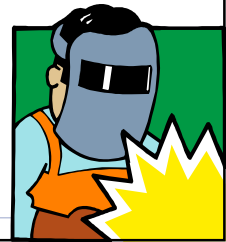


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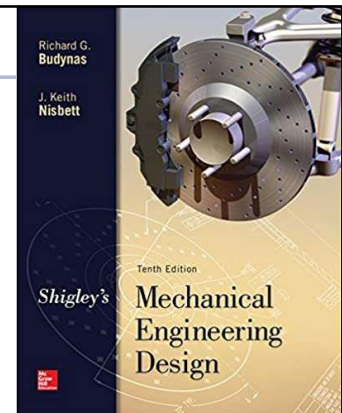
Product Design I

Chapter 9: Welding, Bonding, and the Design of Permanent Joints

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Reference

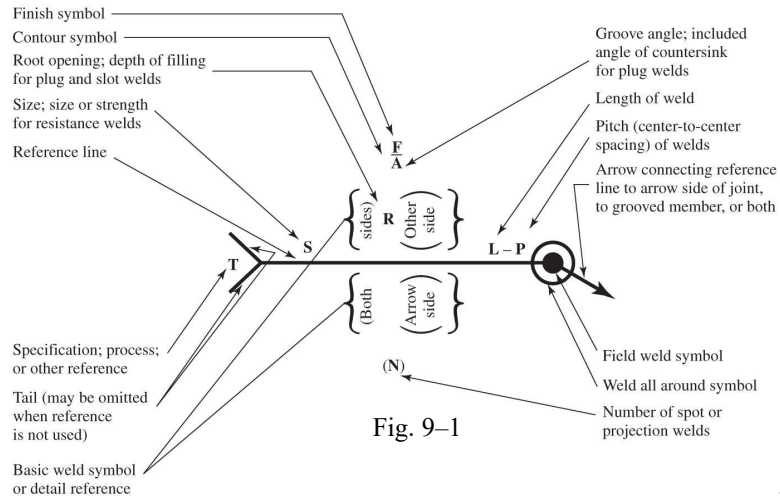


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9-1 Welding Symbols

- Welding symbol standardized by American Welding Society
- Specifies details of weld on machine drawings, shop drawing



3

9-1 Welding Symbols

- *Arrow side* of a joint is the line, side, area, or near member to which the arrow points
- The side opposite the arrow side is the *other side*
- Shape of weld is shown with the symbols below

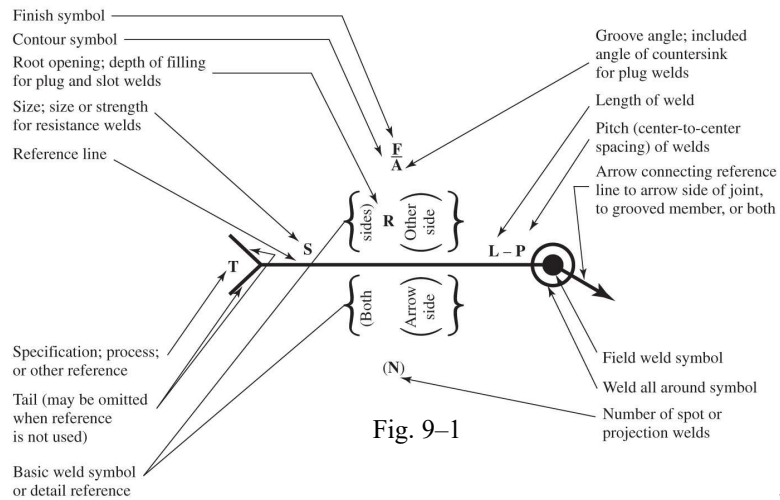
Type of weld							
Bead	Fillet	Plug or slot	Groove				
			Square	V	Bevel	U	J

Fig. 9-2

4

9-1 Welding Symbols

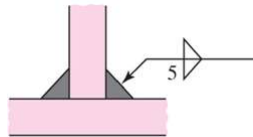
- Welding symbol standardized by American Welding Society
- Specifies details of weld on machine drawings, shop drawing



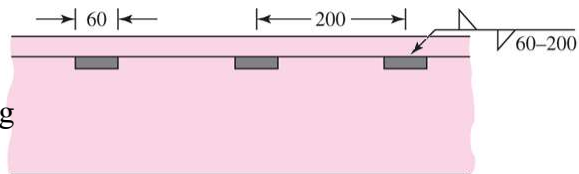
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9-1 Welding Symbols

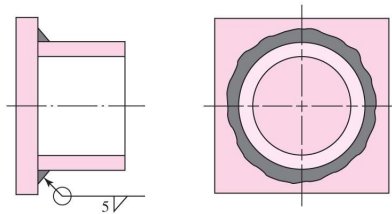
- Weld leg size of 5 mm
- Fillet weld
- Both sides



- Intermittent and staggered 60 mm along on 200 mm centers



- Leg size of 5 mm
- On one side only (outside)
- Circle indicates all the way around



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9-1 Welding Symbols

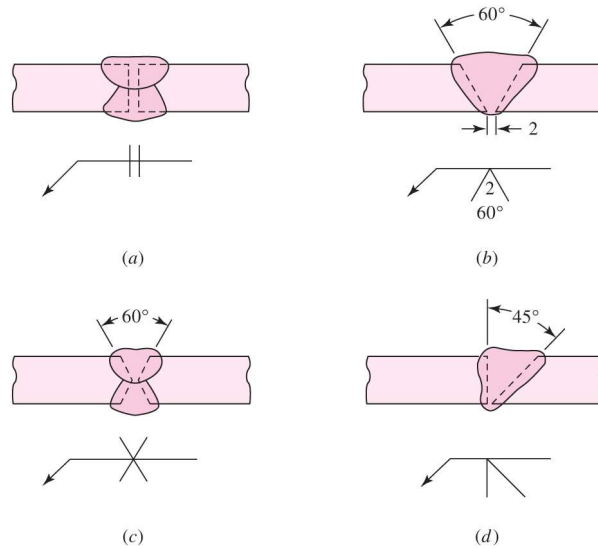


Fig. 9-5

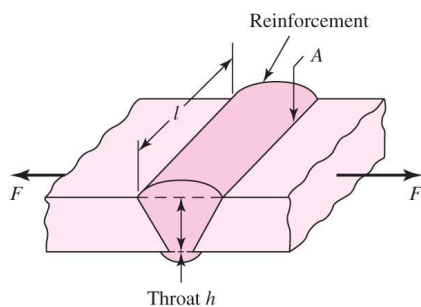
7

9-2 Butt and Fillet Welds

- Simple butt joint loaded in **tension or compression** and **shear**
- Throat h does not include extra reinforcement
- Reinforcement adds some strength for static loaded joints
- Reinforcement adds stress concentration and should be ground off for fatigue loaded joints

