

ME 4300 - Design of Mechanical Systems Quiz and Exam Resource

Stress Transformations

$$\tau_{max,xy} = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} ; \sigma_{p,xy} = \frac{\sigma_x + \sigma_y}{2} \pm \tau_{max,xy} ; \sigma_1 \geq \sigma_2 \geq \sigma_3 ; \tau_{max} = \frac{\sigma_1 - \sigma_3}{2}$$

Stresses and deformations

Tension, Compression: $\sigma = P/A ; \delta = PL/AE ; U = P^2L/2AE$

Direct Shear: $\tau = F/A$

Torsion: $\tau = Tr/J ; \tau_{max} = Tc/J ; \theta = TL/GJ ; U = T^2L/2GJ$

Pure bending: $\sigma = -My/I ; \sigma_{max} = Mc/I ; M/EI = d^2y/dx^2$

$$U = \int M^2/2EI dx ; \delta = \frac{1}{EI} \int M \frac{\partial M}{\partial P} dx$$

Singularity functions:

Concentrated moment at $x=a$: $M(x) = -M_0 \langle x - a \rangle^0$

Concentrated force at $x=a$: $M(x) = P \langle x - a \rangle^1$

Uniformly distributed load starting at $x=a$: $M(x) = \frac{1}{2}w \langle x - a \rangle^2$

Ramp starting at $x=a$: $M(x) = \frac{1}{6}k \langle x - a \rangle^3$

$$\langle x - a \rangle^n = (x - a)^n \quad \text{if } x \geq a, \quad = 0 \quad \text{if } x \leq a$$

$$\int \langle x - a \rangle^n dx = \frac{1}{n+1} \langle x - a \rangle^{n+1} \quad \text{if } n > 0$$

$$\int \langle x - a \rangle^n dx = \langle x - a \rangle^{n+1} \quad \text{if } n \leq 0$$

Shear stress due to bending: $\tau = \frac{VQ}{It}$

$$\tau_{max} = \frac{4V}{3A} \text{ (circular section)} ; \tau_{max} = \frac{3V}{2A} \text{ (rectangular section)} ; \tau_{max} = \frac{V}{A_{web}} \text{ (structural shape)}$$

Castigliano's Theorem: $\delta = \frac{\partial U_{total}}{\partial F_i}$

Columns

Critical slenderness ratio: $\left(\frac{l}{k}\right)_1 = \left(\frac{2\pi^2CE}{S_y}\right)^{1/2}$ if $l/k \geq (l/k)_1$ use Euler, else Johnson

Euler columns: $P_{cr} = \frac{C\pi^2EI}{l^2} ; \frac{P_{cr}}{A} = \frac{C\pi^2E}{(l/k)^2} ; d = \left(\frac{64P_{cr}l^2}{\pi^3CE}\right)^{1/4}$ for round columns

Johnson Columns: $\frac{P_{cr}}{A} = S_y - \left(\frac{S_y l}{2\pi k}\right)^2 \frac{1}{CE} ; d = 2\left(\frac{P_{cr}}{\pi S_y} + \frac{S_y l^2}{\pi^2 CE}\right)^{1/2}$ for round columns

Failure Theories

Ductile materials - Maximum Shear Stress Theory: $\tau_{\max allowable} = \frac{S_y}{2n}$

Ductile materials - Distortion Energy Theory: $\sigma'_{\max allowable} = \frac{S_y}{n}$

$$\text{von Mises stress: } \sigma' = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2}{2}} = \sqrt{\sigma_x^2 - \sigma_x \sigma_y + \sigma_y^2 + 3\tau_{xy}^2}$$

Brittle materials - Coulomb-Mohr Theory:

$$\begin{aligned} \sigma_A \geq \sigma_B \geq 0 \text{ then } \sigma_A &= \frac{S_{ut}}{n} \\ \sigma_A \geq 0 \geq \sigma_B \text{ then } \frac{\sigma_A}{S_{ut}} - \frac{\sigma_B}{S_{uc}} &= \frac{1}{n} \\ 0 \geq \sigma_A \geq \sigma_B \text{ then } \sigma_B &= -\frac{S_{uc}}{n} \end{aligned}$$

Endurance limit: $S'_e = 0.5S_{ut}$ if $S_{ut} \leq 200 \text{ kpsi (1400 MPa)}$, else 100 kpsi (700 MPa)

Fatigue strength: $S_f = aN^b$; $a = \frac{(fS_{ut})^2}{S_e}$; $b = -\frac{1}{3} \log\left(\frac{fS_{ut}}{S_e}\right)$

Endurance limit: $S_e = S'_e k_a k_b k_c k_d k_e$

Surface finish factor: $k_a = aS_{ut}^b$

Size factor: $k_b = 0.879d^{-0.107}$ if $0.11 \leq d \leq 2 \text{ in}$; $k_b = 0.910d^{-0.157}$ if $2 < d \leq 10 \text{ in}$
 $k_b = 1.24d^{-0.107}$ if $2.79 \leq d \leq 51 \text{ mm}$; $k_b = 1.51d^{-0.157}$ if $51 < d \leq 254 \text{ mm}$
 $d_e = 0.370d$ for nonrotating round, $d_e = 0.808\sqrt{hb}$ for nonrotating rectangle
 $k_b = 1$ for axial loads

Loading factor: $k_c = 1$ for bending, 0.85 for axial loads, 0.59 for torsion

Fatigue stress concentration factor: $k_f = 1 + q(k_t - 1)$

Mean stress, stress amplitude: $\sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2}$; $\sigma_a = \frac{\sigma_{\max} - \sigma_{\min}}{2}$

Modified Goodman criteria: $\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}} = \frac{1}{n}$; $\sigma_{rev} = \frac{\sigma_a}{1 - \left(\frac{\sigma_m}{S_{ut}}\right)}$

Gerber criterion: $\frac{n\sigma_a}{S_e} + \left(\frac{n\sigma_m}{S_{ut}}\right)^2 = 1$; $\sigma_{rev} = \frac{\sigma_a}{1 - \left(\frac{\sigma_m}{S_{ut}}\right)^2}$

Static (Langer) failure: $\sigma_a + |\sigma_m| = \frac{S_y}{n}$

Fasteners

Power screws: raising: $T_R = \frac{F d_m}{2} \left(\frac{l + \pi f d_m \sec \alpha}{\pi d_m - f l \sec \alpha} \right)$; lowering: $T_L = \frac{F d_m}{2} \left(\frac{\pi f d_m \sec \alpha - l}{\pi d_m + f l \sec \alpha} \right)$;
self-locking: $\pi f d_m > l$

Bolt stiffness: $k_b = \frac{AE}{l} = \frac{A_d A_t E}{A_d l_t + A_t l_d}$; Member stiffness: $k_m = \frac{0.5774 \pi E d}{\ln \left(\frac{(1.155t + D - d)(D + d)}{(1.155t + D + d)(D - d)} \right)}$; $C = \frac{k_b}{k_b + k_m}$

Bolt torque: $T = K F_i d$

Load factor against overload: $n_L = \frac{S_p A_t - F_i}{CP}$; Factor of safety against yielding: $n_p = \frac{S_p A_t}{CP + F_i} = \frac{S_p}{\sigma_a + \sigma_m}$

Factor of safety against joint separation: $n_o = \frac{F_i}{P(1-C)}$

Non-permanent connections: $F_i = 0.75 A_t S_p$; permanent connections, $F_i = 0.9 A_t S_p$

Fatigue loading between no-load and max load P: $\sigma_a = \frac{CP}{2A_t}$; $\sigma_m = \frac{CP}{2A_t} + \frac{F_i}{A_t}$

Welds

Butt and fillet welds: $\tau = \frac{F}{A_t} = \frac{F}{0.707 hl}$

Joints in torsion: $\tau' = \frac{V}{A_t}$; $\tau'' = \frac{Mr}{J} = \frac{Mr}{0.707 h J_u}$

Joints in bending: $\tau' = \frac{V}{A_t}$; $\tau'' = \frac{Mr}{I} = \frac{Mr}{0.707 h I_u}$

Helical springs

Mean diameter: $D = OD - d = ID + d$; Spring index: $C = D/d$

Stress: $\tau_{max} = K_B \frac{8FD}{\pi d^3}$; $K_B = \frac{4C+2}{4C-3}$;

Spring rate: $k = \frac{d^4 G}{8D^3 N}$

Absolute stability of steel compression springs: $L_0 < 2.63 \frac{D}{\alpha}$

Spring materials: $S_{ut} = \frac{A}{d^m}$; $S_{su} = 0.67 S_{ut}$; $S_{sy} = 0.45 S_{ut}$

