**ME 3000 Design of Mechanical Elements** **Prof. B. Raeymaekers**

**Formulas and tables** **Spring 2016**

---

## 1. Introduction to mechanical design
## 2. Material selection

Modulus of resilience: $u_R = \frac{1}{2}\sigma_y \varepsilon_y = \frac{\sigma_y^2}{2E}$

Modulus of toughness: $u_T = \frac{\sigma_y + \sigma_{ut}}{2}\varepsilon_f$

Reduction in cross-sectional area at fracture: $R = \frac{A_0 - A_f}{A_0}$ with $A_0$ the original cross-section and $A_f$ the cross-section after fracture.

Cold work factor: $W = \frac{A_0 - A_i}{A_0}$

True stress-strain relationship in plastic region: $\sigma = \sigma_0 \varepsilon^m$, with $m$ the strain strengthening exponent and $\sigma_0$ the strain strengthening coefficient.

## 3. Statistical considerations

Variance of the linear combination of two random variables: $s_z^2 = \sum_{i=1}^{2}\sum_{j=1}^{2} C_i C_j s_{ij}$, with $C_i$, $C_j$ weight factors for random variables $i$ and $j$ and $s_{ij}$ = covariance

Normal probability density function: $f(x) = \frac{1}{s_x\sqrt{2\pi}} e^{-\frac{\left(\frac{x-\mu}{s_x}\right)^2}{2}}$, with mean $\mu$, standard deviation $s_x$

Standard normal probability density function: $f(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{(z)^2}{2}}$, with $z = \frac{x-\mu}{s_x}$

Weibull probability density function: $f(x) = \frac{b}{\theta - x_0}\left(\frac{x - x_0}{\theta - x_0}\right)^{b-1}\left\{\exp\left[-\left(\frac{x - x_0}{\theta - x_0}\right)^b\right]\right\}$, with Weibull parameters $x_0$, $b$, $\theta$.

Cumulative normal distribution function: $F(t)=\int_{-\infty}^{t}\frac{1}{s_x\sqrt{2\pi}}e^{-\frac{\left(\frac{x-\mu}{s_x}\right)^2}{2}}dx=\frac{1}{2}\left(1+erf\,\frac{t-\mu}{s_x\sqrt{2}}\right)$

Cumulative Weibull distribution function: $F(t)=1-\exp\left[-\left(\frac{t-x_0}{\theta-x_0}\right)^b\right]$

Transformation from arbitrary normal distribution to standard normal distribution:

What is the probability *p* that a random variable *x* is smaller or equal to a value *t*?

$$p\left(x\le t\right)=p\left(\frac{x-\mu}{s_x}\le\frac{t-\mu}{s_x}\right)=p\left(z\le k\right)$$

## 4. Tolerances

Worst case error: $\delta q_{wce}=\left|\frac{\delta q}{\delta x_1}\right|\delta x_1+\left|\frac{\delta q}{\delta x_2}\right|\delta x_2+...+\left|\frac{\delta q}{\delta x_n}\right|\delta x_n$

Statistical error: $\delta q_{stat}=\left[\left(\frac{\delta q}{\delta x_1}\right)^2\left(\delta x_1\right)^2+\left(\frac{\delta q}{\delta x_2}\right)^2\left(\delta x_2\right)^2+...+\left(\frac{\delta q}{\delta x_n}\right)^2\left(\delta x_n\right)^2\right]^{1/2}$

Preferred tolerance combinations

- Clearance fits: H11/c11, H9/d9, H8/f7, H7/g6, H7/h6, C11/h11, D9/h9, F8/h7, G7/h6
- Transition fits: H7/k6, H7/n6, K7/h6, N7/h6
- Interference fits: H7/p6, H7/s6, H7/u6, P7/h6, S7/h6, U7/h6

## 5. Area moment of inertia

Area moment of inertia about axes *x*, *y*: $\overline{I_{xx}}=\int_A y^2dA$, $\overline{I_{yy}}=\int_A x^2dA$,

Polar area moment of inertia: $I_p=\int_A r^2dA$

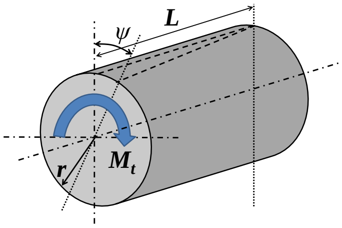
Centroid: $\bar{x}A=\int_A xdA$, $\bar{y}A=\int_A ydA$

Parallel axis theorem: $I_{xx}=\overline{I_{xx}}+d_y^2A$

## 6. Design for static strength

Principal stresses: $\sigma_1, \sigma_2 = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$

Extreme values of shear stress: $\tau_1, \tau_2 = \pm\sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$



Angle of twist: $\Psi = \frac{M_t L}{G I_p}$ (ψ in RAD) with $G = \frac{E}{2(1+\nu)}$

Shear stress as a result of torsion: $\tau = \frac{M_t r}{I_p}$

Theoretical stress concentration factor for normal stresses: $K_t = \sigma_{\max} / \sigma_0$

Theoretical stress concentration factor for shear stresses: $K_{ts} = \tau_{\max} / \tau_0$

Maximum shear stress criterion: $\sigma_y = \sigma_1 - \sigma_3$

Von Mises stress (tri-axial): $\sigma = \left[\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2}{2}\right]^{1/2}$

Von Mises stress (tri-axial): $\sigma = \frac{1}{\sqrt{2}}\left[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)\right]^{1/2}$

Von Mises stress (plane stress): $\sigma = \left[\sigma_x^2 - \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}^2\right]^{1/2}$

Von Mises stress (plane stress – principal stresses): $\sigma = \left[\sigma_A^2 - \sigma_A\sigma_B + \sigma_B^2\right]^{1/2}$

Von Mises stress: $\sigma = \left[\sigma_x^2 + 3\tau_{xy}^2\right]^{1/2}$

Coulomb-Mohr theory (Brittle):

$$\frac{\sigma_A}{\sigma_{ut}} - \frac{\sigma_B}{\sigma_{uc}} = \frac{1}{n} \quad \sigma_A \ge 0, \sigma_B \le 0$$

$$\frac{\sigma_A}{\sigma_{ut}} = \frac{1}{n} \quad \sigma_A \ge \sigma_B \ge 0$$

$$\frac{\sigma_B}{\sigma_{uc}} = -\frac{1}{n} \quad 0 \ge \sigma_A \ge \sigma_B$$

*

## 7. Design for fatigue strength

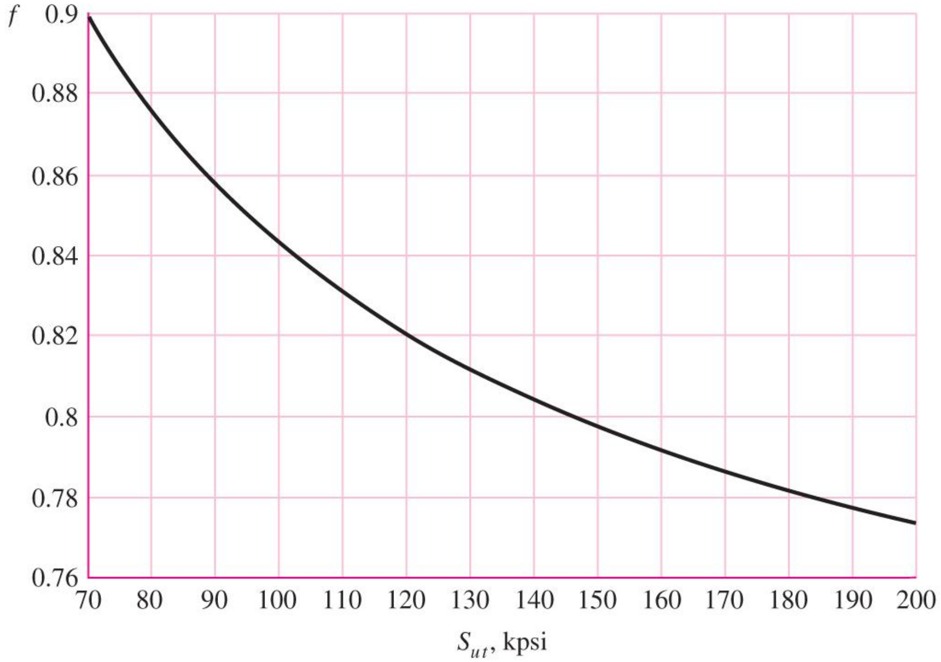
Endurance limit for steels: $\sigma_e' = \begin{cases} 0.5\sigma_{ut} & \sigma_{ut} \le 200kpsi \\ 100kpsi & \sigma_{ut} \ge 200kpsi \\ 700MPa & \sigma_{ut} \ge 1400MPa \end{cases}$

High cycle fatigue: $N = \left(\frac{\sigma_{rev}}{a}\right)^{1/b}$ with $\sigma_{rev}$ the amplitude of the fully reversing (alternating) stress, and $N$ the number of cycles to failure.

Fatigue strength, $\sigma_f = aN^b$, with $\begin{array}{l} a = \dfrac{(f\sigma_{ut})^2}{\sigma_e} \\ b = -\dfrac{1}{3}\log\left(\dfrac{f\sigma_{ut}}{\sigma_e}\right) \end{array}$

Conversion from MPa to kpsi: 1 kpsi = 6.89 MPa

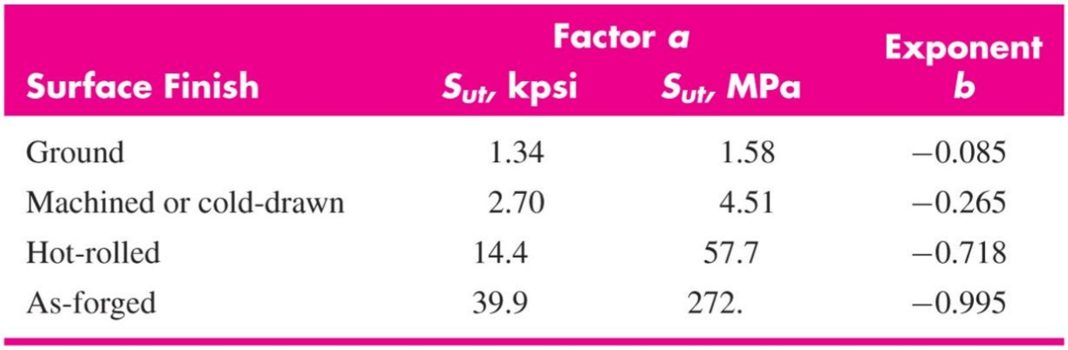
Fatigue strength fraction diagram



Endurance limit modifying factors:

- $k_a = a\sigma_{ut}^b$

*



| Surface Finish | Factor $a$ $S_{ut}$, kpsi | Factor $a$ $S_{ut}$, MPa | Exponent $b$ |
|---|---|---|---|
| Ground | 1.34 | 1.58 | −0.085 |
| Machined or cold-drawn | 2.70 | 4.51 | −0.265 |
| Hot-rolled | 14.4 | 57.7 | −0.718 |
| As-forged | 39.9 | 272. | −0.995 |

- $k_b = \begin{cases} 0.879d^{-0.107} & 0.11 \le d \le 2 \quad [inch] \\ 0.91d^{-0.157} & 2 \le d \le 10 \quad [inch] \\ 1.24d^{-0.107} & 2.79 \le d \le 51 \quad [mm] \\ 1.51d^{-0.157} & 51 \le d \le 254 \quad [mm] \end{cases}$ for bending and torsion loading

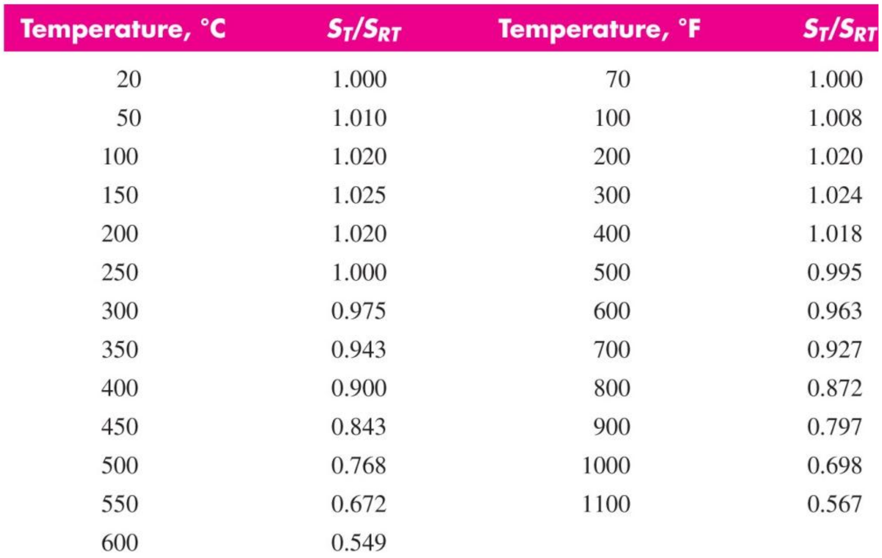
  $k_b = 1$ for axial loading

  $d_{eq} = 0.808\sqrt{bh}$ for a rectangular cross-section with b = width and h = height

