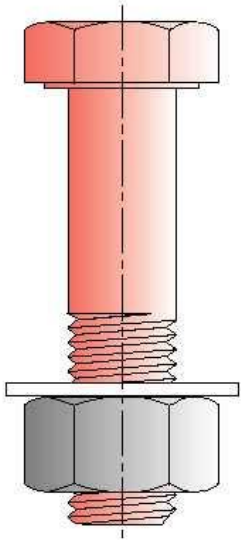
(d) Internal-external tooth



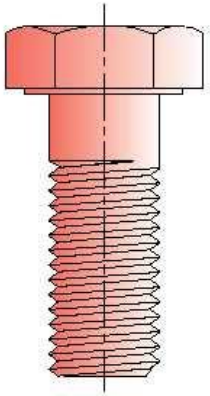
WPI

Screws and fasteners

Fastener design



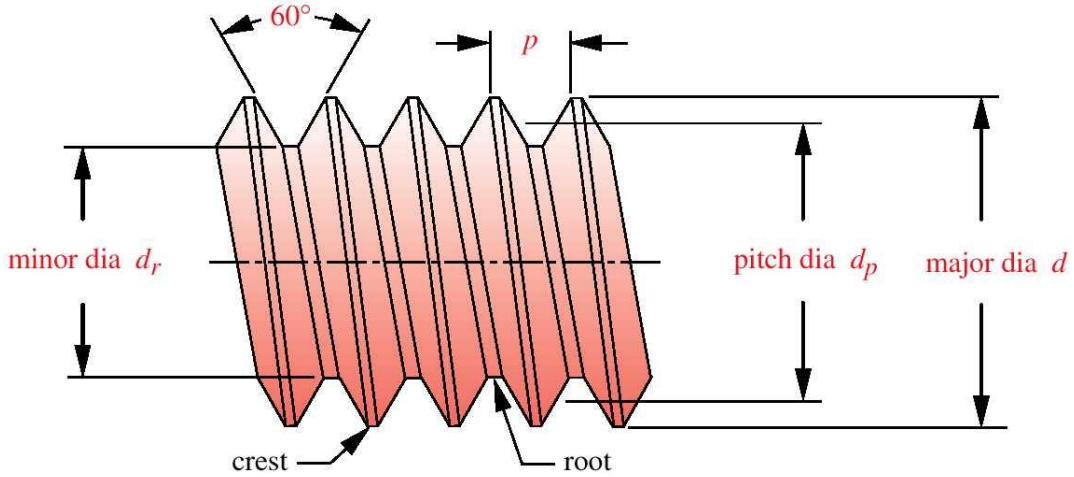
(a) Bolt, washer, and nut



(b) Machine (cap) screw

United National Standard (UNS) and ISO thread form

(UNC - coarse thread; UNF - fine thread; see Table 14-1)



Specification (example):

$$1/4-20\ \text{UNC}-2\text{A}$$

1/4" diameter, d

20- threads per inch (p_d)