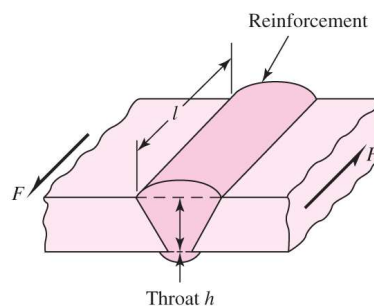
Normal Stress,

$$\sigma = \frac{F}{hl}$$



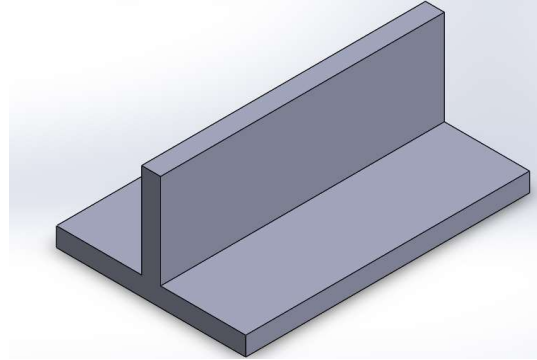
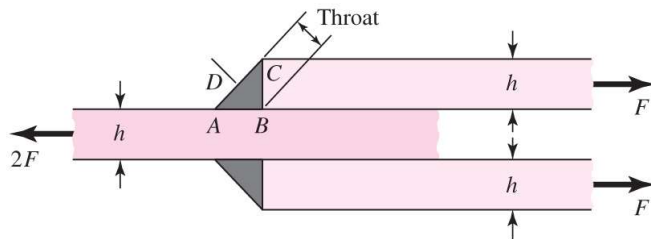
Shear Stress,

$$\tau = \frac{F}{hl}$$



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9-2 Butt and Fillet Welds



9

9-2 Butt and Fillet Welds

- Nominal stresses at angle θ

$$\tau = \frac{F_s}{A} = \frac{F \sin \theta (\cos \theta + \sin \theta)}{hl} = \frac{F}{hl} (\sin \theta \cos \theta + \sin^2 \theta)$$

$$\sigma = \frac{F_n}{A} = \frac{F \cos \theta (\cos \theta + \sin \theta)}{hl} = \frac{F}{hl} (\cos^2 \theta + \sin \theta \cos \theta)$$

- Von Mises Stress at angle θ

$$\sigma' = (\sigma^2 + 3\tau^2)^{1/2} = \frac{F}{hl} [(\cos^2 \theta + \sin \theta \cos \theta)^2 + 3(\sin^2 \theta + \sin \theta \cos \theta)^2]^{1/2}$$

- Largest von Mises stress occurs at $\theta = 62.5^\circ$ with value of $\sigma' = 2.16F/(hl)$
- Maximum shear stress occurs at $\theta = 67.5^\circ$ with value of $\tau_{\max} = 1.207F/(hl)$

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9-2 Butt and Fillet Welds

- Experimental results are more complex

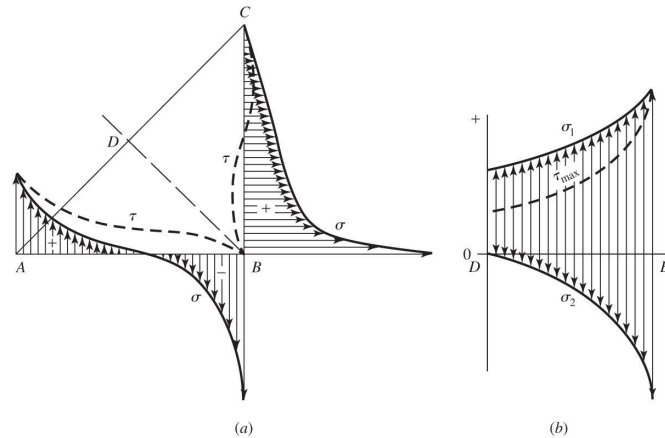


Fig. 9-10

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9-2 Butt and Fillet Welds

Transverse Fillet Weld Simplified Model

- No analytical approach accurately predicts the experimentally measured stresses.
- We will use a **simple and conservative model**
- Assume the external load is carried entirely by **shear forces** on the **minimum throat area**.

$$\tau = \frac{F}{0.707hl} = \frac{1.414F}{hl}$$

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9-3 Stresses in Welded Joints in Torsion

- Fillet welds carrying both direct shear V and moment M

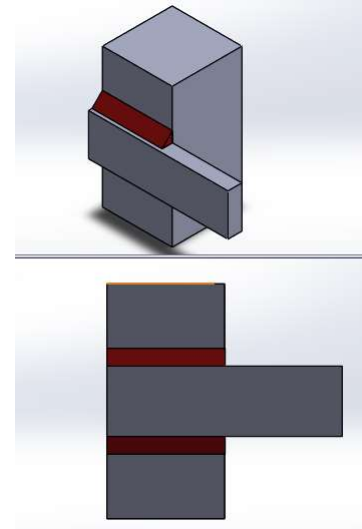
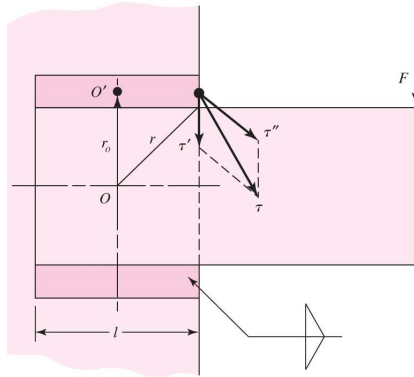
- Primary shear

$$\tau' = \frac{V}{A}$$

- Secondary shear

$$\tau'' = \frac{Mr}{J}$$

- A is the minimum throat area of all welds
- r is distance from centroid of weld group to point of interest
- J is second polar moment of area of weld group about centroid of group



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9-3 Stresses in Welded Joints in Torsion

- Rectangles represent **throat areas**.

- *Always*, $t = 0.707 h$

$$A = A_1 + A_2 = t_1 d + t_2 b$$

$$I_x = \frac{t_1 d^3}{12} \quad I_y = \frac{d t_1^3}{12}$$

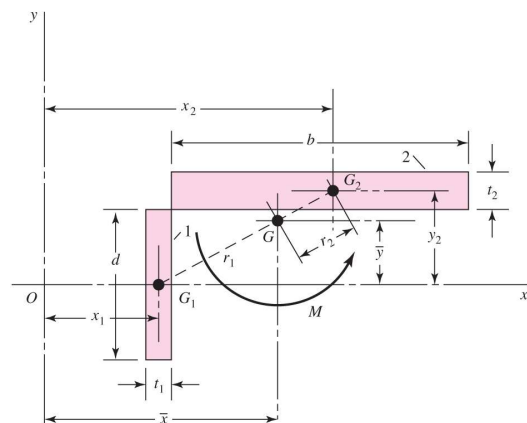
$$J_{G1} = I_x + I_y = \frac{t_1 d^3}{12} + \frac{d t_1^3}{12}$$

$$J_{G2} = \frac{b t_2^3}{12} + \frac{t_2 b^3}{12}$$

$$\bar{x} = \frac{A_1 x_1 + A_2 x_2}{A} \quad \bar{y} = \frac{A_1 y_1 + A_2 y_2}{A}$$

$$r_1 = [(\bar{x} - x_1)^2 + \bar{y}^2]^{1/2} \quad r_2 = [(y_2 - \bar{y})^2 + (x_2 - \bar{x})^2]^{1/2}$$

$$J = (J_{G1} + A_1 r_1^2) + (J_{G2} + A_2 r_2^2)$$



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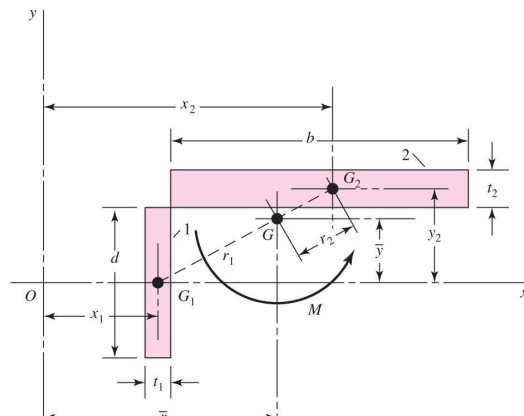
9-3 Stresses in Welded Joints in Torsion

