SOLUTION (6.19)

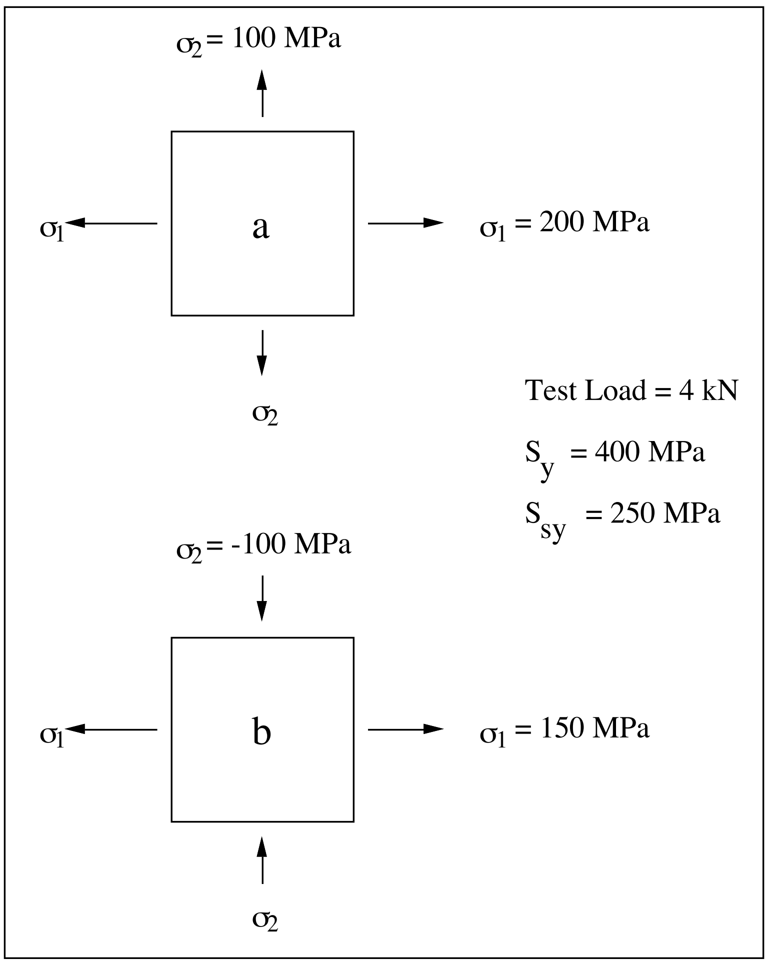
Known: A machine frame made of steel having known S_y and S_{sy} is loaded in a test fixture. The principal stresses at two critical points on the surface are known.

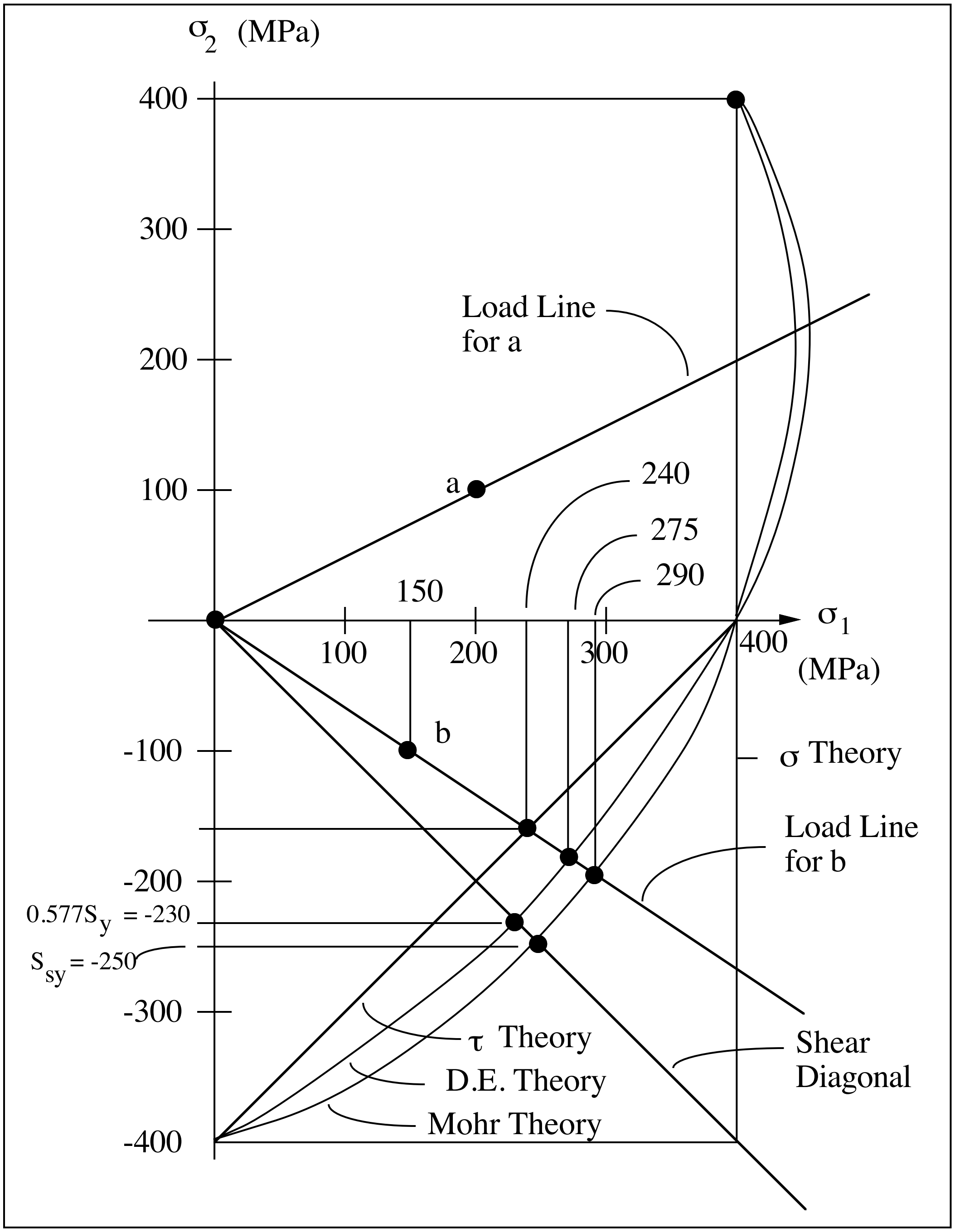
Find: Compute the test load at which the frame will experience initial yielding according to the

(a) maximum-normal-stress theory
(b) maximum-shear-stress theory
(c) maximum-distortion-energy theory

Discuss the relative validity of each theory for this application. Compute the value of test load at which yielding would commence.

Schematic and Given Data:





Assumption: The material is homogeneous.

Analysis:

1. For the maximum-normal-stress theory, the σ_1 - σ_2 plot shows point a to be critical. Failure is predicted at

$$\text{Load} = 4\text{ kN}\left(\frac{400\text{ MPa}}{200\text{ MPa}}\right) = 8\text{ kN} \qquad \blacksquare$$

2. For maximum-shear-stress theory, the σ_1 - σ_2 plot shows point b to be critical. Failure is predicted at

$$\text{Load} = 4\text{ kN}\left(\frac{240\text{ MPa}}{150\text{ MPa}}\right) = 6.4\text{ kN}$$ ■

3. For maximum-distortion-energy theory, the σ_1 - σ_2 plot shows point b to be critical. Failure is predicted at

$$\text{Load} = 4\text{ kN}\left(\frac{275\text{ MPa}}{150\text{ MPa}}\right) = 7.3\text{ kN}$$ ■

More precisely, from Eq. (6.7),
$\sigma_e = [(150)^2 + (-100)^2 - (150)(-100)]^{1/2} = 218$ MPa
Thus, failure is predicted at

