1.1. A solid circular post $ABC$ (see figure) supports a load $P_1 = 11.000 \text{ N}$ acting at the top. A second load $P_2$ is uniformly distributed around the shelf at $B$. The diameters of the upper and lower parts of the post are $d_{AB} = 32 \text{ mm}$ and $d_{BC} = 60 \text{ mm}$, respectively.

a. Calculate the normal stress $\sigma_{AB}$ in the upper part of the post.

b. If it is desired that the lower part of the post have the same compressive stress as the upper part, what should be the magnitude of the load $P_2$?

1.2. Calculate the compressive stress $\sigma_c$ in the circular piston rod (see figure) when a force $P = 40 \text{ N}$ is applied to the brake pedal. Assume that the line of action of the force $P$ is parallel to the piston rod, which has diameter 5 mm. Also, the other dimensions shown in the figure (50 mm and 225 mm) are measured perpendicular to the line of action of the force $P$.

1.3. A steel rod 33.5 m long hangs inside a tall tower and holds a 890 N weight at its lower end (see figure). If the diameter of the circular rod is 6 mm, calculate the maximum normal stress $\sigma_{\text{max}}$ in the rod, taking into account the weight of the rod itself. ($\gamma_{\text{steel}} = 77 \text{ kN/m}^3$)

1.4. A circular aluminum tube of length $L = 400 \text{ mm}$ is loaded in compression by forces $P$ (see figure). The outside and inside diameters are 60 mm and 50 mm, respectively. A strain gage is placed on the outside of the bar to measure normal strains in the longitudinal direction.

a. If the measured strain is $\varepsilon = 550 \times 10^{-6}$, what is the shortening $d$ of the bar?

b. If the compressive stress in the bar is intended to be 40 MPa, what should be the load $P$?

1.5. The cross section of a concrete corner column that is loaded uniformly in compression is shown in the figure.

a. Determine the average compressive stress $\sigma_c$ in the concrete if the load is equal to 14.250 kN.

b. Determine the coordinates $x_c$ and $y_c$ of the point where the resultant load must act in order to produce uniform normal stress in the column.
1.6. A car weighing 130 kN when fully loaded is pulled slowly up a steep inclined track by a steel cable (see figure). The cable has an effective cross-sectional area of 490 mm$^2$, and the angle $\alpha$ of the incline is 30°. Calculate the tensile stress $\sigma_t$ in the cable.

![Diagram of a car being pulled up a steep incline by a steel cable.]

1.7. Two steel wires support a moveable overhead camera weighing $W = 110$ N (see figure) used for close-up viewing of field action at sporting events. At some instant, wire 1 is at an angle $\alpha = 20°$ to the horizontal and wire 2 is at an angle $\beta = 48°$. Both wires have a diameter of 0.75 mm. Determine the tensile stresses $\sigma_1$ and $\sigma_2$ in the two wires.

![Diagram of two steel wires supporting a camera.]

1.8. A long retaining wall is braced by wood shores set at an angle of 30° and supported by concrete thrust blocks, as shown in the first part of the figure. The shores are evenly spaced, 3 m apart. For analysis purposes, the wall and shores are idealized as shown in the second part of the figure. Note that the base of the wall and both ends of the shores are assumed to be pinned. The pressure of the soil against the wall is assumed to be triangularly distributed, and the resultant force acting on a 3-meter length of the wall is $F = 190$ kN. If each shore has a 150 mm $\times$ 150 mm square cross section, what is the compressive stress $\sigma_c$ in the shores?

1.9. A loading crane consisting of a steel girder $ABC$ supported by a cable $BD$ is subjected to a load $P$ (see the figure). The cable has an effective cross-sectional area $A = 481$ mm$^2$. The dimensions of the crane are $H = 1.6$ m, $L_1 = 3$ m, and $L_2 = 1.5$ m.

a. If the load $P = 32$ kN, what is the average tensile stress in the cable?

b. If the cable stretches by 5.1 mm, what is the average strain?

![Diagram of a loading crane with a cable and a load.]

1.10. A pickup truck tailgate supports a crate ($W_C = 650$ N), as shown in the figure. The tailgate weighs $W_T = 260$ N and is supported by two cables (only one is shown in the figure). Each cable has an effective cross-sectional area $A_e = 11$ mm$^2$.

a. Find the tensile force $T$ and normal stress $\sigma$ in each cable.

b. If each cable elongates $\delta = 0.25$ mm due to the weight of both the crate and the tailgate, what is the average strain in the cable?
1.11. A high-strength steel bar used in a large crane has diameter \( d = 50 \) mm. (see figure). The steel has modulus of elasticity \( E = 200 \) GPa and Poisson’s ratio \( \nu = 0.29 \). Because of clearance requirements, the diameter of the bar is limited to 50,825 mm when it is compressed by axial forces. What is the largest compressive load \( P_{\text{max}} \) that is permitted?

1.12. A round bar of 10 mm diameter is made of aluminum alloy 7075-T6 (see figure). When the bar is stretched by axial forces \( P \), its diameter decreases by 0.016 mm. Find the magnitude of the load \( P \). (\( E = 72 \) GPa, \( \nu = 0.33 \), Yield stress \( \sigma_y = 480 \) MPa)

1.13. A nylon bar having diameter \( d_1 = 90 \) mm is placed inside a steel tube having inner diameter \( d_2 = 89.2 \) mm. (see figure). The nylon bar is then compressed by an axial force \( P \). At what value of the force \( P \) will the space between the nylon bar and the steel tube be closed? (For nylon, assume \( E = 2.750 \) MPa and \( \nu = 0.4 \).)

1.14. A prismatic bar of circular cross section is loaded by tensile forces \( P \) (see figure). The bar has length \( L = 1.5 \) m and diameter \( d = 30 \) mm. It is made of aluminum alloy with modulus of elasticity \( E = 75 \) GPa and Poisson’s ratio \( \nu = 1/3 \). If the bar elongates by 3.6 mm, what is the decrease in diameter \( d \)? What is the magnitude of the load \( P \)?

1.15. A bar of monel metal (length \( L = 200 \) mm., diameter \( d = 6.5 \) mm.) is loaded axially by a tensile force \( P = 6.500 \) N (see figure). Using \( E = 172 \) GPa and \( \nu = 0.32 \), determine the increase in length of the bar and the percent decrease in its cross-sectional area.

1.16. A tensile test is performed on a brass specimen 10 mm in diameter using a gage length of 50 mm (see figure). When the tensile load \( P \) reaches a value of 20 kN, the distance between the gage marks has increased by 0.122 mm.
   a. What is the modulus of elasticity \( E \) of the brass?
   b. If the diameter decreases by 0.00830 mm, what is Poisson’s ratio?

1.17. A hollow steel cylinder is compressed by a force \( P \) (see figure). The cylinder has inner diameter \( d_1 = 100 \) mm., outer diameter \( d_2 = 115 \) mm., and modulus of elasticity \( E = 205 \) GPa. When the force \( P \) increases from zero to 180 kN, the outer diameter of the cylinder increases by 11,6 \( \times 10^{-3} \) mm.
   a. Determine the increase in the inner diameter.
   b. Determine the increase in the wall thickness.
   c. Determine Poisson’s ratio for the steel.
1.18. A steel bar of length 2.5 m with a square cross section 100 mm on each side is subjected to an axial tensile force of 1300 kN (see figure). Assume that $E = 200$ GPa and $\nu = 0.3$. Determine the increase in volume of the bar.

1.19. A hollow, brass circular pipe ABC (see figure) supports a load $P_1 = 120$ kN acting at the top. A second load $P_2 = 98$ kN is uniformly distributed around the cap plate at B. The diameters and thicknesses of the upper and lower parts of the pipe are $d_{AB} = 32$ mm, $t_{AB} = 12.5$ mm, $d_{BC} = 58$ mm, and $t_{BC} = 9.5$ mm, respectively. The modulus of elasticity is 96 GPa. When both loads are fully applied, the wall thickness of pipe BC increases by $5 \times 10^{-3}$ mm.
   a. Find the increase in the inner diameter of pipe segment BC.
   b. Find Poisson’s ratio for the brass.
   c. Find the increase in the wall thickness of pipe segment AB and the increase in the inner diameter of AB.

1.20. An aluminum bar ($E = 70$ GPa, $\nu = 0.33$) of diameter 20 mm is stretched by axial forces $P$, causing its diameter to decrease by 0.022 mm. Find the load $P$.

