Ch # 9

Permanent Joints

- – ***Welding***
- – Brazing
- – Soldering
- – Cementing
- – Gluing

- *Welding* is widely used in fabrication
- As a replacement for bolted and riveted joints
- Use for repairing

Types of Welding

- Electric Arc welding
  - Shielded Metal Arc (SMAW) or Stick
  - Metal Inert Gas (MIG)
  - Tungsten Inert Gas (TIG)
  - Flux-cored Arc (FCAW)
  - etc.
- Gas welding
  - Oxy-Acetylene
  - Oxy-Gasoline
  - Butane-Propane
  - etc.
- Thermit welding

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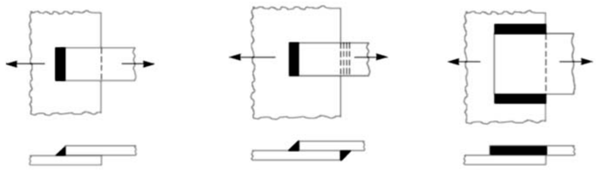
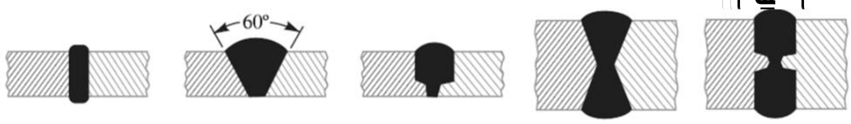
Types of Welded Joints

1. Lap or Fillet



(*a*) Single transverse. (*b*) Double transverse. (*c*) Parallel fillet.

2. Butt

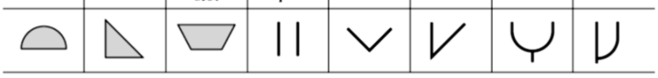


(*a*) Square butt joint. (*b*) Single *V*-butt joint. (*c*) Single *U*-butt joint. (*d*) Double *V*-butt joint. (*e*) Double *U*-butt joint.

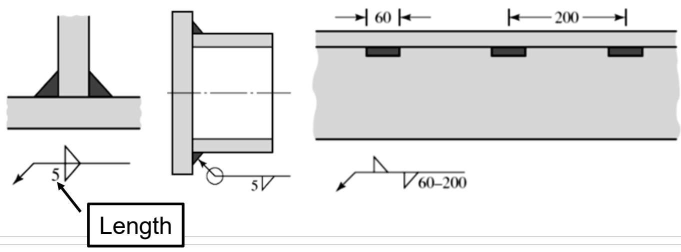
9-1 Welding Symbols

- The most common

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



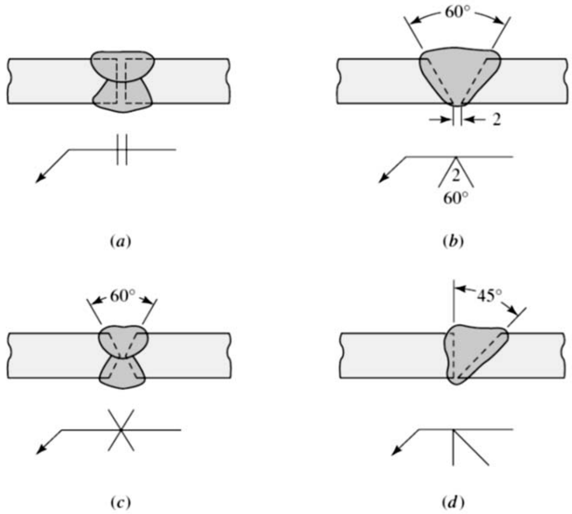
- Representation on manufacturing drawings



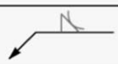
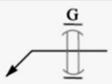
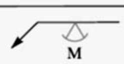
9-1 Welding Symbols…

Figure 9–5

Butt or groove welds: (*a*) square butt-welded on both sides; (*b*) single V with 60° bevel and root opening of 2 mm; (*c*) double V; (*d*) single bevel.



