MECHANICS OF MATERIALS

D

REVIEW FOR THE FUNDAMENTALS OF ENGINEERING EXAMINATION

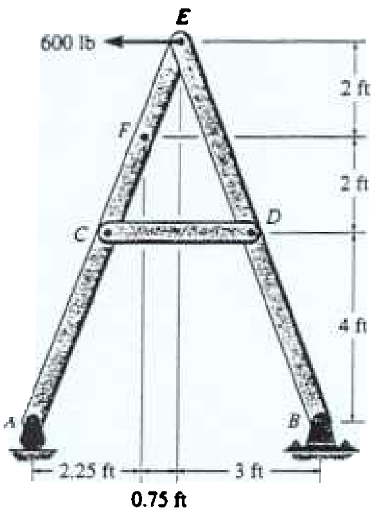
The Fundamentals of Engineering (FE) exam is given semiannually by the National Council of Engineering Examiners (NCEE), and is one of the requirements for obtaining a Professional Engineering License. A portion of this exam contains problems in mechanics of materials, and this appendix provides a review of the subject matter most often asked on this exam.

Before solving any of the problems, you should review the sections indicated in each chapter in order to become familiar with the boldfaced definitions and the procedures used to solve various types of problems. Also, review the example problems in these sections. The following problems are arranged in the same sequence as the topics in each chapter. Partial solutions to *all the problems* are given at the back of this appendix.

Reference: "Mechanics of Materials" by R. C. Hibbeler, 3rd Edition

Chapter 1—Review All Sections

D–1 Determine the resultant internal moment in the member of the frame at point *F*.

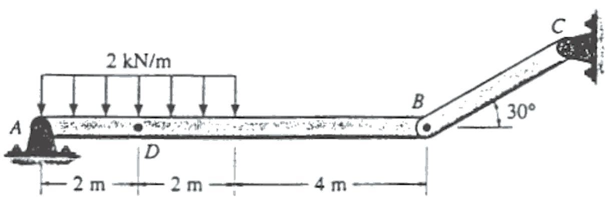


Prob. D–1

D–2 The beam is supported by a pin at *A* and a link *BC*. Determine the resultant internal shear in the beam at point *D*.

D–3 The beam is supported by a pin at *A* and a link *BC*. Determine the average shear stress in the pin at *B* if it has a diameter of 20 mm and is in double shear.

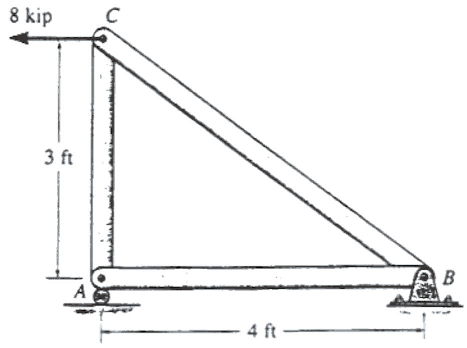
D–4 The beam is supported by a pin at *A* and a link *BC*. Determine the average shear stress in the pin at *A* if it has a diameter of 20 mm and is in single shear.



Probs. D–2/D–3/D–4

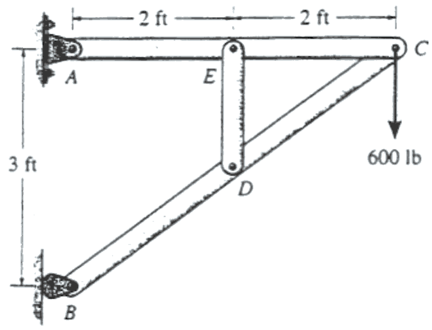
D–5 How many independent stress components are there in three dimensions?

D–6 The bars of the truss each have a cross-sectional area of 2 in.[2] Determine the average normal stress in member *CB*.



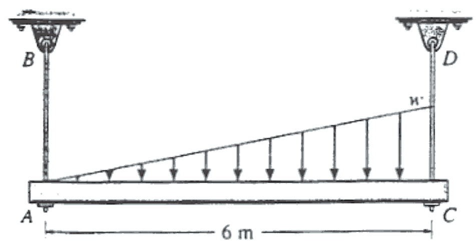
Prob. D–6

D–7 The frame supports the loading shown. The pin at *A* has a diameter of 0.25 in. If it is subjected to double shear, determine the average shear stress in the pin.



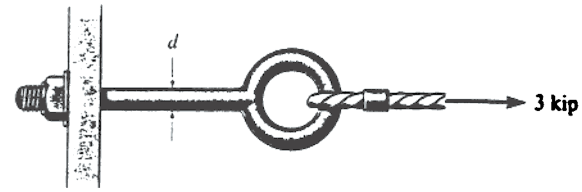
Prob. D–7

D–8 The uniform beam is supported by two rods *AB* and *CD* that have cross-sectional areas of 10 mm^2 and 15 mm^2, respectively. Determine the intensity *w* of the distributed load so that the average normal stress in each rod does not exceed 300 kPa.



Prob. D–8

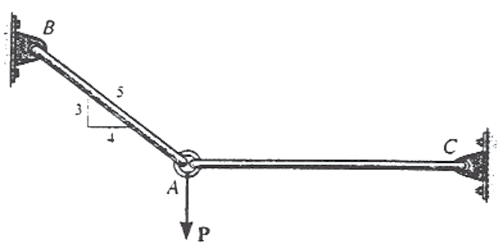
D–9 The bolt is used to support the load of 3 kip. Determine its diameter d to the nearest $\frac{1}{8}$ in. The allowable normal stress for the bolt is $\sigma_{\text{allow}} = 24$ ksi.



Prob. D–9

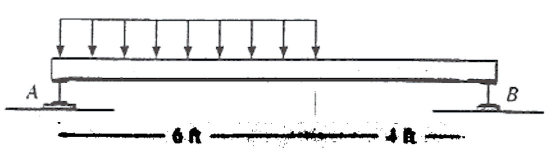
D–10 The two rods support the vertical force of $P = 30$ kN. Determine the diameter of rod AB if the allowable tensile stress for the material is $\sigma_{\text{allow}} = 150$ MPa.

D–11 The rods AB and AC have diameters of 15 mm and 12 mm, respectively. Determine the largest vertical force **P** that can be applied. The allowable tensile stress for the rods is $\sigma_{\text{allow}} = 150$ MPa.



Probs. D–10/D–11

D–12 The allowable bearing stress for the material under the supports A and B is $\sigma_{\text{allow}} = 500$ psi. Determine the maximum uniform distributed load w that can be applied to the beam. The bearing plates at A and B have square cross sections of 3 in. × 3 in. and 2 in. × 2 in., respectively.

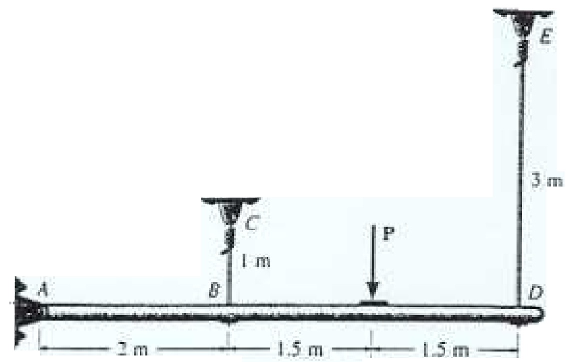


Prob. D–12

Chapter 2—Review All Sections

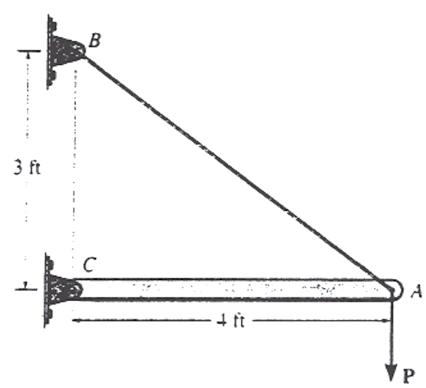
D–13 A rubber band has an unstretched length of 9 in. If it is stretched around a pole having a diameter of 3 in., determine the average normal strain in the band.

D–14 The rigid rod is supported by a pin at A and wires BC and DE. If the maximum allowable normal strain in each wire is $\epsilon_{\text{allow}} = 0.003$, determine the maximum vertical displacement of the load **P**.



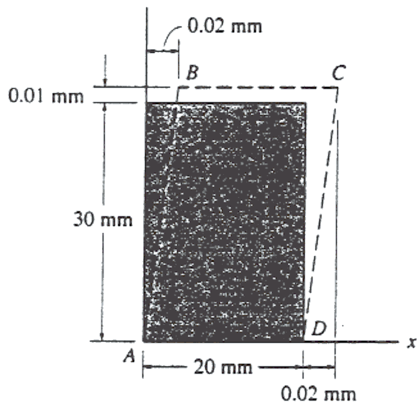
Prob. D–14

D–15 The load **P** causes a normal strain of 0.0045 in./in. in cable AB. Determine the angle of rotation of the rigid beam due to the loading if the beam is originally horizontal before it is loaded.



Prob. D–15

D-16 The square piece of material is deformed into the dashed position. Determine the shear strain at corner C.

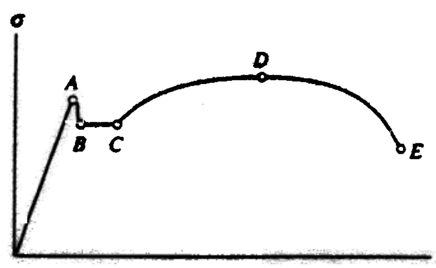


Prob. D-16

Chapter 3—Review Sections 3.1–3.7

D-17 Define homogeneous material.

D-18 Indicate the points on the stress–strain diagram which represent the proportional limit and the ultimate stress.



Prob. D-18

D-19 Define the modulus of elasticity E.

D-20 At room temperature, mild steel is a ductile material. True or false.

D-21 Engineering stress and strain are calculated using the *actual* cross-sectional area and length of the specimen. True or false.