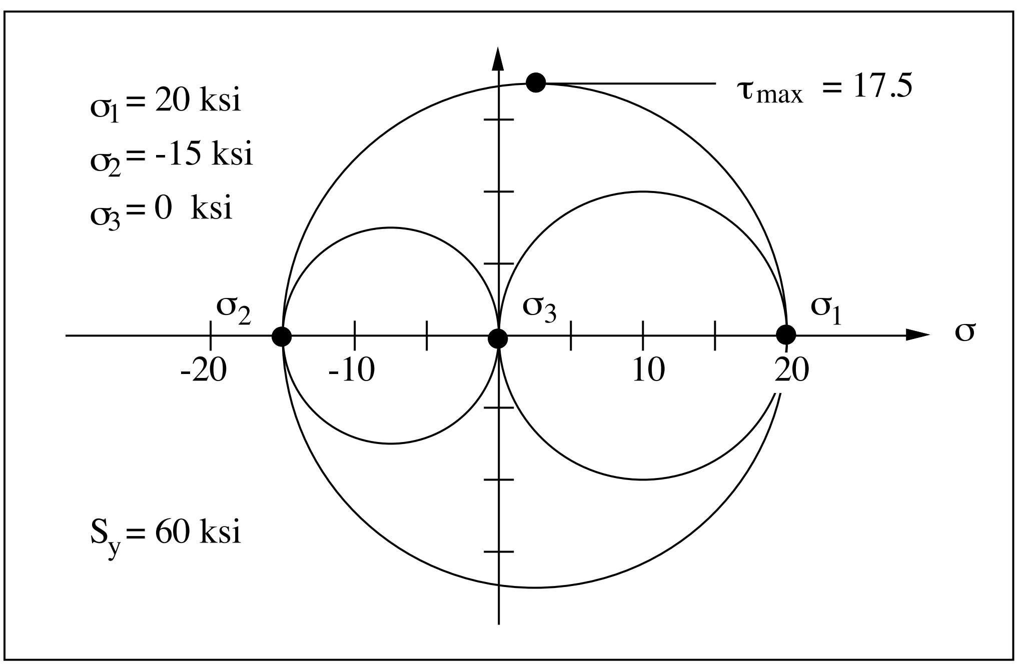
$$\text{Load} = 4\text{ kN}\left(\frac{400\text{ MPa}}{218\text{ MPa}}\right) = 7.3\text{ kN}$$ ■

Comment:
1. Maximum normal stress theory should not be used for this application since it gives good results only for brittle fractures.
2. Maximum shear stress theory may be used but is not very accurate.
3. Maximum distortion energy theory will give the best results for this application.
4. Yielding is expected to begin at a load of 7.3 kN.

SOLUTION (6.20)
Known: A machine component with given critical stresses is ductile, with yield strengths in tension and compression of 60 ksi.

Find: Determine the safety factor according to:
(a) the maximum-normal-stress theory
(b) the maximum-shear-stress theory
(c) the maximum-distortion-energy theory

Schematic and Given Data:



Assumption: The material is homogeneous.

Analysis:

1. From the above Mohr-circle, $\tau_{max} = (20 + 15)/2 = 17.5$ ksi

2. (a) For the maximum-normal-stress theory:
   SF = 60/20 = 3.0 ■

   (b) For the maximum-shear-stress theory:
   SF = $30/\tau_{max}$ = 30/17.5 = 1.72 ■

   (c) For the maximum-distortion-energy theory:
   SF = 60/S', where from Eq. (6.6)

   $$S' = [\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2]^{1/2}$$
   $$= [(20)^2 - (20)(-15) + (-15)^2]^{1/2} = 30.5$$

   thus, SF = 60/30.5 = 1.97 ■

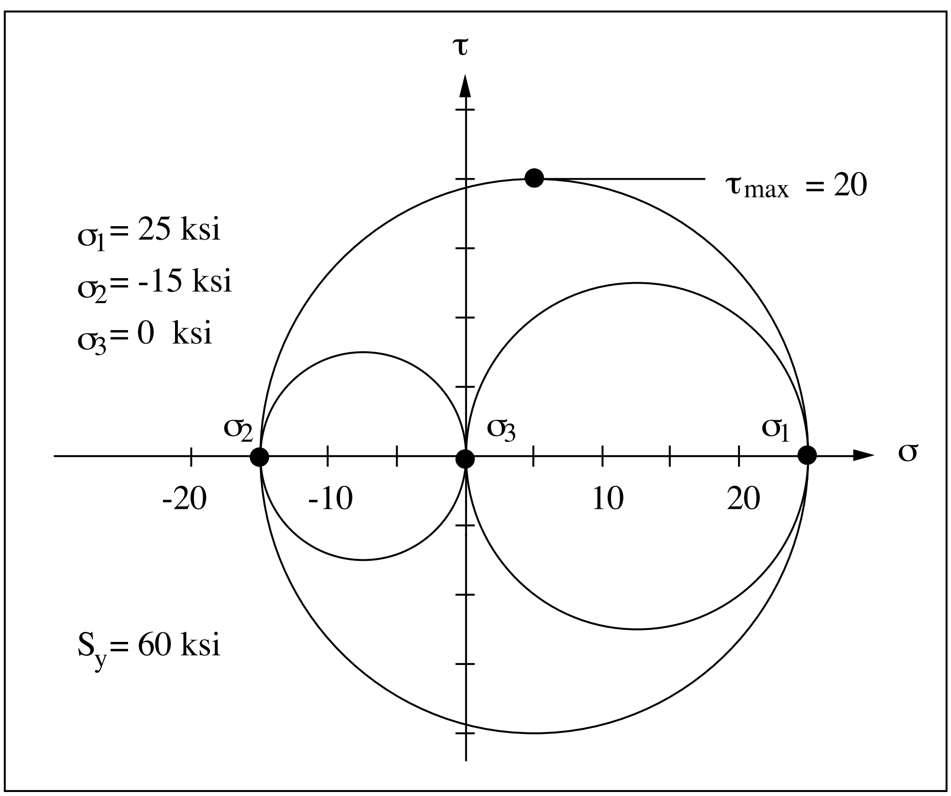
3. The existence of a yield strength implies a ductile material for which:
   - maximum-distortion-energy theory is <u>best</u>
   - maximum-shear-stress theory may be acceptable
   - maximum-normal-stress theory is not appropriate

SOLUTION (6.21)

Known: A machine component with given critical stresses is ductile, with yield strengths in tension and compression of 60 ksi.

Find: Determine the safety factor according to:
(a) the maximum-normal-stress theory
(b) the maximum-shear-stress theory
(c) the maximum-distortion-energy theory

Schematic and Given Data:



Assumption: The material is homogeneous.

Analysis:

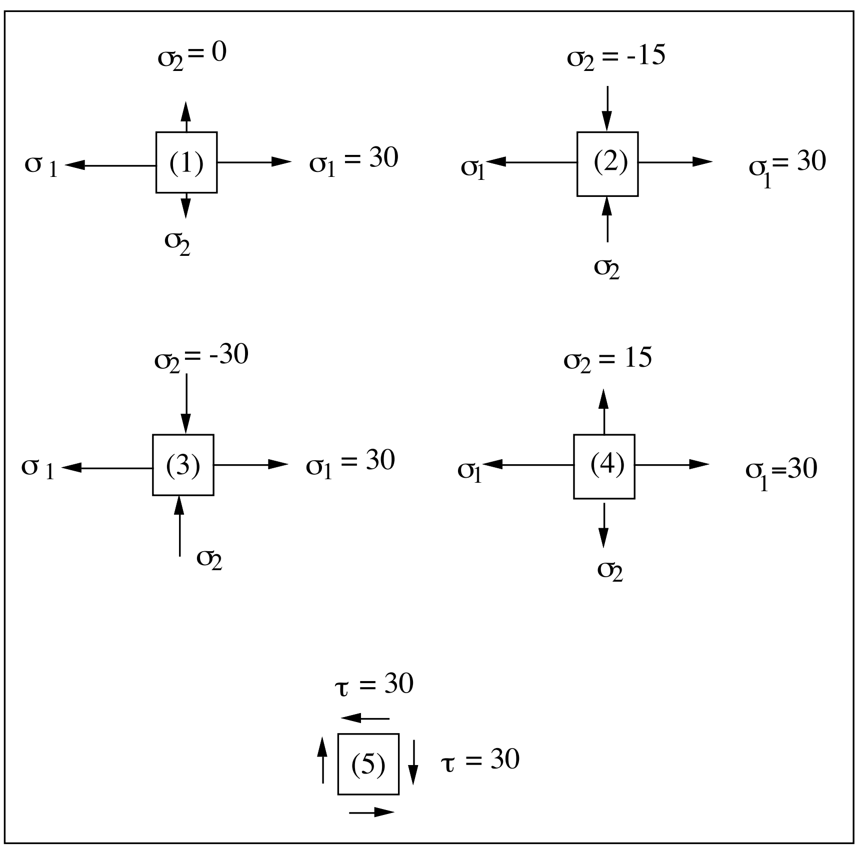
1. From the above Mohr-circle,
   $\tau_{max} = (25 + 15)/2 = 20$ ksi
2. (a) For the maximum-normal-stress theory:
   SF = 60/25 = 2.4 ■
   (b) For the maximum-shear-stress theory:
   SF = $30/\tau_{max}$ = 30/20 = 1.5 ■
   (c) For the maximum-distortion-energy theory:
   SF = 60/S', where from Eq. (6.6)
   $S' = [\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2]^{1/2}$
   $= [(25)^2 - (25)(-15) + (-15)^2]^{1/2} = 35.0$
   thus, SF = 60/35.0 = 1.71 ■
3. The existence of a yield strength implies a ductile material for which:
   • maximum-distortion-energy theory is best
   • maximum-shear-stress theory may be acceptable
   • maximum-normal-stress theory is not appropriate