Coarse series

Class 2-fit, external

Screws and fasteners

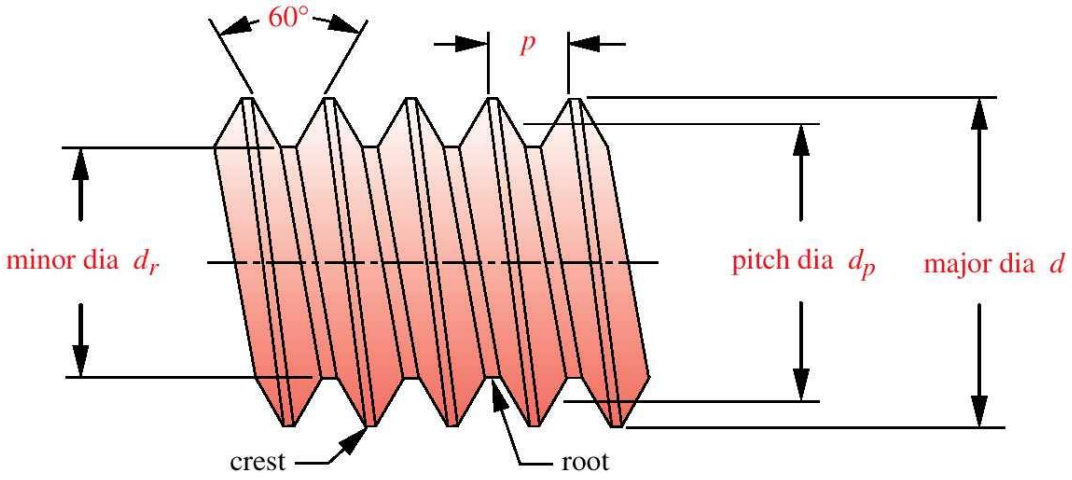
Tensile stress area

Tensile stress area (definition): $A_t = \frac{\pi}{4}\left(\frac{d_p + d_r}{2}\right)^2$

UNS threads: $d_p = d - 0.649519/N$ $\quad d_r = d - 1.299038/N$

ISO threads: $d_p = d - 0.649519\,p$ $\quad d_r = d - 1.226869\,p$

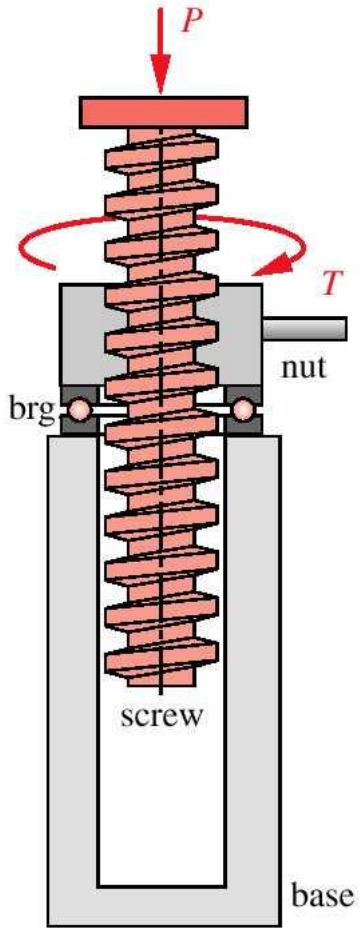
Tensile stress : $\sigma_t = \frac{F}{A_t}$ $\quad$ *Torsional stress :* $\tau = \frac{Tr}{J} = \frac{16T}{\pi d_r^3}$



