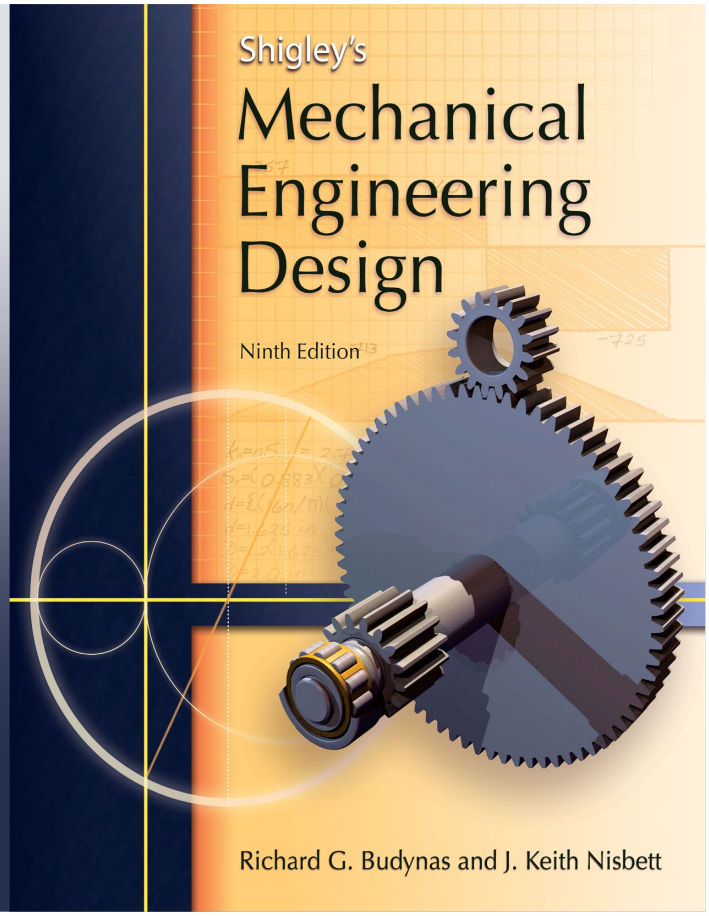
Lecture Slides

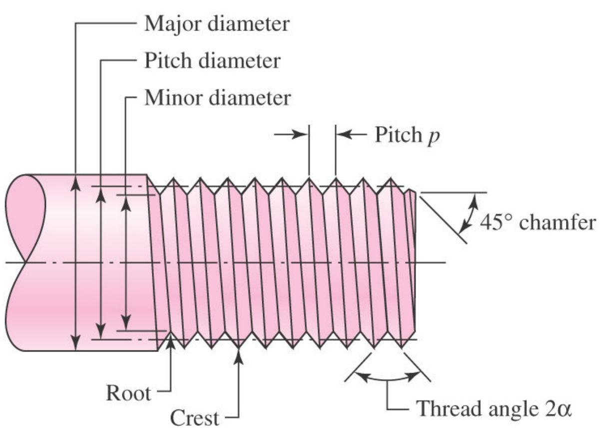
Chapter 8

Screws, Fasteners, and the Design of Nonpermanent Joints



Tensile Stress Area

- The tensile stress area, A_t , is the area of an unthreaded rod with the same tensile strength as a threaded rod.
- It is the effective area of a threaded rod to be used for stress calculations.
- The diameter of this unthreaded rod is the average of the pitch diameter and the minor diameter of the threaded rod.



Tension Loaded Bolted Joints

- **During bolt preload**
  - bolt is stretched
  - members in grip are compressed
- **When external load *P* is applied**
  - Bolt stretches an additional amount δ
  - Members in grip uncompress same amount δ