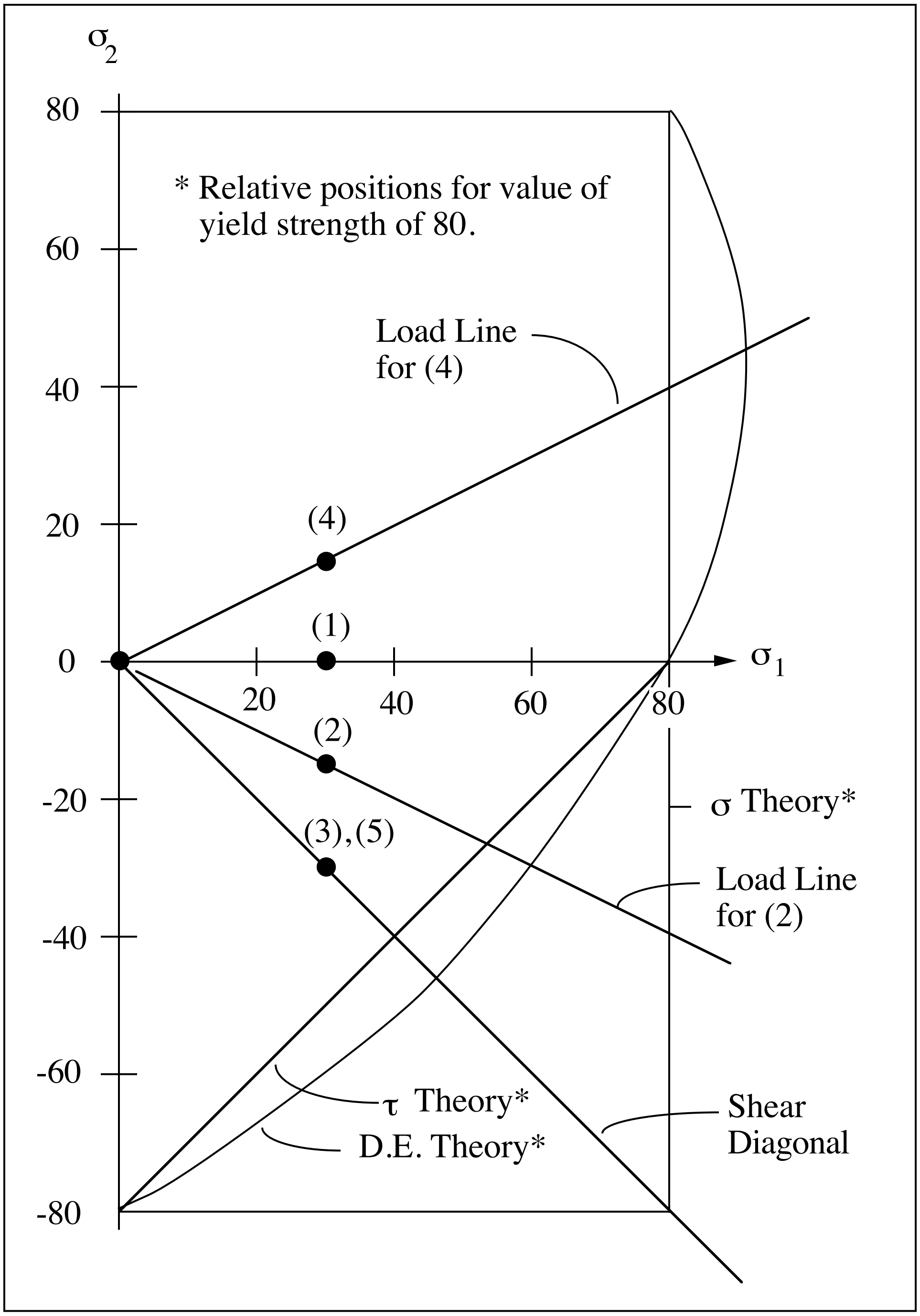
SOLUTION (6.22)

Known: Five states of biaxial stress are given.

Find: Based on using three different failure theories, list the five states in order of increased likelihood of causing failure.

Schematic and Given Data:





Assumption: We assume an arbitrary value for $S_y = 80$ in the above diagram.

Analysis:

1. For the maximum-normal-stress theory $SF = S_y/\sigma_{max}$, and all stress states have the same safety factor. ■
2. For the maximum-shear-stress theory, $SF = S_{sy}/\tau_{max}$, and the order of decreased safety factor would be 1 & 4, 2, 3 & 5. ■
3. For the distortion energy theory, $SF = S_y/\sigma_e$ where from Eq. (6.6), $\sigma_e = (\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2)^{1/2}$. The order of decreased safety factor is 4, 1, 2, 3 & 5. ■

Comments: For $S_y = 80$, the accompanying table lists the safety factors.

Table of Safety Factors

	Stress state	Maximum normal stress, σ_{max}	Maximum shear stress, τ_{max}	Distortion energy stress, σ_e	Maximum normal stress Theory	Maximum shear stress Theory	Distortion energy theory
1.	$\sigma_1 = 30$ $\sigma_2 = 0$	30	15	30	2.7	2.7	2.7
2.	$\sigma_1 = 30$ $\sigma_2 = -15$	30	22.5	39.69	2.7	1.8	2.0
3.	$\sigma_1 = 30$ $\sigma_2 = -30$	30	30	51.96	2.7	1.3	1.5
4.	$\sigma_1 = 30$ $\sigma_2 = 15$	30	15	25.98	2.7	2.7	3.1
5.	$\tau = 30$	30	30	51.96*	2.7	1.3	1.5

* $\sigma_e = (3\tau_{xy}^2)^{1/2}$

SOLUTION (6.23)
Known: The solutions to problems (a) 4.46, (b) 4.49, (c) 4.51, (d) 4.53, (e) 4.55, (f) 4.56, (g) 4.58, (h) 4.62, and (i) 4.67 are given.

Find: Determine the tensile strength a ductile material must have in order to provide a safety factor of 2 with respect to initial yielding at the locations investigated in the above listed problems. Determine the answer using both the maximum-shear-stress theory and the maximum-distortion-energy theory.

Assumption: The materials are homogeneous.

Analysis:

	τ_{max}	Answer Per τ Theory S_y for SF = 2	σ_{eq} From Eqns. (6.5-6.8)	Answer Per D.E. Theory S_y for SF = 2
(a)	97.5 MPa (@ "S")	390 MPa	185.4 MPa	371 MPa
(b)	128 MPa (@ "a")	512 MPa	241.4 MPa	483 MPa
(c)	37.2 ksi	148.8 ksi	68.1 ksi	136 ksi
(d)	17 ksi	68 ksi	31.9 ksi	64 ksi
(e)	34.3 MPa	137.2 MPa	66.0 MPa	132 MPa
(f)	278 MPa	1112 MPa	500 MPa	1000 MPa
(g)	110 MPa	440 MPa	193.6 MPa	387 MPa
(h)	200 MPa	800 MPa	346 MPa	692 MPa
(i)	350 MPa	1400 MPa	608 MPa	1216 MPa

SOLUTION (6.24)
Known: The solutions to problems (a) 4.46, (b) 4.49, (c) 4.51, (d) 4.53, (e) 4.55, (f) 4.56, (g) 4.58, (h) 4.62, and (i) 4.67 are given.

Find: Determine the tensile strength a ductile material must have in order to provide a safety factor of 1.5 with respect to initial yielding at the location(s) investigated in the above listed problems. Determine the answer using both the maximum-shear-stress theory and the maximum-distortion-energy theory.

Assumption: The materials are homogeneous.