Critical frequency of helical springs: $f = \frac{1}{2} \sqrt{\frac{kg}{W}}$

Fatigue loading: unpeened: $S_{sa} = 35$ ksi (241 MPa), $S_{sm} = 55$ ksi (379 MPa)
peened: $S_{sa} = 57.5$ ksi (398 MPa), $S_{sm} = 77.5$ ksi (534 MPa)

$\tau_a = K_B \frac{8F_a D}{\pi d^3}$; $\tau_m = K_B \frac{8F_m D}{\pi d^3}$; $r = \tau_a / \tau_m = F_a / F_m$

Goodman: $S_{se} = \frac{S_{sa}}{1 - (S_{sm} / S_{su})}$; $S_{sa} = \frac{r S_{se} S_{su}}{r S_{su} + S_{se}}$; $n_f = S_{sa} / \tau_a$

Gears

Circular pitch = p

Diametral pitch = $P = N/d$; module = d/N

$pP = \pi$

Train value: $n_{last} = en_{first}$; $e = (-1)^{\# \text{ gear interfaces}} \frac{\text{Product of driving tooth numbers}}{\text{Product of driven tooth numbers}}$

Planetary systems: $e = \frac{n_L - n_a}{n_F - n_a}$

$W_t = 33000 \frac{H}{V}$; W_t (pounds), H (hp), $V = \pi dn/12$ = pitch-line velocity in ft/min, d (in), n (rpm)

$W_t = \frac{60,000 H}{\pi dn}$; W_t (kN), H (kW), d (mm), n (rpm)

Table 4–2 End-Condition Constants for Euler Columns [to Be Used with Equation (4–43)]

End-Condition Constant C			
Column End Conditions	Theoretical Value	Conservative Value	Recommended Value*
Fixed-free	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$
Rounded-rounded	1	1	1
Fixed-rounded	2	1	1.2
Fixed-fixed	4	1	1.2

*To be used only with liberal factors of safety when the column load is accurately known.

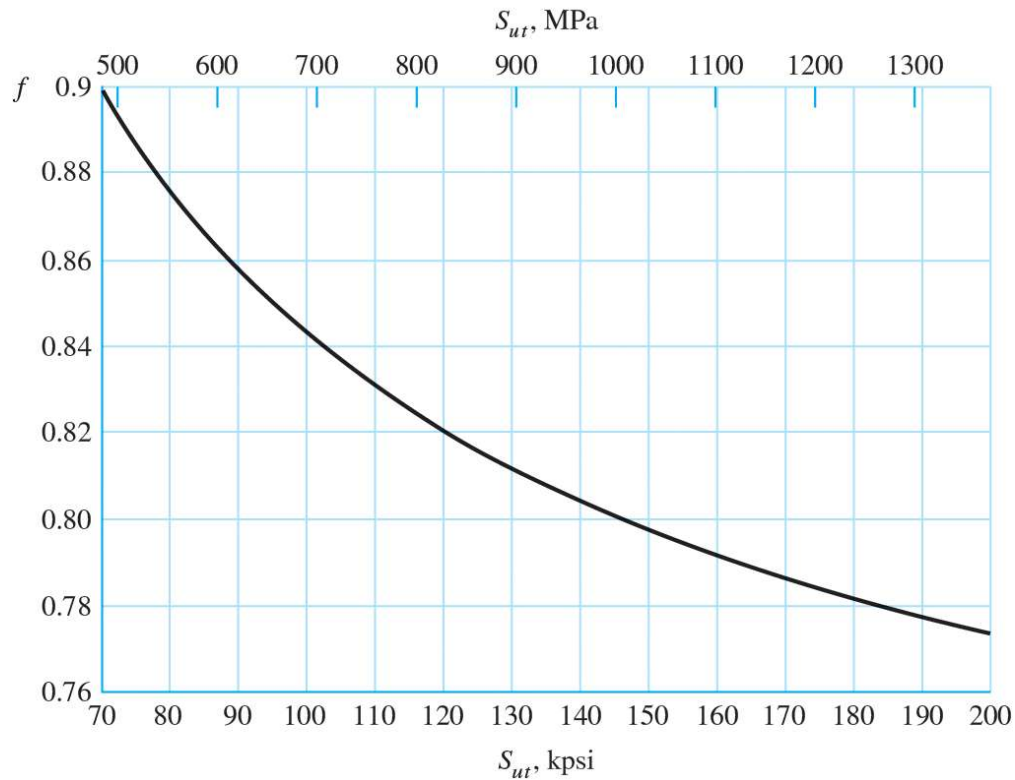
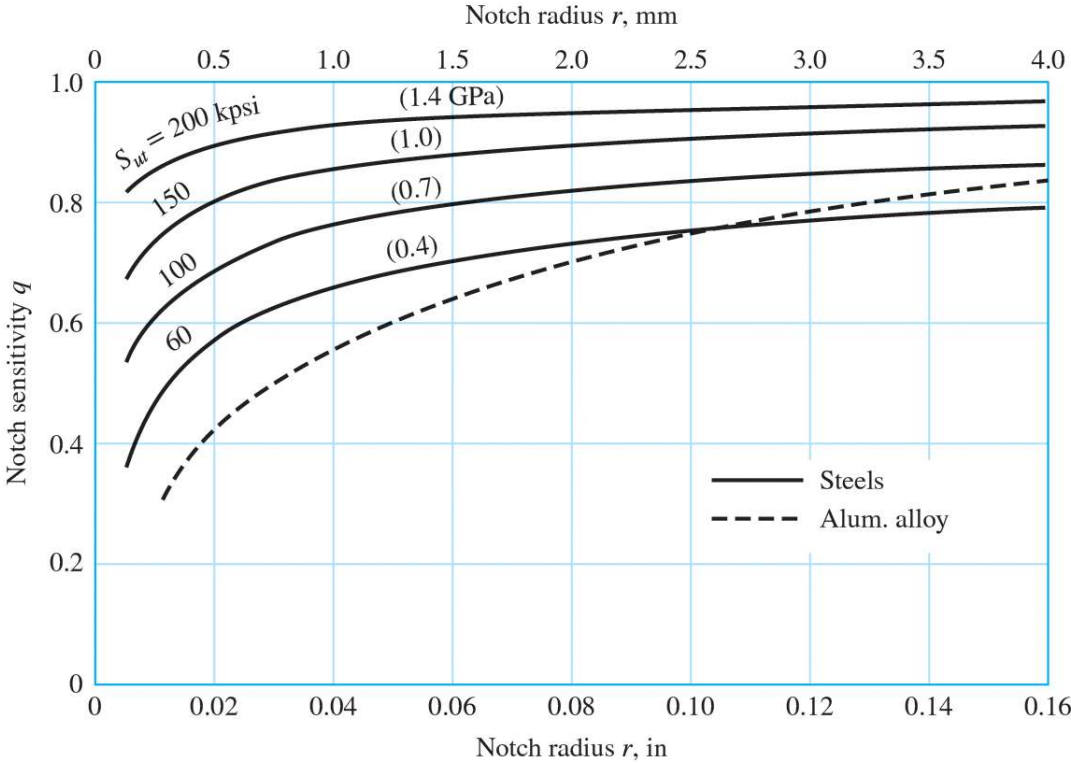


Table 6–2 Curve Fit Parameters for Surface Factor, Equation (6–18)