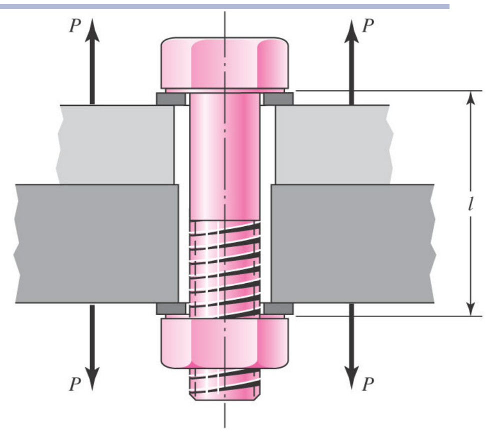


Fig. 8–13

$$\delta = \frac{P_b}{k_b} \quad \text{and} \quad \delta = \frac{P_m}{k_m} \qquad \text{(b)}$$

$$P_m = P_b \frac{k_m}{k_b} \qquad \text{(c)}$$

Stiffness Constant

- Since $P = P_b + P_m$,

$$P_b = \frac{k_b P}{k_b + k_m} = C P \qquad \text{(d)}$$

$$P_m = P - P_b = (1 - C)P \qquad \text{(e)}$$

- C is defined as the *stiffness constant* of the joint

$$C = \frac{k_b}{k_b + k_m} \qquad \text{(f)}$$

- C indicates the proportion of external load P that the bolt will carry. A good design target is around 0.2.

Table 8–12

Computation of Bolt and Member Stiffnesses. Steel members clamped using a $\frac{1}{2}$ in-13 NC steel bolt. $C = \frac{k_b}{k_b + k_m}$

	Stiffnesses, M lbf/in			
Bolt Grip, in	k_b	k_m	C	$1 - C$
2	2.57	12.69	0.168	0.832
3	1.79	11.33	0.136	0.864
4	1.37	10.63	0.114	0.886

Bolt and Member Loads

- The resultant bolt load is

$$F_b = P_b + F_i = CP + F_i \qquad F_m < 0 \tag{8–24}$$

- The resultant load on the members is

$$F_m = P_m - F_i = (1 - C)P - F_i \qquad F_m < 0 \tag{8–25}$$

- These results are only valid if the load on the members remains negative, indicating the members stay in compression.

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

Relating Bolt Torque to Bolt Tension

- The relation between applied torque and bolt preload

$$T = K F_i d \tag{8–27}$$

- T is measured using a torque wrench
- Some recommended values for *K* for various bolt finishes is given in Table 8–15
- **Use *K* = 0.2 for other cases**

Table 8–15

Torque Factors *K* for Use with Eq. (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

Example 8-3

A $\frac{3}{4}$ in-16 UNF $\times$ $2\frac{1}{2}$ in SAE grade 5 bolt is subjected to a load P of 6 kip in a tension joint. The initial bolt tension is $F_i = 25$ kip. The bolt and joint stiffnesses are $k_b = 6.50$ and $k_m = 13.8$ Mlbf/in, 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 Eq. (8–27).

Example 8-3

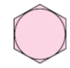
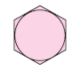
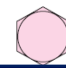
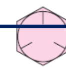
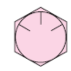
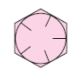
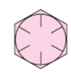
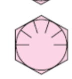
Table 8–2

Size Designation	Nominal Major Diameter in	Coarse Series—UNC: Threads per Inch N	Coarse Series—UNC: Tensile-Stress Area A_t, in²	Coarse Series—UNC: Minor-Diameter Area A_r, in²	Fine Series—UNF: Threads per Inch N	Fine Series—UNF: Tensile-Stress Area A_t, in²	Fine Series—UNF: Minor-Diameter Area A_r, in²
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
$\frac{5}{8}$	0.6250	11	0.226	0.202	18	0.256	0.240
$\frac{3}{4}$	0.7500	10	0.334	0.302	16	0.373	0.351
$\frac{7}{8}$	0.8750	9	0.462	0.419	14	0.509	0.480
1	1.0000	8	0.606	0.551	12	0.663	0.625
$1\frac{1}{4}$	1.2500	7	0.969	0.890	12	1.073	1.024
$1\frac{1}{2}$	1.5000	6	1.405	1.294	12	1.581	1.521

