طراحی اجزاء ۱

فصل هشتم: پیچ، بستها و اتصالات غیر دائم

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دانشگاه سمنان، دانشکده مهندسی مکانیک

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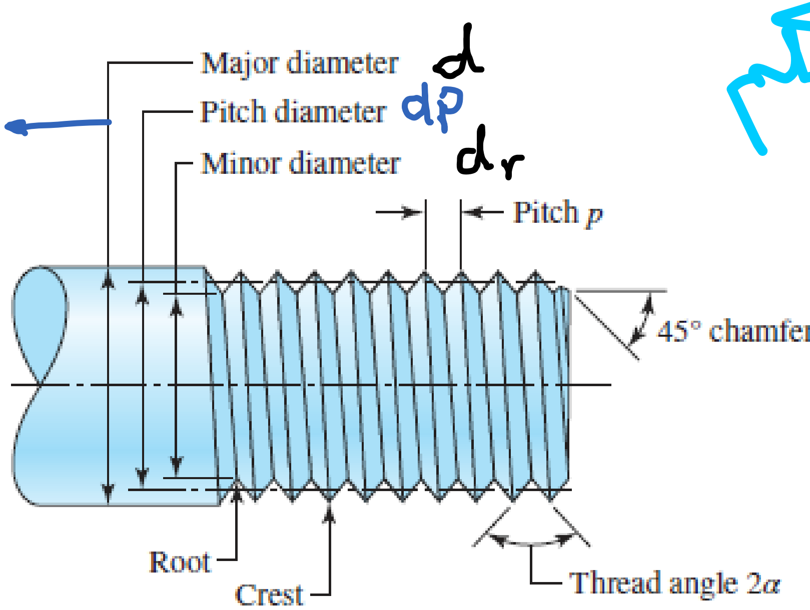
8 Screws, Fasteners, and the Design of Nonpermanent Joints

Chapter Outline

جلسه بیست و یکم

قطر نامی



- ***Pitch*** is the distance between adjacent thread forms measured parallel to the thread axis. The pitch in U.S. units is the reciprocal of the number of thread forms per inch N.
- ***Major diameter d*** is the largest diameter of a screw thread.
- ***Minor*** (or root) ***diameter*** d_r is the smallest diameter of a screw thread.
- ***Pitch diameter*** d_p is a theoretical diameter between the major and minor diameters.
- ***Lead*** l, not shown, is the distance the nut moves parallel to the screw axis when the nut is given one turn. For a single thread, as in Figure 8–1, the lead is the same as the pitch.

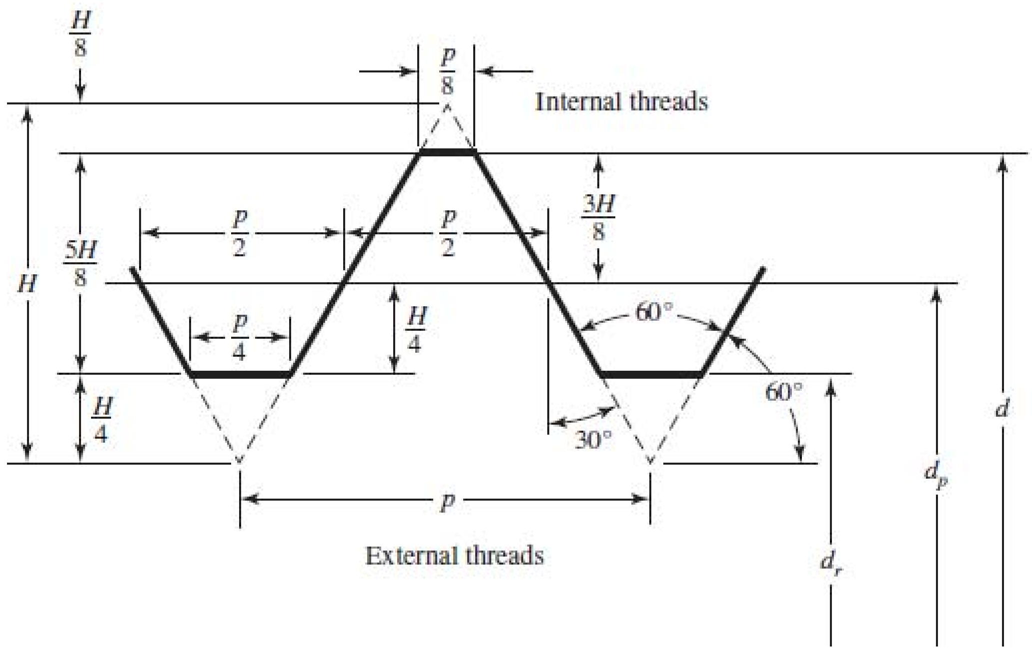


Figure 8–2

Basic profile for metric M and MJ threads.

d = major diameter

d_r = minor diameter

d_p = pitch diameter

p = pitch

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

پیچ دنده مربعی ، دنده آکمه یا دنده کبریتی یا دنده ذوزنقه‌ای

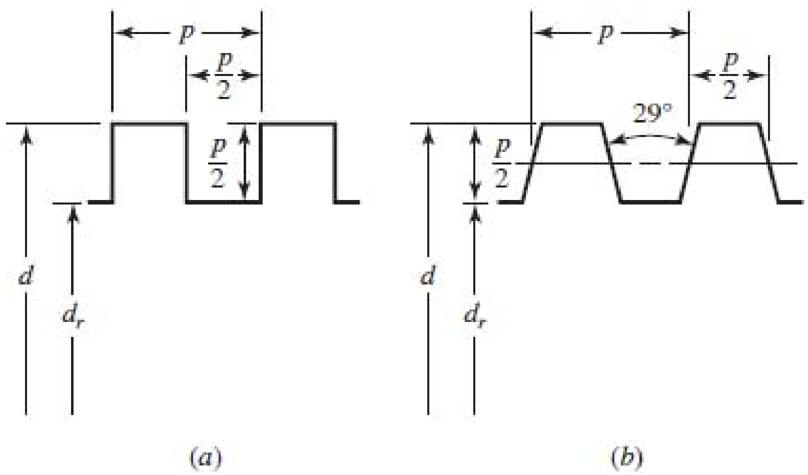


Figure 8–3
(*a*) Square thread; (*b*) Acme thread.

بیشترین بهره‌وری

Table 8–3 Preferred Pitches for Acme Threads

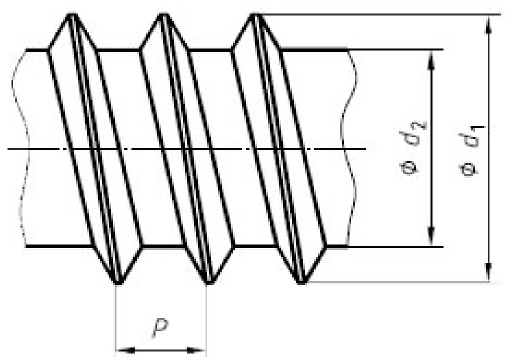
d, in	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{2}$	3
p, in	$\frac{1}{16}$	$\frac{1}{14}$	$\frac{1}{12}$	$\frac{1}{10}$	$\frac{1}{8}$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{1}{5}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$

پیچ‌های خودکار

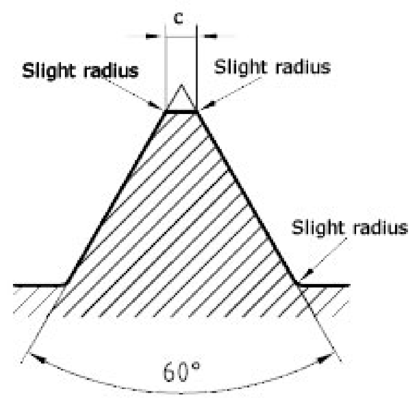
self tapping

SELF TAPPING SCREW THREAD PER ISO 1478

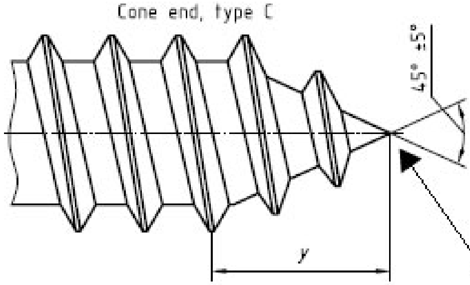
Thread (ST)



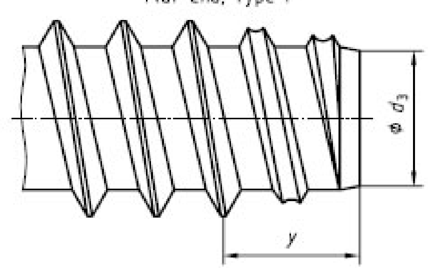
Thread Profile



Cone end, type C

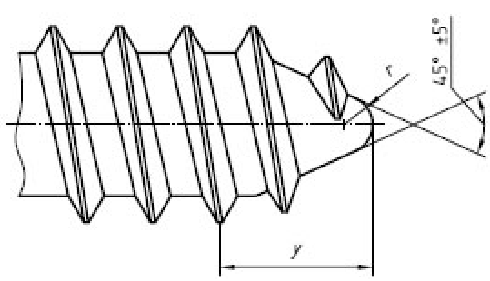


Flat end, type F



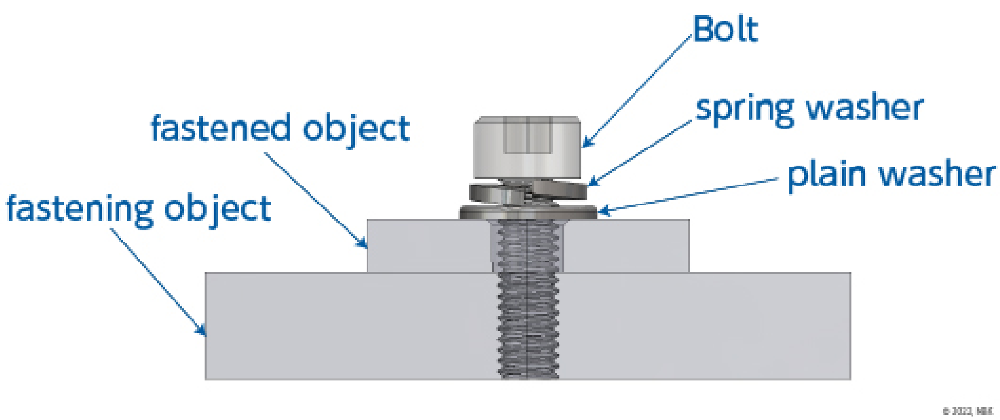
No extrusion of excess metal beyond the apex of the type C cone end resulting from thread rolling shall be permissible.
A slight rounding or truncation of the point is desirable.

Rounded end, type R



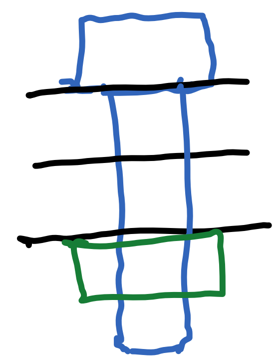
تقسیم بندی پیچها از لحاظ نوع دنده و کاربرد

۱- پیچهای اتصال ، برای متصل کردن دو قطعه یا بیشتر به یکدیگر استفاده می شود



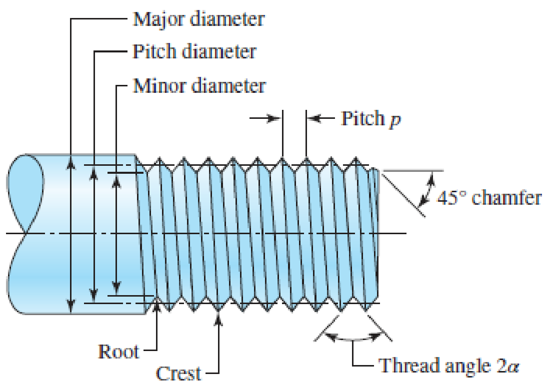
بدون مهره

قطعه دوم رزوه شده و شبیه مهره عمل می کند



با مهره

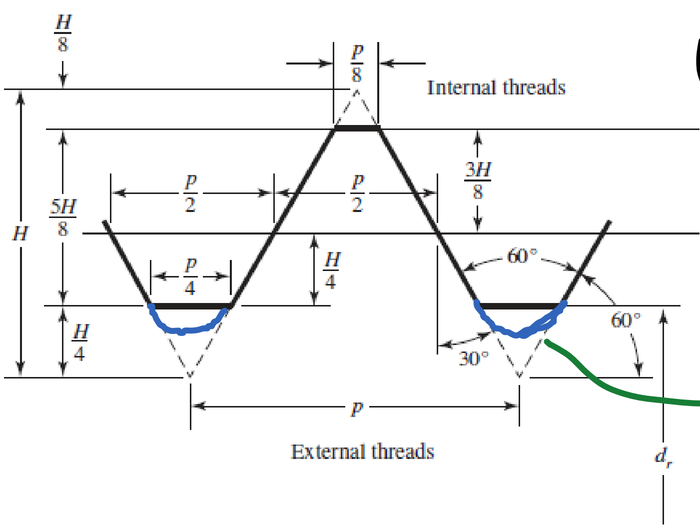
پیچ‌های اتصال



استاندارد

- دنده متریک
  - M
  - MJ
- دنده Unified
  - UN
  - UNR

اینچی، انگلیسی، آمریکایی

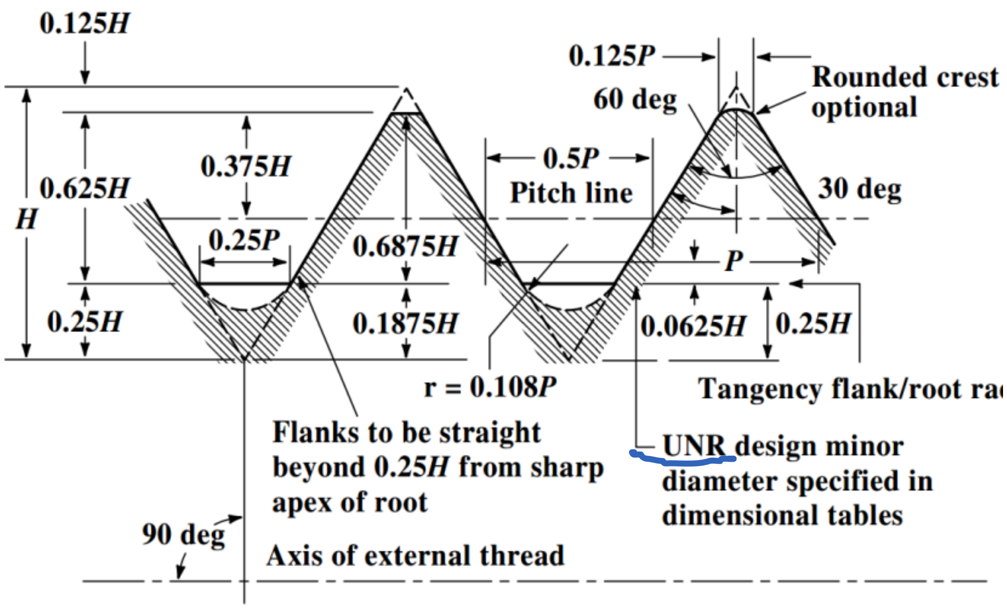


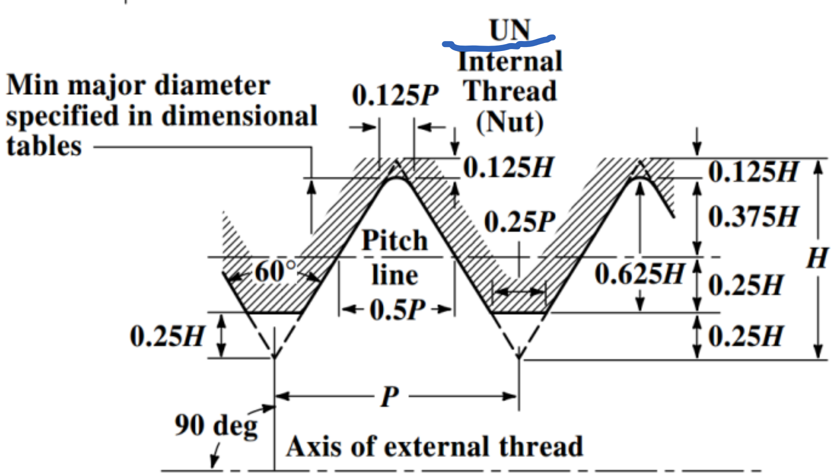
MJ or UNR

جهت کاهش تمرکز تنش در خستگی

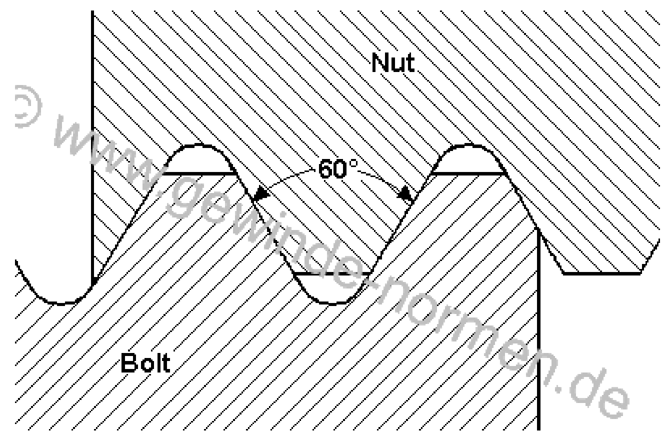
UN , UNR

M , MJ





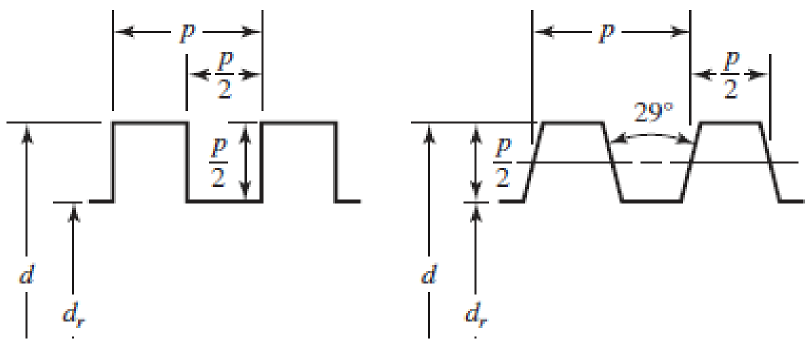
(H = height of sharp V-thread = 0.86603 × pitch)



greater root radius

Power screw

۲- پیچ‌های انتقال قدرت

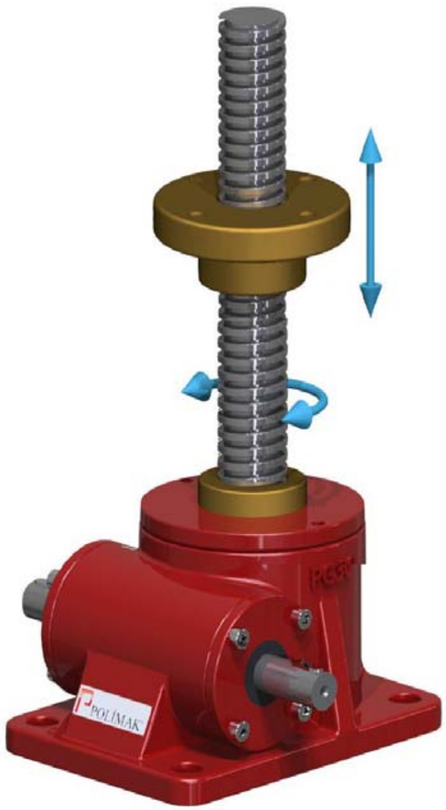


- پیچ دنده مربعی
- پیچ ACME، دنده ذوزنقه‌ای،

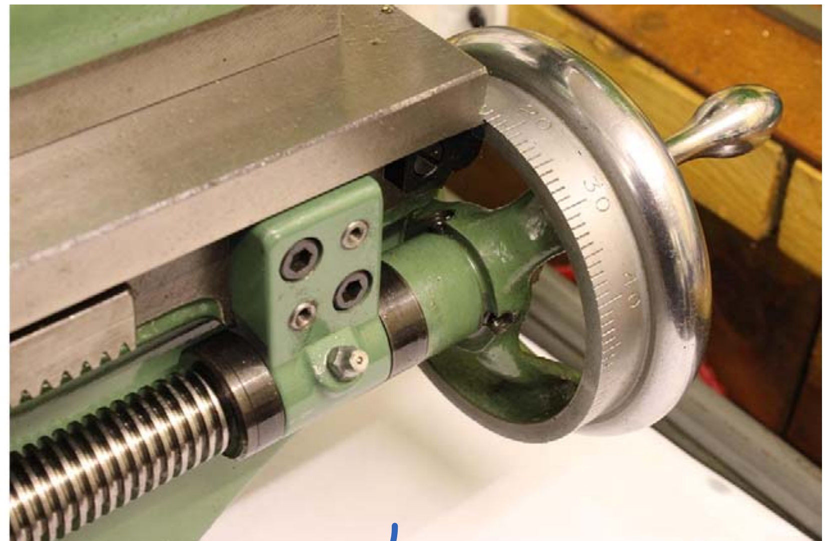
دنده کبریتی، Lead screw

این پیچ‌ها جهت انتقال و جابجایی یک قطعه یا بار مورد استفاده قرار می‌گیرند

- پیچ ثابت است، مهره می‌چرخد
- مهره ثابت است، پیچ می‌چرخد



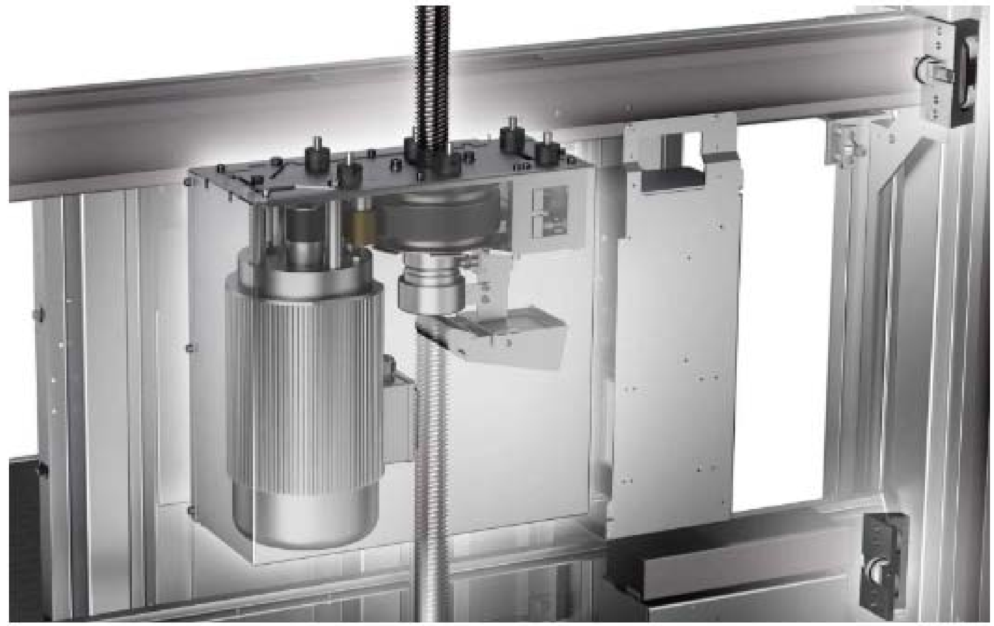
پیچ جابجایی



F

$T_{R,L}$

پیچ خودقفل است



مهره می چرخد

بالابر . Home lift

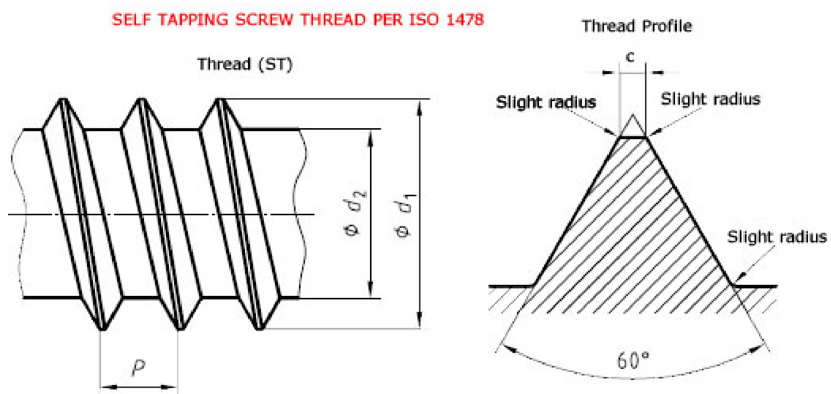
آسانسور

ایمنی بالایی دارد، سرعت پایین

- CNC
- پرینتر سه بعدی

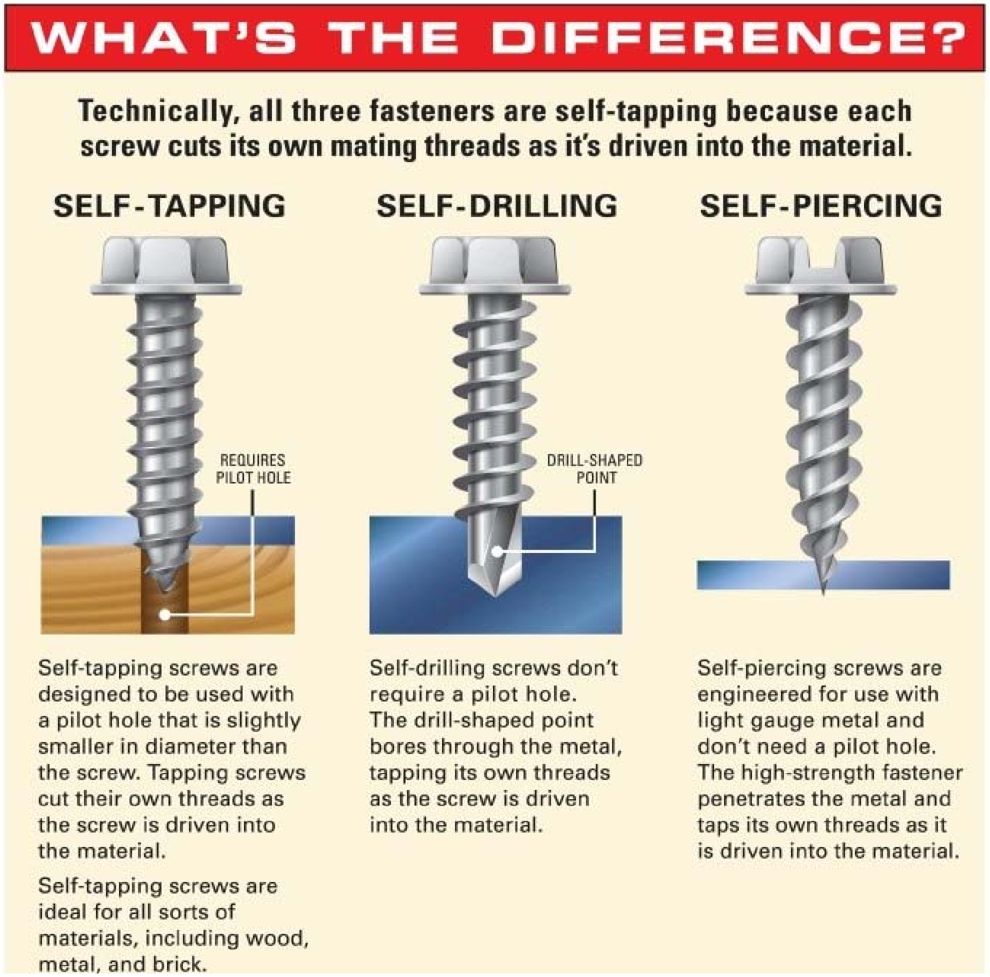
linear motion

۳- پیچ‌های خودکار



- این پیچ‌ها بدون مهره استفاده می‌شوند
- اغلب برای اتصال دو قطعه به هم ، استفاده می‌شوند
- روی قطعه دوم نیاز به قلاویز نیست ،
- خود پیچ قلاویز را روی قطعه ایجاد می‌کند ،
- برای بعضی از انواع آنها نیاز به سوراخ راهنما