D-22 If a rod is subjected to an axial load, there is only strain in the material in the direction of the load. True or false.

D-23 A 100-mm long rod has a diameter of 15 mm. If an axial tensile load of 100 kN is applied, determine its change in length. $E = 200$ GPa.

D-24 A bar has a length of 8 in. and cross-sectional area of 12 in^2. Determine the modulus of elasticity of the material if it is subjected to an axial tensile load of 10 kip and stretches 0.003 in. The material has linear-elastic behavior.

D-25 A 10-mm-diameter brass rod has a modulus of elasticity of $E = 100$ GPa. If it is 4 m long and subjected to an axial tensile load of 6 kN, determine its elongation.

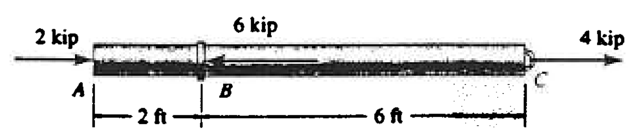
D-26 A 100-mm long rod has a diameter of 15 mm. If an axial tensile load of 10 kN is applied to it, determine its change in diameter. $E = 70$ GPa, $\nu = 0.35$.

Chapter 4—Review Sections 4.1–4.6

D-27 What is Saint-Venant's principle?

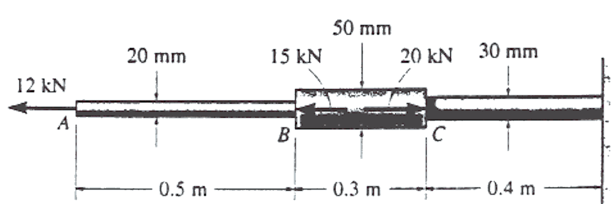
D-28 What are the two conditions for which the principle of superposition is valid?

D-29 Determine the displacement of end A with respect to end C of the shaft. The cross-sectional area is 0.5 in^2 and $E = 29(10^3)$ ksi.



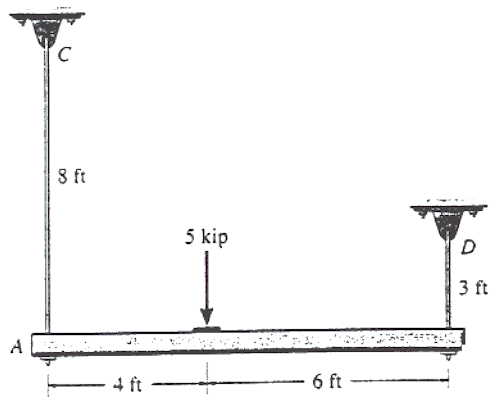
Prob. D-29

D-30 Determine the displacement of end A with respect to C of the shaft. The diameters of each segment are indicated in the figure. $E = 200$ GPa.



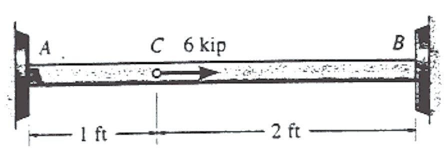
Prob. D-30

D-31 Determine the angle of tilt of the rigid beam when it is subjected to the load of 5 kip. Before the load is applied the beam is horizontal. Each rod has a diameter of 0.5 in., and $E = 29(10^3)$ ksi.



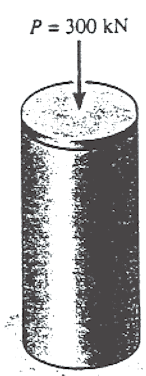
Prob. D-32

D-32 The uniform bar is subjected to the load of 6 kip. Determine the horizontal reactions at the supports A and B.



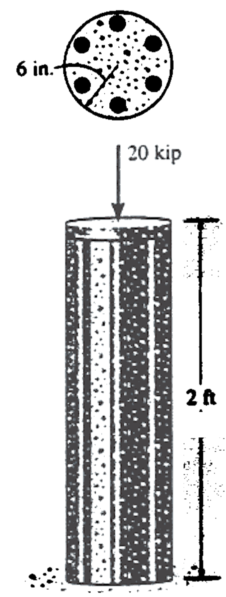
Prob. D-32

D-33 The cylinder is made from steel and has an aluminum core. If its ends are subjected to the axial force of 300 kN, determine the average normal stress in the steel. The cylinder has an outer diameter of 100 mm and an inner diameter of 80 mm. $E_{st} = 200$ GPa, $E_{al} = 73.1$ GPa.



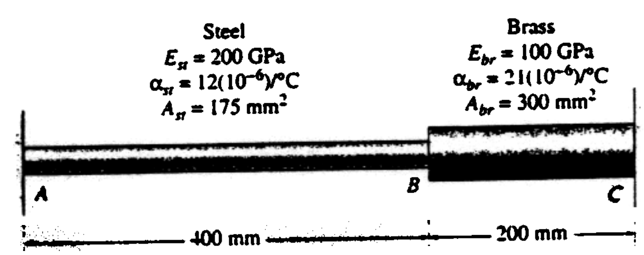
Prob. D-33

D-34 The column is constructed from concrete and six steel reinforcing rods. If it is subjected to an axial force of 20 kip, determine the force supported by the concrete. Each rod has a diameter of 0.75 in. $E_{conc} = 4.20(10^3)$ ksi, $E_{st} = 29(10^3)$ ksi.



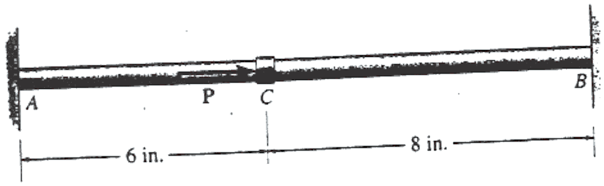
Prob. D-34

D-35 Two bars, each made of a different material, are connected and placed between two walls when the temperature is $T_1 = 15°C$. Determine the force exerted on the (rigid) supports when the temperature becomes $T_2 = 25°C$. The material properties and cross-sectional area of each bar are given in the figure.



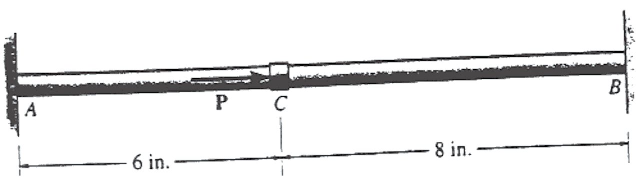
Prob. D-35

D-36 The aluminum rod has a diameter of 0.5 in. and is attached to the rigid supports at A and B when $T_1 = 80°F$. If the temperature becomes $T_2 = 100°F$, and an axial force of $P = 1200$ lb is applied to the rigid collar as shown, determine the reactions at A and B. $\alpha_{al} = 12.8(10^{-6})/°F$, $E_{al} = 10.6(10^6)$ psi.



Prob. D-36

D-37 The aluminum rod has a diameter of 0.5 in. and is attached to the rigid supports at A and B when $T_1 = 80°F$. Determine the force **P** that must be applied to the rigid collar so that, when $T_2 = 50°F$, the reaction at B is zero. $\alpha_{al} = 12.8(10^{-6})/°F$, $E_{al} = 10.6(10^3)$ ksi.

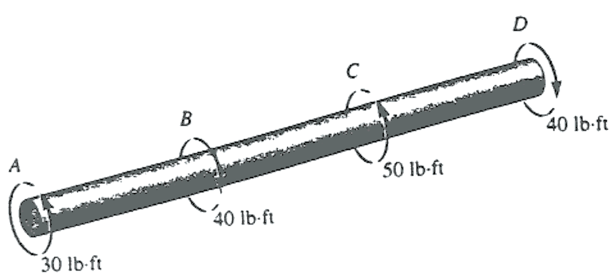


Prob. D-37

Chapter 5—Review Sections 5.1–5.5

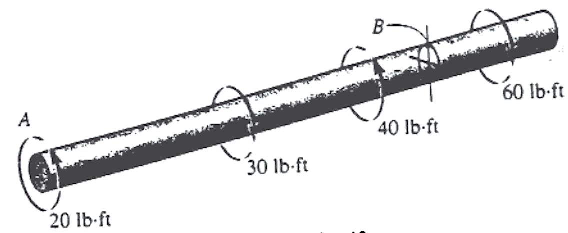
D-38 Can the torsion formula, $\tau = Tc/J$, be used if the cross section is noncircular?

D-39 The solid 0.75-in.-diameter shaft is used to transmit the torques shown. Determine the absolute maximum shear stress developed in the shaft.



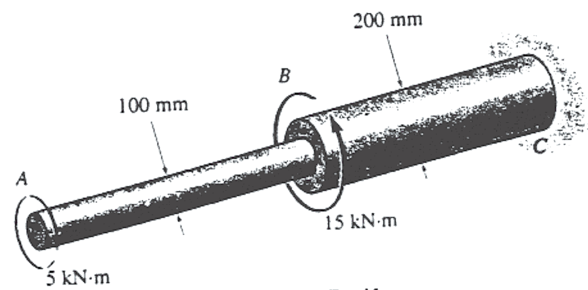
Prob. D-39

D-40 The solid 1.5-in.-diameter shaft is used to transmit the torques shown. Determine the shear stress developed in the shaft at point B.



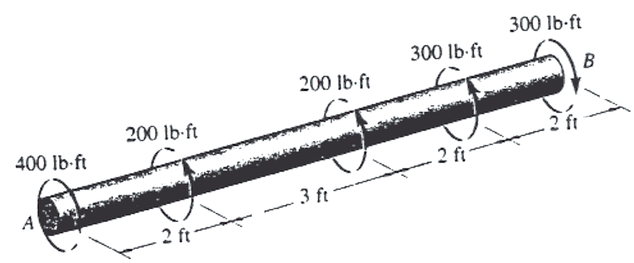
Prob. D-40

D-41 The solid shaft is used to transmit the torques shown. Determine the absolute maximum shear stress developed in the shaft.