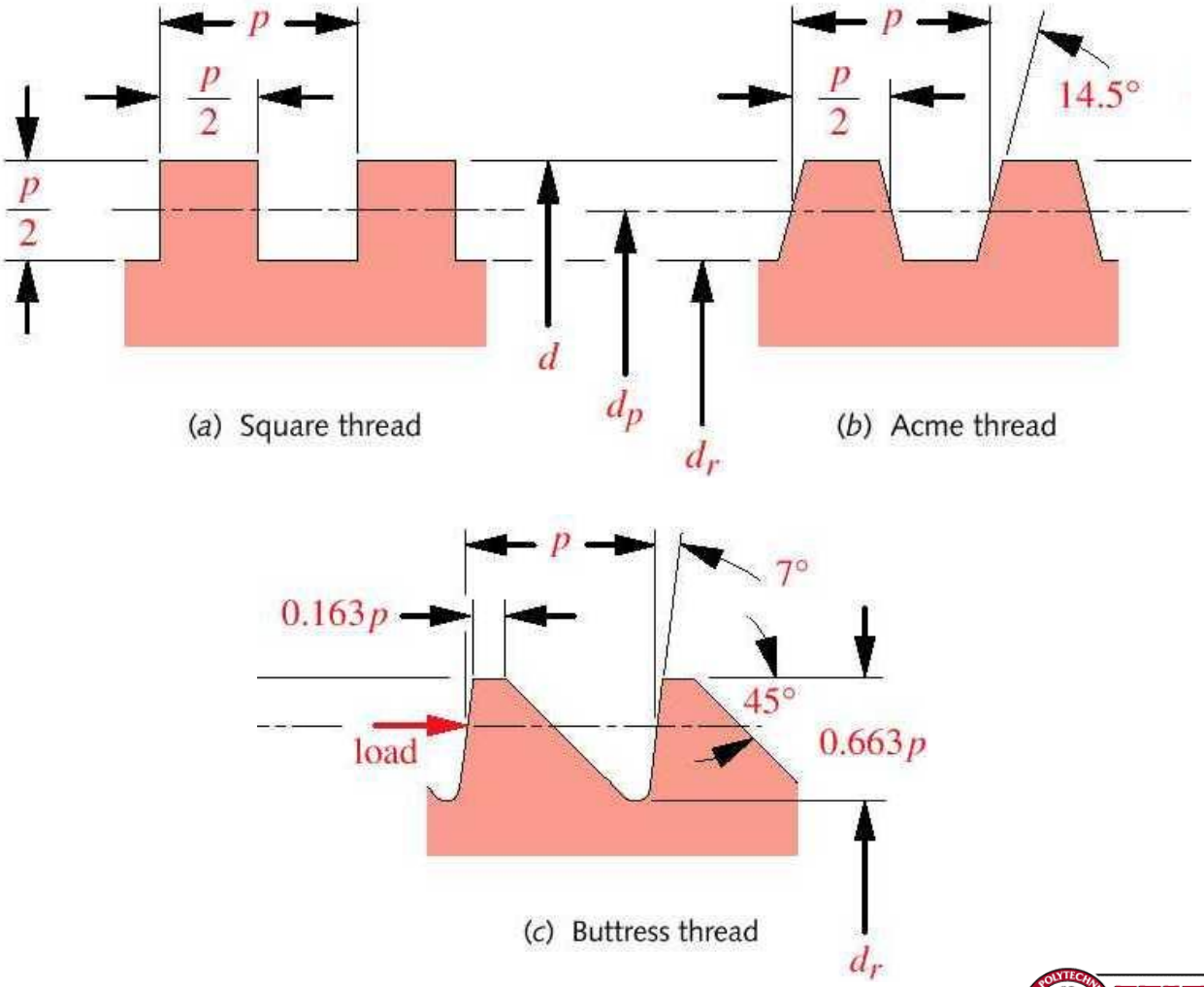
Screws and fasteners

Power screw applications

Power-screw jack



Typical power-screw threads



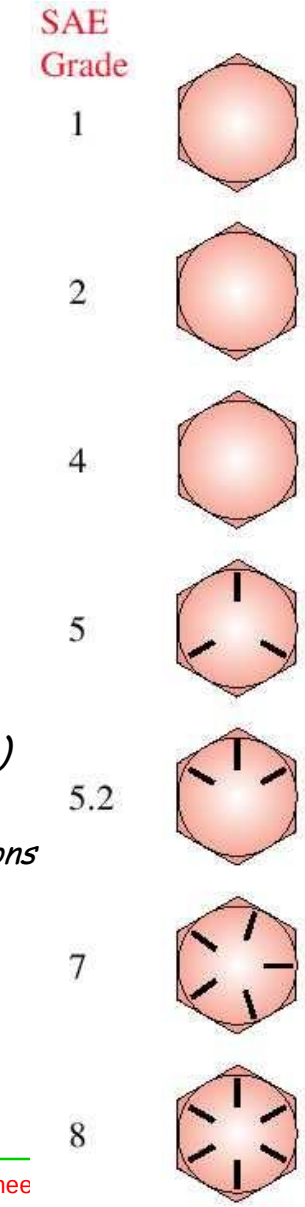
Screws and fasteners

Strength of standard bolts and machine screws

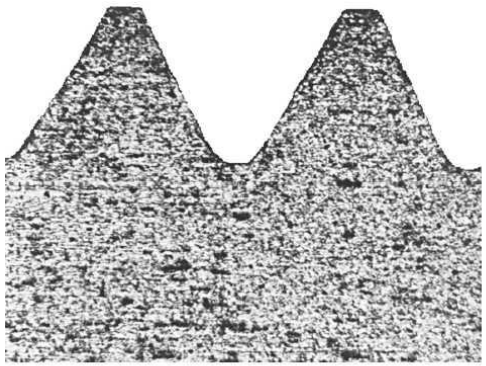
Table 14-6 SAE Specifications and Strengths for Steel Bolts