  $d_{eq} = 0.37d$ for a non-rotating shaft with circular cross-section of diameter $d$

- $k_c = \begin{cases} 1 & bending \\ 0.85 & axial \\ 0.59 & torsion \end{cases}$

- $k_d = \dfrac{\sigma_{y,T}}{\sigma_{y,RT}} \text{ or } \dfrac{\sigma_{ut,T}}{\sigma_{ut,RT}}$



| Temperature, °C | $S_T/S_{RT}$ | Temperature, °F | $S_T/S_{RT}$ |
|---|---|---|---|
| 20 | 1.000 | 70 | 1.000 |
| 50 | 1.010 | 100 | 1.008 |
| 100 | 1.020 | 200 | 1.020 |
| 150 | 1.025 | 300 | 1.024 |
| 200 | 1.020 | 400 | 1.018 |
| 250 | 1.000 | 500 | 0.995 |
| 300 | 0.975 | 600 | 0.963 |
| 350 | 0.943 | 700 | 0.927 |
| 400 | 0.900 | 800 | 0.872 |
| 450 | 0.843 | 900 | 0.797 |
| 500 | 0.768 | 1000 | 0.698 |
| 550 | 0.672 | 1100 | 0.567 |
| 600 | 0.549 | | |

- $k_e = 1 - 0.08z_a$

*

| 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 |
| 99.999 | 4.265 | 0.659 |
| 99.9999 | 4.753 | 0.620 |

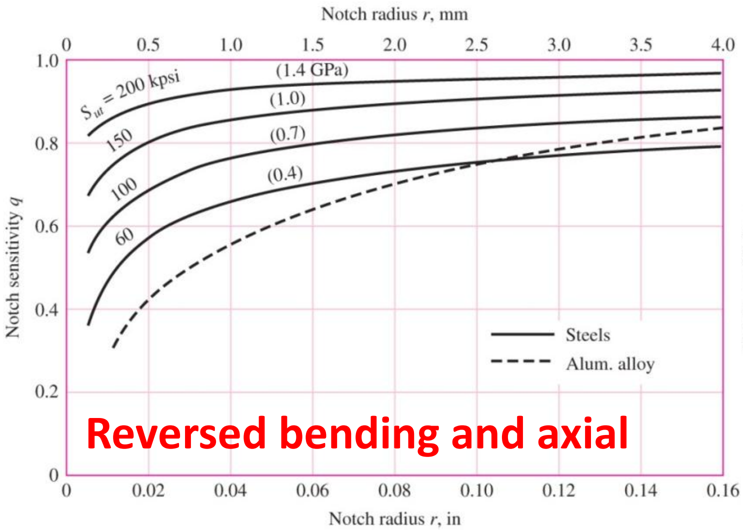
Criteria:

- Goodman line: $\frac{\sigma_m}{\sigma_{ut}} + \frac{\sigma_a}{\sigma_e} = \frac{1}{n}$
- Soderberg line: $\frac{\sigma_m}{\sigma_y} + \frac{\sigma_a}{\sigma_e} = \frac{1}{n}$
- Gerber parabola: $\left(\frac{n\sigma_m}{\sigma_{ut}}\right)^2 + \frac{n\sigma_a}{\sigma_e} = 1$

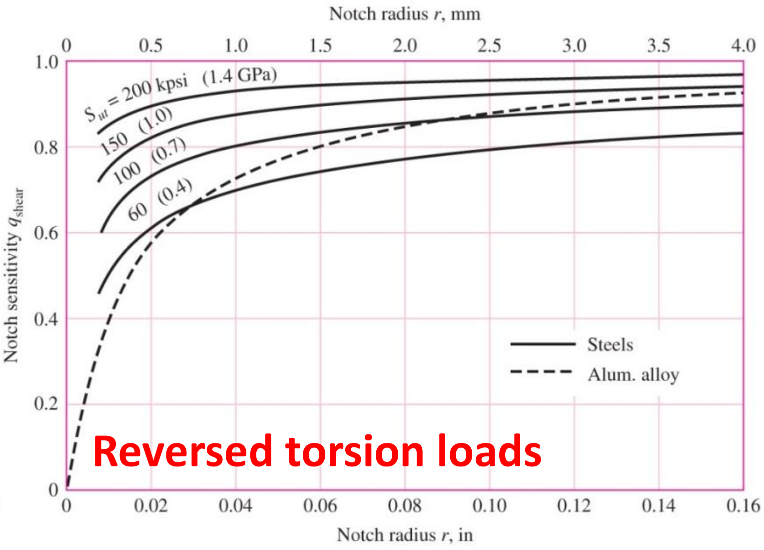
## 8. Design of shafts

Combining two bending moments: $M = \sqrt{M_x^2 + M_y^2}$

Notch sensitivity: $K_f = q\left(K_t - 1\right) + 1$



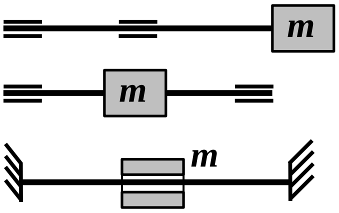
Reversed bending and axial



Reversed torsion loads

*

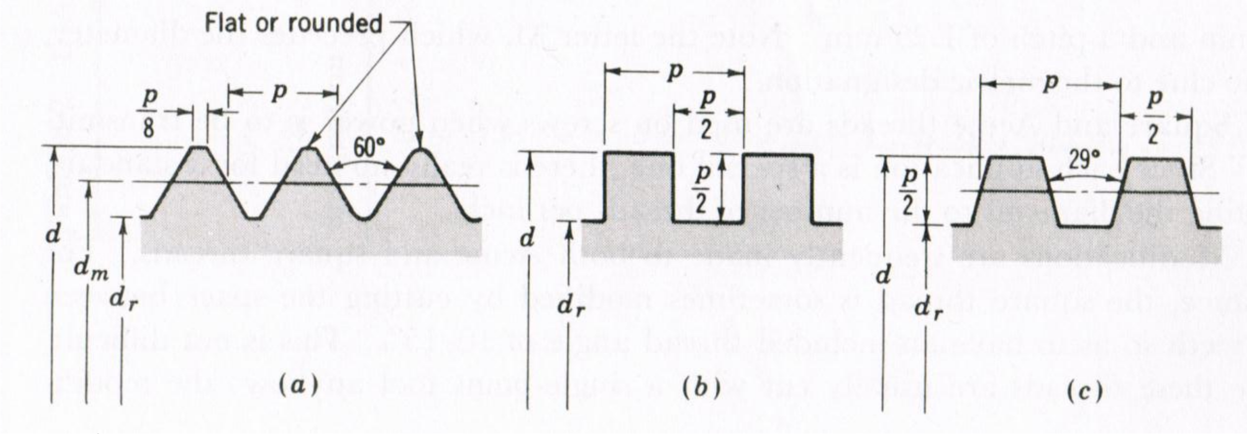
Critical bending RPM of a shaft: $n_c = C\dfrac{30}{\pi}\sqrt{\dfrac{k}{m}}$



$C = 0.9$ mass outside bearings
$C = 1$ mass between bearings
$C = 1.3$ rotating mass on fixed shaft

Lowest critical bending RPM: $\dfrac{1}{n_c^2} \cong \dfrac{1}{n_{c1}^2} + \dfrac{1}{n_{c2}^2} + \ldots + \dfrac{1}{n_{ci}^2} + \ldots$

## 9. Design of bolted joints



Unified thread
width of root flat = *p/4*

Square thread

Trapezoidal thread

Lifting a load *F* with power screw: $M_t = \dfrac{Fd_m}{2}\dfrac{(l + \mu\pi d_m)}{(\pi d_m - \mu l)}$

Lowering a load *F* power screw: $M_t = \dfrac{Fd_m}{2}\dfrac{(\mu\pi d_m - l)}{(\pi d_m + \mu l)}$

Power screw collar friction: $M_t = \dfrac{F\mu_c d_c}{2}$

Axial stiffness of bolt: $k_B = \dfrac{F_i}{\delta_B} = \dfrac{A_B E}{L_B}$ with $A_B$ the cross section of the bolt, *E* the Young's modulus, and $L_B$ the length of the bolt. (simplified calculation)

Load carried by the bolt: $P_B = \left(\dfrac{k_B}{k_B + k_M}\right)P$

Load carried by the members: $P_M = \left(\dfrac{k_M}{k_B + k_M}\right)P$

Resulting force in a bolt: $F_B = F_i + P_B = F_i + \left(\dfrac{k_B}{k_B + k_M}\right)P$

Resulting force in the members: $F_M = P_M - F_i = \left(\dfrac{k_M}{k_B + k_M}\right)P - F_i$

Torque moment $M_t$ needed to achieve a preload $F_i$ in a bolt with major diameter $d$: $M_t = KdF_i$

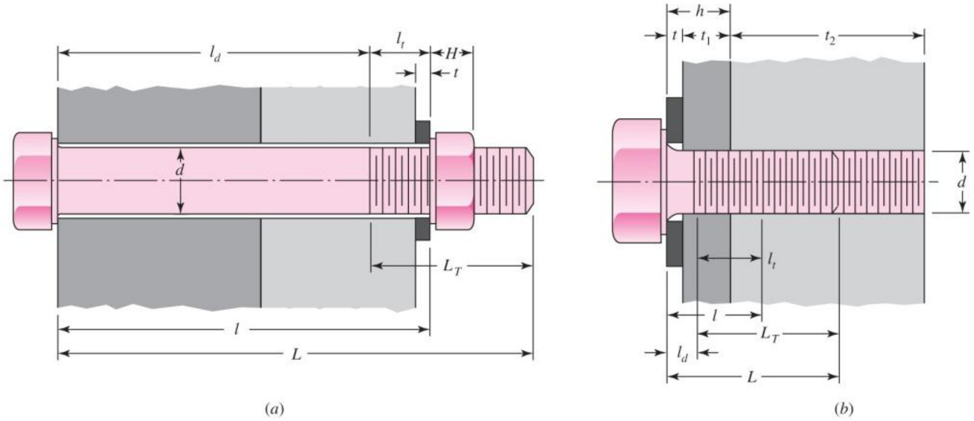
with $K = \dfrac{d_m}{2d}\dfrac{(\tan\lambda + \mu\sec\alpha)}{(1-\mu\tan\lambda\sec\alpha)} + 0.625\mu_c$ and $\alpha$ = 30 degrees for metric thread.

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

**Detailed fastener stiffness calculation:**

**Table 8–7**

Suggested Procedure for Finding Fastener Stiffness



(a) (b)

*

Given fastener diameter $d$ and pitch $p$ in mm or number of threads per inch

Washer thickness: $t$ from Table A–32 or A–33

Nut thickness [Fig. (*a*) only]: $H$ from Table A–31

Grip length:

For Fig. (*a*): $l$ = thickness of all material squeezed between face of bolt and face of nut

For Fig. (*b*):

$$l = \begin{cases} h + t_2/2, & t_2 < d \\ h + d/2, & t_2 \geq d \end{cases}$$

Fastener length (round up using Table A–17*):

For Fig. (*a*): $L > l + H$

For Fig. (*b*): $L > h + 1.5d$

Threaded length $L_T$: Inch series:

$$L_T = \begin{cases} 2d + \frac{1}{4} \text{ in}, & L \leq 6 \text{ in} \\ 2d + \frac{1}{2} \text{ in}, & L > 6 \text{ in} \end{cases}$$

Metric series:

$$L_T = \begin{cases} 2d + 6 \text{ mm}, & L \leq 125 \text{ mm}, d \leq 48 \text{ mm} \\ 2d + 12 \text{ mm}, & 125 < L \leq 200 \text{ mm} \\ 2d + 25 \text{ mm}, & L > 200 \text{ mm} \end{cases}$$

Length of unthreaded portion in grip: $l_d = L - L_T$

Length of threaded portion in grip: $l_t = l - l_d$

Area of unthreaded portion: $A_d = \pi d^2/4$

Area of threaded portion: $A_t$ from Table 8–1 or 8–2

Fastener stiffness: $k_b = \dfrac{A_d A_t E}{A_d l_t + A_t l_d}$

**Member stiffness:**

$$k_M = \frac{\pi E d}{2 \ln\left[5\left(\dfrac{l + 0.5d}{l + 2.5d}\right)\right]}$$

$E$ is Young’s modulus of the members

Preload against fatigue failure (Goodman criterion): $F_i = \dfrac{A_t \sigma_{ut}}{n} - \dfrac{CP}{2}\left(\dfrac{\sigma_{ut}}{\sigma_e} + 1\right)$

*

| 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.

