**Chapter 5**

**5-1** *Sy* = 350 MPa.

MSS: *σ*1−*σ*3= *Sy* /*n*⇒

DE: 



**(a)** MSS: *σ*1 = 100 MPa,*σ*2 = 100 MPa,*σ*3= 0  
 

DE: 

**(b)** MSS: *σ*1 = 100 MPa,*σ*2 = 50 MPa,*σ*3= 0  
 

DE: 

**(c) **



MSS: 

DE: 

**(d) **



MSS: 

DE: 

****

**(e) **



MSS: 

DE: 



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**5-2** *Sy* = 350 MPa.

MSS: *σ*1−*σ*3= *Sy* /*n*⇒

DE: 

**(a)** MSS: 

DE: 

**(b)** MSS: 

DE: 

**(c)** MSS: 

DE: 

**(d)** MSS: 

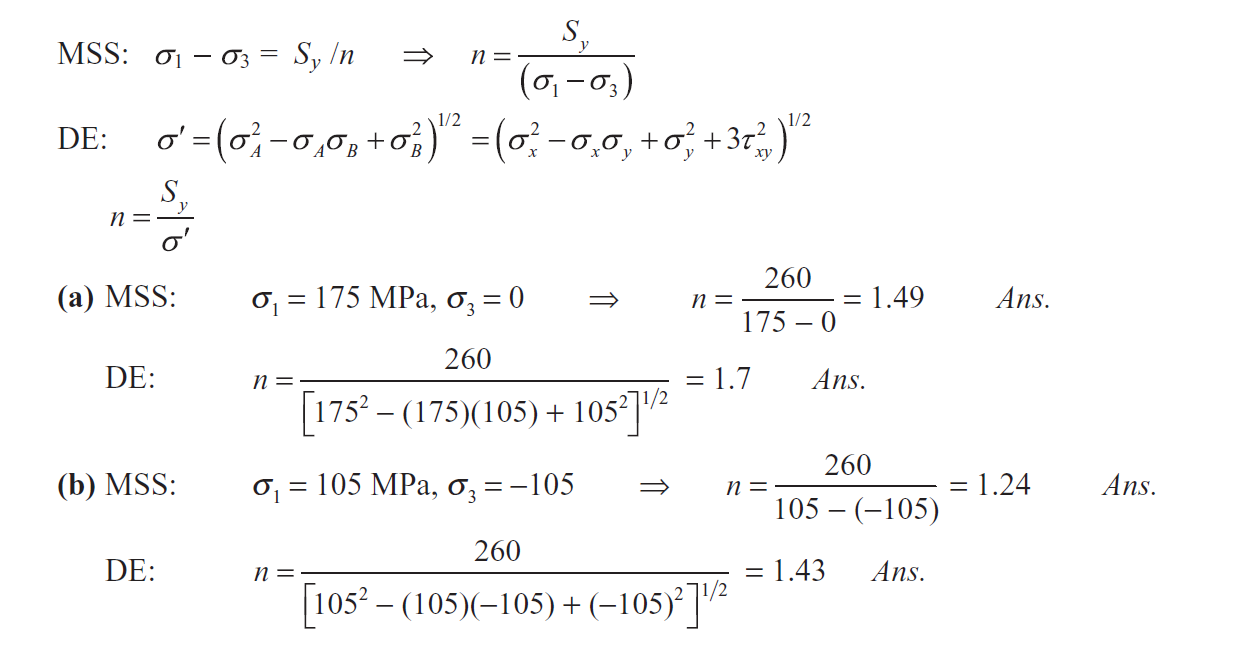
DE: 

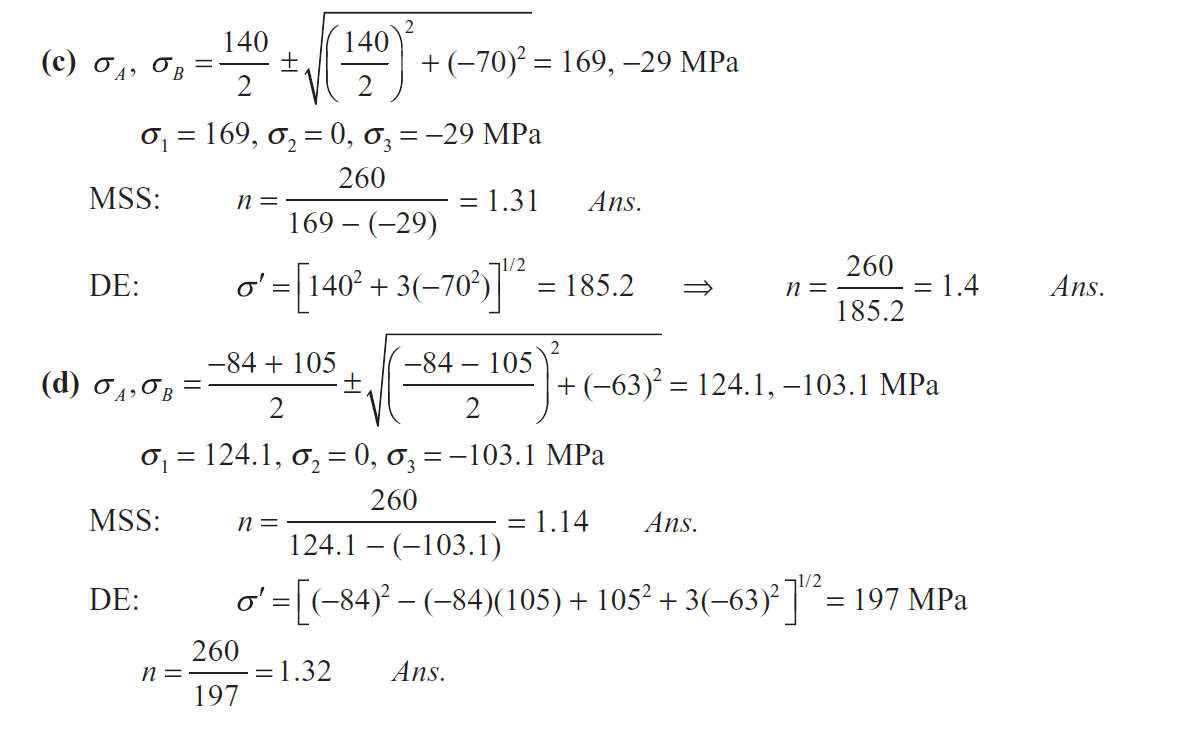
(**e**) MSS: 

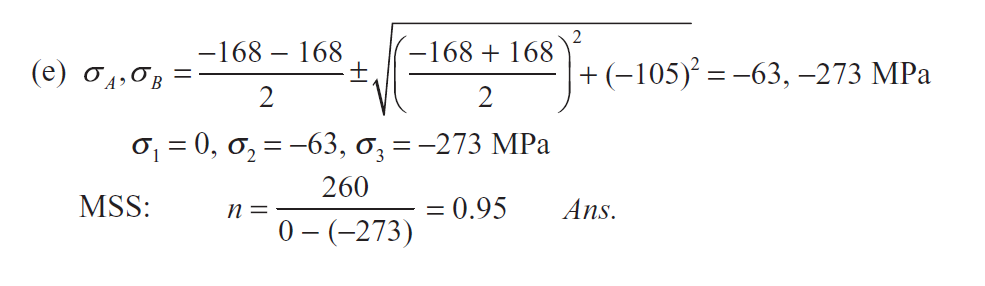
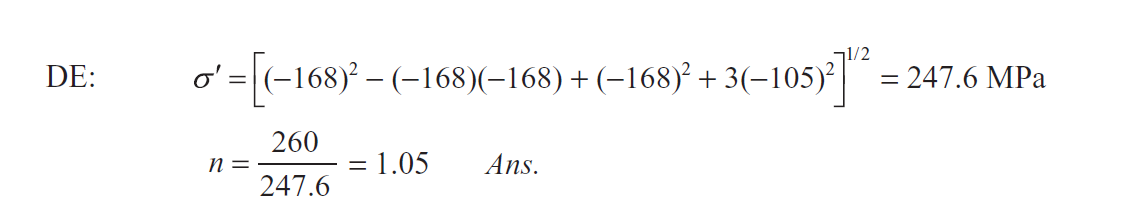
DE: 