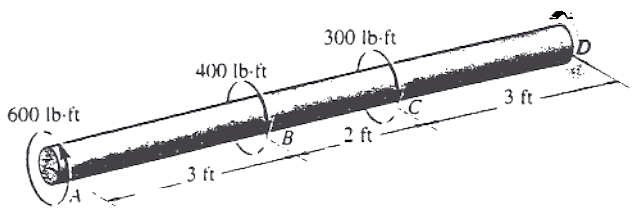
Prob. D-41

D-42 The shaft is subjected to the torques shown. Determine the angle of twist of end A with respect to end B. The shaft has a diameter of 1.5 in. $G = 11(10^3)$ ksi.



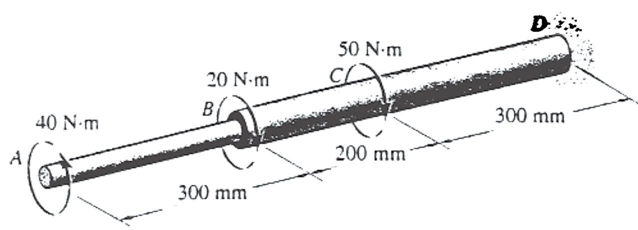
Prob. D-42

D–43 Determine the angle of twist of the 1-in.-diameter shaft at end A when it is subjected to the torsional loading shown. $G = 11(10^3)$ ksi.



Prob. D–43

D–44 The shaft consists of a solid section AB with a diameter of 30 mm, and a tube BD with an inner diameter of 25 mm and outer diameter of 50 mm. Determine the angle of twist at its end A when it is subjected to the torsional loading shown. $G = 75$ GPa.

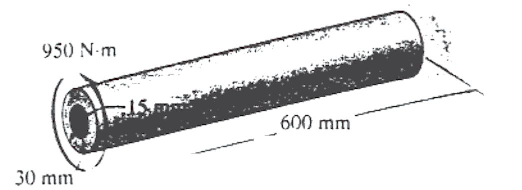


Prob. D–44

D–45 A motor delivers 200 hp to a steel shaft, which is tubular and has an outer diameter of 1.75 in. If it is rotating at 150 rad/s, determine its largest inner diameter to the nearest $\frac{1}{8}$ in. if the allowable shear stress for the material is $\tau_{allow} = 20$ ksi.

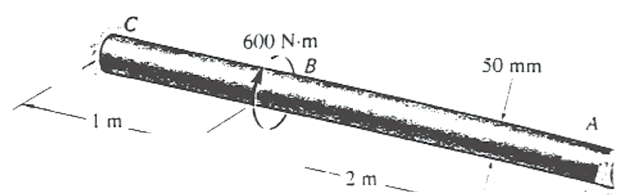
D–46 A motor delivers 300 hp to a steel shaft, which is tubular and has an outer diameter of 2.5 in. and an inner diameter of 2 in. Determine the smallest angular velocity at which it can rotate if the allowable shear stress for the material is $\tau_{allow} = 20$ ksi.

D–47 The shaft is made from a steel tube having a b core. If it is fixed to the rigid support, determine the a of twist that occurs at its end. $G_{st} = 75$ GPa and G 37 GPa.



Prob. D–47

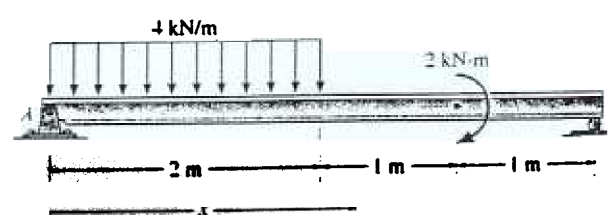
D–48 Determine the absolute maximum shear stress in shaft. JG is constant.



Prob. D–48

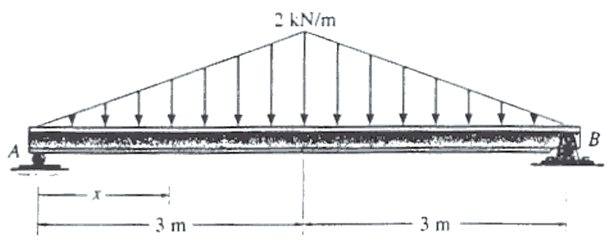
Chapter 6—Review Sections 6.1–6.5

D–49 Determine the internal moment in the beam as function of x, where 2 m $\leq x < 3$ m.



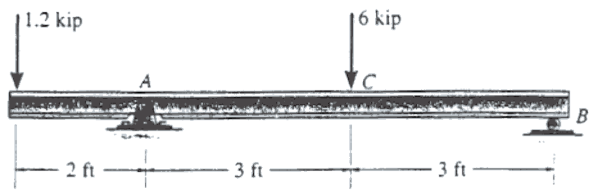
Prob. D–49

D–50 Determine the internal moment in the beam as a function of x, where $0 \leq x \leq 3$ m.



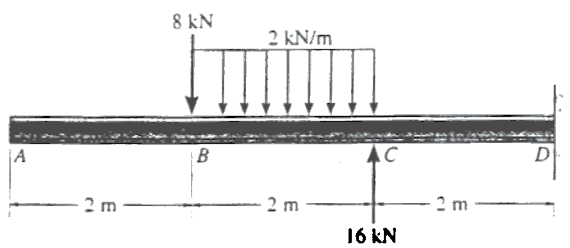
Prob. D–50

D–51 Determine the maximum moment in the beam.



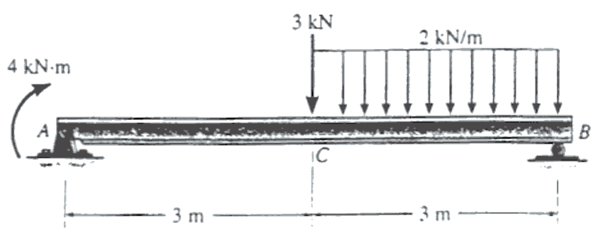
Prob. D–51

D–52 Determine the absolute maximum bending stress in the beam.



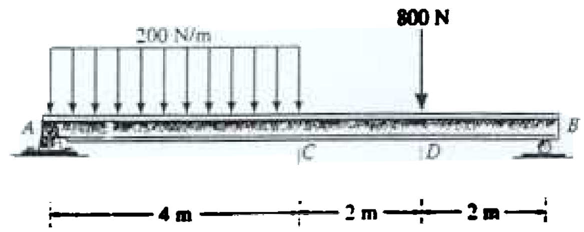
Prob. D–52

D–53 Determine the maximum moment in the beam.



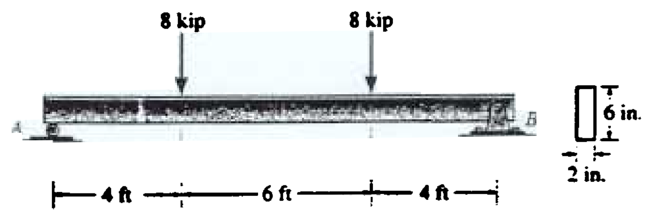
Prob. D–53

D–54 Determine the maximum moment in the beam



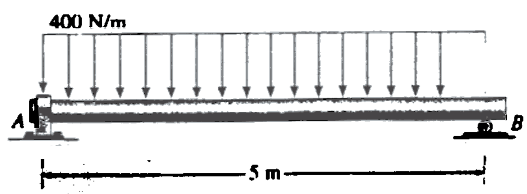
Prob. D–54

D–55 Determine the absolute maximum bending stress in the beam.



Prob. D–55

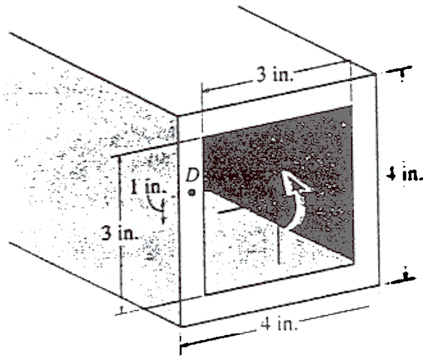
D–56 Determine the maximum bending stress in the 50-mm-diameter rod at C.



Prob. D–56

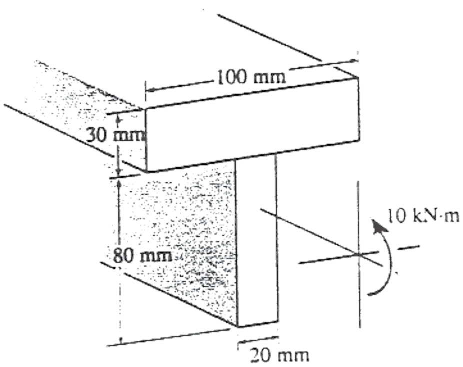
D–57 What is the strain in a beam at the neutral axis?

D-58 Determine the moment M that should be applied to the beam in order to create a compressive stress at point D of 10 ksi.



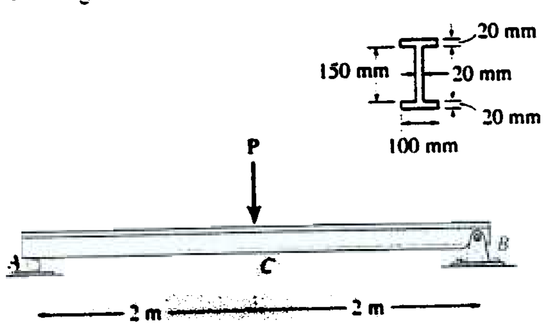
Prob. D-58

Determine the maximum bending stress in the beam.



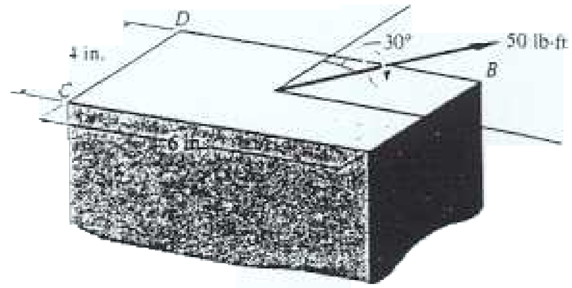
Prob. D-59

D-60 Determine the maximum load P that can be applied to the beam that is made from a material having an allowable bending stress of σ_{allow} = 12 MPa.