**Table 8–1**

Diameters and Areas of Coarse-Pitch and Fine-Pitch Metric Threads.*

| Nominal Major Diameter $d$ mm | Coarse-Pitch Series | | | Fine-Pitch Series | | |
|---|---|---|---|---|---|---|
| | 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.

### 10. Design of welded joints

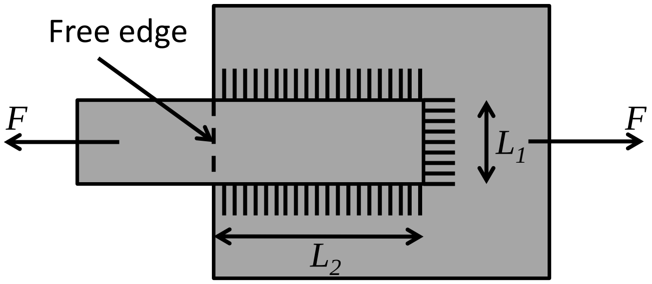
Equivalent normal stress for welded joints: $\sigma_{eq} = \sqrt{\sigma_{\parallel}^2 + \frac{1}{\alpha^2}\left[\sigma_{\perp}^2 + 1.8\left(\tau_{\perp}^2 + \tau_{\parallel}^2\right)\right]}$

$\alpha$ = experimentally determined coefficient dependent on the thickness of the welded joint:

$h \leq 4$ mm, $\alpha = 1$

$h > 4$ mm, $\alpha = 0.8(1+1/h)$

**Combined longitudinal and transverse welded joints subject to in plane loading**



1. No weld at free edge and $L_2 > 1.5L_1$. The entire force $F$ is carried by the longitudinal welds ($L_2$). The transverse weld is not considered.
2. No weld at free edge and $0.5L_1 < L_2 < 1.5L_1$. Total strength of welded joints is the strength of the longitudinal welds $L_2$ increased by 1/3 of the strength of the transverse weld $L_1$ .
3. No weld at free edge and $L_2 < 0.5L_1$. Total strength of welded joints is the strength of the transverse weld $L_1$ increased by 1/3 of the strength of longitudinal welds $L_2$
4. Weld at free edge. Total strength of welded joints is the strength of the weld at the free edge increased by 1/3 of the strength of the other welds.

**Combined longitudinal and transverse welded joints subject to in bending**

Only welded joints in direction of load absorb that load, i.e., a longitudinal load is only absorbed by vertical welded joints, a transverse load is only absorbed by horizontal welded joints.

For torque moment: $\tau_{\parallel} = \frac{M_t}{2hA}$ with $M_t$ the torque moment, $h$ the throat section and $A$ the appropriate surface area inside the "pitch contour" (also valid for non-circular tubes)

## 11. Design of rolling element bearings

Relationship between bearing load and life: $FL^{1/a} = C \Rightarrow \frac{L_1}{L_2} = \left(\frac{F_2}{F_1}\right)^a$

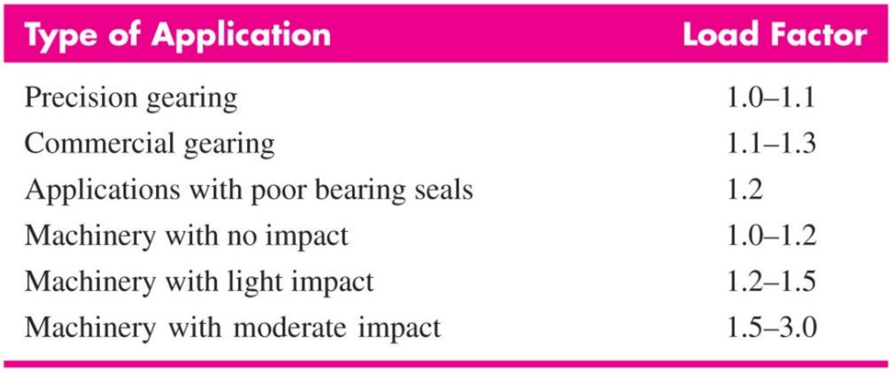
$a = 3$ for ball bearings, and $a = 10/3$ for roller bearings

$$F_R L_R^{1/a} = F_D L_D^{1/a}$$

$$\Rightarrow C_R = F_R = F_D\left[\left(\frac{L_D}{L_R}\right)\right]^{1/a} = F_D\left[\left(\frac{\overline{L}_D}{L_R}\right)\left(\frac{n_D}{n_R}\right)\right]^{1/a}$$

with $C_R$ the basic load rating corresponding to $L_R$ hours of $L_{10}$ life at the speed $n_R$ RPM. The force $F_D$ is the actual radial bearing load to be carried for $L_D$ hours of $L_{10}$ life at a speed of $n_D$ RPM.

$$C_{10} = a_f F_D\left(\frac{x_D}{x_0 + (\theta - x_0)\left[\ln\left(\frac{1}{R_D}\right)\right]^{1/b}}\right)^{1/a} = a_f F_D\left(\frac{\left(\frac{\overline{L}_D}{L_R}\right)\left(\frac{n_D}{n_R}\right)}{x_0 + (\theta - x_0)\left[\ln\left(\frac{1}{R_D}\right)\right]^{1/b}}\right)^{1/a}$$



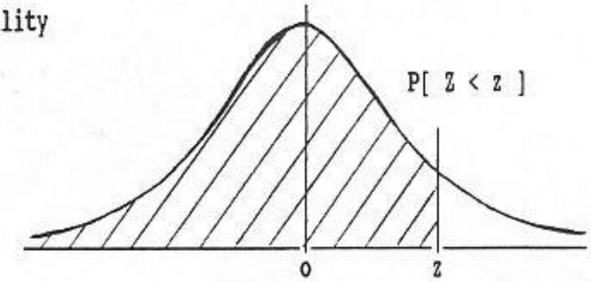
| Type of Application | Load Factor |
|---|---|
| Precision gearing | 1.0–1.1 |
| Commercial gearing | 1.1–1.3 |
| Applications with poor bearing seals | 1.2 |
| Machinery with no impact | 1.0–1.2 |
| Machinery with light impact | 1.2–1.5 |
| Machinery with moderate impact | 1.5–3.0 |

# STANDARD STATISTICAL TABLES

## 1. Areas under the Normal Distribution

The table gives the cumulative probability up to the standardised normal value z
i.e.

$$P[\ Z < z\ ] = \int_{-\infty}^{z} \frac{1}{\sqrt{2\pi}} \exp(-\tfrac{1}{2}Z^2)\ dZ$$



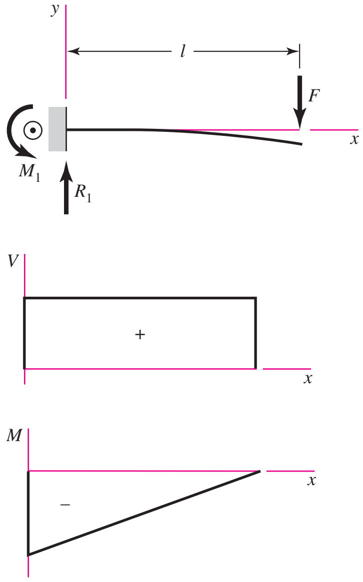
| z | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 0.5000 | 0.5040 | 0.5080 | 0.5120 | 0.5159 | 0.5199 | 0.5239 | 0.5279 | 0.5319 | 0.5359 |
| 0.1 | 0.5398 | 0.5438 | 0.5478 | 0.5517 | 0.5557 | 0.5596 | 0.5636 | 0.5675 | 0.5714 | 0.5753 |
| 0.2 | 0.5793 | 0.5832 | 0.5871 | 0.5910 | 0.5948 | 0.5987 | 0.6026 | 0.6064 | 0.6103 | 0.6141 |
| 0.3 | 0.6179 | 0.6217 | 0.6255 | 0.6293 | 0.6331 | 0.6368 | 0.6406 | 0.6443 | 0.6480 | 0.6517 |
| 0.4 | 0.6554 | 0.6591 | 0.6628 | 0.6664 | 0.6700 | 0.6736 | 0.6772 | 0.6808 | 0.6844 | 0.6879 |
| 0.5 | 0.6915 | 0.6950 | 0.6985 | 0.7019 | 0.7054 | 0.7088 | 0.7123 | 0.7157 | 0.7190 | 0.7224 |
| 0.6 | 0.7257 | 0.7291 | 0.7324 | 0.7357 | 0.7389 | 0.7422 | 0.7454 | 0.7486 | 0.7517 | 0.7549 |
| 0.7 | 0.7580 | 0.7611 | 0.7642 | 0.7673 | 0.7704 | 0.7734 | 0.7764 | 0.7794 | 0.7823 | 0.7854 |
| 0.8 | 0.7881 | 0.7910 | 0.7939 | 0.7967 | 0.7995 | 0.8023 | 0.8051 | 0.8078 | 0.8106 | 0.8133 |
| 0.9 | 0.8159 | 0.8186 | 0.8212 | 0.8238 | 0.8264 | 0.8289 | 0.8315 | 0.8340 | 0.8365 | 0.8389 |
| 1.0 | 0.8413 | 0.8438 | 0.8461 | 0.8485 | 0.8508 | 0.8531 | 0.8554 | 0.8577 | 0.8599 | 0.8621 |
| 1.1 | 0.8643 | 0.8665 | 0.8686 | 0.8708 | 0.8729 | 0.8749 | 0.8770 | 0.8790 | 0.8804 | 0.8830 |
| 1.2 | 0.8849 | 0.8869 | 0.8888 | 0.8907 | 0.8925 | 0.8944 | 0.8962 | 0.8980 | 0.8997 | 0.9015 |
| 1.3 | 0.9032 | 0.9049 | 0.9066 | 0.9082 | 0.9099 | 0.9115 | 0.9131 | 0.9147 | 0.9162 | 0.9177 |
| 1.4 | 0.9192 | 0.9207 | 0.9222 | 0.9236 | 0.9251 | 0.9265 | 0.9279 | 0.9292 | 0.9306 | 0.9319 |
| 1.5 | 0.9332 | 0.9345 | 0.9357 | 0.9370 | 0.9382 | 0.9394 | 0.9406 | 0.9418 | 0.9429 | 0.9441 |
| 1.6 | 0.9452 | 0.9463 | 0.9474 | 0.9484 | 0.9495 | 0.9505 | 0.9515 | 0.9525 | 0.9535 | 0.9545 |
| 1.7 | 0.9554 | 0.9564 | 0.9573 | 0.9582 | 0.9591 | 0.9599 | 0.9608 | 0.9616 | 0.9625 | 0.9633 |
| 1.8 | 0.9641 | 0.9649 | 0.9656 | 0.9664 | 0.9671 | 0.9678 | 0.9686 | 0.9693 | 0.9699 | 0.9706 |
| 1.9 | 0.9713 | 0.9719 | 0.9726 | 0.9732 | 0.9738 | 0.9744 | 0.9750 | 0.9756 | 0.9761 | 0.9767 |
| 2.0 | 0.9773 | 0.9778 | 0.9783 | 0.9788 | 0.9793 | 0.9798 | 0.9803 | 0.9808 | 0.9812 | 0.9817 |
| 2.1 | 0.9821 | 0.9826 | 0.9830 | 0.9834 | 0.9838 | 0.9842 | 0.9846 | 0.9850 | 0.9854 | 0.9857 |
| 2.2 | 0.9861 | 0.9865 | 0.9868 | 0.9871 | 0.9874 | 0.9878 | 0.9881 | 0.9884 | 0.9887 | 0.9890 |
| 2.3 | 0.9893 | 0.9896 | 0.9898 | 0.9901 | 0.9904 | 0.9906 | 0.9909 | 0.9911 | 0.9913 | 0.9916 |
| 2.4 | 0.9918 | 0.9920 | 0.9922 | 0.9924 | 0.9927 | 0.9929 | 0.9931 | 0.9932 | 0.9934 | 0.9936 |
| 2.5 | 0.9938 | 0.9940 | 0.9941 | 0.9943 | 0.9945 | 0.9946 | 0.9948 | 0.9949 | 0.9951 | 0.9952 |
| 2.6 | 0.9953 | 0.9955 | 0.9956 | 0.9957 | 0.9959 | 0.9960 | 0.9961 | 0.9962 | 0.9963 | 0.9964 |
| 2.7 | 0.9965 | 0.9966 | 0.9967 | 0.9968 | 0.9969 | 0.9970 | 0.9971 | 0.9972 | 0.9973 | 0.9974 |
| 2.8 | 0.9974 | 0.9975 | 0.9976 | 0.9977 | 0.9977 | 0.9978 | 0.9979 | 0.9980 | 0.9980 | 0.9981 |
| 2.9 | 0.9981 | 0.9982 | 0.9982 | 0.9983 | 0.9984 | 0.9984 | 0.9985 | 0.9985 | 0.9986 | 0.9986 |