Example 8-3

Table 8–9

SAE Specifications for Steel Bolts

SAE Grade No.	Size Range Inclusive, in	Minimum Proof Strength,* kpsi	Minimum Tensile Strength,* kpsi	Minimum Yield Strength,* kpsi	Material	Head Marking
1	$\frac{1}{4}$–$1\frac{1}{2}$	33	60	36	Low or medium carbon	
2	$\frac{1}{4}$–$\frac{3}{4}$	55	74	57	Low or medium carbon	
	$\frac{7}{8}$–$1\frac{1}{2}$	33	60	36		
4	$\frac{1}{4}$–$1\frac{1}{2}$	65	115	100	Medium carbon, cold-drawn	
5	$\frac{1}{4}$–1	85	120	92	Medium carbon, Q&T	
	$1\frac{1}{8}$–$1\frac{1}{2}$	74	105	81		
5.2	$\frac{1}{4}$–1	85	120	92	Low-carbon martensite, Q&T	
7	$\frac{1}{4}$–$1\frac{1}{2}$	105	133	115	Medium-carbon alloy, Q&T	
8	$\frac{1}{4}$–$1\frac{1}{2}$	120	150	130	Medium-carbon alloy, Q&T	
8.2	$\frac{1}{4}$–1	120	150	130	Low-carbon martensite, Q&T	

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

Tension Loaded Bolted Joints: Static Factors of Safety

Axial Stress:

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

Yielding Factor of Safety:

$$n_p = \frac{S_p}{\sigma_b} = \frac{S_p}{(CP + F_i)/A_t} = \frac{S_p A_t}{CP + F_i} \qquad (8\text{–}28)$$

Number of bolts required:

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

Recommended preload:

$$F_i = \begin{cases} 0.75F_p & \text{for nonpermanent connections, reused fasteners} \\ 0.90F_p & \text{for permanent connections} \end{cases} \qquad (8\text{–}31)$$

$$F_p = A_t S_p \qquad (8\text{–}32)$$

Example

Figure 8–19 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 36 kip. $C = 0.368$

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

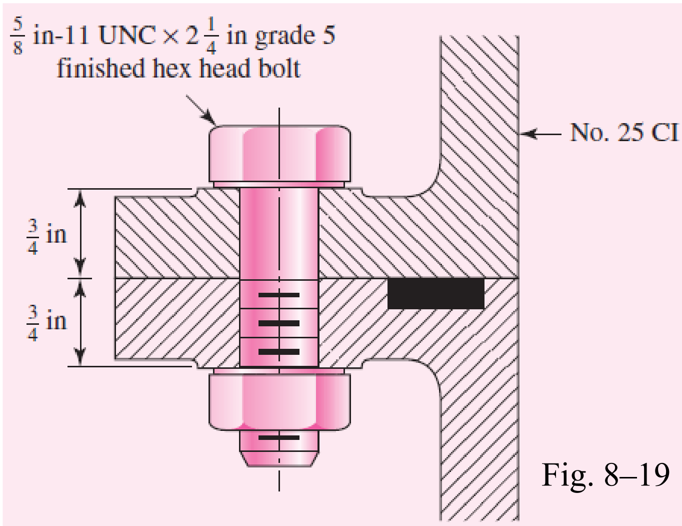


Fig. 8–19

Example

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Example

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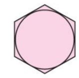
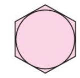
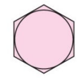
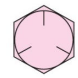
1	$\frac{1}{4}$–$1\frac{1}{2}$	33	60	36	Low or medium carbon	
2	$\frac{1}{4}$–$\frac{3}{4}$	55	74	57	Low or medium carbon	
	$\frac{7}{8}$–$1\frac{1}{2}$	33	60	36		
4	$\frac{1}{4}$–$1\frac{1}{2}$	65	115	100	Medium carbon, cold-drawn	
5	$\frac{1}{4}$–1	85	120	92	Medium carbon, Q&T	
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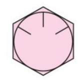
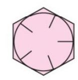
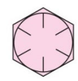
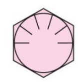
5.2	$\frac{1}{4}$–1	85	120	92	Low-carbon martensite, Q&T	
7	$\frac{1}{4}$–$1\frac{1}{2}$	105	133	115	Medium-carbon alloy, Q&T	
8	$\frac{1}{4}$–$1\frac{1}{2}$	120	150	130	Medium-carbon alloy, Q&T	
8.2	$\frac{1}{4}$–1	120	150	130	Low-carbon martensite, Q&T	