Analysis:

	τ_{max}	Answer Per τ Theory S_y for SF = 1.5	σ_{eq} From Eqns. (6.5-6.8)	Answer Per D.E. Theory S_y for SF = 1.5
(a)	97.5 MPa (@ "S")	293 MPa	185.4 MPa	278 MPa
(b)	128 MPa (@ "a")	384 MPa	241.4 MPa	362 MPa
(c)	37.2 ksi	112 ksi	68.1 ksi	102 ksi
(d)	17 ksi	51 ksi	31.9 ksi	47.9 ksi
(e)	34.3 MPa	102.9 MPa	66.0 MPa	99 MPa
(f)	278 MPa	834 MPa	500 MPa	750 MPa
(g)	110 MPa	330 MPa	193.6 MPa	290 MPa
(h)	200 MPa	600 MPa	346 MPa	519 MPa
(i)	350 MPa	1050 MPa	608 MPa	912 MPa

SOLUTION (6.25)

Known: The solutions to problems (a) 4.46, (b) 4.49, (c) 4.51, (d) 4.53, (e) 4.55, (f) 4.56, (g) 4.58, (h) 4.62, and (i) 4.67 are given.

Find: Use the modified Mohr theory to determine the ultimate tensile strength that would be required of a brittle material in order to provide a safety factor of 4 to a member subjected to the same state(s) of stress as the above listed problems. If overloaded to failure, what would be the orientation of the brittle crack in each case?

Assumptions:
1. The materials are homogeneous.
2. The ultimate compressive strength is 3.5 times the ultimate tensile strength.

Analysis:

	σ_1	ANSWER S_u for SF=4	ANSWER Crack Orientation
(a)	174 MPa (@ "S")	696 MPa	19.3° C.W. from a transverse plane
(b)	225 MPa (@ "a")	900 MPa	20° C.C.W. from a transverse plane
(c)	58 ksi	232 ksi	28.3° C.C.W. from a transverse plane
(d)	30 ksi	120 ksi	19° C.W. from a transverse plane
(e)	63 MPa	252 MPa	16.5° C.W. from a transverse plane
(f)	556 MPa	2224 MPa	51.5° C.W. from a transverse plane
(g)	220 MPa	880 MPa	67.5° C.C.W. from a transverse plane
(h)	400 MPa	1600 MPa	Longitudinal
(i)	600 MPa	2400 MPa	Longitudinal

SOLUTION (6.26)

Known: The solutions to problems (a) 4.46, (b) 4.49, (c) 4.51, (d) 4.53, (e) 4.55, (f) 4.56, (g) 4.58, (h) 4.62, and (i) 4.67 are given.

Find: Use the modified Mohr theory to determine the ultimate tensile strength that would be required of a brittle material in order to provide a safety factor of 3.5 to a member subjected to the same state(s) of stress as the above listed problems. If overloaded to failure, what would be the orientation of the brittle crack in each case?

Assumptions:
1. The materials are homogeneous.
2. The ultimate compressive strength is 3.5 times the ultimate tensile strength.

Analysis:

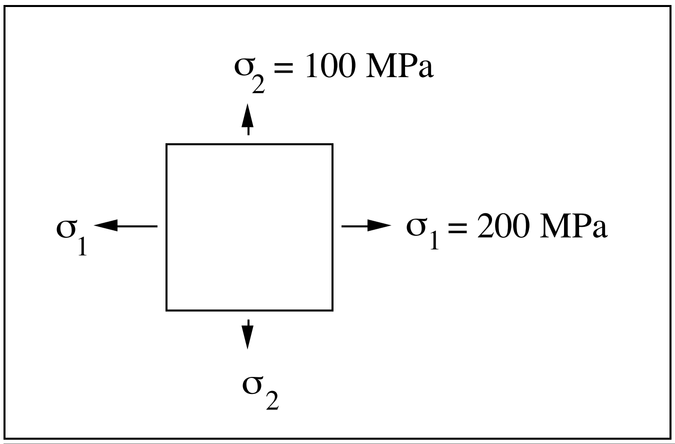
	σ_1	ANSWER S_u for SF=3.5	ANSWER Crack Orientation
(a)	174 MPa (@ "S")	609 MPa	19.3° C.W. from a transverse plane
(b)	225 MPa (@ "a")	788 MPa	20° C.C.W. from a transverse plane
(c)	58 ksi	203 ksi	28.3° C.C.W. from a transverse plane
(d)	30 ksi	105 ksi	19° C.W. from a transverse plane
(e)	63 MPa	221 MPa	16.5° C.W. from a transverse plane
(f)	556 MPa	1946 MPa	51.5° C.W. from a transverse plane
(g)	220 MPa	770 MPa	67.5° C.C.W. from a transverse plane
(h)	400 MPa	1400 MPa	Longitudinal
(i)	600 MPa	2100 MPa	Longitudinal

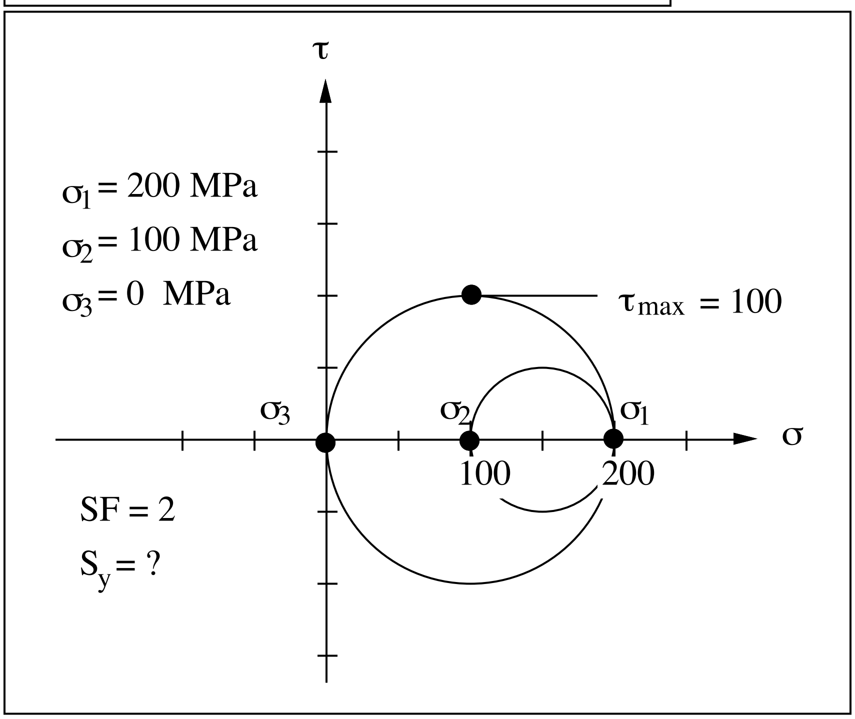
SOLUTION (6.27)

Known: The surface of a steel machine member is subjected to known principal stresses.

Find: Determine the tensile yield strength required to provide a safety factor of 2 with respect to initial yielding.

Schematic and Given Data:





Assumption: The material is homogeneous

Analysis:

1. Maximum-shear-stress theory:
   For $\sigma_1 = 200$ MPa, $\sigma_2 = 100$ MPa, $\sigma_3 = 0$
   $\tau_{max} = (0 + 200)/2 = 100$ MPa.
   Thus, for SF = 2, $S_y = 400$ MPa is required. ■
2. Maximum-distortion-energy theory:
   From Eq. (6.6),

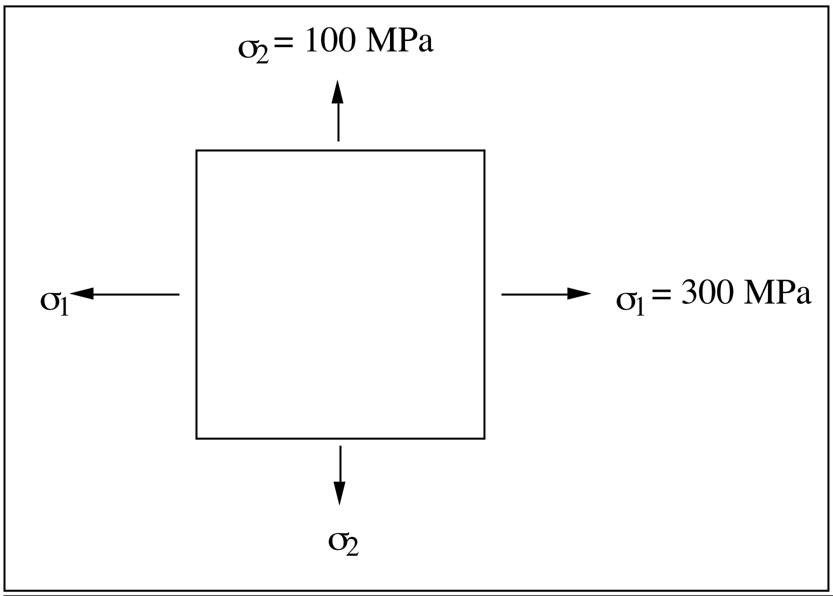
$\sigma_e = (\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2)^{1/2}$
$= [200^2 + 100^2 - (200)(100)]^{1/2} = 173.2$ MPa.
Thus, for SF = 2, $S_y = 346.4$ MPa is required. ■