1.21. An angle bracket having thickness $t = 12$ mm is attached to the flange of a column by two 16 mm diameter bolts (see figure). A uniformly distributed load acts on the top face of the bracket with a pressure $p = 2$ MPa. The top face of the bracket has length $l = 150$ mm and width $b = 65$ mm. Determine the average bearing pressure $\sigma_b$ between the angle bracket and the bolts and the average shear stress $\tau_{\text{aver}}$ in the bolts. (Disregard friction between the bracket and the column.)

1.22. Three steel plates, each 16 mm thick, are joined by two 20-mm diameter rivets as shown in the figure.
   a. If the load $P = 50$ kN, what is the largest bearing stress acting on the rivets?
   b. If the ultimate shear stress for the rivets is 180 MPa, what force $P_{\text{ult}}$ is required to cause the rivets to fail in shear? (Disregard friction between the plates.)

1.23. A bolted connection between a vertical column and a diagonal brace is shown in the figure on the next page. The connection consists of three 5/8-in. bolts that join two 1/4-in. end plates welded to the brace and a 5/8-in. gusset plate welded to the column. The compressive
load $P$ carried by the brace equals 8.0 k. Determine the following quantities:

a. The average shear stress $\tau_{avg}$ in the bolts, and
b. the average bearing stress $\sigma_b$ between the gusset plate and the bolts. (Disregard friction between the plates.)

1.24. Truss members supporting a roof are connected to a 26-mm-thick gusset plate by a 22 mm diameter pin as shown in the figure and photo. The two end plates on the truss members are each 14 mm thick.

a. If the load $P = 80$ kN, what is the largest bearing stress acting on the pin?

b. If the ultimate shear stress for the pin is 190 MPa, what force $P_{ult}$ is required to cause the pin to fail in shear? (Disregard friction between the plates.)

1.25. The upper deck of a football stadium is supported by braces each of which transfers a load $P = 710$ kN to the base of a column [see figure part (a)]. A cap plate at the bottom of the brace distributes the load $P$ to four flange plates ($t_f = 25$ mm.) through a pin ($d_p = 50$ mm.) to two gusset plates ($t_g = 1.5$ in.) [see figure parts (b) and (c)]. Determine the following quantities

a. The average shear stress $\tau_{avg}$ in the pin
b. The average bearing stress between the flange plates and the pin ($\sigma_{bf}$), and also between the gusset plates and the pin ($\sigma_{bg}$). (Disregard friction between the plates.)
1.26. A steel plate of dimensions 2.5×1.5×0.08 m and weighing 23.1 kN is hoisted by steel cables with lengths \( L_1 = 3.2 \) m and \( L_2 = 3.9 \) m that are each attached to the plate by a clevis and pin (see figure). The pins through the clevises are 18 mm in diameter and are located 2.0 m apart. The orientation angles are measured to be \( \theta = 94.4^\circ \) and \( \alpha = 54.9^\circ \). For these conditions, first determine the cable forces \( T_1 \) and \( T_2 \), then find the average shear stress \( \tau_\text{aver} \) in both pin 1 and pin 2, and then the average bearing stress \( \sigma_b \) between the steel plate and each pin. Ignore the mass of the cables.

1.27. A hollow box beam \( ABC \) of length \( L \) is supported at end \( A \) by a 20-mm diameter pin that passes through the beam and its supporting pedestals (see figure). The roller support at \( B \) is located at distance \( L/3 \) from end \( A \).
   a. Determine the average shear stress in the pin due to a load \( P \) equal to 10 kN.
   b. Determine the average bearing stress between the pin and the box beam if the wall thickness of the beam is equal to 12 mm.
   c. Determine the average shear strain \( \gamma_\text{aver} \) in the rubber if the force \( P \) = 16 kN and the shear modulus for the rubber is \( G = 1250 \) kPa.
   d. Find the relative horizontal displacement \( \delta \) between the interior plate and the outer plates.

1.28. A flexible connection consisting of rubber pads (thickness \( t = 9 \) mm) bonded to steel plates is shown in the figure. The pads are 160 mm long and 80 mm wide.
   a. Find the average shear strain \( \gamma_\text{aver} \) in the rubber if the force \( P \) = 16 kN and the shear modulus for the rubber is \( G = 1250 \) kPa.
   b. Find the relative horizontal displacement \( \delta \) between the interior plate and the outer plates.

1.29. An elastomeric bearing pad consisting of two steel plates bonded to a chloroprene elastomer (an artificial rubber) is subjected to a shear force \( V \) during a static loading test (see figure). The pad has dimensions \( a = 150 \) mm and \( b = 250 \) mm, and the elastomer has thickness \( t = 50 \) mm. When the force \( V \) equals 12 kN, the top plate is found to have displaced laterally 8.0 mm with respect to the bottom plate. What is the shear modulus of elasticity \( G \) of the chloroprene?

1.30. The beam is supported by a pin at \( A \) and a short link \( BC \). If \( P = 15 \) kN, determine the average shear stress developed in the pins at \( A \), \( B \), and \( C \). All pins are in double shear as shown, and each has a diameter of 18 mm.
1.31. A bar of solid circular cross section is loaded in tension by forces $P$ (see figure). The bar has length $L = 380$ mm and diameter $d = 6$ mm. The material is a magnesium alloy having modulus of elasticity $E = 42.7$ GPa. The allowable stress in tension is $89.6$ GPa and the elongation of the bar must not exceed $0.08$ mm.

1.32. A tie-down on the deck of a sailboat consists of a bent bar bolted at both ends, as shown in the figure. The diameter $d_B$ of the bar is $6$ mm, the diameter $d_W$ of the washers is $22$ mm, and the thickness $t$ of the fiberglass deck is $10$ mm. If the allowable shear stress in the fiberglass is $2.1$ MPa, and the allowable bearing pressure between the washer and the fiberglass is $3.8$ MPa, what is the allowable load $P_{\text{allow}}$ on the tie-down?

1.33. A ship’s spar is attached at the base of a mast by a pin connection (see figure on the next page). The spar is a steel tube of outer diameter $d_2 = 80$ mm and inner diameter $d_1 = 70$ mm. The steel pin has diameter $d = 25$ mm, and the two plates connecting the spar to the pin have thickness $t = 12$ mm. The allowable stresses are as follows: compressive stress in the spar, $70$ MPa; shear stress in the pin, $45$ MPa; and bearing stress between the pin and the connecting plates, $110$ MPa. Determine the allowable compressive force $P_{\text{allow}}$ in the spar.

1.34. A steel pad supporting heavy machinery rests on four short, hollow, cast iron piers (see figure). The ultimate strength of the cast iron in compression is $344.5$ MPa. The outer diameter of the piers is $d_1 = 114$ mm and the wall thickness is $t = 10$ mm. Using a factor of safety of $4.0$ with respect to the ultimate strength, determine the total load $P$ that may be supported by the pad.

1.35. The rear hatch of a van $[BDCF$ in figure part (a)] is supported by two hinges at $B1$ and $B2$ and by two struts $A1B1$ and $A2B2$ (diameter $d_s = 10$ mm) as shown in figure part (b). The struts are supported at $A1$ and $A2$ by pins, each with diameter $d_p = 9$ mm and passing through an eyelet of thickness $t = 8$ mm at the end of the strut [figure part (b)]. If a closing force $P = 50$ N is applied at $G$ and the mass of the hatch $Mh = 43$ kg is concentrated at $C$

a. What is the force $F$ in each strut? [Use the freebody diagram of one half of the hatch in the figure part (c)]
b. What is the maximum permissible force in the strut, \( F_{\text{allow}} \), if the allowable stresses are as follows: compressive stress in the strut, 70 MPa; shear stress in the pin, 45 MPa; and bearing stress between the pin and the end of the strut, 110 MPa.

1.36. An aluminum tube is required to transmit an axial tensile force \( P = 148 \text{ kN} \) [see figure]. The thickness of the wall of the tube is to be 6 mm. What is the minimum required outer diameter \( d_{\text{min}} \) if the allowable tensile stress is 84 MPa?

1.37. A steel pipe having yield stress \( \sigma_y = 270 \text{ MPa} \) is to carry an axial compressive load \( P = 1200 \text{ kN} \) (see figure). A factor of safety of 1.8 against yielding is to be used. If the thickness \( t \) of the pipe is to be one-eighth of its outer diameter, what is the minimum required outer diameter \( d_{\text{min}} \)?

1.38. Lateral bracing for an elevated pedestrian walkway is shown in the figure part (a). The thickness of the clevis plate \( t_c = 16 \text{ mm} \) and the thickness of the gusset plate \( t_g = 20 \text{ mm} \) [see figure part (b)]. The maximum force in the diagonal bracing is expected to be \( F = 190 \text{ kN} \). If the allowable shear stress in the pin is 90 MPa and the allowable bearing stress between the pin and both the clevis and gusset plates is 150 MPa, what is the minimum required diameter \( d_{\text{min}} \) of the pin?