| z | 3.00 | 3.10 | 3.20 | 3.30 | 3.40 | 3.50 | 3.60 | 3.70 | 3.80 | 3.90 |
|---|---|---|---|---|---|---|---|---|---|---|
| P | 0.9986 | 0.9990 | 0.9993 | 0.9995 | 0.9997 | 0.9998 | 0.9998 | 0.9999 | 0.9999 | 1.0000 |

## 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



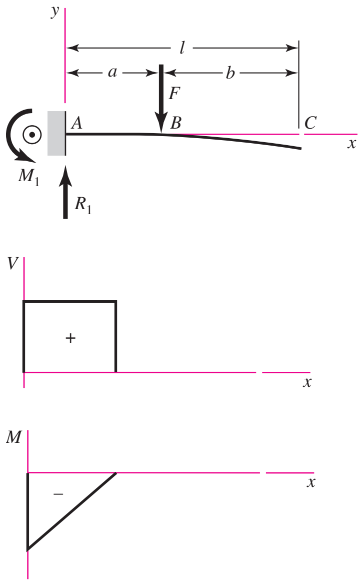
$$R_1 = V = F \qquad M_1 = Fl$$

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

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

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

2 Cantilever—intermediate load



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

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

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

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

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

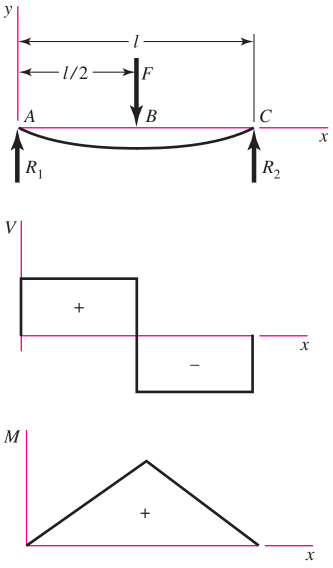
*(continued)*

## 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.)

5 Simple supports—center load



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

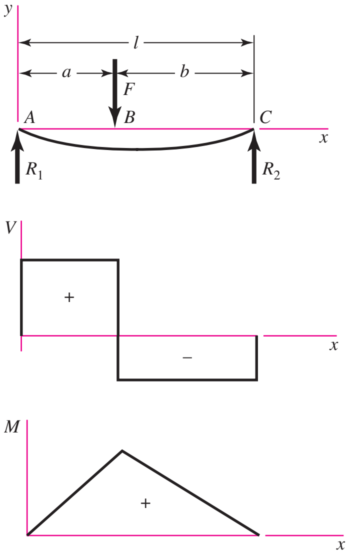
$$V_{AB} = R_1 \qquad V_{BC} = -R_2$$

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

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

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

6 Simple supports—intermediate load



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

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

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

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

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

*(continued)*

## Table A–11

A Selection of International Tolerance Grades—Metric Series (Size Ranges Are for *Over* the Lower Limit and *Including* the Upper Limit. All Values Are in Millimeters)

*Source: Preferred Metric Limits and Fits,* ANSI B4.2-1978. See also BSI 4500.

| Basic Sizes | Tolerance Grades | | | | | |
|---|---|---|---|---|---|---|
| | IT6 | IT7 | IT8 | IT9 | IT10 | IT11 |
| 0–3 | 0.006 | 0.010 | 0.014 | 0.025 | 0.040 | 0.060 |
| 3–6 | 0.008 | 0.012 | 0.018 | 0.030 | 0.048 | 0.075 |
| 6–10 | 0.009 | 0.015 | 0.022 | 0.036 | 0.058 | 0.090 |
| 10–18 | 0.011 | 0.018 | 0.027 | 0.043 | 0.070 | 0.110 |
| 18–30 | 0.013 | 0.021 | 0.033 | 0.052 | 0.084 | 0.130 |
| 30–50 | 0.016 | 0.025 | 0.039 | 0.062 | 0.100 | 0.160 |
| 50–80 | 0.019 | 0.030 | 0.046 | 0.074 | 0.120 | 0.190 |
| 80–120 | 0.022 | 0.035 | 0.054 | 0.087 | 0.140 | 0.220 |
| 120–180 | 0.025 | 0.040 | 0.063 | 0.100 | 0.160 | 0.250 |
| 180–250 | 0.029 | 0.046 | 0.072 | 0.115 | 0.185 | 0.290 |
| 250–315 | 0.032 | 0.052 | 0.081 | 0.130 | 0.210 | 0.320 |
| 315–400 | 0.036 | 0.057 | 0.089 | 0.140 | 0.230 | 0.360 |

## Table A–12

Fundamental Deviations for Shafts—Metric Series
(Size Ranges Are for *Over* the Lower Limit and *Including* the Upper Limit. All Values Are in Millimeters)

*Source: Preferred Metric Limits and Fits,* ANSI B4.2-1978. See also BSI 4500.

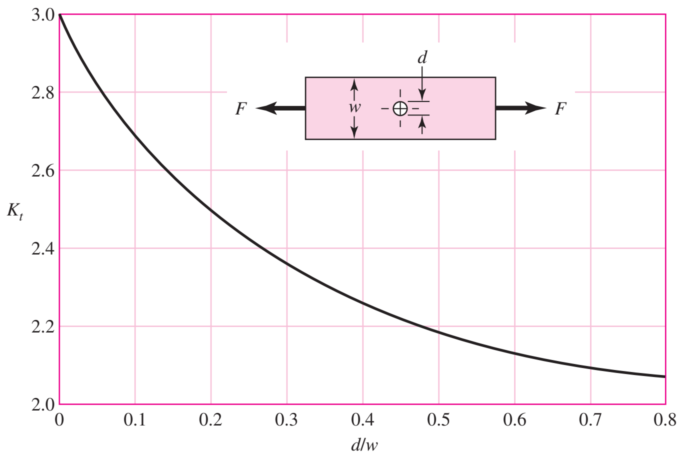
| Basic Sizes | Upper-Deviation Letter | | | | | Lower-Deviation Letter | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | c | d | f | g | h | k | n | p | s | u |
| 0–3 | −0.060 | −0.020 | −0.006 | −0.002 | 0 | 0 | +0.004 | +0.006 | +0.014 | +0.018 |
| 3–6 | −0.070 | −0.030 | −0.010 | −0.004 | 0 | +0.001 | +0.008 | +0.012 | +0.019 | +0.023 |
| 6–10 | −0.080 | −0.040 | −0.013 | −0.005 | 0 | +0.001 | +0.010 | +0.015 | +0.023 | +0.028 |
| 10–14 | −0.095 | −0.050 | −0.016 | −0.006 | 0 | +0.001 | +0.012 | +0.018 | +0.028 | +0.033 |
| 14–18 | −0.095 | −0.050 | −0.016 | −0.006 | 0 | +0.001 | +0.012 | +0.018 | +0.028 | +0.033 |
| 18–24 | −0.110 | −0.065 | −0.020 | −0.007 | 0 | +0.002 | +0.015 | +0.022 | +0.035 | +0.041 |
| 24–30 | −0.110 | −0.065 | −0.020 | −0.007 | 0 | +0.002 | +0.015 | +0.022 | +0.035 | +0.048 |
| 30–40 | −0.120 | −0.080 | −0.025 | −0.009 | 0 | +0.002 | +0.017 | +0.026 | +0.043 | +0.060 |
| 40–50 | −0.130 | −0.080 | −0.025 | −0.009 | 0 | +0.002 | +0.017 | +0.026 | +0.043 | +0.070 |
| 50–65 | −0.140 | −0.100 | −0.030 | −0.010 | 0 | +0.002 | +0.020 | +0.032 | +0.053 | +0.087 |
| 65–80 | −0.150 | −0.100 | −0.030 | −0.010 | 0 | +0.002 | +0.020 | +0.032 | +0.059 | +0.102 |
| 80–100 | −0.170 | −0.120 | −0.036 | −0.012 | 0 | +0.003 | +0.023 | +0.037 | +0.071 | +0.124 |
| 100–120 | −0.180 | −0.120 | −0.036 | −0.012 | 0 | +0.003 | +0.023 | +0.037 | +0.079 | +0.144 |
| 120–140 | −0.200 | −0.145 | −0.043 | −0.014 | 0 | +0.003 | +0.027 | +0.043 | +0.092 | +0.170 |
| 140–160 | −0.210 | −0.145 | −0.043 | −0.014 | 0 | +0.003 | +0.027 | +0.043 | +0.100 | +0.190 |
| 160–180 | −0.230 | −0.145 | −0.043 | −0.014 | 0 | +0.003 | +0.027 | +0.043 | +0.108 | +0.210 |
| 180–200 | −0.240 | −0.170 | −0.050 | −0.015 | 0 | +0.004 | +0.031 | +0.050 | +0.122 | +0.236 |
| 200–225 | −0.260 | −0.170 | −0.050 | −0.015 | 0 | +0.004 | +0.031 | +0.050 | +0.130 | +0.258 |
| 225–250 | −0.280 | −0.170 | −0.050 | −0.015 | 0 | +0.004 | +0.031 | +0.050 | +0.140 | +0.284 |
| 250–280 | −0.300 | −0.190 | −0.056 | −0.017 | 0 | +0.004 | +0.034 | +0.056 | +0.158 | +0.315 |
| 280–315 | −0.330 | −0.190 | −0.056 | −0.017 | 0 | +0.004 | +0.034 | +0.056 | +0.170 | +0.350 |
| 315–355 | −0.360 | −0.210 | −0.062 | −0.018 | 0 | +0.004 | +0.037 | +0.062 | +0.190 | +0.390 |
| 355–400 | −0.400 | −0.210 | −0.062 | −0.018 | 0 | +0.004 | +0.037 | +0.062 | +0.208 | +0.435 |

## Table A–15

Charts of Theoretical Stress-Concentration Factors $K_t^*$

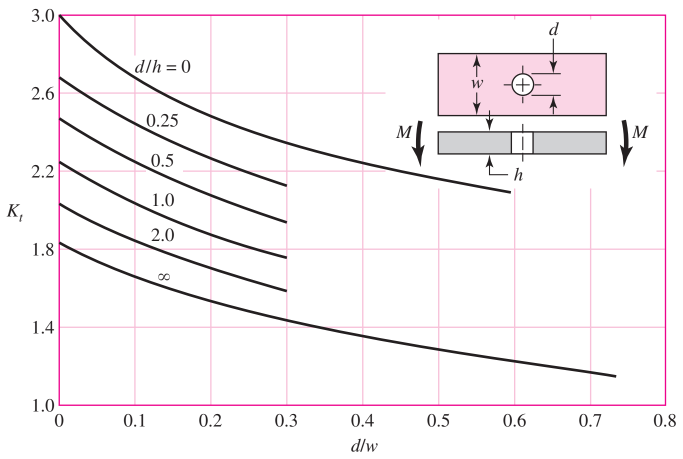
### Figure A–15–1

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



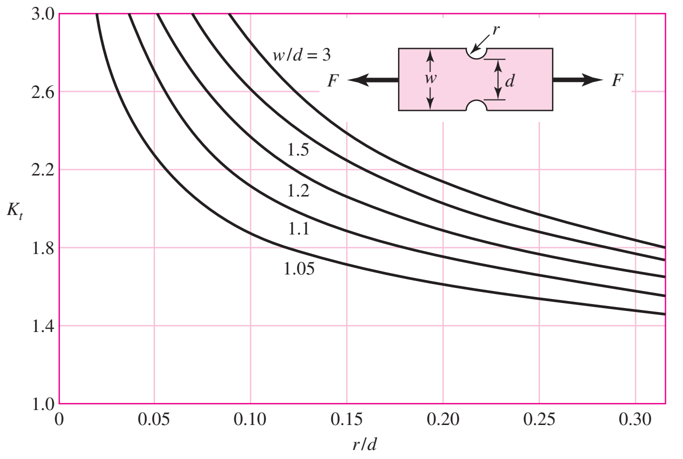
### Figure A–15–2

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.