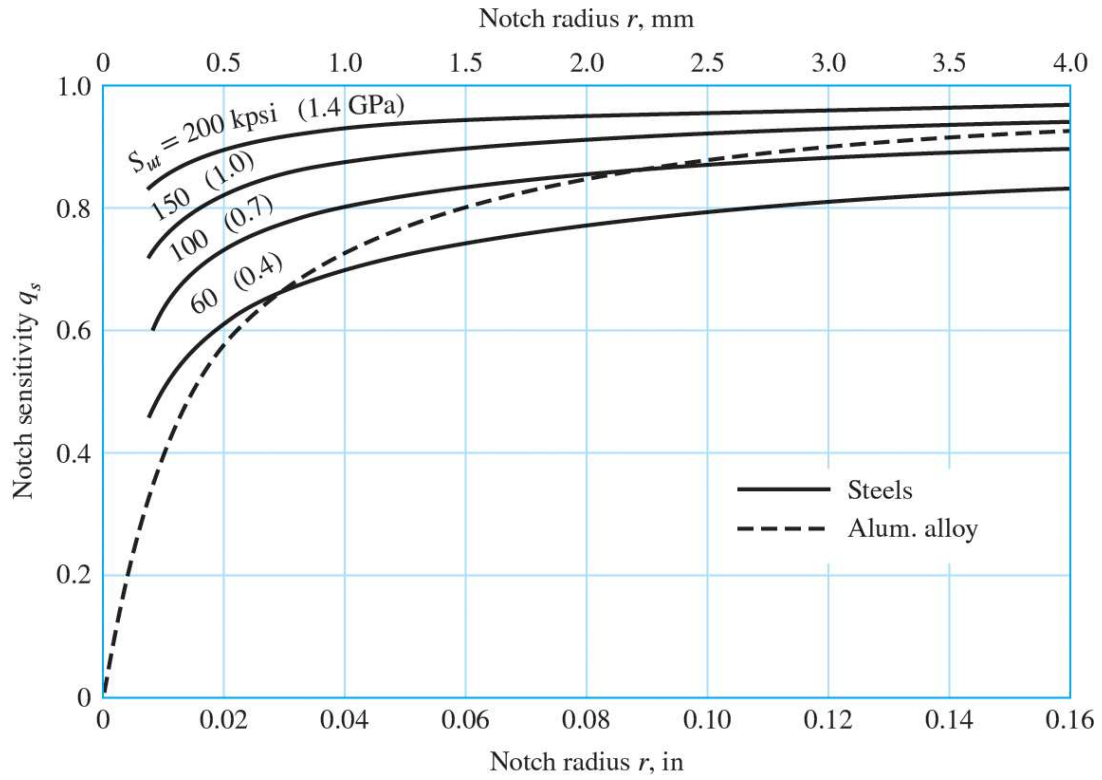
Surface Finish	Factor a		Exponent b
	S_{ut} , kpsi	S_{ut} , MPa	
Ground	1.21	1.38	-0.067
Machined or cold-drawn	2.00	3.04	-0.217
Hot-rolled	11.0	38.6	-0.650
As-forged	12.7	54.9	-0.758

Table 6–4 Reliability Factors k_e Corresponding to 8 Percent Standard Deviation of the Endurance Limit

Reliability, %	Transformation Variate z_a	Reliability Factor k_e
50	0	1.000
90	1.288	0.897
95	1.645	0.868
99	2.326	0.814
99.9	3.091	0.753
99.99	3.719	0.702



Notch-sensitivity for steel and aluminum – reversed bending and axial loads



Notch-sensitivity for steel and aluminum – reversed torsion

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
30	3.5	561	519	2	621	596
36	4	817	759	2	915	884
42	4.5	1120	1050	2	1260	1230
48	5	1470	1380	2	1670	1630
56	5.5	2030	1910	2	2300	2250
64	6	2680	2520	2	3030	2980
72	6	3460	3280	2	3860	3800
80	6	4340	4140	1.5	4850	4800
90	6	5590	5360	2	6100	6020
100	6	6990	6740	2	7560	7470
110				2	9180	9080









*The equations and data used to develop this table have been obtained from ANSI B1.1-1974 and B18.3.1-1978. The minor diameter was found from the equation $d_r = d - 1.226\ 869p$, and the pitch diameter from $d_p = d - 0.649\ 519p$. The mean of the pitch diameter and the minor diameter was used to compute the tensile-stress area.

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

Size Designation	Nominal Major Diameter in	Coarse Series—UNC			Fine Series—UNF		
		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
$\frac{5}{8}$	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










*This table was compiled from ANSI B1.1-1974. The minor diameter was found from the equation $d_r = d - 1.299\ 038p$, and the pitch diameter from $d_p = d - 0.649\ 519p$. The mean of the pitch diameter and the minor diameter was used to compute the tensile-stress area.

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	








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

Table 8-10 ASTM Specifications for Steel Bolts

ASTM Designation 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	

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

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	
4.8	M1.6–M16	310	420	340	Low or medium carbon	
5.8	M5–M24	380	520	420	Low or medium carbon	
8.8	M16–M36	600	830	660	Medium carbon, Q&T	
9.8	M1.6–M16	650	900	720	Medium carbon, Q&T	
10.9	M5–M36	830	1040	940	Low-carbon martensite, Q&T	
12.9	M1.6–M36	970	1220	1100	Alloy, Q&T	

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

NOTE: The size range for Class 8.8 is M1.6 - M36

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

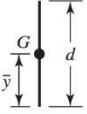
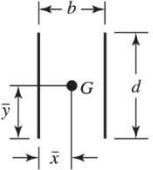
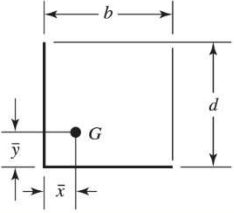
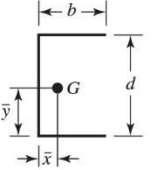
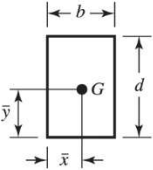
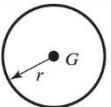
Bolt Condition	<i>K</i>
Nonplated, black finish	0.30
Zinc-plated	0.20
Lubricated	0.18
Cadmium-plated	0.16
With Bowman Anti-Seize	0.12
With Bowman-Grip nuts	0.09

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, including K_f as a strength reducer.

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. 	$A = 1.414hd$	$\bar{x} = b/2$ $\bar{y} = d/2$	$J_u = \frac{d(3b^2 + d^2)}{6}$
3. 	$A = 0.707h(b + d)$	$\bar{x} = \frac{b^2}{2(b + d)}$ $\bar{y} = \frac{d^2}{2(b + d)}$	$J_u = \frac{(b + d)^4 - 6b^2d^2}{12(b + d)}$
4. 	$A = 0.707h(2b + d)$	$\bar{x} = \frac{b^2}{2b + d}$ $\bar{y} = d/2$	$J_u = \frac{8b^3 + 6bd^2 + d^3}{12} - \frac{b^4}{2b + d}$
5. 	$A = 1.414h(b + d)$	$\bar{x} = b/2$ $\bar{y} = d/2$	$J_u = \frac{(b + d)^3}{6}$
6. 	$A = 1.414\pi hr$		$J_u = 2\pi r^3$

* 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.

Table 9–2 Bending Properties of Fillet Welds*

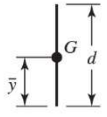
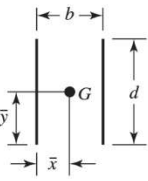
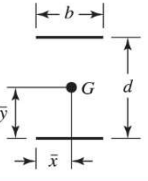
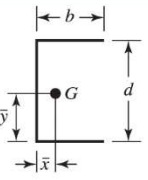
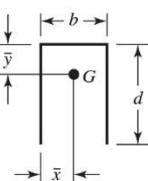
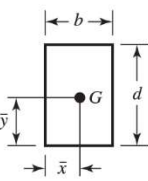
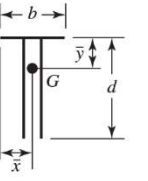
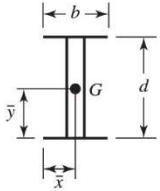
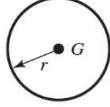
Weld	Throat Area	Location of G	Unit Second Moment of Area
1. 	$A = 0.707hd$	$\bar{x} = 0$ $\bar{y} = d/2$	$I_u = \frac{d^3}{12}$
2. 	$A = 1.414hd$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \frac{d^3}{6}$
3. 	$A = 1.414hb$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \frac{bd^2}{2}$
4. 	$A = 0.707h(2b + d)$	$\bar{x}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

Table 9-2 (Continued)

Weld	Throat Area	Location of G	Unit Second Moment of Area
8. 	$A = 1.414h(b + d)$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \frac{d^2}{6}(3b + d)$
9. 	$A = 1.414\pi hr$		$I_u = \pi r^3$

* I_u , unit second moment of area, is taken about a horizontal axis through G , the centroid of the weld group, h is weld size; the plane of the bending couple is normal to the plane of the paper and parallel to the y -axis; all welds are of the same size.

Table 9-2

Bending Properties of Fillet Welds*

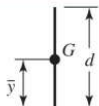
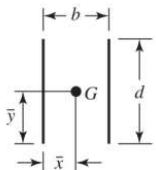
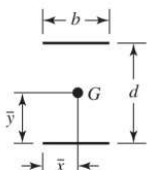
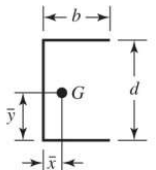
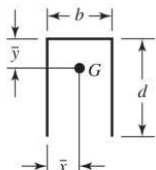
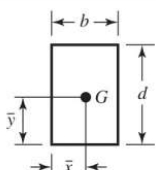
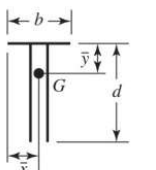
Weld	Throat Area	Location of G	Unit Second Moment of Area
1. 	$A = 0.707hd$	$\bar{x} = 0$ $\bar{y} = d/2$	$I_u = \frac{d^3}{12}$
2. 	$A = 1.414hd$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \frac{d^3}{6}$
3. 	$A = 1.414hb$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \frac{bd^2}{2}$
4. 	$A = 0.707h(2b + d)$	$\bar{x}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

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

*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.