9-1 Welding Symbols…

S. No.	Particulars	Drawing representation	Symbol
1.	Weld all round		○
2.	Field weld		●
3.	Flush contour		—
4.	Convex contour		⌒
5.	Concave contour		◡
6.	Grinding finish	 G	G
7.	Machining finish	 M	M
8.	Chipping finish	 C	C

9-2 Butt and Fillet Welds

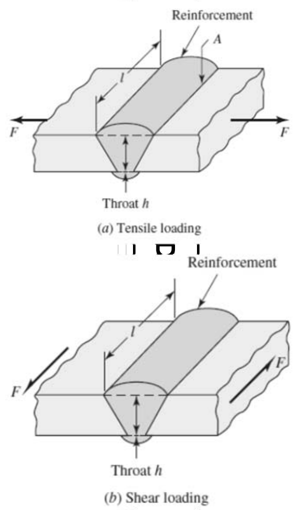
- The *Normal Stress* in the Butt joint due to tension or compression loading

$$\sigma = \frac{F}{hl} \rightarrow (9.1)$$

- The average *Shear Stress* in the Butt joint

$$\tau = \frac{F}{hl} \rightarrow (9.2)$$

- *h* is the throat length



9-2 Butt and Fillet Welds...

- The *Shear Stress* in Transverse Fillet Weld is

$$\tau = \frac{F_s}{tl} \rightarrow (1)$$

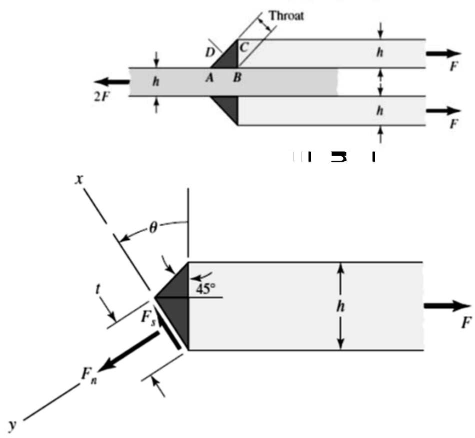
- The *Normal Stress* in the Transvers Fillet Weld is

$$\sigma = \frac{F_n}{tl} \rightarrow (2)$$

- Where

$$F_s = Fcos\theta$$
$$F_n = Fsin\theta$$

- *t* is the throat thickness



9-2 Butt and Fillet Welds...

- t is calculated using *sines law*

$$\frac{t}{sin45^o} = \frac{h}{sin(180^o - 45^o - \theta)}$$
$$= \frac{h}{sin(135^o - \theta)} = \frac{\sqrt{2}h}{cos\theta + sin\theta}$$

- From which

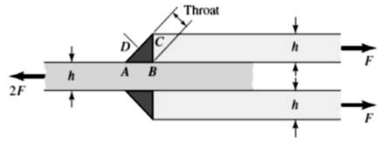
$$t = \frac{h}{cos\theta + \sin\theta}$$

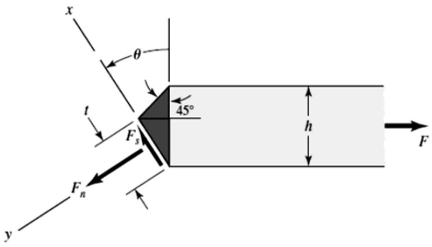
- Put for F_s and t in (1) to get

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

- Put for F_n and t in (2) to get

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





sin(A − B) = sin A cos B − cos A sin B

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9-2 Butt and Fillet Welds...

- The von Mises stress at angle θ is

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

- It is found that the largest von Mises stress occurs at an angle 62.5^o. Then

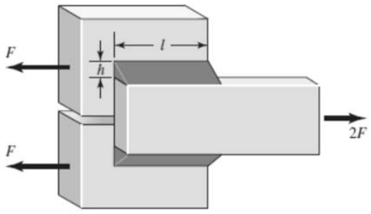
$$\tau = \frac{1.196F}{hl}$$

$$\sigma = \frac{0.623F}{hl}$$

9-2 Butt and Fillet Welds…

- The *Shear Stress* in Parallel Fillet Weld is (only shear stress occurs)

$$\tau = \frac{1.414F}{hl} \rightarrow (9.3)$$



9-3 Stresses in Welded Joints in Torsion

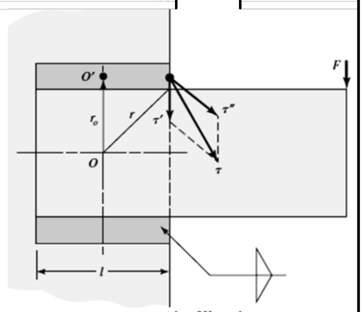
- Locate the critical point(s) and label
- Calculate *primary shear* (*A* is throat area)

