<u>units</u>

Norton Tables 1-4 and 1-5

<u>hardness</u>

Norton Table 2-3

<u>material properties</u>

Norton Appendix A-1 general E G ν ρ

Norton Appendices A-2 and A-3 aluminum

Norton Appendix A-9 steel

6-32 UNC bolts $A_T = 0.0091\ \text{in}^2$ Norton Table 15-1

guess 1010 cold rolled steel $S_{UT} = 53$ ksi Norton Table A-9

$F_{BOLT}\ r = F_{GRIP}\ R$ $F_{BOLT} = F_{GRIP}\ R / r$ $\tau \approx \dfrac{F_{BOLT}}{A_T} = \dfrac{F_{GRIP}\ R}{r\ A_T}$

von Mises $\sigma' = \sqrt{3}\ \tau = \dfrac{\sqrt{3}\ F_{GRIP}\ R}{r\ A_T}$

at failure assume $S_{UT} = \sigma'$

$$F_{GRIP} = \frac{r\ A_T\ S_{UT}}{\sqrt{3}\ \ R} = \frac{(0.55\ \text{in})(0.0091\ \text{in}^2)}{\sqrt{3}\ (6\ \text{in})}\left(\frac{53000\ \text{lbf}}{\text{in}^2}\right) = 25.53\ \text{lbf}$$

σ normal stress
- direct tension/compression
  - $\sigma > 0$ tensile
  - $\sigma < 0$ compressive
- bending
- contact
  - direct load bearing
  - Hertzian contact

τ shear stress
- direct shear
- torsional shear
- pull-out shear
- beam shear

Mohr's circle

σ' von Mises equivalent stress

S strength
- yield
- ultimate
- fatigue

$N = S / \sigma'$ factor of safety

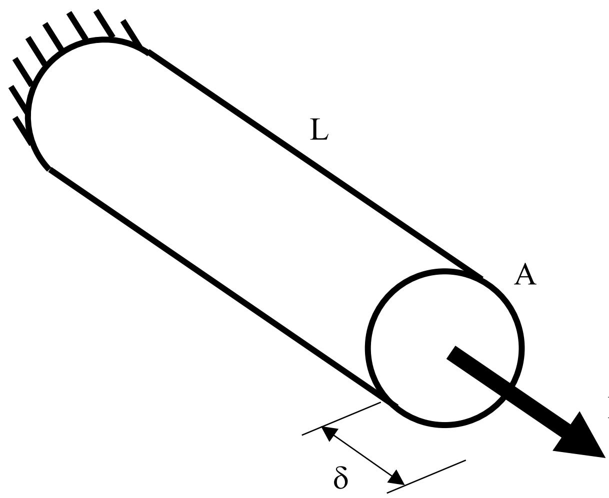
ε strain
- units [μinch per inch]

normal stress

axial tension or compression (Section 4.7 Norton)

uniform across cross-section, uniform along length, independent of cross section shape

$\sigma = P / A \qquad \delta = \dfrac{P\,L}{A\,E}$



normal stress

simple cantilever bending (Sections 4.9 and 4.10 Norton)

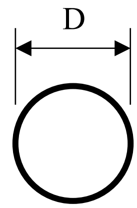
zero at neutral axis, maximum at top and bottom, linear along length

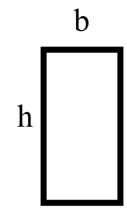
$\sigma = \frac{M\,c}{I}$ $\delta = \frac{P\,L^3}{3\,E\,I}$

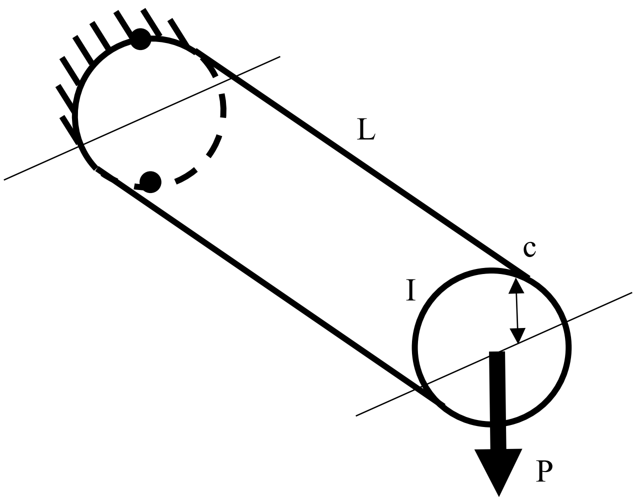
c_{MAX} at top and bottom $M_{MAX} = P\,L$ at fixed end