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

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.

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

Table 10–1 Formulas for the Dimensional Characteristics of Compression Springs (N_a = Number of Active Coils)

Term	Type of Spring Ends			
	Plain	Plain and Ground	Squared or Closed	Squared and Ground
End coils, N_e	0	1	2	2
Total coils, N_t	N_a	$N_a + 1$	$N_a + 2$	$N_a + 2$
Free length, L_0	$pN_a + d$	$p(N_a + 1)$	$pN_a + 3d$	$pN_a + 2d$
Solid length, L_s	$d(N_t + 1)$	dN_t	$d(N_t + 1)$	dN_t
Pitch, p	$(L_0 - d)/N_a$	$L_0/(N_a + 1)$	$(L_0 - 3d)/N_a$	$(L_0 - 2d)/N_a$

Source: Data from *Design Handbook*, 1987, p. 32.

Table 10–2 End-Condition Constants α for Helical Compression Springs*

End Condition	Constant α
Spring supported between flat parallel surfaces (fixed ends)	0.5
One end supported by flat surface perpendicular to spring axis (fixed); other end pivoted (hinged)	0.707
Both ends pivoted (hinged)	1
One end clamped; other end free	2

*Ends supported by flat surfaces must be squared and ground.

Table 10–4 Constants A and m of $S_u = A/d^m$ for Estimating Minimum Tensile Strength of Common Spring Wires

Material	ASTM No.	Exponent m	Diameter, in	A , kpsi · in ^{m}	Diameter, mm	A , MPa · mm ^{m}	Relative Cost of Wire
Music wire*	A228	0.145	0.004–0.256	201	0.10–6.5	2211	2.6
OQ&T wire [†]	A229	0.187	0.020–0.500	147	0.5–12.7	1855	1.3
Hard-drawn wire [‡]	A227	0.190	0.028–0.500	140	0.7–12.7	1783	1.0
Chrome-vanadium wire [§]	A232	0.168	0.032–0.437	169	0.8–11.1	2005	3.1
Chrome-silicon wire	A401	0.108	0.063–0.375	202	1.6–9.5	1974	4.0
302 Stainless wire [#]	A313	0.146	0.013–0.10	169	0.3–2.5	1867	7.6–11
		0.263	0.10–0.20	128	2.5–5	2065	
		0.478	0.20–0.40	90	5–10	2911	
Phosphor-bronze wire ^{**}	B159	0	0.004–0.022	145	0.1–0.6	1000	8.0
		0.028	0.022–0.075	121	0.6–2	913	
		0.064	0.075–0.30	110	2–7.5	932	

*Surface is smooth, free of defects, and has a bright, lustrous finish.

[†]Has a slight heat-treating scale which must be removed before plating.

[‡]Surface is smooth and bright with no visible marks.

[§]Aircraft-quality tempered wire, can also be obtained annealed.

^{||}Tempered to Rockwell C49, but may be obtained untempered.

[#]Type 302 stainless steel.

^{**}Temper CA510.

Source: Data from *Design Handbook*, 1987, p. 19.

Table 10–5 Mechanical Properties of Some Spring Wires

Material	Elastic Limit, Percent of S_{ut}		Diameter d , in	E		G	
	Tension	Torsion		Mpsi	GPa	Mpsi	GPa
Music wire A228	65–75	45–60	<0.032	29.5	203.4	12.0	82.7
			0.033–0.063	29.0	200	11.85	81.7
			0.064–0.125	28.5	196.5	11.75	81.0
			>0.125	28.0	193	11.6	80.0
HD spring A227	60–70	45–55	<0.032	28.8	198.6	11.7	80.7
			0.033–0.063	28.7	197.9	11.6	80.0
			0.064–0.125	28.6	197.2	11.5	79.3
			>0.125	28.5	196.5	11.4	78.6
Oil tempered A239	85–90	45–50		28.5	196.5	11.2	77.2
Valve spring A230	85–90	50–60		29.5	203.4	11.2	77.2
Chrome-vanadium A231 A232	88–93	65–75		29.5	203.4	11.2	77.2
	88–93			29.5	203.4	11.2	77.2
Chrome-silicon A401	85–93	65–75		29.5	203.4	11.2	77.2
Stainless steel							
A313*	65–75	45–55		28	193	10	69.0
17-7PH	75–80	55–60		29.5	208.4	11	75.8
414	65–70	42–55		29	200	11.2	77.2
420	65–75	45–55		29	200	11.2	77.2
431	72–76	50–55		30	206	11.5	79.3
Phosphor-bronze B159	75–80	45–50		15	103.4	6	41.4
Beryllium-copper B197	70	50		17	117.2	6.5	44.8
Inconel alloy X-750	65–70	40–45		31	213.7	11.2	77.2

*Also includes 302, 304, and 316.

Note: See Table 10–6 for allowable torsional stress design values.

Table 13–1

Standard and Commonly Used Tooth Systems for Spur Gears

Tooth System	Pressure Angle ϕ , deg	Addendum a	Dedendum b
Full depth	20	$1/P$ or m	$1.25/P$ or $1.25m$ $1.35/P$ or $1.35m$
	$22\frac{1}{2}$	$1/P$ or m	$1.25/P$ or $1.25m$ $1.35/P$ or $1.35m$
	25	$1/P$ or m	$1.25/P$ or $1.25m$ $1.35/P$ or $1.35m$
	Stub	20	$0.8/P$ or $0.8m$

Table 13-2

Tooth Sizes in General
Uses

Diametral Pitch P (teeth/in)	
Coarse	2, $2\frac{1}{4}$, $2\frac{1}{2}$, 3, 4, 6, 8, 10, 12, 16
Fine	20, 24, 32, 40, 48, 64, 80, 96, 120, 150, 200

Module m (mm/tooth)	
Preferred	1, 1.25, 1.5, 2, 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 32, 40, 50
Next Choice	1.125, 1.375, 1.75, 2.25, 2.75, 3.5, 4.5, 5.5, 7, 9, 11, 14, 18, 22, 28, 36, 45

Table 13-3

Tooth Proportions for
 20° Straight Bevel-Gear
Teeth

Item	Formula												
Working depth	$h_k = 2.0/P$ [= 2.0 m]												
Clearance	$c = (0.188/P) + 0.002$ in [= 0.188 m + 0.05 mm]												
Addendum of gear	$a_G = \frac{0.54}{P} + \frac{0.460}{P(m_{90})^2}$ [= 0.54 m + $\frac{0.46 \text{ m}}{(m_{90})^2}$]												
Gear ratio	$m_G = N_G/N_P$												
Equivalent 90° ratio	$m_{90} = m_G$ when $\Gamma = 90^\circ$ $m_{90} = \sqrt{m_G \frac{\cos \gamma}{\cos \Gamma}}$ when $\Gamma \neq 90^\circ$												
Face width	$F = 0.3A_0$ or $F = \frac{10}{P}$, whichever is smaller [$F = \frac{A_0}{3}$ or $F = 10 \text{ m}$]												
Minimum number of teeth	<table border="1"> <thead> <tr> <th></th> <th>Pinion</th> <th>16</th> <th>15</th> <th>14</th> <th>13</th> </tr> </thead> <tbody> <tr> <td></td> <td>Gear</td> <td>16</td> <td>17</td> <td>20</td> <td>30</td> </tr> </tbody> </table>		Pinion	16	15	14	13		Gear	16	17	20	30
	Pinion	16	15	14	13								
	Gear	16	17	20	30								