SAE Grade Number	Size Range Outside Diameter (in)	Minimum Proof Strength (kpsi)	Minimum Yield Strength (kpsi)	Minimum Tensile Strength (kpsi)	Material
1	0.25–1.5	33	36	60	low or medium carbon
2	0.25–0.75	55	57	74	low or medium carbon
2	0.875–1.5	33	36	60	low or medium carbon
4	0.25–1.5	65	100	115	medium carbon, cold drawn
5	0.25–1.0	85	92	120	medium carbon, Q&T*
5	1.125–1.5	74	81	105	medium carbon, Q&T
5.2	0.25–1.0	85	92	120	low-carbon martensite, Q&T
7	0.25–1.5	105	115	133	medium-carbon alloy, Q&T
8	0.25–1.5	120	130	150	medium-carbon alloy, Q&T
8.2	0.25–1.0	120	130	150	low-carbon martensite, Q&T

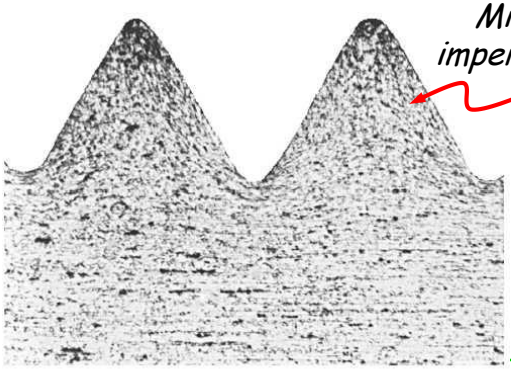
* Quenched and Tempered.



Grain structure of cut and rolled threads (stress concentrations; cracks; etc)