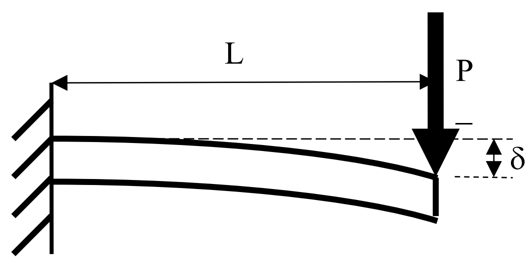
circular $c_{MAX} = D/2$ $I = \pi\,D^4/64$

rectangular $c_{MAX} = h/2$ $I = b\,h^3/12$





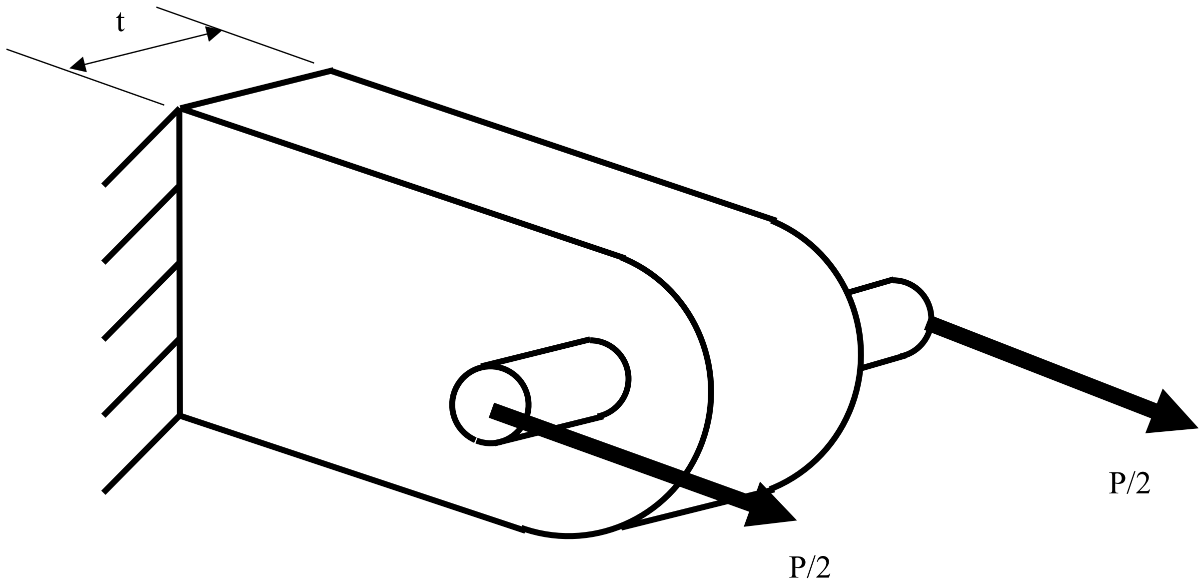


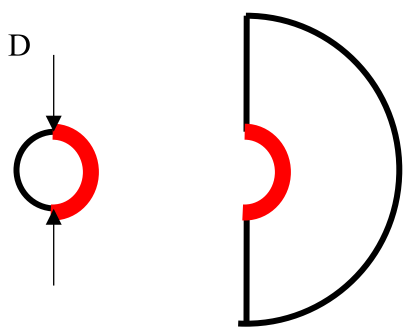


normal stress

direct contact compression (Section 4.8 Norton)

$\sigma = P / A$ projected area tight fit $A = D\ t$ loose fit $A = \pi\ D\ t / 4$





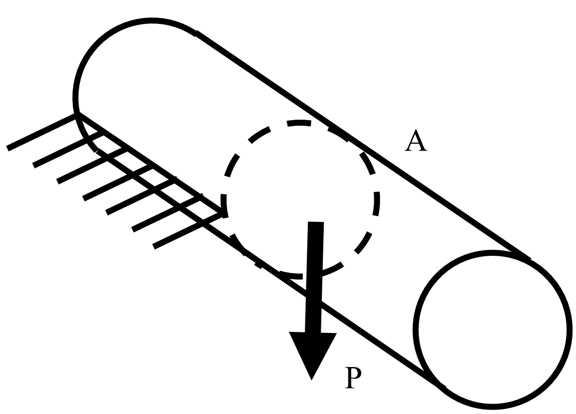
shear stress

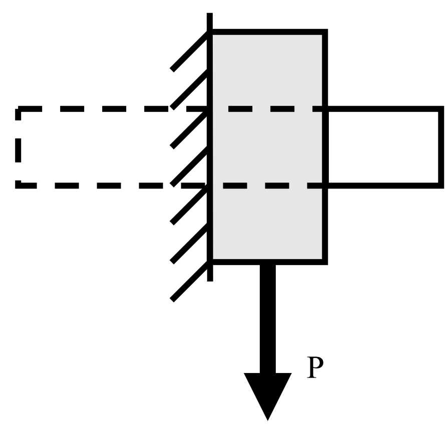
direct shear (Section 4.8 Norton)