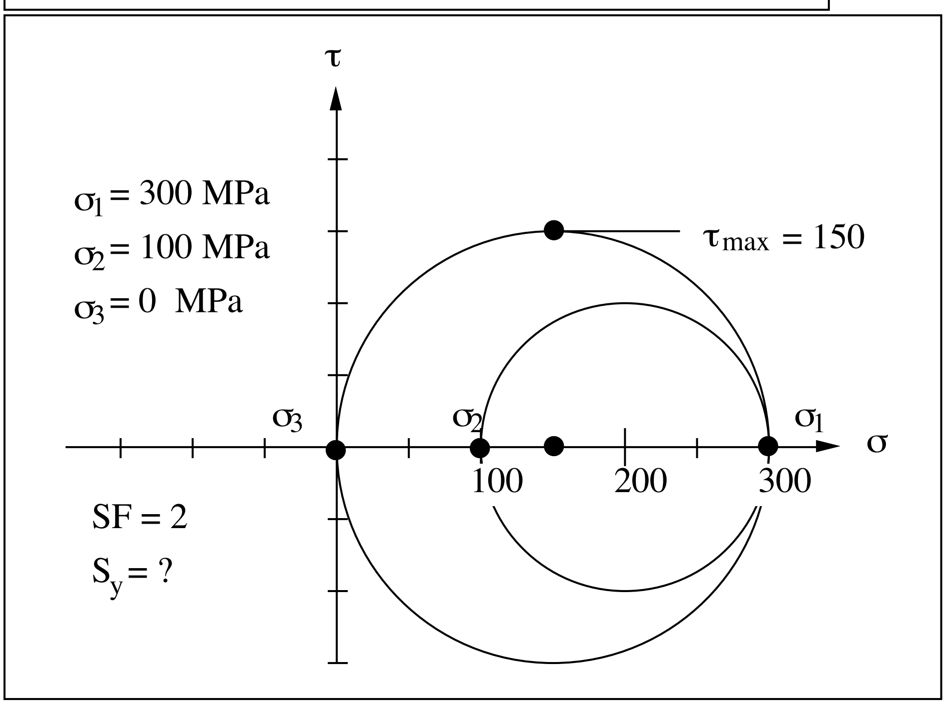
SOLUTION (6.28)

Known: The surface of a steel machine member is subjected to known principal stresses.

Find: Determine the tensile yield strength required to provide a safety factor of 2 with respect to initial yielding.

Schematic and Given Data:





Assumption: The material is homogeneous.

Analysis:

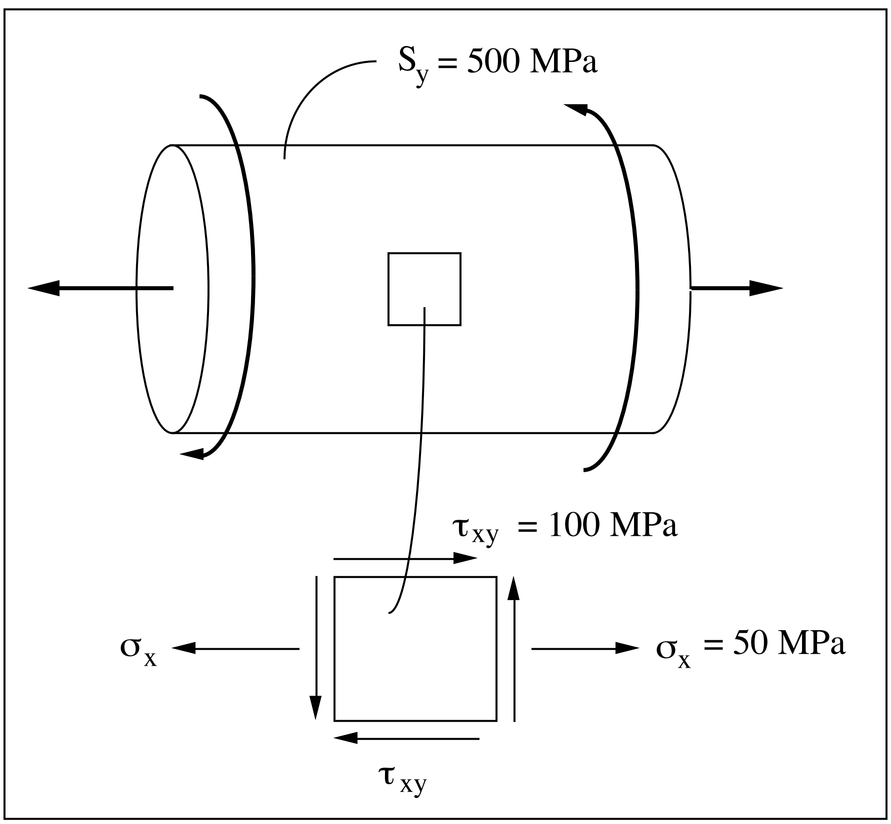
1. Maximum-shear-stress theory:
   For σ_1 = 300 MPa, σ_2 = 100 MPa, $\sigma_3 = 0$
   τ_{max} = (0 + 300)/2 = 150 MPa.
   Thus, for SF = 2, S_y = 600 MPa is required. ■
2. Maximum-distortion-energy theory:
   From Eq. (6.6),
   $\sigma_e = (\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2)^{1/2}$
   $= [300^2 + 100^2 - (300)(100)]^{1/2} = 265$ MPa.
   Thus, for SF = 2, S_y = 530 MPa is required. ■

SOLUTION (6.29)

Known: A round steel bar with S_y = 500 MPa is loaded simultaneously with known axial tension and torsion stresses.

Find: Determine the safety factor.

Schematic and Given Data:



Assumptions:

1. The rod material is ductile.
2. The material is homogeneous.
3. The distortion energy theory is preferred (it is more accurate than the other theories).

Analysis:

1. From Eq. (6.8), the distortion energy stress is
   $\sigma_e = (\sigma_x{}^2 + 3\ \tau_{xy}{}^2)^{1/2} = (50^2 + 3(100)^2)^{1/2}$
   $\sigma_e = 180.3$ MPa
2. The safety factor is
   $SF = S_y/\sigma_e = 500/180.3 = 2.77$

Comment: The maximum shear stress theory predicts a safety factor

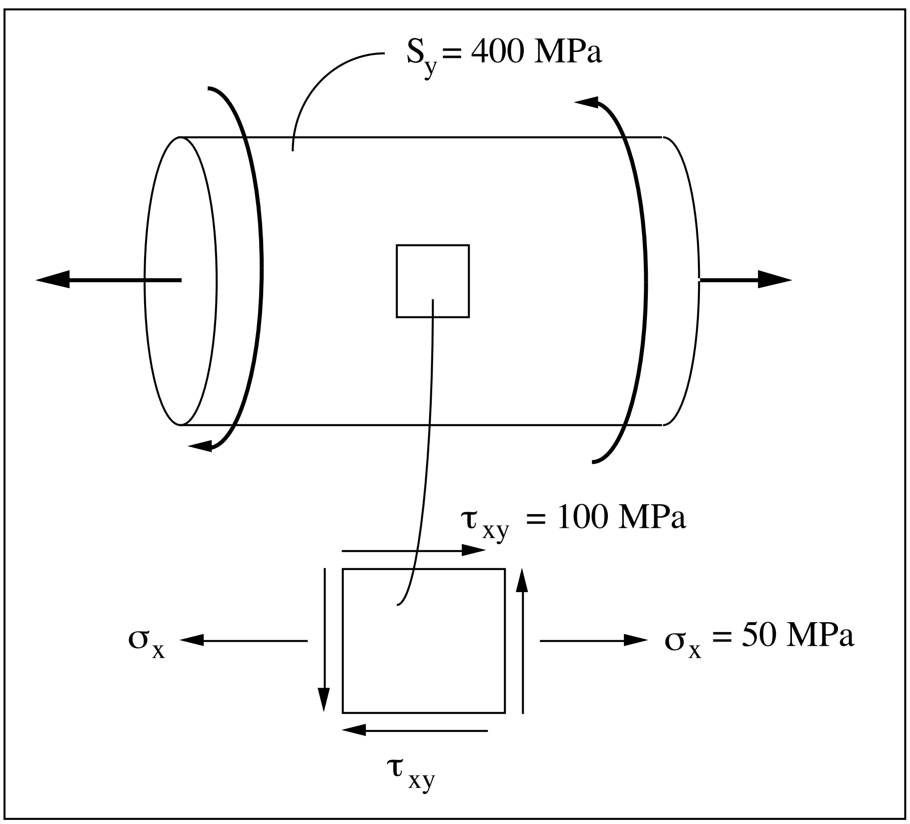
$$SF = \frac{S_{sy}}{\tau_{max}} = \frac{S_y/2}{\sqrt{\tau_{xy}^2 + (\frac{\sigma_x - \sigma_y}{2})^2}} = \frac{250}{\sqrt{100^2 + 25^2}} = 2.43$$