(*a*) Cut threads

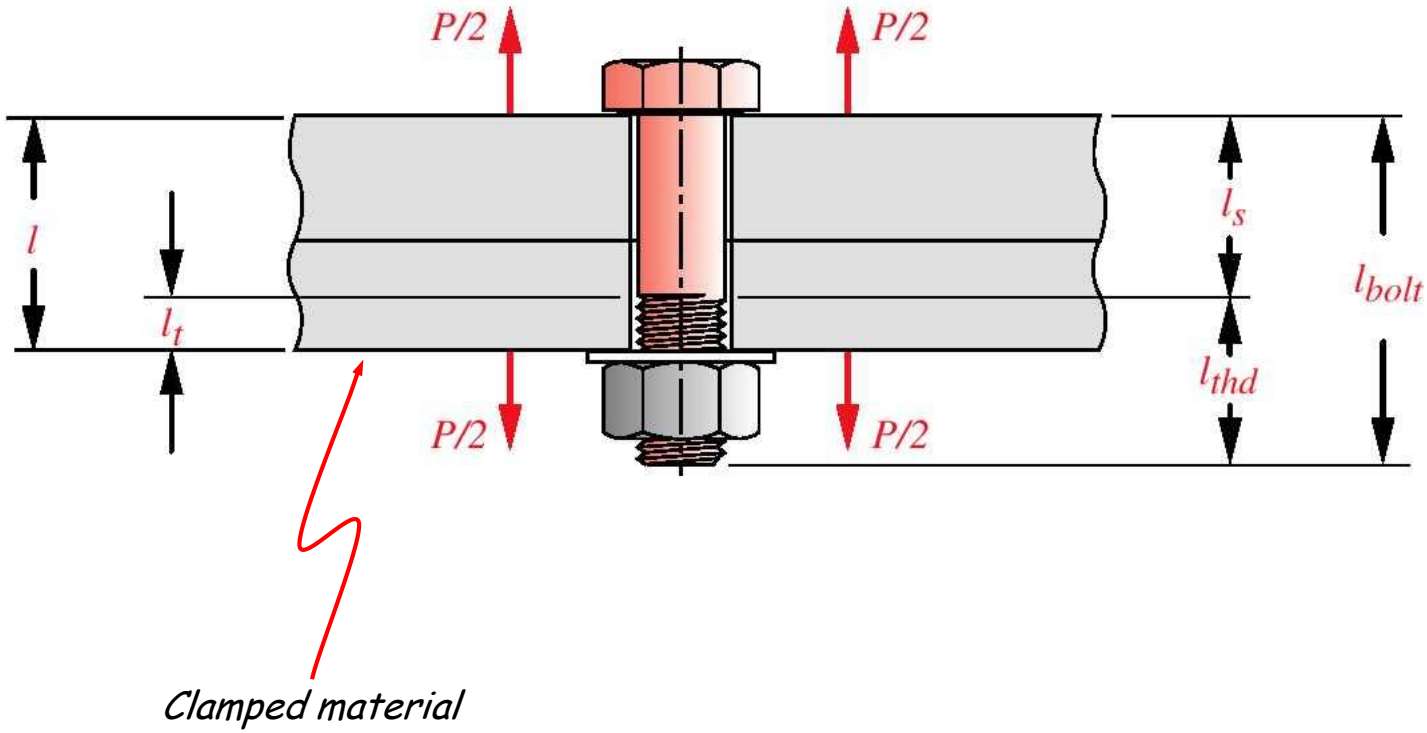


(*b*) Rolled threads

Screws and fasteners

Preloaded fasteners in tension

Bolted assembly in tension: nomenclature

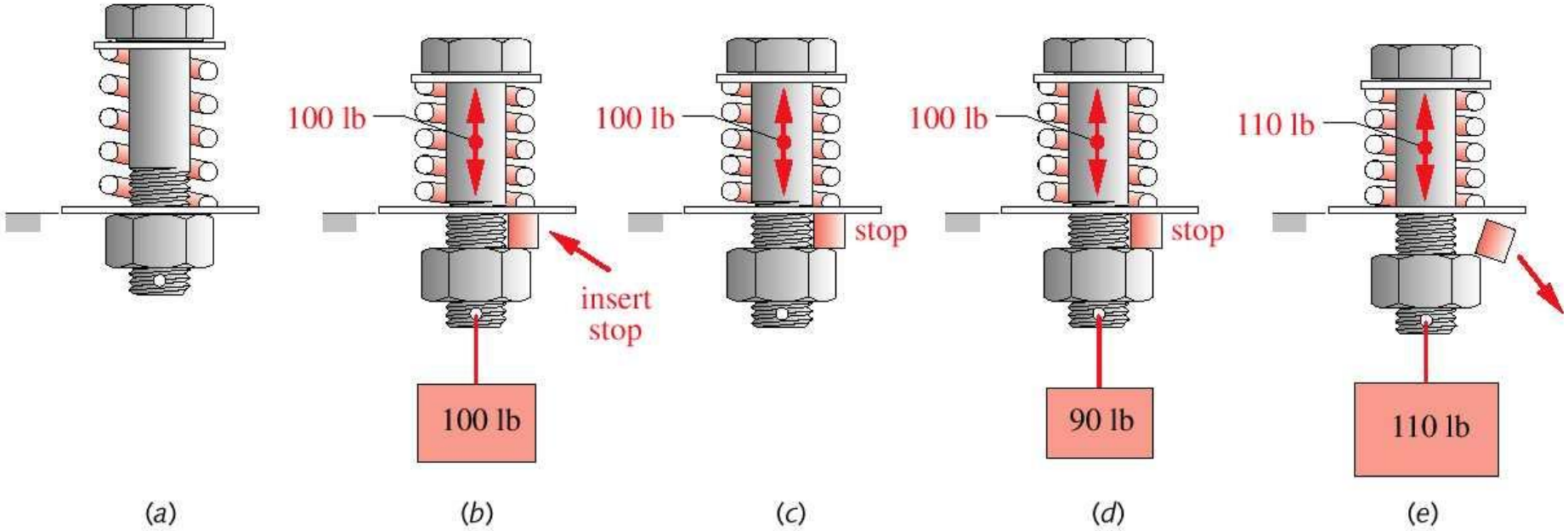




Screws and fasteners

Preloaded fasteners in tension

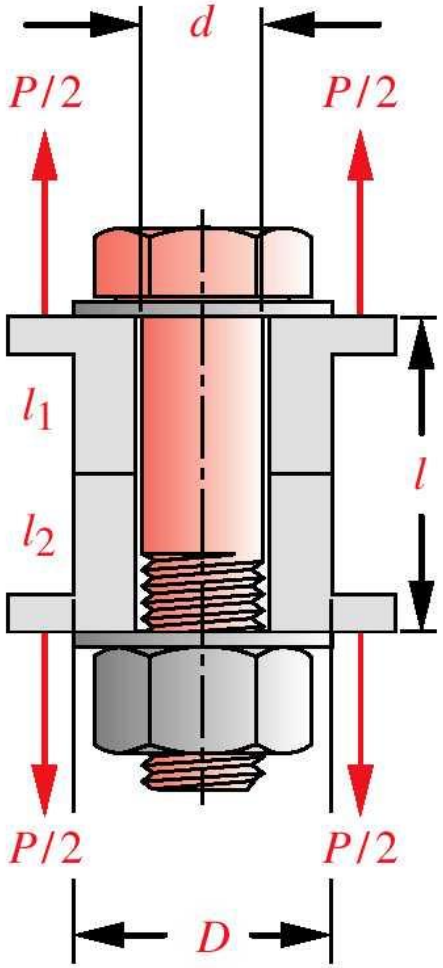
Preloading a bolted assembly: ***note that clamped material is modeled as a spring in compression***

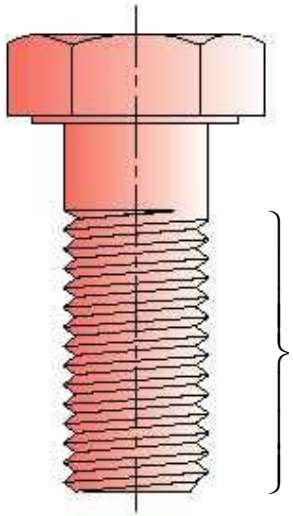


Screws and fasteners

Preloaded fasteners in tension

Preloaded bolt compressing a cylinder





Length of thread = twice bolt diameter + 1/4 inch

(*b*) Machine (cap) screw



Screws and fasteners

Preloaded fasteners in tension

Recall the spring constant for a bar in tension.