پیچهای خودکار

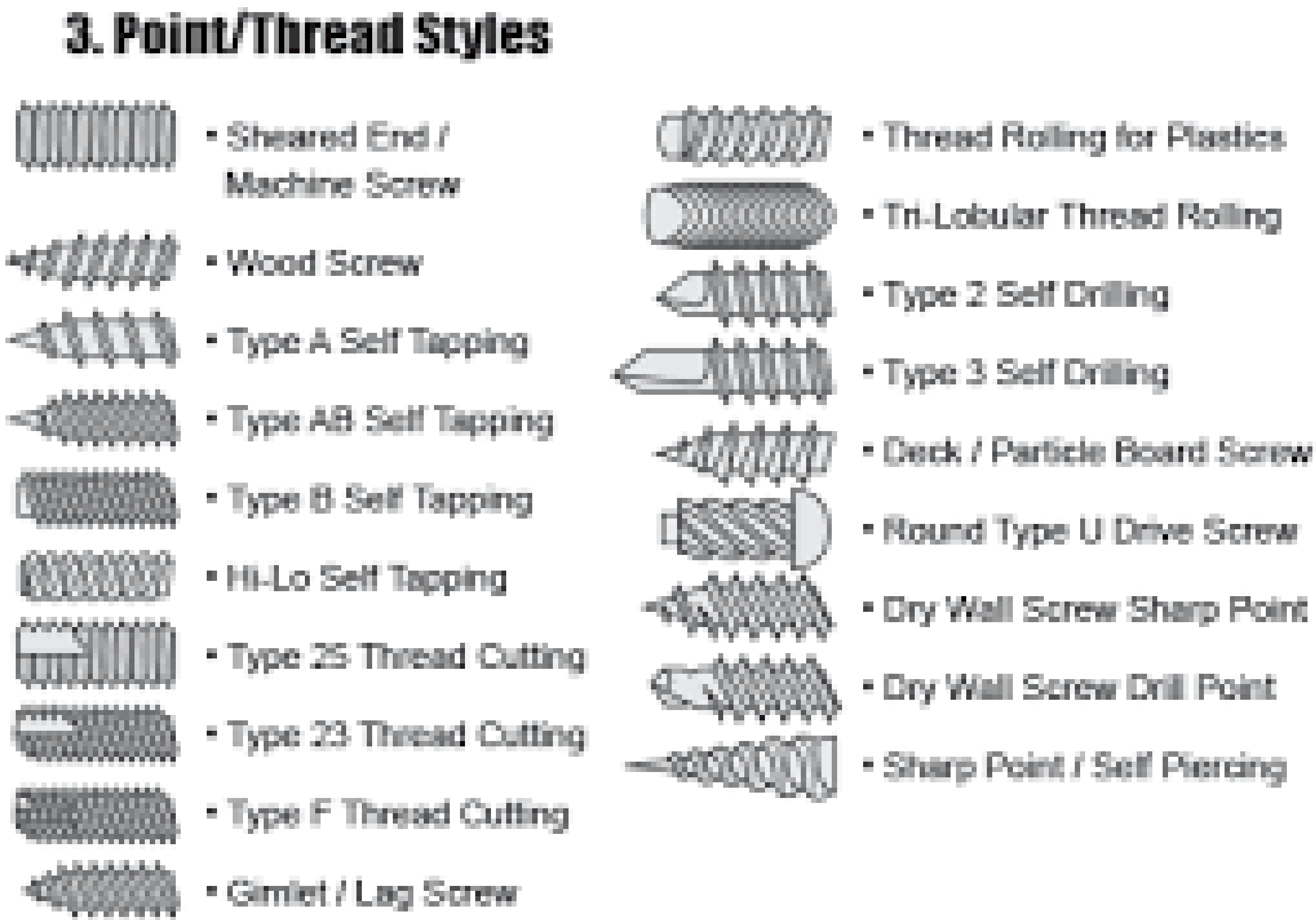


MDF یا چوب پلاستیک

پیچ سرمته

ورق‌های نازک

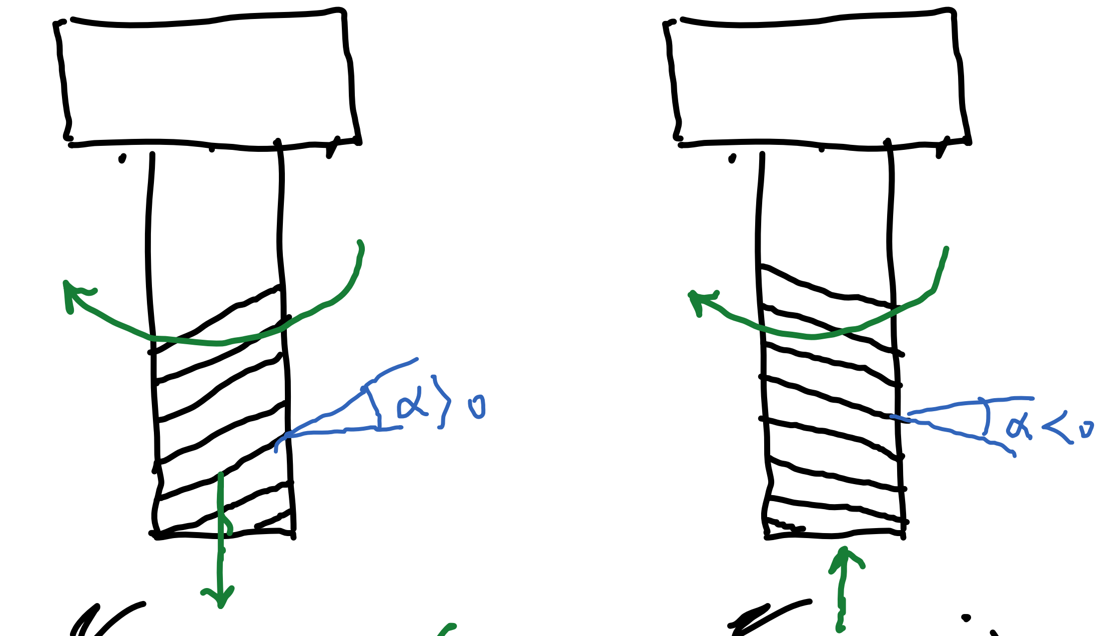
انواع نوک پیچهای حفارگر



- تقسیم بندی های دیگر

- راست گرد
- چپ گرد

بسته به‌ی اتصال



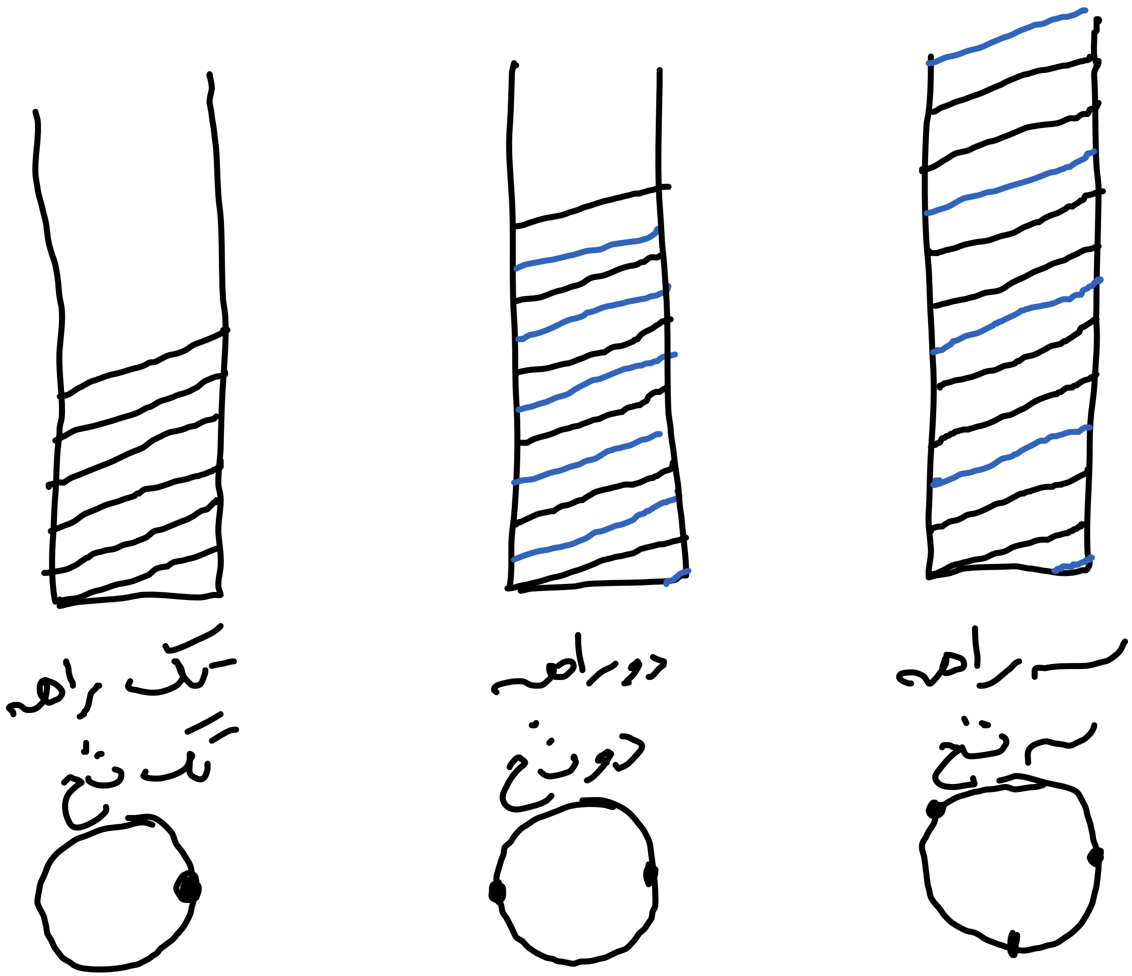
دنده راست گرد ✓

دنده چپ گرد

← اتصالات ویژه

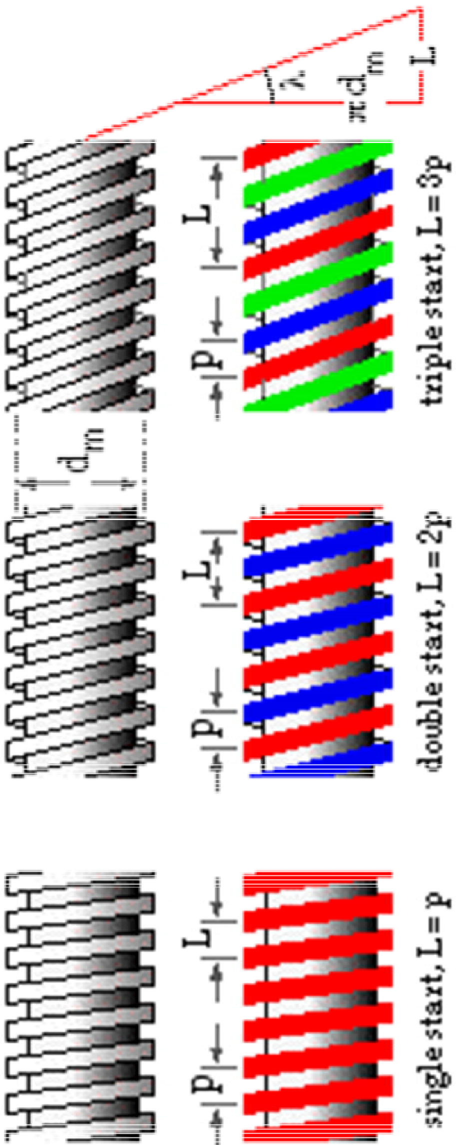
پیچ یک راهه، دوراهه یا چند راهه

در پیچهای قدرت



جهت افزایش سرعت جابجایی مهره

$L = n\,p$



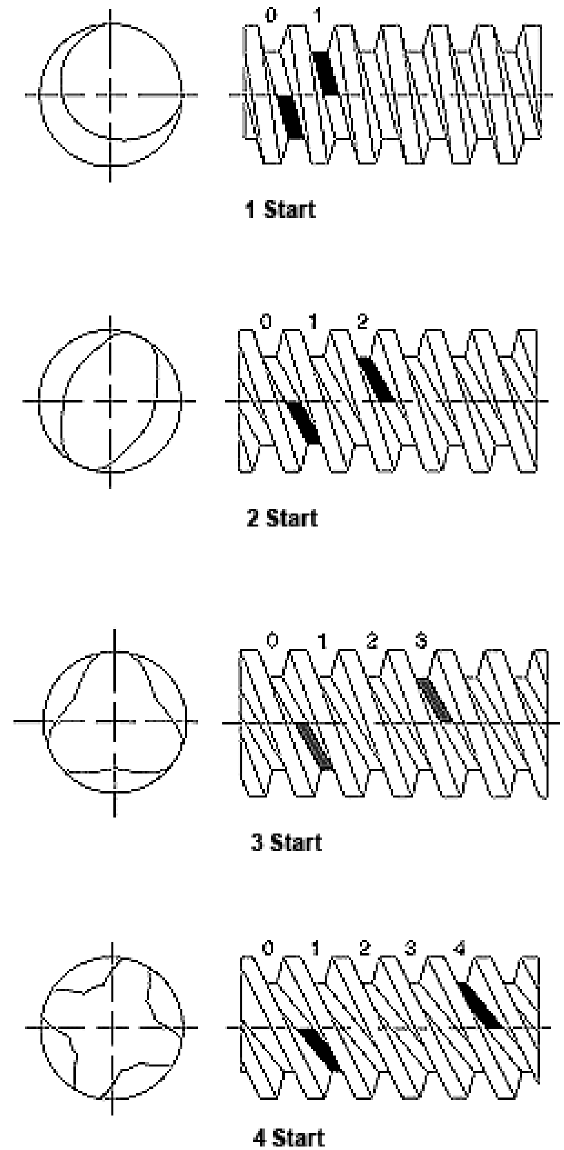
$L = 3P$

$L = 2P$

$L = P$

Lead

پیشروی



$M8\times30 = M8\times1.25\times30$ طول پیچ

استانداردهای پیچ

d p

دنده ریز

$M8\times1.25$ or $M8\times1$

اندازه متریک

Metric size

UNEF extra fine خیلی ریز

UN , UNR امریکای استاندارد ملی یا اینچی یا انگلیسی اندازه

Unified size

d تعداد دنده در یک اینچ

$\frac{5}{8}$ in – 18 UNRF or 0.625 in – 18 UNRF

$\frac{5}{8}$ in – 11 UNR $\frac{5}{8}$ in – 11 UN

دنده معمولی (درشت)

دنده ریز

Table 8–1 **Diameters and Areas of Coarse-Pitch and Fine-Pitch Metric Threads***

	Coarse-Pitch Series			Fine-Pitch Series		
Nominal Major Diameter d mm	Pitch p mm	Tensile-Stress Area A_t mm^2	Minor-Diameter Area A_r mm^2	Pitch p mm	Tensile-Stress Area A_t mm^2	Minor-Diameter Area A_r mm^2
1.6	0.35	1.27	1.07			
2	0.40	2.07	1.79			
2.5	0.45	3.39	2.98			
3	0.5	5.03	4.47			
3.5	0.6	6.78	6.00			
4	0.7	8.78	7.75			
5	0.8	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

$\pi d_r^2/4$

دنده درشت یا معمولی

دنده ریز

UNEF

Table 8–2 Diameters and Area of Unified Screw Threads UNC and UNF*

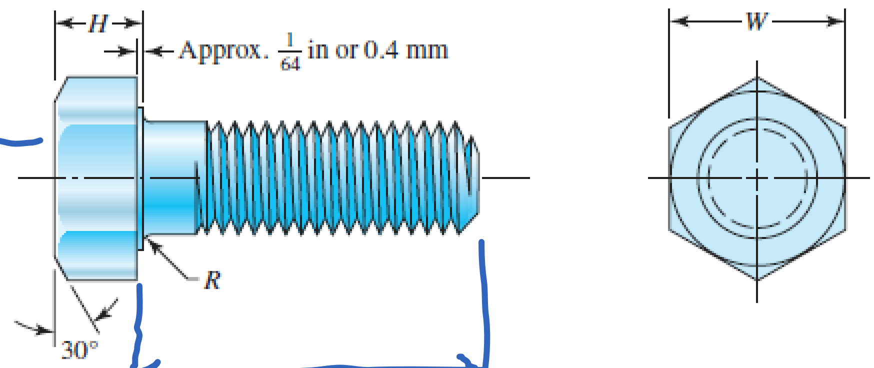
		Coarse Series—UNC			Fine Series—UNF		
Size Designation	Nominal Major Diameter in	Threads per Inch N	Tensile-Stress Area A_t in^2	Minor-Diameter Area A_r in^2	Threads per Inch N	Tensile-Stress Area A_t in^2	Minor-Diameter Area A_r in^2
0	0.0600				80	0.001 80	0.001 51
1	0.0730	64	0.002 63	0.002 18	72	0.002 78	0.002 37
2	0.0860	56	0.003 70	0.003 10	64	0.003 94	0.003 39
3	0.0990	48	0.004 87	0.004 06	56	0.005 23	0.004 51
4	0.1120	40	0.006 04	0.004 96	48	0.006 61	0.005 66
5	0.1250	40	0.007 96	0.006 72	44	0.008 80	0.007 16
6	0.1380	32	0.009 09	0.007 45	40	0.010 15	0.008 74
8	0.1640	32	0.014 0	0.011 96	36	0.014 74	0.012 85
10	0.1900	24	0.017 5	0.014 50	32	0.020 0	0.017 5
12	0.2160	24	0.024 2	0.020 6	28	0.025 8	0.022 6
$\frac{1}{4}$	0.2500	20	0.031 8	0.026 9	28	0.036 4	0.032 6
$\frac{5}{16}$	0.3125	18	0.052 4	0.045 4	24	0.058 0	0.052 4
$\frac{3}{8}$	0.3750	16	0.077 5	0.067 8	24	0.087 8	0.080 9
$\frac{7}{16}$	0.4375	14	0.106 3	0.093 3	20	0.118 7	0.109 0
$\frac{1}{2}$	0.5000	13	0.141 9	0.125 7	20	0.159 9	0.148 6
$\frac{9}{16}$	0.5625	12	0.182	0.162	18	0.203	0.189

انواع سر پیچ و مهره

nut

head

hex head

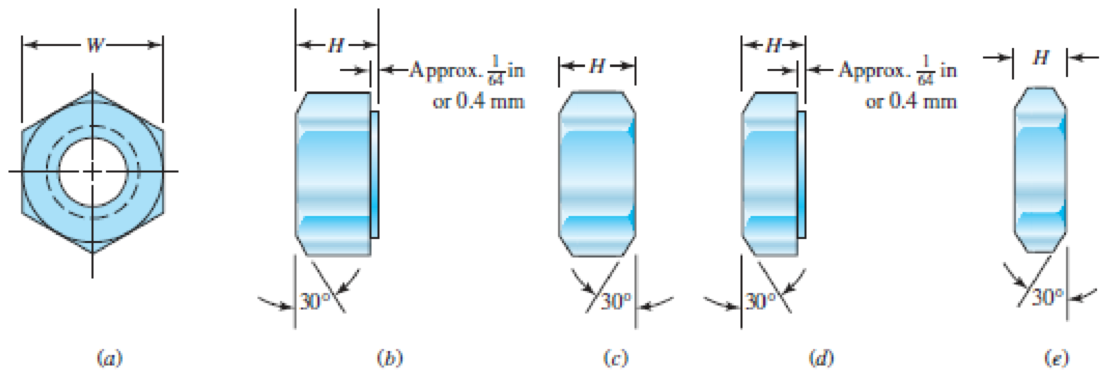


سر پیچ شش گوش

L

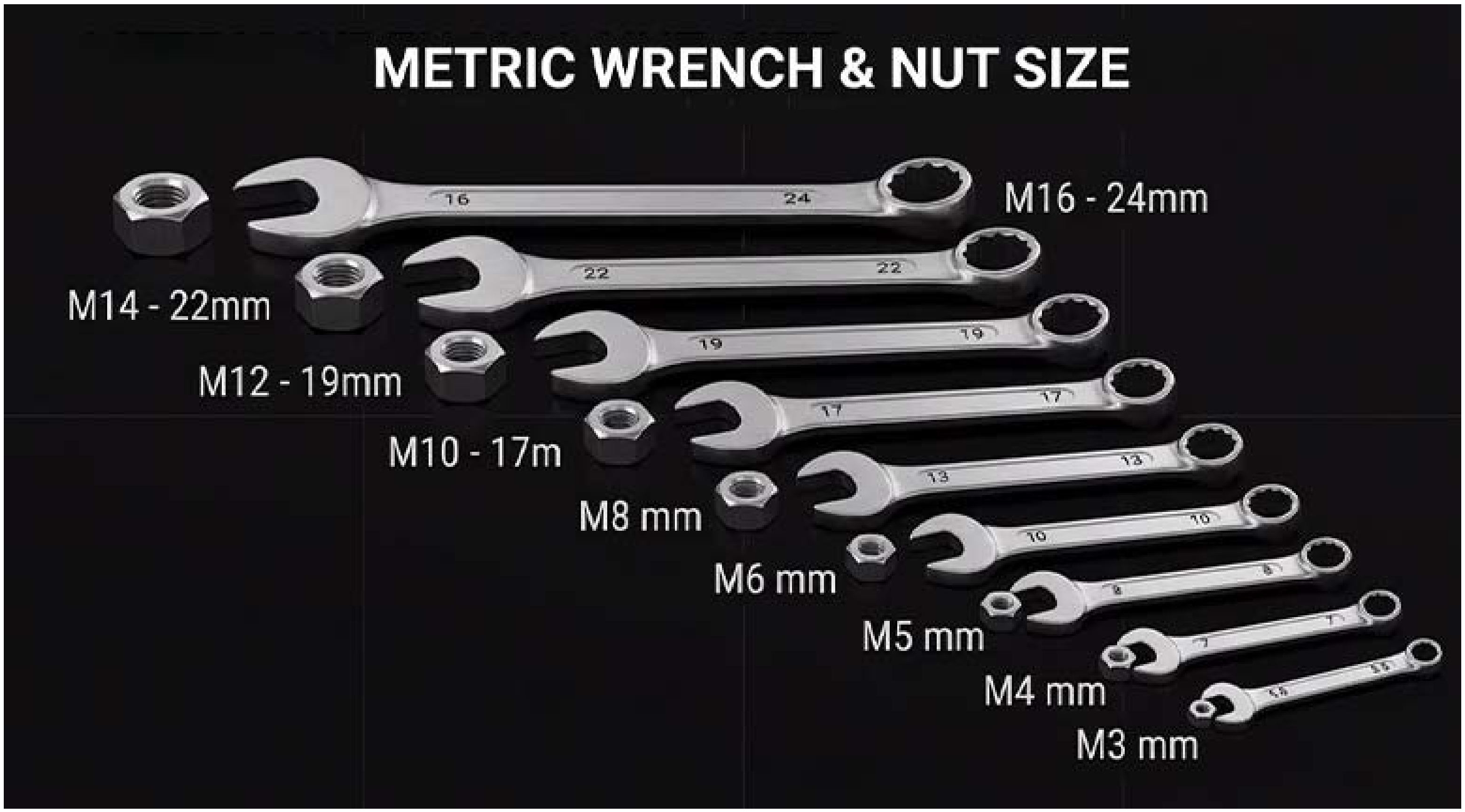
Figure 8–12

Hexagonal nuts: (*a*) end view, general; (*b*) washer-faced regular nut; (*c*) regular nut chamfered on both sides; (*d*) jam nut with washer face; (*e*) jam nut chamfered on both sides.



مهره

آچار تخت


METRIC WRENCH & NUT SIZE
M16 - 24mm
M14 - 22mm
M12 - 19mm
M10 - 17m
M8 mm
M6 mm
M5 mm
M4 mm
M3 mm

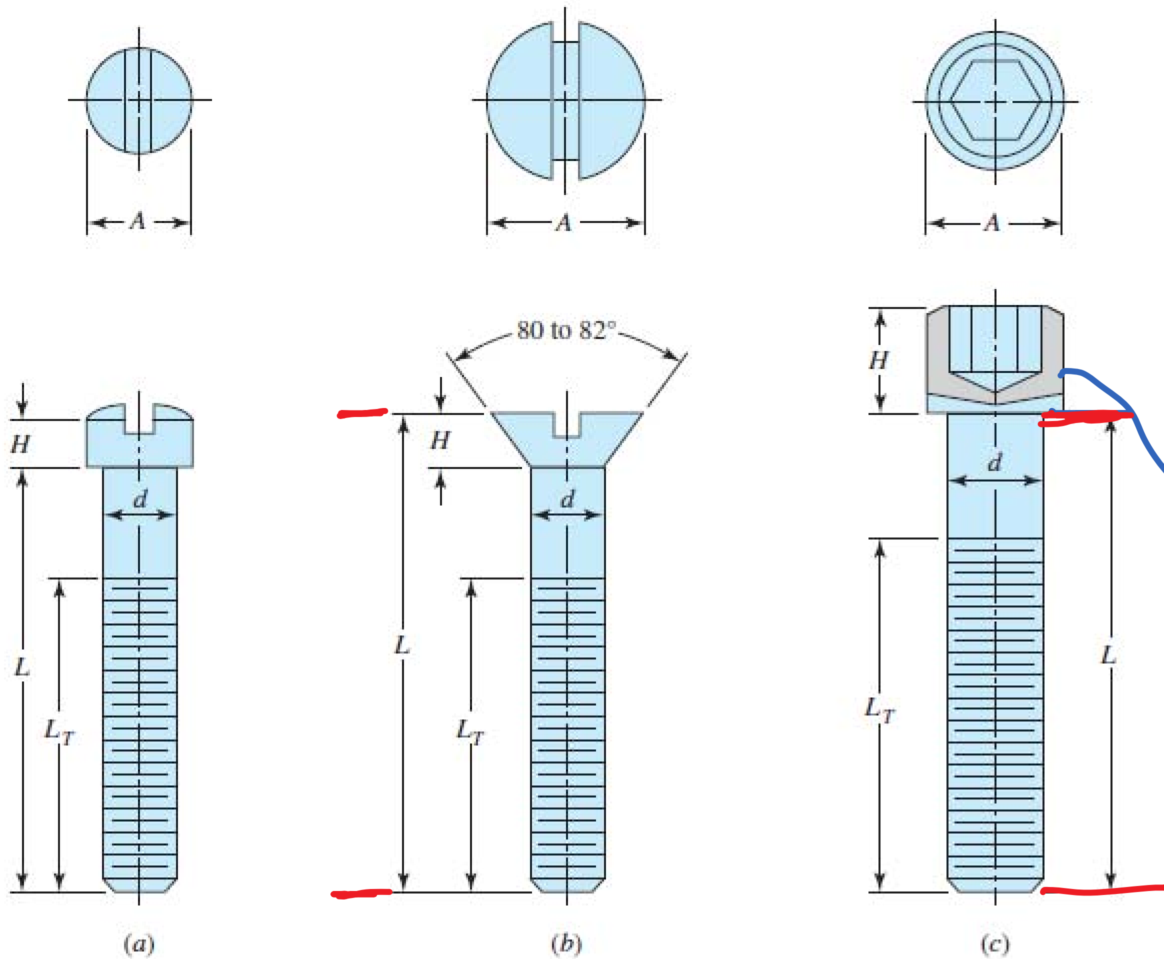


Figure 8–10

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 Figure 8–9, as well as a variety of other head styles. This illustration uses one of the conventional methods of representing threads.