$$\tau' = \frac{V}{A} \rightarrow (9.1)$$

- Calculate the *secondary shear* or torsion

$$\tau'' = \frac{Mr}{J} \rightarrow (9.1)$$

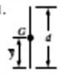
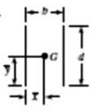
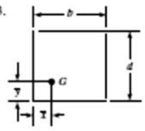
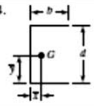
- *r* is the distance from the centroid of the weld group.
- Centroid $\bar{x}$ and $\bar{y}$ can be determined using Table 9-1
- And $J = 0.707hJ_u$
- J_u is taken from Table 9-1



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. 	$A = 0.707\,hd$	$\bar{x} = 0$ $\bar{y} = d/2$	$J_u = d^3/12$
2. 	$A = 1.414\,hd$	$\bar{x} = b/2$ $\bar{y} = d/2$	$J_u = \dfrac{d(3b^2 + d^2)}{6}$
3. 	$A = 0.707h(b + d)$	$\bar{x} = \dfrac{b^2}{2(b+d)}$ $\bar{y} = \dfrac{d^2}{2(b+d)}$	$J_u = \dfrac{(b+d)^4 - 6b^2d^2}{12(b+d)}$
4. 	$A = 0.707h(2b + d)$	$\bar{x} = \dfrac{b^2}{2b+d}$ $\bar{y} = d/2$	$J_u = \dfrac{8b^3 + 6bd^2 + d^3}{12} - \dfrac{b^4}{2b+d}$

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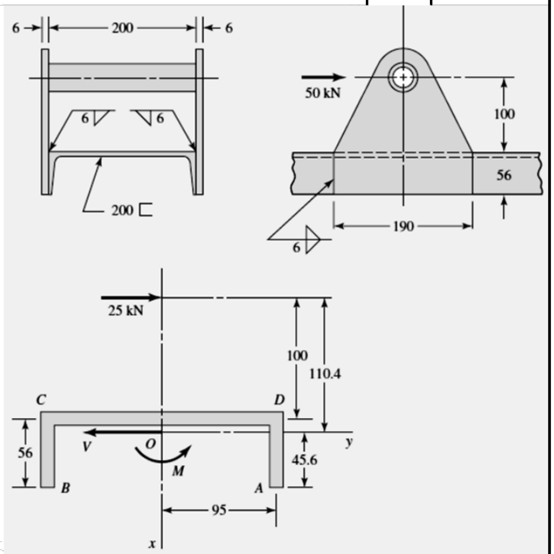
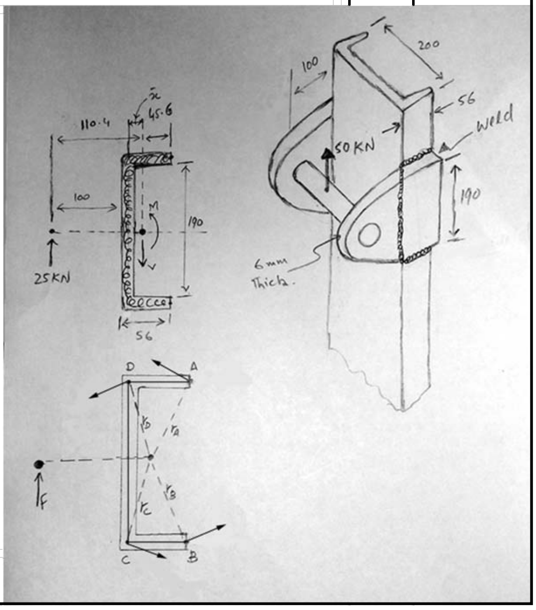
Example 9-1

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



Example 9-1 (Solution)

a) Label the ends and corners of each weld by letter
b) Estimate the primary shear τ'
c) Locate the centroid of the weld pattern $\bar{x}$
d) Find distances r_i
e) Find *J* using Table 9-1
f) Find *M*
g) Find secondary shear τ''
h) Find α (angle of τ'' along $\bar{x}$)
i) Find Shear stresses at all ends and corners
j) Identify the most stress point



9-4 Stresses in Welded Joints in Bending

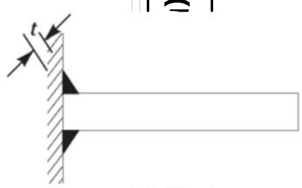
- Figure shows a welded joint subject to eccentric loading
- The eccentric load produces a vertical primary stress as