Prob. D-60

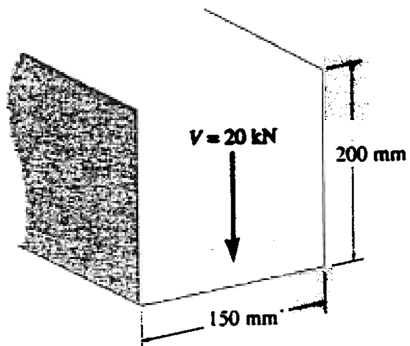
D-61 Determine the maximum stress in the beam's cross section.



Prob. D-61

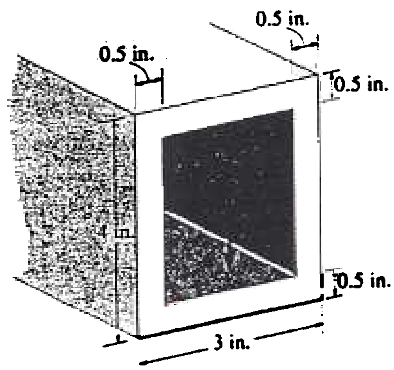
Chapter 7—Review Sections 7.1-7.4

D-62 Determine the maximum shear stress in the beam.



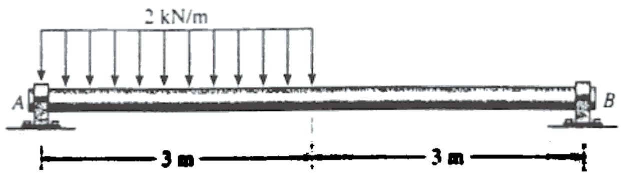
Prob. D-62

D-63 The beam has a rectangular cross section and is subjected to a shear of V = 2 kN. Determine the maximum shear stress in the beam.



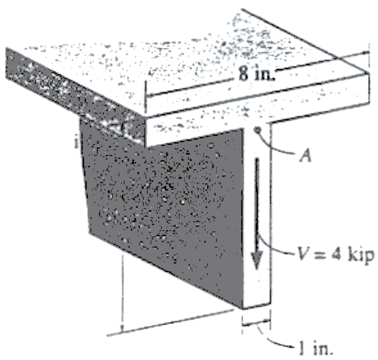
Prob. D-63

D–64 Determine the absolute maximum shear stress in the shaft having a diameter of 60 mm.



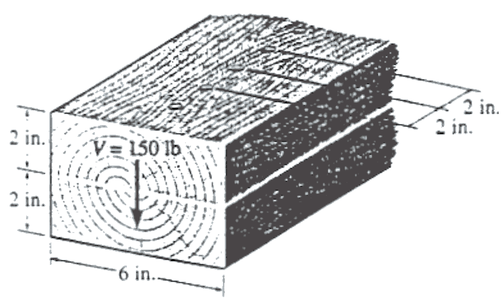
Prob. D–64

D–65 Determine the shear stress in the beam at point A which is located at the top of the web.



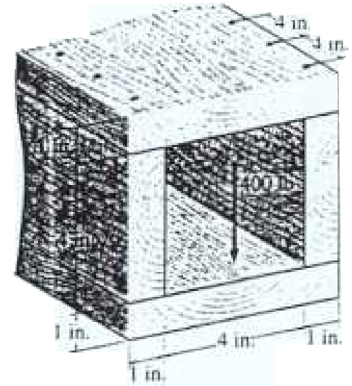
Prob. D–65

D–66 The beam is made from two boards fastened together at the top and bottom with nails spaced every 2 in. If an internal shear force of $V = 150$ lb is applied to the boards, determine the shear force resisted by each nail.



Prob. D–66

D–67 The beam is made from four boards fastened together at the top and bottom with two rows of nails spaced every 4 in. If an internal shear force of $V = 400$ lb is applied to the boards, determine the shear force resisted by each nail.



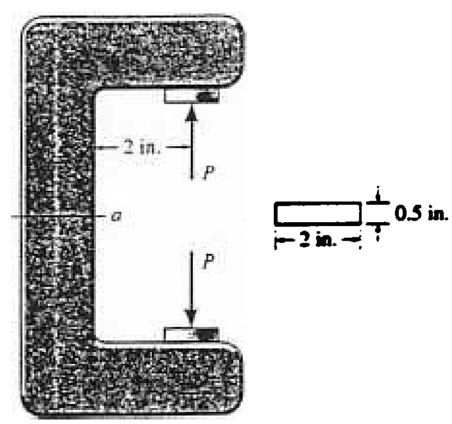
Prob. D–67

Chapter 8—Review All Sections

D–68 A cylindrical tank is subjected to an internal pressure of 80 psi. If the internal diameter of the tank is 30 in., and the wall thickness is 0.3 in., determine the maximum normal stress in the material.

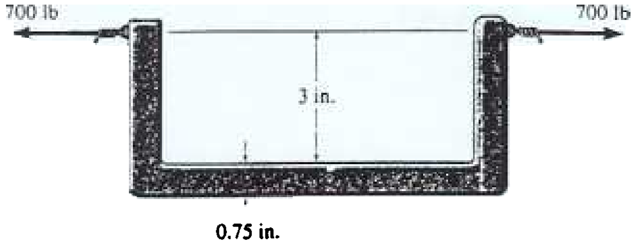
D–69 A pressurized spherical tank is to be made of 0.25-in.-thick steel. If it is subjected to an internal pressure of $p = 150$ psi, determine its inner diameter if the maximum normal stress is not to exceed 10 ksi.

D–70 Determine the magnitude of the load P that will cause a maximum normal stress of $\sigma_{max} = 30$ ksi in the link along section a-a.



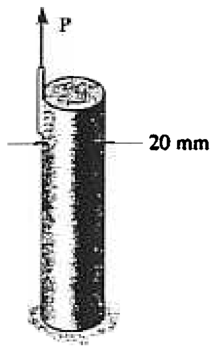
Prob. D–70

D–71 Determine the maximum normal stress in the horizontal portion of the bracket. The bracket has a thickness of 1 in. and a width of 0.75 in.



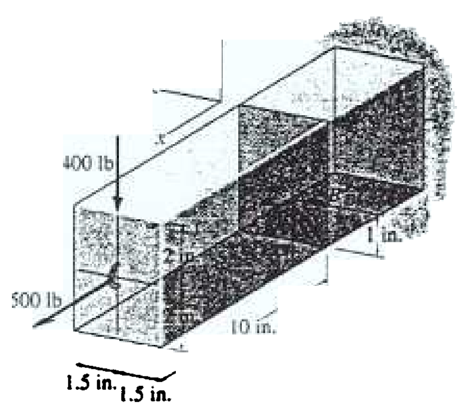
Prob. D–71

D–72 Determine the maximum load P that can be applied to the rod so that the normal stress in the rod does not exceed $\sigma_{max} = 30$ MPa.



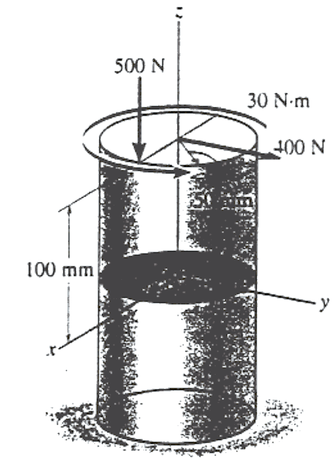
Prob. D–72

D–73 The beam has a rectangular cross section and is subjected to the loading shown. Determine the components of stress σ_x, σ_y and τ_{xy} at point B.



Prob. D–73

D–74 The solid cylinder is subjected to the loading shown. Determine the components of stress at point B.

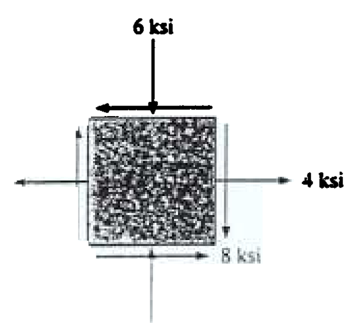


Prob. D–74

Chapter 9—Review Sections 9.1–9.3

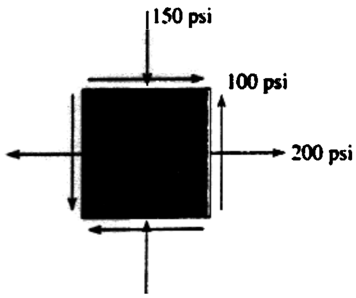
D–75 When the state of stress at a point is represented by the principal stress, no shear stress will act on the element. True or false.

D–76 The state of stress at a point is shown on the element. Determine the maximum principal stress.



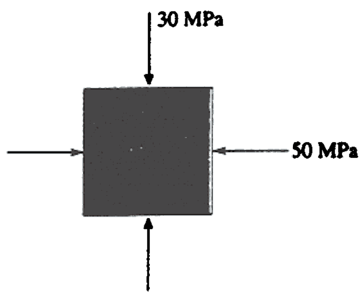
Prob. D–76

D-77 The state of stress at a point is shown on the element. Determine the maximum in-plane shear stress.



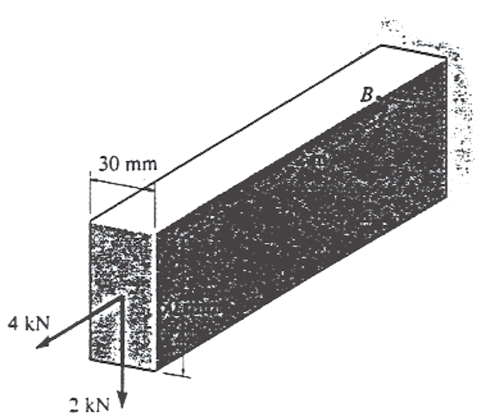
Prob. D-77

D-78 The state of stress at a point is shown on the element. Determine the maximum in-plane shear stress.