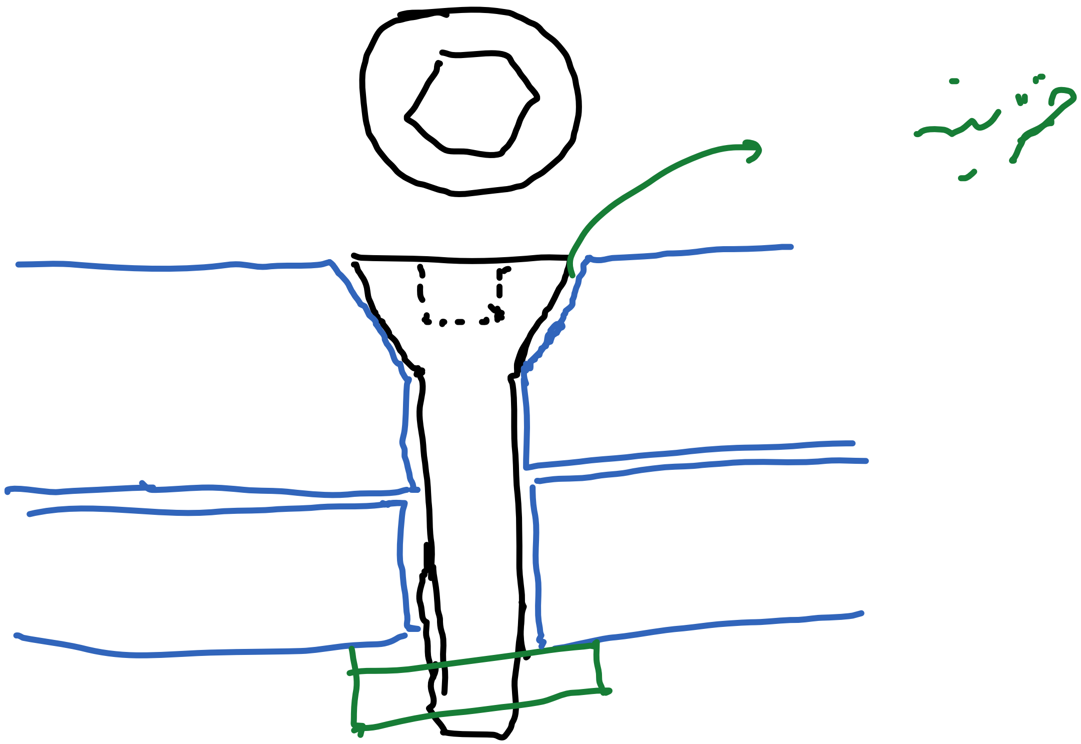
socket head

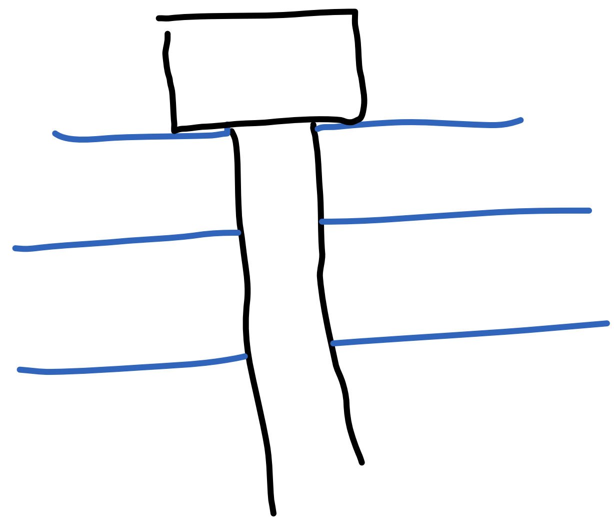
آلنی

آچار آلن

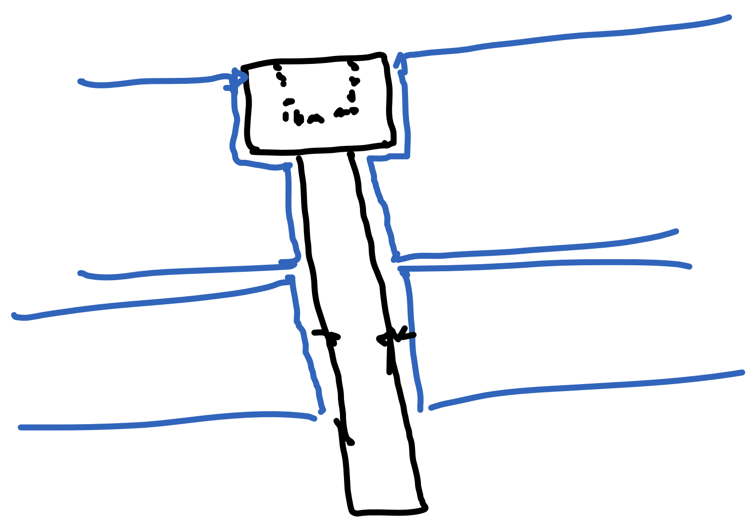
پیچ سرتخت

در پیچهای سرتخت L طول کل پیچ





پیچ آلنی سرتخت

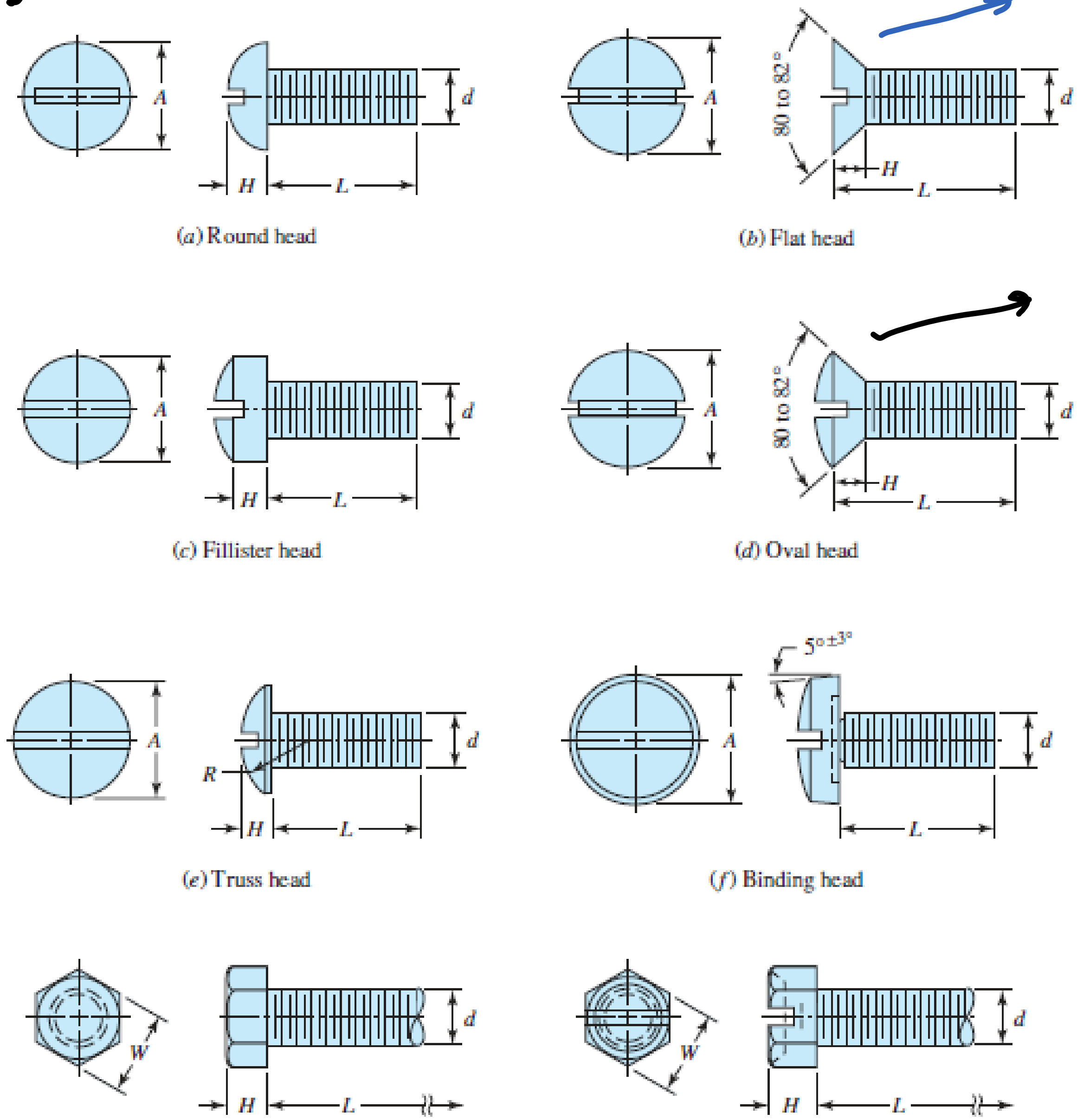


Machine Screw

سرخزینه

سرتخت

سرعدسی



(*a*) Round head

(*b*) Flat head

(*c*) Fillister head

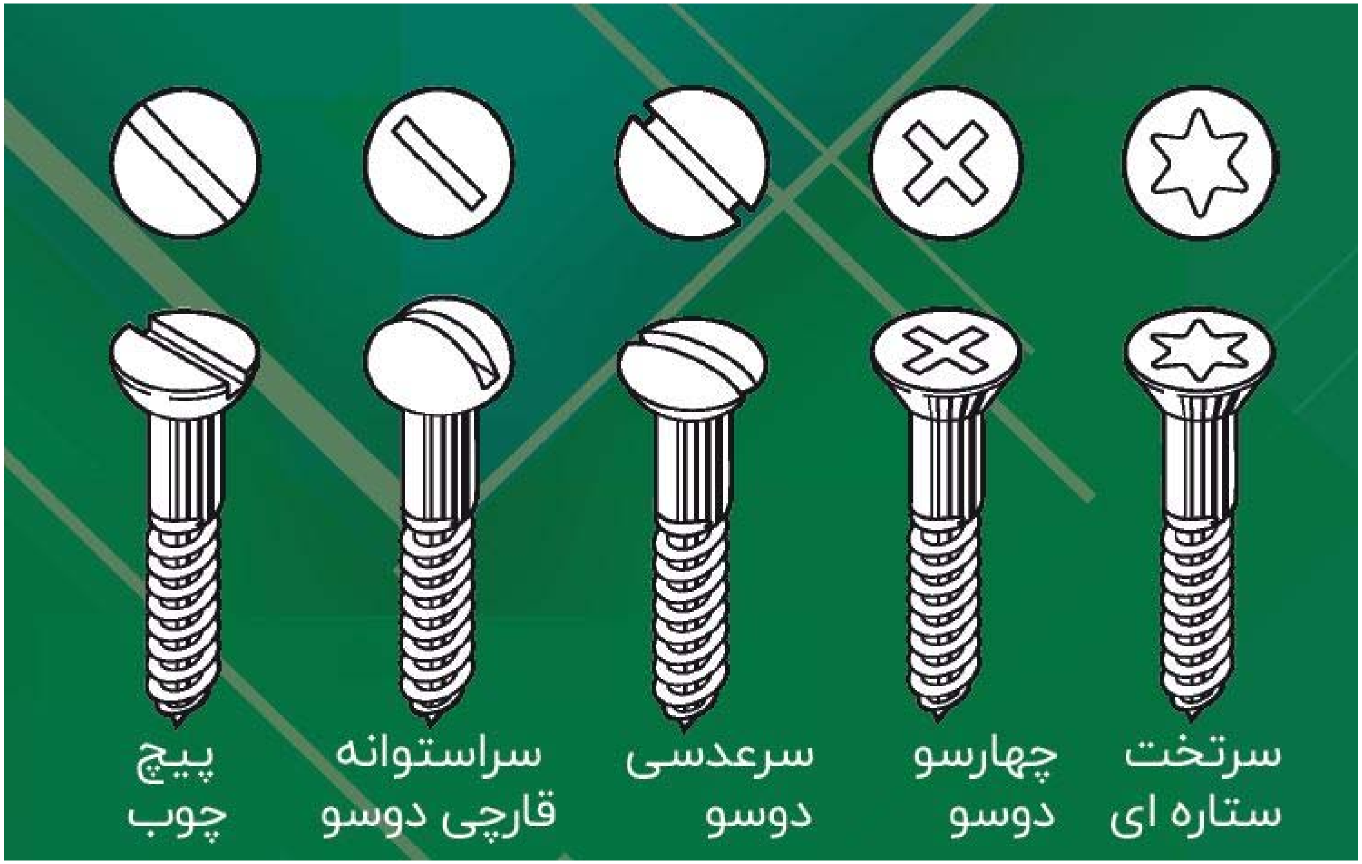
(*d*) Oval head

(*e*) Truss head

(*f*) Binding head

(*g*) Hex head (trimmed)

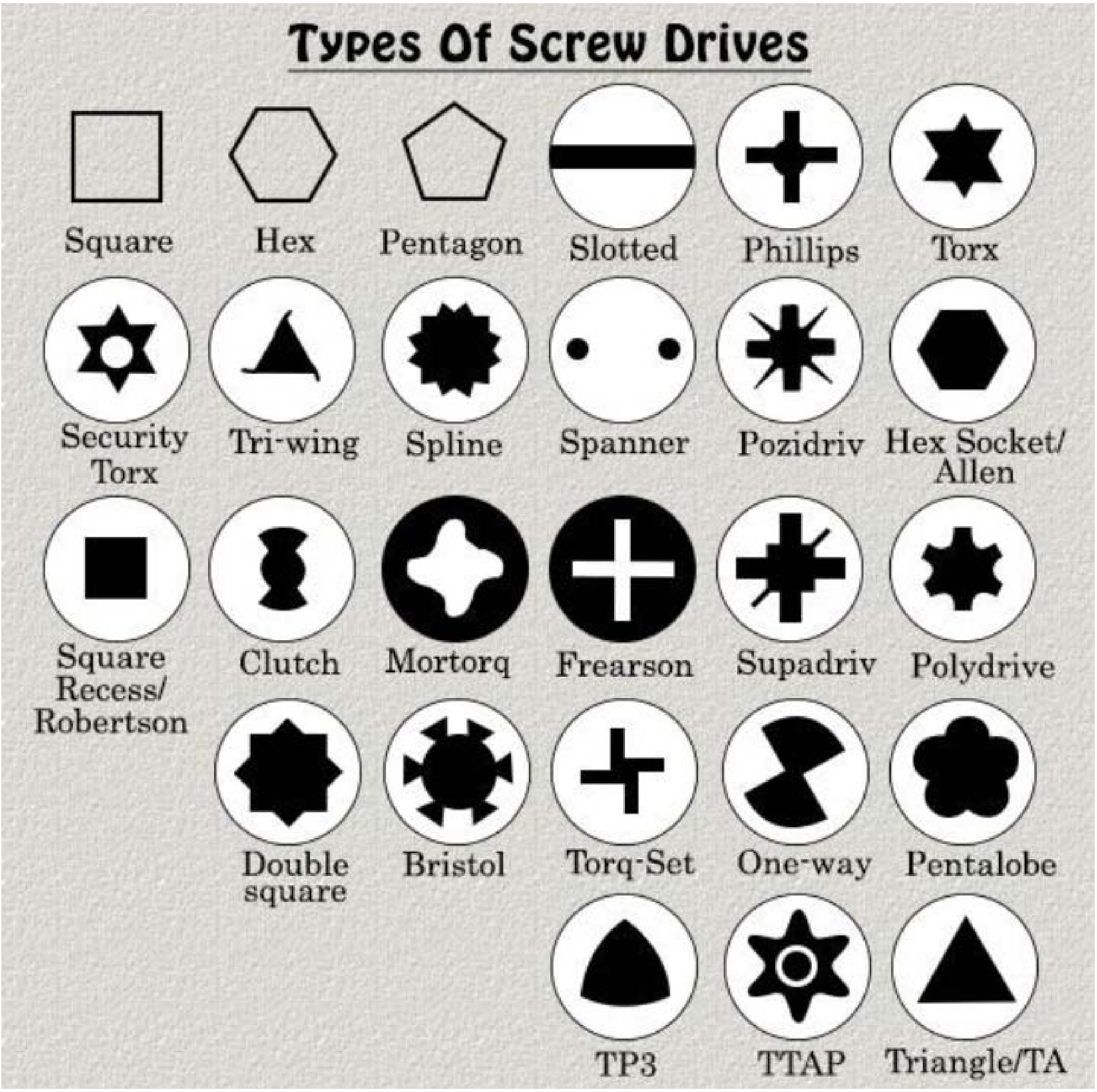
(*h*) Hex head (upset)


پیچ
چوب
سراستوانه
قارچی دوسو
سرعدسی
دوسو
چهارسو
دوسو
سرتخت
ستاره ای


Flat Head
Flange Head
Binding Head
Bugle Head
Dome Head
Raised Head
Truss Head
Combination Head
Pin Head
Sentinel Head
2 Hole Head
Phillips Head
Internal Hex
External Hex
Pozidriv Head
Quadrex Head
Slotted Head
Square Recess
Torx Plus
Star Head
Tri Wing Head
Torx Head

آلنی


Slotted
Cross Slot/ Phillips
Pozidriv
Torx
Security T
Hexagon


Types Of Screw Drives
Square
Hex
Pentagon
Slotted
Phillips
Torx
Security Torx
Tri-wing
Spline
Spanner
Pozidriv
Hex Socket/ Allen
Square Recess/ Robertson
Clutch
Mortorq
Frearson
Supadriv
Polydrive
Double square
Bristol
Torq-Set
One-way
Pentalobe
TP3
TTAP
Triangle/TA

مهره

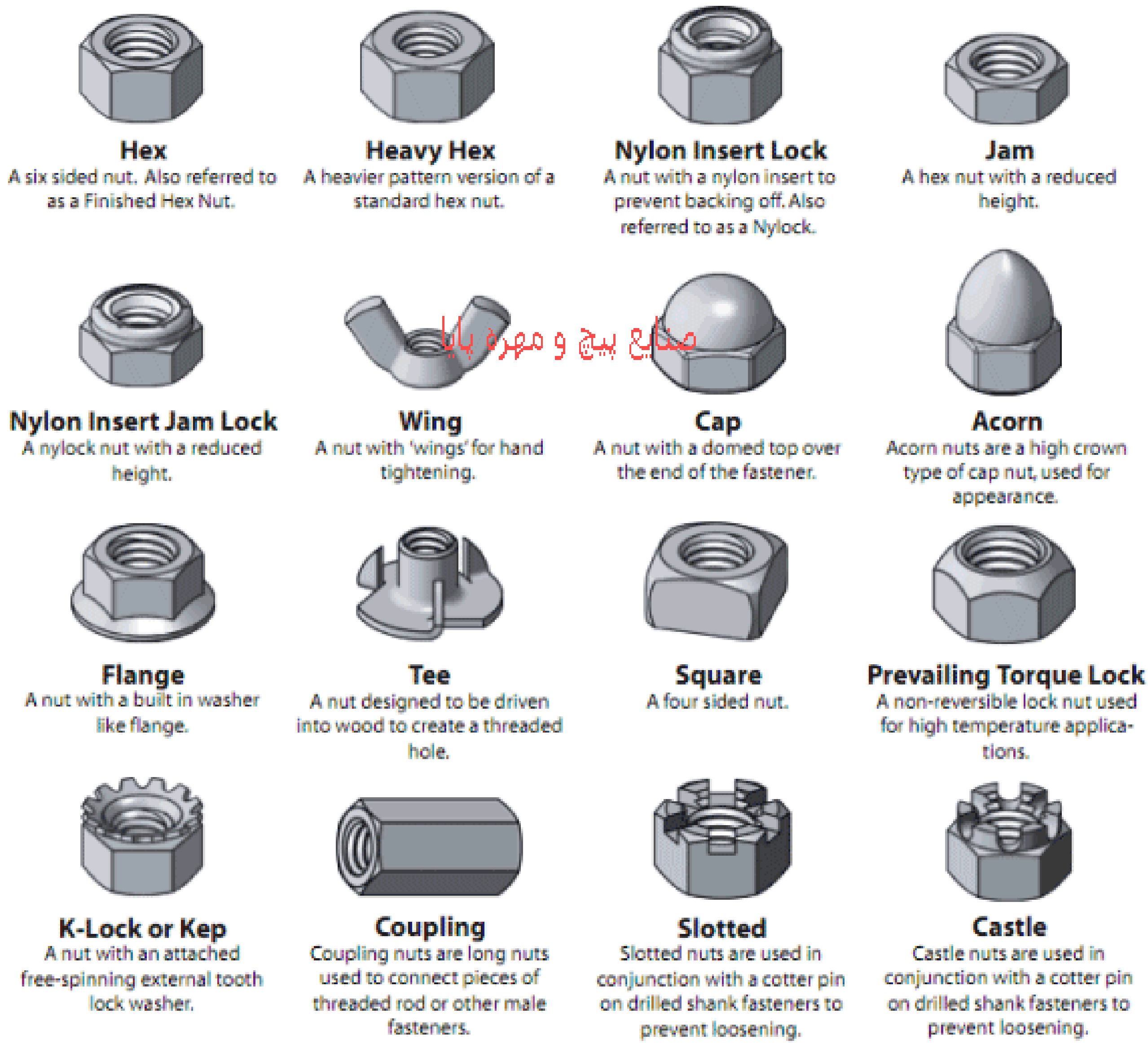
مهره

مهره

آلنی

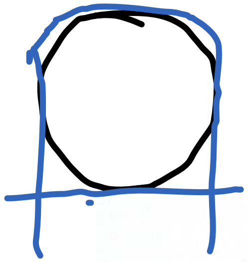
مهره ها

مهره قفلی

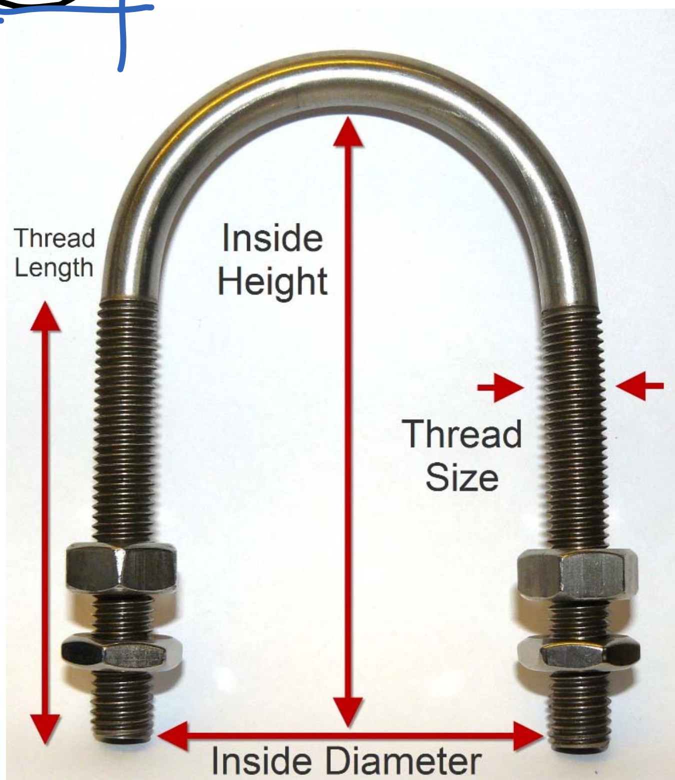


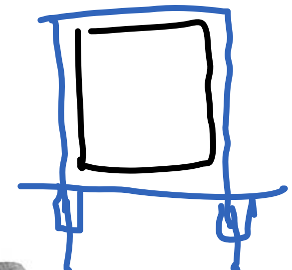
مدلهای دیگر پیچ و مهره

کوربی



U bolt





انواع واشر


flat washer
C washer
finish washer
square washer
Split Lock Washer
Retaining Push Nuts
Internal Tooth Lock Washer
Finger Spring Washer
External Tooth Lock Washer
Keyed washers
belleville washer
crescent spring washer
dome washers
wave spring washer
finger spring washer
torque washers
spherical washer
shoulder washers
fender washers
top hat washers

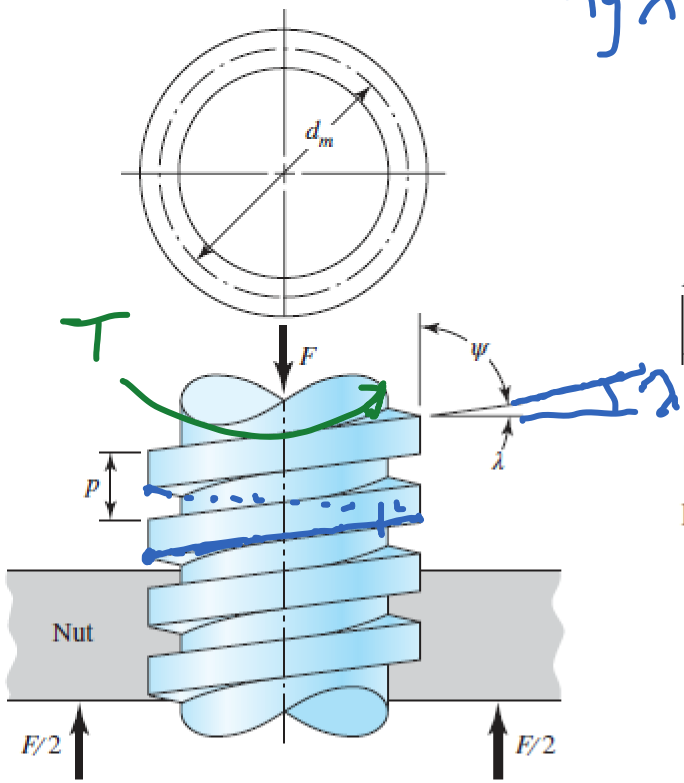
جلسه بیست و دوم

تحلیل پیچهای قدرت

$tg\lambda = \frac{l}{\pi d_m}$

$l = np$

$n=1 \to l$



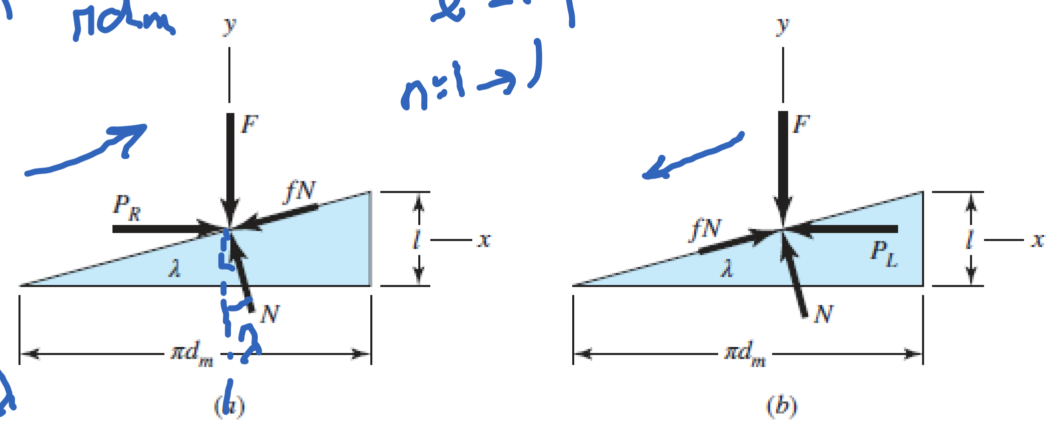
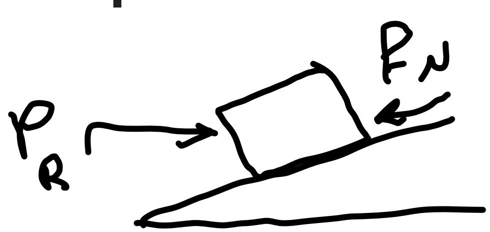


Figure 8–6

Force diagrams: (a) lifting the load; (b) lowering the load.



$l = np$ و $n=1 \to l = p$

تک راهه

فرض شده کل نیرو روی یک دنده اعمال شود

f, μ ضریب اصطکاک

برای بالا رفتن بار

(a)

$$\Sigma F_x = P_R - N\sin\lambda - fN\cos\lambda = 0$$
$$\Sigma F_y = -F - fN\sin\lambda + N\cos\lambda = 0$$

$\Rightarrow N = \cdots \Big) \Rightarrow P_R$

, for lowering the load, we have

(b)

$$\Sigma F_x = -P_L - N\sin\lambda + fN\cos\lambda = 0$$
$$\Sigma F_y = -F + fN\sin\lambda + N\cos\lambda = 0$$

$\cdots\cdots \Big) \Rightarrow P_L$

$\tan\lambda$

$$P_R = \frac{F(\sin\lambda + f\cos\lambda)}{\cos\lambda - f\sin\lambda} \times \frac{\frac{1}{\cos\lambda}}{\frac{1}{\cos\lambda}} \qquad P_R = \frac{F[(l/\pi d_m) + f]}{1 - (fl/\pi d_m)} \;;\; T_R = \frac{Fd_m}{2}\left(\frac{l + \pi f d_m}{\pi d_m - fl}\right)$$

$$P_L = \frac{F(f\cos\lambda - \sin\lambda)}{\cos\lambda + f\sin\lambda} \quad '' \quad P_L = \frac{F[f - (l/\pi d_m)]}{1 + (fl/\pi d_m)} \Rightarrow T_L = \frac{Fd_m}{2}\left(\frac{\pi f d_m - l}{\pi d_m + fl}\right)$$

$T_R = P_R \dfrac{d_m}{2}$ گشتاور مورد نیاز برای بالابردن بار

$$T_R = \frac{Fd_m}{2}\left(\frac{l + \pi f d_m}{\pi d_m - f l}\right)$$

گشتاور مورد نیاز برای بالا بردن بار

$$T_L = \frac{Fd_m}{2}\left(\frac{\pi f d_m - l}{\pi d_m + f l}\right)$$

گشتاور مورد نیاز برای پایین بردن بار

شرط خود قفلی پیچ یا self locking

$$T_L > 0$$

باید حتما یک گشتاور از طرف کاربر اعمال شود تا بار به سمت پایین بیاید. اگر $T_L < 0$ شود بار خود به خود به سمت پایین حرکت می کند.

$$\pi f d_m - l > 0$$

$$\Rightarrow \pi f d_m > l \Rightarrow f > \frac{l}{\pi d_m} \Rightarrow \boxed{f > tg\,\lambda}$$

$$f > tg\lambda$$

ضریب اصطکاک باید بزرگتر از $tg\lambda$ باشد.