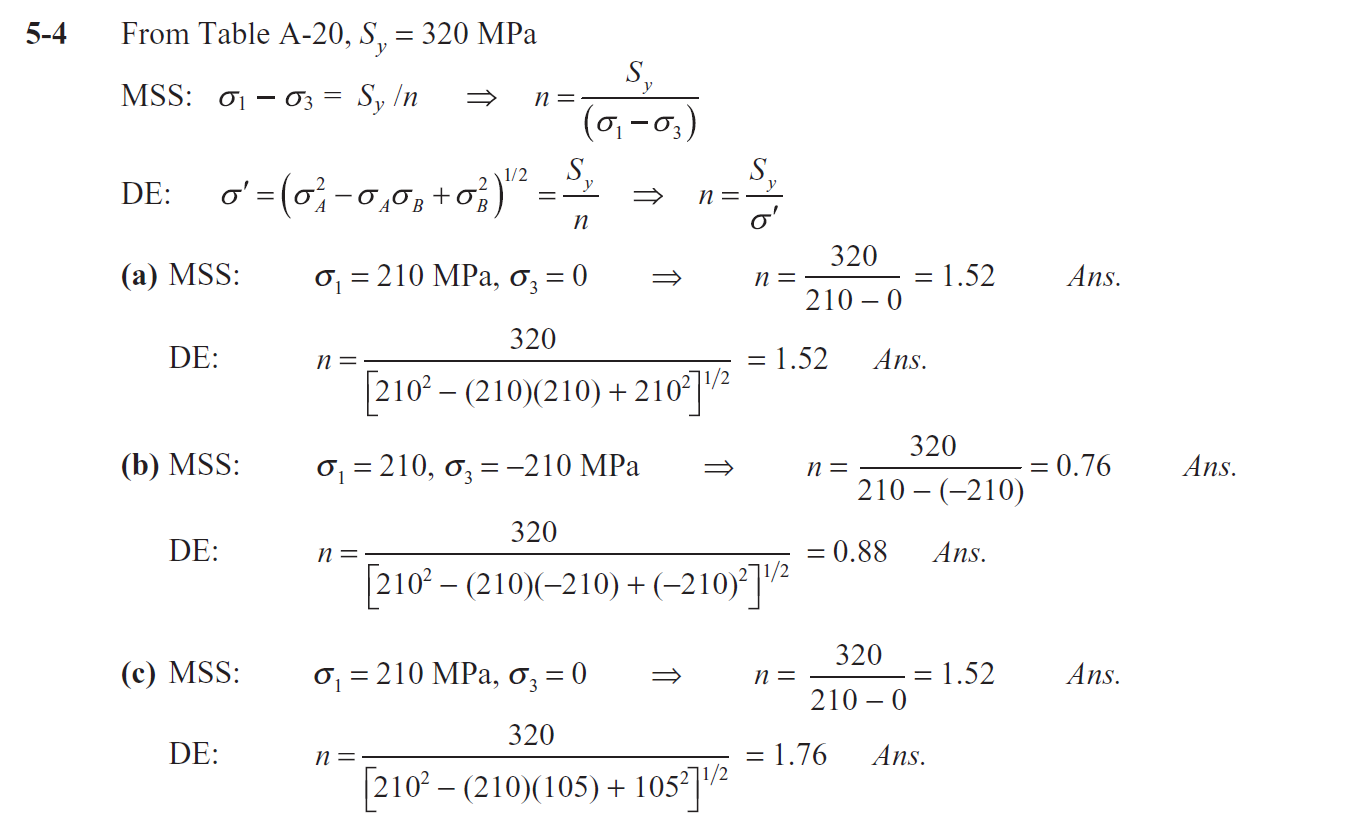
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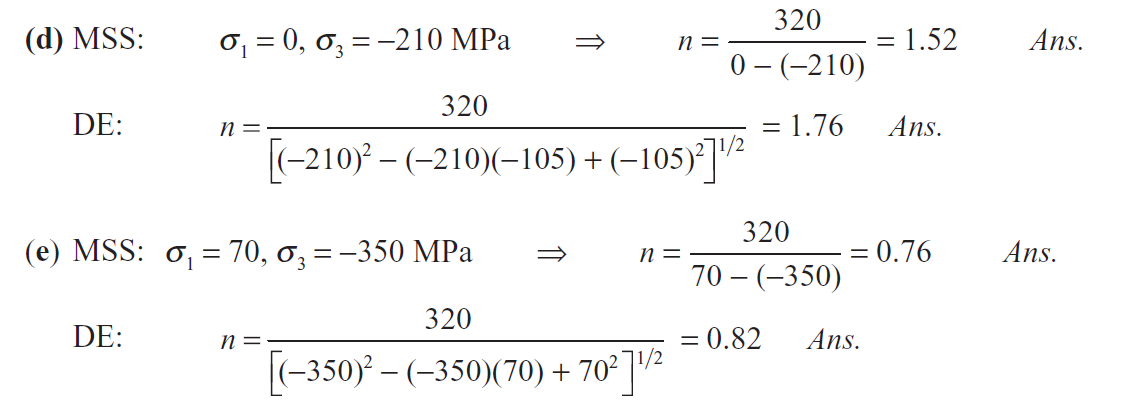
**5-3** From Table A-20, *Sy* = 260MPa





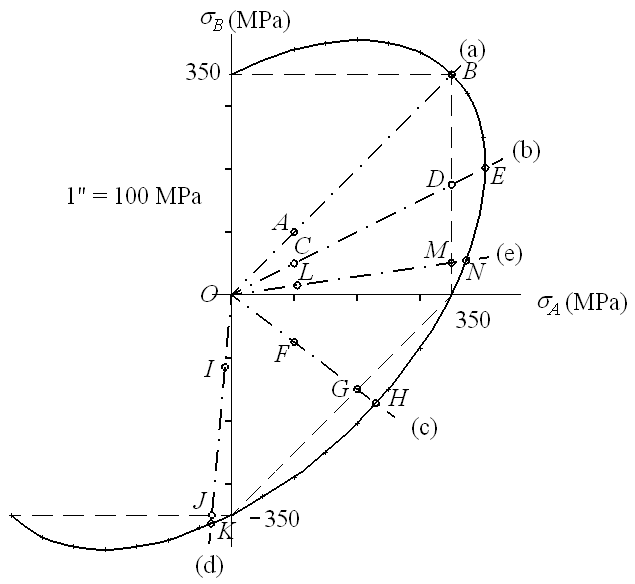
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**5-5** Note: The drawing in this manual may not be to the scale of original drawing. The measurements were taken from the original drawing.



(**a**) MSS and DE:



(**b**) MSS:



DE:



(**c**) MSS:

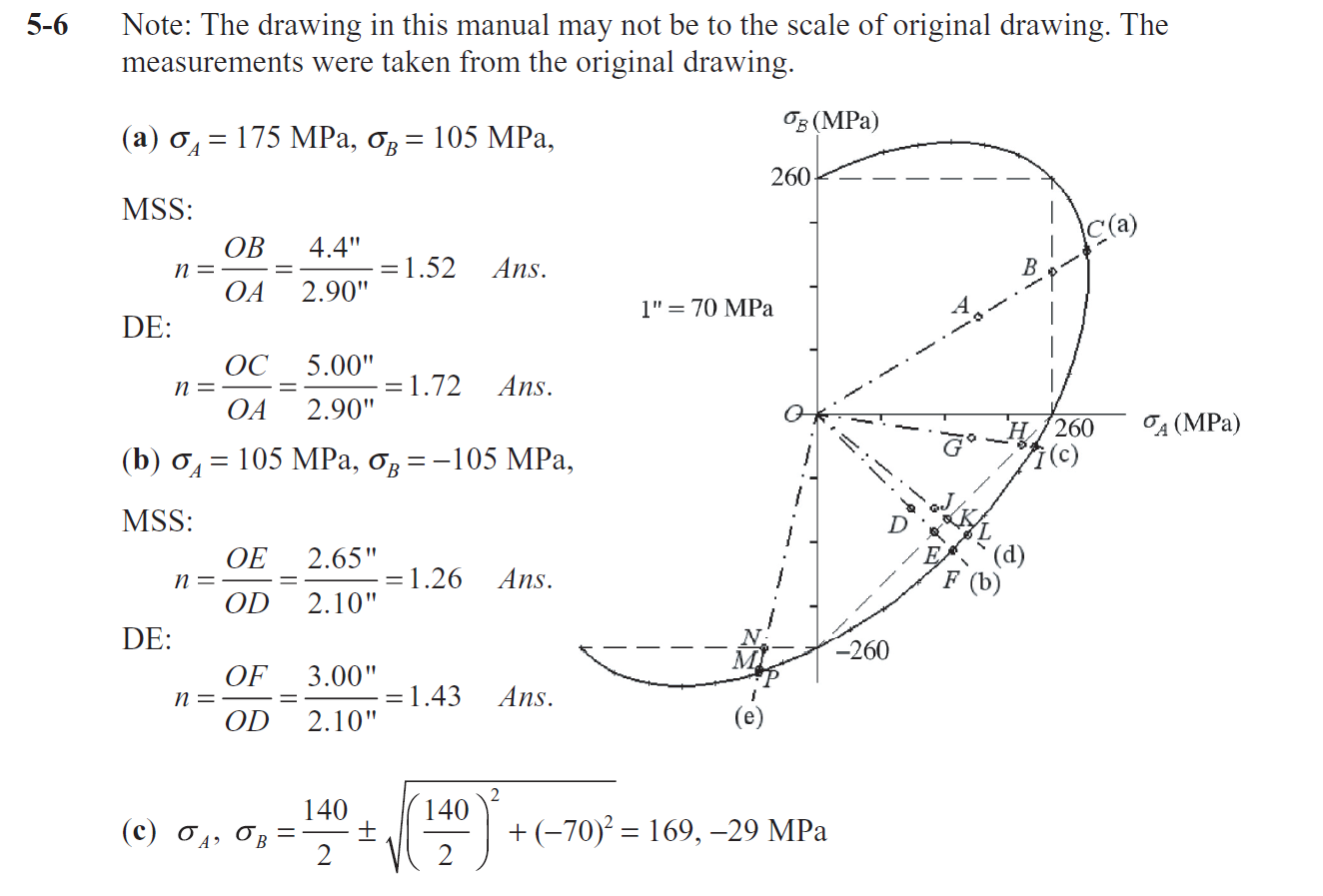


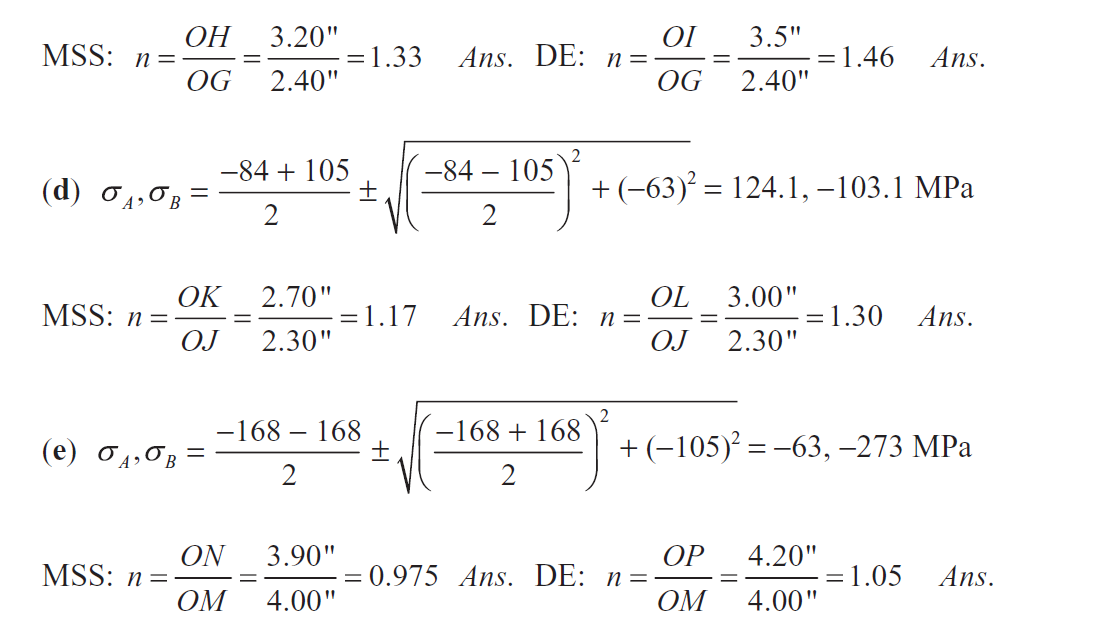
DE: 

(**d**) MSS: , DE: 

(**e**) MSS: , DE: 

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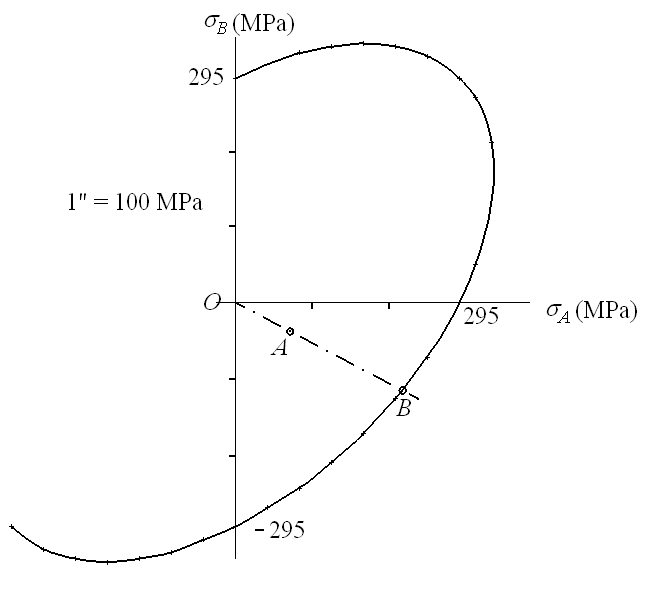


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**5-7** *Sy* = 295 MPa, *σA* = 75 MPa, *σB* = − 35 MPa,

(**a**) 

(**b**) Note: The drawing in this manual may not be to the scale of original drawing. The measurements were taken from the original drawing.