- Note that t^3 terms will be very small compared to b^3 and d^3
- Usually neglected
- Leaves J_{G1} and J_{G2} linear in weld width
- Can normalize by treating each weld as a line with unit thickness t
- Results in *unit second polar moment of area*, J_u
- Since $t = 0.707h$,

$$J = 0.707hJ_u$$

$$J_{G1} = I_x + I_y = \frac{t_1 d^3}{12} + \frac{d t_1^3}{12}$$

$$J_{G2} = \frac{b t_2^3}{12} + \frac{t_2 b^3}{12}$$



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9-3 Stresses in Welded Joints in Torsion

Table 9-1
Torsional Properties of Fillet Welds*

Weld	Throat Area	Location of G	Unit Second Polar Moment of Area
1.	$A = 0.707hd$	$\bar{x} = 0$ $\bar{y} = d/2$	$J_u = d^3/12$
2.	$A = 1.414bd$	$\bar{x} = b/2$ $\bar{y} = d/2$	$J_u = \frac{d(3b^2 + d^2)}{6}$
3.	$A = 0.707h(b + d)$	$\bar{x} = \frac{b^2}{2(b + d)}$ $\bar{y} = \frac{d^2}{2(b + d)}$	$J_u = \frac{(b + d)^3 - 6bd^2}{12(b + d)}$
4.	$A = 0.707h(2b + d)$	$\bar{x} = \frac{b^2}{2b + d}$ $\bar{y} = d/2$	$J_u = \frac{8b^3 + 6bd^2 + d^3}{12} - \frac{b^3}{2b + d}$
5.	$A = 1.414h(b + d)$	$\bar{x} = b/2$ $\bar{y} = d/2$	$J_u = \frac{(b + d)^3}{6}$
6.	$A = 1.414\pi r$		$J_u = 2\pi r^3$

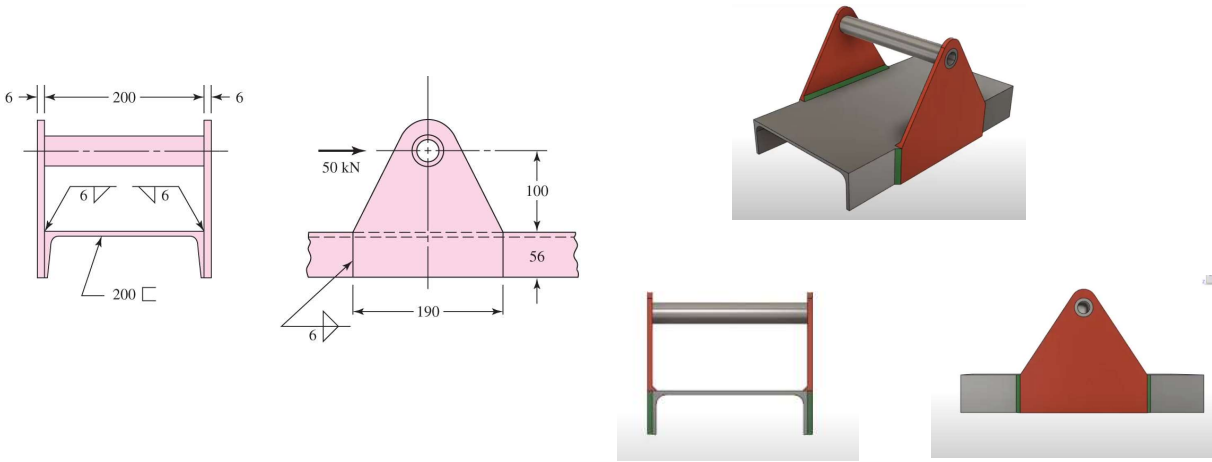
*G is the centroid of weld group; h is weld size; plane of torque couple is in the plane of the paper; all welds are of unit width.

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Example 9–1

A 50-kN load is transferred from a welded fitting into a 200-mm steel channel as illustrated in Fig. 9–14. Estimate the maximum stress in the weld.



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Example 9–1

(a) Label the ends and corners of each weld by letter. See Fig. 9–15. Sometimes it is desirable to label each weld of a set by number.

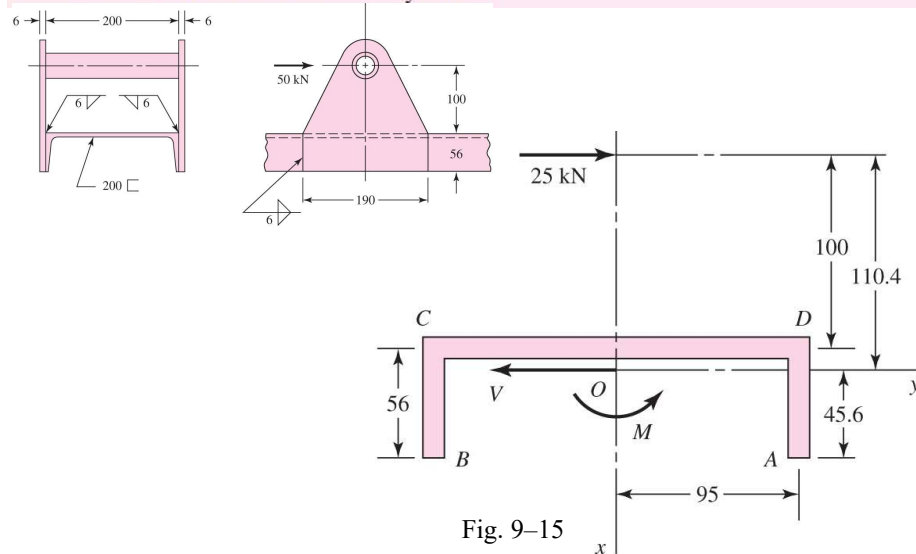


Fig. 9–15

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Example 9-1

(b) Estimate the primary shear stress τ' . As shown in Fig. 9-14, each plate is welded to the channel by means of three 6-mm fillet welds. Figure 9-15 shows that we have divided the load in half and are considering only a single plate. From case 4 of Table 9-1 we find the throat area as

$$A = 0.707(6)[2(56) + 190] = 1280 \text{ mm}^2$$

Then the primary shear stress is

$$\tau' = \frac{V}{A} = \frac{25(10)^3}{1280} = 19.5 \text{ MPa}$$

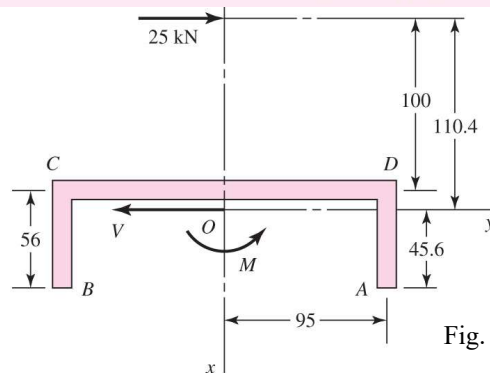


Fig. 9-15

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Example 9-1

(c) Draw the τ' stress, to scale, at each lettered corner or end. See Fig. 9-16.