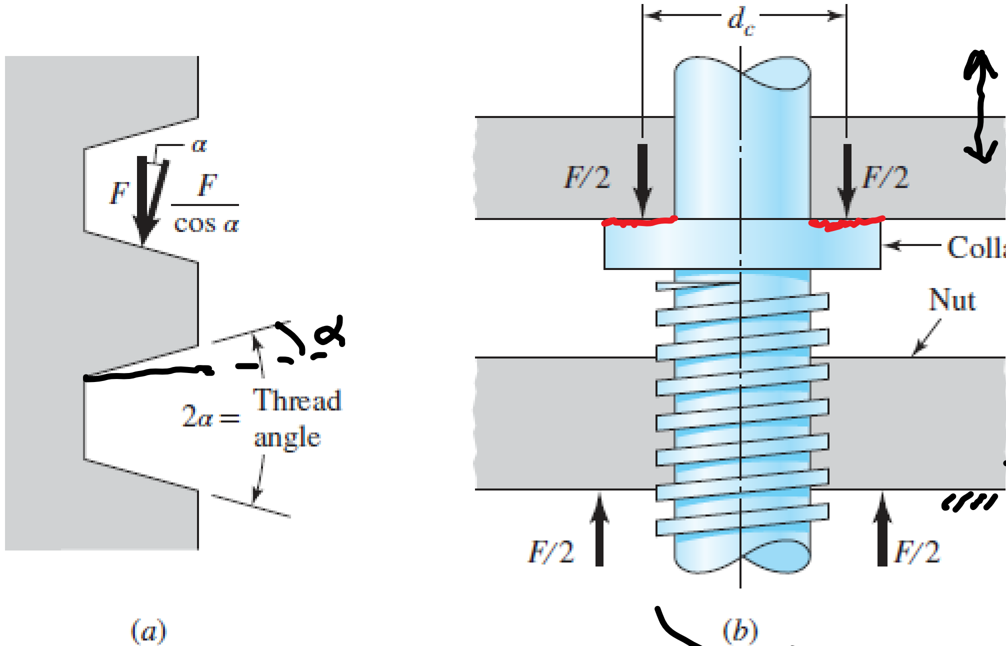
اگر زاویه λ خیلی بزرگ باشد یا
ضریب اصطکاک بین مهره و رزوه پیچ خیلی کم باشد ممکن است
پیچ خاصیت خود قفلی نداشته باشد.

اگر $f=0$ باشد $T_o = \frac{Fl}{2\pi}$

thread eficiency
بازده رزوه.

$$e = \frac{T_o}{T_R} \qquad T_R > T_o$$

دنده، ذوزنقه‌ای باشه با زاویه α



(a)
(b)

(یقه‌پیچ)

مهره ثابت

$T_c = \mu N d_c$

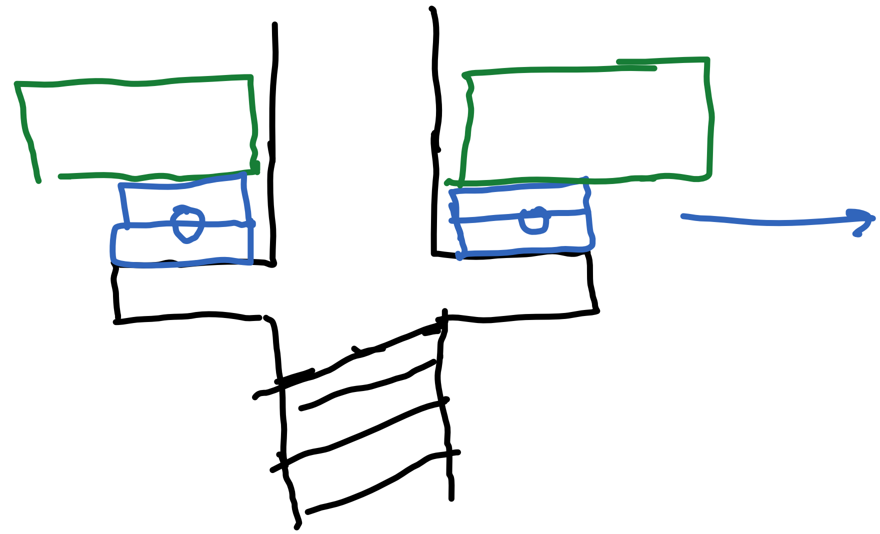
$$T_R = \frac{F d_m}{2}\left(\frac{l + \pi f d_m \sec\alpha}{\pi d_m - f l \sec\alpha}\right)$$

$$T_c = \frac{F f_c d_c}{2}$$

f_c ضریب اصطکاک بین یقه و قطعه

$\sec\alpha = \frac{1}{\cos\alpha}$

اغلب با استفاده از بیرینگ‌ها T_c را حذف می‌کنند



بلبرینگ کف گرد

یا بلبرینگ مخروطی یا

بلبرینگ ساده

deep Grove ball b

در این حالت T_c به حداقل می رسد یا $T_c = 0$

برنج

Table 8–5 Coefficients of Friction f for Threaded Pairs

جنس پیچ

چدن

Screw Material	Nut Material: Steel	Bronze	Brass	Cast Iron
Steel, dry	0.15–0.25	0.15–0.23	0.15–0.19	0.15–0.25
Steel, machine oil	0.11–0.17	0.10–0.16	0.10–0.15	0.11–0.17
Bronze	0.08–0.12	0.04–0.06	—	0.06–0.09

جنس پیچ steel ، جنس مهره چدن ← f ← 0.15 - 0.25

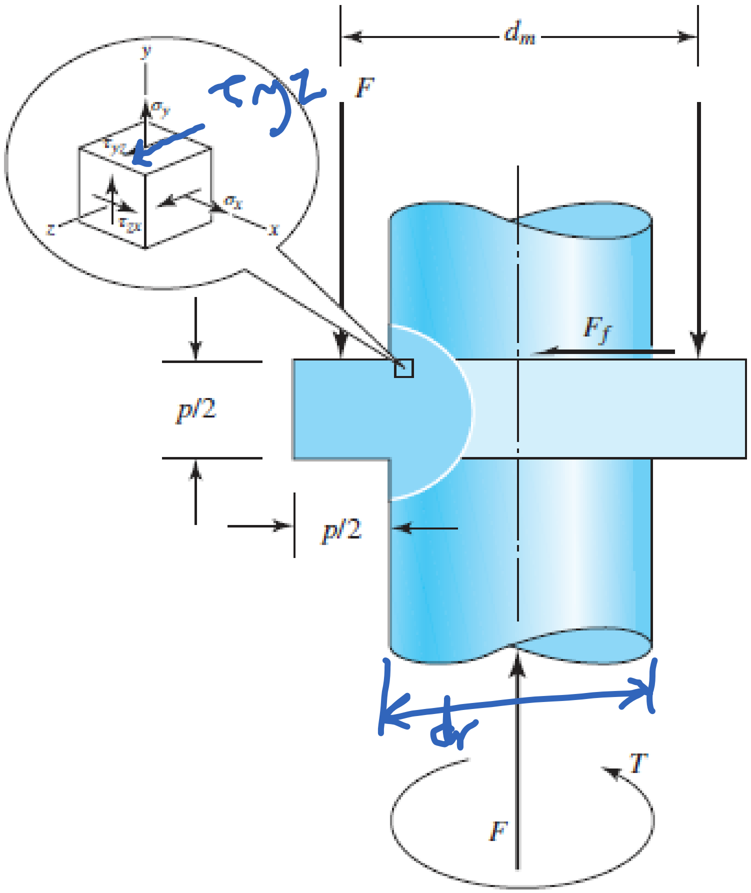
کیفیت ساخت

Table 8–6 Thrust-Collar Friction Coefficients (f_c) یقه

Combination	Running	Starting
Soft steel on cast iron	0.12	0.17
Hard steel on cast iron	0.09	0.15
Soft steel on bronze	0.08	0.10
Hard steel on bronze	0.06	0.08

دینامیکی   استاتیکی

محاسبه تنش‌ها در تنه و دنده‌ها



تنش برشی پیچشی در تنه پیچ

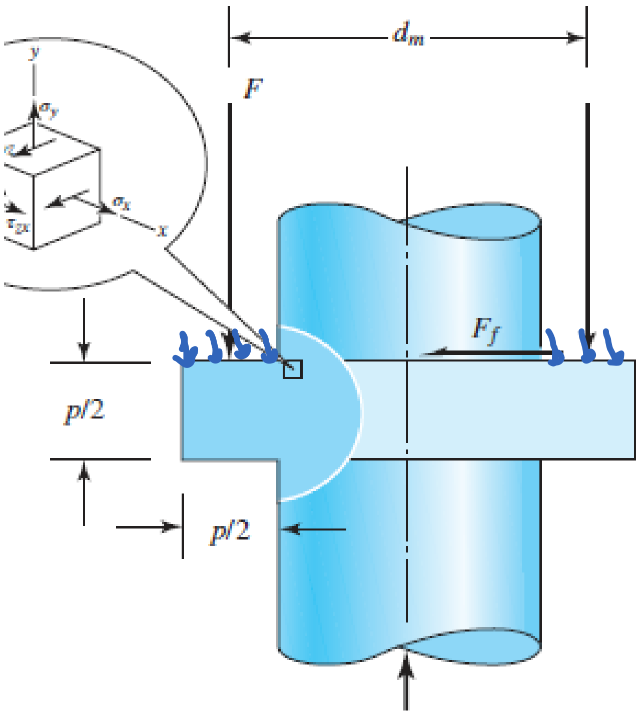
$$\tau_{yz} = \frac{Tc}{J} = \frac{16T}{\pi d_r^3}$$

تنش محوری در تنه پیچ

$$\sigma_y = -\frac{F}{A} = \frac{-4F}{\pi d_r^2}$$

تنش لهیدگی

bearing stress تنش تکیه گاهی



$$\sigma_B = \frac{F}{A} = \frac{F}{\pi d_m p/2} = \frac{2F}{\pi d_m p} = \frac{2\times 0.38F}{\pi d_m p}$$

توزیع بار روی دنده ها

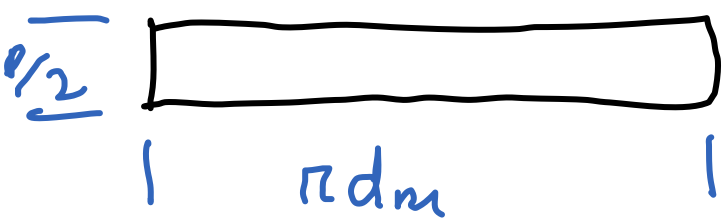
38% درصد بار روی دنده اول

25% دنده دوم " " "

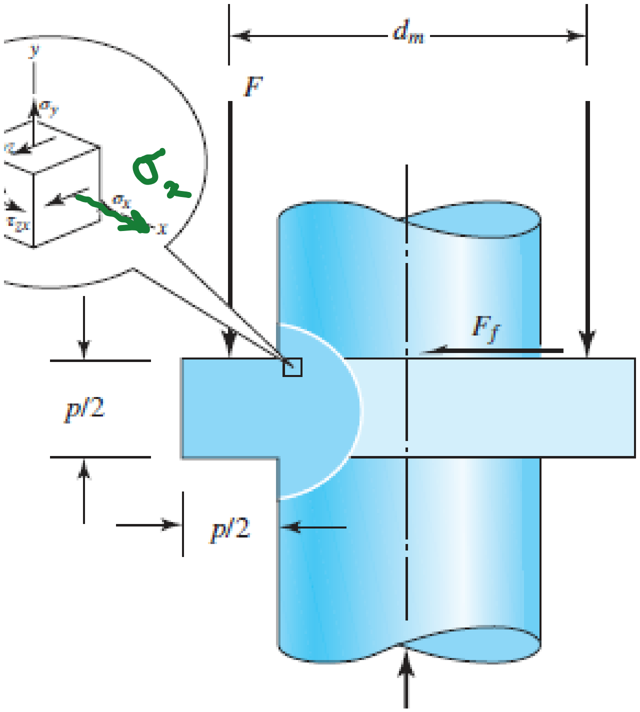
18% سوم " " "

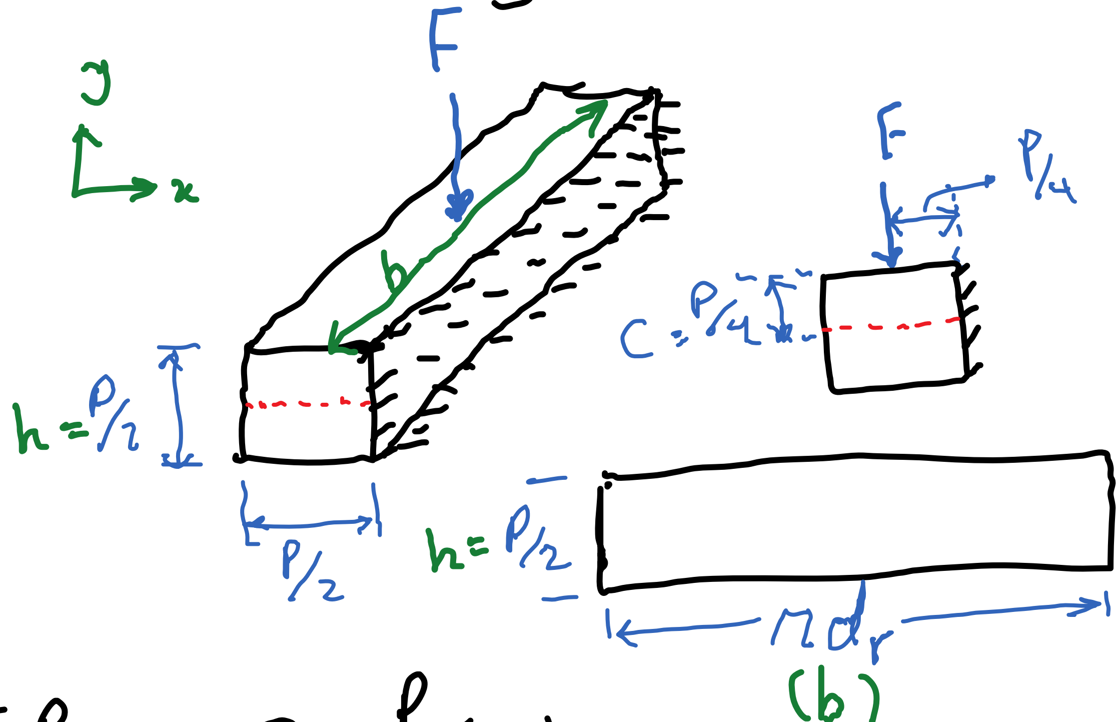
⋮

0% هفتم " " "



تنش خمشی در ریشه دنده



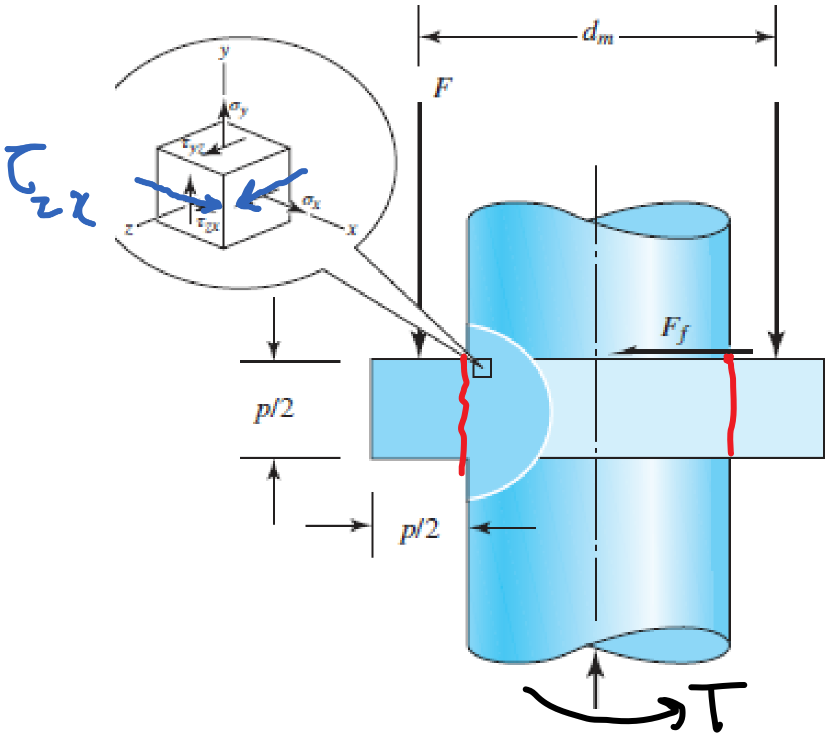


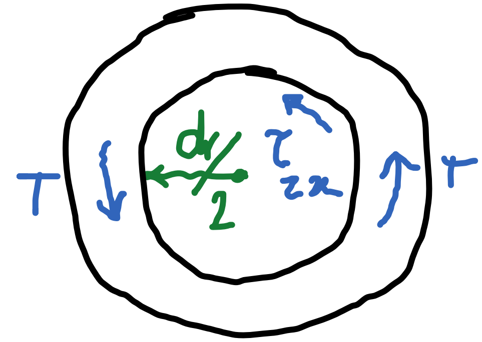
$$\sigma = \frac{Mc}{I}, \quad M = F\frac{P}{4}, \quad C = \frac{P}{4},$$

$$I = \frac{bh^3}{12} = \frac{\pi d_r \left(\frac{P}{2}\right)^3}{12} = \frac{\pi d_r P^3}{12 \times 8}$$

$$\Rightarrow \sigma_x = \frac{6 \times 0.38 F}{\pi d_r P}$$

تنش برشی در ریشه دنده
ناشی از نیروی اصطکاک روی دنده





$$F_s = \tau_{zx} A_s = \tau_{zx} \pi d_r \frac{p}{2} \quad , \quad F_s \times \frac{d_r}{2} = T$$

$$\Rightarrow \quad T = \tau_{zx} \frac{\pi d_r^2 p}{4} \Rightarrow \tau_{zx} = \frac{4T}{\pi d_r^2 p} \quad (0.381$$

$d = 32$, $p = 4mm$, $n = 2$

EXAMPLE 8–1

A square-thread power screw has a major diameter of 32 mm and a pitch of 4 mm with double threads, and it is to be used in an application similar to that in Figure 8–4. The given data include $f = f_c = 0.08$, $d_c = 40$ mm, and $F = 6.4$ kN per screw.

(*a*) Find the thread depth, thread width, pitch diameter, minor diameter, and lead.
(*b*) Find the torque required to raise and lower the load.
(*c*) Find the efficiency during lifting the load.
(*d*) Find the body stresses, torsional and compressive.
(*e*) Find the bearing stress on the first thread.
(*f*) Find the thread bending stress at the root of the first thread.
(*g*) Determine the von Mises stress at the critical stress element where the root of the first thread interfaces with the screw body.

Solution

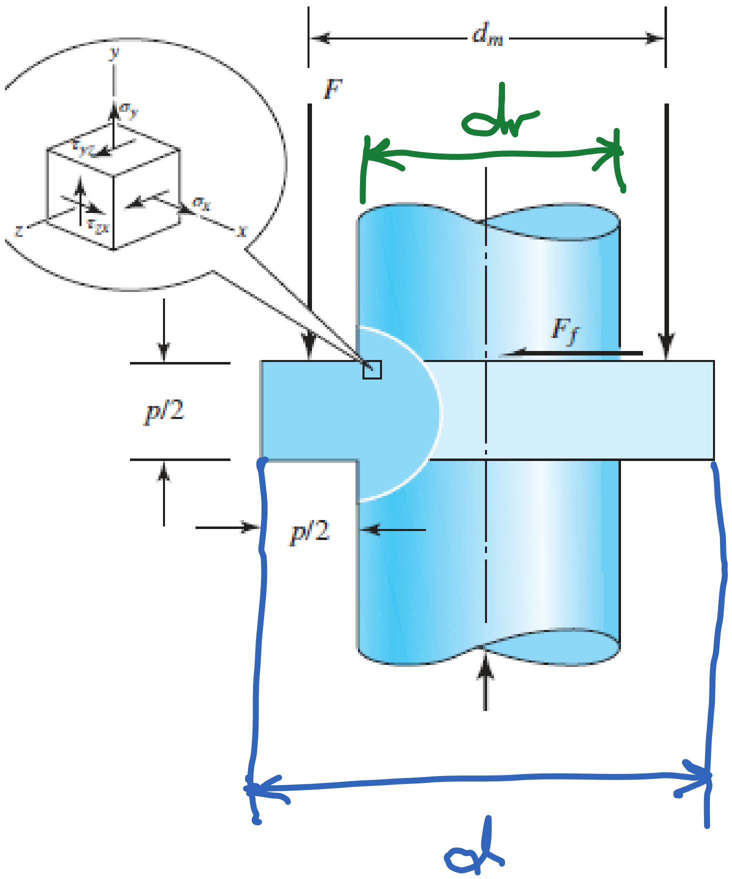
(*a*) From Figure 8–3*a* the thread depth and width are the same and equal to half the pitch, or 2 mm. Also

$$d_m = d - p/2 = 32 - 4/2 = 30 \text{ mm}$$

Answer

$$d_r = d - p = 32 - 4 = 28 \text{ mm}$$

$$l = np = 2(4) = 8 \text{ mm}$$



$$d_r = d - p$$

$$d_m = d - p/2$$

(*b*) Using Equations (8–1) and (8–6), the torque required to turn the screw against the load is

$$T_R = \frac{Fd_m}{2}\left(\frac{l + \pi f d_m}{\pi d_m - f l}\right) + \frac{F f_c d_c}{2}$$

$$= \frac{6.4(30)}{2}\left[\frac{8 + \pi(0.08)(30)}{\pi(30) - 0.08(8)}\right] + \frac{6.4(0.08)40}{2}$$

Answer $$= 15.94 + 10.24 = 26.18 \text{ N} \cdot \text{m}$$

Using Equations (8–2) and (8–6), we find the load-lowering torque is

$$T_L = \frac{Fd_m}{2}\left(\frac{\pi f d_m - l}{\pi d_m + f l}\right) + \frac{F f_c d_c}{2}$$

$$= \frac{6.4(30)}{2}\left[\frac{\pi(0.08)30 - 8}{\pi(30) + 0.08(8)}\right] + \frac{6.4(0.08)(40)}{2}$$

Answer $$= -0.466 + 10.24 = 9.77 \text{ N} \cdot \text{m}$$

The minus sign in the first term indicates that the screw alone is not self-locking and would rotate under the action of the load except for the fact that the collar friction is present and must be overcome, too. Thus the torque required to rotate the screw "with" the load is less than is necessary to overcome collar friction alone.

(*c*) The overall efficiency in raising the load is

Answer $$e = \frac{Fl}{2\pi T_R} = \frac{6.4(8)}{2\pi(26.18)} = 0.311$$

(*d*) The body shear stress τ due to torsional moment T_R at the outside of the screw body is

Answer
$$\tau_{yz} = \tau = \frac{16T_R}{\pi d_r^3} = \frac{16(26.18)(10^3)}{\pi(28^3)} = 6.07 \text{ MPa}$$

The axial nominal normal stress σ is

Answer
$$\sigma_y = \sigma = -\frac{4F}{\pi d_r^2} = -\frac{4(6.4)10^3}{\pi(28^2)} = -10.39 \text{ MPa}$$

(*e*) The bearing stress σ_B is, with one thread carrying $0.38F$,

Answer
$$\sigma_B = -\frac{2(0.38F)}{\pi d_m(1)p} = -\frac{2(0.38)(6.4)10^3}{\pi(30)(1)(4)} = -12.9 \text{ MPa}$$

(*f*) The thread-root bending stress σ_b with one thread carrying $0.38F$ is

Answer
$$\sigma_x = \sigma_b = \frac{6(0.38F)}{\pi d_r(1)p} = \frac{6(0.38)(6.4)10^3}{\pi(28)(1)4} = 41.5 \text{ MPa}$$

(*g*) The tangential shear stress given by Equation (8–12) with one thread carrying $0.38\,T$,

$$\tau_{zx} = -\frac{4(0.38T)}{\pi d_r^2(1)p} = -\frac{4(0.38)26.18(10^3)}{\pi(28^2)4} = -4.04 \text{ MPa}$$

The 3-D stresses for Figure 8–8 are

$$\sigma_x = 41.5 \text{ MPa} \qquad \tau_{xy} = 0$$
$$\sigma_y = -10.39 \text{ MPa} \qquad \tau_{yz} = 6.07 \text{ MPa}$$
$$\sigma_z = 0 \qquad \tau_{zx} = -4.04 \text{ MPa}$$

For the von Mises stress, Equation (5–14) can be written as

Answer
$$\sigma' = \frac{1}{\sqrt{2}}\{[41.5 - (-10.39)]^2 + (-10.39 - 0)^2 + (0 - 41.5)^2 + 6(6.07)^2 + 6(-4.04)^2\}^{1/2}$$
$$= 49.2 \text{ MPa}$$

$$n = \frac{S_y}{\sigma'}$$

σ_B

Table 8–4 **Screw Bearing Pressure p_b**

Screw Material	Nut Material	Safe p_b, MPa	Notes
Steel	Bronze	17.2–24.1	Low speed
Steel	Bronze	11.0–17.2	≤50 mm/s
	Cast iron	6.9–17.2	≤40 mm/s
Steel	Bronze	5.5–9.7	100–200 mm/s
	Cast iron	4.1–6.9	100–200 mm/s
Steel	Bronze	1.0–1.7	≥250 mm/s

Source: Data from H. A. Rothbart and T. H. Brown, Jr., *Mechanical Design Handbook,* 2nd ed., McGraw-Hill, New York, 2006.