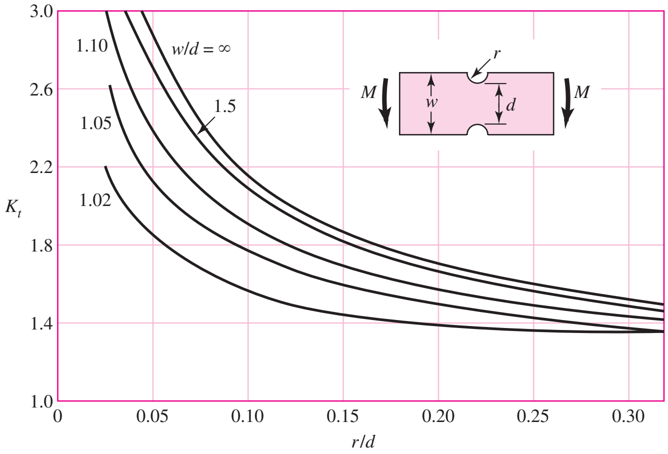


## Table A–15

Charts of Theoretical Stress-Concentration Factors $K_t$[*] *(Continued)*

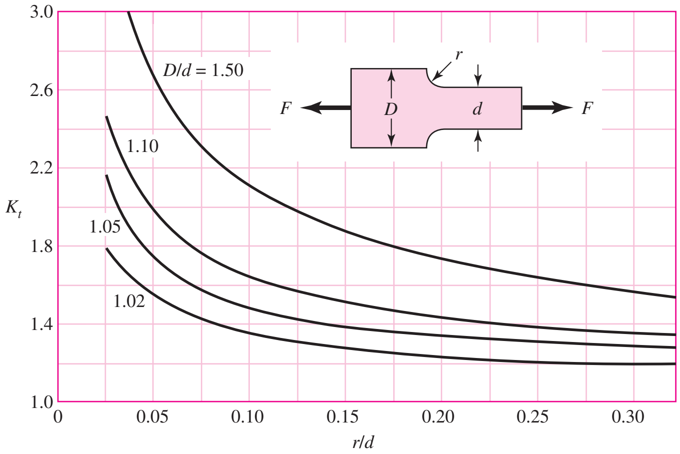
### Figure A–15–4

Notched rectangular bar in bending. $\sigma_0 = Mc/I$, where $c = d/2$, $I = td^3/12$, and $t$ is the thickness.



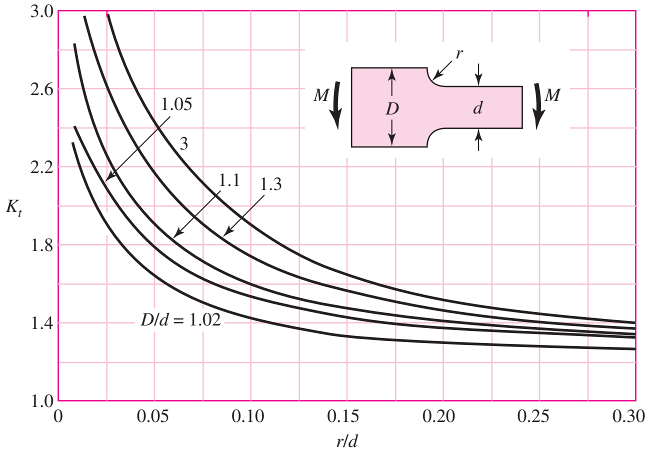
### Figure A–15–5

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



### Figure A–15–6

Rectangular filleted bar in bending. $\sigma_0 = Mc/I$, where $c = d/2$, $I = td^3/12$, $t$ is the thickness.



*(continued)*

---

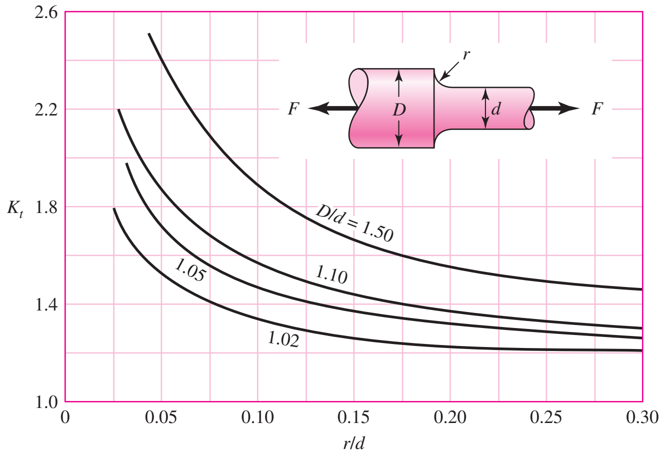
[*] Factors from R. E. Peterson, "Design Factors for Stress Concentration," Machine Design, vol. 23, no. 2, February 1951, p. 169; no. 3, March 1951, p. 161, no. 5, May 1951, p. 159; no. 6, June 1951, p. 173; no. 7, July 1951, p. 155. Reprinted with permission from Machine Design, a Penton Media Inc. publication.

## Table A–15

Charts of Theoretical Stress-Concentration Factors $K_t^*$ *(Continued)*

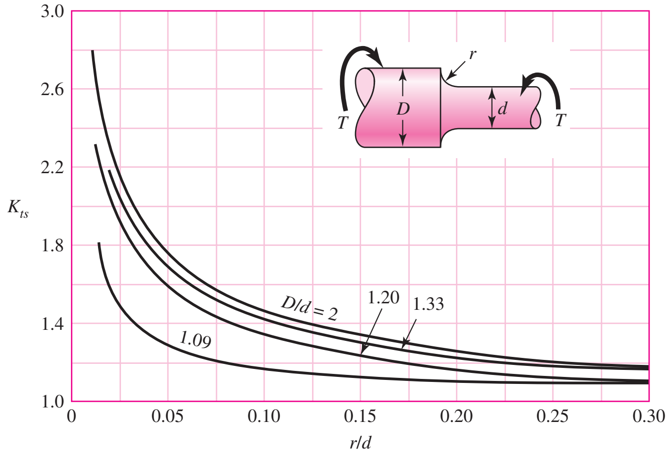
### Figure A–15–7

Round shaft with shoulder fillet in tension. $\sigma_0 = F/A$, where $A = \pi d^2/4$.



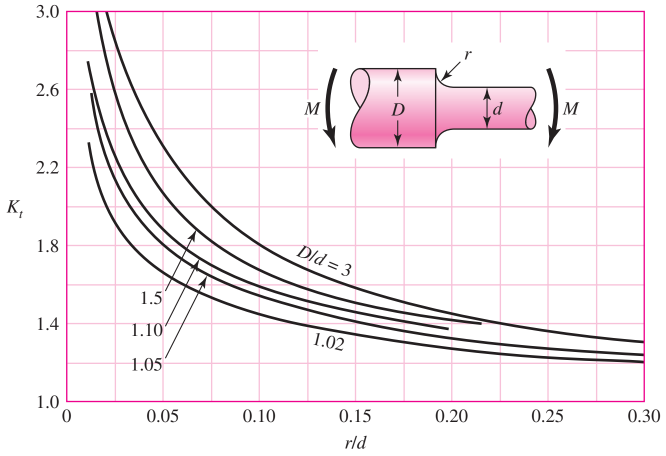
### Figure A–15–8

Round shaft with shoulder fillet in torsion. $\tau_0 = Tc/J$, where $c = d/2$ and $J = \pi d^4/32$.



### Figure A–15–9

Round shaft with shoulder fillet in bending. $\sigma_0 = Mc/I$, where $c = d/2$ and $I = \pi d^4/64$.



## Table A–15

Charts of Theoretical Stress-Concentration Factors $K_t^*$ *(Continued)*

**Figure A–15–10**

Round shaft in torsion with transverse hole.

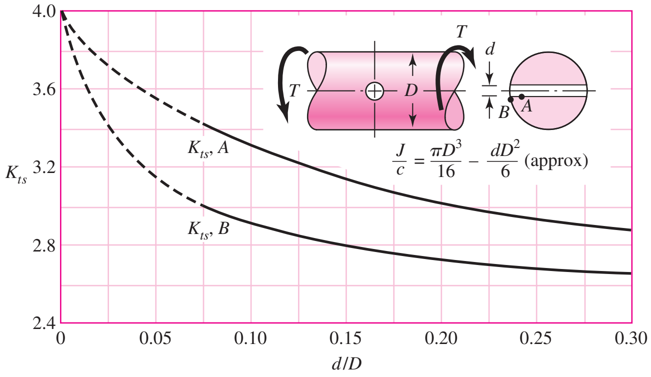


**Figure A–15–11**

Round shaft in bending with a transverse hole. $\sigma_0 = M/[(\pi D^3/32) - (dD^2/6)]$, approximately.

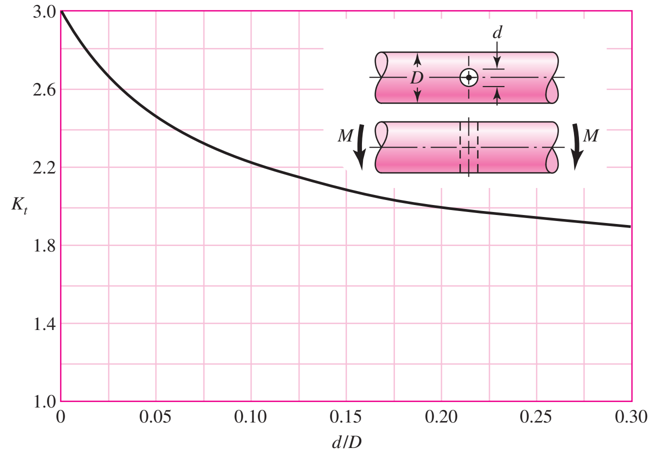
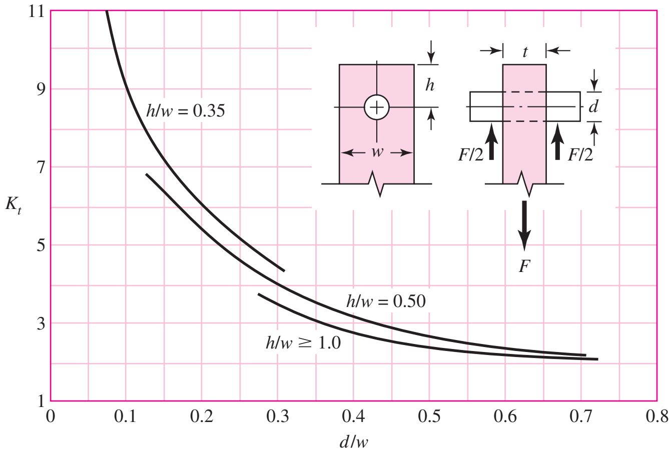


**Figure A–15–12**

Plate loaded in tension by a pin through a hole. $\sigma_0 = F/A$, where $A = (w - d)t$. When clearance exists, increase $K_t$ 35 to 50 percent. *(M. M. Frocht and H. N. Hill, "Stress-Concentration Factors around a Central Circular Hole in a Plate Loaded through a Pin in Hole," J. Appl. Mechanics, vol. 7, no. 1, March 1940, p. A-5.)*



*(continued)*

---

*Factors from R. E. Peterson, "Design Factors for Stress Concentration," Machine Design, vol. 23, no. 2, February 1951, p. 169; no. 3, March 1951, p. 161, no. 5, May 1951, p. 159; no. 6, June 1951, p. 173; no. 7, July 1951, p. 155. Reprinted with permission from Machine Design, a Penton Media Inc. publication.