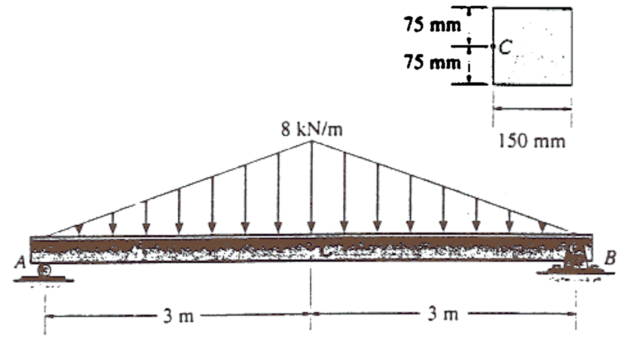
Prob. D-78

D-79 The beam is subjected to the load at its end. Determine the maximum principal stress at point *B*.



Prob. D-79

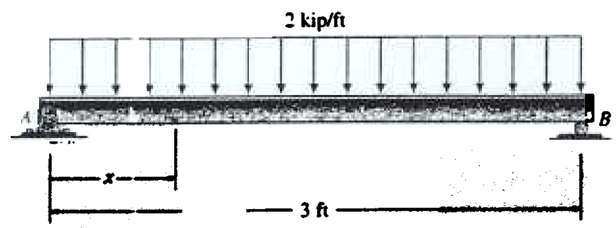
D-80 The beam is subjected to the loading shown. Determine the principal stress at point *C*.



Prob. D-80

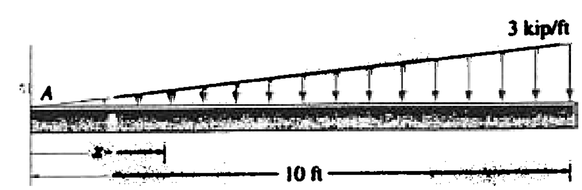
Chapter 12—Review Sections 12.1–12.2, 12.5

D-81 The beam is subjected to the loading shown. Determine the equation of the elastic curve. *EI* is constant.



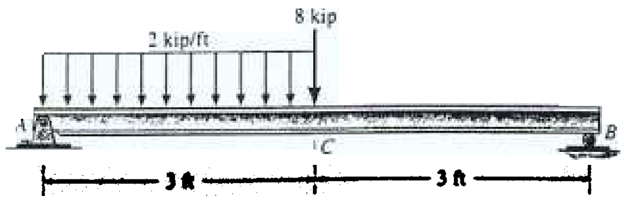
Prob. D-81

D-82 The beam is subjected to the loading shown. Determine the equation of the elastic curve. *EI* is constant.



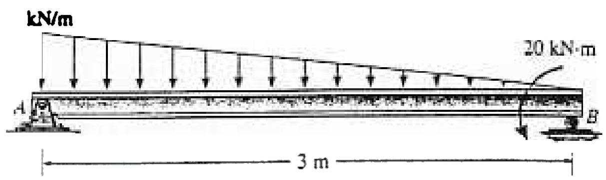
Prob. D-82

D–83 Determine the displacement at point C of the beam shown. Use the method of superposition. EI is constant.



Prob. D–83

D–84 Determine the slope at point A of the beam shown. Use the method of superposition. EI is constant.



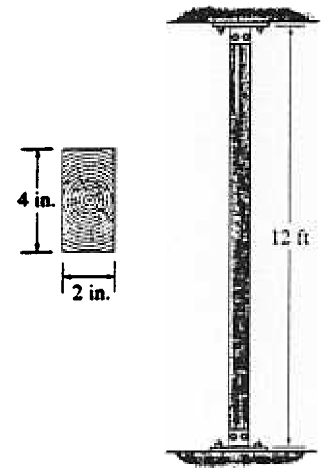
Prob. D–84

Chapter 13—Review Sections 13.1–13.3

D–85 The critical load is the maximum axial load that a column can support when it is on the verge of buckling. This loading represents a case of neutral equilibrium. True or false.

D–86 A 50-in.-long rod is made from a 1-in.-diameter steel rod. Determine the critical buckling load if the ends are fixed supported. $E = 29(10^3)$ ksi, $\sigma_Y = 36$ ksi.

D–87 A 12-ft wooden rectangular column has the dimensions shown. Determine the critical load if the ends are assumed to be pin-connected. $E = 1.6(10^3)$ ksi. Yielding does not occur.



Prob. D–87

D–88 A steel pipe is fixed-supported at its ends. If it is 5 m long and has an outer diameter of 50 mm and a thickness of 10 mm, determine the maximum axial load P that it can carry without buckling. $E_{st} = 200$ GPa, $\sigma_Y = 250$ MPa.

D–89 A steel pipe is pin-supported at its ends. If it is 6 ft long and has an outer diameter of 2 in., determine its smallest thickness so that it can support an axial load of $P = 40$ kip without buckling. $E_{st} = 29(10^3)$ ksi, $\sigma_Y = 36$ ksi.

D–90 Determine the smallest diameter of a solid 40-in.-long steel rod, to the nearest $\frac{1}{16}$ in., that will support an axial load of $P = 3$ kip without buckling. The ends are pin connected. $E_{st} = 29(10^3)$ ksi, $\sigma_Y = 36$ ksi.

Partial Solutions and Answers

D–1 Entire frame:
$\Sigma M_B = 0; A_y = 800$ lb
CD is a two-force member
Member AE:
$\Sigma M_E = 0; F_{CD} = 600$ lb
Segment ACF:
$\Sigma M_F = 0; M_F = 600$ lb · ft *Ans.*

D–2 BC is a two-force member.
Beam AB:
$\Sigma M_B = 0; A_y = 6$ kN
Segment AD:
$\Sigma F_y = 0; V = 2$ kN *Ans.*

D–3 BC is a two-force member.
Beam AB:
$\Sigma M_A = 0; T_{BC} = 4$ kN
Pin B:
$$\tau_B = \frac{T_{BC}/2}{A} = \frac{4/2}{\frac{\pi}{4}(0.02)^2} = 6.37 \text{ kPa}$$ *Ans.*

D–4 BC is a two-force member
Beam AB:
$\Sigma M_A = 0; T_{BC} = 4$ kN
$\Sigma F_x = 0; A_x = 3.464$ kN
$\Sigma F_y = 0; A_y = 6$ kN
$F_A = \sqrt{(3.464)^2 + (6)^2} = 6.928$ kN
$$\tau_A = \frac{F_A}{A} = \frac{6.928}{\frac{\pi}{4}(0.02)^2} = 22.1 \text{ kPa}$$ *Ans.*

D–5 6: $\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{yz}, \tau_{zx}$ *Ans.*

D–6 Joint C:
$\overset{+}{\rightarrow}\Sigma F_x = 0; T_{CB} = 10$ kip
$$\sigma = \frac{T_{CB}}{A} = \frac{10}{2} = 5 \text{ ksi}$$ *Ans.*

D–7 Entire frame
$\Sigma F_y = 0; A_y = 600$ lb
$\Sigma M_B = 0; A_x = 800$ lb
$F_A = \sqrt{(600)^2 + (800)^2} = 1000$ lb
$$\tau_A = \frac{F_A/2}{A} = \frac{1000/2}{\frac{\pi}{4}(0.25)^2} = 10.2 \text{ ksi}$$ *Ans.*

D–8 Beam:
$\Sigma M_A = 0; T_{CD} = 2w$
$\Sigma F_y = 0; T_{AB} = w$
Rod AB:
$$\sigma = \frac{P}{A};\ 300(10^3) = \frac{w}{10};\ w = 3 \text{ MN/m}$$
Rod CD:
$$\sigma = \frac{P}{A};\ 300(10^3) = \frac{2w}{15};\ w = 2.25 \text{ MN/m}$$

D–9 $\sigma = \dfrac{P}{A};\ 24 = \dfrac{3}{\frac{\pi}{4}d^2};\ d = 0.3989$ in.
use $d = 0.5$ in.

D–10 Joint A:
$\Sigma F_y = 0; F_{AB} = 50$ kN
$$\sigma = \frac{P}{A};\ 150(10^6) = \frac{50(10^3)}{\frac{\pi}{4}d^2};\ d = 20.6 \text{ mm}$$

D–11 Joint A:
$\Sigma F_y = 0; F_{AB} = 1.667P$
$\Sigma F_x = 0; F_{AC} = 1.333\,P$
Rod AB:
$$\sigma = \frac{P}{A};\ 150(10^6) = \frac{1.667\,P}{\frac{\pi}{4}(0.015)^2};\ P = 15.9 \text{ kN}$$
Rod AC:
$$\sigma = \frac{P}{A};\ 150(10^6) = \frac{1.333\,P}{\frac{\pi}{4}(0.012)^2};\ P = 12.7 \text{ kN}$$ *Ans.*

D–12 Beam:
$\Sigma M_A = 0; B_y = 1.8\,w$
$\Sigma F_y = 0; A_y = 4.2\,w$
At A:
$$\sigma = \frac{P}{A};\ 500 = \frac{4.2\,w}{(3)(3)};\ w = 1.07 \text{ kip/ft}$$ *Ans.*
At B:
$$\sigma = \frac{P}{A};\ 500 = \frac{1.8\,w}{(2)(2)};\ w = 1.11 \text{ kip/ft}$$

D–13 $$\epsilon = \frac{l - l_0}{l_0} = \frac{\pi(3) - 9}{9} = 0.0472 \text{ in./in.}$$ *Ans.*

D–14 $(\delta_{DE})_{max} = \epsilon_{max}\, l_{DE} = 0.003(3) = 0.009$ m
By proportion from A,
$\delta_{BC} = 0.009\left(\frac{2}{5}\right) = 0.0036$ m
$(\delta_{BC})_{max} = \epsilon_{max}\, l_{BC} = 0.003(1) = 0.003 \text{ m} < 0.0036$ m
Use $\delta_{BC} = 0.003$ m. By proportion from A,
$$\delta_P = 0.003\left(\frac{3.5}{2}\right) = 0.00525 \text{ m} = 5.25 \text{ mm}$$ *Ans.*

