1.1 Two solid cylindrical rods $AB$ and $BC$ are welded together at $B$ and loaded as shown. Knowing that the average normal stress must not exceed 175 MPa in rod $AB$ and 150 MPa in rod $BC$, determine the smallest allowable values of $d_1$ and $d_2$.

1.2 Two solid cylindrical rods $AB$ and $BC$ are welded together at $B$ and loaded as shown. Knowing that $d_1 = 50$ mm and $d_2 = 30$ mm, find the average normal stress at the midsection of (a) rod $AB$, (b) rod $BC$.

1.3 Two solid cylindrical rods $AB$ and $BC$ are welded together at $B$ and loaded as shown. Determine the magnitude of the force $P$ for which the tensile stress in rod $AB$ has the same magnitude as the compressive stress in rod $BC$.

1.4 In Prob. 1.3, knowing that $P = 40$ kips, determine the average normal stress at the midsection of (a) rod $AB$, (b) rod $BC$.

1.5 Two steel plates are to be held together by means of 16-mm-diameter high-strength steel bolts fitting snugly inside cylindrical brass spacers. Knowing that the average normal stress must not exceed 200 MPa in the bolts and 130 MPa in the spacers, determine the outer diameter of the spacers that yields the most economical and safe design.

1.6 Two brass rods $AB$ and $BC$, each of uniform diameter, will be brazed together at $B$ to form a nonuniform rod of total length 100 m which will be suspended from a support at $A$ as shown. Knowing that the density of brass is $8470 \text{ kg/m}^3$, determine (a) the length of rod $AB$ for which the maximum normal stress in $ABC$ is minimum, (b) the corresponding value of the maximum normal stress.

1.7 Each of the four vertical links has an $8 \times 36$-mm uniform rectangular cross section and each of the four pins has a 16-mm diameter. Determine the maximum value of the average normal stress in the links connecting (a) points $B$ and $D$, (b) points $C$ and $E$.

1.8 Knowing that link DE is $\frac{1}{4}$ in. thick and 1 in. wide, determine the normal stress in the central portion of that link when (a) $a = 0$, (b) $a = 90^\circ$.

1.9 Link $AC$ has a uniform rectangular cross section $\frac{1}{2}$ in. thick and $\frac{1}{2}$ in. wide. Determine the normal stress in the central portion of the link.

1.10 Three forces, each of magnitude $P = 4$ kN, are applied to the mechanism shown. Determine the cross-sectional area of the uniform portion of rod $BE$ for which the normal stress in that portion is +100 MPa.
1.11 The frame shown consists of four wooden members, ABC, DEF, BE, and CF. Knowing that each member has a 2 × 4-in. rectangular cross-section and that each pin has a 1/4-in. diameter, determine the maximum value of the average normal stress (a) in member BE, (b) in member CF.

![Fig. P1.11](image)

1.12 For the Pratt bridge truss and loading shown, determine the average normal stress in member BE, knowing that the cross-sectional area of that member is 5.87 in².

![Fig. P1.12](image)

1.13 An aircraft tow bar is positioned by means of a single hydraulic cylinder connected by a 25-mm-diameter steel rod to two identical arm-and-wheel units DEF. The mass of the entire tow bar is 200 kg, and its center of gravity is located at C. For the position shown, determine the normal stress in the rod.

![Fig. P1.13](image)

1.14 A couple M of magnitude 1500 N·m is applied to the crank of an engine. For the position shown, determine (a) the force P required to hold the engine system in equilibrium, (b) the average normal stress in the connecting rod BC, which has a 450-mm² uniform cross-section.

![Fig. P1.14](image)

1.15 When the force P reached 8 kN, the wooden specimen shown failed as shown along the surface indicated by the dashed line. Determine the average shearing stress along that surface at the time of failure.

![Fig. P1.15](image)

1.16 The wooden members A and B are to be joined by plywood splice plates that will be fully glued on the surfaces in contact. As part of the design of the joint, and knowing that the clearance between the ends of the members is to be 1/4 in., determine the smallest allowable length l if the average shearing stress in the glue is not to exceed 120 psi.