1.39. Two bars of rectangular cross section (thickness \( t = 15 \text{ mm} \)) are connected by a bolt in the manner shown in the figure. The allowable shear stress in the bolt is 90 MPa and the allowable bearing stress between the bolt and the bars is 150 MPa. If the tensile load \( P = 31 \text{ kN} \), what is the minimum required diameter \( d_{\text{min}} \) of the bolt?
1.40. A square steel tube of length \( L \) 6 m and width \( b = 250 \text{ mm} \) is hoisted by a crane (see figure). The tube hangs from a pin of diameter \( d \) that is held by the cables at points A and B. The cross section is a hollow square with inner dimension \( b_1 = 210 \text{ mm} \) and outer dimension \( b_2 = 250 \text{ mm} \). The allowable shear stress in the pin is 60 MPa, and the allowable bearing stress between the pin and the tube is 90 MPa. Determine the minimum diameter of the pin in order to support the weight of the tube. (Note: Disregard the rounded corners of the tube when calculating its weight.)

1.41. A tubular post of outer diameter \( d_2 \) is guyed by two cables fitted with turnbuckles (see figure). The cables are tightened by rotating the turnbuckles, thus producing tension in the cables and compression in the post. Both cables are tightened to a tensile force of 110 kN. Also, the angle between the cables and the ground is 60°, and the allowable compressive stress in the post is \( \sigma_c = 35 \text{ MPa} \). If the wall thickness of the post is 15 mm, what is the minimum permissible value of the outer diameter \( d_2 \)?

1.42. A steel column of hollow circular cross section is supported on a circular steel base plate and a concrete pedestal (see figure). The column has outside diameter \( d = 250 \text{ mm} \) and supports a load \( P = 750 \text{ kN} \).

a. If the allowable stress in the column is 55 MPa, what is the minimum required thickness \( t \)? Based upon your result, select a thickness for the column. (Select a thickness that is an even integer, such as 10, 12, 14, . . . , in units of millimeters.)

b. If the allowable bearing stress on the concrete pedestal is 11.5 MPa, what is the minimum required diameter \( D \) of the base plate if it is designed for the allowable load \( P_{\text{allow}} \) that the column with the selected thickness can support?

1.43. A steel cable with nominal diameter 25 mm (\( A = 304 \text{ mm}^2 \)) is used in a construction yard to lift a bridge section weighing 38 kN, as shown in the figure. The cable has an effective modulus of elasticity \( E = 140 \text{ GPa} \). If the cable is 14 m long, how much will it stretch when the load is picked up? If the cable is rated for a maximum load of 70 kN, what is the factor
of safety with respect to failure of the cable?

1.44. A steel wire and a copper wire have equal lengths and support equal loads \( P \) (see figure). The moduli of elasticity for the steel and copper are \( E_s = 205 \) GPa and \( E_c = 125 \) GPa, respectively. (a) If the wires have the same diameters, what is the ratio of the elongation of the copper wire to the elongation of the steel wire? (b) If the wires stretch the same amount, what is the ratio of the diameter of the copper wire to the diameter of the steel wire?

![Image of steel and copper wire](image)

1.45. The three-bar truss ABC shown in the figure has a span \( L = 3 \) m and is constructed of steel pipes having cross-sectional area \( A = 3900 \) mm\(^2\) and modulus of elasticity \( E = 200 \) GPa. A load \( P \) act horizontally to the right at jointC.

a. If \( P = 650 \) kN, what is the horizontal displacement of jointB?

b. What is the maximum permissible load \( P_{\text{max}} \) if the displacement of joint B is limited to 1.5 mm?

![Image of three-bar truss](image)

1.46. An aluminum wire having a diameter \( d = 2 \) mm and length \( L = 3.8 \) m is subjected to a tensile load \( P \). The aluminum has modulus of elasticity \( E = 75 \) GPa. If the maximum permissible elongation of the wire is 3.0 mm and the allowable stress in tension is 60 MPa, what is the allowable load \( P_{\text{max}} \)?

![Image of aluminum wire](image)

1.47. A hollow, circular, steel column \( (E = 205 \) GPa) is subjected to a compressive load \( P \), as shown in the figure. The column has length \( L = 2.4 \) m and outside diameter \( d = 190 \) mm. The load \( P = 380 \) kN. If the allowable compressive stress is 48 MPa and the allowable shortening of the column is 0.5 mm, what is the minimum required wall thickness \( t_{\text{min}} \)?

![Image of hollow, circular column](image)

1.48. The horizontal rigid beam ABCD is supported by vertical bars BE and CF and is loaded by vertical forces \( P_1 = 400 \) kN and \( P_2 = 360 \) kN acting at points A and D, respectively. Bars BE and CF are made of steel \( (E = 200 \) GPa) and have cross-sectional.

![Image of horizontal rigid beam](image)

1.49. A steel bar AD (see figure) has a cross-sectional area of 260 mm\(^2\) and is loaded by forces \( P_1 = 12 \) kN, \( P_2 = 8 \) kN, and \( P_3 = 9 \) kN. The lengths of the segments of the bar area \( a = 1.500 \) mm, \( b = 600 \) mm, and \( c = 900 \) mm. (a) Assuming that the modulus of elasticity \( E = 205 \) GPa, calculate the change in length \( d \) of the bar. Does the bar elongate or shorten? (b) By what amount \( P \) should the load \( P_3 \) be increased so that the bar does not change in length when the three loads are applied?

![Image of steel bar AD](image)
1.50. A two-story building has steel columns $AB$ in the first floor and $BC$ in the second floor, as shown in the figure. The roof load $P_1$ equals 400 kN and the second-floor load $P_2$ equals 720 kN. Each column has length $L = 3.75$ m. The cross-sectional areas of the first- and second-floor columns are $11,000 \text{ mm}^2$ and $3,900 \text{ mm}^2$, respectively.

a. Assuming that $E = 206$ GPa, determine the total shortening $\delta_{AC}$ of the two columns due to the combined action of the loads $P_1$ and $P_2$.

b. How much additional load $P_0$ can be placed at the top of the column (point $C$) if the total shortening $\delta_{AC}$ is not to exceed 4.0 mm?

2.1. Determine the distances $x$ and $y$ to the centroid $C$ of a right triangle having base $b$ and altitude $h$ (see Case 6, Appendix D).

2.2. Determine the distance $y$ to the centroid $C$ of a trapezoid having bases $a$ and $b$ and altitude $h$ (see Case 8, Appendix D).

2.3. Determine the distance $y$ to the centroid $C$ of a semicircle of radius $r$ (see Case 10, Appendix D).

2.4. Determine the distances $x$ and $y$ to the centroid $C$ of a parabolic spandrel of base $b$ and height $h$ (see Case 18, Appendix D).

2.5. Determine the distance $y$ to the centroid $C$ of a trapezoid having bases $a$ and $b$ and altitude $h$ (see Problem 2.2) by dividing the trapezoid into two triangles.
2.6. One quarter of a square of side $a$ is removed (see figure). What are the coordinates $x$ and $y$ of the centroid $C$ of the remaining area?

2.7. Calculate the distance $y$ to the centroid $C$ of the channel section shown in the figure if $a = 150\,\text{mm}$, $b = 250\,\text{mm}$, and $c = 500\,\text{mm}$.

2.8. Determine the distance $\bar{y}$ to the centroid $C$ of the composite area shown in the figure.

2.9. Determine the coordinates $x$ and $y$ of the centroid $C$ of the L-shaped area shown in the figure.

2.10. Determine the coordinates $\bar{x}$ and $\bar{y}$ of the centroid $C$ of the area shown in the figure.

2.11. Determine the moment of inertia $I_x$ of a triangle of base $b$ and altitude $h$ with respect to its base (see Case 4, Appendix D).

2.12. Determine the moment of inertia $I_{BB}$ of a trapezoid having bases $a$ and $b$ and altitude $h$ with respect to its base (see Problem 2.2).

2.13. Determine the moment of inertia $I_x$ of a parabolic spandrel of base $b$ and height $h$ with respect to its base (see Problem 2.4).

2.14. Determine the moment of inertia $I_x$ of a circle of radius $r$ with respect to a diameter (see Case 9, Appendix D).

2.15. Calculate the moment of inertia $I_x$ for the composite circular area shown in the figure. The origin of the axes is at the center of the concentric circles, and the three diameters are 20, 40, and 60 mm.
2.16. Calculate the moments of inertia $I_x$ and $I_y$ with respect to the $x$ and $y$ axes for the L-shaped area shown in the figure for Prob. 2.9.