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

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Fatigue Loading of Tension Joints

- Fatigue methods of Ch. 6 are directly applicable
- With an external load on a **per bolt basis** fluctuating between P_{min} and P_{max}, the mean and alternating stresses can be calculated from

$$\sigma_a = \frac{C(P_{max} - P_{min})}{2A_t} \qquad \sigma_m = \frac{C(P_{max} + P_{min})}{2A_t} + \frac{F_i}{A_t}$$

Endurance Strength for Bolts

- Bolts are standardized, so endurance strengths are known by experimentation, including all modifiers. See Table 8–17.
- Fatigue stress-concentration factor K_f is also included as a reducer of the endurance strength, so it should not be applied to the bolt stresses.

Table 8–17

Fully Corrected Endurance Strengths for Bolts and Screws with Rolled Threads*

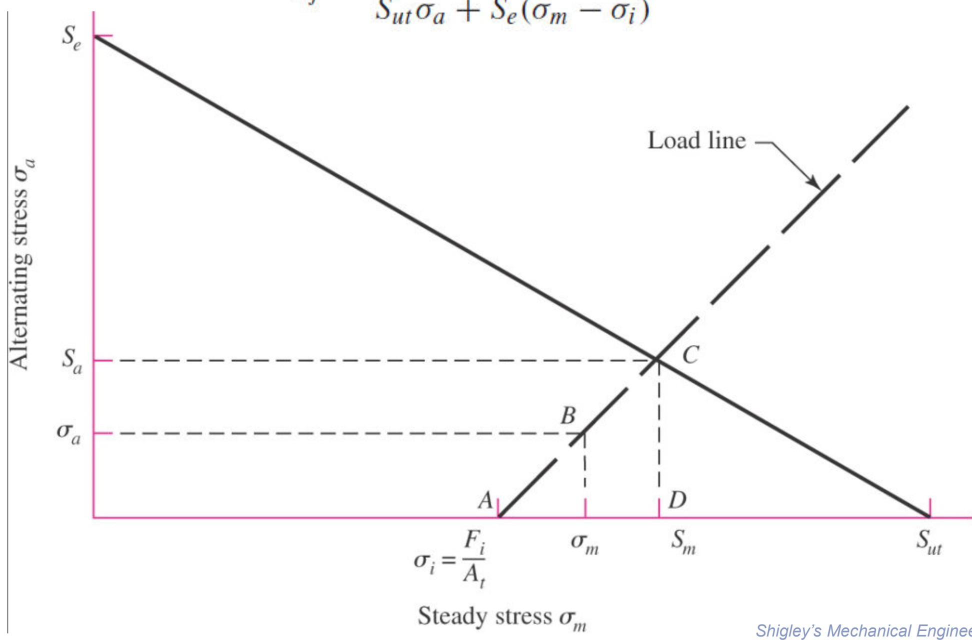
Grade or Class	Size Range	Endurance Strength
SAE 5	$\frac{1}{4}$–1 in	18.6 kpsi
	$1\frac{1}{8}$–$1\frac{1}{2}$ in	16.3 kpsi
SAE 7	$\frac{1}{4}$–$1\frac{1}{2}$ in	20.6 kpsi
SAE 8	$\frac{1}{4}$–$1\frac{1}{2}$ in	23.2 kpsi
ISO 8.8	M16–M36	129 MPa
ISO 9.8	M1.6–M16	140 MPa
ISO 10.9	M5–M36	162 MPa
ISO 12.9	M1.6–M36	190 MPa

*Repeatedly applied, axial loading, fully corrected.