SOLUTION (6.30)

Known: A round steel bar with $S_y = 400$ MPa is loaded simultaneously with known axial tension and torsion stresses.

Find: Determine the safety factor.

Schematic and Given Data:



Assumptions:

1. The rod material is ductile.
2. The material is homogeneous.
3. The distortion energy theory is preferred (it is more accurate than the other theories).

Analysis:

1. From Eq. (6.8), the distortion energy stress is
   $\sigma_e = (\sigma_x^2 + 3\,\tau_{xy}^2)^{1/2} = (50^2 + 3(100)^2)^{1/2}$
   $\sigma_e = 180.3$ MPa
2. The safety factor is
   $SF = S_y/\sigma_e = 400/180.3 = 2.22$ ■

Comment: The maximum shear stress theory predicts a safety factor

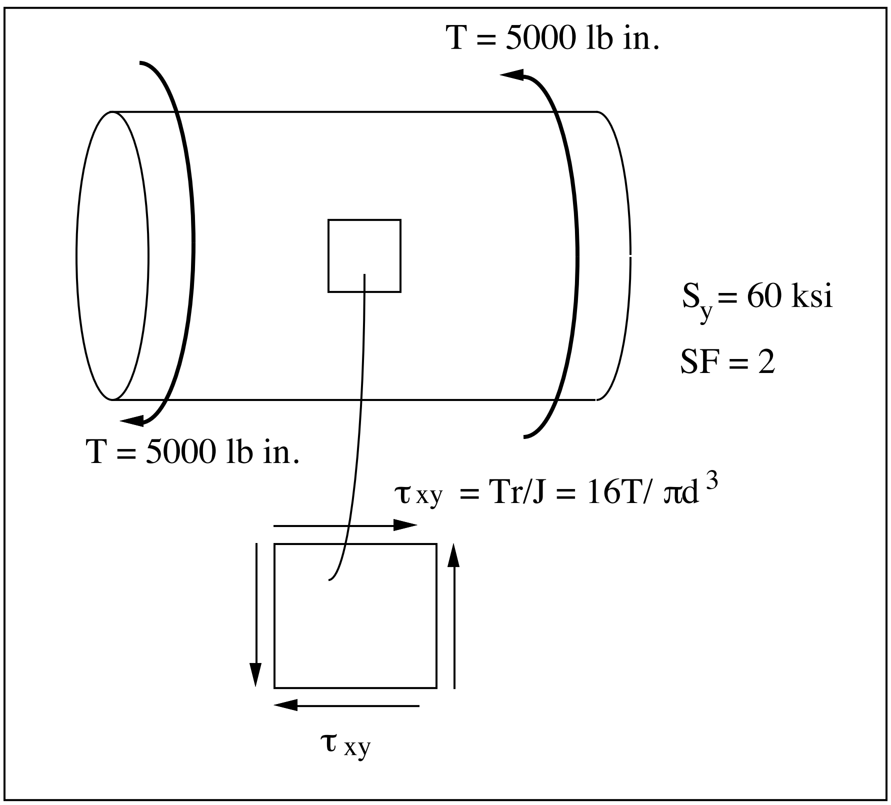
$$SF = \frac{S_{sy}}{\tau_{max}} = \frac{S_y/2}{\sqrt{\tau_{xy}^2 + (\frac{\sigma_x - \sigma_y}{2})^2}} = \frac{200}{\sqrt{100^2 + 25^2}} = 1.94$$

SOLUTION (6.31)

Known: A round shaft of known strength and specified safety factor is loaded with a known torque.

Find: Determine the shaft diameter.

Schematic and Given Data:



Assumption: The shaft material is homogeneous.

Analysis:

(a) For the maximum-normal-stress theory,

$$SF = 2 = \frac{S_y}{\sigma_{max}} = \frac{S_y}{\tau_{xy}} = \frac{60{,}000}{\frac{16(5000)}{\pi d^3}}$$

Solving for d, gives d = 0.95 in. ■

(b) For the maximum-shear-stress theory,

$$SF = 2 = \frac{S_{sy}}{\tau_{max}} = \frac{S_y/2}{\tau_{xy}} = \frac{30{,}000}{\frac{16(5000)}{\pi d^3}}$$

Solving for d, gives d = 1.19 in. ■

(c) From Eq. (6.8), $\sigma_e = \sqrt{0 + 3\tau^2} = \sqrt{3}\,\tau$. For the distortion-energy theory,

$$SF = 2 = \frac{S_y}{\sigma_e} = \frac{60{,}000}{\frac{\sqrt{3}\ 16(5000)}{\pi d^3}}$$

Solving for d, gives d = 1.14 in. ■

Comments:

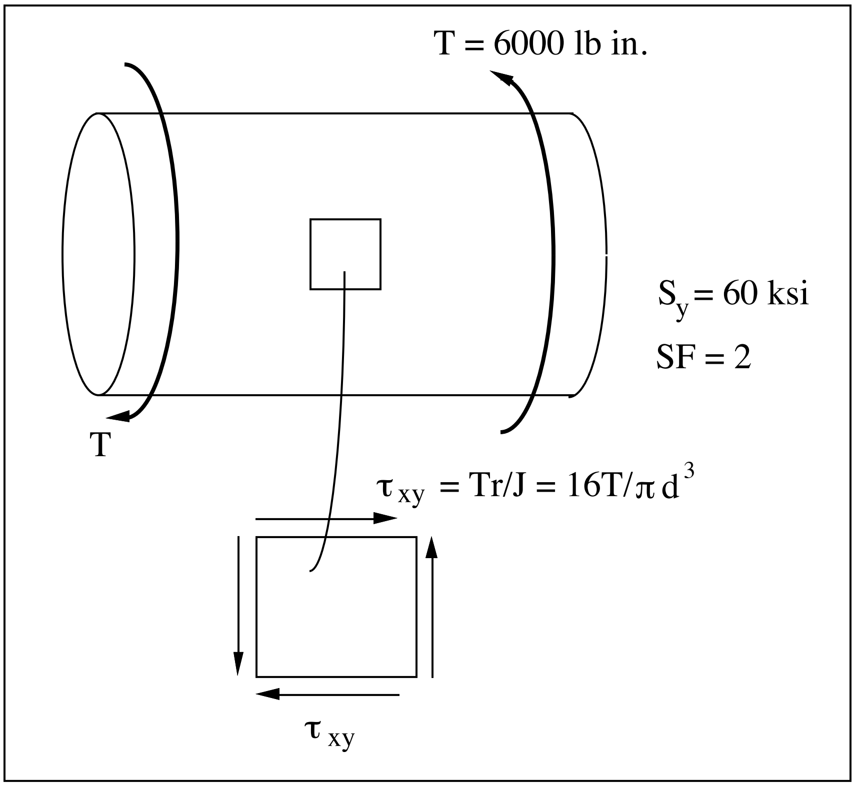
1. If the shaft is a ductile material, the distortion-energy theory is the most accurate, followed by the maximum-shear-stress theory . If the shaft were a brittle material, then the normal-stress-theory would be the most appropriate of the three theories used in the analysis.
2. A steel shaft with S_y = 60,000 psi would have an elongation in 2 in. of approximately 20%, and hence would be a ductile material. Indeed, most steel shafts are ductile.
3. Good test data pertaining to actual material and torsion loading would be recommended to improve the failure theory prediction.