2.17. A semicircular area of radius 150 mm has a rectangular cutout of dimensions 50 mm x 100 mm (see figure). Calculate the moments of inertia $I_x$ and $I_y$ with respect to the $x$ and $y$ axes. Also, calculate the corresponding radii of gyration $r_x$ and $r_y$.

2.18. The moment of inertia with respect to axis 1-1 of the scalene triangle shown in the figure is $90 \times 10^3$ mm$^4$. Calculate its moment of inertia $I_2$ with respect to axis 2-2.

2.19. Calculate the moment of inertia $I_{xc}$ with respect to an axis through the centroid $C$ and parallel to the $x$ axis for the composite area shown in the figure for Prob. 2.8.

2.20. Calculate the centroidal moments of inertia $I_{xc}$ and $I_{yc}$ with respect to axes through the centroid $C$ and parallel to the $x$ and $y$ axes, respectively, for the L-shaped area shown in the figure for Prob. 2.9.

2.21. The wide-flange beam section shown in the figure has a total height of 250 mm and a constant thickness of 15 mm. Determine the flange width $b$ if it is required that the centroidal moments of inertia $I_x$ and $I_y$ be in the ratio 3 to 1, respectively.

2.22. Determine the polar moment of inertia $I_P$ of an isosceles triangle of base $b$ and altitude $h$ with respect to its apex (see Case 5, Appendix D).

2.23. Determine the polar moment of inertia $(IP)_C$ with respect to the centroid $C$ for a circular sector (see Case 13, Appendix D).

2.24. Obtain a formula for the polar moment of inertia $I_P$ with respect to the midpoint of the hypotenuse for a right triangle of base $b$ and height $h$ (see Case 6, Appendix D).
2.25. Determine the polar moment of inertia \((IP)_C\) with respect to the centroid \(C\) for a quarter-circular spandrel.

\[
y = f(x) = h \left(1 - \frac{x^2}{b^2}\right)
\]

2.26. Using integration, determine the product of inertia \(I_{xy}\) for the parabolic semisegment shown in Fig. 12-5 (see also Case 17 in Appendix D).

2.27. Using integration, determine the product of inertia \(I_{xy}\) for the quarter-circular spandrel shown in Problem 2.25.

2.28. Find the relationship between the radius \(r\) and the distance \(b\) for the composite area shown in the figure in order that the product of inertia \(I_{xy}\) will be zero.

2.29. Obtain a formula for the product of inertia \(I_{xy}\) of the symmetrical L-shaped area shown in the figure.

2.30. Calculate the product of inertia \(I_{xy}\) for the composite area shown in Prob. 2.8.

2.31. Determine the product of inertia \(I_{xyc}\) with respect to centroidal axes \(xc\) and \(yc\) parallel to the \(x\) and \(y\) axes, respectively, for the L-shaped area shown in Prob. 2.9.

2.32. Determine the moments of inertia \(I_{x1}\) and \(I_{y1}\) and the product of inertia \(I_{x1y1}\) for a square with sides \(b\), as shown in the figure. (Note that the \(x1y1\) axes are centroidal axes rotated through an angle \(u\) with respect to the \(xy\) axes.)

2.33. Determine the moments and product of inertia with respect to the \(x1y1\) axes for the rectangle shown in the figure. (Note that the \(x1\) axis is a diagonal of the rectangle.)

2.34. Calculate the moments of inertia \(I_{x1}\) and \(I_{y1}\) and the product of inertia \(I_{x1y1}\) with respect to the \(x1y1\) axes for the L-shaped area shown in the figure if \(a = 150\) mm, \(b = 100\) mm, \(t = 15\) mm, and \(\theta = 30^\circ\).

2.35. Calculate the moments of inertia \(I_{x1}\) and \(I_{y1}\) and the product of inertia \(I_{x1y1}\) with respect to the \(x1y1\) axes for the Z-section.
shown in the figure if \( b = 80 \text{ mm} \), \( h = 120 \text{ mm} \), \( t = 12 \text{ mm} \), and \( \theta = 30^\circ \).

2.36. Determine the angles \( \theta_{p1} \) and \( \theta_{p2} \) defining the orientations of the principal axes through the origin \( O \) and the corresponding principal moments of inertia \( I_1 \) and \( I_2 \) for the L-shaped area described in Prob. 2.34 (\( a = 150 \text{ mm} \), \( b = 100 \text{ mm} \), and \( t = 15 \text{ mm} \)).

2.37. Determine the angles \( \theta_{p1} \) and \( \theta_{p2} \) defining the orientations of the principal axes through the centroid \( C \) and the corresponding principal centroidal moments of inertia \( I_1 \) and \( I_2 \) for the Z-section described in Prob. 2.35.

2.38. Determine the angles \( \theta_{p1} \) and \( \theta_{p2} \) defining the orientations of the principal centroidal axes and the corresponding principal moments of inertia \( I_1 \) and \( I_2 \) for the L-shaped area shown in the figure if \( a = 80 \text{ mm} \), \( b = 150 \text{ mm} \), and \( t = 16 \text{ mm} \).

3.1. A copper rod of length \( L = 450 \text{ mm} \) is to be twisted by torques \( T \) (see figure) until the angle of rotation between the ends of the rod is \( 3.0^\circ \). If the allowable shear strain in the copper is 0.0006 rad, what is the maximum permissible diameter of the rod?

3.2. A circular steel tube of length \( L = 0.90 \text{ m} \) is loaded in torsion by torques \( T \) (see figure).
   a. If the inner radius of the tube is \( r_1 = 40 \text{ mm} \) and the measured angle of twist between the ends is \( 0.5^\circ \), what is the shear strain \( \gamma_1 \) (in radians) at the inner surface?
   b. If the maximum allowable shear strain is 0.0005 rad and the angle of twist is to be kept at \( 0.5^\circ \) by adjusting the torque \( T \), what is the maximum permissible outer radius \( r_2 \) max?

3.3. When drilling a hole in a table leg, a furniture maker uses a hand-operated drill (see figure) with a bit of diameter \( d = 4.0 \text{ mm} \). (a) If the resisting torque supplied by the table leg is equal to 0.3 N\( \cdot \)m, what is the maximum shear stress in the drill bit? (b) If the shear modulus of elasticity of the steel is \( G = 75 \text{ GPa} \), what is the rate of twist of the drill bit (degrees per meter)?

3.4. An aluminum bar of solid circular cross section is twisted by torques \( T \) acting at the ends. The dimensions and shear modulus of elasticity are as follows: \( L = 1.2 \text{ m} \), \( d = 30 \text{ mm} \), and \( G = 28 \text{ GPa} \).
   a. Determine the torsional stiffness of the bar.
   b. If the angle of twist of the bar is \( 4^\circ \), what is the maximum shear stress? What is the maximum shear strain (in radians)?
3.5. The steel shaft of a socket wrench has a diameter of 8.0 mm and a length of 200 mm (see figure). If the allowable stress in shear is 60 MPa, what is the maximum permissible torque \( T_{\text{max}} \) that may be exerted with the wrench? Through what angle \( \phi \) (in degrees) will the shaft twist under the action of the maximum torque? (Assume \( G = 78 \text{ GPa} \) and disregard any bending of the shaft.)

3.6. A propeller shaft for a small yacht is made of a solid steel bar 100 mm in diameter. The allowable stress in shear is 50 MPa, and the allowable rate of twist is 2.0° in 3 meters. Assuming that the shear modulus of elasticity is \( G = 80 \text{ GPa} \), determine the maximum torque \( T_{\text{max}} \) that can be applied to the shaft.

3.7. The steel axle of a large winch on an ocean liner is subjected to a torque of 1.5 kNm (see figure). What is the minimum required diameter \( d_{\text{min}} \) if the allowable shear stress is 50 MPa and the allowable rate of twist is 0.8°/m? (Assume that the shear modulus of elasticity is 80 GPa.)