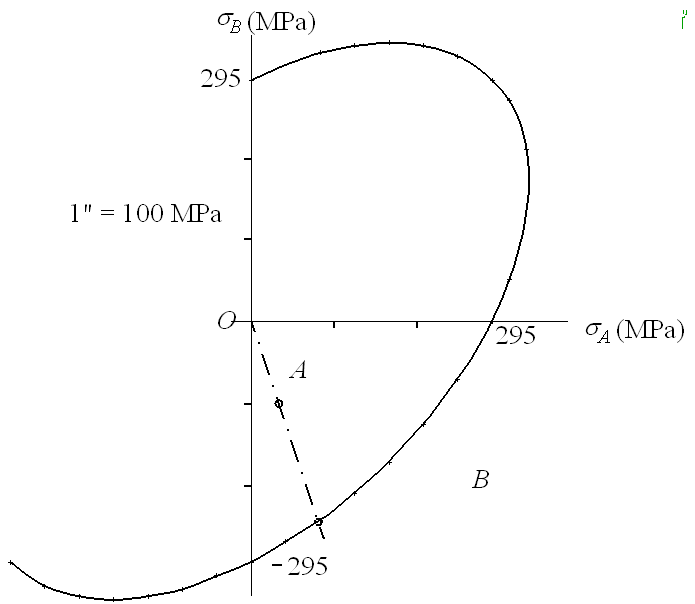


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**5-8** *Sy* = 295 MPa, *σA* = 30 MPa, *σB* = − 100 MPa,

(**a**) 

(**b**) Note: The drawing in this manual may not be to the scale of original drawing. The measurements were taken from the original drawing.





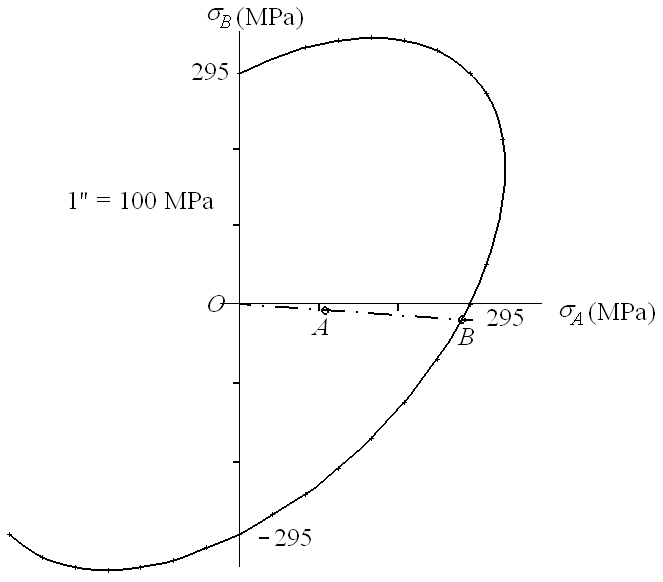
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**5-9** *Sy* = 295 MPa, 

(**a**) 

(**b**) Note: The drawing in this manual may not be to the scale of original drawing. The measurements were taken from the original drawing.



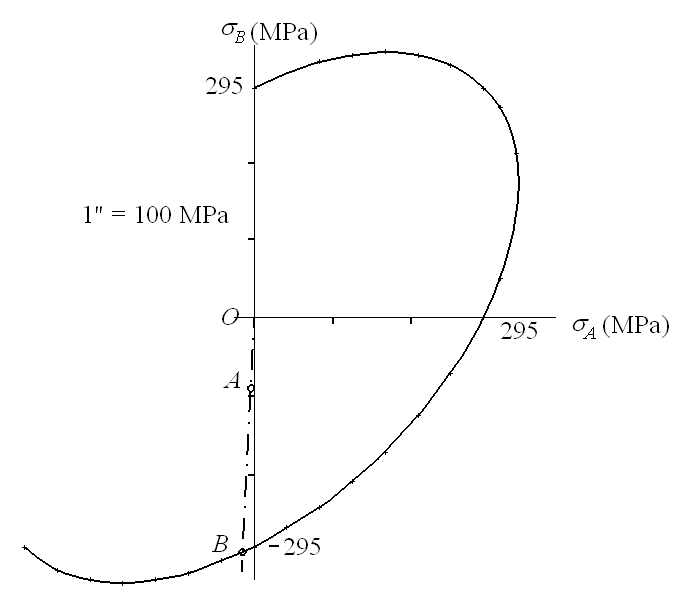


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**5-10** *Sy* = 295 MPa, 

(**a**) 

(**b**) Note: The drawing in this manual may not be to the scale of original drawing. The measurements were taken from the original drawing.

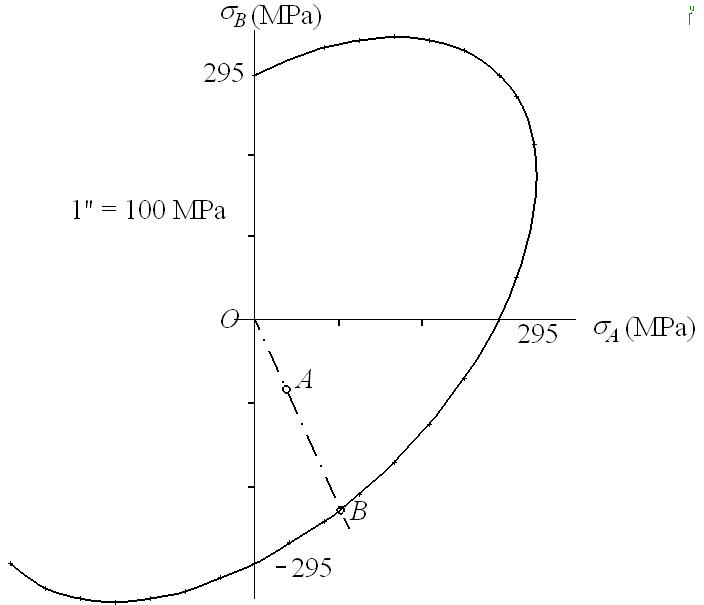
 

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**5-11** *Sy* = 295 MPa, 

(**a**) 

(**b**) Note: The drawing in this manual may not be to the scale of original drawing. The measurements were taken from the original drawing.





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**5-12** *Syt* = 413.69MPa, *Syc* = 517.11MPa. Eq. (5-26) for yield is



(**a**) ⇒

(**b**) ⇒

(**c**) , ⇒

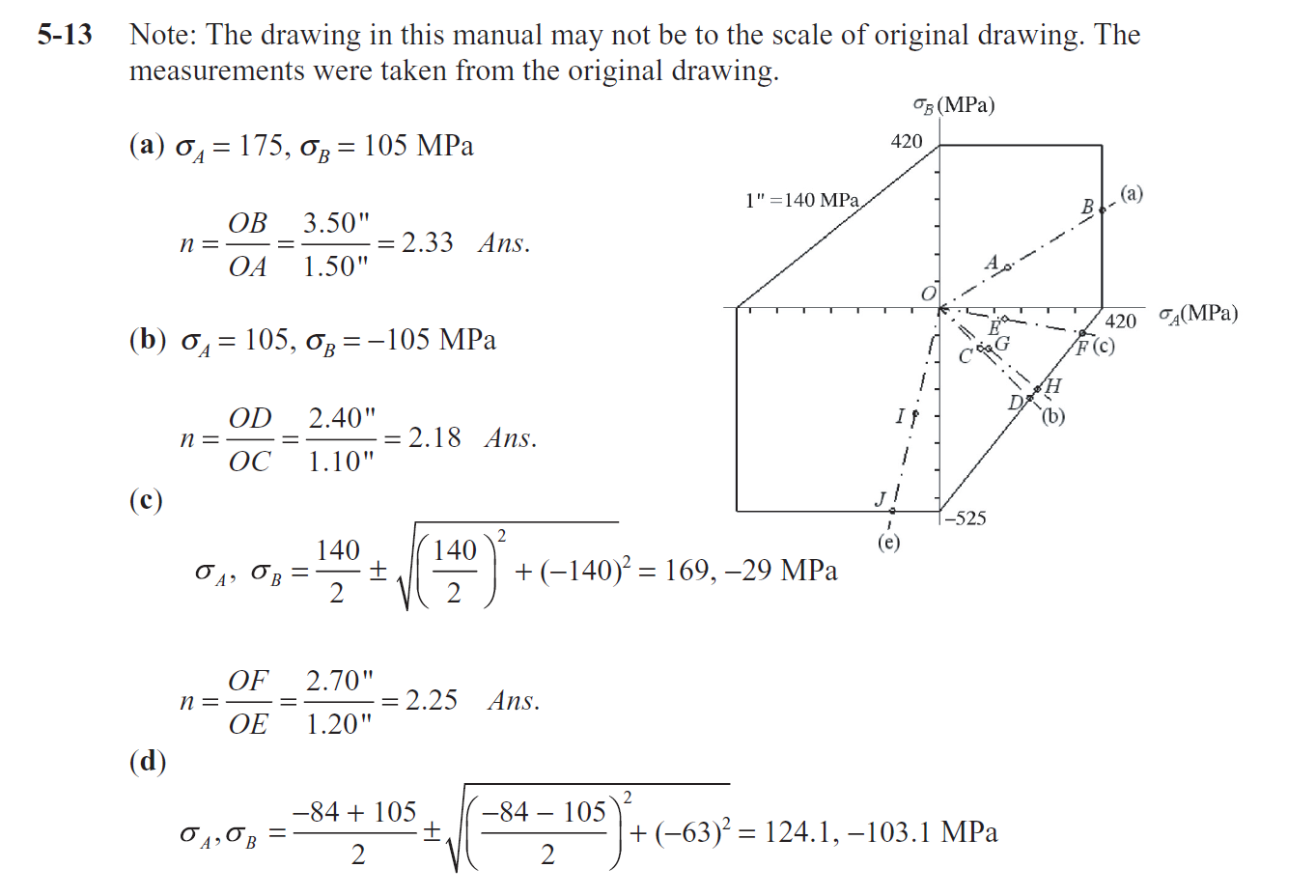
(**d**) 