SOLUTION (6.32)

Known: A round shaft of known strength and specified safety factor is loaded with a known torque.

Find: Determine the shaft diameter.

Schematic and Given Data:



Assumption: The shaft material is homogeneous.

Analysis:

(a) For the maximum-normal-stress theory,

$$SF = 2 = \frac{S_y}{\sigma_{max}} = \frac{S_y}{\tau_{xy}} = \frac{60{,}000}{\dfrac{16(6000)}{\pi d^3}}$$

Solving for d, gives d = 1.01 in.

(b) For the maximum-shear-stress theory,

$$SF = 2 = \frac{S_{sy}}{\tau_{max}} = \frac{S_y/2}{\tau_{xy}} = \frac{30{,}000}{\dfrac{16(6000)}{\pi d^3}}$$

Solving for d, gives d = 1.27 in. ■

(c) From Eq. (6.8), $\sigma_e = \sqrt{0 + 3\tau^2} = \sqrt{3}\,\tau$. For the distortion-energy theory,

$$SF = 2 = \frac{S_y}{\sigma_e} = \frac{60{,}000}{\dfrac{\sqrt{3}\;16(6000)}{\pi d^3}}$$

Solving for d, gives d = 1.21 in. ■

Comments:

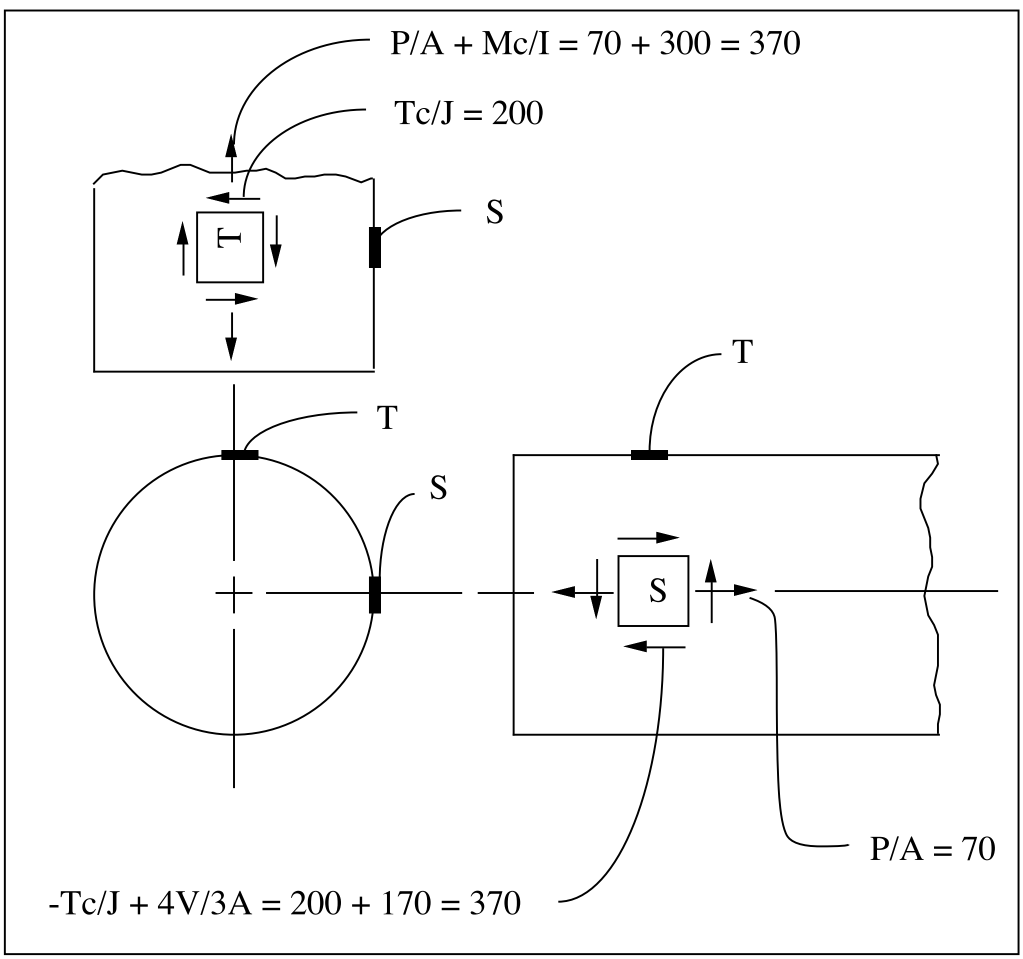
1. If the shaft is a ductile material, the distortion-energy theory is the most accurate, followed by the maximum-shear-stress theory (most steel shafts are ductile). If the shaft were a brittle material, then the normal-stress-theory would be the most appropriate of the three theories used in the analysis.
2. Good test data pertaining to actual material and torsion loading would be recommended to improve the failure theory prediction.

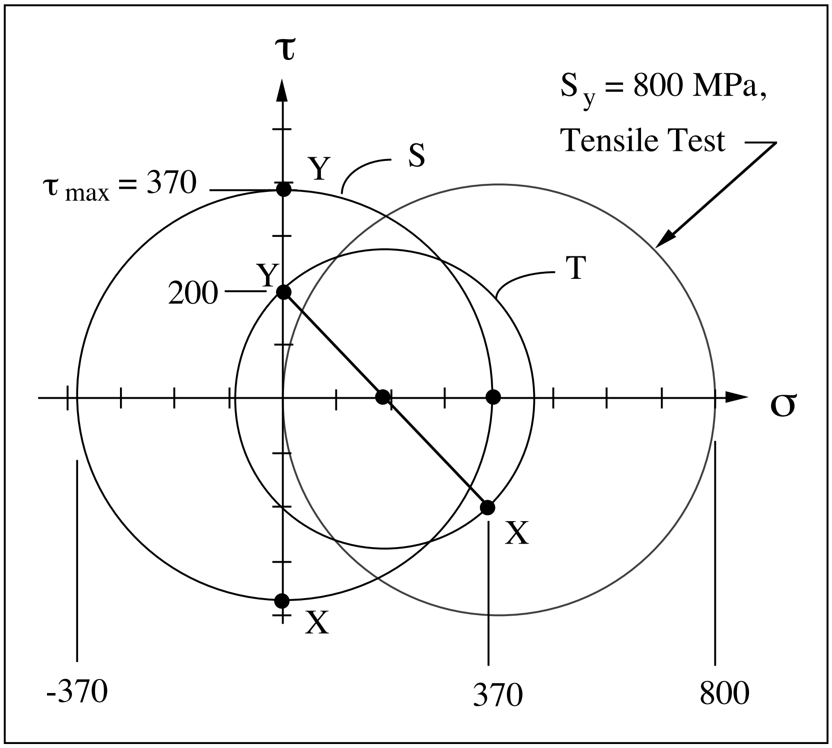
SOLUTION (6.33)

Known: A round steel bar of given strength is subjected to known tensile, torsional, bending and transverse shear stresses.

Find: (a) Draw a sketch showing the maximum normal and shear stress, and (b) determine the safety factor for yield failure.

Schematic and Given Data:





Assumption: The location T (top) is subjected to torsion and bending tension, but no transverse shear. Location S (side) is on a neutral bending axis and is on the side where 4V/3A and Tc/J are additive.

Analysis:

1. The Mohr circle plot shows "S" has the higher shear stress, and "T" the higher tensile stress. These locations are 90^o apart.

2. The safety factor with respect to initial yielding according to the maximum-shear-stress theory is

$$SF = \frac{S_y/2}{\tau_{max}} = \frac{400}{370} = 1.08$$ ■

3. From Eq. (6.8),

$$\sigma_e = \sqrt{3}(370) = 641 \text{ MPa}$$

4. The safety factor according to the distortion energy theory is

$$SF = \frac{S_y}{\sigma_e} = \frac{800}{641} = 1.25$$ ■

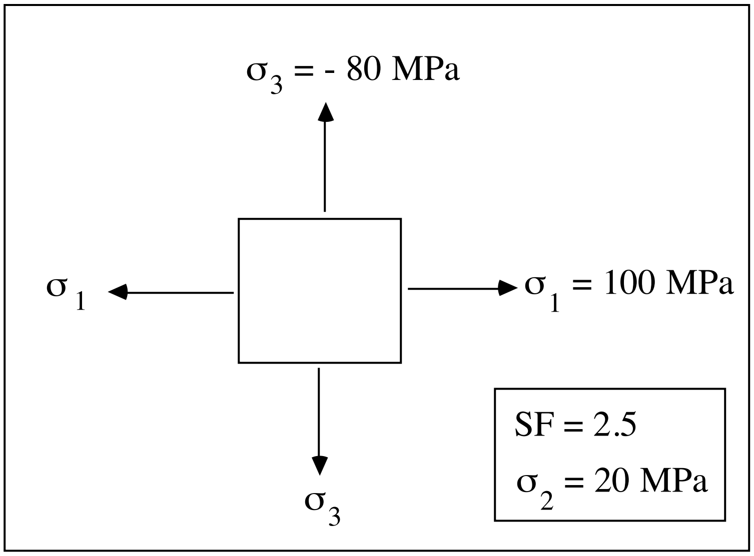
Comments:

1. The effect of tensile force P/A is not considered while calculating the stresses on location S. If it is considered the safety factors according to the maximum shear stress theory and distortion energy theory are 1.076 and 1.24 respectively.
2. The maximum shear stress theory is more conservative in predicting failure than the distortion energy theory.