D–15 $l_{AB} = \sqrt{(4)^2 + (3)^2} = 5$ ft
$l'_{AB} = 5 + 5(0.0045) = 5.0225$ ft
The angle BCA was originally $\theta = 90°$. Using the cosine law, the new angle BCA (θ') is
$5.0225 = \sqrt{(3)^2 + (4)^2 - 2(3)(4)\cos\theta}$
$\theta = 90.538°$
Thus
$\Delta\theta' = 90.538° - 90° = 0.538°$ *Ans.*

D–16 $\angle BCD = \angle BAD = \tan^{-1}\dfrac{30.01}{0.02} = 89.962°$

$\gamma_{xy} = (90° - 89.962°)\dfrac{\pi}{180°} = 0.666(10^{-3})$ rad *Ans.*

D–17 Material has uniform properties throughout. *Ans.*

D–18 Proportional limit is A. *Ans.*
Ultimate stress is D. *Ans.*

D–19 The initial slope of the $\sigma - \epsilon$ diagram. *Ans.*

D–20 True *Ans.*

D–21 False. Use the *original* cross-sectional area and length. *Ans.*

D–22 False. There is also strain in the perpendicular direction due to the Poisson effect. *Ans.*

D–23 $\epsilon = \dfrac{\sigma}{E} = \epsilon\dfrac{P}{AE}$

$$\delta = \epsilon L = \frac{PL}{AE} = \frac{100(10^3)(0.100)}{\frac{\pi}{4}(0.015)^2\,200(10^9)} = 0.283 \text{ mm}$$ *Ans.*

D–24 $\epsilon = \dfrac{\sigma}{E} = \dfrac{P}{AE}$

$$\delta = \epsilon L = \frac{PL}{AE};\ 0.003 = \frac{(10000)(8)}{2\,E}$$
$E = 2.22(10^6)$ psi *Ans.*

D–25 $\epsilon = \dfrac{\sigma}{E} = \dfrac{P}{AE}$

$$\delta = \epsilon L = \frac{PL}{AE} = \frac{6(10^3)\,4}{\frac{\pi}{4}(0.01)^2\,100(10^9)} = 3.06 \text{ mm}$$ *Ans.*

D–26 $\sigma = \dfrac{P}{A} = \dfrac{10(10^3)}{\frac{\pi}{4}(0.015)^2} = 56.59$ MPa

$$\epsilon_{long} = \frac{\sigma}{E} = \frac{56.59(10^6)}{70(10^9)} = 0.808(10^{-3})$$
$$\epsilon_{lat} = -\nu\epsilon_{long} = -0.35(0.808(10^{-3})) = -0.283(10^{-3})$$ *Ans.*

D–27 Stress distributions tend to smooth out on sections further removed from the load. *Ans.*

D–28 1.) Linear-elastic material.
2.) No large deformations. *Ans.*

D–29 $$\delta_{A/C} = \sum\frac{PL}{AE} = \frac{-2(2)(12)}{0.5(29(10^3))} + \frac{4(6)(12)}{0.5(29(10^3))}$$
$= 0.0166$ in. *Ans.*

D–30 $$\delta_{A/C} = \sum\frac{PL}{AE} = \frac{12(10^3)(0.5)}{\frac{\pi}{4}(0.02)^2\,200(10^9)} + \frac{27(10^3)(0.3)}{\frac{\pi}{4}(0.05)^2\,200(10^9)} = 0.116 \text{ mm}$$ *Ans.*

D–31 Beam AB:
$\Sigma M_A = 0;\ F_{BD} = 2$ kip
$\Sigma F_y = 0;\ F_{AC} = 3$ kip
$$\delta_A = \frac{PL}{AE} = \frac{3(8)(12)}{\frac{\pi}{4}(0.5)^2\,29(10^3)} = 0.0506 \text{ in.}$$
$$\delta_B = \frac{PL}{AE} = \frac{2(3)(12)}{\frac{\pi}{4}(0.5)^2\,29(10^3)} = 0.01264 \text{ in.}$$
$$\theta = \frac{\Delta\delta}{l_{AB}} = \frac{\delta_A - \delta_B}{l_{AB}} = \frac{0.0506 - 0.01264}{10(12)}$$
$= 0.000315$ rad $= 0.0181°$ *Ans.*

D–32 Equilibrium:
$F_A + F_B = 6$
Compatibility:
$$\delta_{C/A} = \delta_{C/B};\ \frac{F_A\,(1)}{AE} = \frac{F_B\,(2)}{AE}$$
$F_A = 4$ kip, $F_B = 2$ kip *Ans.*

D–33 Equilibrium:
$P_{st} + P_{al} = 300\,(10^3)$
Compatibility:
$$\delta_{st} = \delta_{al};\ \frac{P_{st}\,L}{[\frac{\pi}{4}(0.1)^2 - \frac{\pi}{4}(0.08)^2]\,200(10^9)} = \frac{P_{al}\,L}{[\frac{\pi}{4}(0.08)^2]\,73.1\,(10^9)}$$

$P_{st} = 181.8$ kN
$P_{al} = 118$ kN
$$\sigma_{st} = \frac{P_{st}}{A} = \frac{181.8}{[\frac{\pi}{4}(0.1)^2 - \frac{\pi}{4}(0.08)^2]} = 64.3 \text{ MPa}$$ *Ans.*

D–34 Equilibrium:

$P_{conc} + P_{st} = 20$

Compatibility:

$$\delta_{conc} = \delta_{st};\ \frac{P_{conc}(2)}{[\pi(6)^2 - 6(\frac{\pi}{4})(0.75)^2]\,4.20(10^3)}$$

$$= \frac{P_{st}(2)}{6(\frac{\pi}{4})(0.75)^2\,29(10^3)}$$

$P_{conc} = 17.2$ kip *Ans.*

$P_{st} = 2.84$ kip

D–35 $\delta_{temp} = \Sigma\alpha\Delta TL$

$\delta_{load} = \Sigma\frac{PL}{AE}$

Compatibility: $\delta_{temp} + \delta_{load} = 0$

$$12(10^{-6})(25-15)(0.4) + 21(10^{-6})(25-15)(0.2)$$

$$\frac{-F(0.4)}{175(10^{-6})(200(10^9))} - \frac{F(0.2)}{300(10^{-6})(100(10^9))} = 0$$

$F = 4.97$ kN *Ans.*

D–36 Equilibrium:

$F_A + F_B = 1200$

Compatibility

Remove support at B. Require

$\delta_B = (\delta_{B/A})_{temp} + (\delta_{B/A})_{load} = 0$

$$\alpha\Delta TL + \sum\frac{PL}{AE} = 0$$

$$12.8(10^{-6})(100-80)(14) +$$

$$\frac{1200(6)}{\frac{\pi}{4}(0.5)^2\,10.6(10^6)} - \frac{F_B(14)}{\frac{\pi}{4}(0.5)^2\,10.6(10^6)} = 0$$

$F_B = 1.05$ kip *Ans.*

$F_A = 153$ lb *Ans.*

D–37 Equilibrium:

$F_A + F_B = P$

Since $F_B = 0$, $F_A = P$

Compatibility

Remove support at B. Require

$\delta_B = (\delta_{B/A})_{temp} + (\delta_{B/A})_{load} = 0$

$$\alpha\Delta TL + \frac{PL}{AE} = 0$$

$$12.8(10^{-6})(50-80)(14) + \frac{P(6)}{\frac{\pi}{4}(0.5)^2\,10.6(10^6)} = 0$$

$P = 1.86$ kip *Ans.*

D–38 No, it is only valid for circular cross sections. Noncircular cross sections will warp. *Ans.*

D–39 $T_{max} = T_{CD} = 40$ lb · ft

$$\tau_{max} = \frac{Tc}{J} = \frac{40(12)(0.375)}{\frac{\pi}{2}(0.375)^4} = 5.79 \text{ ksi}$$

D–40 Equilibrium of segment AB:

$T_B = 30$ lb · ft

$$T_B = \frac{Tc}{J} = \frac{30(12)(0.75)}{\frac{\pi}{2}(0.75)^4} = 543 \text{ psi}$$ *Ans.*

D–41 Segment AB:

$$\tau_{max} = \frac{Tc}{J} = \frac{5(10^3)(0.05)}{\frac{\pi}{2}(0.05)^4} = 25.5 \text{ MPa}$$

Segment BC:

$$\tau_{max} = \frac{Tc}{J} = \frac{10(10^3)(0.1)}{\frac{\pi}{2}(0.1)^4} = 6.37 \text{ MPa}$$

D–42 $$\phi_{A/B} = \sum\frac{TL}{JG} = \frac{-400(12)(2)(12)}{\frac{\pi}{2}(0.75)^4\,11(10^6)}$$

$$-\frac{200(12)(3)(12)}{\frac{\pi}{2}(0.75)^4\,11(10^6)} + 0 + \frac{300(12)(2)(12)}{\frac{\pi}{2}(0.75)^4\,11(10^6)}$$

$= -0.0211$ rad $= 0.0211$ rad clockwise when viewed from A. *Ans.*

D–43 $$\phi_A = \sum\frac{TL}{JG} = \frac{600(12)(3)(12)}{\frac{\pi}{2}(0.5)^4 11(10^6)}$$

$$+\frac{200(12)(2)(12)}{\frac{\pi}{2}(0.5)^4\,11(10^6)} - \frac{100(12)(3)(12)}{\frac{\pi}{2}(0.5)^4\,11(10^6)}$$

$= 0.253$ rad counterclockwise when viewed from A. *Ans.*

D–44 $$\phi_A = \sum\frac{TL}{JG} = \frac{40(0.3)}{\frac{\pi}{2}(0.015)^4\,75(10^9)}$$

$$+\frac{20(0.2)}{\frac{\pi}{2}[(0.025)^4 - (0.0125)^4]\,75(10^9)}$$

$$-\frac{30(0.3)}{\frac{\pi}{2}[(0.025)^4 - (0.0125)^4]\,75(10^9)}$$

$= -0.209\,(10^{-3})$ rad $= 0.209\,(10^{-3})$ rad clockwise when viewed from A. *Ans.*

D–45 $P = 200 \text{ hp}\left(\dfrac{550 \text{ ft}\cdot\text{lb/s}}{1 \text{ hp}}\right) = 110\,000 \text{ ft}\cdot\text{lb/s}$

$$T = \frac{P}{\omega} = \frac{110\,000}{150} = 733.33 \text{ lb}\cdot\text{ft}$$

$$\tau_{allow} = \frac{Tc}{J};\ 20(10^3) = \frac{733.33(0.875)}{\frac{\pi}{2}[(0.875)^4 - r_i^4]}$$

$r_i = 0.867$ in.