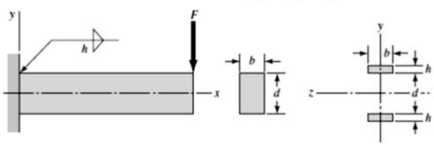
$$\tau' = \frac{V}{A} \rightarrow (a)$$

- and a horizontal bending stress as

$$\tau'' = \frac{Mc}{I} \rightarrow (b)$$

- Where $c = \frac{d}{2}$ and $I = 0.707hI_u$
- I_u is taken from Table 9.2





(a)
(b) Weld pattern

9-4 Stresses in Welded Joints in Bending…

- The vertical and horizontal stress components are vector sum to give the total weld stress

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

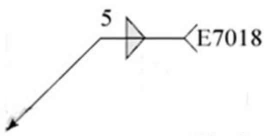
Table 9–2

Bending Properties of Fillet Welds*

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.	$A = 0.707h(2b + d)$	$\bar{x} = \frac{b^2}{2b + d}$ $\bar{y} = d/2$	$I_u = \frac{d^2}{12}(6b + d)$
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.	$A = 0.707h(b + 2d)$	$\bar{x} = b/2$ $\bar{y} = \frac{d^2}{b + 2d}$	$I_u = \frac{2d^3}{3} - 2d^2\bar{y} + (b + 2d)\bar{y}^2$

- Welding Electrode Classification

- Also known as Filler rod
- Represented on drawing as →
- Written as Exxxx-X, (E7018-X)
  - E Indicates that this is an electrode
  - 70 Indicates how strong this electrode is when welded, measured in thousands of psi.
  - 1 Indicates in what welding positions it can be used.
  - 8 Indicates the coating, penetration, and current type used. (See Weld Classification Table)
  - X Indicates that there are more requirements. (See Additional Requirements of weld)



Machine Design II)

- Welding Electrode Classification…

ME-305 (Machine Design II)

- Welding positions
  - 1 Flat, Horizontal, Vertical (up), Overhead
  - 2 Flat, Horizontal
  - 4 Flat, Horizontal, Overhead, Vertical (down)

9-5 The Strength of the Welded Joints

- Welding Electrode properties

Table 9–3
Minimum Weld-Metal Properties

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

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

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.

9-5 The Strength of the Welded Joints…

ME

- Minimum fillet weld sizes

Table 9–6

Allowable Steady Loads and Minimum Fillet Weld Sizes

Schedule A: Allowable Load for Various Sizes of Fillet Welds

	Strength Level of Weld Metal (EXX)						
	60*	70*	80	90*	100	110*	120
	Allowable shear stress on throat, MPa of fillet weld or partial penetration groove weld						
$\tau =$	124	145	165	186	207	228	248
	Allowable Unit Force on Fillet Weld, N/mm						
†$f =$	87.67h	102.52h	116.66h	131.5h	146.35h	161.2h	175.34h
Leg Size h, mm	Allowable Unit Force for Various Sizes of Fillet Welds N/mm						
25	2192	2563	2916	3288	3659	4030	4383
22	1929	2255	2566	2893	3220	3546	3857
20	1753	2050	2333	2630	2927	3224	3506
16	1403	1640	1866	2104	2342	2579	2805
12	1052	1230	1400	1578	1756	1934	2104
11	964	1127	1283	1447	1610	1773	1927
10	877	1025	1167	1315	1463	1612	1753
8	701	820	933	1052	1171	1290	1403
6	526	615	700	789	878	967	1052

Schedule B: Minimum Fillet Weld Size, h

Material Thickness of Thicker Part Joined, mm		Weld Size, mm
*To 6 incl.		3
Over 6	To 12	5
Over 12	To 20	6
†Over 20	To 38	8
Over 38	To 58	10
Over 58	To 150	12
Over 150		16

Not to exceed the thickness of the thinner part.

*Minimum size for bridge application does not go below 5 mm.

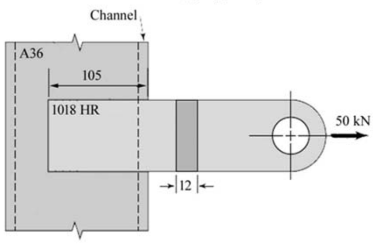
†For minimum fillet weld size, schedule does not go above 8 mm fillet weld for every 20 mm material.