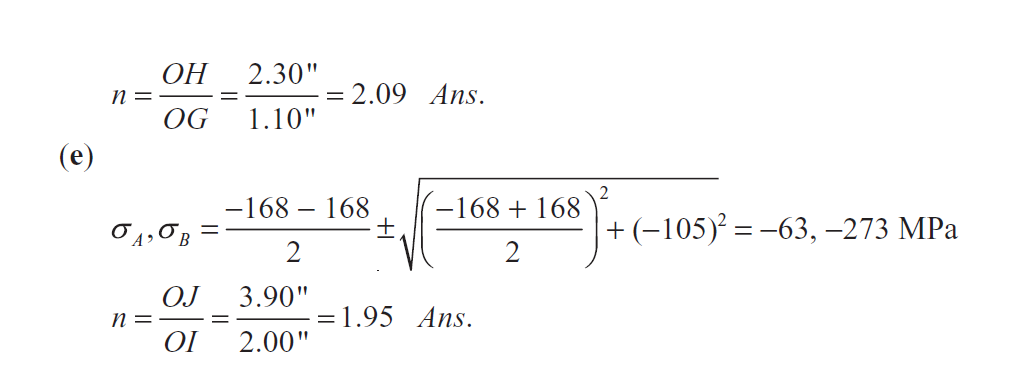
⇒

(**e**) 

⇒

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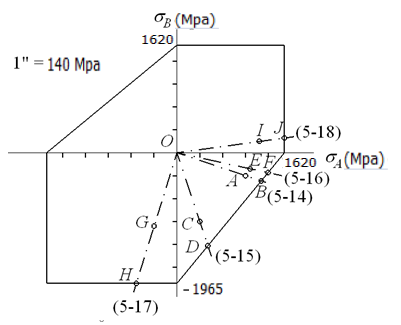


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**5-14** Since *εf*> 0.05, and *Syt*≠*Syc*, the Coulomb-Mohr theory for ductile materials will be used.

(**a**) From Eq. (5-26),



 (**b**) Plots for Problems 5-14 to 5-18 are found here. Note: The drawing in this manual may not be to the scale of original drawing. The measurements were taken from the original drawing.



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**5-15** (**a**) From Eq. (5-26),



(**b**) The plot for this problem is found on the page for Prob. 5-14. Note: The drawing in this manual may not be to the scale of original drawing. The measurements were taken from the original drawing.



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**5-16** 

(**a**) From Eq. (5-26),



(**b**) The plot for this problem is found on the page for Prob. 5-14. Note: The drawing in this manual may not be to the scale of original drawing. The measurements were taken from the original drawing.



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**5-17** 

(**a**) From Eq. (5-26),



(**b**) The plot for this problem is found on the page for Prob. 5-14. Note: The drawing in this manual may not be to the scale of original drawing. The measurements were taken from the original drawing.



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**5-18** 

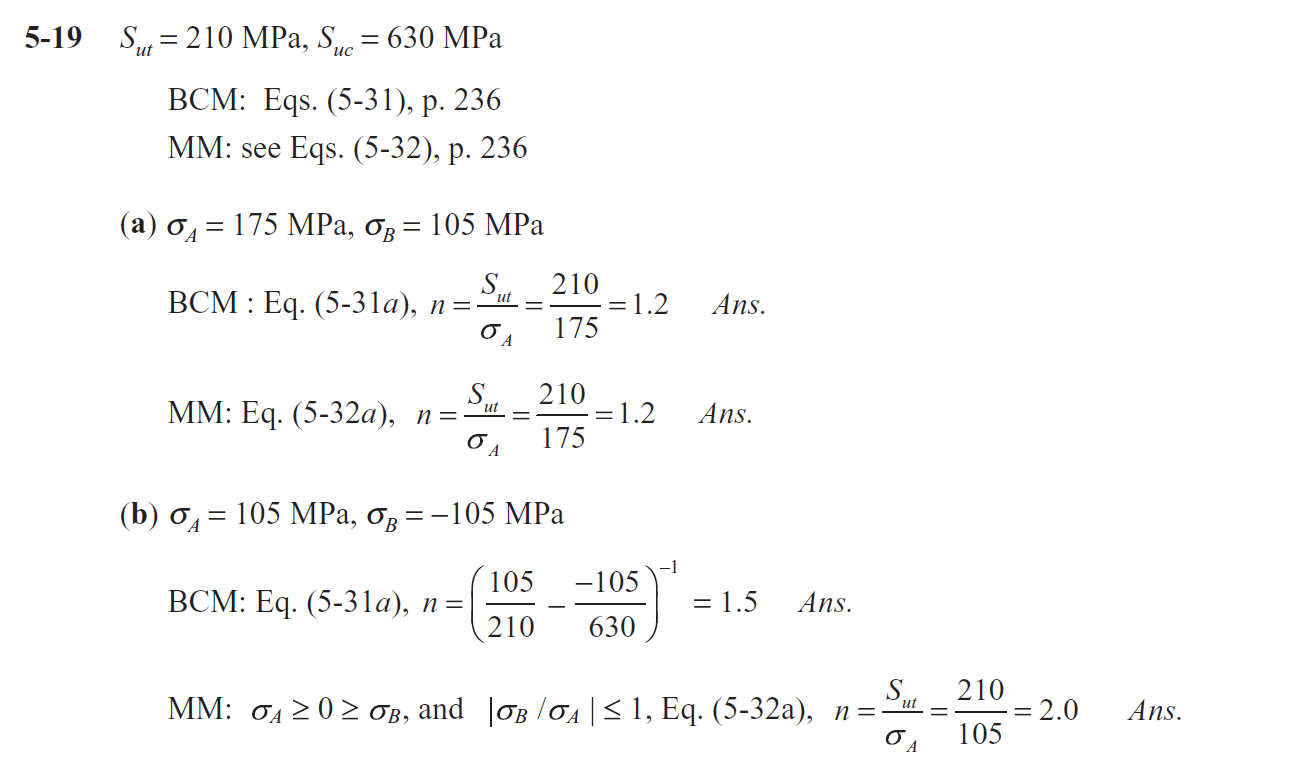
(**a**) From Eq. (5-26),

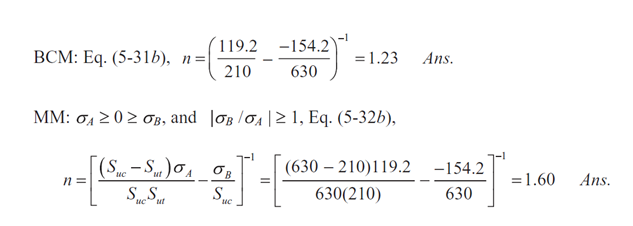
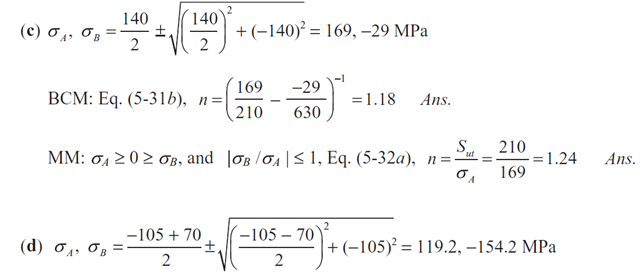


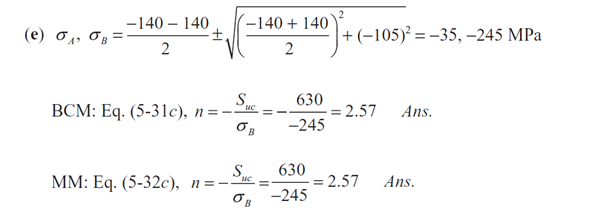
(**b**) The plot for this problem is found on the page for Prob. 5-14. Note: The drawing in this manual may not be to the scale of original drawing. The measurements were taken from the original drawing.