Deflection, δ: $$E\frac{\delta}{l}=\frac{F}{A} \Rightarrow \delta=\frac{F\,l}{A\,E}$$

Equivalent spring constant, k: $$k=\frac{F}{\delta}=\frac{A\,E}{l}$$

Recall the spring constant for different stiffness sections.

Total spring constant, k_{total} : $$\frac{1}{k_{total}}=\frac{1}{k_1}+\frac{1}{k_2}+\ldots\frac{1}{k_n}$$



Screws and fasteners

Preloaded fasteners in tension

Spring constant for a round bolt is:

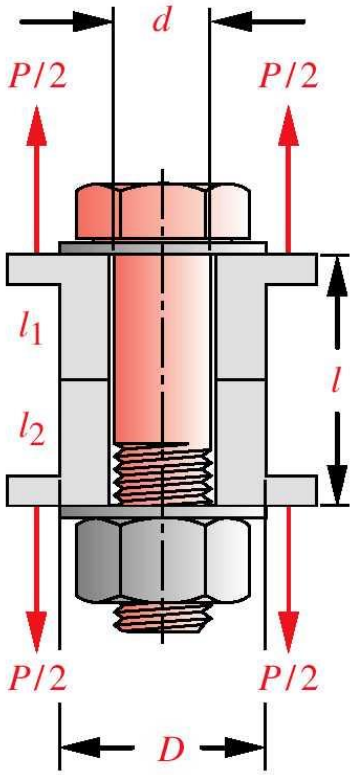
$$\frac{1}{k_b} = \frac{l_t}{A_t E_b} + \frac{l - l_t}{A_b E_b}$$

Spring constant for, equivalent, cylindrical clamped material:

$$\frac{1}{k_m} = \frac{l_1}{A_{m_1} E_1} + \frac{l_2}{A_{m_2} E_2}$$

*If clamped **materials** are the same:* $E_1 = E_2 = E_m$

$$\Rightarrow \quad k_m = \frac{A_m E_m}{l} = \frac{\pi D_{eff}^2}{4} \frac{E_m}{l}$$