9-6 Static Loading

ME-305 (M

Example 9-3

- A 12mm thick attachment, made of 1018HR steel, is to be welded to a A36 channel as shown. The normal static force is 50 kN. Specify the weldment by deciding;
  - the weld Pattern
  - The electrode number
  - type of the weld
  - the leg size



- Materials properties
  - 1018HR $\Rightarrow S_y = 220\text{ MPa}, S_{ut} = 400\text{ Mpa}$
  - A36 $\Rightarrow S_y = 250\text{ MPa}, S_{ut} = 400\text{ Mpa}$
- Joint type = Fillet

9-6 Static Loading…

Example 9-3 (Soln.)

1. Decide the weld pattern ➔ Parallel, Top and bottom
2. Choose weld metal (Welding wire)
   - E60xx has S_y = 345 MPa which is greater than the S_y of 1018HR & A36 and is selected with *E6010*
3. Find out the allowable stress of the weld assembly i.e. minimum of S_y of 1018HR, A36 and E6010
   - Take S_y = 220 and S_{ut} = 400 (smallest in all)
   - Calculate permissible Stress using Table 9-4 as;

$$\tau_{all} = 0.4S_y = 0.4 \times 220 = 88 \text{ MPa}$$

ME-305 (Machine Design II)

9-6 Static Loading…

Example 9-3 (Soln.)…

4. calculate *nh* using eq. 9-3 (for parallel fillet weld). Where *n* is the number of bead

$$\tau = \tau_{all} = \frac{1.414F}{nhl}$$

$$nh = \frac{1.414 \times F}{l \times t_{all}} = \frac{1.414 \times 50 \times 10^3}{105 \times 88} = 7.65$$

5. Make a Table

Number of beads (n)	Leg size (h)
1	7.65→8 mm
~~2~~	~~3.83→4 mm~~
3	2.55→ 3 mm
4	1.9→2mm

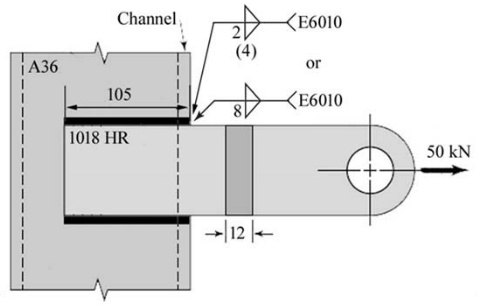
ME-305 (Machine Design II)

9-6 Static Loading…

ME-305 (Machine Design II)

Example 9-3 (Soln.)…

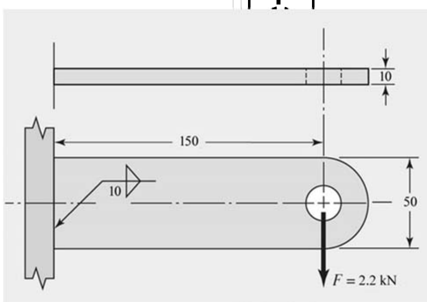
- Decisions:
  - Electrode: E6010
  - Weld pattern: Parallel Fillet, Top and Bottom
  - Leg size: Either 1 bead of 8 mm OR 4 beads of 2 mm (Specify either 2mm or 8mm on drawing, not both)



9-6 Static Loading…

Example 9-4

- Perform an adequacy assessment (by calculating the fos) of the statically loaded welded cantilever carrying 2.2kN. The cantilever is made of AISI 1018HR steel and welded with a 10-mm fillet weld as shown in the figure. An E6010 electrode was used, and the design factor was 3.0.
  a) Use the conventional method for the weld metal.
  b) Use the conventional method for the attachment (cantilever) metal.
  c) Use a welding code for the weld metal.



9-6 Static Loading…

Example 9-4 (soln.)

(a) Adequacy of the Weldment

- The weld pattern is "Fillet" and under "Bending". From Table 9-2,

$$A = 1.41hd = 1.41 \times 10 \times 50 = 707 \text{ mm}^2$$

$$I_u = \frac{d^3}{6} = \frac{50^3}{6} = 20833 \text{ mm}^3$$

$$I = 0.707hI_u = 0.707 \times 10 \times 20833 = 147289 \text{ mm}^4$$

- From Table 9-3, for E6010,

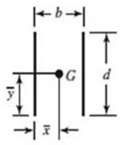
$$S_y = 345 \text{ Mpa}, S_{ut} = 427 \text{ Mpa}$$

- Primary shear τ'

$$\tau' = \frac{F}{A} = \frac{2200}{707} = 3.1 \text{ MPa}$$

Table 9-2
Bending Properties of Fillet Welds*

Weld	Throat Area
2.	