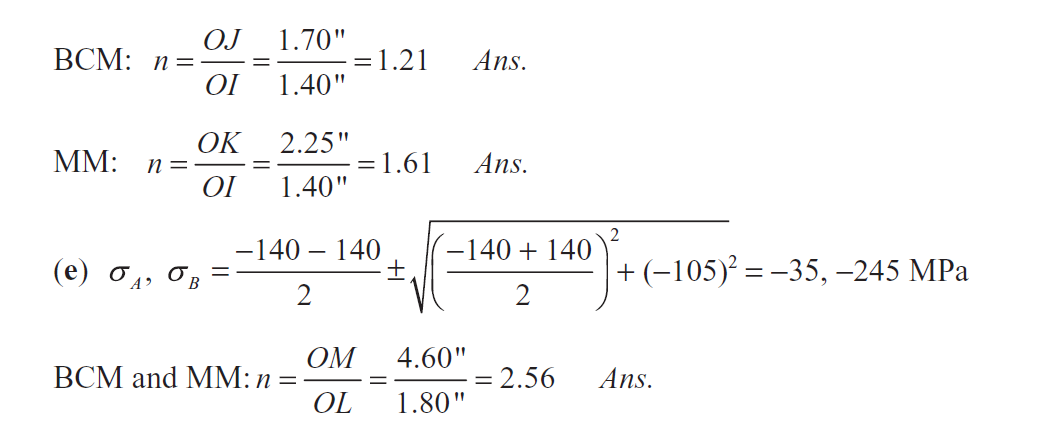
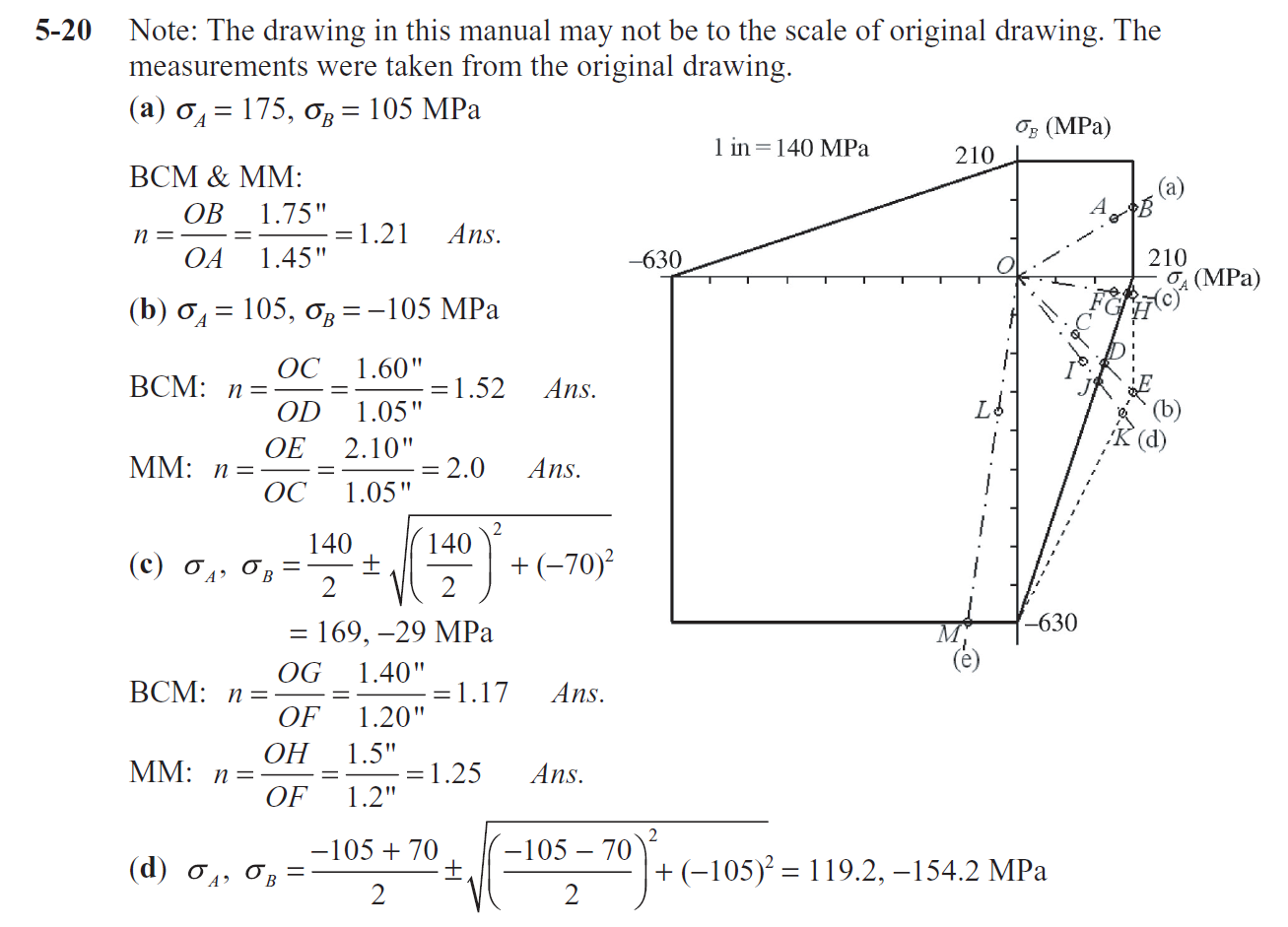
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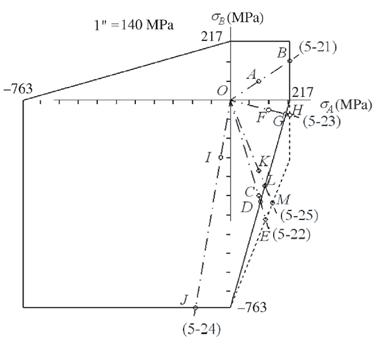
**5-21** From Table A-24, *Sut* = 217 MPa, *Suc* = 763 MPa

BCM: Eqs. (5-31), MM: Eqs. (5-32)

(**a**) *σA* = 103.4, *σB* = 68.95 MPa

BCM: Eq. (5-31*a*), 

MM: Eq. (5-32*a*), 

 (**b),** (**c**) The plot is shown below is for Probs. 5-21 to 5-25. Note: The drawing in this manual may not be to the scale of original drawing. The measurements were taken from the original drawing.

BCM and MM:



\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**5-22** *Sut* = 217 MPa, *Suc* = 763 MPa

BCM: Eq. (5-31), MM: Eqs. (5-32)

(**a**) *σA* = 103.425, *σB* = − 344.75 MPa, |*σB* /*σA*|> 1

BCM: Eq. (5-31*b*),

MM: Eq. (5-32*b*), 

(**b**), (**c**) The plot is shown in the solution to Prob. 5-21.

BCM: 

MM: 

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**5-23** From Table A-24, *Sut* = 217 MPa, *Suc* = 763 MPa

BCM: Eq. (5-31), MM: Eqs. (5-32)



(**a**) BCM: Eq. (5-32*b*), 

MM: Eq. (5-32*a*),

(**b**), (**c**) The plot is shown in the solution to Prob. 5-21.

BCM: 

MM: 

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**5-24** From Table A-24, *Sut* = 217 MPa, *Suc* = 763 MPa

BCM: Eq. (5-31), MM: Eqs. (5-32)



(**a**) BCM: Eq. (5-31*c*), 

MM: Eq. (5-32*c*),

(**b**), (**c**) The plot is shown in the solution to Prob. 5-21.

BCM and MM: 

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**5-25** From Table A-24, *Sut* = 217 MPa, *Suc* = 763 MPa

BCM: Eq. (5-31),MM: Eqs. (5-32)



(**a**) BCM: Eq. (5-31*b*), 

MM: Eq. (5-32*b*),

(**b**), (**c**) The plot is shown in the solution to Prob. 5-21.

BCM: 

MM: 

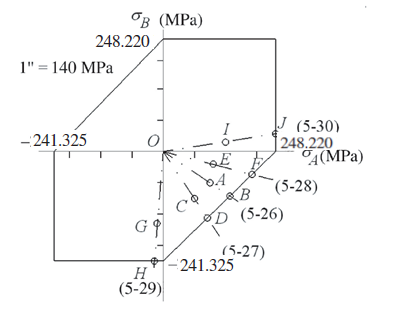
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**5-26** *Sut* = 248.220, *Suc* = 241.325 MPa

BCM: Eq. (5-31),

(**a**) *σA* = 103.42, *σB* = − 68395 MPa.

BCM: Eq. (5-31*b*), 

 (**b)** The plot is shown below is for Probs. 5-26 to 5-30. Note: The drawing in this manual may not be to the scale of original drawing. The measurements were taken from the original drawing.



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**5-27** *Sut* = 248.220, *Suc* = 241.325 MPa

BCM: Eq. (5-31),

(**a**) *σA* = 103.42, *σB* = − 103.42 MPa.

BCM: Eq. (5-31*b*),

(**b**) The plot is shown in the solution to Prob. 5-26.



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**5-28** *Sut* = 248.220, *Suc* = 241.325 MPa

BCM: Eq. (5-31),

(**a**) 

BCM: Eq. (5-31*b*),

(**b**) The plot is shown in the solution to Prob. 5-26.



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**5-29** *Sut* = 248.220, *Suc* = 241.325 MPa

BCM: Eq. (5-31),

(**a**) 

BCM: Eq. (5-31*c*), 

(**b**) The plot is shown in the solution to Prob. 5-26.



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**5-30** *Sut* = 248.220, *Suc* = 241.325 MPa

BCM: Eq. (5-31),

(**a**) 

BCM: Eq. (5-31*a*), 

(**b**) The plot is shown in the solution to Prob. 5-26.

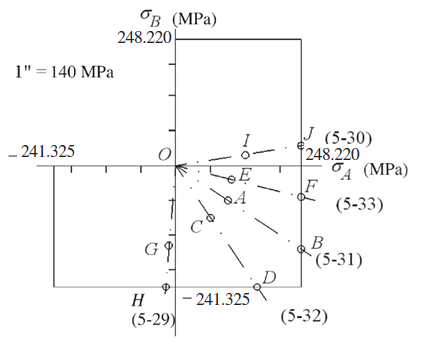


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**5-31** *Sut* = 248.220, *Suc* = 241.325 MPa. MM: Use Eq. (5-32).For this problem, MM reduces to the MNS theory.

(**a**) *σA* = 103.42, *σB* = − 68.95 MPa. Eq. (5-32*a*),

(**b)** The plot on the next page is for Probs. 5-31 to 5-35. Note: The drawing in this manual may not be to the scale of original drawing. The measurements were taken from the original drawing.

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**5-32** *Sut* = 248.220, *Suc* = 241.325 MPa*,* MM: Use Eq. (5-32).For this problem, MM reduces to the MNS theory.

(**a**) *σA* = 68.95, *σB* = − 103.42 MPa. Eq. (5-32b) is not valid and must use Eq, (5-32c), 

(**b)** The plot is shown in the solution to Prob. 5-31.



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**5-33** *Sut* = 248.220, *Suc* = 241.325 MPa. MM: Use Eq. (5-32).For this problem, MM reduces to the MNS theory.

(**a**) 



(**b**) The plot is shown in the solution to Prob. 5-31.



\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**5-34** *Sut* = 248.220, *Suc* = 241.325 MPa. MM: Use Eq. (5-32).For this problem, MM reduces to the MNS theory.

(**a**) 



(**b**) The plot is shown in the solution to Prob. 5-31.



\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**5-35** *Sut* = 248.220, *Suc* = 241.325 MPa. MM: Use Eq. (5-32).For this problem, MM reduces to the MNS theory.

(**a**) 



(**b**) The plot is shown in the solution to Prob. 5-31.