(d) Locate the centroid of the weld pattern. Using case 4 of Table 9-1, we find

$$\bar{x} = \frac{(56)^2}{2(56) + 190} = 10.4 \text{ mm}$$

This is shown as point O on Figs. 9-15 and 9-16.

(e) Find the distances r_i (see Fig. 9-16):

$$r_A = r_B = [(190/2)^2 + (56 - 10.4)^2]^{1/2} = 105 \text{ mm}$$

$$r_C = r_D = [(190/2)^2 + (10.4)^2]^{1/2} = 95.6 \text{ mm}$$

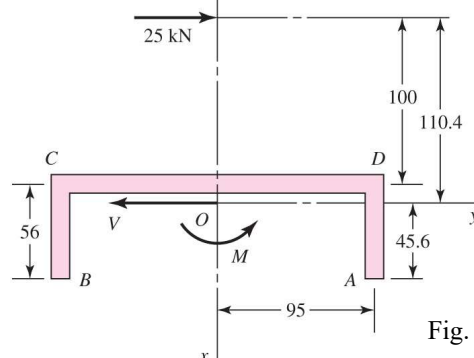


Fig. 9-15

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Example 9-1

(f) Find J . Using case 4 of Table 9-1 again, with Eq. (9-6), we get

$$J = 0.707(6) \left[\frac{8(56)^3 + 6(56)(190)^2 + (190)^3}{12} - \frac{(56)^4}{2(56) + 190} \right]$$

$$= 7.07(10)^6 \text{ mm}^4$$

(g) Find M :

$$M = Fl = 25(100 + 10.4) = 2760 \text{ N} \cdot \text{m}$$

(h) Estimate the secondary shear stresses τ'' at each lettered end or corner:

$$\tau_A'' = \tau_B'' = \frac{Mr}{J} = \frac{2760(10)^3(105)}{7.07(10)^6} = 41.0 \text{ MPa}$$

$$\tau_C'' = \tau_D'' = \frac{2760(10)^3(95.6)}{7.07(10)^6} = 37.3 \text{ MPa}$$

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Example 9-1

(i) Draw the τ'' stress at each corner and end. See Fig. 9-16. Note that this is a free-body diagram of one of the side plates, and therefore the τ' and τ'' stresses represent what the channel is doing to the plate (through the welds) to hold the plate in equilibrium.

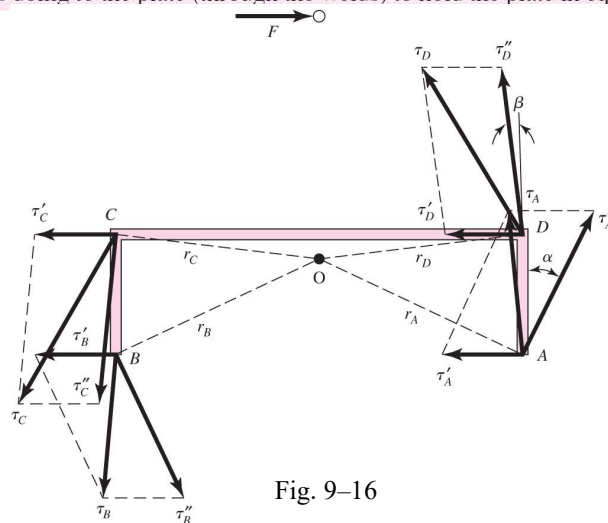


Fig. 9-16

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Example 9-1

(j) At each point labeled, combine the two stress components as vectors (since they apply to the same area). At point A, the angle that τ_A'' makes with the vertical, α , is also the angle r_A makes with the horizontal, which is $\alpha = \tan^{-1}(45.6/95) = 25.64^\circ$. This angle also applies to point B. Thus

$$\tau_A = \tau_B = \sqrt{(19.5 - 41.0 \sin 25.64^\circ)^2 + (41.0 \cos 25.64^\circ)^2} = 37.0 \text{ MPa}$$

Similarly, for C and D, $\beta = \tan^{-1}(10.4/95) = 6.25^\circ$. Thus

$$\tau_C = \tau_D = \sqrt{(19.5 + 37.3 \sin 6.25^\circ)^2 + (37.3 \cos 6.25^\circ)^2} = 43.9 \text{ MPa}$$

(k) Identify the most highly stressed point: $\tau_{\max} = \tau_C = \tau_D = 43.9 \text{ MPa}$

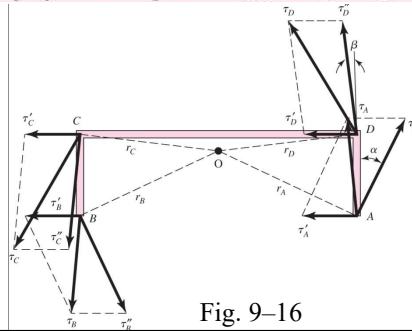


Fig. 9-16

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9-4 Stresses in Welded Joints in Bending

- Fillet welds carry both shear V and moment M

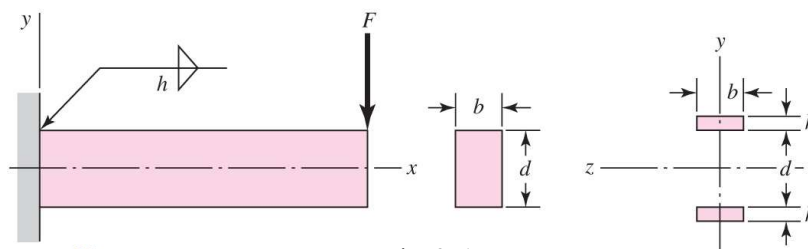


Fig. 9-17

$$\tau' = \frac{V}{A}$$

$$I_u = \frac{bd^2}{2} \quad I = 0.707hI_u = 0.707h \frac{bd^2}{2}$$

$$\tau'' = \frac{Mc}{I} = \frac{Md/2}{0.707hbd^2/2} = \frac{1.414M}{bdh}$$


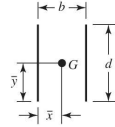
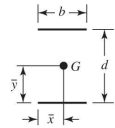
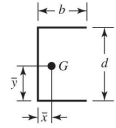
$$\tau = (\tau'^2 + \tau''^2)^{1/2}$$