Table A-5 Physical Constants of Materials

Material	Modulus of Elasticity E		Modulus of Rigidity G		Poisson's Ratio ν	Unit Weight w		
	Mpsi	GPa	Mpsi	GPa		lbf/in ³	lbf/ft ³	kN/m ³
Aluminum (all alloys)	10.4	71.7	3.9	26.9	0.333	0.098	169	26.6
Beryllium copper	18.0	124.0	7.0	48.3	0.285	0.297	513	80.6
Brass	15.4	106.0	5.82	40.1	0.324	0.309	534	83.8
Carbon steel	30.0	207.0	11.5	79.3	0.292	0.282	487	76.5
Cast iron (gray)	14.5	100.0	6.0	41.4	0.211	0.260	450	70.6
Copper	17.2	119.0	6.49	44.7	0.326	0.322	556	87.3
Douglas fir	1.6	11.0	0.6	4.1	0.33	0.016	28	4.3
Glass	6.7	46.2	2.7	18.6	0.245	0.094	162	25.4
Inconel	31.0	214.0	11.0	75.8	0.290	0.307	530	83.3
Lead	5.3	36.5	1.9	13.1	0.425	0.411	710	111.5
Magnesium	6.5	44.8	2.4	16.5	0.350	0.065	112	17.6
Molybdenum	48.0	331.0	17.0	117.0	0.307	0.368	636	100.0
Monel metal	26.0	179.0	9.5	65.5	0.320	0.319	551	86.6
Nickel silver	18.5	127.0	7.0	48.3	0.322	0.316	546	85.8
Nickel steel	30.0	207.0	11.5	79.3	0.291	0.280	484	76.0
Phosphor bronze	16.1	111.0	6.0	41.4	0.349	0.295	510	80.1
Stainless steel (18-8)	27.6	190.0	10.6	73.1	0.305	0.280	484	76.0
Titanium alloys	16.5	114.0	6.2	42.4	0.340	0.160	276	43.4

Table A-8 Properties of Round Tubing w_a = unit weight of aluminum tubing, lbf/ft w_s = unit weight of steel tubing, lbf/ft m = unit mass, kg/m A = area, in² (cm²) I = second moment of area, in⁴ (cm⁴) J = second polar moment of area, in⁴ (cm⁴) k = radius of gyration, in (cm) Z = section modulus, in³ (cm³) $d \times t$ = size (OD) and thickness, in (mm)

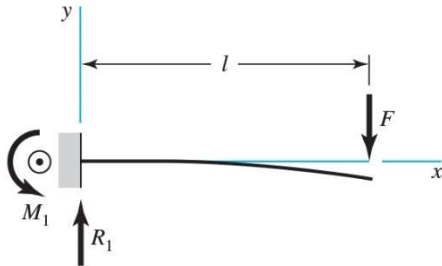
Size, in	w_a	w_s	A	I	k	Z	J
$1 \times \frac{1}{8}$	0.416	1.128	0.344	0.034	0.313	0.067	0.067
$1 \times \frac{1}{4}$	0.713	2.003	0.589	0.046	0.280	0.092	0.092
$1\frac{1}{2} \times \frac{1}{8}$	0.653	1.769	0.540	0.129	0.488	0.172	0.257
$1\frac{1}{2} \times \frac{1}{4}$	1.188	3.338	0.982	0.199	0.451	0.266	0.399
$2 \times \frac{1}{8}$	0.891	2.670	0.736	0.325	0.664	0.325	0.650
$2 \times \frac{1}{4}$	1.663	4.673	1.374	0.537	0.625	0.537	1.074
$2\frac{1}{2} \times \frac{1}{8}$	1.129	3.050	0.933	0.660	0.841	0.528	1.319
$2\frac{1}{2} \times \frac{1}{4}$	2.138	6.008	1.767	1.132	0.800	0.906	2.276
$3 \times \frac{1}{4}$	2.614	7.343	2.160	2.059	0.976	1.373	4.117
$3 \times \frac{3}{8}$	3.742	10.51	3.093	2.718	0.938	1.812	5.436
$4 \times \frac{3}{16}$	2.717	7.654	2.246	4.090	1.350	2.045	8.180
$4 \times \frac{3}{8}$	5.167	14.52	4.271	7.090	1.289	3.544	14.180

Size, mm	m	A	I	k	Z	J
12 × 2	0.490	0.628	0.082	0.361	0.136	0.163
16 × 2	0.687	0.879	0.220	0.500	0.275	0.440
16 × 3	0.956	1.225	0.273	0.472	0.341	0.545
20 × 4	1.569	2.010	0.684	0.583	0.684	1.367
25 × 4	2.060	2.638	1.508	0.756	1.206	3.015
25 × 5	2.452	3.140	1.669	0.729	1.336	3.338
30 × 4	2.550	3.266	2.827	0.930	1.885	5.652
30 × 5	3.065	3.925	3.192	0.901	2.128	6.381
42 × 4	3.727	4.773	8.717	1.351	4.151	17.430
42 × 5	4.536	5.809	10.130	1.320	4.825	20.255
50 × 4	4.512	5.778	15.409	1.632	6.164	30.810
50 × 5	5.517	7.065	18.118	1.601	7.247	36.226

Table A-9 Shear, Moment, and Deflection of Beams

(Note: Force and moment reactions are positive in the directions shown; equations for shear force V and bending moment M follow the sign conventions given in Sec. 3-2.)

1 Cantilever—end load

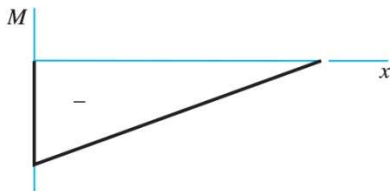
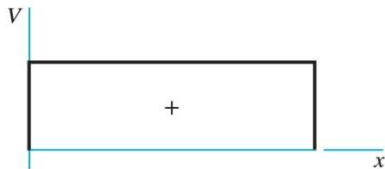


$$R_1 = V = F \quad M_1 = Fl$$

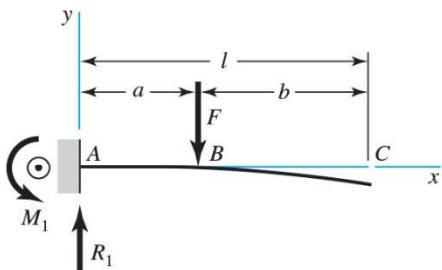
$$M = F(x - l)$$

$$y = \frac{Fx^2}{6EI}(x - 3l)$$

$$y_{\max} = -\frac{Fl^3}{3EI}$$



2 Cantilever—intermediate load



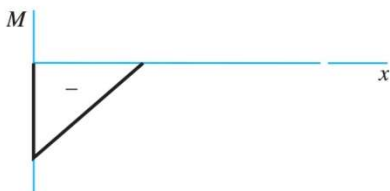
$$R_1 = V = F \quad M_1 = Fa$$

$$M_{AB} = F(x - a) \quad M_{BC} = 0$$

$$y_{AB} = \frac{Fx^2}{6EI}(x - 3a)$$

$$y_{BC} = \frac{Fa^2}{6EI}(a - 3x)$$

$$y_{\max} = \frac{Fa^2}{6EI}(a - 3l)$$

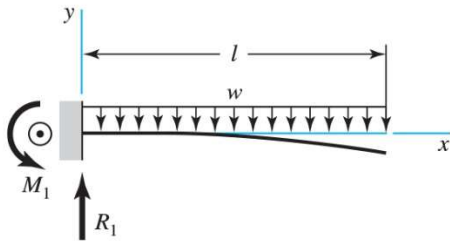


(Continued)

Table A-9 Shear, Moment, and Deflection of Beams (Continued)

(Note: Force and moment reactions are positive in the directions shown; equations for shear force V and bending moment M follow the sign conventions given in Sec. 3-2.)

3 Cantilever—uniform load

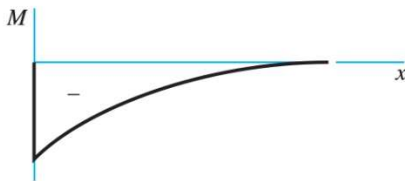
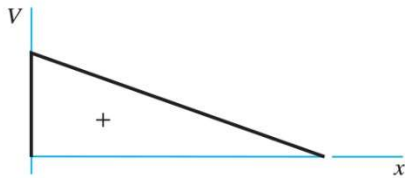


$$R_1 = wl \quad M_1 = \frac{wl^2}{2}$$

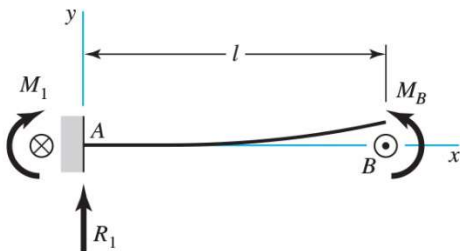
$$V = w(l - x) \quad M = -\frac{w}{2}(l - x)^2$$

$$y = \frac{wx^2}{24EI}(4lx - x^2 - 6l^2)$$

$$y_{\max} = -\frac{wl^4}{8EI}$$



4 Cantilever—moment load



$$R_1 = V = 0 \quad M_1 = M = M_B$$

$$y = \frac{M_B x^2}{2EI} \quad y_{\max} = \frac{M_B l^2}{2EI}$$

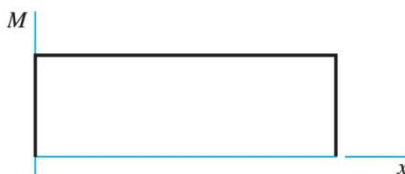
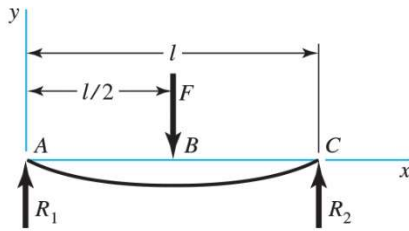


Table A-9 Shear, Moment, and Deflection of Beams (Continued)

(Note: Force and moment reactions are positive in the directions shown; equations for shear force V and bending moment M follow the sign conventions given in Sec. 3-2.)