Fatigue Factor of Safety

- Fatigue factor of safety based on Goodman line and constant preload load line:

$$n_f = \frac{S_e(S_{ut} - \sigma_i)}{S_{ut}\sigma_a + S_e(\sigma_m - \sigma_i)} \quad (8\text{–}38)$$



Example*

Figure 8–19 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 36 kip. $C = 0.368$

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

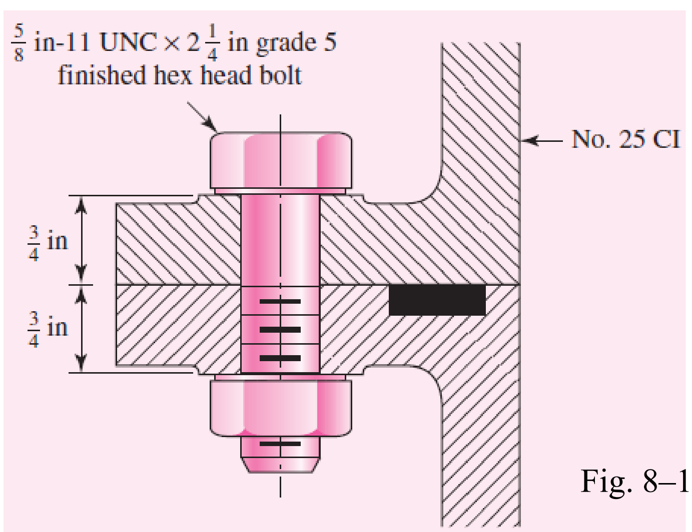


Fig. 8–19

Find the fatigue Safety factor for Fluctuating force of Fmin=0 Fmax=20 kip

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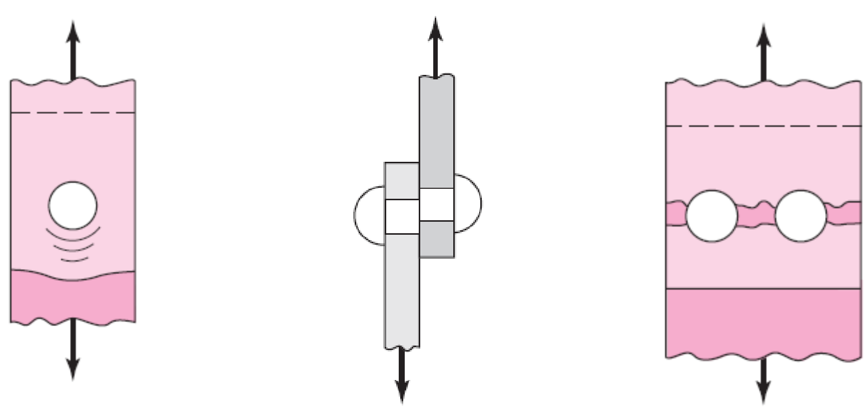
Bolted and Riveted Joints Loaded in Shear

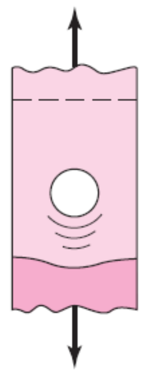
- Several failure modes are considered
  - (a) Bearing in the bolts
  - (b) Bearing in members
  - (c) Shear in bolts
  - (d) Tensile yielding of the members across the bolt holes



Failure by Bearing Stress

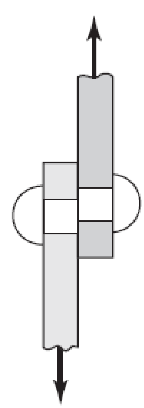
- Failure by crushing known as *bearing stress*
- Bolt or member with lowest strength will crush first
- Customary to assume uniform distribution over projected contact area, $A = td$
- t is the thickness of the thinnest plate and d is the bolt diameter

$$\sigma = -\frac{F}{A} \qquad (8\text{–}55)$$



Failure by Shear of Bolt

- Simple direct shear $\tau = \frac{F}{A}$ (8–53)
- Use the total cross sectional area of bolts that carry the load.

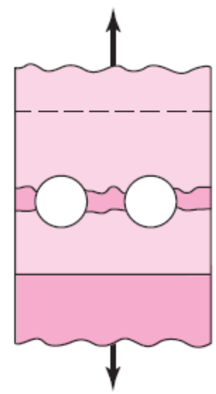


Failure by Tensile Rupture of Member

- Simple tensile failure

$$\sigma = \frac{F}{A} \qquad (8\text{–}54)$$

- Use the smallest net area of the member, with holes removed



Example 8-6

Two 1- by 4-in 1018 cold-rolled steel bars are butt-spliced with two $\frac{1}{2}$- by 4-in 1018 cold-rolled splice plates using four $\frac{3}{4}$ in-16 UNF grade 5 bolts as depicted in Fig. 8–24. For a design factor of $n_d = 1.5$ estimate the static load F that can be carried if the bolts lose preload.

