6. Fasteners and Fastening methods

Objectives

- Describe many types of fastening systems and their uses.
- Understand principles of stress area, pitch diameters, and thread types and forms.
- Understand different types of tensioning systems and how preloaded joints are created and the analysis of appropriate tightening loads.
- Describe principles of elastic analysis and how the preload affects the ability of joints to resist future loading and/or pressures.
- Recognize types of fastening systems, their basic principles, and where they may be applicable.

Introduction

- Principal purpose of fasteners are
  - Disassembly for inspection and repair
  - Modular design, where a product consists of a number of subassemblies.

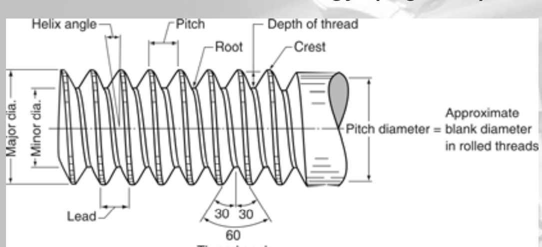
Fastener types

- **Removable:** This type permits the parts to be readily disconnected without damaging the fastener, e.g. nut and bolt.
- **Semi-permanent:** For this type, the parts can be disconnected, but some damage usually occurs to the fastener, e.g. cotter pin
- **Permanent:** When this type of fastener is used, the parts will never be disassembled. e.g. rivets and welding

Fastener application

- **Primary function**
- **Appearance**
- **Number of fasteners**
- **Operating conditions**
- **Frequency of disassembly**
- **Adjustability**
- **Types of materials**
- **Consequences of failure**

Screw thread terminology (Fig. 6.1)



Screw thread terminology

- **Major diameter:** The major diameter is the largest diameter of the thread. It determines the nominal size.
- **Minor diameter:** It is the smallest diameter of the thread. In external thread, it is also called as root diameter.
- **Pitch:** is the axial distance between any point of one thread and the corresponding point of an adjacent thread.
- **Lead:** The distance a bolt advances into a nut in one revolution is called lead.

Cross-section of a Unified thread

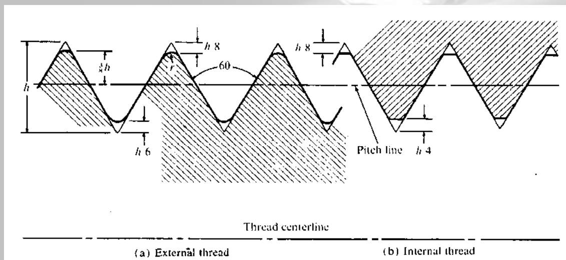


FIGURE 11.2 Cross section of the unified screw thread

TABLE 6.1

AMERICAN STANDARD THREAD DIMENSIONS

Size	Basic Major Diameter (in.)	Coarse Threads: UNC Threads per Inch	Coarse Threads: UNC Tensile Stress Area (in.^{2})	Fine Threads: UNF Threads per Inch	Fine Threads: UNF Tensile Stress Area (in.^{2})
Numbered Sizes					
0	.060 0			80	.001 80
1	.073 0	64	.002 63	72	.002 78
2	.086 0	56	.003 70	64	.003 94
3	.099 0	48	.004 87	56	.005 23
4	.112 0	40	.006 04	48	.006 61
5	.125 0	40	.007 96	44	.008 30
6	.138 0	32	.009 09	40	.010 15
8	.164 0	32	.014 0	36	.014 74
10	.190 0	24	.017 5	32	.020 0
12	.216 0	24	.024 2	28	.025 8
Fractional Sizes					
¼	.250 0	20	.031 8	28	.036 4
5/16	.312 5	18	.052 4	24	.058 0
3/8	.375 0	16	.077 5	24	.087 8
7/16	.437 5	14	.106 3	20	.118 7
½	.500 0	13	.141 9	20	.159 9
9/16	.562 5	12	.182	18	.203
5/8	.625 0	11	.226	18	.256
¾	.750 0	10	.334	16	.373
7/8	.875 0	9	.462	14	.509
1	1.000	8	.606	12	.663
1⅛	1.125	7	.763	12	.856
1¼	1.250	7	.969	12	1.073
1⅜	1.375	6	1.155	12	1.315
1½	1.500	6	1.405	12	1.581
1¾	1.750	5	1.90		
2	2.000	4½	2.50		