3.8. A hollow steel shaft used in a construction auger has outer diameter \( d_2 = 150 \text{ mm} \) and inner diameter \( d_1 = 100 \text{ mm} \). The steel has shear modulus of elasticity \( G = 75 \text{ GPa} \). For an applied torque of 16 kN-m., determine the following quantities: (a) shear stress \( \tau_2 \) at the outer surface of the shaft, (b) shear stress \( \tau_1 \) at the inner surface, and (c) rate of twist \( \theta \) (degrees per unit of length)

3.9. A hollow aluminum tube used in a roof structure has an outside diameter \( d_2 = 100 \text{ mm} \) and an inside diameter \( d_1 = 80 \text{ mm} \) (see figure). The tube is 2.5 m long, and the aluminum has shear modulus \( G = 28 \text{ GPa} \).
   a. If the tube is twisted in pure torsion by torques acting at the ends, what is the angle of twist \( \phi \) (in degrees) when the maximum shear stress is 50 MPa?

b. What diameter \( d \) is required for a solid shaft (see figure) to resist the same torque with the same maximum stress?

c. What is the ratio of the weight of the hollow tube to the weight of the solid shaft?

3.10. A stepped shaft ABC consisting of two solid circular segments is subjected to torques \( T_1 \) and \( T_2 \) acting in opposite directions, as shown in the figure. The larger segment of the shaft has diameter \( d_1 = 58 \text{ mm} \) and length \( L_1 = 760 \text{ mm} \); the smaller segment has diameter \( d_2 = 45 \text{ mm} \) and length \( L_2 = 500 \text{ mm} \). The material is steel with shear modulus \( G = 206 \text{ GPa} \), and the torques are \( T_1 = 2,250 \text{ kN-m} \) and \( T_2 = 0,900 \text{ kN-m} \). Calculate the following quantities: (a) the maximum shear stress \( \tau_{\text{max}} \) in the shaft, and (b) the angle of twist \( \phi_C \) (in degrees) at end C.

3.11. A stepped shaft ABCD consisting of solid circular segments is subjected to three torques, as shown in the figure. The torques have magnitudes 1,4 kN-m., 1,0 kN-m, and 1,0 kN-m. The length of each segment is 600 mm. And the diameters of the segments are 75 mm, 65 mm, and 50 mm. The material is steel with shear modulus of elasticity \( G = 205 \text{ GPa} \). (a) Calculate the maximum shear stress \( \tau_{\text{max}} \) in the shaft. (b) Calculate the angle of twist \( \phi_D \) (in degrees) at end D.
3.12. A solid circular bar ABC consists of two segments, as shown in the figure. One segment has diameter \( d_1 = 50 \text{ mm} \) and length \( L_1 = 1.25 \text{ m} \); the other segment has diameter \( d_2 = 40 \text{ mm} \) and length \( L_2 = 1.0 \text{ m} \). What is the allowable torque \( T_{\text{allow}} \) if the shear stress is not to exceed 30 MPa and the angle of twist between the ends of the bar is not to exceed 1.5°? (Assume \( G = 80 \text{ GPa} \).)

![Diagram of circular bar](image)

3.13. A hollow tube ABCDE constructed of monel metal is subjected to five torques acting in the directions shown in the figure. The magnitudes of the torques are \( T_1 = 0.11 \text{ kN} \cdot \text{m} \), \( T_2 = T_4 = 0.06 \text{ kN} \cdot \text{m} \), and \( T_3 = T_5 = 0.09 \text{ kN} \cdot \text{m} \). The tube has an outside diameter \( d_2 = 25 \text{ mm} \). The allowable shear stress is 80 MPa and the allowable rate of twist is 2.0°/ft. Determine the maximum permissible inside diameter \( d_1 \) of the tube.

![Diagram of hollow tube](image)

3.14. A hollow circular tube having an inside diameter of 250 mm and a wall thickness of 25 mm. (see figure) is subjected to a torque \( T = 135 \text{ kN} \cdot \text{m} \). Determine the maximum shear stress in the tube using (a) the approximate theory of thin-walled tubes, and (b) the exact torsion theory. Does the approximate theory give conservative or nonconservative results?

![Diagram of hollow circular tube](image)

3.15. A thin-walled aluminum tube of rectangular cross section (see figure) has a centerline dimensions \( b = 150 \text{ mm} \) and \( h = 100 \text{ mm} \). The wall thickness \( t \) is constant and equal to 6 mm. (a) Determine the shear stress in the tube due to a torque \( T = 1.65 \text{ kN} \cdot \text{m} \). (b) Determine the angle of twist (in degrees) if the length \( L \) of the tube is 1.2 m and the shear modulus \( G \) is 75 GPa.

![Diagram of rectangular cross section](image)

3.16. Calculate the shear stress \( t \) and the angle of twist \( \phi \) (in degrees) for a steel tube (\( G = 76 \text{ GPa} \)) having the cross section shown in the figure. The tube has length \( L = 1.5 \text{ m} \) and is subjected to a torque \( T = 10 \text{ kN} \cdot \text{m} \).

![Diagram of steel tube](image)

3.17. A thin tubular shaft of circular cross section (see figure) with inside diameter 100 mm is subjected to a torque of 5000 N\cdot m. If the allowable shear stress is 42 MPa, determine the required wall thickness \( t \) by using

a. the approximate theory for a thin walled tube, and

b. the exact torsion theory for a circular bar.

![Diagram of circular cross section](image)
4.1. A simply supported wood beam $AB$ with span length $L = 3.5$ m carries a uniform load of intensity $q = 6.4$ kN/m (see figure). Calculate the maximum bending stress $s_{\text{max}}$ due to the load $q$ if the beam has a rectangular cross section with width $b = 140$ mm and height $h = 240$ mm.

4.2. Each girder of the lift bridge (see figure) is 55 m long and simply supported at the ends. The design load for each girder is a uniform load of intensity 25 kN/m. The girders are fabricated by welding three steel plates so as to form an I-shaped cross section (see figure) having section modulus $S = 58.99 \times 10^6$ mm$^3$. What is the maximum bending stress $\sigma_{\text{max}}$ in a girder due to the uniform load?

4.3. A freight-car axle $AB$ is loaded approximately as shown in the figure, with the forces $P$ representing the car loads (transmitted to the axle through the axle boxes) and the forces $R$ representing the rail loads (transmitted to the axle through the wheels). The diameter of the axle is $d = 80$ mm, the distance between centers of the rails is $L$, and the distance between the forces $P$ and $R$ is $b = 200$ mm. Calculate the maximum bending stress $s_{\text{max}}$ in the axle if $P = 47$ kN.

4.4. A seesaw weighing 45 N/m of length is occupied by two children, each weighing 400 N (see figure). The center of gravity of each child is 2.4 m from the fulcrum. The board is 5.8 m long, 200 mm. wide, and 40 mm. thick.

4.5. During construction of a highway bridge, the main girders are cantilevered outward from one pier toward the next (see figure). Each girder has a cantilever length of 46 m and an I-shaped cross section with dimensions as shown in the figure. The load on each girder (during construction) is assumed to be 11.0 kN/m, which includes the weight of the girder. Determine the maximum bending stress in a girder due to this load.

4.6. The horizontal beam $ABC$ of an oil-well pump has the cross section shown in the figure. If the vertical pumping force acting at end $C$ is 40 kN, and if the distance from the line of action of that force to point $B$ is 4.25 m, what is the maximum bending stress in the beam due to the pumping force?

4.7. A railroad tie (or sleeper) is subjected to two rail loads, each of magnitude $P = 175$ kN, acting as shown in the figure. The reaction $q$ of the ballast is assumed to be uniformly distributed over the length of the tie, which has cross-sectional dimensions $b = 300$ mm and $h = 250$ mm. Calculate the maximum bending stress $s_{\text{max}}$ in the tie due to the loads $P$, assuming the distance $L = 1500$ mm and the overhang length $a = 500$ mm.
4.8. A small dam of height \( h = 2.0 \) m is constructed of vertical wood beams \( AB \) of thickness \( t = 120 \) mm, as shown in the figure. Consider the beams to be simply supported at the top and bottom. Determine the maximum bending stress \( \sigma_{\text{max}} \) in the beams, assuming that the weight density \( g \) of water equals 10 kN/m\(^3\).

4.9. Determine the maximum tensile stress \( \tau \) and maximum compressive stress \( \sigma_c \) due to the load \( P \) acting on the simple beam \( AB \) (see figure). Data are as follows: \( P = 5.4 \) kN, \( L = 3.0 \) m, \( d = 1.2 \) m, \( b = 75 \) mm, \( t = 25 \) mm, \( h = 100 \) mm, and \( h_1 = 75 \) mm.

4.10. A cantilever beam \( AB \) with a rectangular cross section has a longitudinal hole drilled throughout its length (see figure). The beam supports a load \( P = 600 \) N. The cross section is 25 mm wide and 50 mm high, and the hole has a diameter of 10 mm. Find the bending stresses at the top of the beam, at the top of the hole, and at the bottom of the beam.