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**5-36** Given: AISI 1006 CD steel, *F* = 0.55 kN, *P* = 4.0 kN, and *T* = 25 N⋅m. From Table A-20, *Sy* =280 MPa. Apply the DE theory to stress elements *A* and *B*

*A*: 







*B*: 







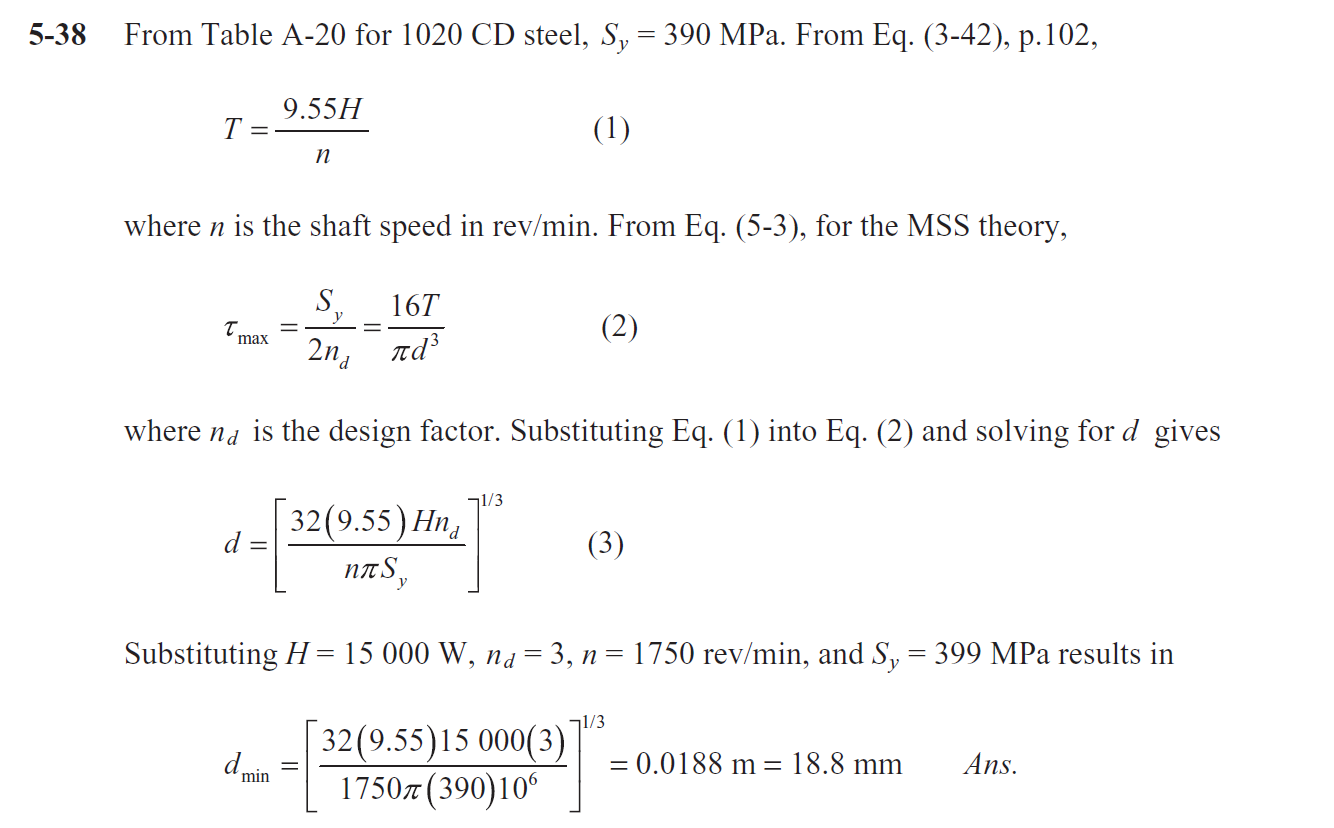
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**5-37** From Prob. 3-45, the critical location is at the top of the beam at *x* = 0.6858 m from the left end, where there is only a bending stress of *σ* = − 51.41 MPa. Thus, *σ′* = 51.41 MPa and

(*Sy*)min = *nσ′* = 2(51.41) = 102.81 MPa

Choose (*Sy*)min = 103.4 MPa *Ans*.

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**5-39** Given: *d* = 30 mm, AISI 1018 steel, *H* = 10 kW, *n* = 200 rev/min.

Table A-20, *Sy* = 220 MPa

Eq. (3-44): *T* = 9.55 *H/n* = 9.55(10)103/200 = 477.5 N۰m



**(a)** Eq. (5-3): 

**(b)** From Eq. (5-13), 

Eq. (5-19): 

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**5-40** Given: *d* = 20 mm, AISC 1035 HR steel, *ns* = 400 rev/min, *ny* = 1.5.

Table A-20, *Sy* = 270 MPa

**(a)** Eq. (5-30): 

Substituting Eq. (3-44) in the equation for *τ*max gives



**(b)** From Eq. (5-13):

Thus,



\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**5-41** Table A-20 for AISI 1040 CD steel, *Sy* = 490 MPa.

From Prob. 3-47,

*A*: *σx* =79.6 MPa, *τxy* = 63.7 MPa. 

*B*: *τ*max = *τzx* = 53.1 MPa. *C:τ*max = *τzx* = 116.8 MPa.

Critical case is at point *C*.

**(a)** MSS Theory: 

**(b)** DE Theory: 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-42** Table A-20 for AISI 1040 CD steel, *Sy* = 490 MPa

From Prob. 3-53, 

**(a)** MSS Theory: 

**(b)** DE Theory, Eq. (5-13): 

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**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-43** Table A-20 for AISI 1020 CD steel, *Sy* = 390 MPa

From Prob. 3-54, 

**(a)** MSS Theory: 

**(b)** DE Theory, Eq. (5-13): 

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**5-44** Table A-20 for AISI 1035 CD steel, *Sy* = 461.95 MPa

From Prob. 3-55, 

**(a)** MSS Theory: 

**(b)** DE Theory, Eq. (5-13): 

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**5-45** Table A-20 for AISI 1040 CD steel, *Sy* = 71 kpsi

From Prob. 3-101, 

**(a)** MSS Theory: 

**(b)** DE Theory, Eq. (5-13): 

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**5-46** Table A-20 for AISI 1040 CD steel, *Sy* = 489.53 MPa

From Prob. 3-102, 

**(a)** MSS Theory: 

**(b)** DE Theory, Eq. (5-13): 

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**5-47** Table A-21 for AISI 4140 steel Q & T 204 oC ,*Sy* = 140 MPa, *F* = 66720 N.

Σ*MA* = 0 = 0.0762 *RD*− 0.0508 *F* ⇒*RD* = 44480 N,

Σ*Fy* = 0 = *RA*+ *RD*−*F*⇒*RA* = 66720 − 44480 = 22240 N

Critical sections are at points *B* and *C* where the areas are minimal.

*B*: *dB* = 0.02794 m, *MB* = *RA* (0.0254) = 565 N۰m, *VB* = *RA* =22240 N, *TB* = 791 N m

*AB* = (π/4)0.02794 2 = 0.613(10-3 )m2,

*C*: *dC* = 0.033 m, *MC* = *RD* (0.0254) = 1130 N۰m, *VC* = *RD* = 44480 N, *TC* = 791 N m

*AC* = (π/4) 0.0332 = 0.856(10-3 ) m2,

Critical locations are at the outer surfaces where bending stresses are maximum, and at the center planes where the transverse shear stresses are maximum. In both cases, there exists the torsional shear stresses.

*B*: Outer surface: 





Center plane:







*C*: Outer surface: 





Center plane:







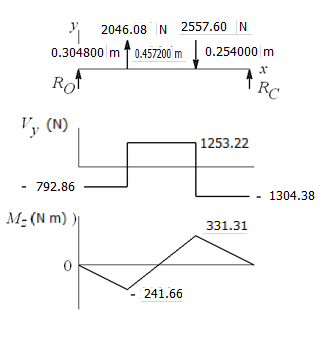
**(a)** MSS Theory: Critical location is at point *B* at the center plane:



**(b)** DE Theory: Critical location is at point *B* at the outer surface:

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**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-48** Σ*MO* = 0 = 1.016 *RC*− 0.762(2557.6) +0.3048(2046)

*RC* = 1304 N

Σ*Fy* = 0 = *RO* +1304 +2046 − 2558

*RO* = − 793 N

*M*max = 331 N۰m





**(a)**

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**(b)** Eq. (5-15): *σ’* = [2062 +3 (52.68)2]1/2 = 225.25 MPa

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**5-49** Given: AISI 1010 HR, *ny* = 2, *L* = 0.5 m, *F* = 150 N, *T* = 25 N۰m

Table A-20, *Sy* = 180 MPa.

*Mz* = *FL* = 150 (0.5) = 75 N۰m





**(a)**



**(b)**



\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**5-50** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-79, in the plane of analysis

*σ*1 = 113.76 MPa, *σ*2 = − 8.20 MPa, and *τ*max = 60.95 MPa

The state of stress is *plane stress*. Thus, the three-dimensional principal stresses are

*σ*1 =113.76 MPa, *σ*2 = 0, and *σ*3 = − 8.20 MPa

**MSS**: From Eq. (5-3),

Note: Whenever the two principal stresses of a plane stress state are of opposite sign, the maximum shear stress found in the analysis is the *true* maximum shear stress. Thus, the factor of safety could have been found from



**DE**: The von Mises stress can be found from the principal stresses or from the stresses found in part (d) of Prob. 3-79. That is,

Eqs. (5-13) and (5-19) 

or, Eqs. (5-15) and (5-19) using the results of part (d) of Prob. 3-79



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**5-51** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-80, in the plane of analysis

*σ*1 = 275 MPa, *σ*2 = − 12.1 MPa, and *τ*max = 144 MPa

The state of stress is *plane stress*. Thus, the three-dimensional principal stresses are

*σ*1 =275 MPa, *σ*2 = 0, and *σ*3 = − 12.1 MPa

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-13) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-52** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-81, in the plane of analysis

*σ*1 = 155.82 MPa, *σ*2 = − 7.86 MPa, and *τ*max = 82.05 MPa

The state of stress is *plane stress*. Thus, the three-dimensional principal stresses are

*σ*1 =155.82 MPa, *σ*2 = 0, and *σ*3 = − 7.86 MPa

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-13) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-53** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-82, in the plane of analysis

*σ*1 = 78.2 MPa, *σ*2 = − 5.27 MPa, and *τ*max = 41.7 MPa

The state of stress is *plane stress*. Thus, the three-dimensional principal stresses are

*σ*1 =78.2 MPa, *σ*2 = 0, and *σ*3 = − 5.27 MPa

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-13) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-54** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-83, in the plane of analysis

*σ*1 = 253.04 MPa, *σ*2 = − 10.14 MPa, and *τ*max = 131.69 MPa

The state of stress is *plane stress*. Thus, the three-dimensional principal stresses are

*σ*1 =253.04 MPa, *σ*2 = 0, and *σ*3 = − 10.14 MPa

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-13) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-55** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-84, in the plane of analysis

*σ*1 = 376 MPa, *σ*2 = − 42.4 MPa, and *τ*max = 209 MPa

The state of stress is *plane stress*. Thus, the three-dimensional principal stresses are

*σ*1 = 376 MPa, *σ*2 = 0, and *σ*3 = − 42.4 MPa

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-13) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-56** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-85, in the plane of analysis

*σ*1 = 49.57 MPa, *σ*2 = − 117.21 MPa, and *τ*max = 83.43 MPa

The state of stress is *plane stress*. Thus, the three-dimensional principal stresses are

*σ*1 = 49.57 MPa, *σ*2 = 0, and *σ*3 = − 117.21 MPa

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-13) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-57** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-87, in the plane of analysis

*σ*1 = 11.84 MPa, *σ*2 = − 247.25 MPa, and *τ*max = 129.20 MPa

The state of stress is *plane stress*. Thus, the three-dimensional principal stresses are

*σ*1 = 11.84 MPa, *σ*2 = 0, and *σ*3 = − 247.25 MPa

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-13) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-58** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-88,

Bending: *σB* = 68.6 MPa, Torsion: *τB* = 37.7 MPa

For a plane stressanalysis it was found that *τ*max = 51.0 MPa. With combined bending and torsion, the plane stress analysis yields the true *τ*max.