9-6 Static Loading…

Example 9-4 (soln.)…

- Secondary shear τ''

$$\tau'' = \frac{Mc}{I} = \frac{F \times d \times c}{I} = \frac{2200 \times 150 \times 25}{147289} = 56 \text{ MPa}$$

- The shear stress is

$$\tau = (\tau'^2 + \tau''^2)^{1/2} = 56.1 \text{ Mpa}$$

- fos

$$n = \frac{S_{sy}}{\tau} = \frac{0.577S_y}{\tau} = \frac{0.577 \times 345}{56.1} = 3.55$$

- Since $n \geq n_d$ i.e. $3.55 \geq 3.0$, the weld metal is "Adequate".

9-6 Static Loading…

Example 9-4 (soln.)…

(b) Adequacy of the Attachments

- Bending stress in the attachment

$$\sigma = \frac{Mc}{I} = \frac{(2200\times150)\times(^{50}/_{2})}{\frac{1}{12}\times10\times50^{3}} = 79.2 \text{ MPa}$$

- From Table A-20, for 1018 HR steel, $S_y = 220$ Mpa
- fos

$$n = \frac{S_y}{\sigma} = \frac{220}{79.2} = 2.78$$

- Since $n < n_d$ i.e. $2.78 < 3.0$, the attachment is "Not adequate".

ME-305 (Machine Design II)

9-6 Static Loading…

Example 9-4 (soln.)…

(c) Adequacy of the Weldment (using Welding Code)

- From part (a)

$$\tau = 56.1 \text{ Mpa}$$

- From Table 9-3, Allowable shear stress on the throat of E6010 fillet weld is $\tau_{all} = 124$ Mpa, then

$$n = \frac{\tau_{all}}{\tau} = \frac{124}{56.1} = 2.2 \rightarrow \text{(i)}$$

- But τ_{all} is calculated using DE theory and already includes a fos which is

$$n = \frac{0.577S_y}{\tau_{all}} = \frac{0.577\times345}{124} = 1.6 \rightarrow \text{(ii)}$$

- The fos will be (i) multiply by (ii)

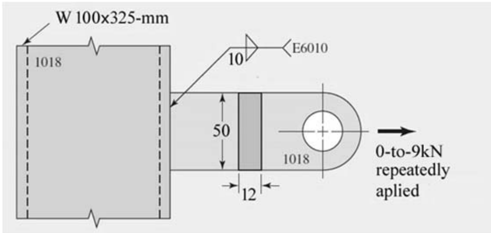
$$n = 2.2\times1.6 = 3.53 \text{ [Adequate]}$$

ME-305 (Machine Design II)

9-7 Fatigue Loading

Example 9-6

- The 1018 steel strap of Figure has a repeatedly applied load of 9 kN ($F_a = F_m = 4.5$ kN). Determine the fatigue factor of safety of the weldment using Gerber fatigue failure criterion.



9-7 Fatigue Loading…

Example 9-6 (Soln.)

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

Where

- $S_{su} = 0.67S_{ut}$
- $\tau_m = \tau_a = K_{fs}\frac{F}{A_s}$
- $A_s = 2 \times (0.707hl)$
- $S_{se} = k_a k_b k_c k_d k_e k_f S'_{se}$
- $S'_{se} = S'_e = 0.5S_{ut}$

$n = 5.99$

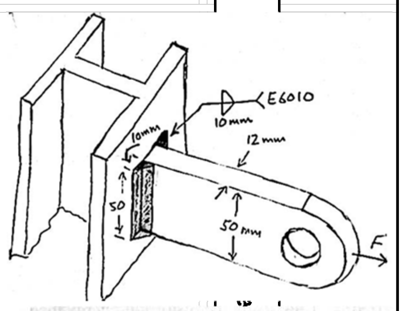


Table 9–5

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

Problems

- 9-2, 3, 8, 9, 14, 17, 20, 22, 26, 35, 45, 52

From
Shigley's Mechanical Engineering Design, 9th Ed.