4.11. A small dam of height \( h = 1.8 \) m is constructed of vertical wood beams \( AB \), as shown in the figure. The wood beams, which have thickness \( t = 60 \) mm., are simply supported by horizontal steel beams at \( A \) and \( B \). Construct a graph showing the maximum bending stress \( \sigma_{\text{max}} \) in the wood beams versus the depth \( d \) of the water above the lower support at \( B \). Plot the stress \( \sigma_{\text{max}} \) (MPa) as the ordinate and the depth \( d \) (m) as the abscissa. (Note: The weight density \( g \) of water equals 10 kN/m\(^3\)).

4.12. A fiberglass bracket \( ABCD \) of solid circular cross section has the shape and dimensions shown in the figure. A vertical load \( P = 36 \) N acts at the free end \( D \). Determine the minimum permissible diameter \( d_{\text{min}} \) of the bracket if the allowable bending stress in the material is 30 MPa and \( b = 35 \) mm. (Disregard the weight of the bracket itself.)

4.13. A pontoon bridge (see figure) is constructed of two longitudinal wood beams, known as balks, that span between adjacent pontoons and support the transverse floor beams, which are called chesses. For purposes of design, assume that a uniform floor load of 8.0 kPa acts over the chesses. (This load includes an allowance for the weights of the chesses and balks.) Also, assume that the chesses are 2.0 m long and that the balks are simply supported with a span of 3.0 m. The allowable bending stress in the wood is 16 MPa. If the balks have a square cross section, what is their minimum required width \( b_{\text{min}} \)?
4.14. The wood joists supporting a plank floor (see figure) are 40 mm × 180 mm in cross section (actual dimensions) and have a span length \( L = 4.0 \) m. The floor load is 3.6 kPa, which includes the weight of the joists and the floor. Calculate the maximum permissible spacing \( s \) of the joists if the allowable bending stress is 15 MPa. (Assume that each joist may be represented as a simple beam carrying a uniform load.)

4.15. A so-called “trapeze bar” in a hospital room provides a means for patients to exercise while in bed (see figure). The bar is 2.1 m long and has a cross section in the shape of a regular octagon. The design load is 1.2 kN applied at the midpoint of the bar, and the allowable bending stress is 200 MPa. Determine the minimum height \( h \) of the bar. (Assume that the ends of the bar are simply supported and that the weight of the bar is negligible.)

4.16. A horizontal shelf \( AD \) of length \( L = 900 \) mm, width \( b = 300 \) mm, and thickness \( t = 20 \) mm is supported by brackets at \( B \) and \( C \) [see part (a) of the figure]. The brackets are adjustable and may be placed in any desired positions between the ends of the shelf. A uniform load of intensity \( q \), which includes the weight of the shelf itself, acts on the shelf [see part (b) of the figure]. Determine the maximum permissible value of the load \( q \) if the allowable bending stress in the shelf is \( \sigma_{\text{allow}} = 5.0 \) MPa and the position of the supports is adjusted for maximum load-carrying capacity.

4.17. A steel beam \( ABC \) is simply supported at \( A \) and \( B \) and has an overhang \( BC \) of length \( L = 150 \) mm (see figure on the next page). The beam supports a uniform load of intensity \( q = 3.5 \) kN/m over its entire length of 450 mm. The cross section of the beam is rectangular with width \( b \) and height \( 2b \). The allowable bending stress in the steel is \( \sigma_{\text{allow}} = 60 \) MPa and its weight density is \( \gamma = 77.0 \) kN/m³.
   a. Disregarding the weight of the beam, calculate the required width \( b \) of the rectangular cross section.
   b. Taking into account the weight of the beam, calculate the required width \( b \).

4.18. Calculate the maximum shear stress \( \tau_{\text{max}} \) and the maximum bending stress \( \sigma_{\text{max}} \) in a simply supported wood beam (see figure) carrying a uniform load of 18.0 kN/m (which includes the weight of the beam) if the length is 1.75 m and the cross section is rectangular with width 150 mm and height 250 mm.
4.19. A cantilever beam of length \( L = 2 \text{ m} \) supports a load \( P = 8.0 \text{ kN} \) (see figure). The beam is made of wood with cross-sectional dimensions 120 mm \( \times \) 200 mm. Calculate the shear stresses due to the load \( P \) at points located 25 mm, 50 mm, 75 mm, and 100 mm from the top surface of the beam. From these results, plot a graph showing the distribution of shear stresses from top to bottom of the beam.

![Beam Diagram](image1)

4.20. A laminated plastic beam of square cross section is built up by gluing together three strips, each 10 mm \( \times \) 30 mm in cross section (see figure). The beam has a total weight of 3.2 N and is simply supported with span length \( L = 320 \text{ mm} \). Considering the weight of the beam, calculate the maximum permissible load \( P \) that may be placed at the midpoint if
a. the allowable shear stress in the glued joints is 0.3 MPa, and
b. the allowable bending stress in the plastic is 8 MPa.

![Beam Diagram](image2)

4.21. A simply supported wood beam of rectangular cross section and span length 1.2 m carries a concentrated load \( P \) at midspan in addition to its own weight (see figure). The cross section has width 140 mm and height 240 mm. The weight density of the wood is 5.4 \( \text{kN/m}^3 \). Calculate the maximum permissible value of the load \( P \) if (a) the allowable bending stress is 8.5 MPa, and (b) the allowable shear stress is 0.8 MPa.

![Beam Diagram](image3)

4.22. A simple log bridge in a remote area consists of two parallel logs with planks across them (see figure). The logs are Douglas fir with average diameter 300 mm. A truck moves slowly across the bridge, which spans 2.5 m. Assume that the weight of the truck is equally distributed between the two logs. Because the wheelbase of the truck is greater than 2.5 m, only one set of wheels is on the bridge at a time. Thus, the wheel load on one log is equivalent to a concentrated load \( W \) acting at any position along the span. In addition, the weight of one log and the planks it supports is equivalent to a uniform load of 850 N/m acting on the log. Determine the maximum permissible wheel load \( W \) based upon (a) an allowable bending stress of 7.0 MPa, and (b) an allowable shear stress of 0.75 MPa.

![Bridge Diagram](image4)

4.23. A sign for an automobile service station is supported by two aluminum poles of hollow circular cross section, as shown in the figure. The poles are being designed to resist a wind pressure of 3.6 kPa against the full area of the sign. The dimensions of the poles and sign are \( h_1 = 6.0 \text{ m} \), \( h_2 = 1.5 \text{ m} \), and \( b = 3 \text{ m} \). To prevent buckling of the walls of the poles, the thickness \( t \) is specified as one-tenth the outside diameter \( d \). (a) Determine the minimum required diameter of the poles based upon an allowable bending stress of 50 MPa in the aluminum. (b) Determine the minimum required diameter based upon an allowable shear stress of 14 MPa.

![Sign Diagram](image5)
4.24. A bridge girder \( AB \) on a simple span of length \( L = 14 \) m supports a uniform load of intensity \( q \) that includes the weight of the girder (see figure). The girder is constructed of three plates welded to form the cross section shown. Determine the maximum permissible load \( q \) based upon (a) an allowable bending stress \( \sigma_{\text{allow}} = 110 \) MPa, and (b) an allowable shear stress \( \tau_{\text{allow}} = 50 \) MPa.

4.25. A welded steel girder having the cross section shown in the figure is fabricated of two 280 mm \( \times \) 25 mm flange plates and a 600 mm \( \times \) 15 mm web plate. The plates are joined by four fillet welds that run continuously for the length of the girder. Each weld has an allowable load in shear of 900 kN/m. Calculate the maximum allowable shear force \( V_{\text{max}} \) for the girder.

4.26. A box beam of wood is constructed of two 260 mm \( \times \) 50 mm boards and two 260 mm \( \times \) 25 mm boards (see figure). The boards are nailed at a longitudinal spacing \( s = 100 \) mm. If each nail has an allowable shear force \( F = 1200 \) N, what is the maximum allowable shear force \( V_{\text{max}} \)?

4.27. Two wood box beams (beams A and B) have the same outside dimensions (200 mm \( \times \) 360 mm) and the same thickness \( t = 20 \) mm throughout, as shown in the figure on the next page. Both beams are designed for a shear force \( V = 3.2 \) kN.
   a. What is the maximum longitudinal spacing \( s_A \) for the nails in beam A?
   b. What is the maximum longitudinal spacing \( s_B \) for the nails in beam B?
   c. Which beam is more efficient in resisting the shear force?