5 Simple supports—center load



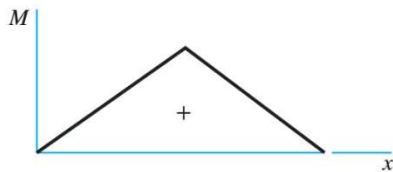
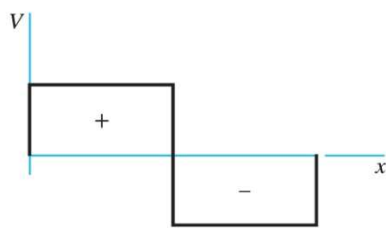
$$R_1 = R_2 = \frac{F}{2}$$

$$V_{AB} = R_1 \quad V_{BC} = -R_2$$

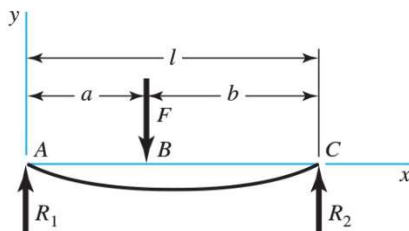
$$M_{AB} = \frac{Fx}{2} \quad M_{BC} = \frac{F}{2}(l-x)$$

$$y_{AB} = \frac{Fx}{48EI}(4x^2 - 3l^2)$$

$$y_{\max} = -\frac{Fl^3}{48EI}$$



6 Simple supports—intermediate load



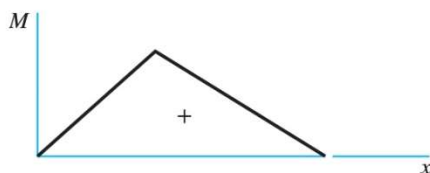
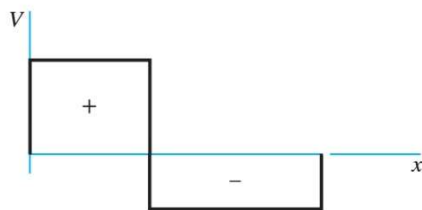
$$R_1 = \frac{Fb}{l} \quad R_2 = \frac{Fa}{l}$$

$$V_{AB} = R_1 \quad V_{BC} = -R_2$$

$$M_{AB} = \frac{Fbx}{l} \quad M_{BC} = \frac{Fa}{l}(l-x)$$

$$y_{AB} = \frac{Fbx}{6EI}(x^2 + b^2 - l^2)$$

$$y_{BC} = \frac{Fa(l-x)}{6EI}(x^2 + a^2 - 2lx)$$



(Continued)

Table A-15 Charts of Theoretical Stress-Concentration Factors K_t^*

Figure A-15-1

Bar in tension or simple compression with a transverse hole. $\sigma_0 = F/A$, where $A = (w - d)t$ and t is the thickness.

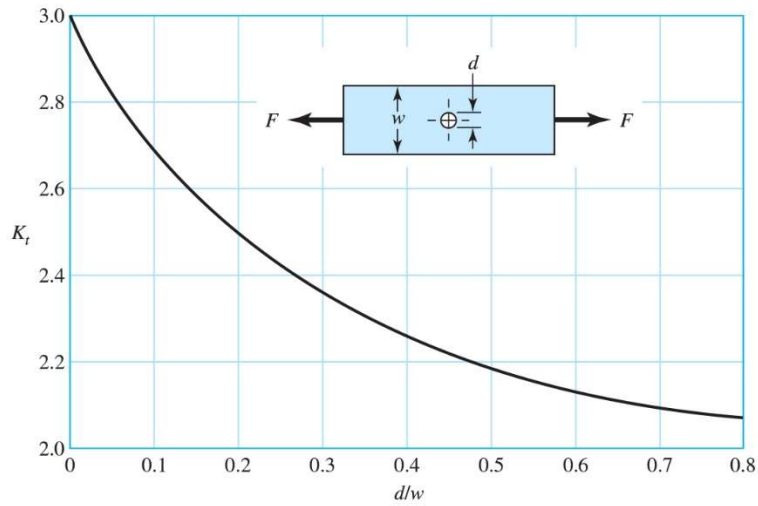


Figure A-15-2

Rectangular bar with a transverse hole in bending. $\sigma_0 = Mc/I$, where $I = (w - d)h^3/12$.

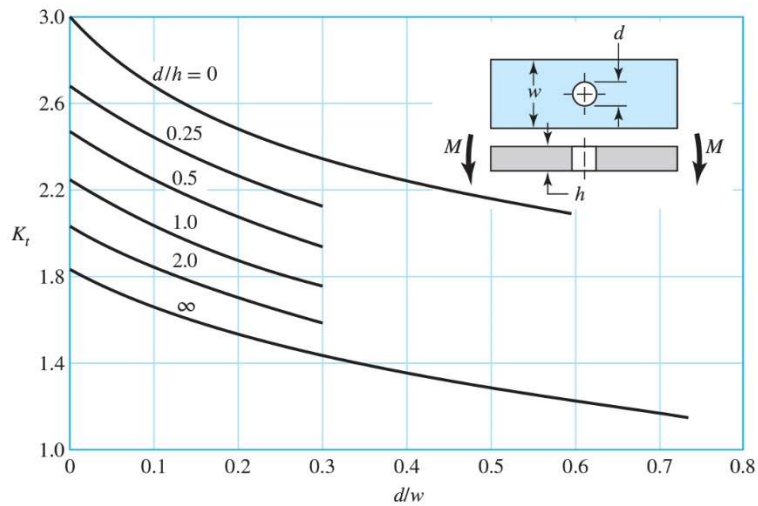


Figure A-15-3

Notched rectangular bar in tension or simple compression. $\sigma_0 = F/A$, where $A = dt$ and t is the thickness.

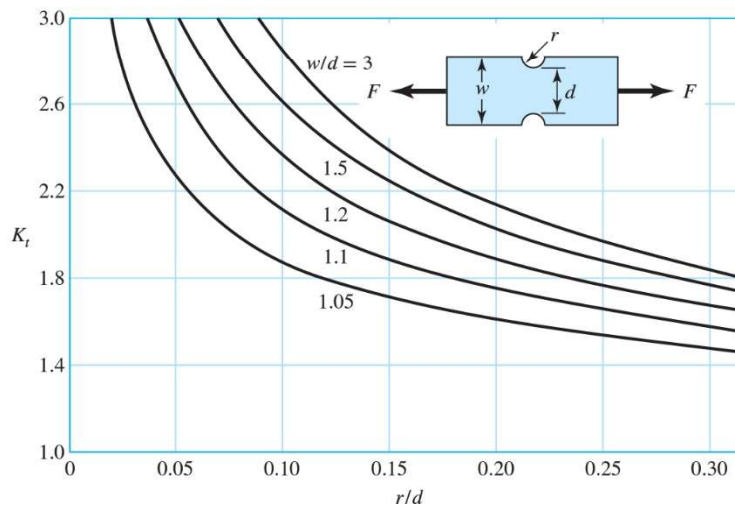


Table A-17 Preferred Sizes and Renard (R-Series) Numbers

(When a choice can be made, use one of these sizes; however, not all parts or items are available in all the sizes shown in the table.)