![Fig. P1.16](image)

1.17 A load P is applied to a steel rod supported at shown by an aluminum plate into which a 0.6-in.-diameter hole has been drilled. Knowing that the shearing stress must not exceed 18 ksi in the steel rod and 10 ksi in the aluminum plate, determine the largest load P that can be applied to the rod.

![Fig. P1.17](image)

1.18 Two wooden planks, each 22 mm thick and 160 mm wide, are joined by the glued mortise joint shown. Knowing that the joint will fail when the average shearing stress in the glue reaches 820 kPa, determine the smallest allowable length l of the cuts if the joint is to withstand an axial load of magnitude P = 7.6 kN.

![Fig. P1.18](image)
PROBLEMS

1.29 The 1.4-kip load P is applied by two wooden members of uniform cross section that are joined by the simple glued scarf splice shown. Determine the normal and shearing stresses in the glued splice.

1.30 Two wooden members of uniform rectangular cross section are joined by the simple scarf splice shown. Knowing that the maximum allowable tensile stress in the glued splice is 75 psi, determine (a) the largest load P that can be safely supported, (b) the corresponding shearing stress in the splice.

1.31 Two wooden members of uniform rectangular cross section are joined by the simple glued scarf splice shown. Knowing that \( P = 11 \text{ kips} \), determine the normal and shearing stresses in the glued splice.

1.32 Two wooden members of uniform rectangular cross section are joined by the simple scarf splice shown. Knowing that the maximum allowable shearing stress in the glued splice is 60 ksi, determine (a) the largest load P that can be safely applied, (b) the corresponding tensile stress in the splice.

1.33 A steel pipe of 12-in. outer diameter is fabricated from \( \frac{1}{2} \text{-in.} \) thick plate by welding along a helix that forms an angle of 25° with a plane perpendicular to the axis of the pipe. Knowing that the maximum allowable normal and shearing stresses in the directions respectively normal and tangential to the weld are \( s = 12 \text{ ksi} \) and \( \tau = 7.2 \text{ ksi} \), determine the magnitude of P of the largest axial force that can be applied to the pipe.

1.34 A steel pipe of 12-in. outer diameter is fabricated from \( \frac{1}{2} \text{-in.} \) thick plate by welding along a helix that forms an angle of 25° with a plane perpendicular to the axis of the pipe. Knowing that a 66 kip axial force is applied to the pipe, determine the normal and shearing stresses in directions respectively normal and tangential to the weld.

1.35 A 10,000-kN load P is applied to the granite block shown. Determine the resulting maximum value of (a) the normal stress, (b) the shearing stress. Specify the orientation of that plane on which each of these maximum values occurs.

1.36 A centric load P is applied to the granite block shown. Knowing that the resulting maximum value of the shearing stress in the block is 15 MPa, determine (a) the magnitude of P, (b) the orientation of the surface on which the maximum shearing stress occurs, (c) the normal stress exerted on that surface, (d) the maximum value of the normal stress in the block.

1.37 Link BC is 6 mm thick, has a width of 125 mm, and is made of a steel with a 450-MPa ultimate strength in tension. What is the safety factor used if the structure shown was designed to support a 16-kN load P?

1.38 Link BC is 6 mm thick and is made of a steel with a 450-MPa ultimate strength in tension. What should be its width so as if the structure shown is being designed to support a 20-kN load P with a factor of safety of 3?

1.39 A \( \frac{1}{2} \)-in.-diameter rod made of the same material as rods AC and AD in the truss shown was tested to failure and an ultimate load of 29 kips was recorded. Using a factor of safety of 3.0, determine the required diameter (a) of rod AC, (b) of rod AD.

1.40 In the truss shown, members AC and AD consist of rods made of the same metal alloy. Knowing that AC is of 1-in. diameter and that the ultimate load for that rod is 75 kips, determine (a) the factor of safety for AC, (b) the required diameter of AD if it is desired that both rods have the same factor of safety.