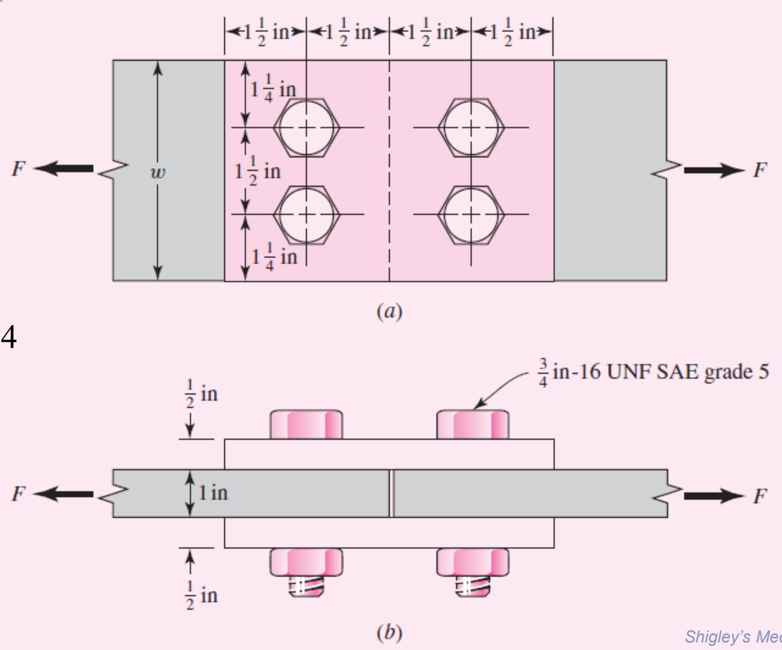


Fig. 8–24

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Shear Joints with Eccentric Loading

- *Eccentric* loading is when the load does not pass along a line of symmetry of the fasteners.
- Requires finding moment about centroid of bolt pattern
- Centroid location

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

$$\bar{y} = \frac{A_1y_1 + A_2y_2 + A_3y_3 + A_4y_4 + A_5y_5}{A_1 + A_2 + A_3 + A_4 + A_5} = \frac{\sum_1^n A_i y_i}{\sum_1^n A_i} \qquad (8\text{–}56)$$

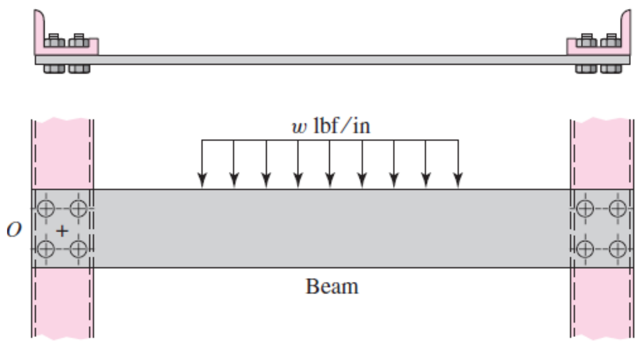
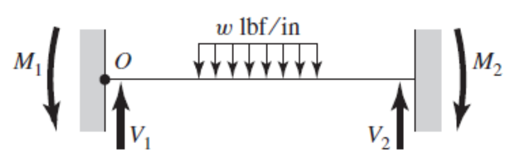