جهت آنکه سایش بین مهره و دنده زیاد نباشد باید

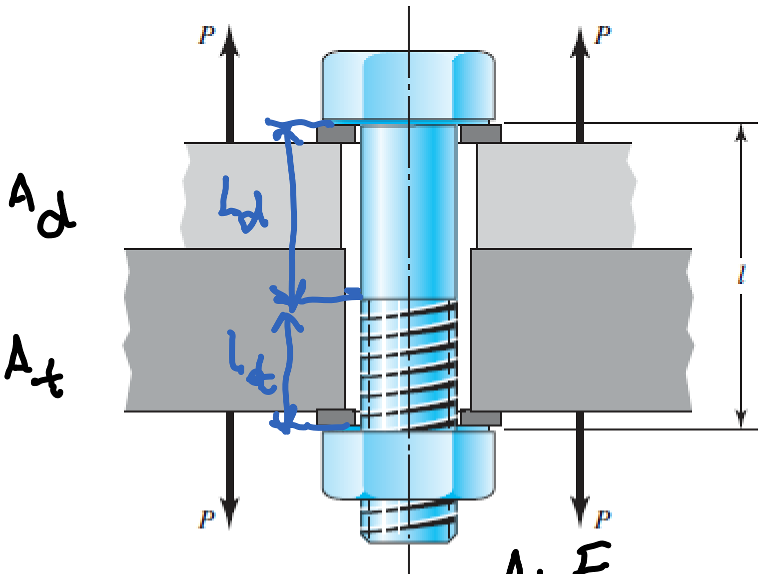
$$\sigma_B < p_b$$

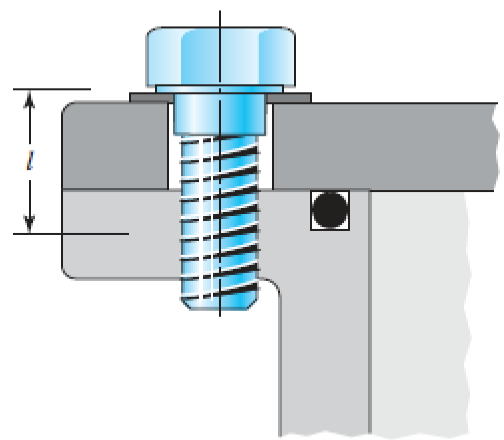
fastener stiffness

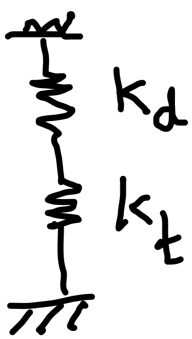
سفتی پیچ

اتصالات تحت کشش

جلسه بیست و سوم







$$k_d = \frac{A_d E}{l_d}$$

$$k_t = \frac{A_t E}{l_t}$$

$$\frac{1}{k} = \frac{1}{k_d} + \frac{1}{k_t} \Rightarrow k$$

$$\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2} \qquad \text{or} \qquad k = \frac{k_1 k_2}{k_1 + k_2}$$

for two springs in series. From Equation (4–4), the spring rates of the unthreaded portions of the bolt in the clamped zone are, respectively,

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

where A_t = tensile-stress area (Tables 8–1, 8–2)

l_t = length of threaded portion of grip

A_d = major-diameter area of fastener

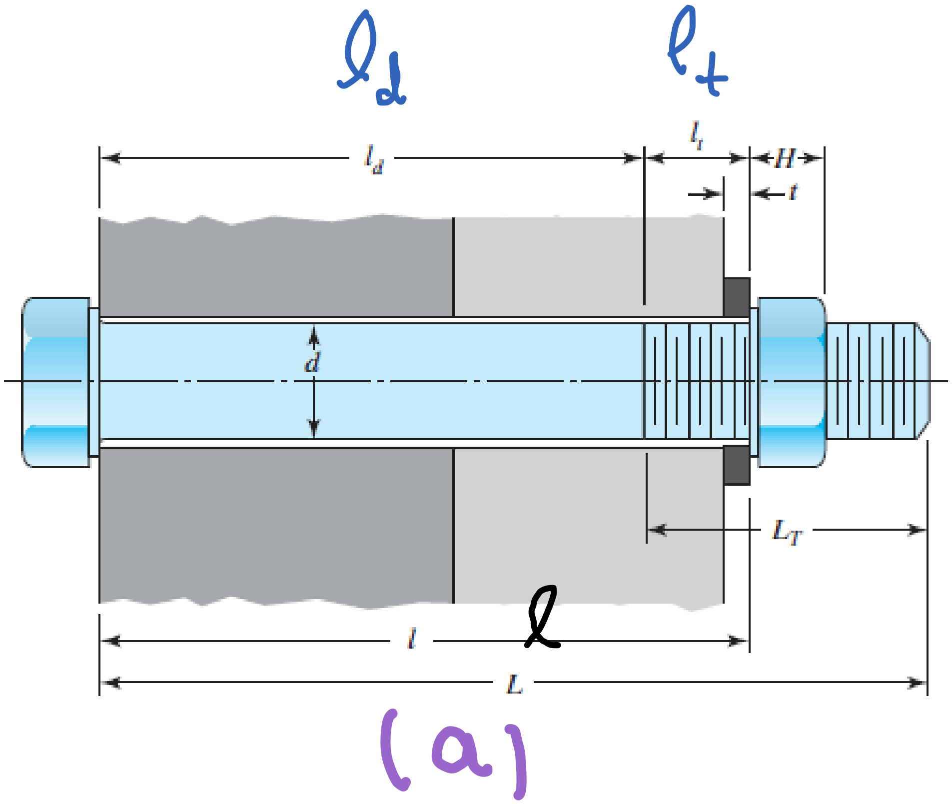
l_d = length of unthreaded portion in grip

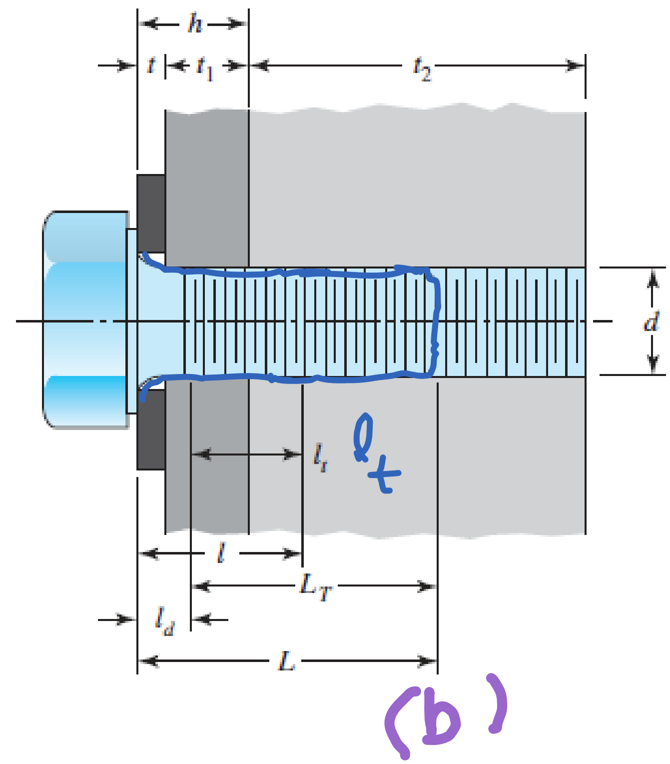
Substituting these stiffnesses in Equation (8–15) gives

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d}$$

$A_d = \frac{\pi d^2}{4}$, $M8 \rightarrow d = 8$

$M10 \rightarrow d = 10$





اگر واشر استفاده شده باشد ضخامت واشر در l_d یا l_t در نظر گرفته می‌شود

Given fastener diameter d and pitch p in mm or number of threads per inch

Washer thickness: t from Table A–32 or A–33

Nut thickness [Figure (a) only]: H from Table A–31

Grip length:

For Figure (a): l = thickness of all material squeezed between face of bolt and face of nut

For Figure (b): $l = \begin{cases} h + t_2/2, & t_2 < d \\ h + d/2, & t_2 \geq d \end{cases}$

پیچ

Fastener length (round up using Table A–17*):

For Figure (a): $L > l + H$

For Figure (b): $L > h + 1.5d$

طول پیچ باید به طوری باشد که حداقل دو رزوه از مهره بیرون بیاید

Threaded length L_T: Inch series:

$$L_T = \begin{cases} 2d + \frac{1}{4}\text{ in}, & L \leq 6\text{ in} \\ 2d + \frac{1}{2}\text{ in}, & L > 6\text{ in} \end{cases}$$

Metric series:

$$L_T = \begin{cases} 2d + 6\text{ mm}, & L \leq 125\text{ mm}, d \leq 48\text{ mm} \\ 2d + 12\text{ mm}, & 125 < L \leq 200\text{ mm} \\ 2d + 25\text{ mm}, & L > 200\text{ mm} \end{cases}$$

Length of unthreaded portion in grip: $l_d = L - L_T$

Length of threaded portion in grip: $l_t = l - l_d$

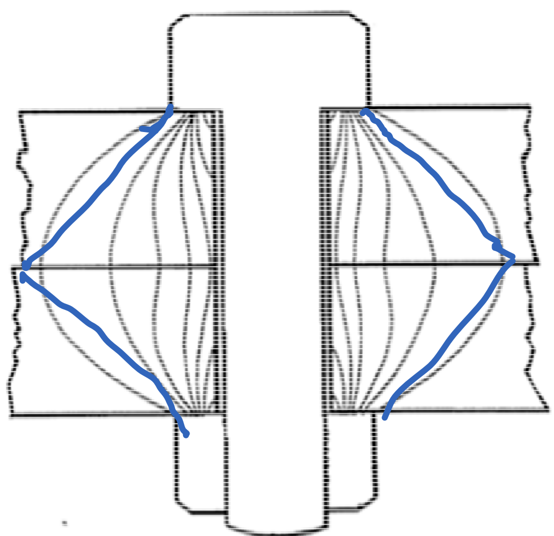
Area of unthreaded portion: $A_d = \pi d^2/4$

Area of threaded portion: A_t from Table 8–1 or 8–2

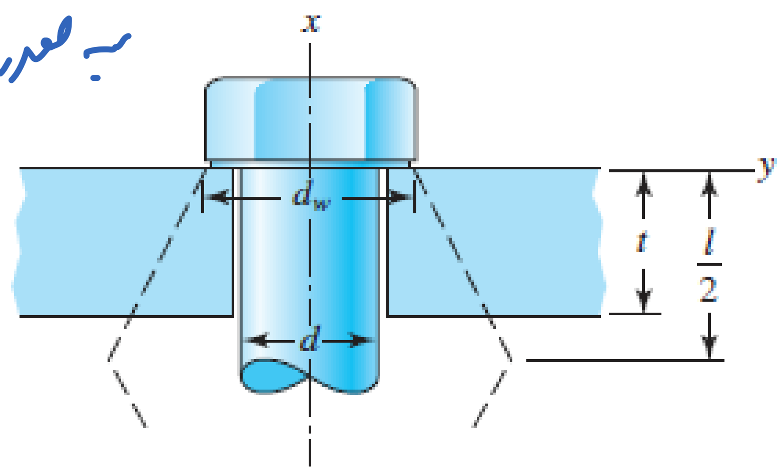
Fastener stiffness: $k_b = \dfrac{A_d A_t E}{A_d l_t + A_t l_d}$

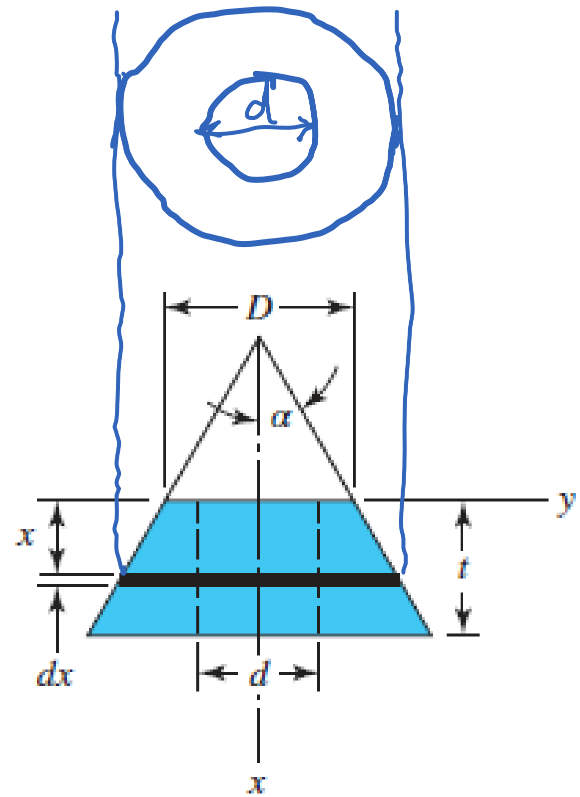
member stiffness سفتی عضو

$\alpha = 30^\circ \qquad 25^\circ < \alpha < 33^\circ$



به صورت مخروط درا





$$d\delta = \frac{P\,dx}{EA}$$

The area of the element is

$$A = \pi(r_o^2 - r_i^2) = \pi\left[\left(x\tan\alpha + \frac{D}{2}\right)^2 - \left(\frac{d}{2}\right)^2\right]$$

$$= \pi\left(x\tan\alpha + \frac{D+d}{2}\right)\left(x\tan\alpha + \frac{D-d}{2}\right)$$

Substituting this in Equation (a) and integrating gives a total contraction of

$$\delta = \frac{P}{\pi E}\int_0^t \frac{dx}{[x\tan\alpha + (D+d)/2][x\tan\alpha + (D-d)/2]}$$

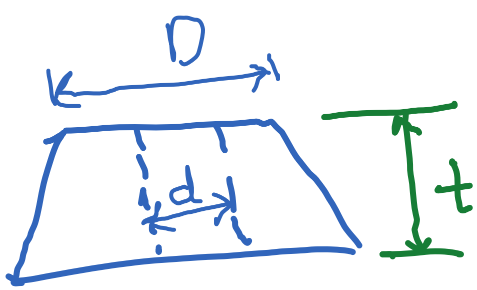
Using a table of integrals, we find the result to be

$$\delta = \frac{P}{\pi E d \tan\alpha} \ln \frac{(2t\tan\alpha + D - d)(D + d)}{(2t\tan\alpha + D + d)(D - d)}$$

Thus the spring rate or stiffness of this frustum is

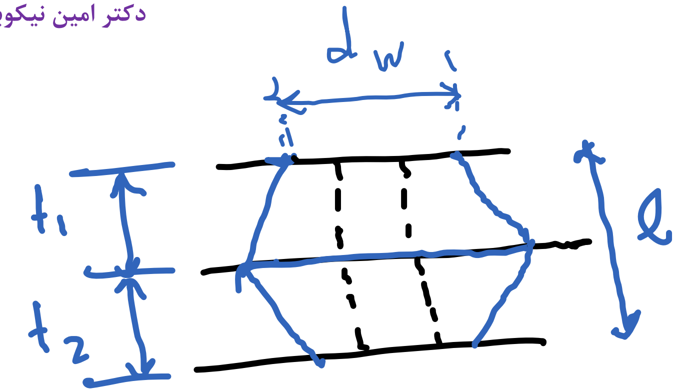
$$k = \frac{P}{\delta} = \frac{\pi E d \tan\alpha}{\ln \dfrac{(2t\tan\alpha + D - d)(D + d)}{(2t\tan\alpha + D + d)(D - d)}}$$

With $\alpha = 30°$, this becomes



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

D قطر کوچک مخروط
d قطر پیچ



$t_1 = t_2 = l/2$, $E_1 = E_2$

$k_1 = k_2 \rightarrow \frac{1}{k_m} = \frac{1}{k_1} + \frac{1}{k_1}$

$k_m = k/2$

frusta back to back, then they act as two identical springs in series. From Equation (8–18) we learn that $k_m = k/2$. Using the grip as $l = 2t$ and d_w as the diameter of the washer face, from Equation (8–19) we find the spring rate of the members to be

$$k_m = \frac{\pi E d \tan\alpha}{2 \ln \dfrac{(l \tan\alpha + d_w - d)(d_w + d)}{(l \tan\alpha + d_w + d)(d_w - d)}} \tag{8–21}$$

The diameter of the washer face is about 50 percent greater than the fastener diameter for standard hexagon-head bolts and cap screws. Thus we can simplify Equation (8–21) by letting $d_w = 1.5d$. If we also use $\alpha = 30°$, then Equation (8–21) can be written as

$$k_m = \frac{0.5774\pi E d}{2 \ln \left(5 \dfrac{0.5774 l + 0.5d}{0.5774 l + 2.5d}\right)} \tag{8–22}$$

$D = d_w = 1.5d$

Table 8–8 Stiffness Parameters of Various Member Materials†

Material Used	Poisson Ratio	Elastic Modulus GPa	Elastic 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

EXAMPLE 8–2

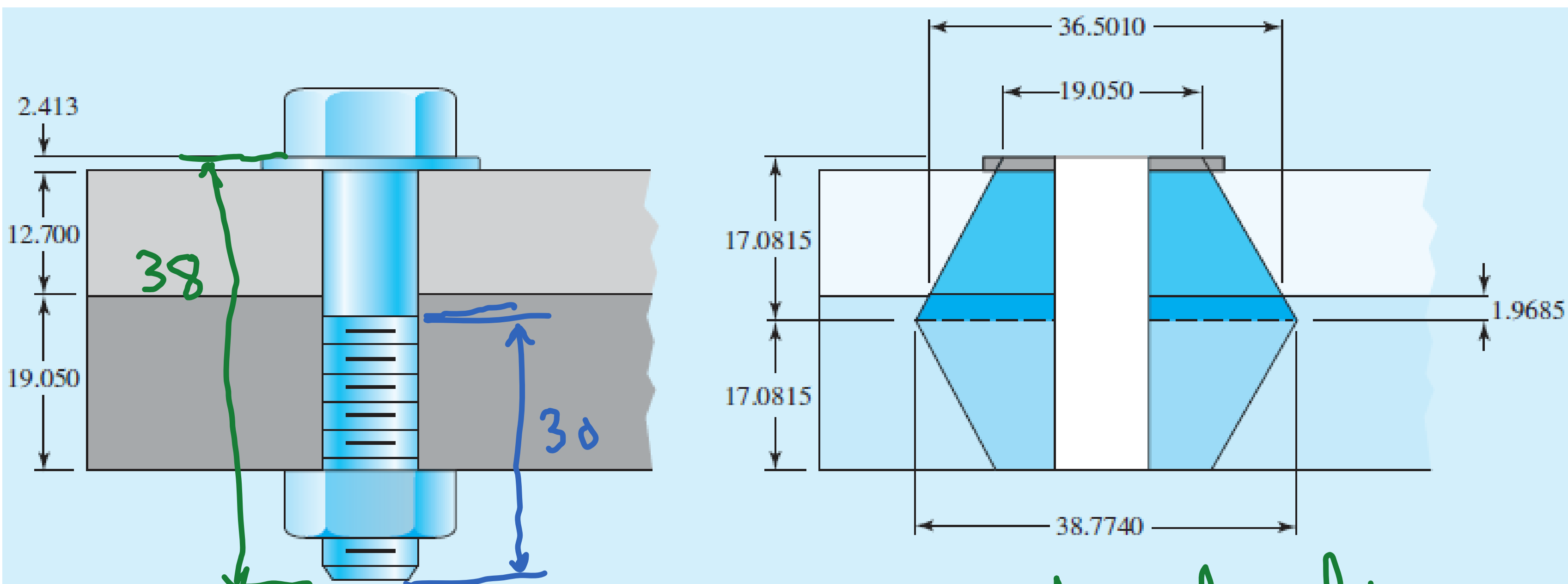
As shown in Figure 8–17*a*, two plates are clamped by washer-faced M12 × 1.25 × 38.1 mm SAE grade 5 bolts each with a standard 12 N steel plain washer.

(*a*) Determine the member spring rate k_m if the top plate is steel and the bottom plate is gray cast iron.

(*b*) Using the method of conical frusta, determine the member spring rate k_m if both plates are steel.

(*c*) Using Equation (8–23), determine the member spring rate k_m if both plates are steel. Compare the results with part (*b*).

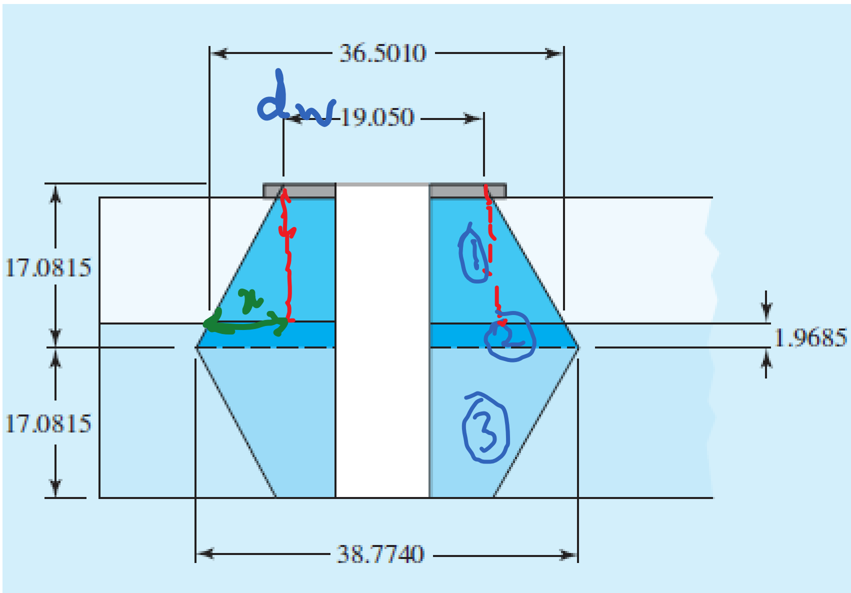
(*d*) Determine the bolt spring rate k_b.

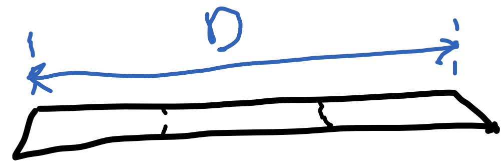


$l_d = 38 - 30 \qquad l_t = l - l_d$

$tg\alpha = \frac{x}{t_1}$

$d_w = 1.5d \simeq 18 \simeq 19$

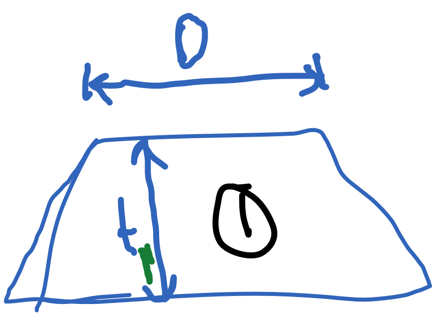




$d = 12$

$t = 1.96 \; , \; 2.1$

$D = 1.5d + 2t_1 tg\alpha$



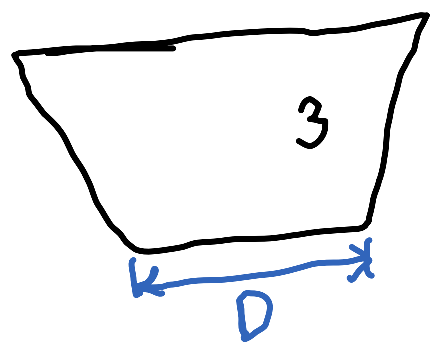
$d = 12$

$D = 1.5d = 19$

$t_1 = 17.08 - 1.96$

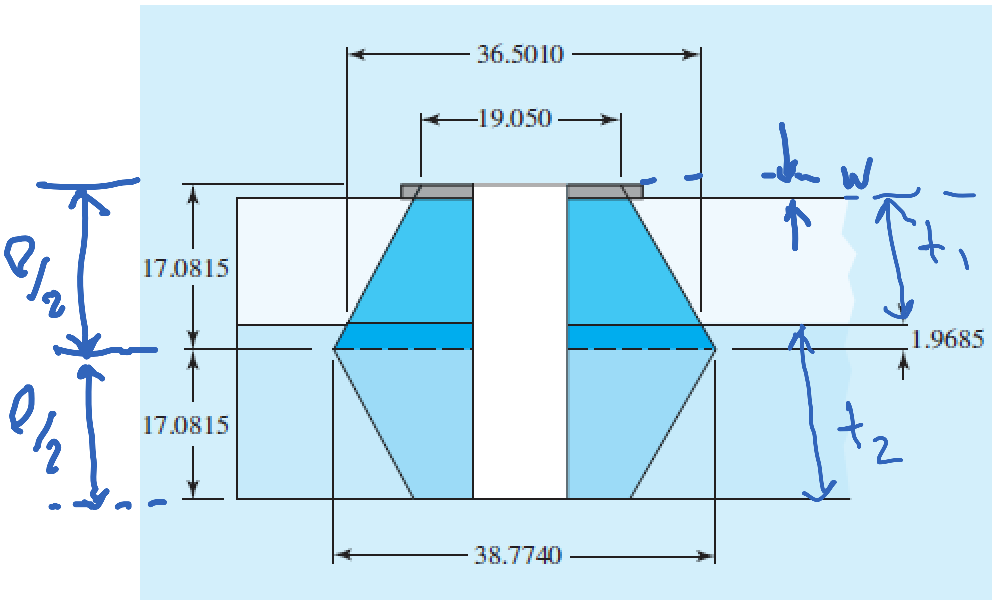
$E = 207 \; GPa$

15.12 یا 14.8



$d = 12 \; , \; D = 1.5d \simeq 19$

$t \simeq 17.05$



ضخامت واشر

$$l = w + t_1 + t_2$$

$$l/2 = 17.08$$

$$l/2 - t_1 - w$$

Solution

From Table A–32, the thickness of a standard 12 N plain washer is 2.8 mm.

(*a*) As shown in Figure 8–17*b*, the frusta extend halfway into the joint the distance

$$\frac{l}{2} = \frac{1}{2}(\overset{t_1}{12} + \overset{t_2}{19.05} + \overset{w}{2.8}) = 16.925 \text{ mm} = 17.07$$

The distance between the joint line and the dotted frusta line is 16.925 − 12.00 − 2.8 = 2.125 mm. Thus, the top frusta consist of the steel washer, steel plate, and 2.125 mm of the cast iron. Since the washer and top plate are both steel with $E = 207(10^9)$ Pa, they can be considered a single frustum of 14.8 mm thick. The outer diameter of the frustum of the steel member at the joint interface is 19.05 + 2(14.8) tan 30° = 36.1396 mm. The outer diameter at the midpoint of the entire joint is 19.05 + 2(16.925) tan 30° = 38.5933 mm. Using Equation (8–20), the spring rate of the steel is

$$k_1 = \frac{0.5774\pi(207) \times (10^3)12}{\ln\left\{\dfrac{[1.155(14.800) + 19.050 - 12](19.05 + 12)}{[1.155(14.800) + 19.050 + 12](19.05 - 12)}\right\}} = 5.69 \times 10^6 \text{ N/mm}$$

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

$D = 1.5d, \quad d = 12$

$207 \times 10^9 \times 12 \times 10^{-3} \simeq \sim \times 10^6$

N.m

From Tables 8–8 or A–5, for gray cast iron, $E = 100$ GPa. Thus for the upper cast-iron frustum

$$k_2 = \frac{0.5774\pi(100)(10^3)(12)}{\ln\left\{\dfrac{[1.155(2.1250) + 36.1396 - 12.000](36.1396 + 12)}{[1.155(2.1250) + 36.1396 + 12.000](36.1396 - 12)}\right\}} = 4.62 \times 10^7 \text{ N/mm}$$

For the lower cast-iron frustum

$$k_3 = \frac{0.5774\pi(100)(10^3)(12)}{\ln\left\{\dfrac{[1.155(16.9250) + 19.050 - 12](19.05 + 12)}{[1.155(16.9250) + 19.050 + 12](19.05 - 12)}\right\}} = 2.59 \times 10^6 \text{ N/mm}$$

The three frusta are in series, so from Equation (8–18)

$$\frac{1}{k_m} = \frac{1}{5.69 \times 10^6} + \frac{1}{4.62 \times 10^7} + \frac{1}{2.59 \times 10^6}$$

Answer

This results in $k_m = 1.71 \times 10^6$ N/mm.