Fraction of Inches

$\frac{1}{64}, \frac{1}{32}, \frac{1}{16}, \frac{3}{32}, \frac{1}{8}, \frac{5}{32}, \frac{3}{16}, \frac{1}{4}, \frac{5}{16}, \frac{3}{8}, \frac{7}{16}, \frac{1}{2}, \frac{9}{16}, \frac{5}{8}, \frac{11}{16}, \frac{3}{4}, \frac{7}{8}, 1, 1\frac{1}{4}, 1\frac{1}{2}, 1\frac{3}{4}, 2, 2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}, 3,$
 $3\frac{1}{4}, 3\frac{1}{2}, 3\frac{3}{4}, 4, 4\frac{1}{4}, 4\frac{1}{2}, 4\frac{3}{4}, 5, 5\frac{1}{4}, 5\frac{1}{2}, 5\frac{3}{4}, 6, 6\frac{1}{4}, 7, 7\frac{1}{2}, 8, 8\frac{1}{2}, 9, 9\frac{1}{2}, 10, 10\frac{1}{2}, 11, 11\frac{1}{2}, 12,$
 $12\frac{1}{2}, 13, 13\frac{1}{2}, 14, 14\frac{1}{2}, 15, 15\frac{1}{2}, 16, 16\frac{1}{2}, 17, 17\frac{1}{2}, 18, 18\frac{1}{2}, 19, 19\frac{1}{2}, 20$

Decimal Inches

0.010, 0.012, 0.016, 0.020, 0.025, 0.032, 0.040, 0.05, 0.06, 0.08, 0.10, 0.12, 0.16, 0.20, 0.24, 0.30,
0.40, 0.50, 0.60, 0.80, 1.00, 1.20, 1.40, 1.60, 1.80, 2.0, 2.4, 2.6, 2.8, 3.0, 3.2, 3.4, 3.6, 3.8, 4.0, 4.2,
4.4, 4.6, 4.8, 5.0, 5.2, 5.4, 5.6, 5.8, 6.0, 7.0, 7.5, 8.5, 9.0, 9.5, 10.0, 10.5, 11.0, 11.5, 12.0, 12.5,
13.0, 13.5, 14.0, 14.5, 15.0, 15.5, 16.0, 16.5, 17.0, 17.5, 18.0, 18.5, 19.0, 19.5, 20

Millimeters

0.05, 0.06, 0.08, 0.10, 0.12, 0.16, 0.20, 0.25, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 1.0, 1.1, 1.2,
1.4, 1.5, 1.6, 1.8, 2.0, 2.2, 2.5, 2.8, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 8.0, 9.0, 10, 11, 12, 14,
16, 18, 20, 22, 25, 28, 30, 32, 35, 40, 45, 50, 60, 80, 100, 120, 140, 160, 180, 200, 250, 300

Renard Numbers*

1st choice, R5: 1, 1.6, 2.5, 4, 6.3, 10

2d choice, R10: 1.25, 2, 3.15, 5, 8

3d choice, R20: 1.12, 1.4, 1.8, 2.24, 2.8, 3.55, 4.5, 5.6, 7.1, 9

4th choice, R40: 1.06, 1.18, 1.32, 1.5, 1.7, 1.9, 2.12, 2.36, 2.65, 3, 3.35, 3.75, 4.25, 4.75, 5.3, 6,
6.7, 7.5, 8.5, 9.5

*May be multiplied or divided by powers of 10.

Table A-18 Geometric Properties

Part 1 Properties of Sections

A = area

G = location of centroid

$$I_x = \int y^2 dA = \text{second moment of area about } x \text{ axis}$$

$$I_y = \int x^2 dA = \text{second moment of area about } y \text{ axis}$$

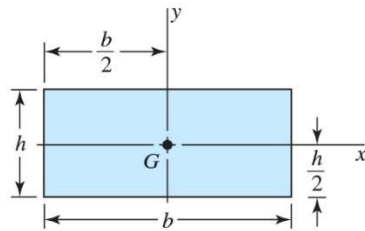
$$I_{xy} = \int xy dA = \text{mixed moment of area about } x \text{ and } y \text{ axes}$$

$$J_G = \int r^2 dA = \int (x^2 + y^2) dA = I_x + I_y$$

= second polar moment of area about axis through G

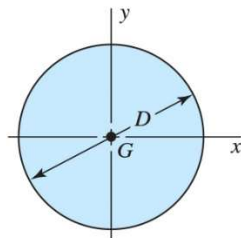
$$k_x^2 = I_x/A = \text{squared radius of gyration about } x \text{ axis}$$

Rectangle



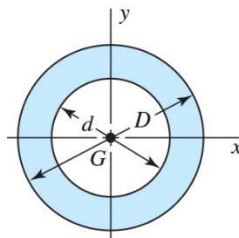
$$A = bh \quad I_x = \frac{bh^3}{12} \quad I_y = \frac{b^3h}{12} \quad I_{xy} = 0$$

Circle



$$A = \frac{\pi D^2}{4} \quad I_x = I_y = \frac{\pi D^4}{64} \quad I_{xy} = 0 \quad J_G = \frac{\pi D^4}{32}$$

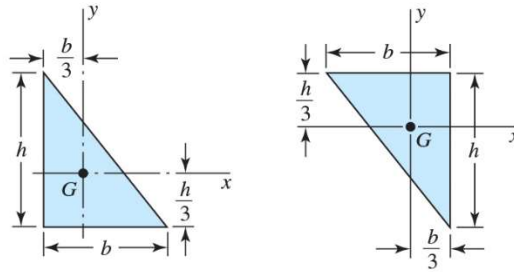
Hollow circle



$$A = \frac{\pi}{4}(D^2 - d^2) \quad I_x = I_y = \frac{\pi}{64}(D^4 - d^4) \quad I_{xy} = 0 \quad J_G = \frac{\pi}{32}(D^4 - d^4)$$

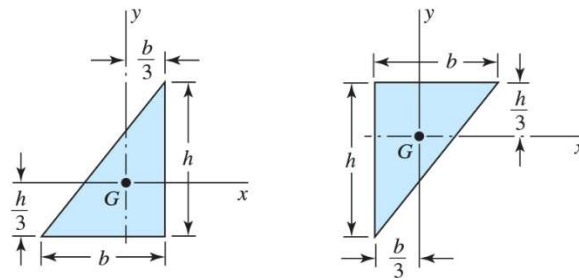
Table A-18 Geometric Properties (Continued)

Right triangles



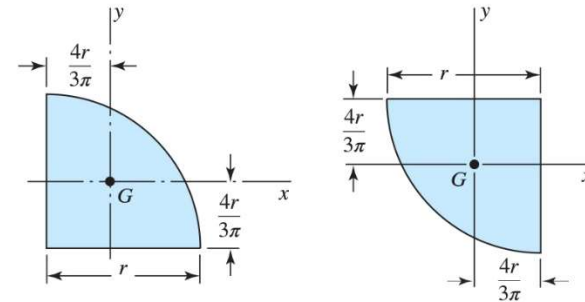
$$A = \frac{bh}{2} \quad I_x = \frac{bh^3}{36} \quad I_y = \frac{b^3h}{36} \quad I_{xy} = \frac{-b^2h^2}{72}$$

Right triangles



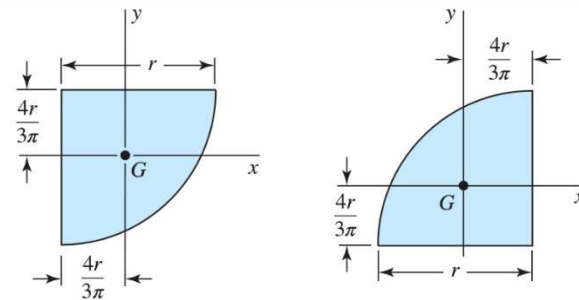
$$A = \frac{bh}{2} \quad I_x = \frac{bh^3}{36} \quad I_y = \frac{b^3h}{36} \quad I_{xy} = \frac{b^2h^2}{72}$$

Quarter-circles



$$A = \frac{\pi r^2}{4} \quad I_x = I_y = r^4 \left(\frac{\pi}{16} - \frac{4}{9\pi} \right) \quad I_{xy} = r^4 \left(\frac{1}{8} - \frac{4}{9\pi} \right)$$

Quarter-circles



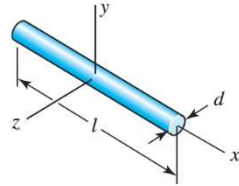
$$A = \frac{\pi r^2}{4} \quad I_x = I_y = r^4 \left(\frac{\pi}{16} - \frac{4}{9\pi} \right) \quad I_{xy} = r^4 \left(\frac{4}{9\pi} - \frac{1}{8} \right)$$

(Continued)

Table A–18 Geometric Properties (Continued)