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-15) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-59** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-90,

Bending: *σC* = 23.86 MPa, Torsion: *τC* = 6.08 MPa

For a plane stress analysis it was found that *τ*max = 13.38 MPa. With combined bending and torsion, the plane stress analysis yields the true *τ*max.

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-15) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-60** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-91, in the plane of analysis

*σ*1 = 122.73 MPa, *σ*2 = − 10.07 MPa, and *τ*max = 66.26 MPa

The state of stress is *plane stress*. Thus, the three-dimensional principal stresses are

*σ*1 = 122.73 MPa, *σ*2 = 0, and *σ*3 = − 10.07 MPa

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-13) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-61** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-92, in the plane of analysis

*σ*1 = 120.66 MPa, *σ*2 = − 7.79 MPa, and *τ*max = 64.33 MPa

The state of stress is *plane stress*. Thus, the three-dimensional principal stresses are

*σ*1 = 120.66 MPa, *σ*2 = 0, and *σ*3 = − 7.79 MPa

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-13) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-62** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-93, in the plane of analysis

*σ*1 = 148.24 MPa, *σ*2 = − 8.27 MPa, and *τ*max = 78.60 MPa

The state of stress is *plane stress*. Thus, the three-dimensional principal stresses are

*σ*1 = 148.24 Mpa, *σ*2 = 0, and *σ*3 = − 8.27 MPa

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-13) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-63** From Table A-20, *Sy* = 370 Mpa. From the solution of Prob. 3-94, the concern was failure due to twisting of the flat bar where it was found that *τ*max = 98.39 MPa in the middle of the longest side of the rectangular cross section. The bar is also in bending, but the bending stress is zero where *τ*max exists.

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-15) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-64** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-95, in the plane of analysis

*σ*1 = 239.25 MPa, *σ*2 = − 46.19 MPa, and *τ*max = 142.72 MPa

The state of stress is *plane stress*. Thus, the three-dimensional principal stresses are

*σ*1 = 239.25 MPa, *σ*2 = 0, and *σ*3 = − 46.19 MPa

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-13) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-65** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-96, in the plane of analysis

*σ*1 = 352.32 MPa, *σ*2 = − 31.58 MPa, and *τ*max = 191.67 MPa

The state of stress is *plane stress*. Thus, the three-dimensional principal stresses are

*σ*1 = 352.32 MPa, *σ*2 = 0, and *σ*3 = − 31.58 MPa

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-13) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-66** From Table A-20, *Sy* = 370 MPa. From the solution of Prob. 3-97, in the plane of analysis

*σ*1 = 411.62 MPa, *σ*2 = − 27.03 MPa, and *τ*max = 219.05 MPa

The state of stress is *plane stress*. Thus, the three-dimensional principal stresses are

*σ*1 = 411.62 MPa, *σ*2 = 0, and *σ*3 = − 27.03 MPa

**MSS**: From Eq. (5-3), 

**DE**: From Eqs. (5-13) and (5-19) 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-67** For Prob. 3-95, from Prob. 5-64 solution, with 1018 CD, DE theoryyields, *n* = 1.40.

From Table A-21, for 4140 Q&T @204.4°C, *Sy* = 238 kpsi. From Prob. 3-98 solution which considered stress concentrations for Prob. 3-95

*σ*1 = 365.42 MPa, *σ*2 = − 58.47 MPa, and *τ*max = 211.67 MPa

**DE**: From Eqs. (5-13) and (5-19) 

Using the 4140 versus the 1018 CD, the factor of safety increases by a factor of

4.12/1.40 = 2.94. *Ans*.

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-68** Design Decisions Required:

* Material and condition
* Design factor
* Failure model
* Diameter of pin

Using *F* = 1850.46 N from Ex. 5-3,





Decision 1: Select the same material and condition of Ex. 5-3 (AISI 1035 steel, *Sy* = 550 MPa)

Decision 2: Since we prefer the pin to yield, set *nd* a little larger than 1. Further explanation will follow.

Decision 3: Use the Distortion Energy static failure theory.

Decision 4: Initially set *nd* = 1





Choose preferred size of 



Set design factor to 

Adequacy Assessment:







**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-69** From Table A-20, for a thin walled cylinder made of AISI 1020 CD steel, *Syt* = 390 MPa, *Sut* = 470 MPa.

Since *r/t* = 190.5/1.587 = 120 > 10, the shell can be considered thin-wall. From the solution of Prob. 3-106 the principal stresses are



From Eq. (5-12)



For yield, *σ′ = Sy*⇒ 61*p* = 390 (106) ⇒*p* = 6.44 MPa *Ans*.

For rupture, 

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**5-70** Given: AISI CD 1040 steel, *ny* = 2, OD = 50 mm, ID = 42 mm, *L* = 150 mm.

Table A-20, *Sy* = 490 MPa

At *r* = *ri* = 21 mm, Eq. (3-51) gives



Closed end, Eq. (3-52) gives



**(a)**



**(b)** Eq. (5-12):





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**5-71** Given: AISI 1040 CD steel, OD = 50 mm, ID = 42 mm, *L* = 150 mm, *pi* = 40 MPa

Table A-20, *Sy* = 490 MPa

At *r* = *ri* = 21 mm, Eq. (3-51) gives



Closed end, Eq. (3-52) gives



**(a)**



**(b)** Eq. (5-12):





\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**5-72** For AISI 1020 HR steel, from Tables A-5 and A-20,*w* = 76.5 kN/m3, *Sy* = 210 MPa, and

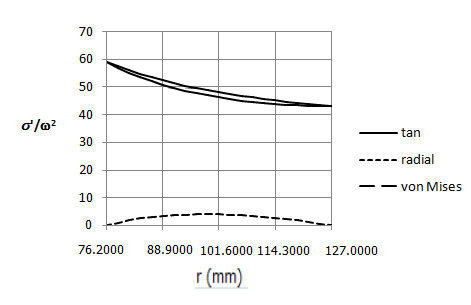
*ν* = 0.292. Then,*ρ = w/g* . For the problem, *ri* = 76 mm, and *ro* = 127 mm. Substituting into Eqs. (3-55), gives



For the distortion-energy theory, the von Mises stress will be

 (3)

Although it was noted that the maximum radial stress occurs at *r* = (*rori* )1/2 we are more interested as to where the von Mises stress is a maximum. One could take the derivative of Eq. (3) and set it to zero to find where the maximum occurs. However, it is much easier to plot *σ′/ω* 2 for 76 ≤*r*≤ 127 mm.Plotting Eqs. (1) through (3) results in



It can be seen that there is no maxima, and the greatest value of the von Mises stress is the tangential stress at *r = ri*. Substituting *r* = 76 mm into Eq. (1) and setting *σ′ = Sy* gives





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**5-73** Since *r/t* = 44.45/1.65 = 26.9 > 10, we can use thin-walled equations. From Eqs. (3-53) and (3-54),





These are all principal stresses, thus, from Eq. (5-12),





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**5-74** From Table A-20, ****

With*pi* = 0, Eqs. (3-49) are



For the distortion-energy theory, the von Mises stress is



We see that the maximum von Mises stress occurs where*r* is a minimum at*r = ri*. Here,

*σr* = 0 and thus *σ′* = −*σt* . Setting −*σt* = *Sy* = 320 MPa at *r* = 0.1 m in Eq. (1) results in



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**5-75** From Table A-24, *Sut* = 210 MPa for grade 30 cast iron. From Table A-5, *ν* = 0.211 and

*w* = 70576 N/m3. In Prob. 5-72, it was determined that the maximum stress was the tangential stress at the inner radius, where the radial stress is zero. Thus at the inner radius, Eq. (3-55) gives

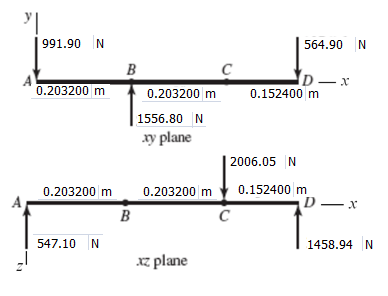


*n* = 60(1452)/(2*π* ) = 13 870 rev/min *Ans*.

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**5-76** From Table A-20, for AISI 1035 CD, *Sy* = 460 MPa.

From force and bending-moment equations, the ground reaction forces are found in two planes as shown.



The maximum bending moment will be at *B* or *C*. Check which is larger.In the *xy* plane,



In the *xz* plane, 



So point *C* governs. The torque transmitted between *B* and *C* is *T* = (1334.46−222.41)(0.1016) = 113 N·m. The stresses are





For combined bending and torsion, the maximum shear stress is found from



Max Shear Stress theory is chosen as a conservative failure theory. From Eq. (5-3)



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**5-77** As in Prob. 5-76, we will assume this to be a statics problem. Since the proportions are unchanged, the bearing reactions will be the same as in Prob. 5-76 and the bending moment will still be a maximum at point *C*. Thus

*xy*plane: 

*xz* plane: 

So





Since the torsional stress is unchanged,



For combined bending and torsion, the maximum shear stress is found from



Using the MSS theory, as was used in Prob. 5-76, gives



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**5-78** For AISI 1018 HR, Table A-20 gives *Sy* = 220 Mpa. Transverse shear stress is a maximum at the neutral axis, and zero at the outer radius. Bending stress is a maximum at the outer radius, and zero at the neutral axis.

Model (*c*): From Prob. 3-41, at outer radius,



At neutral axis,



The bending stress at the outer radius dominates. *n* = 1.80 *Ans.*

Model (*d*): Assume the bending stress at the outer radius will dominate, as in model (*c*). From Prob. 3-41,



Model (*e*):From Prob. 3-41,



Model (*d*) is the most conservative, thus safest, and requires the least modeling time.