(*b*) If the entire joint is steel, Equation (8–22) with $l = 2(16.925) = 33.85$ mm gives

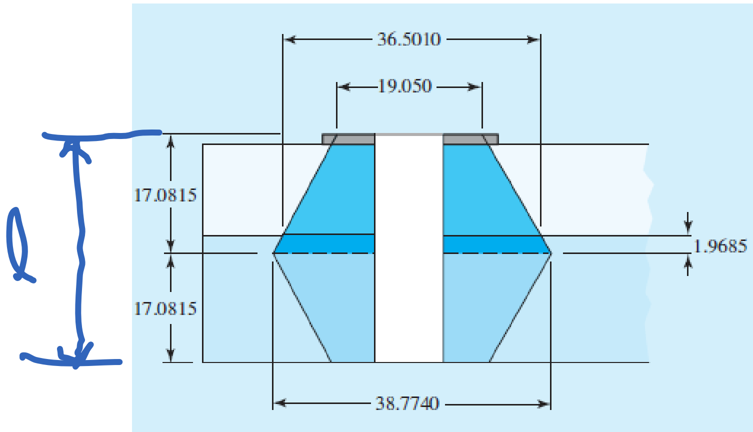
Answer
$$k_m = \frac{0.5774\pi(207)(10^3)(12)}{2\ln\left\{5\left[\dfrac{0.5774(33.85)+0.5(12)}{0.5774(33.85)+2.5(12)}\right]\right\}} = 2.38\times10^6 \text{ N/mm.}$$

(*c*) From Table 8–8, $A = 0.787\ 15$, $B = 0.628\ 73$. Equation (8–23) gives

Answer
$$k_m = 207(10^3)(12)(0.787\ 15)\exp[0.628\ 73(12)/33.8500] = 2.44\times10^6 \text{ N/mm}$$

For this case, the difference between the results for Equations (8–22) and (8–23) is less than 2 percent.
(*d*) Following the procedure of Table 8–7, the threaded length of a 12-mm bolt is $L_T = 2(12) + 6 = 30$ mm. The length of the unthreaded portion is $l_d = 38.1 - 30.0 = 8.1$ mm. The length of the unthreaded portion in grip is $l_t = 33.85 - 8.1 = 25.75$ mm. The major diameter area is $A_d = (\pi/4)(12^2) = 113.10$ mm^2. From Table 8–1, the tensile-stress area is $A_t = 92.1$ mm^2. From Equation (8–17)

Answer
$$k_b = \frac{113.1(92.1)207(10^3)}{113.1(25.75)+92.1(8.1)} = 5.89\times10^5 \text{ N/mm}$$



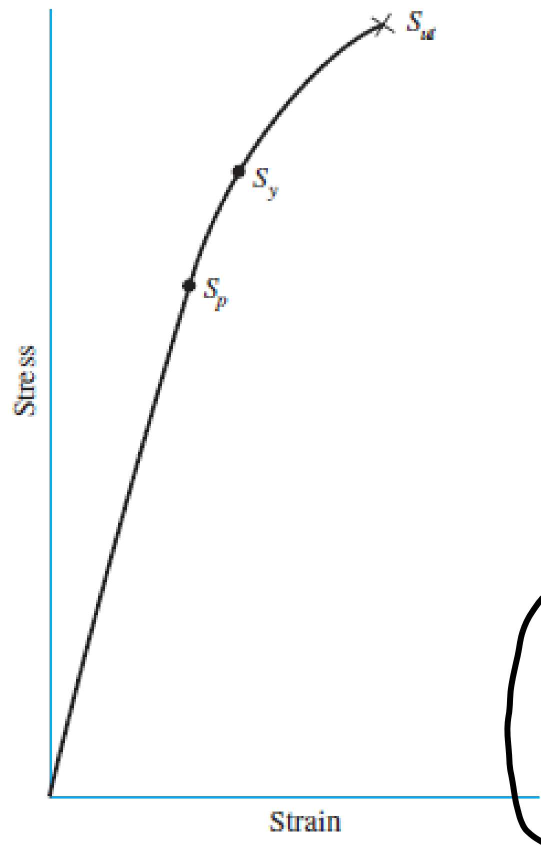
$$k_m = \frac{0.5774\pi Ed}{2\ln\left(5\dfrac{0.5774l+0.5d}{0.5774l+2.5d}\right)}$$

$l = 2\times17.08$

bolt strenght

استحکام پیچ

جلسه بیست و چهارم



1. استحکام گواه Proof strenght

$S_p \simeq 0.85$ تا $0.9\, S_y$

جدول 8-11 متریک

Grade 4.6 a.b

$S_{ut} = a \times 100$, $S_y = 0.b \times S_{ut}$

$S_{ut} = 400\,\text{MPa}$, $S_y = 0.6 \times 400 = 240\,\text{MPa}$

Table 8–9 SAE Specifications for Steel Bolts

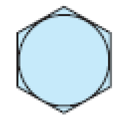
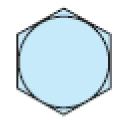
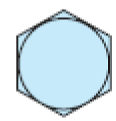
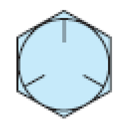
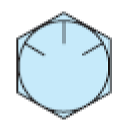
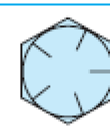
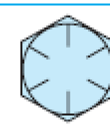
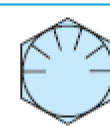
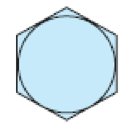
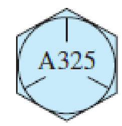
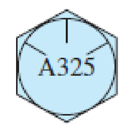
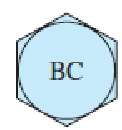
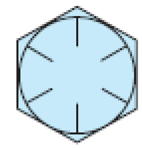
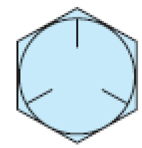
SAE Grade No.	Size Range Inclusive, in	Minimum Proof Strength,* kpsi	Minimum Tensile Strength,* kpsi	Minimum Yield Strength,* kpsi	Material	Head Marking
1	$\frac{1}{4}$–$1\frac{1}{2}$	33	60	36	Low or medium carbon	
2	$\frac{1}{4}$–$\frac{3}{4}$ $\frac{7}{8}$–$1\frac{1}{2}$	55 33	74 60	57 36	Low or medium carbon	
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 74	120 105	92 81	Medium carbon, Q&T	
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	

Table 8–10 ASTM Specifications for Steel Bolts

ASTM Desig-nation No.	Size Range, Inclusive, in	Minimum Proof Strength,* kpsi	Minimum Tensile Strength,* kpsi	Minimum Yield Strength,* kpsi	Material	Head Marking
A307	$\frac{1}{4}$–$1\frac{1}{2}$	33	60	36	Low carbon	
A325, type 1	$\frac{1}{2}$–1 $1\frac{1}{8}$–$1\frac{1}{2}$	85 74	120 105	92 81	Medium carbon, Q&T	
A325, type 2	$\frac{1}{2}$–1 $1\frac{1}{8}$–$1\frac{1}{2}$	85 74	120 105	92 81	Low-carbon, martensite, Q&T	
A325, type 3	$\frac{1}{2}$–1 $1\frac{1}{8}$–$1\frac{1}{2}$	85 74	120 105	92 81	Weathering steel, Q&T	
A354, grade BC	$\frac{1}{4}$–$2\frac{1}{2}$ $2\frac{3}{4}$–4	105 95	125 115	109 99	Alloy steel, Q&T	

A354, grade BD	$\frac{1}{4}$–4	120	150	130	Alloy steel, Q&T	
A449	$\frac{1}{4}$–1 $1\frac{1}{8}$–$1\frac{1}{2}$ $1\frac{3}{4}$–3	85 74 55	120 105 90	92 81 58	Medium-carbon, Q&T	
A490, type 1	$\frac{1}{2}$–$1\frac{1}{2}$	120	150	130	Alloy steel, Q&T	
A490, type 3	$\frac{1}{2}$–$1\frac{1}{2}$	120	150	130	Weathering steel, Q&T	

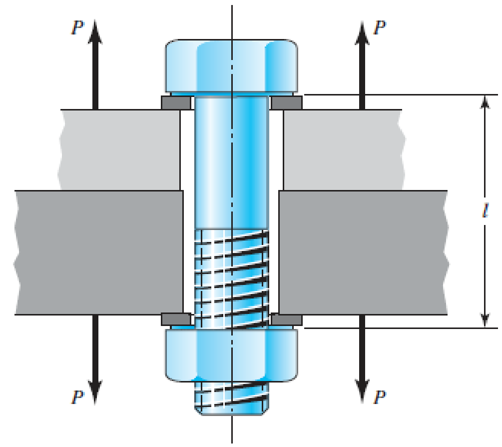
S_p S_{ut} S_y

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

Tension - Joint اتصال تحت کشش

با پیش بار



F_i = preload پیش بار

P_{total} = Total external tensile load applied to the joint

P = external tensile load per bolt

P_b = portion of P taken by bolt

P_m = portion of P taken by members

$F_b = P_b + F_i$ = resultant bolt load

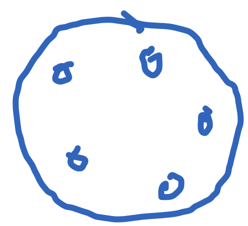
$F_m = P_m - F_i$ = resultant load on members

C = fraction of external load P carried by bolt

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

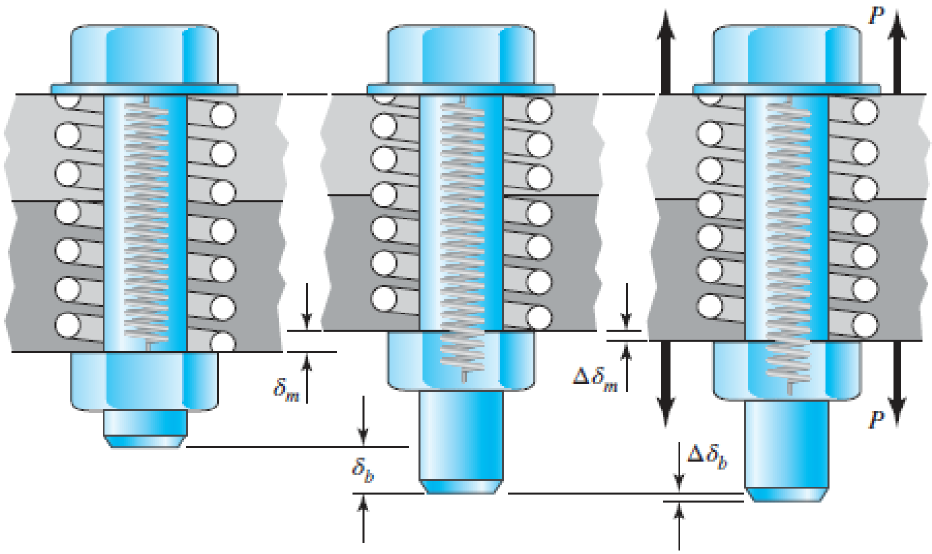
N = Number of bolts in the joint

$$P = \frac{P_{total}}{N}$$



$\rightarrow N = 5$

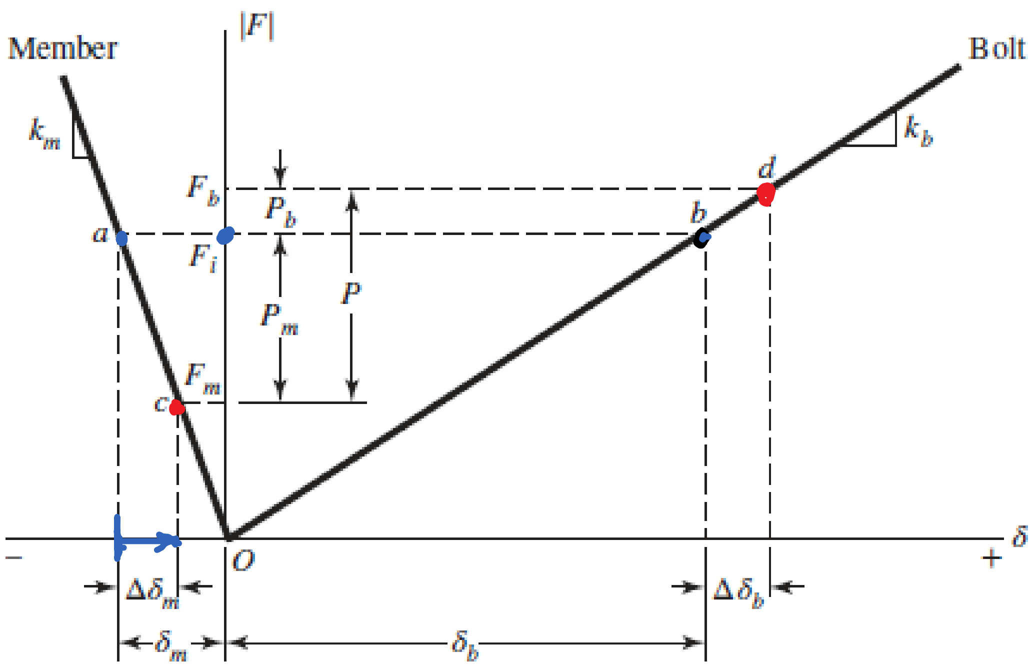
$$P_b = CP \quad , \quad P_m = (1-C)P$$



(a) No preload (b) Preload (c) External load

$$\Delta\delta_b = \frac{P_b}{k_b} = \Delta\delta_m = \frac{P_m}{k_m}$$

$$P_m = \frac{k_m}{k_b} P_b$$



a, b } بعد از اعمال پیش بار

c, d } بعد از اعمال بار خارجی P

$P_b + P_m = P$

$P_b = C P$

$$P_b = \frac{k_b P}{k_b + k_m} = CP$$

$$P_m = P - P_b = (1 - C)P$$

$$C = \frac{k_b}{k_b + k_m}$$

ness constant of the joint. The resultant bolt load is

$$F_b = P_b + F_i = CP + F_i \qquad F_m < 0$$

load on the connected members is

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

اگر $F_m > 0$ شود یعنی قطعات از یکدیگر جدا شده‌اند.

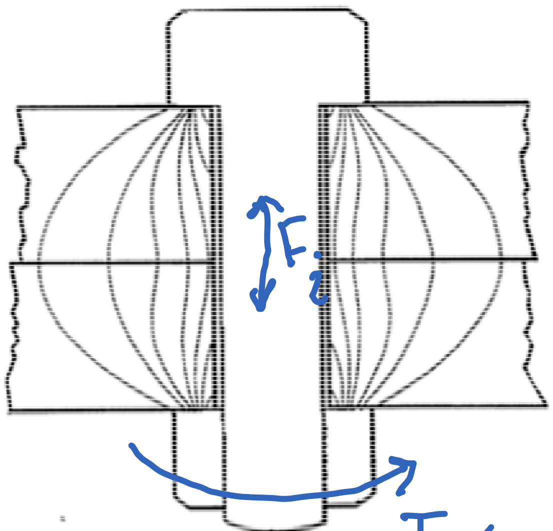
پیش بار

ارتباط بین گشتاور پیچ و نیروی کشش پیچ

bolt torque

$$T = K F_i d$$

T با ترک متر تنظیم می شود.



T

آبکاری شده

آبکاری می شد با روی

Table 8–15 Torque Factors K for Use with Equation (8–27)

Bolt Condition	K
Nonplated, black finish	0.30
Zinc-plated	0.20
Lubricated	0.18
Cadmium-plated	0.16
With Bowman Anti-Seize	0.12
With Bowman-Grip nuts	0.09

Ex. 8.3

A M20 × 1.5 × 63.5 mm SAE grade 5 bolt is subjected to a load P of 26.69 kN in a tension joint. The initial bolt tension is $F_i = 111.205$ kN. The bolt and joint stiffnesses are $k_b = 1.14$ and $k_m = 2.42$ MN/mm, respectively.
(*a*) Determine the preload and service load stresses in the bolt. Compare these to the SAE minimum proof strength of the bolt.
(*b*) Specify the torque necessary to develop the preload, using Equation (8–27).
(*c*) Specify the torque necessary to develop the preload, using Equation (8–26) with $f = f_c = 0.15$.

درس داده نشد.

Solution

From Table 8–1, $A_t = 240.645$ mm^2.
(*a*) The preload stress is

Answer

$$\sigma_i = \frac{F_i}{A_t} = \frac{111.205}{240.645} = 462.11 \text{ MPa}$$

Preload stress $\sigma_i = \dfrac{F_i}{A_t} = 462$ MPa

Service load st— $\sigma_b = \dfrac{F_b}{A_t} =$ ✓

$F_b = F_i + cP =$ ✓ , $c = \dfrac{k_b}{k_b + k_m} =$ ✓

Solution

From Table 8–1, $A_t = 240.645\ \text{mm}^2$.

(*a*) The preload stress is

Answer

$$\sigma_i = \frac{F_i}{A_t} = \frac{111.205}{240.645} = 462.11\ \text{MPa}$$

The stiffness constant is

$$C = \frac{k_b}{k_b + k_m} = \frac{1.14}{1.14 + 2.42} = 0.321$$

From Equation (8–24), the stress under the service load is

$$\sigma_b = \frac{F_b}{A_t} = \frac{CP + F_i}{A_t} = C\frac{P}{A_t} + \sigma_i$$

Answer

$$= \frac{0.321 \times 26.69\ (1000)}{240.65} + \ 462.11 = 497.66\ \text{MPa}$$

From Table 8–9, the SAE minimum proof strength of the bolt is $S_p = 586.075$ MPa. The preload and service load stresses are respectively 21 and 15 percent less than the proof strength.

$1.1 < \frac{S_p}{\sigma_b} < 1.15$ $\quad \sigma_b < S_p \quad$ $497 < 586$ ✓✓

(b)

$$T = KF_i d = 0.2(111.205)(10^3)(20) = 444820 \text{ N} \cdot \text{mm}$$

وقتی اتصال تحت بار کششی استاتیکی با پیش بار

$$\sigma_b = \frac{F_b}{A_t} = \frac{CP + F_i}{A_t}$$

$$n_p = \frac{S_p}{\sigma_b} = \frac{S_p}{(CP + F_i)/A_t}$$

فاکتور تسلیم yielding factor

$$n_p = \frac{S_p A_t}{CP + F_i}$$

$1.1 < n_p < 1.2$

$$\sigma_b = \frac{F_b}{A_t} = \frac{F_i + CP}{A_t}$$

Load factor فاکتور بار

n_L

$$S_p = \frac{F_i + C n_L P}{A_t} \Rightarrow n_L = \frac{S_p A_t - F_i}{CP}$$

$$P \rightarrow \frac{P_t}{N}$$

فاکتور جدایش اتصال

P_0 نیروی خارجی که اتصال در آستانه جدایش قرار می گیرد.

$$F_m = (1-C)P - F_i$$

$$\Rightarrow 0 = (1-C)P_0 - F_i$$

$$\Rightarrow P_0 = \frac{F_i}{1-C} \quad ,$$

$$n_0 = \frac{P_0}{P} = \frac{F_i}{(1-C)P}$$

F_i: رابطه تجربی برای نیروی پیش بار

$$F_i = \begin{cases} 0.75F_p & \text{for nonpermanent connections, reused fasteners} \\ 0.90F_p & \text{for permanent connections} \end{cases}$$

→ غیردائمی

→ دائمی

بندرت باز و بسته می شود

where F_p is the proof load, obtained from the equation

$$F_p = A_t S_p$$

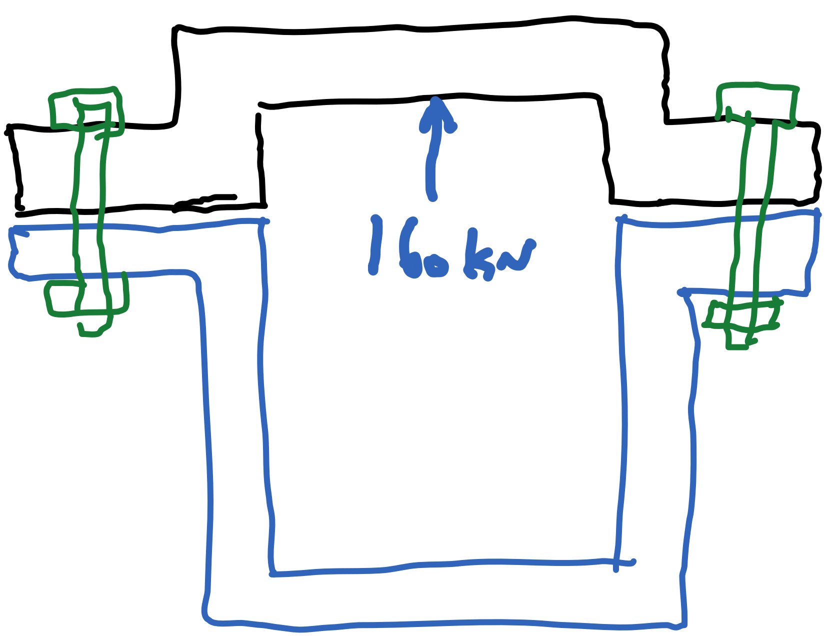
EXAMPLE 8–4

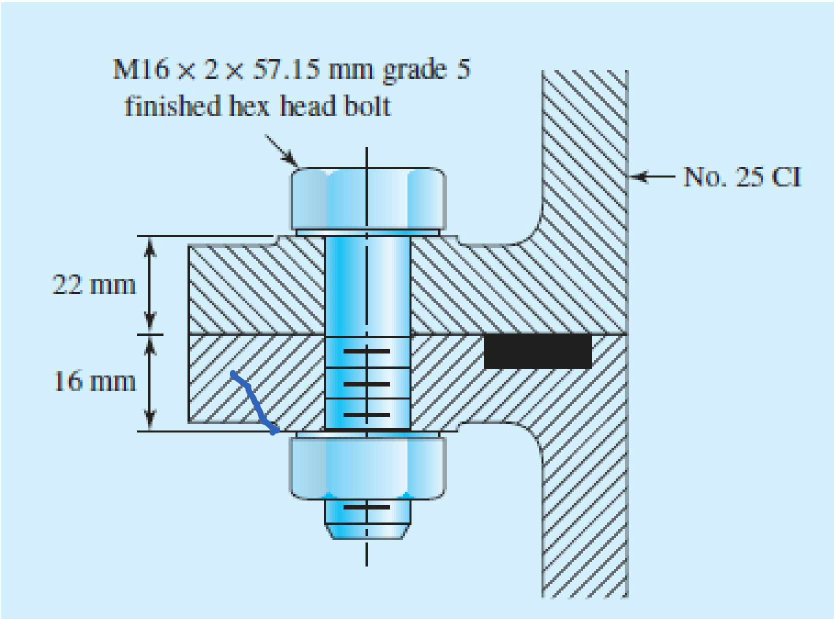
Figure 8–21 is a cross section of a grade 25 cast-iron pressure vessel. A total of N bolts are to be used to resist a separating force of 160 kN.

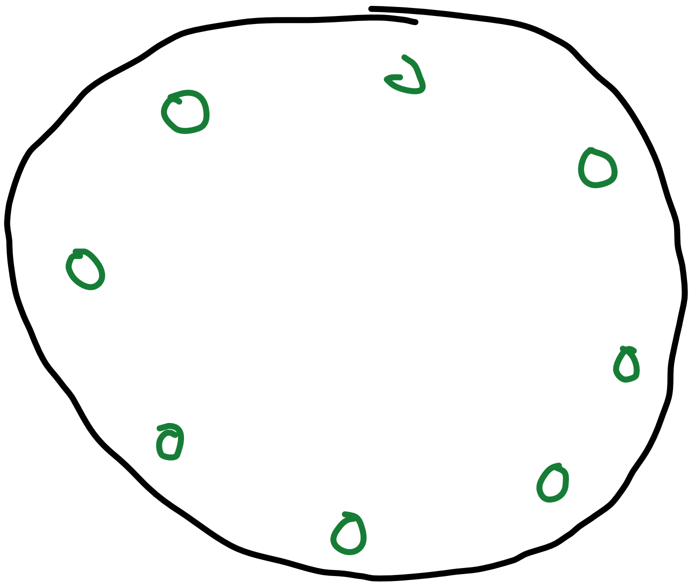
(a) Determine k_b, k_m, and C.

(b) Find the number of bolts required for a load factor of 2 where the bolts may be reused when the joint is taken apart.

(c) With the number of bolts obtained in part (b), determine the realized load factor for overload, the yielding factor of safety, and the load factor for joint separation.

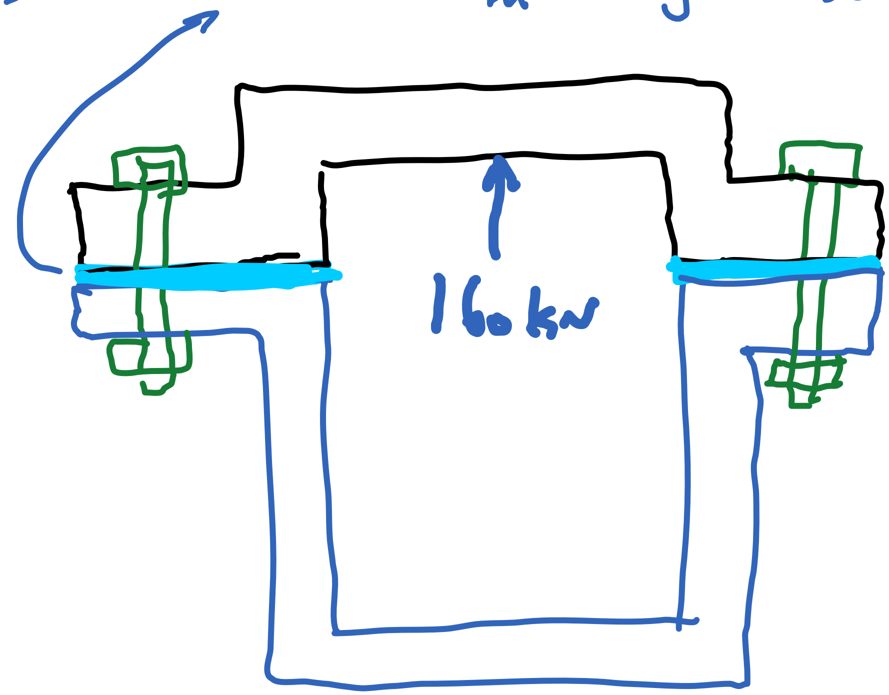


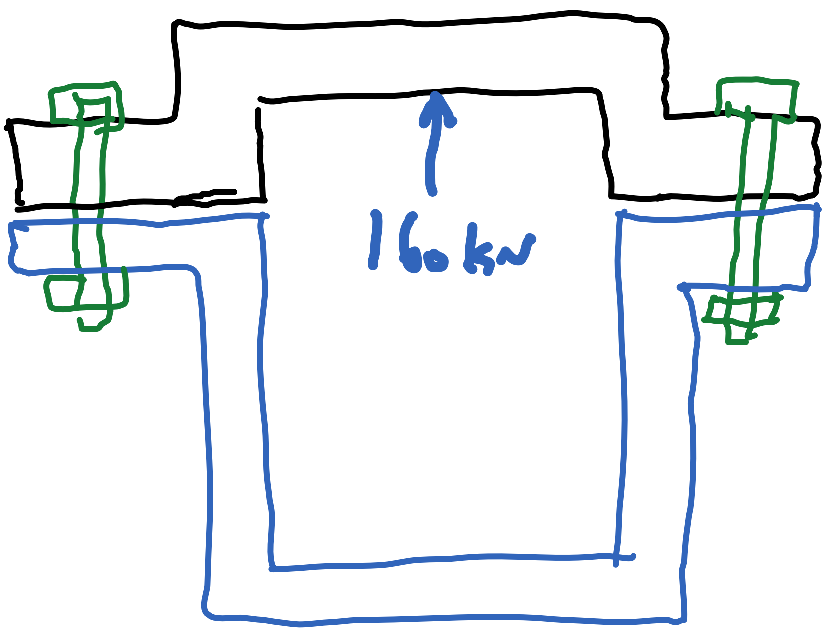




اگر واشر به صورت کامل بین دو عضو قرار گیرد آنگاه:

$K_m = k_g$

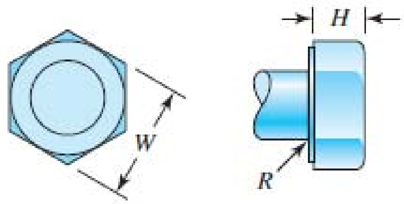




سفتی اتصال برابر با سفتی واشر است

$$\frac{1}{k_m} = \cancel{\frac{1}{k_1}} + \frac{1}{k_g} + \cancel{\frac{1}{k_2}} \Rightarrow k_m = k_g$$

Table A–29 Dimensions of Square and Hexagonal Bolts



Nominal Size, in	Head Type										
	Square		Regular Hexagonal			Heavy Hexagonal			Structural Hexagonal		
	W	H	W	H	R_{min}	W	H	R_{min}	W	H	R_{min}
Nominal Size, mm											
M5	8	3.58	8	3.58	0.2						
M6			10	4.38	0.3						
M8			13	5.68	0.4						
M10			16	6.85	0.4						
M12			18	7.95	0.6	21	7.95	0.6			
M14			21	9.25	0.6	24	9.25	0.6			
M16			24	10.75	0.6	27	10.75	0.6	27	10.75	0.6
M20			30	13.40	0.8	34	13.40	0.8	34	13.40	0.8
M24			36	15.90	0.8	41	15.90	0.8	41	15.90	1.0
M30			46	19.75	1.0	50	19.75	1.0	50	19.75	1.2
M36			55	23.55	1.0	60	23.55	1.0	60	23.55	1.5

Table A–31 Dimensions of Hexagonal Nuts

Nominal Size, in	Width W	Height H Regular Hexagonal	Thick or Slotted	JAM
Nominal Size, mm				
M5	8	4.7	5.1	2.7
M6	10	5.2	5.7	3.2
M8	13	6.8	7.5	4.0
M10	16	8.4	9.3	5.0
M12	18	10.8	12.0	6.0
M14	21	12.8	14.1	7.0
M16	24	14.8	16.4	8.0
M20	30	18.0	20.3	10.0
M24	36	21.5	23.9	12.0
M30	46	25.6	28.6	15.0
M36	55	31.0	34.7	18.0

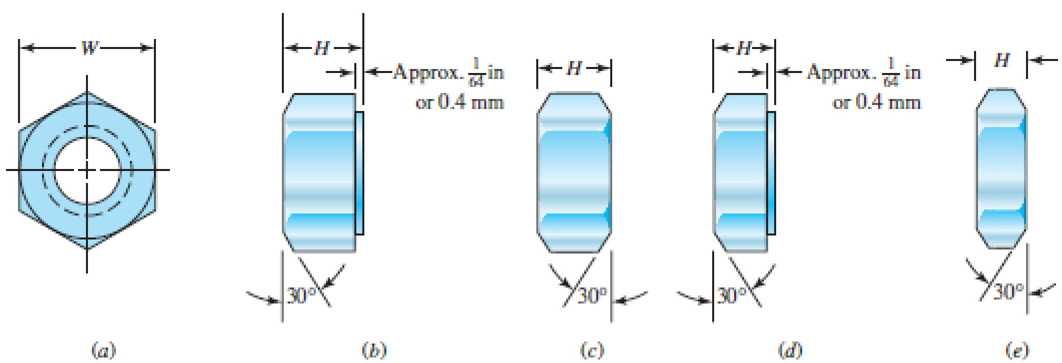


Figure 8–12

Hexagonal nuts: (*a*) end view, general; (*b*) washer-faced regular nut; (*c*) regular nut chamfered on both sides; (*d*) jam nut with washer face; (*e*) jam nut chamfered on both sides.