TABLE 6.2

METRIC THREAD DIMENSIONS

Basic Major Diameter (mm)	Coarse Threads Pitch (mm)	Coarse Threads Tensile Stress Area (mm^2)	Fine Threads Pitch (mm)	Fine Threads Tensile Stress Area (mm^2)
1	.25	.460		
1.6	.35	1.27	.20	1.57
2	.4	2.07	.25	2.45
2.5	.45	3.39	.35	3.70
3	.5	5.03	.35	5.61
4	.7	8.78	.5	9.79
5	.8	14.2	.5	16.1
6	1	20.1	.75	22.0
8	1.25	36.6	1	39.2
10	1.5	58.0	1.25	61.2
12	1.75	84.3	1.25	92.1
16	2	157	1.5	167
20	2.5	245	1.5	272
24	3	353	2	384
30	3.5	561	2	621
36	4	817	3	865
42	4.5	1,121		
48	5	1,473		

TABLE 6.3

SAE GRADES OF STEELS FOR FASTENERS

Grade Number	Bolt Size (in.)	Tensile Strength (ksi)	Yield Strength (ksi)	Proof Strength (ksi)
1	¼–1½	60	36	33
2	¼–¾	74	57	55
	>¾–1½	60	36	33
4	¼–1½	115	100	65
5	¼–1	120	92	85
	>1–1½	105	81	74
7	¼–1½	133	115	105
8	¼–1½	150	130	120

Tightening Methods

- Using a torque wrench with a specified torque limit
- Turning through a specified angle after full engagement
- Hydraulic tensioning – use a hydraulic cylinder to stretch a bolt for imparting an initial tension

Torquing Methods

- Relationship between torque and preload
- Torque, $T \approx C\ D\ F_i$
- D = nominal diameter of thread
- F_i = desired initial preload
- C = torque coefficient
  - = 0.15 for lubricated assemblies
  - = 0.20 for non lubricated with traces of oil
  - = 0.34 for dry assemblies

Example Problem 6-1: Torquing Methods

- A ¾-UNC-grade 5 bolt is to be preloaded to 85 percent of its proof strength.
- The length of engagement is 5 inches.
- The bolt is new and non-lubricated but likely has traces of cutting oil present.
- Determine the required torque:

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Example Problem 6-1: Torquing Methods

$A_S = 0.334\ in^2$ (Table 6-1)

$S_p = 85\ ksi$ (Table 6-3)

$F = SA$

$F_i = 0.85\ S_p\ A_s$

$F_i = 0.85\ (85{,}000\ lb/in^2)\ (0.334\ in^2)$

$F_i = 24{,}130\ lb$

– Using C = 0.2 non-lubricated with traces of oil:

$T = C\ D\ F_i$ (6-1)

$T = 0.2\ (¾\ in)\ 24{,}130\ lb$

$T = 3620\ in\text{-}lb$ or $302\ ft\text{-}lb$

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Turn-of-the-Nut method

- Find the elongation needed to produce the appropriate preload

$$\text{Elongation, } \delta = \frac{F\ L}{A\ E}$$

- Required torque angle = $\dfrac{\delta\ 360}{\text{pitch}}$

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Example Problem 6-2: Turn-of-the-Nut Method

- From prior problem, determine the angle of rotation needed, using the turn-of-nut method.

(6-3)

$$\delta = \frac{FL}{AE} \text{ or } \frac{SL}{E}$$

$$\delta = \frac{24{,}130\ lb \quad 5\ in}{.334\ in^2 \quad 30x10^6\ lb/in^2}$$

$$\delta = .012\ in$$

(6-4)

$$torque\ angle = \frac{\delta\ 360°}{pitch}$$

(Table 6-1)

Pitch for ¾ UNC is .1 inch:

$$torque\ angle = \frac{.012\ in \quad 360°}{.1\ in}$$

$$torque\ angle = 43.4°$$

– Note again that the nut should be tightened, then turned snug, before turning this angle.