Model (*c*) is probably the most accurate, but model (*e*) yields the same results with less modeling effort.

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**5-79** For AISI 1018 HR, from Table A-20, *Sy* = 220 MPa. Model (*d*) yields the largest bending moment, so designing to it is the most conservative approach. The bending moment is

*M* = 312.5 lbf⋅in. For this case, the principal stresses are



Using a conservative yielding failure theory use the MSS theory and Eq. (5-3)



Thus, 

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**5-80** When the ring is set, the hoop tension in the ring is equal to the screw tension.



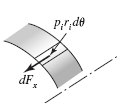
The differential hoop tension *dF*at *r* for the ring of width *w*, is. Integration yields

 (1)

The screw equation is

 (2)

From Eqs. (1) and (2)









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**5-81** *T* = 20 N⋅m, *Sy* = 450 MPa

**(a)** From Prob. 5-80, *T* = 0.2 *Fi d*



**(b)** From Prob. 5-80, *F =wripi*



**(c)** 





**(d)**









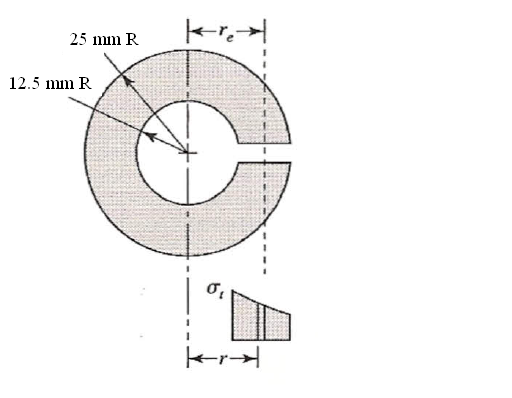
**(e)** Maximum Shear Stress Theory



Distortion Energy theory



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**5-82** The moment about the center caused by

the force *F* is *F re*where*re* is the effective

radius. This is balanced by the moment

about the center caused by the tangential

(hoop) stress. For the ring of width *w*



From Prob. 5-80, *F = wri pi*. Therefore,



For the conditions of Prob. 5-80, *ri* = 12.5 mm and *ro* = 25 mm



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**5-83** (**a**) The nominal radial interference is *δ*nom = (2.002 − 2.001) /2 = 0.0005 in.

From Eq. (3-57),



**Inner member**: *pi* = 0, *po* =*p* =3072 psi. At fit surface *r =R =* 1 in,

Eq. (3-49): 

*σr* = −*p* = − 3072 psi

Eq. (5-13): 

**Outer member**: *pi* = *p* = 3072 psi, *po* = 0. At fit surface *r =R =* 1 in,

Eq. (3-49): 

*σr* = −*p* = − 3072 psi

Eq. (5-13): 

(**b**) For a solid inner tube,



**Inner member**: *σt* = *σr* = −*p* = − 4167 psi



**Outer member**: *pi* = *p* = 4167 psi, *po* = 0. At fit surface *r =R =* 1 in,

Eq. (3-49): 

*σr* = −*p* = − 4167 psi

Eq. (5-13): 

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**5-84** From Table A-5, E = 207 (103) MPa. The nominal radial interference is *δ*nom = (40−39.98) /2 = 0.01 mm.

From Eq. (3-57),



**Inner member**: *pi* = 0, *po* = *p* = 26.64 MPa. At fit surface *r =R =*20 mm,

Eq. (3-49): 

*σr* = −*p* = −26.64 MPa

Eq. (5-13): 

**Outer member**: *pi* = *p* = 26.64 MPa, *po* = 0. At fit surface *r =R =*20 mm,

Eq. (3-49): 

*σr* = −*p* = −26.64MPa

Eq. (5-13): 

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**5-85** From Table A-5, E = 207 (103) MPa. The nominal radial interference is *δ*nom = (40.008 − 39.972) /2 = 0.018 mm.

From Eq. (3-57),



**Inner member**: *pi* = 0, *po* = *p* = 47.94 MPa. At fit surface *r =R =* 20 mm,

Eq. (3-49): 

*σr* = −*p* = − 47.94 MPa

Eq. (5-13): 

**Outer member**: *pi* = *p* = 47.94 MPa, *po* = 0. At fit surface *r =R =* 20 mm,

Eq. (3-49): 

*σr* = −*p* = −47.94 MPa

Eq. (5-13): 

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**5-86** From Table A-5, for carbon steel, *Es* = 207 GPa, and *νs*= 0.292. While for *Eci*= 100 GPa, and *νci*= 0.211.For ASTM grade 20 cast iron, from Table A-24, *Sut* = 154 MPa.

For midrange values, *δ* = (50.8254 − 50.8051)/2 = 0.0102 mm.

Eq. (3-50):



At fit surface, with *pi = p =*18.02 MPa, and *po =* 0, from Eq. (3-50)



*σr* = −*p* = −18.02 MPa

From Modified-Mohr theory, Eq. (5-32a), since *σA*> 0 >*σB* and |*σB* /*σA*|<1,



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**5-87** *E* = 207 GPa

Eq. (3-57) can be written in terms of diameters,





**Outer member:**From Eq. (3-50),

Outer radius: 



Inner radius: 



Bending (no slipping): *I* = (*π* /64)(504− 404) = 181.1 (103) mm4

At  

At  

Torsion: *J =* 2*I* = 362.2 (103) mm4

At  

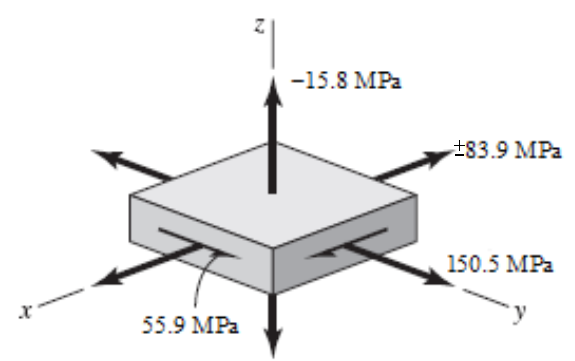
At  

Outer radius, is plane stress. Since the tangential stress is positive the von Mises stress will be a maximum with a negative bending stress. That is,



Eq. (5-15) 





Inner radius, 3D state of stress

From Eq. (5-14) with *τyz* = *τzx* = 0 and *σx* = + 83.9 MPa



With *σx* = − 83.9 MPa





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**5-88** From the solution of Prob. 5-87, *p* = 15.80 MPa

**Inner member:**From Eq. (3-50),

Outer radius: 



Inner radius: 



Bending (no slipping): *I* = (*π* /64)(504− 404) = 181.1 (103) mm4

At  

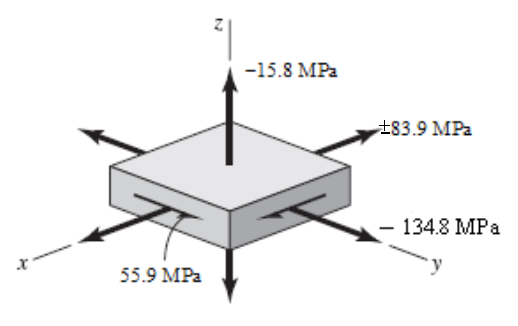
At  

Torsion: *J =* 2*I* = 362.2 (103) mm4

At  

At  

Outer radius,3D state of stress



From Eq. (5-14) with*τyz* = *τzx* = 0 and *σx* = + 83.9 MPa



With *σx* = − 83.9 MPa





Inner radius, plane stress. Worst case is when *σx* is positive



Eq. (5-15)





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**5-89** For AISI 1040 HR, from Table A-20,*Sy* = 290 MPa.

From Prob. 3-124,*p*max = 65.2 MPa. From Eq. (3-50) at the inner radius *R* of the outer member,





These are principal stresses. From Eq. (5-13)





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**5-90** For AISI 1040 HR, from Table A-20, *Sy* = 290 MPa.

From Prob. 3-125, *p*max = 62.05 MPa. From Eq. (3-50) at the inner radius *R* of the outer member,





These are principal stresses. From Eq. (5-13)





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**5-91** For AISI 1040 HR, from Table A-20, *Sy* = 290 MPa.

From Prob. 3-126, *p*max = 91.6 MPa. From Eq. (3-50) at the inner radius *R* of the outer member,





These are principal stresses. From Eq. (5-13)





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**5-92** For AISI 1040 HR, from Table A-20, *Sy* = 290 MPa.

From Prob. 3-127, *p*max = 89.22 MPa. From Eq. (3-50) at the inner radius *R* of the outer member,





These are principal stresses. From Eq. (5-13)





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**5-93** For AISI 1040 HR, from Table A-20, *Sy* = 290 MPa.

From Prob. 3-128, *p*max = 134 MPa. From Eq. (3-50) at the inner radius *R* of the outer member,





These are principal stresses. From Eq. (5-13)





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**5-94** For AISI 1040 HR, from Table A-20, *Sy* = 290 MPa.

From Prob. 3-129, *p*max = 131.90 MPa. From Eq. (3-50) at the inner radius *R* of the outer member,





These are principal stresses. From Eq. (5-13)





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**5-95**

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*Plane stress*: The third principal stress is zero and



*Plane strain*: Equations for *σ*1 and*σ*2 are still valid,. However,



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**5-96** For *θ* = 0 and plane strain, the principal stress equations of Prob. 5-95 give



(**a**) DE: Eq. (5-18) 

or, *σ*1− 2*νσ*1 = *Sy*



(**a**) MSS: Eq. (5-3) , with *n* =1 *σ*1−*σ*3 = *Sy*⇒*σ*1− 2*νσ*1 = *Sy*



Radius of largest circle



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**5-97** Given: *a* = 16 mm, *KIc* = 80 MPa⋅ and****

**(a)** Ignoring stress concentration

*F = SyA* =950(100−16)(12) = 958(103) N = 958kN*Ans*.

**(b)** From Fig. 5-26:*h/b* = 1, *a/b* = 16/100 = 0.16, *β* = 1.3

Eq. (5-37) 



*F* = 329.4(103) N = 329.4 kN*Ans*.

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**5-98** Given: *a* = 12.7 mm, *KIc* = 496.44 MPa⋅ and *Sy* = 170 MPa, *Sut* = 1323.84 MPa

*ro* = 355.6/50.8 = 177.8 mm, *ri* = (355.6 − 50.8)/2 = 152.4 mm



Fig. 5-30: *β* 2.4

Eq. (5-37): 

Eq. (3-50) at *r* = *ro* = 177.8 mm: 

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