Table A–33 Dimensions of Metric Plain Washers (All Dimensions in Millimeters)

Washer Size*	Minimum ID	Maximum OD	Maximum Thickness	Washer Size*	Minimum ID	Maximum OD	Maximum Thickness
1.6 N	1.95	4.00	0.70	10 N	10.85	20.00	2.30
1.6 R	1.95	5.00	0.70	10 R	10.85	28.00	2.80
1.6 W	1.95	6.00	0.90	10 W	10.85	39.00	3.50
2 N	2.50	5.00	0.90	12 N	13.30	25.40	2.80
2 R	2.50	6.00	0.90	12 R	13.30	34.00	3.50
2 W	2.50	8.00	0.90	12 W	13.30	44.00	3.50
2.5 N	3.00	6.00	0.90	14 N	15.25	28.00	2.80
2.5 R	3.00	8.00	0.90	14 R	15.25	39.00	3.50
2.5 W	3.00	10.00	1.20	14 W	15.25	50.00	4.00
3 N	3.50	7.00	0.90	16 N	17.25	32.00	3.50
3 R	3.50	10.00	1.20	16 R	17.25	44.00	4.00
3 W	3.50	12.00	1.40	16 W	17.25	56.00	4.60
3.5 N	4.00	9.00	1.20	20 N	21.80	39.00	4.00
3.5 R	4.00	10.00	1.40	20 R	21.80	50.00	4.60
3.5 W	4.00	15.00	1.75	20 W	21.80	66.00	5.10
4 N	4.70	10.00	1.20	24 N	25.60	44.00	4.60
4 R	4.70	12.00	1.40	24 R	25.60	56.00	5.10
4 W	4.70	16.00	2.30	24 W	25.60	72.00	5.60
5 N	5.50	11.00	1.40	30 N	32.40	56.00	5.10
5 R	5.50	15.00	1.75	30 R	32.40	72.00	5.60
5 W	5.50	20.00	2.30	30 W	32.40	90.00	6.40
6 N	6.65	13.00	1.75	36 N	38.30	66.00	5.60
6 R	6.65	18.80	1.75	36 R	38.30	90.00	6.40
6 W	6.65	25.40	2.30	36 W	38.30	110.00	8.50
8 N	8.90	18.80	2.30				
8 R	8.90	25.40	2.30				
8 W	8.90	32.00	2.80				

N = narrow; R = regular; W = wide.

Solution

(*a*) The grip is $l = 38.1$ mm. From Table A–31, the nut thickness is 14.8 mm. Adding two threads beyond the nut of 4.62 mm gives a bolt length of

$$L = 14.8 + 38.1 + 4.62 = 57.52 \text{ mm}$$

From Table A–17 the next fraction size bolt is $L = 60$ mm. From Equation (8–13), the thread length is $L_T = 2(16) + 6 = 38$ mm. Thus, the length of the unthreaded portion in the grip is $l_d = 60 - 38 = 22$ mm. The threaded length in the grip is $l_t = l - l_d = 16$ mm. From Table 8–2, $A_t = 157$ mm^2. The major-diameter area is $A_d = \pi(16)^2/4 = 201.07$ mm^2. The bolt stiffness is then

Answer

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{201.07(157)(207)(10^{-3})}{201.07(16) + 157(22)}$$

$$= 0.976 \text{ MN/mm}$$

From Table A–24, for no. 25 cast iron we will use $E = 96.46$ GPa. The stiffness of the members, from Equation (8–22), is

Answer

$$k_m = \frac{0.5774\pi E d}{2\ln\left(5\dfrac{0.5774l + 0.5d}{0.5774l + 2.5d}\right)} = \frac{0.5774\pi(96.46)(16)(10^{-3})}{2\ln\left[5\dfrac{0.5774(38) + 0.5(16)}{0.5774(38) + 2.5(16)}\right]}$$

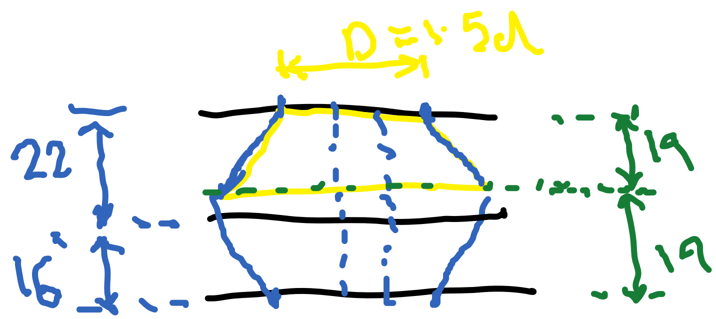
$$= 1.5862 \text{ MN/mm}$$

If you are using Eq. (8–23), from Table 8–8, $A = 0.778\,71$ and $B = 0.616\,16$, and

$$k_m = EdA\exp(Bd/l)$$
$$= 96.46(16)(0.778\,71)\exp[0.616\,16(16)/38]$$
$$= 1.5578 \text{ MN/mm}$$

which is only 1.79 percent lower than the previous result.

From the first calculation for k_m, the stiffness constant C is



$22+16 = 38$, $38/2 = 19$

Answer

$$C = \frac{k_b}{k_b + k_m} = \frac{0.98}{0.98 + 1.5862} = 0.3818$$

(*b*) From Table 8–9, $S_p = 600$ MPa. Then, using Equations (8–31) and (8–32), we find the recommended preload to be

$$F_i = 0.75A_t S_p = 0.75(157)(600)(10^{-3}) = 70.65 \text{ kN}$$

For N bolts, Equation (8–29) can be written

$$n_L = \frac{S_p A_t - F_i}{C(P_{\text{total}}/N)}$$

or

$$N = \frac{C n_L P_{\text{total}}}{S_p A_t - F_i} = \frac{0.3818(2)(160)}{600(157)(10^{-3}) - 70.65} = 5.18$$

رابطه برای محاسبه
تعداد پیچها

Answer

Six bolts should be used to provide the specified load factor. $N = 6$

(*c*) With six bolts, the load factor actually realized is

Answer
$$n_L = \frac{600(157)(10^{-3}) - 70.65}{0.3818(160/6)} = 2.31$$

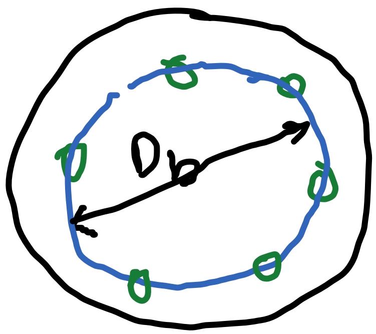
From Equation (8–28), the yielding factor of safety is

Answer
$$n_p = \frac{S_p A_t}{C(P_{\text{total}}/N) + F_i} = \frac{600(157)(10^{-3})}{0.3818(160/6) + 70.65} = 1.17$$

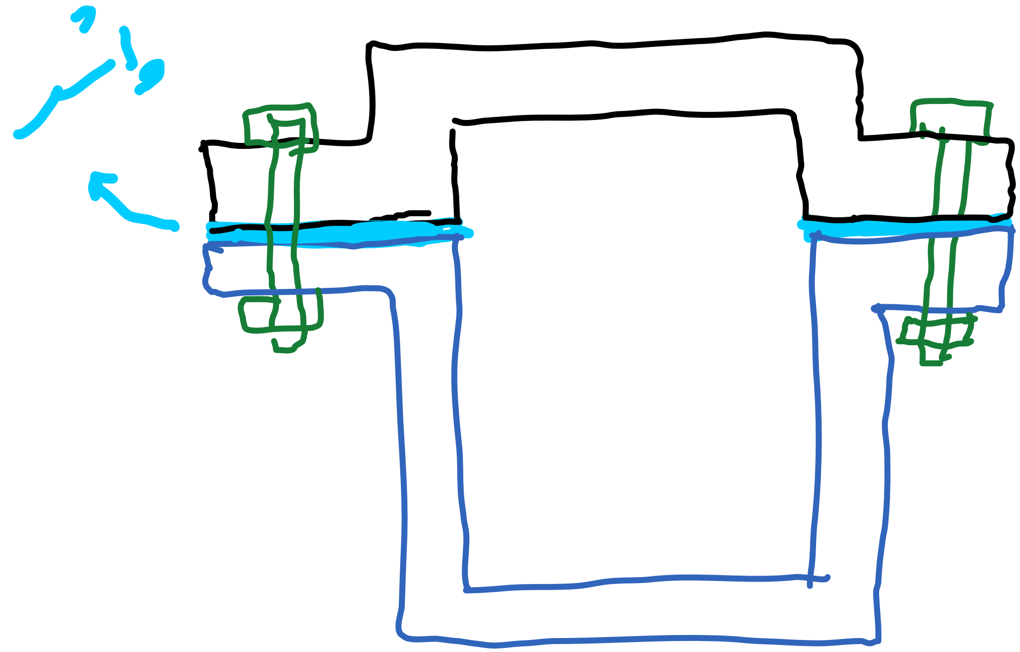
From Equation (8–30), the load factor guarding against joint separation is

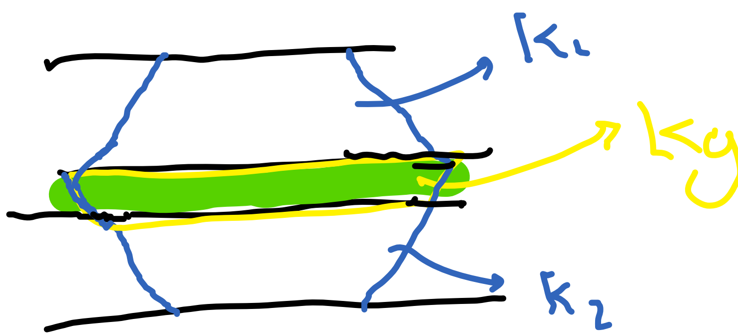
Answer
$$n_0 = \frac{F_i}{(P_{\text{total}}/N)(1 - C)} = \frac{70.65}{(160/6)(1 - 0.3818)} = 4.29$$

Gasketed Joint — اتصال واشردار



$$3 < \frac{\pi D_b}{N d} < 6$$





$$k_m = k_g$$

اتصالات تحت برش

جلسه بیست و پنجم

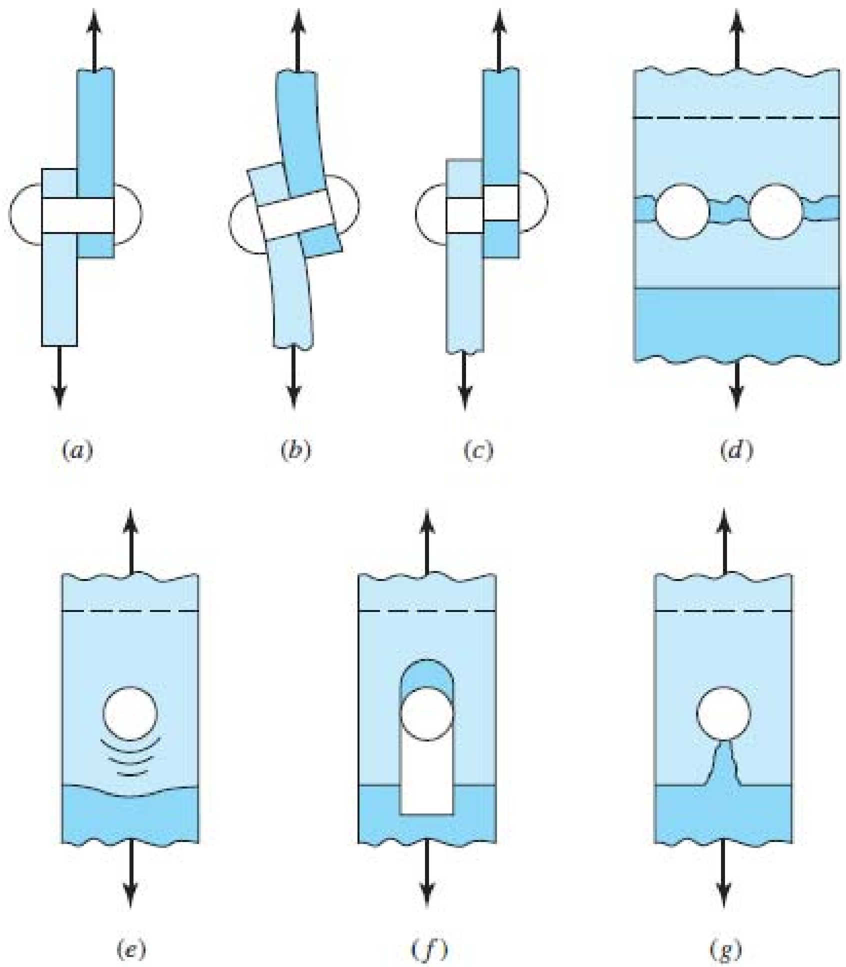
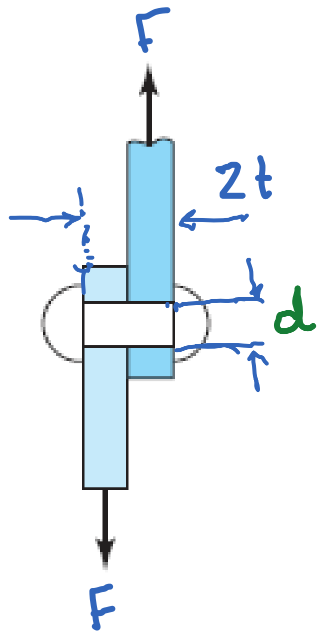
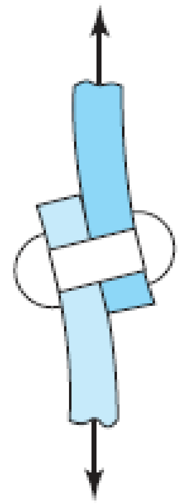


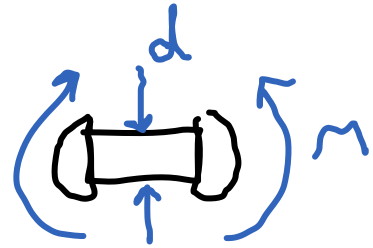
Figure 8–25

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.

تنش خمشی در پرچ یا پیچ





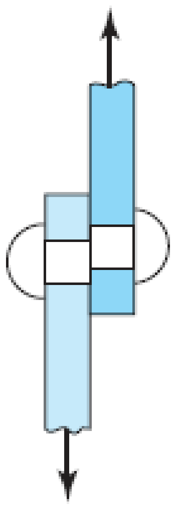


$$M = Ft$$

$$\sigma = \frac{MC}{I} = \frac{M d/2}{\pi d^4/64} = \frac{32M}{\pi d^3} = \frac{32Ft}{\pi d^3}$$

$$n = \frac{(S_y)_{screw}}{\sigma}$$

تنش برشی در پرچ یا پیچ



$$\tau = \frac{F}{A} = \frac{4F}{\pi d^2}$$

$A_2 \quad A_2$

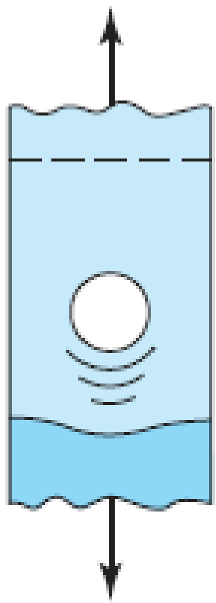
$$n = \frac{0.577 (S_y)_{screw}}{\tau}$$

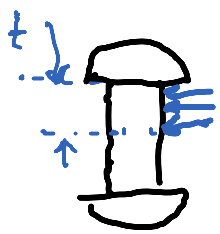
$$S_{sy} = 0.5\, S_y$$

$$S_{sy} = 0.577\, S_y$$

تنش تکیه گاهی یا لهیدگی در پیچ یا عضو

Bearing stress





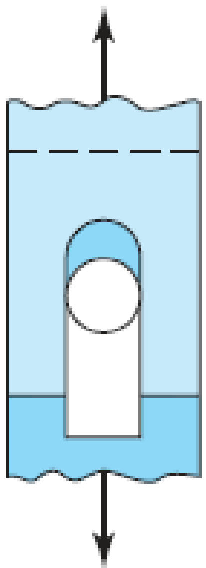
$$\sigma = \frac{F}{A} = \frac{F}{dt}$$

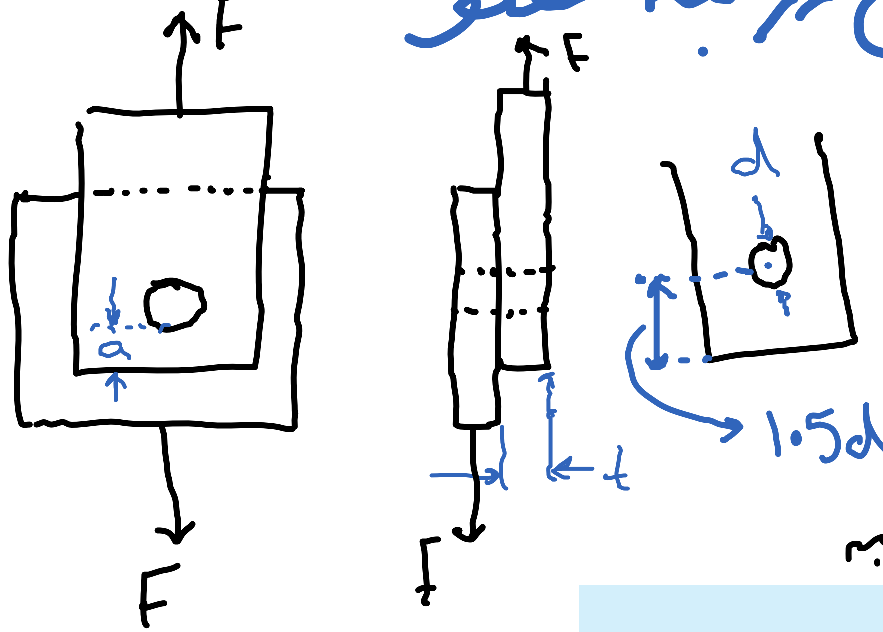
همین تنش به عضو هم اعمال می شود

$$n = \frac{(S_y)_{screw}}{\sigma}$$

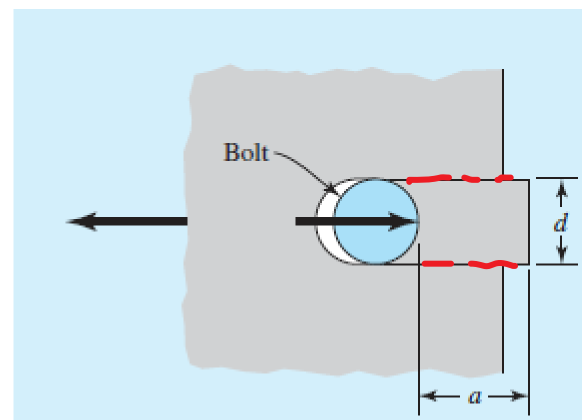
$$n = \frac{(S_y)_{member}}{\sigma}$$

برش در لبه عضو





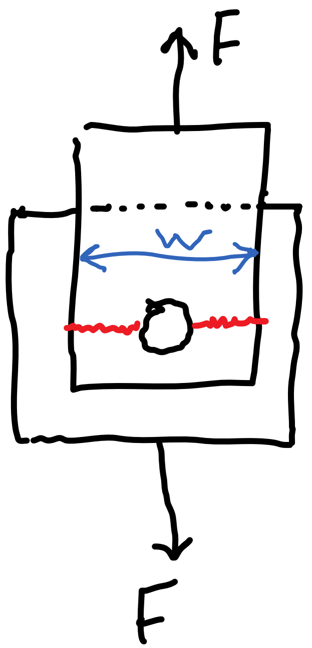
جهت اجتناب از
برش عضو در لبه

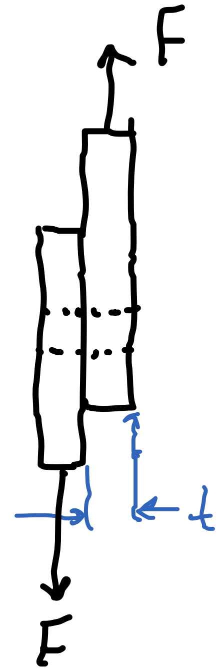


$$\tau = \frac{F}{A} = \frac{F}{2at}$$

$$n = \frac{0.57\,(S_y)_{member}}{\tau}$$

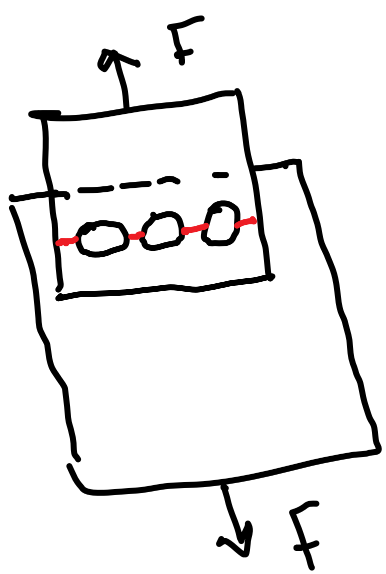
تنش کششی در عضو





$$\sigma = \frac{F}{A} = \frac{F}{(w-d)t}$$

$$n = \frac{(S_y)_{member}}{\sigma}$$



$$\rightarrow \quad \sigma = \frac{F}{(w-3d)t}$$

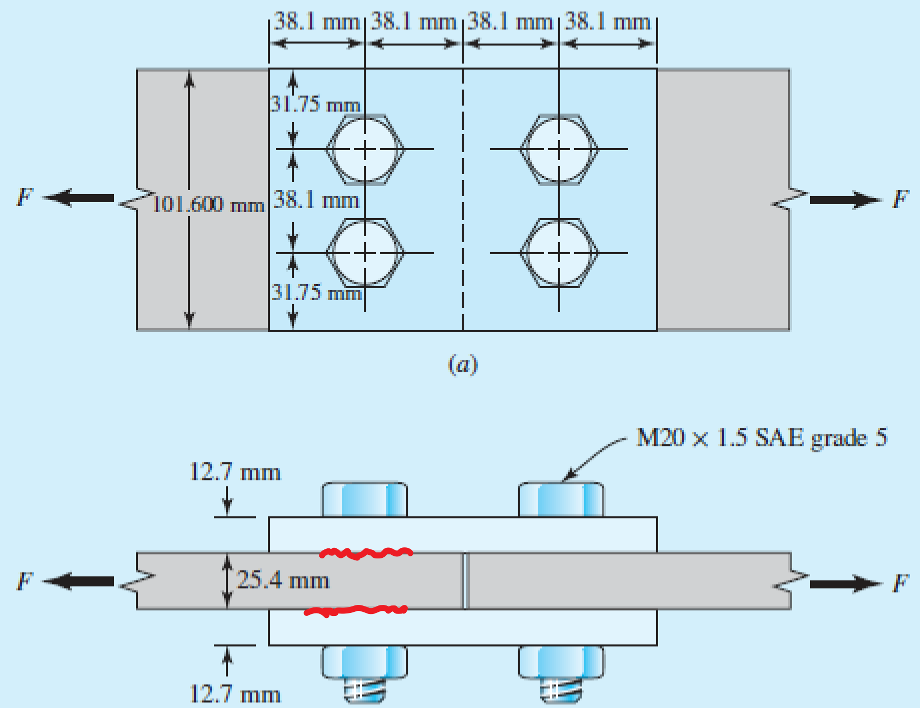
EXAMPLE 8–6

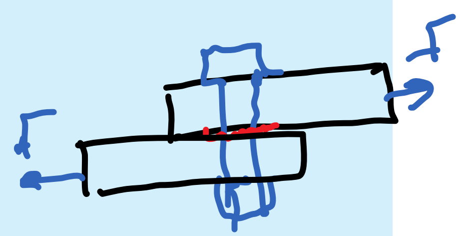
Two 25.4 by 101.6 mm 1018 cold-rolled steel bars are butt-spliced with two 12.7 by 101.6 mm 1018 cold-rolled splice plates using four M20 × 1.5 mm grade 5 bolts as depicted in Figure 8–26. For a design factor of $n_d = 1.5$ estimate the static load F that can be carried if the bolts lose preload.

Solution

From Table A–20, minimum strengths of $S_y = 370$ MPa and $S_{ut} = 440$ MPa are found for the members, and from Table 8–11 minimum strengths of $S_p = 600$ MPa, $S_y = 660$ MPa, and $S_{ut} = 830$ MPa for the bolts are found.

Figure 8–26





$F/2$ is transmitted by each of the splice plates, but since the areas of the splice plates are half those of the center bars, the stresses associated with the plates are the same. So for stresses associated with the plates, the force and areas used will be those of the center plates.

Bearing in bolts, all bolts loaded:

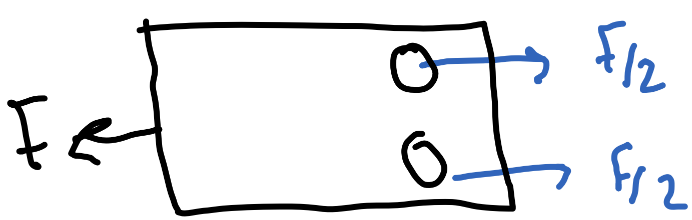
$$\sigma = \frac{F}{2td} = \frac{S_y}{n_d}$$

$$F = \frac{2td\, S_y}{n_d} = \frac{2(25.4)(20)(660)}{1.5} = 447 \text{ kN}$$

Bearing in members, all bolts active:

$$\sigma = \frac{F}{2td} = \frac{(S_y)_{\text{mem}}}{n_d}$$

$$F = \frac{2td(S_y)_{\text{mem}}}{n_d} = \frac{2(25.4)(20)(370)}{1.5} = 250.61 \text{ kN}$$



Shear of bolt, all bolts active: If the bolt threads do not extend into the shear planes for four shanks:

$$\tau = \frac{F}{4\pi d^2/4} = 0.577\frac{S_y}{n_d}$$

$$F = 0.577\pi d^2 \frac{S_y}{n_d} = 0.577\pi(20)^2 \frac{660}{1.5} = 319 \text{ kN}$$

If the bolt threads extend into a shear plane:

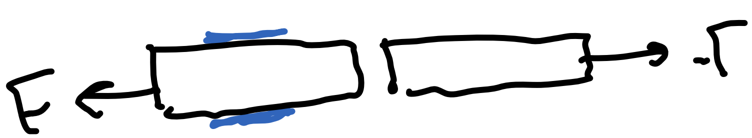
$$\tau = \frac{F}{4A_r} = 0.577\frac{S_y}{n_d}$$

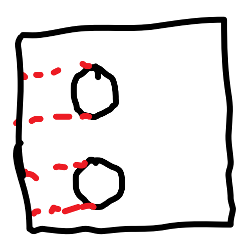
$$F = \frac{0.577(4)A_r S_y}{n_d} = \frac{0.577(4)259(660)}{1.5} = 263 \text{ kN}$$

Edge shearing of member at two margin bolts: From Figure 8–27,

$$\tau = \frac{F}{4at} = \frac{0.577(S_y)_{\text{mem}}}{n_d}$$

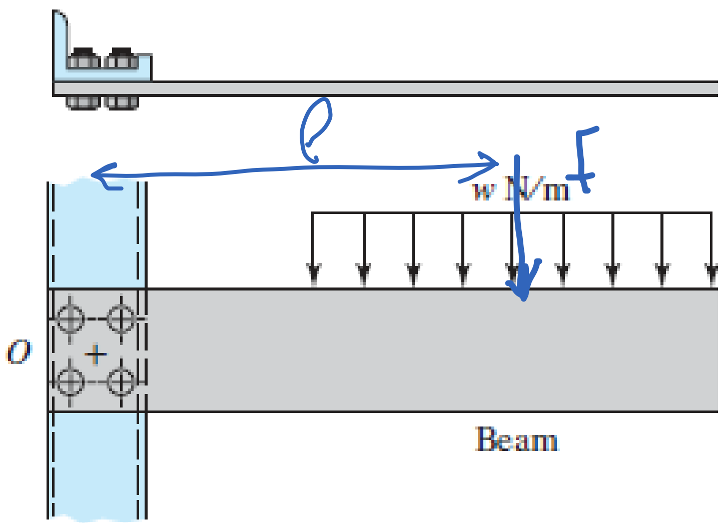
$$F = \frac{4at0.577(S_y)_{\text{mem}}}{n_d} = \frac{4(28.575)(25.4)0.577(370)}{1.5} = 413 \text{ kN}$$

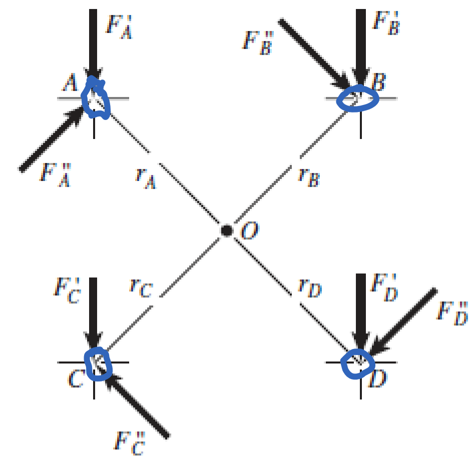




$F_{mem} = 250$ kN

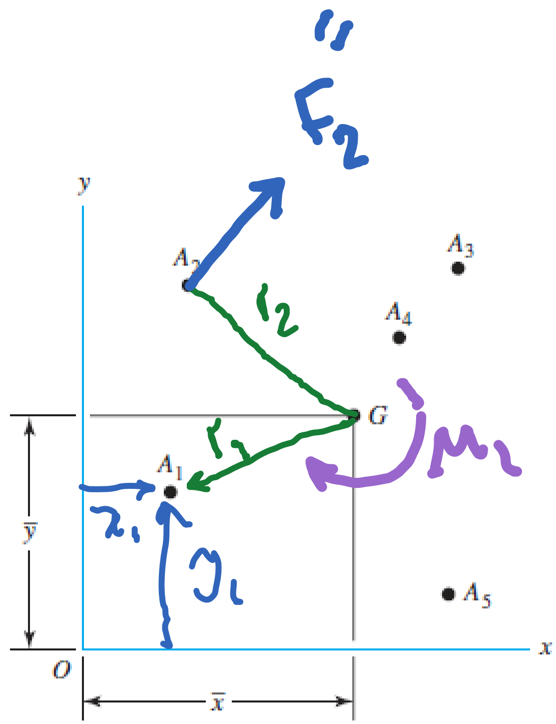
اتصال تحت نیروی برشی خارج از مرکز





$$F'_A = F'_B = F'_C = F'_D = F/4$$

$$M = F\ell$$



$$F_n'' = \frac{M_1 r_n}{r_A^2 + r_B^2 + r_C^2 + \cdots}$$

$$\bar{x} = \frac{A_1x_1 + A_2x_2 + A_3x_3 + A_4x_4 + A_5x_5}{A_1 + A_2 + A_3 + A_4 + A_5} = \frac{\sum_1^n A_i x_i}{\sum_1^n A_i}$$

$$\bar{y} = \frac{A_1y_1 + A_2y_2 + A_3y_3 + A_4y_4 + A_5y_5}{A_1 + A_2 + A_3 + A_4 + A_5} = \frac{\sum_1^n A_i y_i}{\sum_1^n A_i}$$

In many instances the centroid can be located by symmetry.