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Heating Method

- Use the linear expansion of the material under heat
- We know that Elongation, $\delta = \alpha\ L\ \Delta T$
- Temperature required for the elongation $\Delta T = \dfrac{\delta}{\alpha\ L}$

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Example Problem 6-3: Heating Methods

- In Example Problem 6-1, to obtain the same preload, determine the temperature we would need to heat this bolt above the service temperature.

(Appendix 8)

$$\alpha = \frac{6.5\ x\ 10^{-6}\ in}{in\ °F}$$

(6-5)

$$\Delta T = \frac{\delta}{\alpha L}$$

$$\Delta T = \frac{.012\ in}{\frac{6.5\ x\ 10^{-6}\ in \quad 5\ in}{in\ °F}}$$

$$\Delta T = 370°\ F$$

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Elastic Analysis of Bolted Connections

- Bolted connection – residual tension in the bolt, residual compression in the clamped part
- Applied load to the part gets compensated by this to some extent.

$$\text{Elongation, } \delta = \frac{F\,L}{A\,E}$$

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Elastic Analysis of Bolted Connections

- If k is the stiffness of the joint $k = \frac{F}{\delta}$
- The stiffness of the bolt is $k_b = \frac{A_b\,E_b}{L_b}$
- The stiffness of the joint is $k_c = \frac{A_c\,E_c}{L_c}$
  - E – Young's modulus
  - A – Area of cross section
  - L – Grip length

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Elastic Analysis of Bolted Connections

- Recommended preload, F_i is given by

$$F_i = Q\,F_e\left(\frac{k_c}{k_b + k_c}\right) \quad \text{Eq 6.7}$$

  - Q – margin factor (similar to safety factor)
  - F_e – Applied load
- New load on bolt is $F_t = F_i + \Delta F_b$

$$\Delta F_b = F_e\left(\frac{k_b}{k_b + k_c}\right)$$

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Elastic Analysis of Bolted Connections

- Total force on the bolt

$$F_t = F_i + F_e\left(\frac{k_b}{k_b + k_c}\right) \quad \text{Eq 6.8}$$

- Total force on the flange

$$F_c = F_i - F_e\left(\frac{k_c}{k_b + k_c}\right) \quad \text{Eq 6.9}$$

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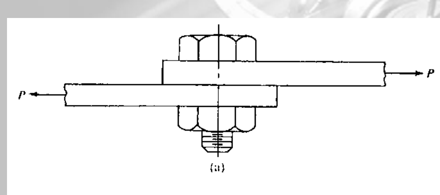
Force analysis of fasteners



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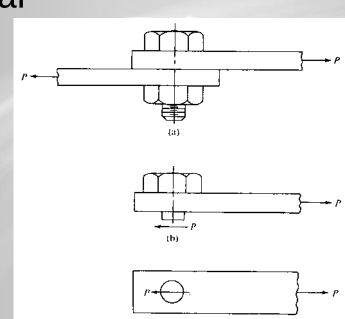
Bolt in shear

$$\tau = \frac{P}{A}$$

τ = Shear stress in the bolt

P = Applied shear force

A = cross-sectional area of the bolt



Multiple fasteners

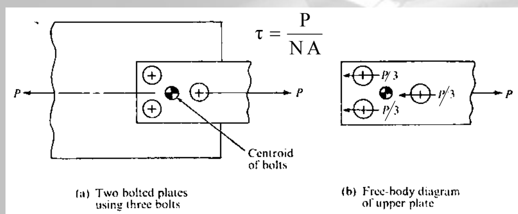


FIGURE 11.38 Fastener with multiple bolts loaded in shear (zero eccentricity design)

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Eccentric loading

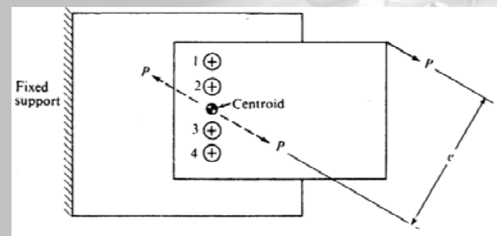

FIGURE 11.39 Eccentrically loaded bolted connector loaded in shear

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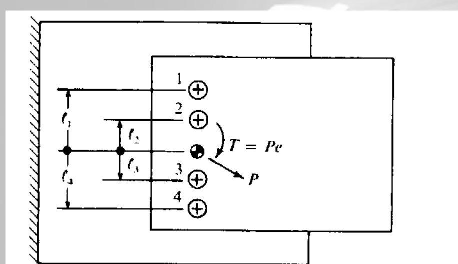
Dual loading