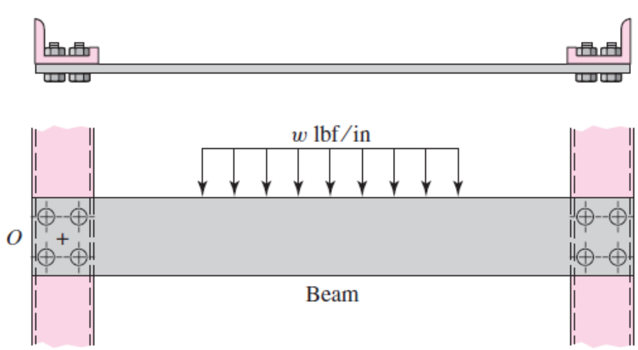
Fig. 8–27*a*

Shear Joints with Eccentric Loading

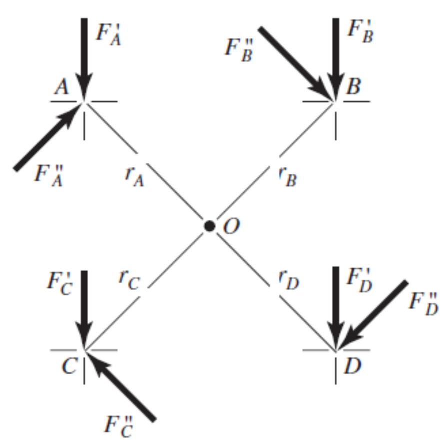
(a) Example of eccentric loading
(b) Free body diagram
(c) Close up of bolt pattern



(*b*)



(*a*)



(*c*)

Fig. 8–27

Shear Joints with Eccentric Loading

- *Direct Shear (Primary Shear)*
- ***Primary shear is divided equally among the bolts.***

$$F' = V_1/n$$

- *Moment (Secondary Shear)*
- ***Secondary shear is not divided equally. The force taken by each bolt depends upon its radial distance from the centroid.***

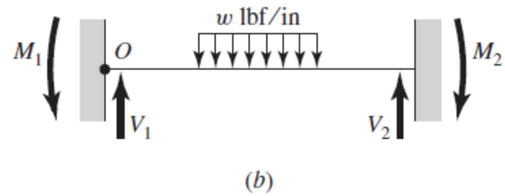
$$\frac{F''_A}{r_A} = \frac{F''_B}{r_B} = \frac{F''_C}{r_C}$$

- ***Moment is equal to***

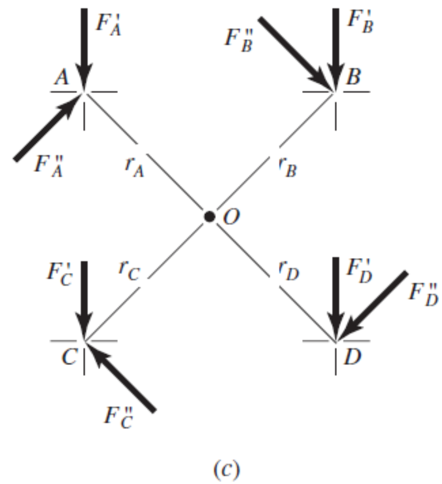
$$M_1 = F''_A r_A + F''_B r_B + F''_C r_C + \cdots$$

- ***Combining the above two equations***

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



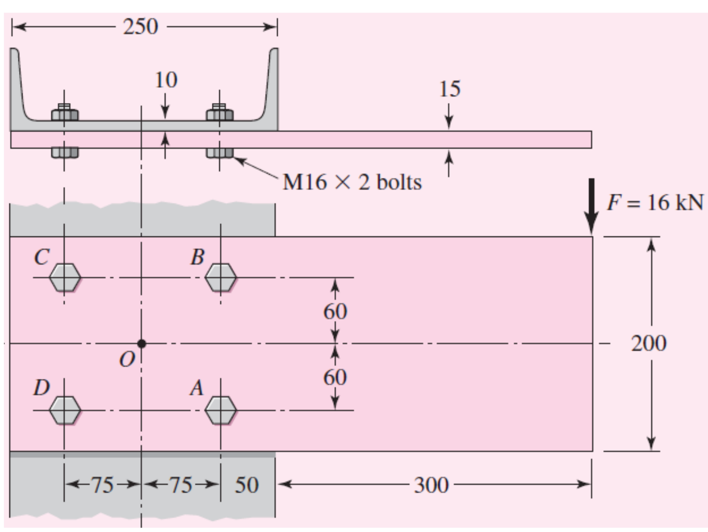
(b)



(c)

Example 8-7

- Compute the shear stresses in each bolt for the loading shown. Bolt diameters are 16 mm each.



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