## Table A–15

Charts of Theoretical Stress-Concentration Factors $K_t^*$ *(Continued)*

**Figure A–15–13**

Grooved round bar in tension. $\sigma_0 = F/A$, where $A = \pi d^2/4$.

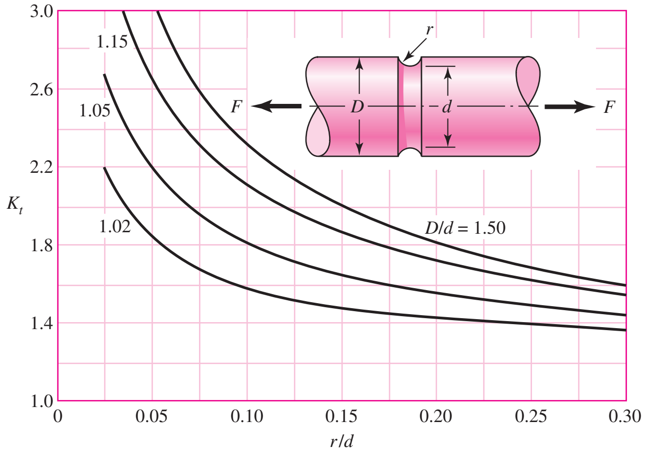


**Figure A–15–14**

Grooved round bar in bending. $\sigma_0 = Mc/I$, where $c = d/2$ and $I = \pi d^4/64$.

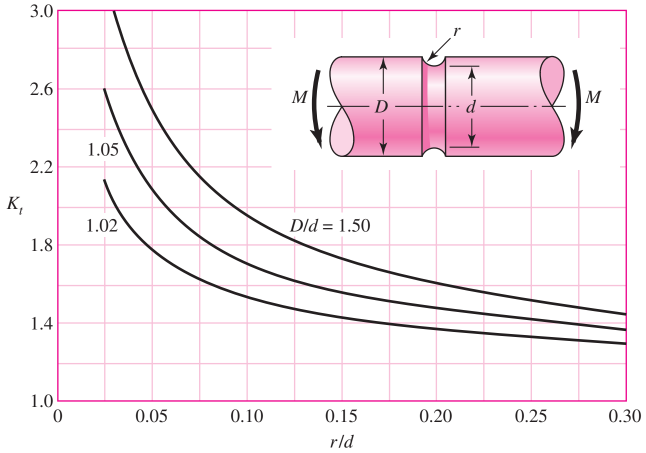
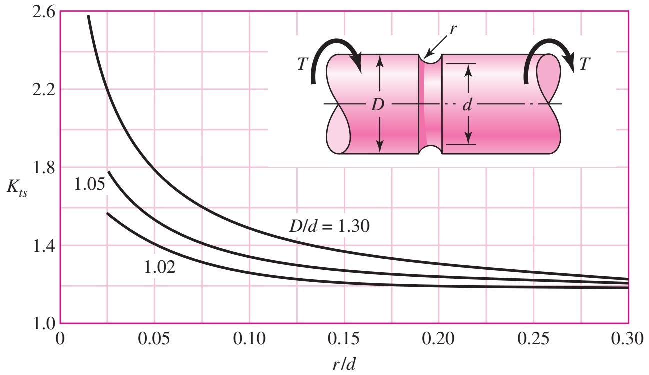


**Figure A–15–15**

Grooved round bar in torsion. $\tau_0 = Tc/J$, where $c = d/2$ and $J = \pi d^4/32$.



---

*Factors from R. E. Peterson, "Design Factors for Stress Concentration," Machine Design, vol. 23, no. 2, February 1951, p. 169; no. 3, March 1951, p. 161, no. 5, May 1951, p. 159; no. 6, June 1951, p. 173; no. 7, July 1951, p. 155. Reprinted with permission from Machine Design, a Penton Media Inc. publication.

## Table A–15

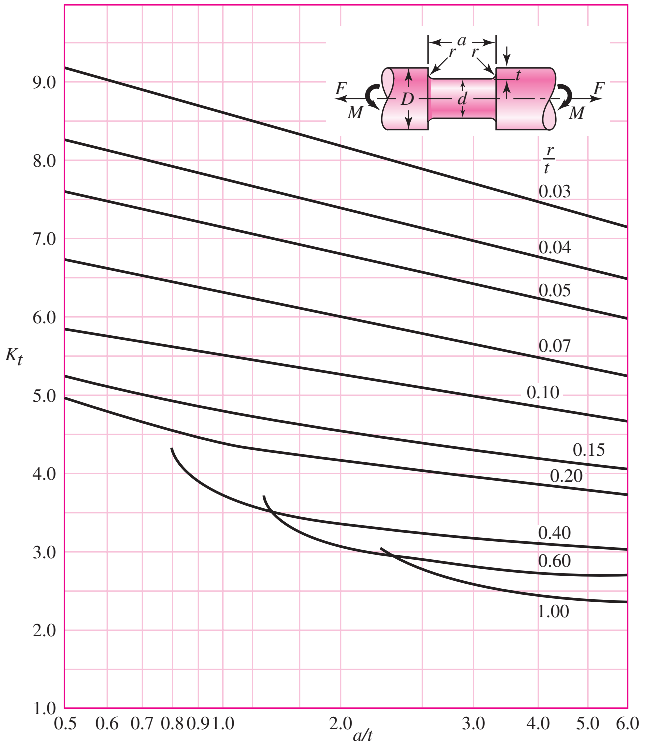
Charts of Theoretical Stress-Concentration Factors $K_t^*$ *(Continued)*

### Figure A–15–16

Round shaft with flat-bottom groove in bending and/or tension.

$$\sigma_0 = \frac{4F}{\pi d^2} + \frac{32M}{\pi d^3}$$

*Source:* W. D. Pilkey, *Peterson's Stress-Concentration Factors,* 2nd ed. John Wiley & Sons, New York, 1997, p. 115.



*(continued)*

## Table A–15

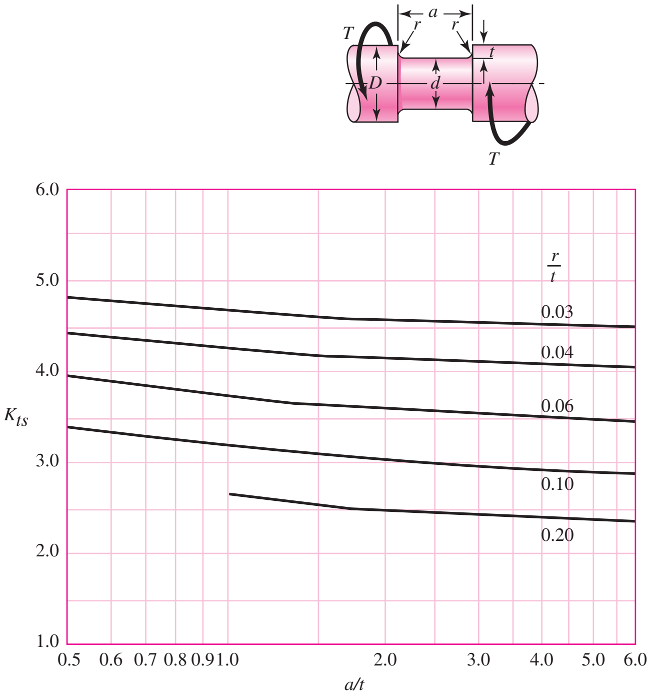
Charts of Theoretical Stress-Concentration Factors $K_t^*$ *(Continued)*

### Figure A–15–17

Round shaft with flat-bottom groove in torsion.

$$\tau_0 = \frac{16T}{\pi d^3}$$

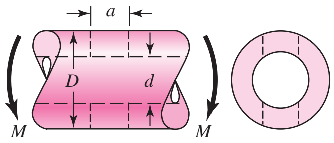
*Source:* W. D. Pilkey, *Peterson's Stress-Concentration Factors,* 2nd ed. John Wiley & Sons, New York, 1997, p. 133



## Table A–16

### Approximate Stress-Concentration Factor $K_t$ for Bending of a Round Bar or Tube with a Transverse Round Hole

*Source:* R. E. Peterson, *Stress-Concentration Factors,* Wiley, New York, 1974, pp. 146, 235.



The nominal bending stress is $\sigma_0 = M/Z_{\text{net}}$ where $Z_{\text{net}}$ is a reduced value of the section modulus and is defined by

$$Z_{\text{net}} = \frac{\pi A}{32D}(D^4 - d^4)$$

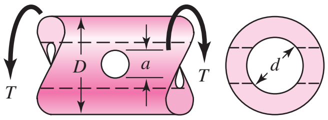
Values of $A$ are listed in the table. Use $d = 0$ for a solid bar

| | d/D | | | | | |
|---|---|---|---|---|---|---|
| | 0.9 | | 0.6 | | 0 | |
| a/D | A | $K_t$ | A | $K_t$ | A | $K_t$ |
| 0.050 | 0.92 | 2.63 | 0.91 | 2.55 | 0.88 | 2.42 |
| 0.075 | 0.89 | 2.55 | 0.88 | 2.43 | 0.86 | 2.35 |
| 0.10 | 0.86 | 2.49 | 0.85 | 2.36 | 0.83 | 2.27 |
| 0.125 | 0.82 | 2.41 | 0.82 | 2.32 | 0.80 | 2.20 |
| 0.15 | 0.79 | 2.39 | 0.79 | 2.29 | 0.76 | 2.15 |
| 0.175 | 0.76 | 2.38 | 0.75 | 2.26 | 0.72 | 2.10 |
| 0.20 | 0.73 | 2.39 | 0.72 | 2.23 | 0.68 | 2.07 |
| 0.225 | 0.69 | 2.40 | 0.68 | 2.21 | 0.65 | 2.04 |
| 0.25 | 0.67 | 2.42 | 0.64 | 2.18 | 0.61 | 2.00 |
| 0.275 | 0.66 | 2.48 | 0.61 | 2.16 | 0.58 | 1.97 |
| 0.30 | 0.64 | 2.52 | 0.58 | 2.14 | 0.54 | 1.94 |

*(continued)*

## **Table A–16** *(Continued)*

Approximate Stress-Concentration Factors $K_{ts}$ for a Round Bar or Tube Having a Transverse Round Hole and Loaded in Torsion *Source:* R. E. Peterson, *Stress-Concentration Factors,* Wiley, New York, 1974, pp. 148, 244.