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9-4 Stresses in Welded Joints in Bending

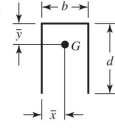
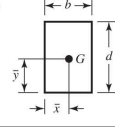
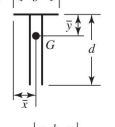
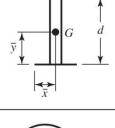

Bending Properties of Fillet Welds (Table 9-2)

Weld	Throat Area	Location of G	Unit Second Moment of Area
1. 	$A = 0.707hd$	$\bar{x} = 0$ $\bar{y} = d/2$	$I_u = \frac{d^3}{12}$
2. 	$A = 1.414hd$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \frac{d^3}{6}$
3. 	$A = 1.414hb$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \frac{bd^2}{2}$
4. 	$A = 0.707h(2b + d)$	$\bar{x} = \frac{b^2}{2b + d}$ $\bar{y} = d/2$	$I_u = \frac{d^2}{12}(6b + d)$

ing Design

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9-4 Stresses in Welded Joints in Bending

5. 	$A = 0.707h(b + 2d)$	$\bar{x} = b/2$ $\bar{y} = \frac{d^2}{b + 2d}$	$I_u = \frac{2d^3}{3} - 2d^2\bar{y} + (b + 2d)\bar{y}^2$
6. 	$A = 1.414h(b + d)$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \frac{d^2}{6}(3b + d)$
7. 	$A = 0.707h(b + 2d)$	$\bar{x} = b/2$ $\bar{y} = \frac{d^2}{b + 2d}$	$I_u = \frac{2d^3}{3} - 2d^2\bar{y} + (b + 2d)\bar{y}^2$
8. 	$A = 1.414h(b + d)$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \frac{d^2}{6}(3b + d)$
9. 	$A = 1.414\pi r$		$I_u = \pi r^3$

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9-5 The Strength of Welded Joints

- Must check for failure in parent material and in weld
- Weld strength is dependent on choice of electrode material
- Weld material is often stronger than parent material
- Parent material experiences heat treatment near weld
- Cold drawn parent material may become more like hot rolled in vicinity of weld
- Often welded joints are designed by following codes rather than designing by the conventional factor of safety method

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9-5 The Strength of Welded Joints

Minimum Weld-Metal Properties (Table 9-3)

AWS Electrode Number*	Tensile Strength kpsi (MPa)	Yield Strength, kpsi (MPa)	Percent Elongation
E60xx	62 (427)	50 (345)	17–25
E70xx	70 (482)	57 (393)	22
E80xx	80 (551)	67 (462)	19
E90xx	90 (620)	77 (531)	14–17
E100xx	100 (689)	87 (600)	13–16
E120xx	120 (827)	107 (737)	14

*The American Welding Society (AWS) specification code numbering system for electrodes. This system uses an E prefixed to a four- or five-digit numbering system in which the first two or three digits designate the approximate tensile strength. The last digit includes variables in the welding technique, such as current supply. The next-to-last digit indicates the welding position, as, for example, flat, or vertical, or overhead. The complete set of specifications may be obtained from the AWS upon request.

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9-5 The Strength of Welded Joints

Stresses Permitted by the AISC Code for Weld Metal (Table 9–4)

Type of Loading	Type of Weld	Permissible Stress	n^*
Tension	Butt	$0.60S_y$	1.67
Bearing	Butt	$0.90S_y$	1.11
Bending	Butt	$0.60-0.66S_y$	1.52-1.67
Simple compression	Butt	$0.60S_y$	1.67
Shear	Butt or fillet	$0.30S_{ut}^\dagger$	

*The factor of safety n has been computed by using the distortion-energy theory.

†Shear stress on base metal should not exceed $0.40S_y$ of base metal.

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9-5 The Strength of Welded Joints

- K_{fs} appropriate for application to shear stresses
- Use for parent metal and for weld metal

Table 9–5

Fatigue

Stress-Concentration

Factors, K_{fs}

Type of Weld	K_{fs}
Reinforced butt weld	1.2
Toe of transverse fillet weld	1.5
End of parallel fillet weld	2.7
T-butt joint with sharp corners	2.0

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9-5 The Strength of Welded Joints

Allowable Load or Various Sizes of Fillet Welds (Table 9-6)

Strength Level of Weld Metal (EXX)							
	60*	70*	80	90*	100	110*	120
Allowable shear stress on throat, ksi (1000 psi) of fillet weld or partial penetration groove weld							
$\tau =$	18.0	21.0	24.0	27.0	30.0	33.0	36.0
Allowable Unit Force on Fillet Weld, kip/linear in							
$^{\dagger}f =$	12.73h	14.85h	16.97h	19.09h	21.21h	23.33h	25.45h
Leg Size h, in	Allowable Unit Force for Various Sizes of Fillet Welds kip/linear in						
1	12.73	14.85	16.97	19.09	21.21	23.33	25.45
7/8	11.14	12.99	14.85	16.70	18.57	20.41	22.27
3/4	9.55	11.14	12.73	14.32	15.92	17.50	19.09
5/8	7.96	9.28	10.61	11.93	13.27	14.58	15.91
1/2	6.37	7.42	8.48	9.54	10.61	11.67	12.73
7/16	5.57	6.50	7.42	8.35	9.28	10.21	11.14
3/8	4.77	5.57	6.36	7.16	7.95	8.75	9.54
5/16	3.98	4.64	5.30	5.97	6.63	7.29	7.95
1/4	3.18	3.71	4.24	4.77	5.30	5.83	6.36
3/16	2.39	2.78	3.18	3.58	3.98	4.38	4.77
1/8	1.59	1.86	2.12	2.39	2.65	2.92	3.18
1/16	0.795	0.930	1.06	1.19	1.33	1.46	1.59

*Fillet welds actually tested by the joint AISC-AWS Task Committee.
 $^{\dagger}f = 0.707h \tau_{all}$.

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9-5 The Strength of Welded Joints

Minimum Fillet Weld Size, h (Table 9-6)

Material Thickness of Thicker Part Joined, in	Weld Size, in
*To $\frac{1}{4}$ incl.	$\frac{1}{8}$
Over $\frac{1}{4}$ To $\frac{1}{2}$	$\frac{3}{16}$
Over $\frac{1}{2}$ To $\frac{3}{4}$	$\frac{1}{4}$
† Over $\frac{3}{4}$ To $1\frac{1}{2}$	$\frac{5}{16}$
Over $1\frac{1}{2}$ To $2\frac{1}{4}$	$\frac{3}{8}$
Over $2\frac{1}{4}$ To 6	$\frac{1}{2}$
Over 6	$\frac{5}{8}$

Not to exceed the thickness of the thinner part.

*Minimum size for bridge application does not go below $\frac{3}{16}$ in.

† For minimum fillet weld size, schedule does not go above $\frac{5}{16}$ in fillet weld for every $\frac{3}{4}$ in material.