4.28. A beam of T cross section is formed by nailing together two boards having the dimensions shown in the figure. If the total shear force \( V \) acting on the cross section is 1600 N and each nail may carry 750 N in shear, what is the maximum allowable nail spacing \( s \)?
4.29. A vertical pole of aluminum is fixed at the base and pulled at the top by a cable having a tensile force $T$ (see figure). The cable is attached at the outer surface of the pole and makes an angle $\alpha = 25^\circ$ at the point of attachment. The pole has length $L = 2.0$ m and a hollow circular cross section with outer diameter $d_2 = 260$ mm and inner diameter $d_1 = 200$ mm. Determine the allowable tensile force $T_{allow}$ in the cable if the allowable compressive stress in the aluminum pole is 90 MPa.

4.30. A steel bar of solid circular cross section is subjected to an axial tensile force $T = 26$ kN and a bending moment $M = 3.2$ kN-m (see figure). Based upon an allowable stress in tension of 120 MPa, determine the required diameter $d$ of the bar. (Disregard the weight of the bar itself.)

4.31. A flying buttress transmits a load $P = 25$ kN, acting at an angle of $60^\circ$ to the horizontal, to the top of a vertical buttress $AB$ (see figure). The vertical buttress has height $h = 5.0$ m and rectangular cross section of thickness $t = 1.5$ m and width $b = 1.0$ m (perpendicular to the plane of the figure). The stone used in the construction weighs $\gamma = 26$ kN/m$^3$. What is the required weight $W$ of the pedestal and statue above the vertical buttress (that is, above section $A$) to avoid any tensile stresses in the vertical buttress?

4.32. A plain concrete wall (i.e., a wall with no steel reinforcement) rests on a secure foundation and serves as a small dam on a creek (see figure on the next page). The height of the wall is $h = 1.8$ m and the thickness of the wall is $t = 300$ mm.

a. Determine the maximum tensile and compressive stresses $\sigma_t$ and $\sigma_c$, respectively, at the base of the wall when the water level reaches the top ($d = h$). Assume plain concrete has weight density $\gamma_c = 22$ kN/m$^3$.

b. Determine the maximum permissible depth $d_{max}$ of the water if there is to be no tension in the concrete.
5.1. An element in plane stress is subjected to stresses $\sigma_x = 80$ MPa, $\sigma_y = 52$ MPa, and $\tau_{xy} = 48$ MPa, as shown in the figure. Determine the stresses acting on an element oriented at an angle $\theta = 60^\circ$ from the $x$ axis, where the angle $\theta$ is positive when counterclockwise. Show these stresses on a sketch of an element oriented at the angle $\theta$.

5.2. Solve Problem 5.1 for $\sigma_x = -9,900$ psi, $\sigma_y = -3,400$ psi, $\tau_{xy} = 3,600$ psi, and $\theta = 50^\circ$.

5.3. The stresses acting on element $A$ in the web of a train rail are found to be 42 MPa tension in the horizontal direction and 140 MPa compression in the vertical direction (see figure). Also, shear stresses of magnitude 60 MPa act in the directions shown. Determine the stresses acting on an element oriented at a counterclockwise angle of 48° from the horizontal. Show these stresses on a sketch of an element oriented at this angle.

5.4. An element in plane stress from the fuselage of an airplane is subjected to compressive stresses of magnitude 25.5 MPa in the horizontal direction and tensile stresses of magnitude 6.5 MPa in the vertical direction (see figure). Also, shear stresses of magnitude 12.0 MPa act in the directions shown. Determine the stresses acting on an element oriented at a clockwise angle of 40° from the horizontal. Show these stresses on a sketch of an element oriented at this angle.

5.5. The stresses acting on element $B$ in the web of a wide-flange beam are found to be 54 MPa compression in the horizontal direction and 12 MPa compression in the vertical direction (see figure). Also, shear stresses of magnitude 20 MPa act in the directions shown. Determine the stresses acting on an element oriented at a clockwise angle of 42.5° from the horizontal. Show these stresses on a sketch of an element oriented at this angle.

5.6. The polyethylene liner of a settling pond is subjected to stresses $\sigma_x = 2.100$ kPa, $\sigma_y = 300$ kPa, and $\tau_{xy} = -560$ kPa, as shown by the plane stress element in the first part of the figure. Determine the normal and shear stresses acting on a seam oriented at an angle of 22.5° to the element, as shown in the second part of the figure. Show these stresses on a sketch of an element having its sides parallel and perpendicular to the seam.

5.7. A rectangular plate of dimensions 100 mm. $\times$ 250 mm. is formed by welding two triangular plates (see figure). The plate is subjected to a compressive stress of 2.5 MPa in the long direction and a tensile stress of 12 MPa in the short direction. Determine the normal stress $\sigma_w$ acting perpendicular to the line of the weld and the shear stress $\tau_w$ acting parallel to the weld. (Assume that the normal stress $\sigma_w$ is positive when it acts in tension against the weld and the shear stress $\tau_w$ is positive when it acts counterclockwise against the weld.)
5.8. At a point on the surface of a machine the material is in biaxial stress with $\sigma_x = 32$ MPa and $\sigma_y = -50$ MPa, as shown in the first part of the figure. The second part of the figure shows an inclined plane $aa$ cut through the same point in the material but oriented at an angle $\theta$. Determine the value of the angle $\theta$ between zero and 90° such that no normal stress acts on plane $aa$. Sketch a stress element having plane $aa$ as one of its sides and show all stresses acting on the element.

5.9. An element in plane stress from the frame of a racing car is oriented at a known angle $\theta$ (see figure). On this inclined element, the normal and shear stresses have the magnitudes and directions shown in the figure. Determine the normal and shear stresses acting on an element whose sides are parallel to the $xy$ axes; that is, determine $\sigma_x$, $\sigma_y$, and $\tau_{xy}$. Show the results on a sketch of an element oriented at $\theta = 0°$.

5.10. The surface of an airplane wing is subjected to plane stress with normal stresses $\sigma_x$ and $\sigma_y$ and shear stress $\tau_{xy}$ as shown in the figure. At a counterclockwise angle $\theta = 30°$ from the $x$ axis the normal stress is 35 MPa tension, and at an angle $\theta = 50°$ it is 10 MPa compression. If the stress $\sigma_x$ equals 100 MPa tension, what are the stresses $\sigma_y$ and $\tau_{xy}$?

5.11. An element in plane stress is subjected to stresses $\sigma_x = 80$ MPa, $\sigma_y = 52$ MPa, and $\tau_{xy} = 48$ MPa (see the figure for Problem 5.1). Determine the principal stresses and show them on a sketch of a properly oriented element.

5.12. An element in plane stress is subjected to stresses $\sigma_x = 42$ MPa, $\sigma_y = -140$ MPa, and $\tau_{xy} = -60$ MPa. Determine the principal stresses and show them on a sketch of a properly oriented element.

5.13. An element in plane stress is subjected to stresses $\sigma_x = -25.5$ MPa, $\sigma_y = 6.5$ MPa, and $\tau_{xy} = -12.0$ MPa. Determine the maximum shear stresses and associated normal stresses and show them on a sketch of a properly oriented element.

5.14. An element in plane stress is subjected to stresses $\sigma_x = -54$ MPa, $\sigma_y = -12$ MPa, and $\tau_{xy} = 20$ MPa. Determine the maximum shear stresses and associated normal stresses and show them on a sketch of a properly oriented element.

5.15. A propeller shaft subjected to combined torsion and axial thrust is designed to resist a shear stress of 63 MPa and a compressive stress of 90 MPa (see figure).

a. Determine the principal stresses and show them on a sketch of a properly oriented element.

b. Determine the maximum shear stresses and associated normal stresses and show them on a sketch of a properly oriented element.

5.16. An element in plane stress is subjected to stresses $\sigma_x = -68.5$ MPa and $\tau_{xy} = 39.2$ MPa (see figure). It is known that one of the principal stresses equals 26.3 MPa in tension. Determine the stress $\sigma_y$.

b. Determine the other principal stress and the orientation of the principal planes; then show the principal
stresses on a sketch of a properly oriented element.

5.17. An element in uniaxial stress is subjected to tensile stresses \( \sigma_x = 55 \text{ MPa} \), as shown in the figure. Using Mohr’s circle, determine (a) the stresses acting on an element oriented at an angle \( \theta = 30^\circ \) from the x axis (minus means clockwise) and (b) the maximum shear stresses and associated normal stresses. Show all results on sketches of properly oriented elements.

5.18. An element in biaxial stress is subjected to stresses \( \sigma_x = -60 \text{ MPa} \) and \( \sigma_y = 20 \text{ MPa} \), as shown in the figure. Using Mohr’s circle, determine (a) the stresses acting on an element oriented at a counterclockwise angle \( \theta = 22.5^\circ \) from the x axis and (b) the maximum shear stresses and associated normal stresses. Show all results on sketches of properly oriented elements.