The maximum stress occurs on the inside of the hole, slightly below the shaft surface. The nominal shear stress is $\tau_0 = TD/2J_{\text{net}}$, where $J_{\text{net}}$ is a reduced value of the second polar moment of area and is defined by

$$J_{\text{net}} = \frac{\pi A(D^4 - d^4)}{32}$$

Values of $A$ are listed in the table. Use $d = 0$ for a solid bar.

| | d/D | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.9 | | 0.8 | | 0.6 | | 0.4 | | 0 | |
| **a/D** | **A** | **$K_{ts}$** | **A** | **$K_{ts}$** | **A** | **$K_{ts}$** | **A** | **$K_{ts}$** | **A** | **$K_{ts}$** |
| 0.05 | 0.96 | 1.78 | | | | | | | 0.95 | 1.77 |
| 0.075 | 0.95 | 1.82 | | | | | | | 0.93 | 1.71 |
| 0.10 | 0.94 | 1.76 | 0.93 | 1.74 | 0.92 | 1.72 | 0.92 | 1.70 | 0.92 | 1.68 |
| 0.125 | 0.91 | 1.76 | 0.91 | 1.74 | 0.90 | 1.70 | 0.90 | 1.67 | 0.89 | 1.64 |
| 0.15 | 0.90 | 1.77 | 0.89 | 1.75 | 0.87 | 1.69 | 0.87 | 1.65 | 0.87 | 1.62 |
| 0.175 | 0.89 | 1.81 | 0.88 | 1.76 | 0.87 | 1.69 | 0.86 | 1.64 | 0.85 | 1.60 |
| 0.20 | 0.88 | 1.96 | 0.86 | 1.79 | 0.85 | 1.70 | 0.84 | 1.63 | 0.83 | 1.58 |
| 0.25 | 0.87 | 2.00 | 0.82 | 1.86 | 0.81 | 1.72 | 0.80 | 1.63 | 0.79 | 1.54 |
| 0.30 | 0.80 | 2.18 | 0.78 | 1.97 | 0.77 | 1.76 | 0.75 | 1.63 | 0.74 | 1.51 |
| 0.35 | 0.77 | 2.41 | 0.75 | 2.09 | 0.72 | 1.81 | 0.69 | 1.63 | 0.68 | 1.47 |
| 0.40 | 0.72 | 2.67 | 0.71 | 2.25 | 0.68 | 1.89 | 0.64 | 1.63 | 0.63 | 1.44 |

## 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, $6\frac{1}{2}$, 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–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 Processing | 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 |
| 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 |

## Table A–21

Mean Mechanical Properties of Some Heat-Treated Steels

[These are typical properties for materials normalized and annealed. The properties for quenched and tempered (Q&T) steels are from a single heat. Because of the many variables, the properties listed are global averages. In all cases, data were obtained from specimens of diameter 0.505 in, machined from 1-in rounds, and of gauge length 2 in. unless noted, all specimens were oil-quenched.] *Source: ASM Metals Reference Book,* 2d ed., American Society for Metals, Metals Park, Ohio, 1983.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| **AISI No.** | **Treatment** | **Temperature °C (°F)** | **Tensile Strength MPa (kpsi)** | **Yield Strength, MPa (kpsi)** | **Elongation, %** | **Reduction in Area, %** | **Brinell Hardness** |
| 1030 | Q&T* | 205 (400) | 848 (123) | 648 (94) | 17 | 47 | 495 |
| | Q&T* | 315 (600) | 800 (116) | 621 (90) | 19 | 53 | 401 |
| | Q&T* | 425 (800) | 731 (106) | 579 (84) | 23 | 60 | 302 |
| | Q&T* | 540 (1000) | 669 (97) | 517 (75) | 28 | 65 | 255 |
| | Q&T* | 650 (1200) | 586 (85) | 441 (64) | 32 | 70 | 207 |
| | Normalized | 925 (1700) | 521 (75) | 345 (50) | 32 | 61 | 149 |
| | Annealed | 870 (1600) | 430 (62) | 317 (46) | 35 | 64 | 137 |
| 1040 | Q&T | 205 (400) | 779 (113) | 593 (86) | 19 | 48 | 262 |
| | Q&T | 425 (800) | 758 (110) | 552 (80) | 21 | 54 | 241 |
| | Q&T | 650 (1200) | 634 (92) | 434 (63) | 29 | 65 | 192 |
| | Normalized | 900 (1650) | 590 (86) | 374 (54) | 28 | 55 | 170 |
| | Annealed | 790 (1450) | 519 (75) | 353 (51) | 30 | 57 | 149 |
| 1050 | Q&T* | 205 (400) | 1120 (163) | 807 (117) | 9 | 27 | 514 |
| | Q&T* | 425 (800) | 1090 (158) | 793 (115) | 13 | 36 | 444 |
| | Q&T* | 650 (1200) | 717 (104) | 538 (78) | 28 | 65 | 235 |
| | Normalized | 900 (1650) | 748 (108) | 427 (62) | 20 | 39 | 217 |
| | Annealed | 790 (1450) | 636 (92) | 365 (53) | 24 | 40 | 187 |
| 1060 | Q&T | 425 (800) | 1080 (156) | 765 (111) | 14 | 41 | 311 |
| | Q&T | 540 (1000) | 965 (140) | 669 (97) | 17 | 45 | 277 |
| | Q&T | 650 (1200) | 800 (116) | 524 (76) | 23 | 54 | 229 |
| | Normalized | 900 (1650) | 776 (112) | 421 (61) | 18 | 37 | 229 |
| | Annealed | 790 (1450) | 626 (91) | 372 (54) | 22 | 38 | 179 |
| 1095 | Q&T | 315 (600) | 1260 (183) | 813 (118) | 10 | 30 | 375 |
| | Q&T | 425 (800) | 1210 (176) | 772 (112) | 12 | 32 | 363 |
| | Q&T | 540 (1000) | 1090 (158) | 676 (98) | 15 | 37 | 321 |
| | Q&T | 650 (1200) | 896 (130) | 552 (80) | 21 | 47 | 269 |
| | Normalized | 900 (1650) | 1010 (147) | 500 (72) | 9 | 13 | 293 |
| | Annealed | 790 (1450) | 658 (95) | 380 (55) | 13 | 21 | 192 |
| 1141 | Q&T | 315 (600) | 1460 (212) | 1280 (186) | 9 | 32 | 415 |
| | Q&T | 540 (1000) | 896 (130) | 765 (111) | 18 | 57 | 262 |

*(continued)*

**Table A–21** *(Continued)*

Mean Mechanical Properties of Some Heat-Treated Steels
[These are typical properties for materials normalized and annealed. The properties for quenched and tempered (Q&T) steels are from a single heat. Because of the many variables, the properties listed are global averages. In all cases, data were obtained from specimens of diameter 0.505 in, machined from 1-in rounds, and of gauge length 2 in. Unless noted, all specimens were oil-quenched.] *Source: ASM Metals Reference Book,* 2d ed., American Society for Metals, Metals Park, Ohio, 1983.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| **AISI No.** | **Treatment** | **Temperature °C (°F)** | **Tensile Strength MPa (kpsi)** | **Yield Strength, MPa (kpsi)** | **Elongation, %** | **Reduction in Area, %** | **Brinell Hardness** |
| 4130 | Q&T* | 205 (400) | 1630 (236) | 1460 (212) | 10 | 41 | 467 |
| | Q&T* | 315 (600) | 1500 (217) | 1380 (200) | 11 | 43 | 435 |
| | Q&T* | 425 (800) | 1280 (186) | 1190 (173) | 13 | 49 | 380 |
| | Q&T* | 540 (1000) | 1030 (150) | 910 (132) | 17 | 57 | 315 |
| | Q&T* | 650 (1200) | 814 (118) | 703 (102) | 22 | 64 | 245 |
| | Normalized | 870 (1600) | 670 (97) | 436 (63) | 25 | 59 | 197 |
| | Annealed | 865 (1585) | 560 (81) | 361 (52) | 28 | 56 | 156 |
| 4140 | Q&T | 205 (400) | 1770 (257) | 1640 (238) | 8 | 38 | 510 |
| | Q&T | 315 (600) | 1550 (225) | 1430 (208) | 9 | 43 | 445 |
| | Q&T | 425 (800) | 1250 (181) | 1140 (165) | 13 | 49 | 370 |
| | Q&T | 540 (1000) | 951 (138) | 834 (121) | 18 | 58 | 285 |
| | Q&T | 650 (1200) | 758 (110) | 655 (95) | 22 | 63 | 230 |
| | Normalized | 870 (1600) | 1020 (148) | 655 (95) | 18 | 47 | 302 |
| | Annealed | 815 (1500) | 655 (95) | 417 (61) | 26 | 57 | 197 |
| 4340 | Q&T | 315 (600) | 1720 (250) | 1590 (230) | 10 | 40 | 486 |
| | Q&T | 425 (800) | 1470 (213) | 1360 (198) | 10 | 44 | 430 |
| | Q&T | 540 (1000) | 1170 (170) | 1080 (156) | 13 | 51 | 360 |
| | Q&T | 650 (1200) | 965 (140) | 855 (124) | 19 | 60 | 280 |

*Water-quenched

## Table A–22

Results of Tensile Tests of Some Metals* *Source:* J. Datsko, "Solid Materials," chap. 32 in Joseph E. Shigley, Charles R. Mischke, and Thomas H. Brown, Jr. (eds.-in-chief), *Standard Handbook of Machine Design,* 3rd ed., McGraw-Hill, New York, 2004, pp. 32.49–32.52.

| | | | Strength (Tensile) | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Number** | **Material** | **Condition** | **Yield $S_y$, MPa (kpsi)** | **Ultimate $S_u$, MPa (kpsi)** | **Fracture, $\sigma_f$, MPa (kpsi)** | **Coefficient $\sigma_0$, MPa (kpsi)** | **Strain Strength, Exponent $m$** | **Fracture Strain $\epsilon_f$** |
| 1018 | Steel | Annealed | 220 (32.0) | 341 (49.5) | 628 (91.1)[†] | 620 (90.0) | 0.25 | 1.05 |
| 1144 | Steel | Annealed | 358 (52.0) | 646 (93.7) | 898 (130)[†] | 992 (144) | 0.14 | 0.49 |
| 1212 | Steel | HR | 193 (28.0) | 424 (61.5) | 729 (106)[†] | 758 (110) | 0.24 | 0.85 |
| 1045 | Steel | Q&T 600°F | 1520 (220) | 1580 (230) | 2380 (345) | 1880 (273)[†] | 0.041 | 0.81 |
| 4142 | Steel | Q&T 600°F | 1720 (250) | 1930 (210) | 2340 (340) | 1760 (255)[†] | 0.048 | 0.43 |
| 303 | Stainless steel | Annealed | 241 (35.0) | 601 (87.3) | 1520 (221)[†] | 1410 (205) | 0.51 | 1.16 |
| 304 | Stainless steel | Annealed | 276 (40.0) | 568 (82.4) | 1600 (233)[†] | 1270 (185) | 0.45 | 1.67 |
| 2011 | Aluminum alloy | T6 | 169 (24.5) | 324 (47.0) | 325 (47.2)[†] | 620 (90) | 0.28 | 0.10 |
| 2024 | Aluminum alloy | T4 | 296 (43.0) | 446 (64.8) | 533 (77.3)[†] | 689 (100) | 0.15 | 0.18 |
| 7075 | Aluminum alloy | T6 | 542 (78.6) | 593 (86.0) | 706 (102)[†] | 882 (128) | 0.13 | 0.18 |

*Values from one or two heats and believed to be attainable using proper purchase specifications. The fracture strain may vary as much as 100 percent.

[†] Derived value.

## Table A–24

Mechanical Properties of Three Non-Steel Metals *(Continued)*

(b) Mechanical Properties of Some Aluminum Alloys

[These *are typical* properties for sizes of about $\frac{1}{2}$ in; similar properties can be obtained by using proper purchase specifications. The values given for fatigue strength correspond to $50(10^7)$ cycles of completely reversed stress. Alluminum alloys do not have an endurance limit. Yield strengths were obtained by the 0.2 percent offset method.]

| Aluminum Association Number | Temper | Strength | | | Elongation in 2 in, % | Brinell Hardness $H_B$ |
|---|---|---|---|---|---|---|
| | | Yield, $S_y$, MPa (kpsi) | Tensile, $S_u$, MPa (kpsi) | Fatigue, $S_f$, MPa (kpsi) | | |
| Wrought: | | | | | | |
| 2017 | O | 70 (10) | 179 (26) | 90 (13) | 22 | 45 |
| 2024 | O | 76 (11) | 186 (27) | 90 (13) | 22 | 47 |
| | T3 | 345 (50) | 482 (70) | 138 (20) | 16 | 120 |
| 3003 | H12 | 117 (17) | 131 (19) | 55 (8) | 20 | 35 |
| | H16 | 165 (24) | 179 (26) | 65 (9.5) | 14 | 47 |
| 3004 | H34 | 186 (27) | 234 (34) | 103 (15) | 12 | 63 |
| | H38 | 234 (34) | 276 (40) | 110 (16) | 6 | 77 |
| 5052 | H32 | 186 (27) | 234 (34) | 117 (17) | 18 | 62 |
| | H36 | 234 (34) | 269 (39) | 124 (18) | 10 | 74 |
| Cast: | | | | | | |
| 319.0* | T6 | 165 (24) | 248 (36) | 69 (10) | 2.0 | 80 |
| 333.0[†] | T5 | 172 (25) | 234 (34) | 83 (12) | 1.0 | 100 |
| | T6 | 207 (30) | 289 (42) | 103 (15) | 1.5 | 105 |
| 335.0* | T6 | 172 (25) | 241 (35) | 62 (9) | 3.0 | 80 |
| | T7 | 248 (36) | 262 (38) | 62 (9) | 0.5 | 85 |

*Sand casting.

[†] Permanent-mold casting.