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9-5 The Strength of Welded Joints

		Strength Level of Weld Metal (EXX)						
		60*	70*	80	90*	100	110*	120
<u>Allowable Load or Various Sizes of Fillet Welds (Table 9–6)</u>		Allowable shear stress on throat, ksi (1000 psi) of fillet weld or partial penetration groove weld						
		$\tau =$	18.0	21.0	24.0	27.0	30.0	33.0
		Allowable Unit Force on Fillet Weld, kip/linear in						
		$\dagger f =$	12.73 <i>h</i>	14.85 <i>h</i>	16.97 <i>h</i>	19.09 <i>h</i>	21.21 <i>h</i>	23.33 <i>h</i>
Leg Size <i>h</i> , in		Allowable Unit Force for Various Sizes of Fillet Welds kip/linear in						
		1	12.73	14.85	16.97	19.09	21.21	23.33
	7/8	11.14	12.99	14.85	16.70	18.57	20.41	22.27
	3/4	9.55	11.14	12.73	14.32	15.92	17.50	19.09
	5/8	7.96	9.28	10.61	11.93	13.27	14.58	15.91
	1/2	6.37	7.42	8.48	9.54	10.61	11.67	12.73
	7/16	5.57	6.50	7.42	8.35	9.28	10.21	11.14
	3/8	4.77	5.57	6.36	7.16	7.95	8.75	9.54
	5/16	3.98	4.64	5.30	5.97	6.63	7.29	7.95
	1/4	3.18	3.71	4.24	4.77	5.30	5.83	6.36
	3/16	2.39	2.78	3.18	3.58	3.98	4.38	4.77
	1/8	1.59	1.86	2.12	2.39	2.65	2.92	3.18
	1/16	0.795	0.930	1.06	1.19	1.33	1.46	1.59

*Fillet welds actually tested by the joint AISC-AWS Task Committee.
 $\dagger f = 0.707h \tau_{all}$.

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9-5 The Strength of Welded Joints

Stresses Permitted by the AISC Code for Weld Metal (Table 9–4)

Type of Loading	Type of Weld	Permissible Stress	<i>n</i> *
Tension	Butt	$0.60S_y$	1.67
Bearing	Butt	$0.90S_y$	1.11
Bending	Butt	$0.60-0.66S_y$	1.52–1.67
Simple compression	Butt	$0.60S_y$	1.67
Shear	Butt or fillet	$0.30S_{ut}^{\dagger}$	

*The factor of safety *n* has been computed by using the distortion-energy theory.

\dagger Shear stress on base metal should not exceed $0.40S_y$ of base metal.

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Example 9–2

A $\frac{1}{2}$ -in by 2-in rectangular-cross-section UNS G10150 HR bar carries a static load of 16.5 kip. It is welded to a gusset plate with a $\frac{3}{8}$ -in fillet weld 2 in long on both sides with an E70XX electrode as depicted in Fig. 9–18. Use the welding code method.

(a) Is the weld metal strength satisfactory?

(b) Is the attachment strength satisfactory?

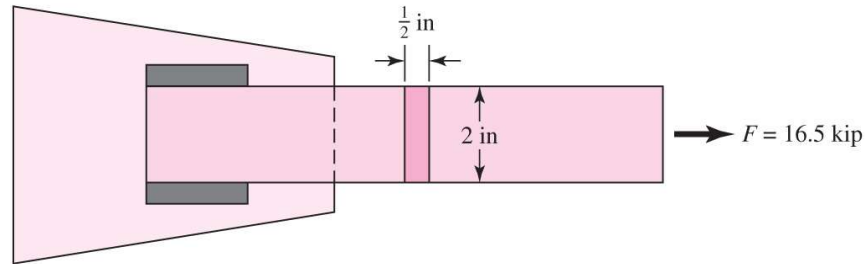


Fig. 9–18

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Table A–20

Deterministic ASTM Minimum Tensile and Yield Strengths for Some Hot-Rolled (HR) and Cold-Drawn (CD) Steels [The strengths listed are estimated ASTM minimum values in the size range 18 to 32 mm ($\frac{3}{4}$ to $1\frac{1}{4}$ in). These strengths are suitable for use with the design factor defined in Sec. 1–10, provided the materials conform to ASTM A6 or A568 requirements or are required in the purchase specifications. Remember that a numbering system is not a specification.] *Source:* 1986 SAE Handbook, p. 2.15.

1 UNS No.	2 SAE and/or AISI No.	3 Process- ing	4 Tensile Strength, MPa (kpsi)	5 Yield Strength, MPa (kpsi)	6 Elongation in 2 in, %	7 Reduction in Area, %	8 Brinell Hardness
G10060	1006	HR	300 (43)	170 (24)	30	55	86
		CD	330 (48)	280 (41)	20	45	95
G10100	1010	HR	320 (47)	180 (26)	28	50	95
		CD	370 (53)	300 (44)	20	40	105
G10150	1015	HR	340 (50)	190 (27.5)	28	50	101
		CD	390 (56)	320 (47)	18	40	111
G10180	1018	HR	400 (58)	220 (32)	25	50	116
		CD	440 (64)	370 (54)	15	40	126

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Example 9–2

(a) From Table 9–6, allowable force per unit length for a $\frac{3}{8}$ -in E70 electrode metal is 5.57 kip/in of weldment; thus

$$F = 5.57l = 5.57(4) = 22.28 \text{ kip}$$

Since $22.28 > 16.5$ kip, weld metal strength is satisfactory.

(b) Check shear in attachment adjacent to the welds. From Table A–20, $S_y = 27.5$ kpsi. Then, from Table 9–4, the allowable attachment shear stress is

$$\tau_{\text{all}} = 0.4S_y = 0.4(27.5) = 11 \text{ kpsi}$$

The shear stress τ on the base metal adjacent to the weld is

$$\tau = \frac{F}{2hl} = \frac{16.5}{2(0.375)2} = 11 \text{ kpsi}$$

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Example 9–2

Since $\tau_{\text{all}} \geq \tau$, the attachment is satisfactory near the weld beads. The tensile stress in the shank of the attachment σ is

$$\sigma = \frac{F}{tl} = \frac{16.5}{(1/2)2} = 16.5 \text{ kpsi}$$

The allowable tensile stress σ_{all} , from Table 9–4, is $0.6S_y$ and, with welding code safety level preserved,

$$\sigma_{\text{all}} = 0.6S_y = 0.6(27.5) = 16.5 \text{ kpsi}$$

Since $\sigma \leq \sigma_{\text{all}}$, the shank tensile stress is satisfactory.

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Example 9–3

A specially rolled A36 structural steel section for the attachment has a cross section as shown in Fig. 9–19 and has yield and ultimate tensile strengths of 36 and 58 kpsi, respectively. It is statically loaded through the attachment centroid by a load of $F = 24$ kip. Unsymmetrical weld tracks can compensate for eccentricity such that there is no moment to be resisted by the welds. Specify the weld track lengths l_1 and l_2 for a $\frac{5}{16}$ -in fillet weld using an E70XX electrode. This is part of a design problem in which the design variables include weld lengths and the fillet leg size.