5.19. An element in pure shear is subjected to stresses \( \tau_{xy} = -16 \text{ MPa} \), as shown in the figure. Using Mohr’s circle, determine (a) the stresses acting on an element oriented at a counterclockwise angle \( \theta = 20^\circ \) from the x axis and (b) the principal stresses. Show all results on sketches of properly oriented elements.

An element in plane stress is subjected to stresses \( \sigma_x, \sigma_y, \) and \( \tau_{xy} \) (see figure). For 5.20 – 5.22, using Mohr’s circle, determine the stresses acting on an element oriented at an angle \( \theta \) from the x axis. Show these stresses on a sketch of an element oriented at the angle \( \theta \). (Note: The angle \( \theta \) is positive when counterclockwise and negative when clockwise.)

5.20. \( \sigma_x = 21 \text{ MPa}, \sigma_y = 11 \text{ MPa}, \tau_{xy} = 8 \text{ MPa}, \theta = 50^\circ \)
5.21. \( \sigma_x = -44 \text{ MPa}, \sigma_y = -194 \text{ MPa}, \tau_{xy} = -36 \text{ MPa}, \theta = -35^\circ \)
5.22. \( \sigma_x = 31 \text{ MPa}, \sigma_y = -5 \text{ MPa}, \tau_{xy} = 33 \text{ MPa}, \theta = 45^\circ \)

An element in plane stress is subjected to stresses \( \sigma_x, \sigma_y, \) and \( \tau_{xy} \) (see figure). For 5.23 – 5.26, using Mohr’s circle, determine (a) the principal stresses and (b) the maximum shear stresses and associated normal stresses. Show all results on sketches of properly oriented elements.

5.23. \( \sigma_x = -31,5 \text{ MPa}, \sigma_y = 31,5 \text{ MPa}, \tau_{xy} = 30 \text{ MPa} \)
5.24. \( \sigma_x = 0, \sigma_y = -22,4 \text{ MPa}, \tau_{xy} = -6,6 \text{ MPa} \)
5.25. \( \sigma_x = -3,1 \text{ MPa}, \sigma_y = 7,9 \text{ MPa}, \tau_{xy} = -13,2 \text{ MPa} \)
6.1. A horizontal beam AB is pin-supported at end A and carries a load Q at end B, as shown in the figure. The beam is supported at C by a pinned-end column. The column is a solid steel bar (E = 200 GPa) of square cross section having length $L = 1.8$ m and side dimensions $b = 60$ mm. Based upon the critical load of the column, determine the allowable load Q if the factor of safety with respect to buckling is $n = 2.0$.

![Beam AB](image)

6.2. The multifaceted glass roof over the lobby of a museum building is supported by the use of pretensioned cables. At a typical joint in the roof structure, a strut AB is compressed by the action of tensile forces $F$ in a cable that makes an angle $a = 75\degree$ with the strut (see figure). The strut is a circular tube of aluminum ($E = 72$ GPa) with outer diameter $d_2 = 50$ mm and inner diameter $d_1 = 40$ mm. The strut is 1.0 m long and is assumed to be pinconnected at both ends. Using a factor of safety $n = 2.5$ with respect to the critical load, determine the allowable force $F$ in the cable.

![Strut AB](image)

6.3. A pinned-end strut of aluminum ($E = 72$ GPa) with length $L = 1.8$ m is constructed of circular tubing with outside diameter $d = 50$ mm (see figure). The strut must resist an axial load $P = 18$ kN with a factor of safety $n = 2.0$ with respect to the critical load. Determine the required thickness $t$ of the tube.

![Strut](image)

6.4. The truss ABC shown in the figure supports a vertical load $W$ at joint B. Each member is a slender circular steel pipe ($E = 200$ GPa) with outside diameter 100 mm and wall thickness 6.0 mm. The distance between supports is 7.0 m. Joint B is restrained against displacement perpendicular to the plane of the truss. Determine the critical value $W_{cr}$ of the load.

![Truss ABC](image)

6.5. An aluminum pipe column ($E = 210$ GPa) with length $L = 1.2$ m has inside and outside diameters $d_1 = 36$ mm. And $d_2 = 40$ mm, respectively (see figure). The column is supported only at the ends and may buckle in any direction. Calculate the critical load $P_{cr}$ for the following end conditions: (1) pinned-pinned, (2) fixed-free, (3) fixed-pinned, and (4) fixed-fixed.

![Column](image)

6.6. A vertical post AB is embedded in a concrete foundation and held at the top by two cables (see figure). The post is a hollow steel tube with modulus of elasticity 200 GPa, outer diameter 40 mm, and thickness 5 mm. The cables are tightened equally by turnbuckles. If a factor of safety of 3.0 against Euler buckling in the plane of the figure is desired, what is the maximum allowable tensile force $T_{allow}$ in the cables?

![Post AB](image)
6.7. The roof beams of a warehouse are supported by pipe columns (see figure on the next page) having outer diameter \( d_2 = 100 \) mm and inner diameter \( d_1 = 90 \) mm. The columns have length \( L = 4.0 \) m, modulus \( E = 210 \) GPa, and fixed supports at the base. Calculate the critical load \( P_{cr} \) of one of the columns using the following assumptions: (1) the upper end is pinned; (2) the upper end is fixed.

6.8. An aluminum tube \( AB \) of circular cross section is fixed at the base and pinned at the top to a horizontal beam supporting a load \( Q = 200 \) kN (see figure). Determine the required thickness \( t \) of the tube if its outside diameter \( d \) is 100 mm and the desired factor of safety with respect to Euler buckling is \( n = 3.0 \). (Assume \( E = 72 \) GPa.)

6.9. A steel bar having a square cross section (50 mm \( \times \) 50 mm) and length \( L = 2.0 \) m is compressed by axial loads that have a resultant \( P = 60 \) kN acting at the midpoint of one side of the cross section (see figure). Assuming that the modulus of elasticity \( E \) is equal to 210 GPa and that the ends of the bar are pinned, calculate the maximum deflection \( \delta \) and the maximum bending moment \( M_{max} \).

6.10. An aluminum box column of square cross section is fixed at the base and free at the top (see figure). The outside dimension \( b \) of each side is 100 mm and the thickness \( t \) of the wall is 8 mm. The resultant of the compressive loads acting on the top of the column is a force \( P = 50 \) kN acting at the outer edge of the column at the midpoint of one side. What is the longest permissible length \( L_{max} \) of the column if the deflection at the top is not to exceed 30 mm? (Assume \( E = 73 \) GPa.)

6.11. A steel post \( AB \) of hollow circular cross section is fixed at the base and free at the top (see figure). The inner and outer diameters are \( d_1 = 96 \) mm and \( d_2 = 110 \) mm, respectively, and the length \( L = 4.0 \) m. A cable \( CBD \) passes through a fitting that is welded to the side of the post. The distance between the plane of the cable (plane \( CBD \)) and the axis of the post is \( e = 100 \) mm, and the angles between the cable and the ground are a 53.13°. The cable is pretensioned by tightening the turnbuckles. If the deflection at the top of the post is limited to \( \delta = 20 \) mm, what is the maximum allowable tensile force \( T \) in the cable? (Assume \( E = 205 \) GPa.)
6.12. A brass bar ($E = 100$ GPa) with a square cross section is subjected to axial forces having a resultant $P$ acting at distance $e$ from the center (see figure). The bar is pin supported at the ends and is 0.6 m in length. The side dimension $b$ of the bar is 30 mm and the eccentricity $e$ of the load is 10 mm. If the allowable stress in the brass is 150 MPa, what is the allowable axial force $P_{allow}$?

6.13. A pinned-end column of length $L = 2.1$ m is constructed of steel pipe ($E = 210$ GPa) having inside diameter $d_1 = 60$ mm and outside diameter $d_2 = 68$ mm (see figure). A compressive load $P = 10$ kN acts with eccentricity $e = 30$ mm.
   a. What is the maximum compressive stress $\sigma_{max}$ in the column?
   b. If the allowable stress in the steel is 50 MPa, what is the maximum permissible length $L_{max}$ of the column?

6.14. A circular aluminum tube with pinned ends supports a load $P = 18$ kN acting at distance $e = 50$ mm from the center (see figure). The length of the tube is 3.5 m and its modulus of elasticity is 73 GPa. If the maximum permissible stress in the tube is 20 MPa, what is the required outer diameter $d_2$ if the ratio of diameters is to be $d_1/d_2 = 0.9$?