$d_i = 1.73$ in. use $d_i = 1.625$ in. $= 1\frac{5}{8}$ in. *Ans.*

D–46 $P = 300 \text{ hp}\left(\dfrac{550 \text{ ft}\cdot\text{lb/s}}{1 \text{ hp}}\right) = 165\,000 \text{ ft}\cdot\text{lb/s}$

$$T = \frac{P}{\omega} = \frac{165\,000}{\omega}$$

$$\tau_{max} = \frac{Tc}{J};\ 20(10^3) = \frac{\frac{165\,000}{\omega}(12)(1.25)}{\frac{\pi}{2}[(1.25)^4 - (1)^4]}$$

$\omega = 54.7$ rad/s *Ans.*

D–47 Equilibrium:

$T_{st} + T_{br} = 950$

Compatibility: $\phi_{st} = \phi_{br}$;

$$\frac{T_{st}(0.6)}{\frac{\pi}{2}[(0.03)^4 - (0.015)^4]\,75(10^9)} = \frac{T_{br}(0.6)}{\frac{\pi}{2}(0.015)^4\,37(10^9)}$$

$T_{br} = 30.25 \text{ N}\cdot\text{m}$

$T_{st} = 919.8 \text{ N}\cdot\text{m}$

$$\phi = \phi_{br} = \frac{30.25(0.6)}{\frac{\pi}{2}(0.015)^4\,37(10^9)} = 0.00617 \text{ rad}$$ *Ans.*

D–48 Equilibrium:

$T_A + T_C = 600$

Compatibility:

$$\delta_{B/C} = \delta_{B/A};\ \frac{T_C(1)}{JG} = \frac{T_A(2)}{JG}$$

$T_A = 200 \text{ N}\cdot\text{m}$

$T_C = 400 \text{ N}\cdot\text{m}$

$$\tau_{max} = \frac{Tc}{J} = \frac{400(0.025)}{\frac{\pi}{2}(0.025)^4} = 16.3 \text{ MPa}$$ *Ans.*

D–49 $A_y = 5.5$ kN

Use section of length x.

$\circlearrowleft + \Sigma M = 0;\ -5.5x + 4(2)(x-1) + M = 0$

$M = 8 - 2.5x$ *Ans.*

D–50 $A_y = 3$ kN

Use section of length x.

Intensity of $w = \frac{2}{3}x$ at x.

$$\circlearrowleft + \Sigma M = 0;\ -3x + \left(\frac{1}{3}x\right)\left[\frac{1}{2}(x)\left(\frac{2}{3}x\right)\right] + M = 0$$

$$M = 3x - \frac{x^3}{9}$$ *Ans.*

D–51 $B_y = 2.6$ kip

$A_y = 4.6$ kip

Draw M-diagram

$M_{max} = 7.80 \text{ k}\cdot\text{ft}$ (at C) *Ans.*

D–52 Draw M-diagram

$M_{max} = 20 \text{ kN}\cdot\text{m}$ (at C) *Ans.*

D–53 $A_y = 2.33$ kN

$B_y = 6.617$ kN

Draw M-diagram

$M_{max} = 11 \text{ kN}\cdot\text{m}$ (at C) *Ans.*

D–54 $A_y = B_y = 800$ N

Draw M-diagram

$M_{max} = 1600 \text{ N}\cdot\text{m}$ (within CD) *Ans.*

D–55 $A_y = B_y = 8$ kip

$M_{max} = 8(4) = 32 \text{ kip}\cdot\text{ft}$

$$\sigma = \frac{Mc}{I} = \frac{32(12)(3)}{\frac{1}{12}(2)(6)^3} = 32 \text{ ksi}$$ *Ans.*

D–56 $A_y = B_y = 1000$ N

$M_{max} = 1250 \text{ N}\cdot\text{m}$

$$\sigma_{max} = \frac{Mc}{I} = \frac{1250(0.025)}{\frac{\pi}{4}(0.025)^4} = 50.9 \text{ MPa}$$ *Ans.*

D–57 $\epsilon = 0$ *Ans.*

D–58 $$\sigma = \frac{My}{I};\ 10(10^3) = \frac{M(1)}{[\frac{1}{12}(4)(4)^3 - \frac{1}{12}(3)(3)^3]}$$

$M = 145.8 \text{ kip}\cdot\text{in.} = 12.2 \text{ kip}\cdot\text{ft}$ *Ans.*

–59 From bottom of cross section

$$\bar{y} = \frac{\Sigma \tilde{y} A}{\Sigma A} = \frac{40(80)(20) + 95(30)(100)}{80(20) + 30(100)} = 75.870 \text{ mm}$$

$$I = \frac{1}{12}(20)(80)^3 + 20(80)(75.870 - 40)^2$$

$$+ \frac{1}{12}(100)(30)^3 + 100(30)(95 - 75.870)^2 = 4.235(10^{-6}) \text{ m}$$

$$\sigma_{\max} = \frac{Mc}{I} = \frac{10(10^3)(0.075870)}{4.235\,(10^{-6})} = 179 \text{ MPa} \qquad \textit{Ans.}$$

–60 $A_y = P/2$

$M_{\max} = P/2\,(2) = P$ (at C)

$$I = \frac{1}{12}(0.02)(0.150)^3 + 2\left[\frac{1}{12}(0.1)(0.02)^3 + (0.1)(0.02)(0.085)^2\right]$$

$$= 34.66\,(10^{-6}) \text{ m}^4$$

$$\sigma = \frac{Mc}{I};\ 12\,(10^6) = \frac{P\,(0.095)}{34.66\,(10^{-6})}$$

$P = 4.38$ kN *Ans.*

–61 Maximum stress occurs at D or A.

$$(\sigma_{\max})_D = \frac{(50 \cos 30^\circ)\, 12\,(3)}{\frac{1}{12}(4)\,(6)^3} + \frac{(50 \sin 30^\circ)\, 12\,(2)}{\frac{1}{12}(6)(4)^3} = 40.4 \text{ psi} \qquad \textit{Ans.}$$

–62 Q is upper or lower half of cross section.

$$\tau_{\max} = \frac{VQ}{It} = \frac{20(10^3)\,[(0.05)(0.1)(0.15)]}{[\frac{1}{12}(0.150)(0.2)^3](0.15)} = 1 \text{ MPa}$$

Ans.

D–63 $I = \frac{1}{12}(3)(4)^3 - \frac{1}{12}(2)(3)^3 = 11.5 \text{ in}^4$

Q is upper or lower half of cross section.

$Q = (1)\,(2)\,(3) - (0.75)\,(1.5)\,(2) = 3.75 \text{ in}^3$

$$\tau_{\max} = \frac{VQ}{It} = \frac{2(3.75)}{11.5\,(1)} = 0.652 \text{ ksi} \qquad \textit{Ans.}$$

D–64 $A_y = 4.5$ kN, $B_y = 1.5$ kN

$V_{\max} = 4.5$ kN (at A)

Q is upper half of cross section.

$$\tau_{\max} = \frac{VQ}{It} = \frac{4.5(10^3)\,[(\frac{4(0.03)}{3\pi})\,\frac{1}{2}\,\pi\,(0.03)^2]}{[\frac{1}{4}\,\pi\,(0.03)^4]\,(0.06)}$$

$= 2.12$MPa *Ans*

D–65 From the bottom:

$$\bar{y} = \frac{\Sigma \tilde{y} A}{\Sigma A} = \frac{3(6)(1) + 6.5(1)(8)}{6(1) + 1(8)} = 5 \text{ in.}$$

$$I = \frac{1}{12}(1)(6)^3 + 6(1)(5 - 3)^2 + \frac{1}{12}(8)(1)^3 +$$

$$8(1)\,(6.5 - 5)^2 = 84.667 \text{ in}^4$$

$$\tau = \frac{VQ}{It} = \frac{4(10^3)[8\,(1)(6.5 - 5)]}{84.667\,(1)} = 567 \text{ psi} \qquad \textit{Ans}$$

D–66 $I = \frac{1}{12}(6)(4)^3 = 32 \text{ in}^4$

$$q = \frac{VQ}{I} = \frac{150[(1)(6)(2)]}{32} = 56.25 \text{ lb/in.}$$

$F = qs = (56.25 \text{ lb/in.})\,(2 \text{ in.}) = 112.5$ lb

D–67 $I = \frac{1}{12}(6)(6)^3 - \frac{1}{12}(4)(4)^3 = 86.67 \text{ in}^4$

$$q = \frac{VQ}{I} = \frac{400(2.5)(6)(1)}{86.67} = 69.23 \text{ lb/in.}$$

For one nail

$q = 69.23/2 = 34.62$ lb/in.

$F = qs = 34.62$ lb/in. $(4$ in.$) = 138$ lb *Ans.*

D–68 $\sigma = \frac{pr}{t} = \frac{80(15)}{0.3} = 4000 \text{ psi} = 4 \text{ ksi}$ *Ans.*

D–69 $\sigma = \frac{pr}{2t};\ 10\,(10^3) = \frac{150\,r}{2\,(0.25)}$

$r = 33.3$ in.