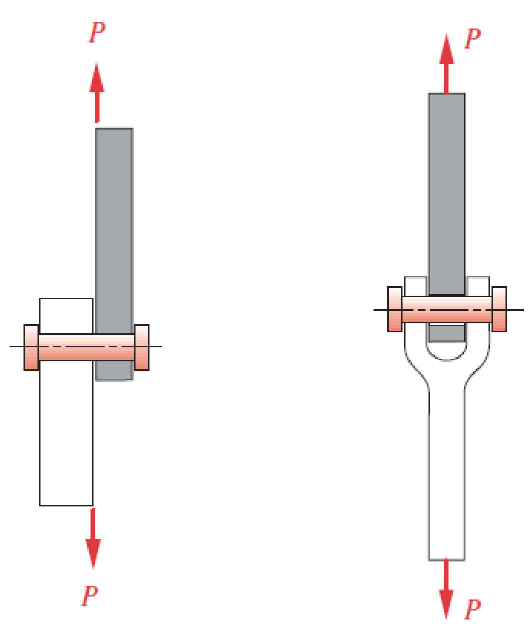
uniform across cross-section

$\tau = P / A$

(dual direct shear for clevis pins)







(a) Pivot in single shear (less than ideal)

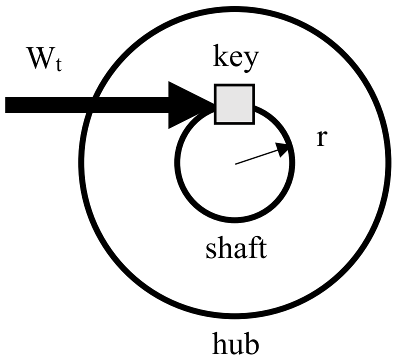
(b) Pivot in double shear (preferred)

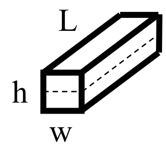
shear stress

direct shear for key

uniform across cross-section

$T = W_t \, r$ $\tau = W_t / A$ $A = w \, L$



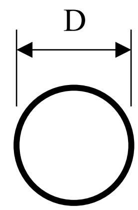


shear stress

torsional shear (Section 4.12 Norton)

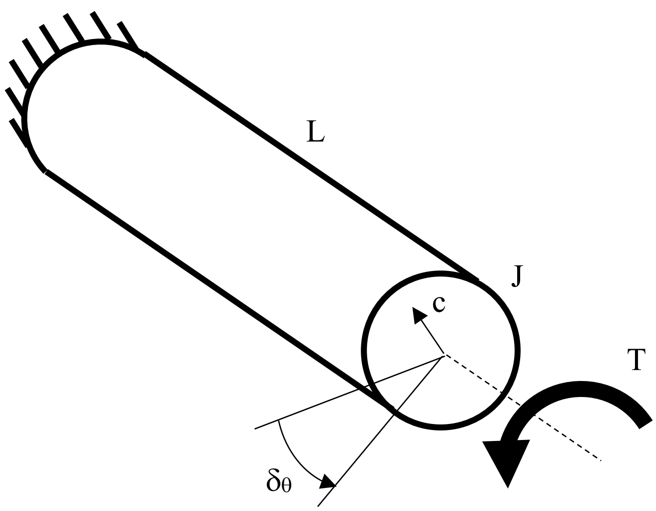
zero at center, maximum outside, uniform along length

$\tau = \dfrac{T\,c}{J} = \dfrac{16\,T}{\pi\,D^3}$ $\delta_\theta = \dfrac{T\,L}{J\,G}$ only for circular cross-section