SOLUTION (6.34)
Known: A steel member has a specified safety factor and given stresses.

Find: Determine the tensile yield strength with respect to initial yielding according to: (a) the maximum-shear-stress theory, (b) the maximum-distortion-energy theory.

Schematic and Given Data:



Analysis:

(a) For the maximum-shear-stress theory,
with $\sigma_1 = 100$ MPa, $\sigma_2 = 20$ MPa, and $\sigma_3 = -80$ MPa, we have
$\tau_{max} = (100 + 80)/2 = 90$ MPa
$S_y = (2.5)(2)(\tau_{max}) = 450$ MPa ■

(b) For the maximum-distortion-stress theory, using Eq.(6.5)

$$\sigma_e = \frac{\sqrt{2}}{2}\left[(\sigma_2-\sigma_1)^2+(\sigma_3-\sigma_1)^2+(\sigma_3-\sigma_2)^2\right]^{1/2} = \frac{\sqrt{2}}{2}\left[(-80)^2+(-180)^2+(-100)^2\right]^{1/2} = 156 \text{ MPa}$$

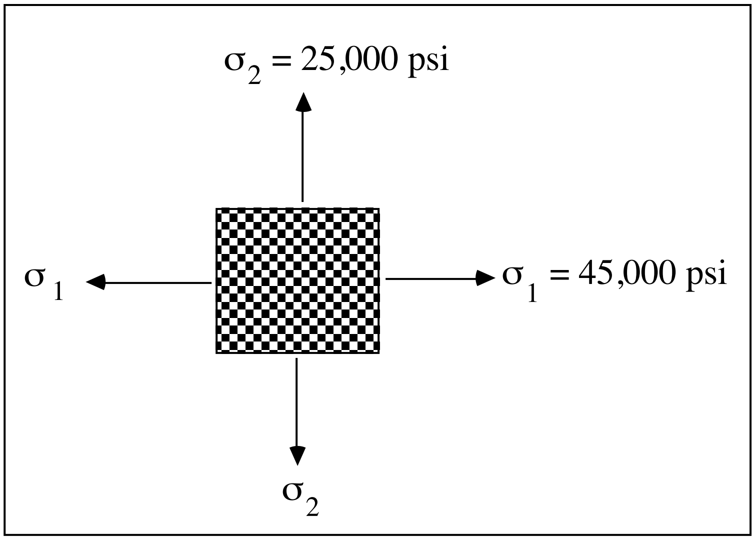
The yield strength is $S_y = 2.5(\sigma_e) = 390$ MPa ■

SOLUTION (6.35)

Known: A downhold oil tool has known biaxial static stresses, an ultimate tensile strength of 97,000 psi and a yield strength of 63,300 psi.

Find: Determine the safety factor according to:
(a) the maximum-normal-stress theory
(b) the maximum-shear-stress theory
(c) the maximum-distortion-energy theory

Schematic and Given Data:



Analysis:

1. Maximum-normal-stress theory
   For $\sigma_1 = 45{,}000$ psi, $S_y = 63{,}300$ psi

   $SF = S_y/\sigma_1 = 63{,}300/45{,}000 = 1.4$ ■

2. Maximum-shear-stress theory
   For $\sigma_1 = 45{,}000$ psi, $\sigma_2 = 25{,}000$ psi, $\sigma_3 = 0$

   $\tau_{max} = (0 + 45{,}000)/2 = 22{,}500$ psi

   $SF = S_{sy}/\tau_{max} = 31{,}650/22{,}500 = 1.41$ ■

3. Maximum-distortion-energy theory

   $\sigma_e = (\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2)^{1/2}$

   $= \left[(45{,}000)^2+(25{,}000)^2-(45{,}000)(25{,}000)\right]^{1/2}$
   $= 39{,}051$ psi

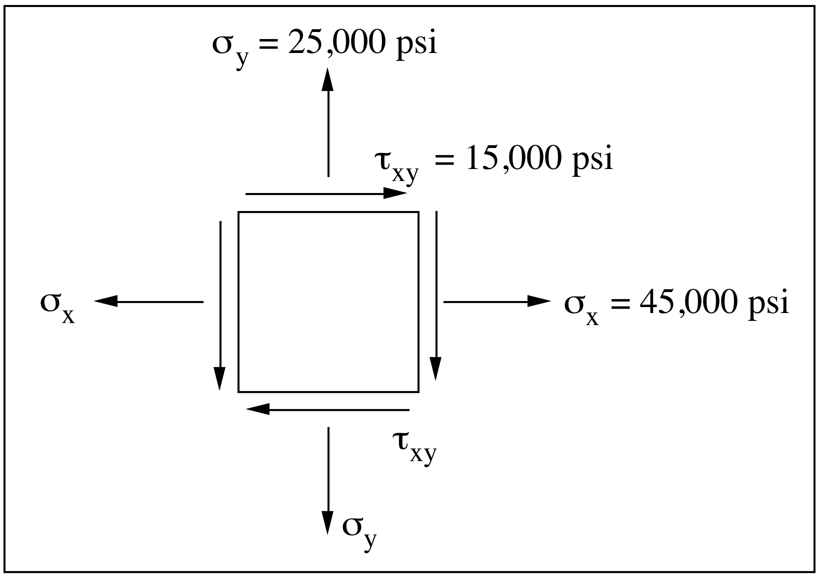
   The safety factor is $SF = S_y/\sigma_e = 63{,}300/39{,}051 = 1.62$ ■

SOLUTION (6.36)

Known: A lawn mower component has known stresses, an ultimate tensile strength of 97,000 psi, and a yield strength of 63,300 psi.

Find: Determine the safety factor according to:
(a) the maximum-normal-stress theory
(b) the maximum-shear-stress theory
(c) the maximum-distortion-energy theory

Schematic and Given Data:



Analysis:

1. Maximum-normal-stress theory
From, Eq. (4.16)

$$\sigma_1 = \left(\frac{\sigma_x+\sigma_y}{2}\right) + \left[\left(\frac{\sigma_x-\sigma_y}{2}\right)^2 + (\tau_{xy})^2\right]^{\frac{1}{2}}$$

$$= \left(\frac{45{,}000 + 25{,}000}{2}\right) + \left[\left(\frac{20{,}000}{2}\right)^2 + (15{,}000)^2\right]^{\frac{1}{2}}$$

$$= 53{,}028 \text{ psi}$$

$$SF = S_y / \sigma_1 = 63{,}300/53{,}028 = 1.19$$ ■

2. Maximum-shear-stress theory
From, Eq. (4.18)

$$\tau_{max} = \left[\tau_{xy}^2 + \left(\frac{\sigma_x - \sigma_y}{2}\right)^2\right]^{1/2}$$

$$= \left[(15{,}000)^2 + \left(\frac{20{,}000}{2}\right)^2\right]^{1/2} = 18{,}028 \text{ psi}$$

$$SF = \frac{S_y}{2\tau_{max}} = \frac{63,300}{2(18,028)} = 1.8$$ ■

3. Maximum-distortion-energy theory
From, Eq. (6.7)

$$\sigma_e = \left[\sigma_x^2 + \sigma_y^2 - \sigma_x\sigma_y + 3\tau_{xy}^2\right]^{1/2}$$

$$\sigma_e = \left[(45,000)^2 + (25,000)^2 - (45,000)(25,000) + 3(15,000)^2\right]^{1/2}$$

$$= 46,904 \text{ psi}$$

$SF = S_y/\sigma_e = 63,300/46,904 = 1.35$ ■