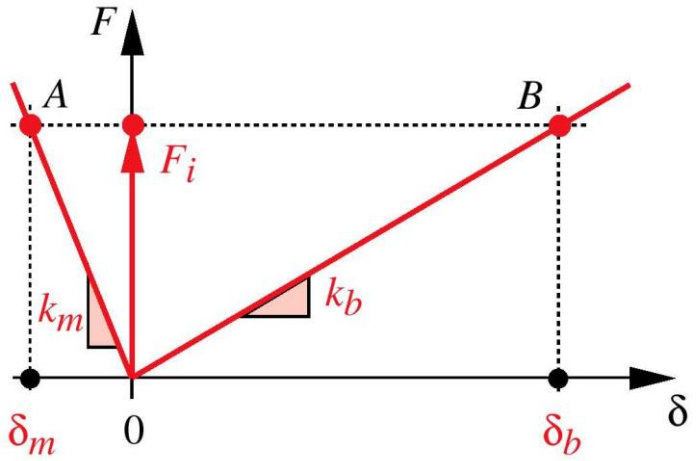




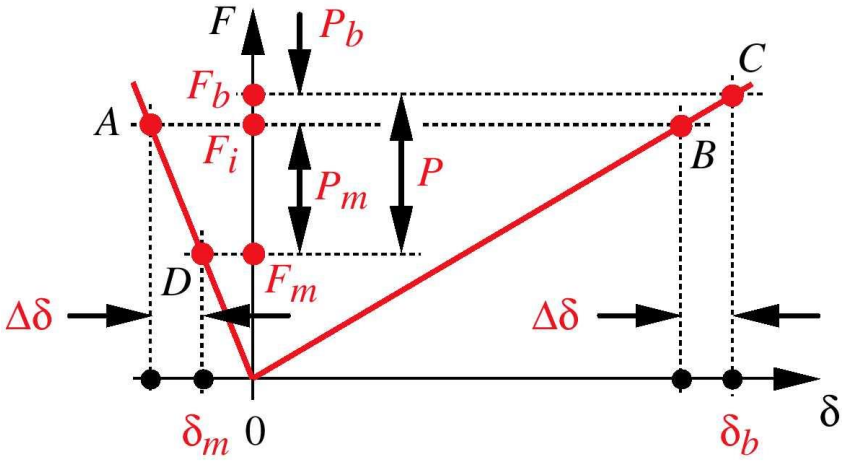
WPI

Screws and fasteners

Preloaded fasteners in tension: static load



(a) Preload force and initial deflections



(b) Load deflection and resulting forces

Load: supported by bolt and material:

$$P = P_m + P_b$$

Compressive load in the material:

$$F_m = F_i - P_m \;\; ; \;\; F_m \geq 0$$

Tensile load in the bolt:

$$F_b = F_i + P_b$$



Screws and fasteners

Preloaded fasteners in tension: static load

Key calculations showing advantage of preloaded fasteners:

Change in deflection: $$\Delta\delta = \frac{P_b}{k_b} = \frac{P_m}{k_m} \Rightarrow P_b = \frac{k_b}{k_m} P_m$$

Using: $$P = P_m + P_b \Rightarrow P_b = \frac{k_b}{k_m + k_b} P = CP$$

Bolt supports fraction of total load !!!

Also, using: $$P = P_m + P_b \Rightarrow P_m = \frac{k_m}{k_m + k_b} P = (1 - C)P$$

Material supports most of total load !!!



Screws and fasteners

Preloaded fasteners in tension: static load

Key calculations showing advantage of preloaded fasteners:

Material load: $F_m = F_i - (1-C)P$

Bolt load: $F_b = F_i + CP$

Solve to determine optimal pre-load, F_i

Joint separation load (set $F_m = 0$): $P_o = \frac{F_i}{1-C}$

Safety factor against joint separation: $N_{separation} = \frac{P_o}{P} = \frac{F_i}{P(1-C)}$



Examples

- Review and Master: Example 14-2



Reading

- Chapters 15 of textbook
- Review notes and text: ES2501, ES2502, ES2503

Homework assignment

- Author's: 15-1
- Solve: 15-2, 15-7, 15-11, 15-23m