c_{MAX} at outside T constant along length

circular $c_{MAX} = D/2$ $J = \pi\,D^4/32$

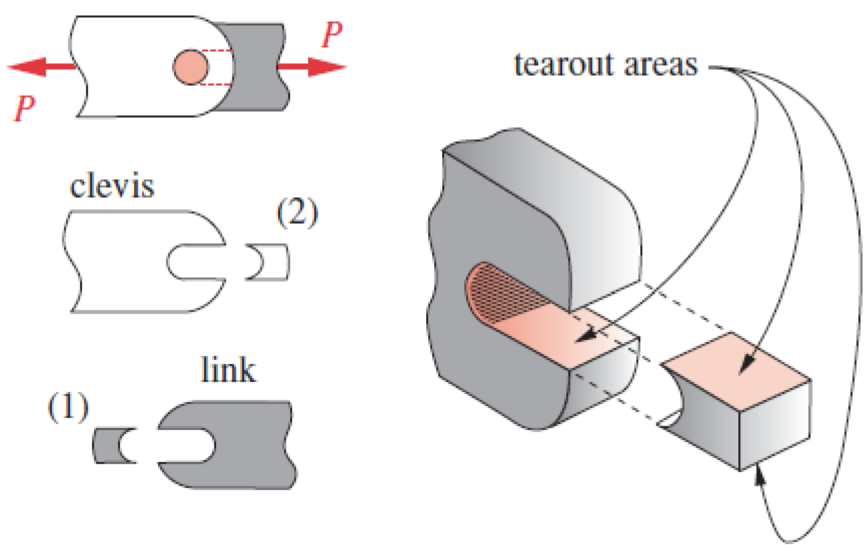


shear stress

pullout shear (Section 4.8 Norton)

uniform across cross-sections

$\tau = P / A$ $\quad A = 2\,h\,t$ $\quad h = \sqrt{R_o^{\,2} - R_i^{\,2}}$



(b) Tearout failure

shear stress

beam shear (Section 4.9 Norton)

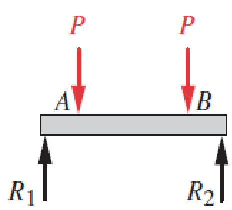
maximum at neutral axis, zero at top and bottom, varies along length

$$\tau = \frac{V\,Q}{I\,b} \qquad Q = \int_{y1}^{c} y\,dA$$

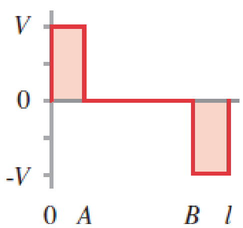
circular $\tau_{MAX} = \dfrac{4V}{3A}$

rectangular $\tau_{MAX} = \dfrac{3V}{2A}$

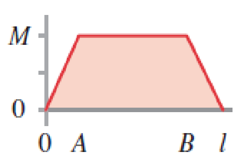
bending is maximum at top and bottom, zero at neutral axis



loading diagram



shear diagram



moment diagram

combined stress

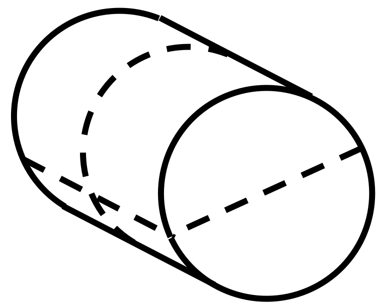
thin wall pressure vessel (Section 4.17 Norton)

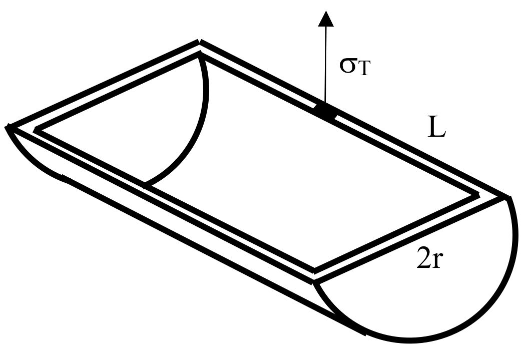
r = nominal radius   t = wall thickness   L = length   p = pressure

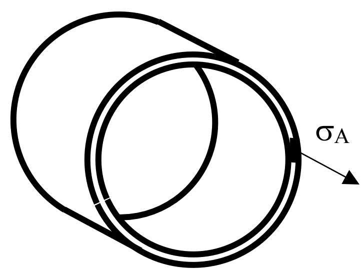
$t < r/10$

tangential (hoop) $\sigma_T = \dfrac{p(2\,r\,L)}{2\,L\,t} = \dfrac{p\,r}{t}$ (sidewalls only)

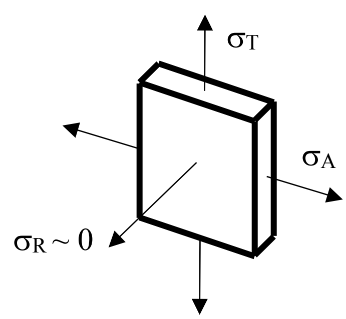
axial $\sigma_A = \dfrac{p(\pi\,r^2)}{2\,\pi\,r\,t} = \dfrac{p\,r}{2\,t}$







also valid for hemispherical ends



combined stress

torsion bar