$d = 66.7$ in. *Ans.*

D–70 At the section through centroidal axis

$N = P$

$V = 0$

$M = (2 + 1)P = 3P$

$$\sigma = \frac{P}{A} + \frac{Mc}{I}$$

$$30 = \frac{P}{2(0.5)} + \frac{(3P)(1)}{\frac{1}{12}(0.5)(2)^3}$$

$P = 3$ kip *Ans.*

D–71 At a section through the center of bracket on centroidal axis.

$N = 700$ lb

$V = 0$

$M = 700(3 + 0.375) = 2362.5 \text{ lb} \cdot \text{in.}$

$$\sigma = \frac{P}{A} + \frac{Mc}{I} = \frac{700}{0.75(1)} + \frac{2362.5(0.375)}{[\frac{1}{12}(1)(0.75)^3]}$$

$= 26.1$ ksi *Ans.*

D–72 At a cross section

$N = P, M = P\,(0.01)$

$$\sigma_{\max} = \frac{P}{A} + \frac{Mc}{I}$$

$$30(10^6) = \frac{P}{\pi\,(0.01)^2} + \frac{P\,(0.01)}{\frac{1}{4}\,\pi\,(0.01)^4}$$

$P = 23.5$ N *Ans.*

D–73 At section through B:

$N = 500$ lb, $V = 400$ lb, $M = 400\ (10) = 4000$ lb. in.

Axial load:

$$\sigma_x = \frac{P}{A} = \frac{500}{4\,(3)} = 41.667 \text{ psi (T)}$$

Shear load:

$$\tau_{xy} = \frac{VQ}{It} = \frac{400[(1.5)(3)(1)]}{[\frac{1}{12}(3)(4)^3]\,3} = 37.5 \text{ psi}$$

Bending moment:

$$\sigma_x = \frac{My}{I} = \frac{4000(1)}{\frac{1}{12}\,(3)(4)^3} = 250 \text{ psi (C)}$$

Thus

$\sigma_x = 41.667 - 250 = 208$ psi (C) *Ans.*

$\sigma_y = 0$ *Ans.*

$\tau_{xy} = 37.5$ psi *Ans.*

D–74 At section B:

$N_z = 500$ N, $V_y = 400$ N, $M_x = 400\ (0.1) = 40$ N · m

$M_y = 500\ (0.05) = 25$ N · m, $T_z = 30$ N · m

Axial load:

$$\sigma_z = \frac{P}{A} = \frac{500}{\pi\,(0.05)^2} = 63.66 \text{ kPa (C)}$$

Shear load:

$\tau_{zy} = 0$ since at B, $Q = 0$.

Moment about x axis:

$$\sigma_z = \frac{Mc}{I} = \frac{40(0.05)}{\frac{\pi}{4}\,(0.05)^4} = 407.4 \text{ kPa (C)}$$

Moment about y axis:

$\sigma_z = 0$ since B is on neutral axis.

Torque:

$$\tau_{zx} = \frac{Tc}{J} = \frac{30(0.05)}{\frac{\pi}{2}\,(0.05)^4} = 153 \text{ kPa}$$

Thus

$\sigma_x = 0$ *Ans.*

$\sigma_y = 0$ *Ans.*

$\sigma_z = 63.66 + 407.4 = 471$ kPa *Ans.*

$\tau_{xy} = 0$ *Ans.*

$\tau_{zy} = 0$ *Ans.*

$\tau_{zx} = 153$ kPa *Ans.*

D–75 True *Ans.*

D–76 $\sigma_x = 4$ ksi, $\sigma_y = -6$ ksi, $\tau_{xy} = -8$ ksi

Apply Eq. 9-5, $\sigma_1 = 8.43$ ksi, $\sigma_2 = -10.4$ ksi

D–77 $\sigma_x = 200$ psi, $\sigma_y = -150$ psi, $\tau_{xy} = 100$ psi

Apply Eq. 9-7, $\tau_{\substack{\max \\ \text{in-plane}}} = 202$ psi

D–78 $\sigma_x = -50$ MPa, $\sigma_y = -30$ MPa, $\tau_{xy} = 0$

Use Eq. 9-7, $\tau_{\substack{\max \\ \text{in-plane}}} = 10$ MPa

D–79 At the cross section through B:

$N = 4$ kN, $V = 2$ kN, $M = 2\ (2) = 4$ kN · m

$$\sigma_B = \frac{P}{A} + \frac{Mc}{I} = \frac{4}{0.03(0.06)} + \frac{4(0.03)}{\frac{1}{12}(0.03)(0.06)^3}$$

$= 224$ kPa (T)

Note $\tau_B = 0$ since $Q = 0$.

Thus

$\sigma_1 = 224$ kPa *Ans.*

$\sigma_2 = 0$ *Ans.*

D–80 $A_y = B_y = 12$ kN

Segment AC:

$V_C = 0$, $M_C = 24$ kN · m

$\tau_C = 0$ (since $V_C = 0$)

$\sigma_C = 0$ (since C is on neutral axis)

$\sigma_1 = \sigma_2 = 0$ *Ans.*

D–81 $A_y = 3$ kip

Use section having a length x.

$$\circlearrowleft + \Sigma M = 0;\ -3x + 2x\left(\frac{x}{2}\right) + M = 0$$

$M = 3x - x^2$

$$EI\,\frac{d^2v}{dx^2} = 3x - x^2$$

Integrate twice, use

$v = 0$ at $x = 0$, $v = 0$ at $x = 3$ m

$$v = \frac{1}{EI}\,(-\,x^4 + 0.5\,x^3 - 2.25x)$$ *Ans.*

D–82 $A_y = 15$ kip

$M_A = 100$ kip · ft

Use section having a length x.

Intensity of $w = \left(\frac{3}{10}\right)x$ at x.

$\circlearrowleft + \Sigma M = 0;$

$$-15x + 100 + \left(\frac{1}{3}x\right)\left[\frac{1}{2}\left(\frac{3}{10}x\right)(x)\right] + M = 0$$

$M = 15x - 0.05\,x^3 - 100$

$$EI\,\frac{d^2v}{dx^2} = 15x - 0.05\,x^3 - 100$$

Integrate twice, use

$v = 0$ at $x = 0$, $dv/dx = 0$ at $x = 0$

$$v = \frac{1}{EI}\,(2.5x^3 - 0.0025\,x^5 - 50\,x^2)$$ *Ans.*

-83 From Appendix C, consider distributed and concentrated loads separately.

$$\Delta_C = \frac{5wL^4}{768\ EI} + \frac{PL^3}{48\ EI}$$

$$\frac{5(2)(6)^4}{768\ EI} + \frac{8\ (6)^3}{48\ EI} = \frac{52.875\ \text{kip}\cdot\text{ft}^3}{EI}\ \downarrow \qquad \textit{Ans.}$$

-84 From Appendix C, consider distributed load and couple moment separately.

$$\theta_A = \frac{w_0 L^3}{45\ EI} + \frac{ML}{6\ EI}$$

$$= \frac{4\ (3)^3}{45\ EI} + \frac{20\ (3)}{6\ EI} = \frac{12.4\ \text{kip}\cdot\text{ft}^2}{EI} \qquad \textit{Ans.}$$

-85 True *Ans.*

-86 $$P = \frac{\pi^2\ EI}{(KL)^2} = \frac{\pi^2\ (29\ (10^3))\ (\frac{\pi}{4}\ (0.5)^4)}{[0.5\ (50)]^2} = 22.5\ \text{kip} \qquad \textit{Ans.}$$

$$\sigma = \frac{P}{A} = \frac{22.5}{\pi(0.5)^2} = 28.6\ \text{ksi} < \sigma_Y\ \text{OK}$$

87 $$P = \frac{\pi^2\ EI}{(KL)^2} = \frac{\pi^2\ (1.6)(10^3)\ [\frac{1}{12}\ (4)(2)^3]}{[1\ (12)(12)]^2} = 2.03\ \text{kip} \qquad \textit{Ans.}$$

D–88 $$A = \pi((0.025)^2 - (0.015)^2) = 1.257\ (10^{-3})\ \text{m}^2$$

$$I = \tfrac{1}{4}\ \pi\ ((0.025)^4 - (0.015)^4) = 267.04\ (10^{-9})\ \text{m}^4$$

$$P = \frac{\pi^2\ EI}{(KL)^2} = \frac{\pi^2\ (200\ (10^9))(267.04)(10^{-9})}{[0.5(5)]^2}$$

$$= 84.3\ \text{kN} \qquad \textit{Ans.}$$

$$\sigma = \frac{P}{A} = \frac{84.3\ (10^3)}{1.257\ (10^{-3})} = 67.1\ \text{MPa} < 250\ \text{MPa}\ \ \text{OK}$$

D–89 $$P = \frac{\pi^2\ EI}{(KL)^2};\ 40 = \frac{\pi^2\ 29(10^3)[\frac{\pi}{4}\ (1^4 - r_2{}^4)]}{[1\ (6)(12)]^2}$$

$$r_2 = 0.528\ \text{in.}$$

$$\sigma = \frac{P}{A} = \frac{40}{\pi\ [(1)^2 - (0.528)^2]} = 17.6\ \text{ksi} < 36\ \text{ksi OK}$$

Thus $t = 1 - 0.528 = 0.472$ in. *Ans.*

D–90 $$P = \frac{\pi^2\ EI}{(KL)^2};\ 3 = \frac{\pi^2\ 29(10^3)\ (\frac{\pi}{4}\ r^4)}{[1\ (40)]^2}$$

$$r = 0.382\ \text{in.}$$

$$\sigma = \frac{P}{A} = \frac{3}{\pi\ (0.382)^2} = 6.53\ \text{ksi} < 36\ \text{ksi OK}$$

$$d = 2r = 0.765$$

Use $d = \frac{13}{16}$ in. (0.8125 in.) *Ans.*