RE 11.40 Dual loads on bolts as a result of eccentricity

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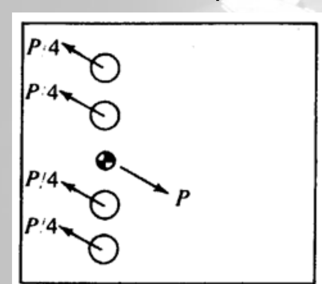
Shear force on multiple fasteners



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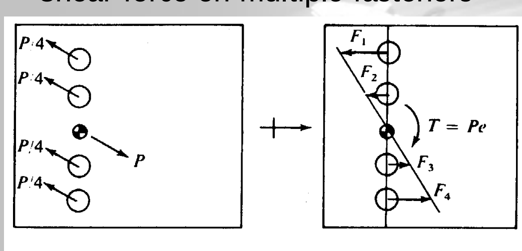
Shear force on multiple fasteners



(a) Direct shear (P/4) (b) Secondary shear (F_1, F_2, F_3 and F_4)

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Shear force on multiple fasteners

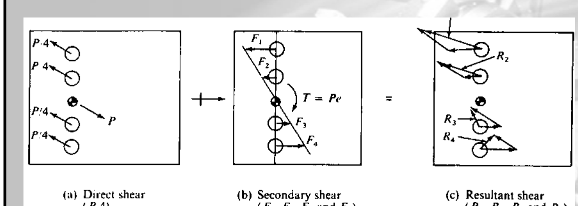


FIGURE 11.41 Vector addition of direct and secondary shear forces

Secondary shear forces

- Direction is perpendicular to the line running from the center of the bolt to the centroid
- Direction opposes the applied torque, T
- Magnitude is proportional to the distance from the center of the bolt to the centroid

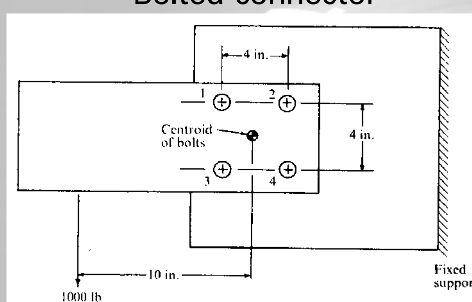
Secondary shear forces

$$\frac{F_1}{F_2} = \frac{l_1}{l_2}$$

$$F_1 l_1 + F_2 l_2 + F_3 l_3 + F_4 l_4 - P\,e = 0$$

$$F_1 = \frac{P\,e\,l_1}{l_1^2 + l_2^2 + l_3^2 + l_4^2}$$

Bolted connector



Bolted connector

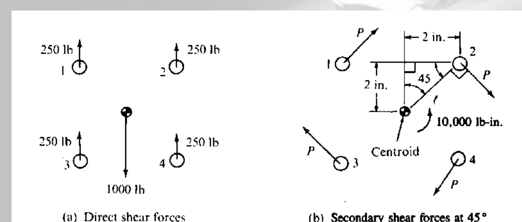


FIGURE 11.43 Direct and secondary shear forces (a) Direct shear forces (b) Secondary shear forces at 45°

Graphical addition

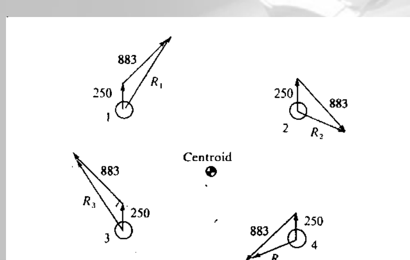


FIGURE 11.44 Graphical addition of direct and secondary shear forces

"Mr. Osborne, may I be excused? My brain is full."

Figure 3.3 Long-term memory problems.

Conclusions

- A variety of mechanical fasteners are discussed.
- Screw thread is the most important part of a fastener.
- Force acting on various fasteners have been analyzed.