EXAMPLE 8–7

Shown in Figure 8–30 is a 15- by 200-mm rectangular steel bar cantilevered to a 250-mm steel channel using four tightly fitted bolts located at *A*, *B*, *C*, and *D*. Assume the bolt threads do not extend into the joint.

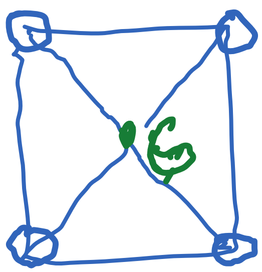
For the $F = 16$ kN load shown find

(*a*) The resultant load on each bolt

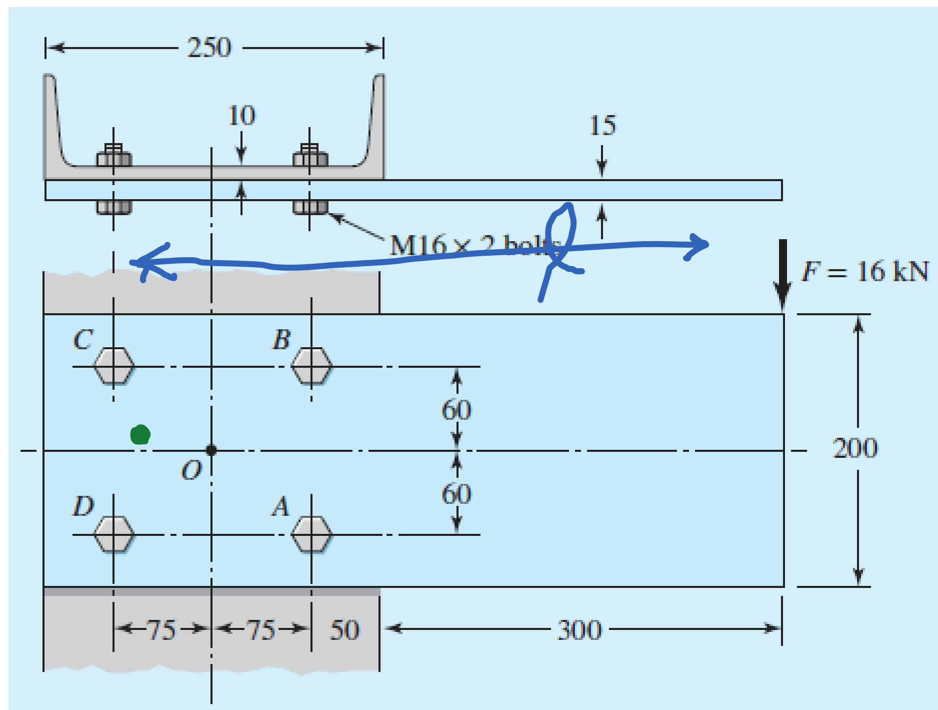
(*b*) The maximum shear stress in each bolt

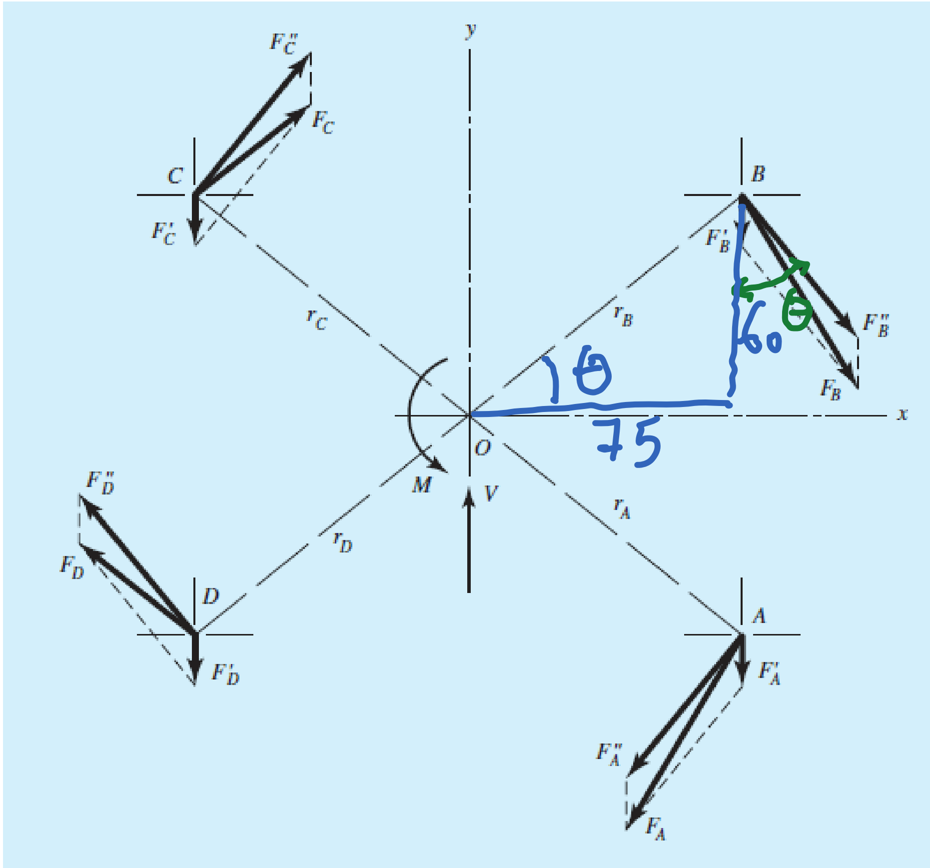
(*c*) The maximum bearing stress

(*d*) The critical bending stress in the bar



$$M = F\ell = 16\times10^{3}\times 425\times10^{-3}$$
$$= 6800\ N\cdot m$$





$$r = \sqrt{60^2 + 75^2} = 96$$

$$F_A = F_B$$

$$F_C = F_D$$

$$F_A > F_C$$

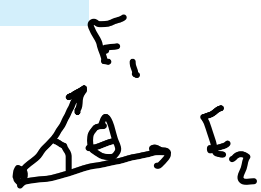
$$tg\theta = \frac{60}{75} \Rightarrow \theta = 38.6$$

The primary shear load per bolt is

$$F' = \frac{V}{n} = \frac{16}{4} = 4 \text{ kN}$$

y shear forces are equal, and Equation (8–

$$F'' = \frac{Mr}{4r^2} = \frac{M}{4r} = \frac{6800}{4(96.0)} = 17.7 \text{ kN}$$



$$F^2 = F_1^2 + F_2^2 + 2F_1F_2 \cos\theta$$

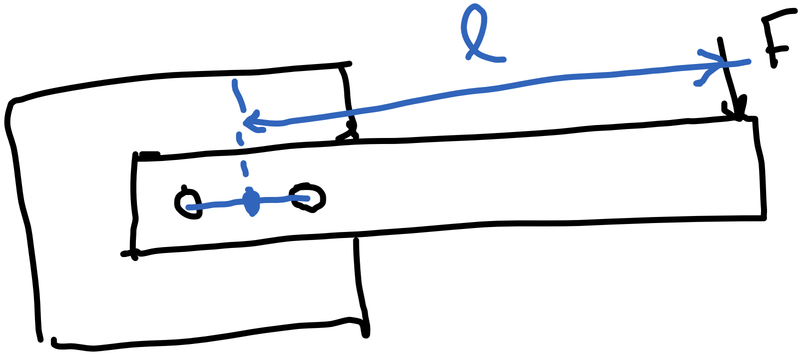
$$= 4^2 + 17.7^2 + 2 \times 4 \times 17.7 \cos 38.6$$

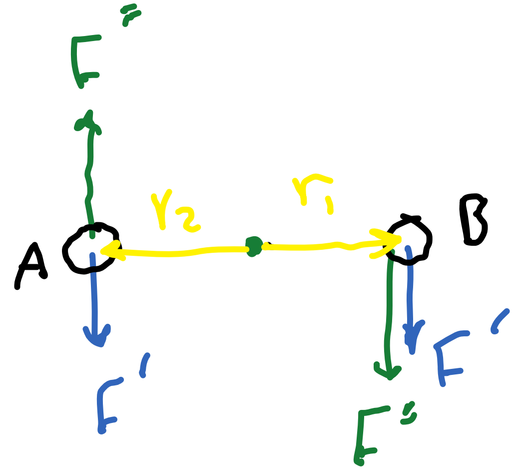
$$\Rightarrow F = 21 \text{ kN}$$

$\theta = 90 + 38.6$ برای D و C ،

$\Rightarrow \quad F_C = F_D = 14.8 \text{ kN}$

$$\tau = \frac{F}{A} = \frac{21 \times 10^3}{\pi d^2 / 4} \quad , \quad \frac{\pi d_r^2}{4}$$

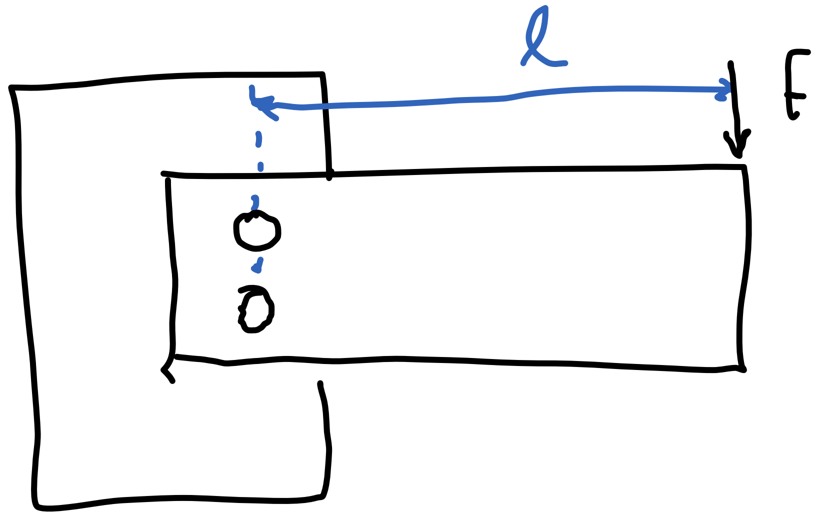




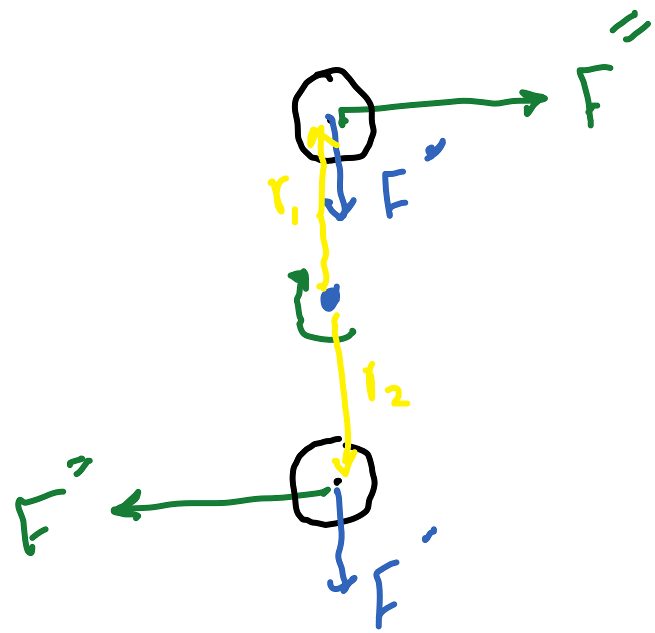
$$F' = F/2$$

$$F_B = F' + F''$$

$$F'' = \frac{Mr}{2r^2} = \frac{M}{2r}$$

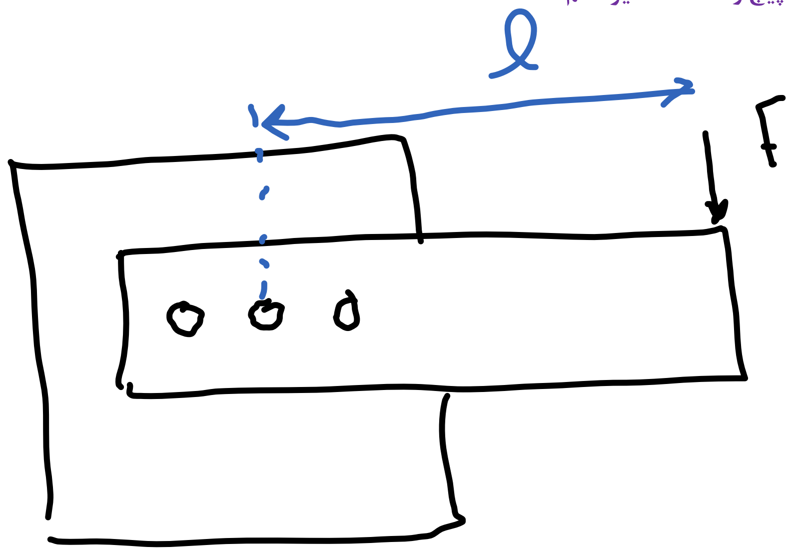


$$M = F\ell$$

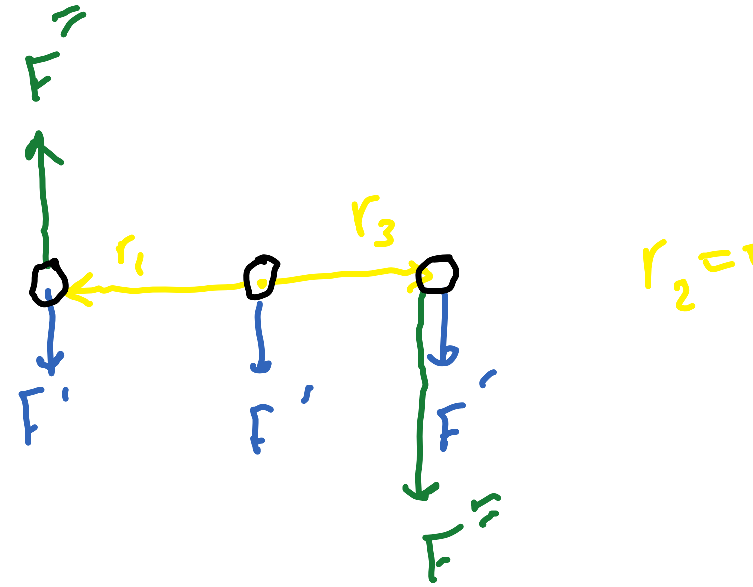


$$F' = F/2$$

$$F_A = F_B = \sqrt{F'^2 + F''^2}$$

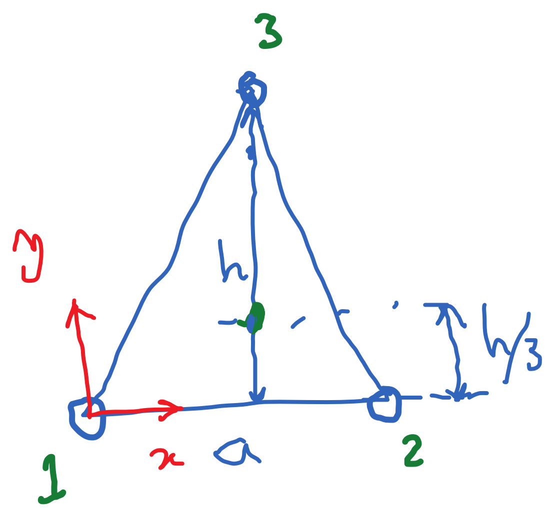


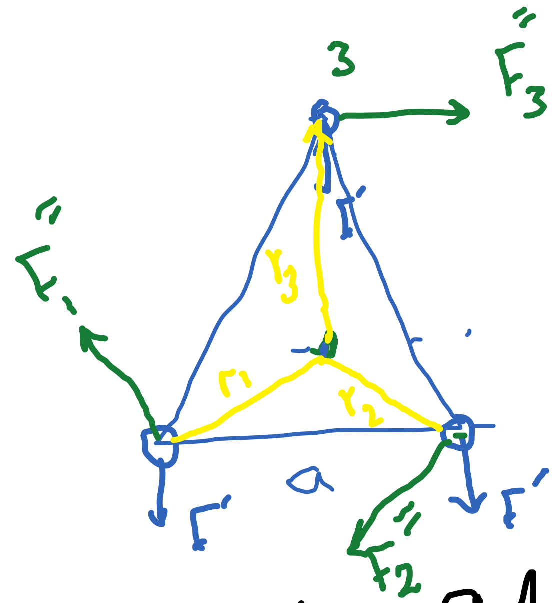
$$M = Fl$$



$$F' = F/3$$

$$F''_i = \frac{M r_i}{\sum r_i^{2}} \longrightarrow F''_3 = 0$$





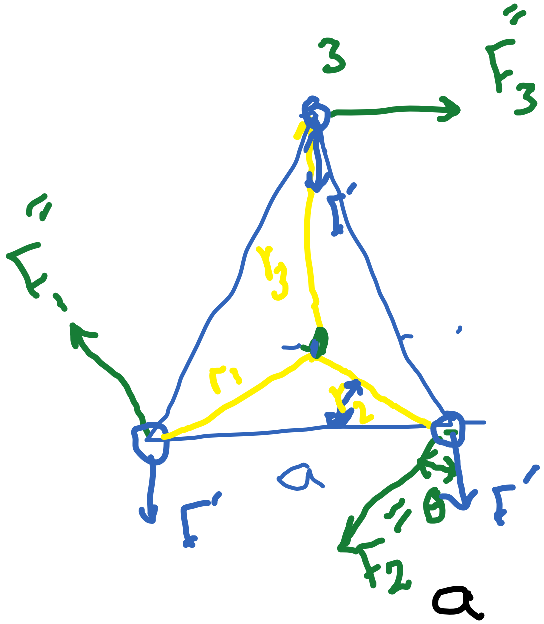
$$F_1'' = F_2''$$

$$\bar{x} = \frac{\sum x_i A_i}{\sum A_i} = \frac{\cancel{x_1 A_1} + x_2 A_2 + x_3 A_3}{3A} = \frac{aA + \frac{a}{2}A}{3A} = \frac{1}{2}a$$

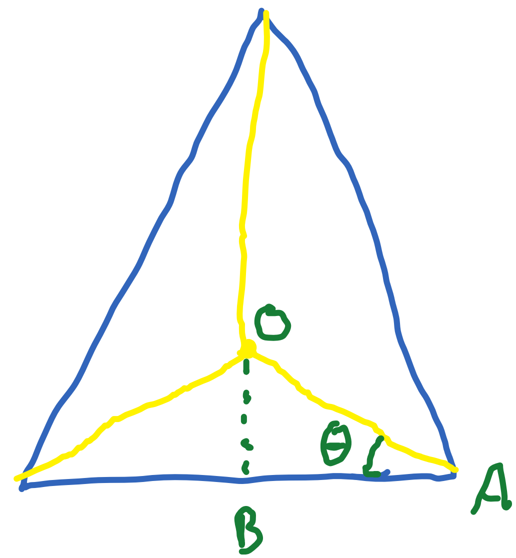
$$\bar{y} = \frac{\sum y_i A_i}{\sum A_i} = \frac{\cancel{y_1 A} + \cancel{y_2 A} + y_3 A}{3A} = \frac{hA}{3A} = \frac{h}{3}$$

$$F_1'' = F_2'' = \frac{M r_1}{2r_1^2 + r_3^2}$$

$$F_3'' = \frac{M r_3}{2r_1^2 + r_3^2}$$



$$F_3 = \sqrt{F'^2 + F_3''^2}$$

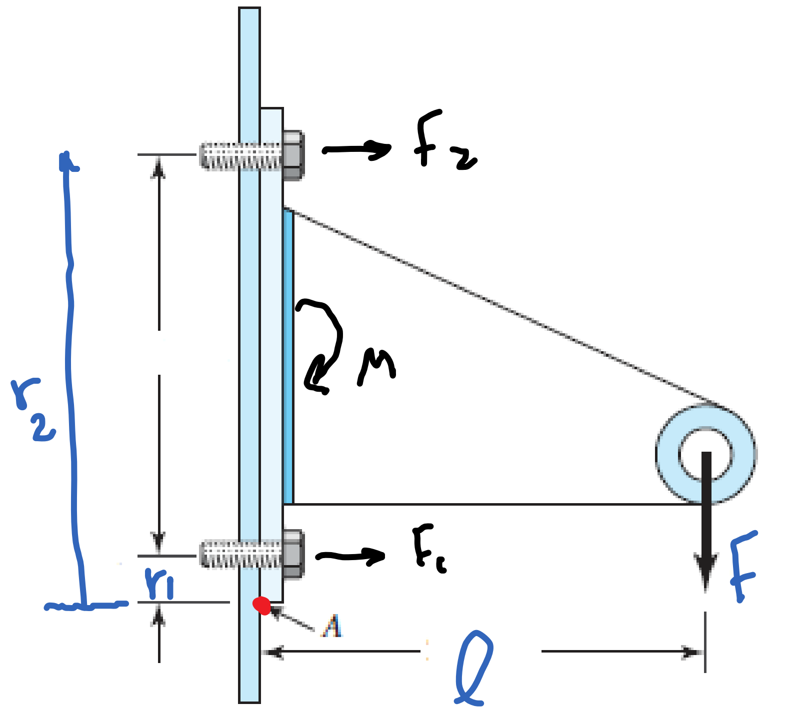


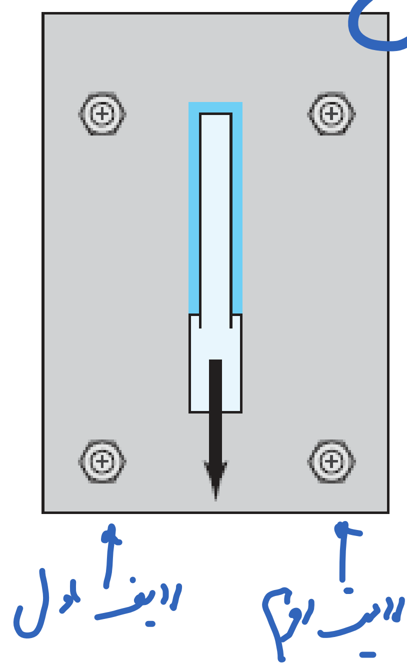
$$tg\theta = \frac{OB}{AB} = \frac{h/3}{a/2} \Rightarrow \theta$$

$$F_2^2 = F'^2 + F_2''^2 + 2F'F_2''\cos\theta \Rightarrow F_2 = ✓$$

اتصال تحت بار خارج از محور

پیچ تحت کشش

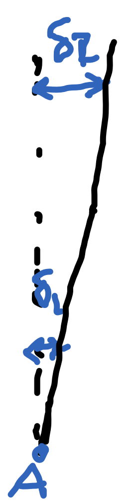




$$M_t = F\,l$$

$$M = \frac{M_t}{2}$$

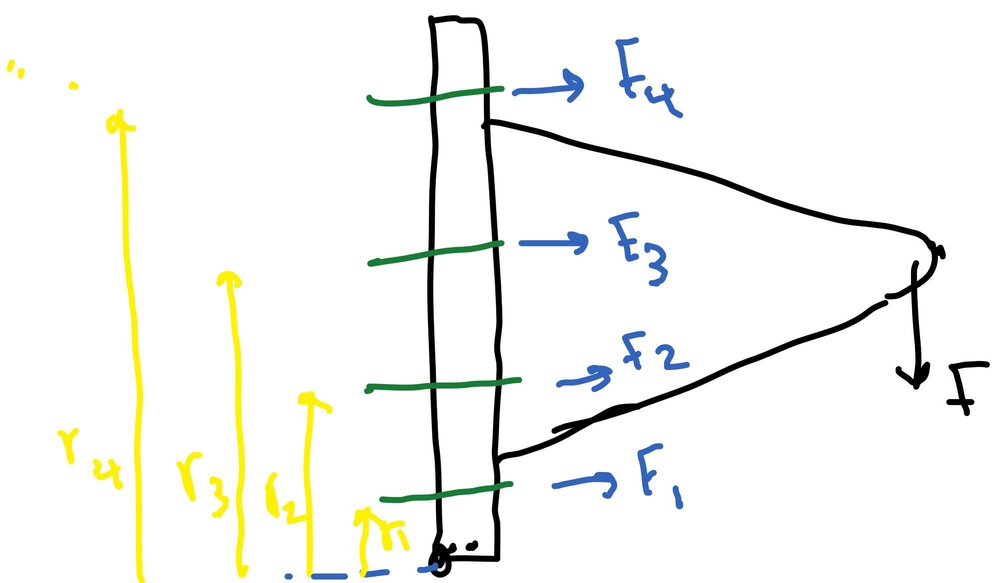
دو ردیف پیچ داریم



$$F_1 = \frac{M\,r_1}{r_1^2 + r_2^2}$$

$$F_2 = \frac{M\,r_2}{r_1^2 + r_2^2}$$

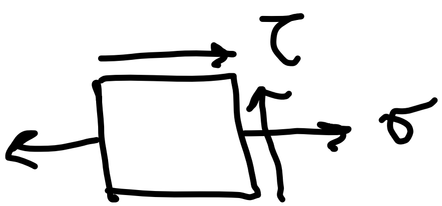
عضو حول نقطه A می خواهد دوران کند



$$F_i = \frac{M r_i}{\sum r_i^2}$$

نیرویی که به پیچها اعمال می‌شود
کششی است .

$$\sigma_i = \frac{F_i}{A_{r_i}} \quad , \quad \tau = \frac{F}{n}$$



$$\rightarrow \sigma' = \left(\sigma^2 + 3\tau^2\right)^{1/2}$$

تکالیف فصل هشتم

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۸-۶

۸-۳۳

۸-۶۷

۸-۷۷

۸-۸۵