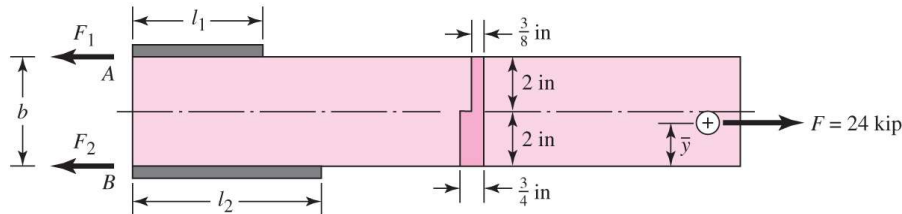


Fig. 9–19

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Example 9–3

The y coordinate of the section centroid of the attachment is

$$\bar{y} = \frac{\sum y_i A_i}{\sum A_i} = \frac{1(0.75)2 + 3(0.375)2}{0.75(2) + 0.375(2)} = 1.67 \text{ in}$$

Summing moments about point B to zero gives

$$\sum M_B = 0 = -F_1 b + F \bar{y} = -F_1(4) + 24(1.67)$$

from which

$$F_1 = 10 \text{ kip}$$

It follows that

$$F_2 = 24 - 10.0 = 14.0 \text{ kip}$$

The weld throat areas have to be in the ratio $14/10 = 1.4$, that is, $l_2 = 1.4l_1$. The weld length design variables are coupled by this relation, so l_1 is the weld length design variable. The other design variable is the fillet weld leg size h , which has been decided by the problem statement. From Table 9–4, the allowable shear stress on the throat τ_{all} is

$$\tau_{\text{all}} = 0.3(70) = 21 \text{ kpsi}$$

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Example 9–3

The shear stress τ on the 45° throat is

$$\begin{aligned}\tau &= \frac{F}{(0.707)h(l_1 + l_2)} = \frac{F}{(0.707)h(l_1 + 1.4l_1)} \\ &= \frac{F}{(0.707)h(2.4l_1)} = \tau_{\text{all}} = 21 \text{ kpsi}\end{aligned}$$

from which the weld length l_1 is

$$l_1 = \frac{24}{21(0.707)0.3125(2.4)} = 2.16 \text{ in}$$

and

$$l_2 = 1.4l_1 = 1.4(2.16) = 3.02 \text{ in}$$

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Example 9–3

The shear stress τ on the 45° throat is

$$\begin{aligned}\tau &= \frac{F}{(0.707)h(l_1 + l_2)} = \frac{F}{(0.707)h(l_1 + 1.4l_1)} \\ &= \frac{F}{(0.707)h(2.4l_1)} = \tau_{\text{all}} = 21 \text{ kpsi}\end{aligned}$$

from which the weld length l_1 is

$$l_1 = \frac{24}{21(0.707)0.3125(2.4)} = 2.16 \text{ in}$$

and

$$l_2 = 1.4l_1 = 1.4(2.16) = 3.02 \text{ in}$$

These are the weld-bead lengths required by weld metal strength. The attachment shear stress allowable in the base metal, from Table 9–4, is

$$\tau_{\text{all}} = 0.4S_y = 0.4(36) = 14.4 \text{ kpsi}$$

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Example 9–3

The shear stress τ in the base metal adjacent to the weld is

$$\tau = \frac{F}{h(l_1 + l_2)} = \frac{F}{h(l_1 + 1.4l_1)} = \frac{F}{h(2.4l_1)} = \tau_{\text{all}} = 14.4 \text{ kpsi}$$

from which

$$l_1 = \frac{F}{14.4h(2.4)} = \frac{24}{14.4(0.3125)2.4} = 2.22 \text{ in}$$

$$l_2 = 1.4l_1 = 1.4(2.22) = 3.11 \text{ in}$$

These are the weld-bead lengths required by base metal (attachment) strength. The base metal controls the weld lengths. For the allowable tensile stress σ_{all} in the shank of the attachment, the AISC allowable for tension members is $0.6S_y$; therefore,

$$\sigma_{\text{all}} = 0.6S_y = 0.6(36) = 21.6 \text{ kpsi}$$

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Example 9–3

The nominal tensile stress σ is *uniform* across the attachment cross section because of the load application at the centroid. The stress σ is

$$\sigma = \frac{F}{A} = \frac{24}{0.75(2) + 2(0.375)} = 10.7 \text{ kpsi}$$

Since $\sigma \leq \sigma_{\text{all}}$, the shank section is satisfactory. With l_1 set to a nominal $2\frac{1}{4}$ in, l_2 should be $1.4(2.25) = 3.15$ in.

Set $l_1 = 2\frac{1}{4}$ in, $l_2 = 3\frac{1}{4}$ in. The small magnitude of the departure from $l_2/l_1 = 1.4$ is not serious. The joint is essentially moment-free.

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Example 9–4

Perform an adequacy assessment of the statically loaded welded cantilever carrying 500 lbf depicted in Fig. 9–20. The cantilever is made of AISI 1018 HR steel and welded with a $\frac{3}{8}$ -in fillet weld as shown in the figure. An E6010 electrode was used, and the design factor was 3.0.

- Use the conventional method for the weld metal.
- Use the conventional method for the attachment (cantilever) metal.
- Use a welding code for the weld metal.

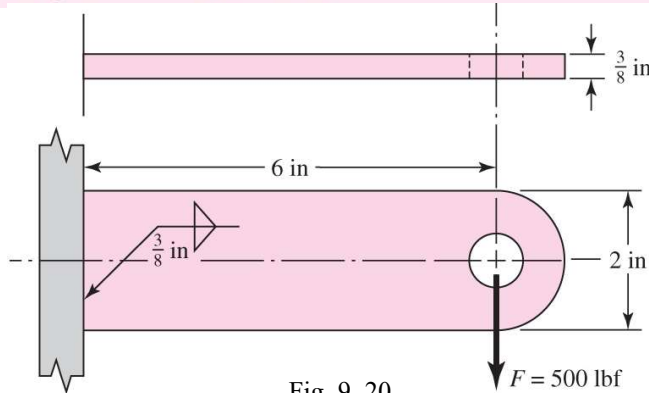


Fig. 9–20

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Example 9–4

(a) From Table 9–3, $S_y = 50$ kpsi, $S_{ut} = 62$ kpsi. From Table 9–2, second pattern, $b = 0.375$ in, $d = 2$ in, so

$$A = 1.414hd = 1.414(0.375)2 = 1.06 \text{ in}^2$$

$$I_u = d^3/6 = 2^3/6 = 1.33 \text{ in}^3$$

$$I = 0.707hI_u = 0.707(0.375)1.33 = 0.353 \text{ in}^4$$

Primary shear:

$$\tau' = \frac{F}{A} = \frac{500(10^{-3})}{1.06} = 0.472 \text{ kpsi}$$

Secondary shear:

$$\tau'' = \frac{Mr}{I} = \frac{500(10^{-3})(6)(1)}{0.353} = 8.50 \text{ kpsi}$$

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Example 9–4

The shear magnitude τ is the Pythagorean combination

$$\tau = (\tau'^2 + \tau''^2)^{1/2} = (0.472^2 + 8.50^2)^{1/2} = 8.51 \text{ kpsi}$$

The factor of safety based on a minimum strength and the distortion-energy criterion is

$$n = \frac{S_{sy}}{\tau} = \frac{0.577(50)}{8.51} = 3.39$$

Since $n \geq n_d$, that is, $3.39 \geq 3.0$, the weld metal has satisfactory strength.