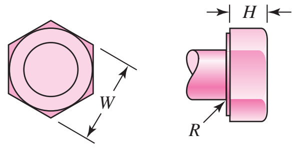
(c) Mechanical Properties of Some Titanium Alloys

| Titanium Alloy | Condition | Yield, $S_y$ (0.2% offset) MPa (kpsi) | Strength Tensile, $S_{ut}$ MPa (kpsi) | Elongation in 2 in, % | Hardness (Brinell or Rockwell) |
|---|---|---|---|---|---|
| Ti-35A[†] | Annealed | 210 (30) | 275 (40) | 30 | 135 HB |
| Ti-50A[†] | Annealed | 310 (45) | 380 (55) | 25 | 215 HB |
| Ti-0.2 Pd | Annealed | 280 (40) | 340 (50) | 28 | 200 HB |
| Ti-5 Al-2.5 Sn | Annealed | 760 (110) | 790 (115) | 16 | 36 HRC |
| Ti-8 Al-1 Mo-1 V | Annealed | 900 (130) | 965 (140) | 15 | 39 HRC |
| Ti-6 Al-6 V-2 Sn | Annealed | 970 (140) | 1030 (150) | 14 | 38 HRC |
| Ti-6Al-4V | Annealed | 830 (120) | 900 (130) | 14 | 36 HRC |
| Ti-13 V-11 Cr-3 Al | Sol. + aging | 1207 (175) | 1276 (185) | 8 | 40 HRC |

[†] Commercially pure alpha titanium.

## Table A–29

Dimensions of Square and Hexagonal Bolts



| | Head Type | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nominal Size, in** | **Square** | | **Regular Hexagonal** | | | **Heavy Hexagonal** | | | **Structural Hexagonal** | | |
| | $W$ | $H$ | $W$ | $H$ | $R_{\min}$ | $W$ | $H$ | $R_{\min}$ | $W$ | $H$ | $R_{\min}$ |
| $\frac{1}{4}$ | $\frac{3}{8}$ | $\frac{11}{64}$ | $\frac{7}{16}$ | $\frac{11}{64}$ | 0.01 | | | | | | |
| $\frac{5}{16}$ | $\frac{1}{2}$ | $\frac{13}{64}$ | $\frac{1}{2}$ | $\frac{7}{32}$ | 0.01 | | | | | | |
| $\frac{3}{8}$ | $\frac{9}{16}$ | $\frac{1}{4}$ | $\frac{9}{16}$ | $\frac{1}{4}$ | 0.01 | | | | | | |
| $\frac{7}{16}$ | $\frac{5}{8}$ | $\frac{19}{64}$ | $\frac{5}{8}$ | $\frac{19}{64}$ | 0.01 | | | | | | |
| $\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{21}{64}$ | $\frac{3}{4}$ | $\frac{11}{32}$ | 0.01 | $\frac{7}{8}$ | $\frac{11}{32}$ | 0.01 | $\frac{7}{8}$ | $\frac{5}{16}$ | 0.009 |
| $\frac{5}{8}$ | $\frac{15}{16}$ | $\frac{27}{64}$ | $\frac{15}{16}$ | $\frac{27}{64}$ | 0.02 | $1\frac{1}{16}$ | $\frac{27}{64}$ | 0.02 | $1\frac{1}{16}$ | $\frac{25}{64}$ | 0.021 |
| $\frac{3}{4}$ | $1\frac{1}{8}$ | $\frac{1}{2}$ | $1\frac{1}{8}$ | $\frac{1}{2}$ | 0.02 | $1\frac{1}{4}$ | $\frac{1}{2}$ | 0.02 | $1\frac{1}{4}$ | $\frac{15}{32}$ | 0.021 |
| 1 | $1\frac{1}{2}$ | $\frac{21}{32}$ | $1\frac{1}{2}$ | $\frac{43}{64}$ | 0.03 | $1\frac{5}{8}$ | $\frac{43}{64}$ | 0.03 | $1\frac{5}{8}$ | $\frac{39}{64}$ | 0.062 |
| $1\frac{1}{8}$ | $1\frac{11}{16}$ | $\frac{3}{4}$ | $1\frac{11}{16}$ | $\frac{3}{4}$ | 0.03 | $1\frac{13}{16}$ | $\frac{3}{4}$ | 0.03 | $1\frac{13}{16}$ | $\frac{11}{16}$ | 0.062 |
| $1\frac{1}{4}$ | $1\frac{7}{8}$ | $\frac{27}{32}$ | $1\frac{7}{8}$ | $\frac{27}{32}$ | 0.03 | 2 | $\frac{27}{32}$ | 0.03 | 2 | $\frac{25}{32}$ | 0.062 |
| $1\frac{3}{8}$ | $2\frac{1}{16}$ | $\frac{29}{32}$ | $2\frac{1}{16}$ | $\frac{29}{32}$ | 0.03 | $2\frac{3}{16}$ | $\frac{29}{32}$ | 0.03 | $2\frac{3}{16}$ | $\frac{27}{32}$ | 0.062 |
| $1\frac{1}{2}$ | $2\frac{1}{4}$ | 1 | $2\frac{1}{4}$ | 1 | 0.03 | $2\frac{3}{8}$ | 1 | 0.03 | $2\frac{3}{8}$ | $\frac{15}{16}$ | 0.062 |
| **Nominal Size, mm** | | | | | | | | | | | |
| M5 | 8 | 3.58 | 8 | 3.58 | 0.2 | | | | | | |
| M6 | | | 10 | 4.38 | 0.3 | | | | | | |
| M8 | | | 13 | 5.68 | 0.4 | | | | | | |
| M10 | | | 16 | 6.85 | 0.4 | | | | | | |
| M12 | | | 18 | 7.95 | 0.6 | 21 | 7.95 | 0.6 | | | |
| M14 | | | 21 | 9.25 | 0.6 | 24 | 9.25 | 0.6 | | | |
| M16 | | | 24 | 10.75 | 0.6 | 27 | 10.75 | 0.6 | 27 | 10.75 | 0.6 |
| M20 | | | 30 | 13.40 | 0.8 | 34 | 13.40 | 0.8 | 34 | 13.40 | 0.8 |
| M24 | | | 36 | 15.90 | 0.8 | 41 | 15.90 | 0.8 | 41 | 15.90 | 1.0 |
| M30 | | | 46 | 19.75 | 1.0 | 50 | 19.75 | 1.0 | 50 | 19.75 | 1.2 |
| M36 | | | 55 | 23.55 | 1.0 | 60 | 23.55 | 1.0 | 60 | 23.55 | 1.5 |

## Table A–30

Dimensions of Hexagonal Cap Screws and Heavy Hexagonal Screws ($W$ = Width across Flats; $H$ = Height of Head; See Figure in Table A–29)

| Nominal Size, in | Minimum Fillet Radius | Type of Screw | | Height $H$ |
|---|---|---|---|---|
| | | Cap $W$ | Heavy $W$ | |
| $\frac{1}{4}$ | 0.015 | $\frac{7}{16}$ | | $\frac{5}{32}$ |
| $\frac{5}{16}$ | 0.015 | $\frac{1}{2}$ | | $\frac{13}{64}$ |
| $\frac{3}{8}$ | 0.015 | $\frac{9}{16}$ | | $\frac{15}{64}$ |
| $\frac{7}{16}$ | 0.015 | $\frac{5}{8}$ | | $\frac{9}{32}$ |
| $\frac{1}{2}$ | 0.015 | $\frac{3}{4}$ | $\frac{7}{8}$ | $\frac{5}{16}$ |
| $\frac{5}{8}$ | 0.020 | $\frac{15}{16}$ | $1\frac{1}{16}$ | $\frac{25}{64}$ |
| $\frac{3}{4}$ | 0.020 | $1\frac{1}{8}$ | $1\frac{1}{4}$ | $\frac{15}{32}$ |
| $\frac{7}{8}$ | 0.040 | $1\frac{5}{16}$ | $1\frac{7}{16}$ | $\frac{35}{64}$ |
| 1 | 0.060 | $1\frac{1}{2}$ | $1\frac{1}{8}$ | $\frac{39}{64}$ |
| $1\frac{1}{4}$ | 0.060 | $1\frac{7}{8}$ | 2 | $\frac{25}{32}$ |
| $1\frac{3}{8}$ | 0.060 | $2\frac{1}{16}$ | $2\frac{3}{16}$ | $\frac{27}{32}$ |
| $1\frac{1}{2}$ | 0.060 | $2\frac{1}{4}$ | $2\frac{3}{8}$ | $\frac{15}{16}$ |
| **Nominal Size, mm** | | | | |
| M5 | 0.2 | 8 | | 3.65 |
| M6 | 0.3 | 10 | | 4.15 |
| M8 | 0.4 | 13 | | 5.50 |
| M10 | 0.4 | 16 | | 6.63 |
| M12 | 0.6 | 18 | 21 | 7.76 |
| M14 | 0.6 | 21 | 24 | 9.09 |
| M16 | 0.6 | 24 | 27 | 10.32 |
| M20 | 0.8 | 30 | 34 | 12.88 |
| M24 | 0.8 | 36 | 41 | 15.44 |
| M30 | 1.0 | 46 | 50 | 19.48 |
| M36 | 1.0 | 55 | 60 | 23.38 |

## Table A–31

Dimensions of Hexagonal Nuts

| | | Height *H* | | |
|---|---|---|---|---|
| **Nominal Size, in** | **Width *W*** | **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 |
|---|---|---|---|
| 1.6 N | 1.95 | 4.00 | 0.70 |
| 1.6 R | 1.95 | 5.00 | 0.70 |
| 1.6 W | 1.95 | 6.00 | 0.90 |
| 2 N | 2.50 | 5.00 | 0.90 |
| 2 R | 2.50 | 6.00 | 0.90 |
| 2 W | 2.50 | 8.00 | 0.90 |
| 2.5 N | 3.00 | 6.00 | 0.90 |
| 2.5 R | 3.00 | 8.00 | 0.90 |
| 2.5 W | 3.00 | 10.00 | 1.20 |
| 3 N | 3.50 | 7.00 | 0.90 |
| 3 R | 3.50 | 10.00 | 1.20 |
| 3 W | 3.50 | 12.00 | 1.40 |
| 3.5 N | 4.00 | 9.00 | 1.20 |
| 3.5 R | 4.00 | 10.00 | 1.40 |
| 3.5 W | 4.00 | 15.00 | 1.75 |
| 4 N | 4.70 | 10.00 | 1.20 |
| 4 R | 4.70 | 12.00 | 1.40 |
| 4 W | 4.70 | 16.00 | 2.30 |
| 5 N | 5.50 | 11.00 | 1.40 |
| 5 R | 5.50 | 15.00 | 1.75 |
| 5 W | 5.50 | 20.00 | 2.30 |
| 6 N | 6.65 | 13.00 | 1.75 |
| 6 R | 6.65 | 18.80 | 1.75 |
| 6 W | 6.65 | 25.40 | 2.30 |
| 8 N | 8.90 | 18.80 | 2.30 |
| 8 R | 8.90 | 25.40 | 2.30 |
| 8 W | 8.90 | 32.00 | 2.80 |
| 10 N | 10.85 | 20.00 | 2.30 |
| 10 R | 10.85 | 28.00 | 2.80 |
| 10 W | 10.85 | 39.00 | 3.50 |
| 12 N | 13.30 | 25.40 | 2.80 |
| 12 R | 13.30 | 34.00 | 3.50 |
| 12 W | 13.30 | 44.00 | 3.50 |
| 14 N | 15.25 | 28.00 | 2.80 |
| 14 R | 15.25 | 39.00 | 3.50 |
| 14 W | 15.25 | 50.00 | 4.00 |
| 16 N | 17.25 | 32.00 | 3.50 |
| 16 R | 17.25 | 44.00 | 4.00 |
| 16 W | 17.25 | 56.00 | 4.60 |
| 20 N | 21.80 | 39.00 | 4.00 |
| 20 R | 21.80 | 50.00 | 4.60 |
| 20 W | 21.80 | 66.00 | 5.10 |
| 24 N | 25.60 | 44.00 | 4.60 |
| 24 R | 25.60 | 56.00 | 5.10 |
| 24 W | 25.60 | 72.00 | 5.60 |
| 30 N | 32.40 | 56.00 | 5.10 |
| 30 R | 32.40 | 72.00 | 5.60 |
| 30 W | 32.40 | 90.00 | 6.40 |
| 36 N | 38.30 | 66.00 | 5.60 |
| 36 R | 38.30 | 90.00 | 6.40 |
| 36 W | 38.30 | 110.00 | 8.50 |

N = narrow; R = regular; W = wide.
*Same as screw or bolt size.