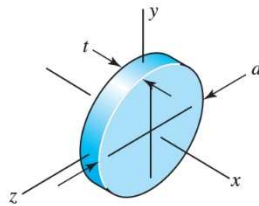
Part 2 Properties of Solids (ρ = Mass Density, Mass per Unit Volume)

Rods



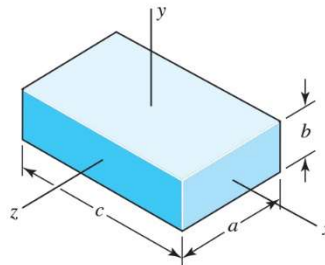
$$m = \frac{\pi d^2 l \rho}{4} \quad I_y = I_z = \frac{ml^2}{12}$$

Round disks



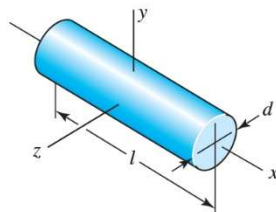
$$m = \frac{\pi d^2 t \rho}{4} \quad I_x = \frac{md^2}{8} \quad I_y = I_z = \frac{md^2}{16}$$

Rectangular prisms



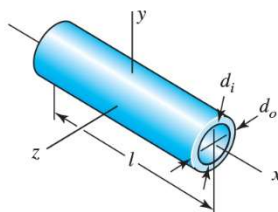
$$m = abc\rho \quad I_x = \frac{m}{12}(a^2 + b^2) \quad I_y = \frac{m}{12}(a^2 + c^2) \quad I_z = \frac{m}{12}(b^2 + c^2)$$

Cylinders



$$m = \frac{\pi d^2 l \rho}{4} \quad I_x = \frac{md^2}{8} \quad I_y = I_z = \frac{m}{48}(3d^2 + 4l^2)$$

Hollow cylinders



$$m = \frac{\pi(d_o^2 - d_i^2)l\rho}{4} \quad I_x = \frac{m}{8}(d_o^2 + d_i^2) \quad I_y = I_z = \frac{m}{48}(3d_o^2 + 3d_i^2 + 4l^2)$$

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.]

1	2	3	4	5	6	7	8
UNS No.	SAE and/or AISI No.	Process- ing	Tensile Strength, MPa (kpsi)	Yield Strength, MPa (kpsi)	Elongation in 2 in, %	Reduction in Area, %	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
G10200	1020	HR	380 (55)	210 (30)	25	50	111
		CD	470 (68)	390 (57)	15	40	131
G10300	1030	HR	470 (68)	260 (37.5)	20	42	137
		CD	520 (76)	440 (64)	12	35	149
G10350	1035	HR	500 (72)	270 (39.5)	18	40	143
		CD	550 (80)	460 (67)	12	35	163
G10400	1040	HR	520 (76)	290 (42)	18	40	149
		CD	590 (85)	490 (71)	12	35	170
G10450	1045	HR	570 (82)	310 (45)	16	40	163
		CD	630 (91)	530 (77)	12	35	179
G10500	1050	HR	620 (90)	340 (49.5)	15	35	179
		CD	690 (100)	580 (84)	10	30	197
G10600	1060	HR	680 (98)	370 (54)	12	30	201
G10800	1080	HR	770 (112)	420 (61.5)	10	25	229
G10950	1095	HR	830 (120)	460 (66)	10	25	248

Source: Data from 1986 SAE Handbook, p. 2.15.

Table A–31 Dimensions of Hexagonal Nuts

Nominal Size, in	Width <i>W</i>	Height <i>H</i>		
		Regular Hexagonal	Thick or Slotted	JAM
$\frac{1}{4}$	$\frac{7}{16}$	$\frac{7}{32}$	$\frac{9}{32}$	$\frac{5}{32}$
$\frac{5}{16}$	$\frac{1}{2}$	$\frac{17}{64}$	$\frac{21}{64}$	$\frac{3}{16}$
$\frac{3}{8}$	$\frac{9}{16}$	$\frac{21}{64}$	$\frac{13}{32}$	$\frac{7}{32}$
$\frac{7}{16}$	$\frac{11}{16}$	$\frac{3}{8}$	$\frac{29}{64}$	$\frac{1}{4}$
$\frac{1}{2}$	$\frac{3}{4}$	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{5}{16}$
$\frac{9}{16}$	$\frac{7}{8}$	$\frac{31}{64}$	$\frac{39}{64}$	$\frac{5}{16}$
$\frac{5}{8}$	$\frac{15}{16}$	$\frac{35}{64}$	$\frac{23}{32}$	$\frac{3}{8}$
$\frac{3}{4}$	$1\frac{1}{8}$	$\frac{41}{64}$	$\frac{13}{16}$	$\frac{27}{64}$
$\frac{7}{8}$	$1\frac{5}{16}$	$\frac{3}{4}$	$\frac{29}{32}$	$\frac{31}{64}$
1	$1\frac{1}{2}$	$\frac{55}{64}$	1	$\frac{35}{64}$
$1\frac{1}{8}$	$1\frac{11}{16}$	$\frac{31}{32}$	$1\frac{5}{32}$	$\frac{39}{64}$
$1\frac{1}{4}$	$1\frac{7}{8}$	$1\frac{1}{16}$	$1\frac{1}{4}$	$\frac{23}{32}$
$1\frac{3}{8}$	$2\frac{1}{16}$	$1\frac{11}{64}$	$1\frac{3}{8}$	$\frac{25}{32}$
$1\frac{1}{2}$	$2\frac{1}{4}$	$1\frac{9}{32}$	$1\frac{1}{2}$	$\frac{27}{32}$

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

Table A–32 Basic Dimensions of American Standard Plain Washers (All Dimensions in Inches)

Fastener Size	Washer Size	Diameter		Thickness
		ID	OD	
#6	0.138	0.156	0.375	0.049
#8	0.164	0.188	0.438	0.049
#10	0.190	0.219	0.500	0.049
#12	0.216	0.250	0.562	0.065
$\frac{1}{4}$ N	0.250	0.281	0.625	0.065
$\frac{1}{4}$ W	0.250	0.312	0.734	0.065
$\frac{5}{16}$ N	0.312	0.344	0.688	0.065
$\frac{5}{16}$ W	0.312	0.375	0.875	0.083
$\frac{3}{8}$ N	0.375	0.406	0.812	0.065
$\frac{3}{8}$ W	0.375	0.438	1.000	0.083
$\frac{7}{16}$ N	0.438	0.469	0.922	0.065
$\frac{7}{16}$ W	0.438	0.500	1.250	0.083
$\frac{1}{2}$ N	0.500	0.531	1.062	0.095
$\frac{1}{2}$ W	0.500	0.562	1.375	0.109
$\frac{9}{16}$ N	0.562	0.594	1.156	0.095
$\frac{9}{16}$ W	0.562	0.625	1.469	0.109
$\frac{5}{8}$ N	0.625	0.656	1.312	0.095
$\frac{5}{8}$ W	0.625	0.688	1.750	0.134
$\frac{3}{4}$ N	0.750	0.812	1.469	0.134
$\frac{3}{4}$ W	0.750	0.812	2.000	0.148
$\frac{7}{8}$ N	0.875	0.938	1.750	0.134
$\frac{7}{8}$ W	0.875	0.938	2.250	0.165
1 N	1.000	1.062	2.000	0.134
1 W	1.000	1.062	2.500	0.165
$1\frac{1}{8}$ N	1.125	1.250	2.250	0.134
$1\frac{1}{8}$ W	1.125	1.250	2.750	0.165
$1\frac{1}{4}$ N	1.250	1.375	2.500	0.165
$1\frac{1}{4}$ W	1.250	1.375	3.000	0.165
$1\frac{3}{8}$ N	1.375	1.500	2.750	0.165
$1\frac{3}{8}$ W	1.375	1.500	3.250	0.180
$1\frac{1}{2}$ N	1.500	1.625	3.000	0.165
$1\frac{1}{2}$ W	1.500	1.625	3.500	0.180
$1\frac{5}{8}$	1.625	1.750	3.750	0.180
$1\frac{3}{4}$	1.750	1.875	4.000	0.180
$1\frac{7}{8}$	1.875	2.000	4.250	0.180
2	2.000	2.125	4.500	0.180
$2\frac{1}{4}$	2.250	2.375	4.750	0.220
$2\frac{1}{2}$	2.500	2.625	5.000	0.238
$2\frac{3}{4}$	2.750	2.875	5.250	0.259
3	3.000	3.125	5.500	0.284

N = narrow; W = wide; use W when not specified.

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.

*Same as screw or bolt size.