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Example 9–4

(b) From Table A–20, minimum strengths are $S_{ut} = 58$ kpsi and $S_y = 32$ kpsi. Then

$$\sigma = \frac{M}{I/c} = \frac{M}{bd^2/6} = \frac{500(10^{-3})6}{0.375(2^2)/6} = 12 \text{ kpsi}$$

$$n = \frac{S_y}{\sigma} = \frac{32}{12} = 2.67$$

Since $n < n_d$, that is, $2.67 < 3.0$, the joint is unsatisfactory as to the attachment strength.

(c) From part (a), $\tau = 8.51$ kpsi. For an E6010 electrode Table 9–6 gives the allowable shear stress τ_{all} as 18 kpsi. Since $\tau < \tau_{all}$, the weld is satisfactory. Since the code already has a design factor of $0.577(50)/18 = 1.6$ included at the equality, the corresponding factor of safety to part (a) is

$$n = 1.6 \frac{18}{8.51} = 3.38$$

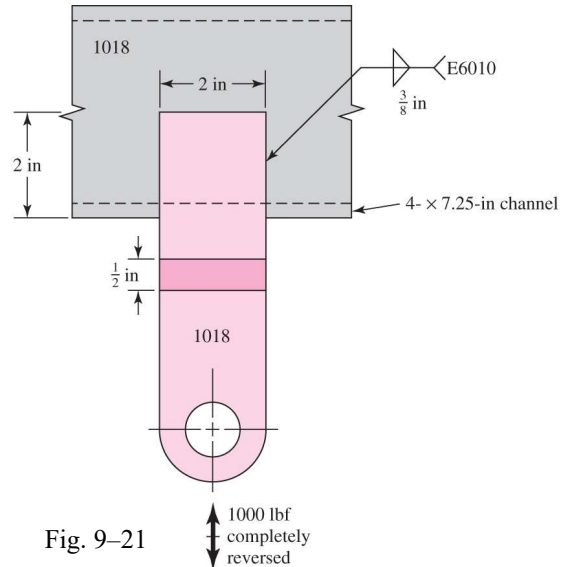
which is consistent.

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Example 9–5

The 1018 steel strap of Fig. 9–21 has a 1000 lbf, completely reversed load applied. Determine the factor of safety of the weldment for infinite life.



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Example 9–5

From Table A–20 for the 1018 attachment metal the strengths are $S_{ut} = 58$ kpsi and $S_y = 32$ kpsi. For the E6010 electrode, from Table 9–3 $S_{ut} = 62$ kpsi and $S_y = 50$ kpsi. The fatigue stress-concentration factor, from Table 9–5, is $K_{fs} = 2.7$. From Table 6–2, p. 288, $k_a = 39.9(58)^{-0.995} = 0.702$. For case 2 of Table 9–5, the shear area is:

$$A = 1.414(0.375)(2) = 1.061 \text{ in}^2$$

For a uniform shear stress on the throat, $k_b = 1$.

From Eq. (6–26), p. 290, for torsion (shear),

$$k_c = 0.59 \quad k_d = k_e = k_f = 1$$

From Eqs. (6–8), p. 282, and (6–18), p. 287,

$$S_{se} = 0.702(1)0.59(1)(1)(1)0.5(58) = 12.0 \text{ kpsi}$$

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Example 9–5

From Table 9–5, $K_{fs} = 2.7$. Only primary shear is present. So, with $F_a = 1000$ lbf and $F_m = 0$

$$\tau'_a = \frac{K_{fs} F_a}{A} = \frac{2.7(1000)}{1.061} = 2545 \text{ psi} \quad \tau'_m = 0 \text{ psi}$$

In the absence of a midrange component, the fatigue factor of safety n_f is given by

$$n_f = \frac{S_{se}}{\tau'_a} = \frac{12\,000}{2545} = 4.72$$

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Example 9–6

The 1018 steel strap of Fig. 9–22 has a repeatedly applied load of 2000 lbf ($F_a = F_m = 1000$ lbf). Determine the fatigue factor of safety fatigue strength of the weldment.

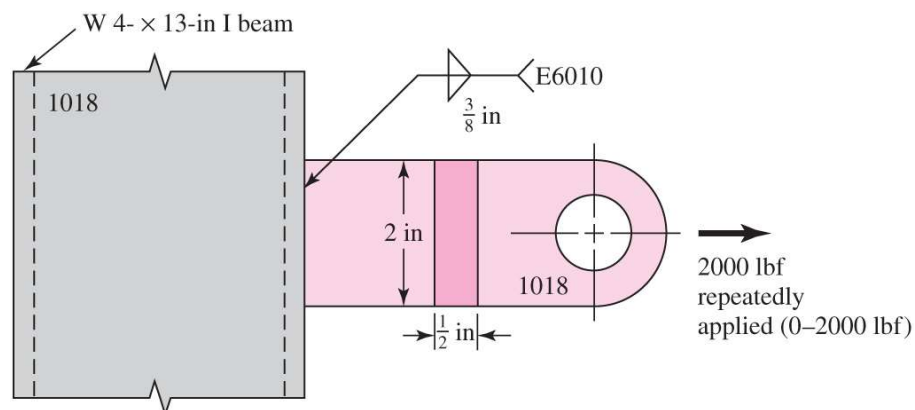


Fig. 9–22

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Example 9–6

From Table 6–2, p. 288, $k_a = 39.9(58)^{-0.995} = 0.702$. From case 2 of Table 9–2

$$A = 1.414(0.375)(2) = 1.061 \text{ in}^2$$

For uniform shear stress on the throat $k_b = 1$.

From Eq. (6–26), p. 290, $k_c = 0.59$. From Eqs. (6–8), p. 282, and (6–18), p. 287,

$$S_{se} = 0.702(1)0.59(1)(1)(1)0.5(58) = 12.0 \text{ kpsi}$$

From Table 9–5, $K_{fs} = 2$. Only primary shear is present:

$$\tau'_a = \tau'_m = \frac{K_{fs}F_a}{A} = \frac{2(1000)}{1.061} = 1885 \text{ psi}$$

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Example 9–6

From Eq. (6–54), p. 317, $S_{su} \doteq 0.67S_{ut}$. This, together with the Gerber fatigue failure criterion for shear stresses from Table 6–7, p. 307, gives

$$n_f = \frac{1}{2} \left(\frac{0.67S_{ut}}{\tau_m} \right)^2 \frac{\tau_a}{S_{se}} \left[-1 + \sqrt{1 + \left(\frac{2\tau_m S_{se}}{0.67S_{ut} \tau_a} \right)^2} \right]$$

$$n_f = \frac{1}{2} \left[\frac{0.67(58)}{1.885} \right]^2 \frac{1.885}{12.0} \left\{ -1 + \sqrt{1 + \left[\frac{2(1.885)12.0}{0.67(58)1.885} \right]^2} \right\} = 5.85$$

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