1.41 Link AB is to be made of a steel for which the ultimate normal stress is 500 MPa. Determine the cross-sectional area of AB for which the factor of safety will be 3.50. Assume that the link will be adequately reinforced around the pins at A and B.
1.42 A steel loop ABCD of length 1.2 m and of 10-mm diameter is placed as shown around a 24-mm-diameter aluminum rod AC. Cables BE and DF, each of 12-mm diameter, are used to apply the load Q. Knowing that the ultimate strength of the steel used for the loop and the cables is 480 MPa and that the ultimate strength of the aluminum used for the rod is 260 MPa, determine the largest load Q that can be applied if an overall factor of safety of 3 is desired.

1.43 Two wooden members shown, which support a 3.6-kip load, are joined by plywood splices fully glued on the surfaces in contact. The ultimate shearing stress in the glue is 360 psi and the clearance between the members is 3/8 in. Determine the required length L of each splice if a factor of safety of 2.75 is to be achieved.

1.44 Two plates, each 3 5/8 in. thick, are used to splice a plastic strip as shown. Knowing that the ultimate shearing stress of the bonding between the surfaces is 130 psi, determine the factor of safety with respect to shear when \( P = 325 \) lb.

1.45 A load P is supported as shown by a steel pin that has been inserted in a short wooden member hanging from the ceiling. The ultimate strength of the wood used is 60 MPa in tension and 7.5 MPa in shear, while the ultimate strength of the steel is 450 MPa in shear.

Knowing that \( b = 40 \) mm, \( c = 55 \) mm, and \( d = 12 \) mm, determine the load P if an overall factor of safety of 3.2 is desired.

1.46 For the support of Prob. 1.45, knowing that the diameter of the pin is \( d = 16 \) mm and that the magnitude of the load is \( P = 20 \) kN, determine (a) the factor of safety for the pin, (b) the required values of \( b \) and \( c \) if the factor of safety for the wooden member is the same as that found in part a for the pin.

1.47 Three steel bolts are to be used to attach the steel plate shown to a wooden beam. Knowing that the plate will support a 110-kN load, that the ultimate shearing stress for the steel used is 260 MPa, and that a factor of safety of 3.5 is desired, determine the required diameter of the bolts.

1.48 Three 18-mm-diameter steel bolts are to be used to attach the steel plate shown to a wooden beam. Knowing that the plate will support a 110-kN load and that the ultimate shearing stress for the steel used is 260 MPa, determine the factor of safety for this design.

1.49 A steel plate \( 3 \) in. thick is embedded in a horizontal concrete slab and is used to anchor a high-strength vertical cable as shown. The diameter of the hole in the plate is \( 1 \) in., the ultimate strength of the steel used is 36 ksi, and the ultimate bonding stress between plate and concrete is 200 psi. Knowing that a factor of safety of 3.00 is desired when \( P = 2.5 \) kips, determine (a) the required width \( w \) of the plate, (b) the minimum depth \( b \) to which a plate of that width should be embedded in the concrete slab. (Neglect the normal stresses between the concrete and the bottom edge of the plate.)

Determine the factor of safety for the cable anchor in Prob. 1.49 when \( P = 3 \) kips, knowing that \( a = 2 \) in. and \( b = 7.5 \) in.
1.51 In the steel structure shown, a 6-mm-diameter pin is used at C and a 10-mm-diameter pin is used at B and D. The ultimate shearing stress is 150 MPa at all connections, and the ultimate normal stress is 400 MPa in link BD. Knowing that a factor of safety of 3.0 is desired, determine the largest load \( P \) that can be applied at A. Note that link BD is not reinforced around the pin holes.

![Fig. P1.51](image)

1.52 Solve Prob. 1.51, assuming that the structure has been redesigned to use 12-mm-diameter pins at B and D and no other change has been made.

1.53 Each of the two vertical links CF connecting the two horizontal members AD and BC has a uniform rectangular cross section \( \frac{1}{4} \) in. thick and 1 in. wide, and is made of a steel with an ultimate strength in tension of 80 ksi. The pins at C and F each have a 1-in. diameter and are made of a steel with an ultimate strength in shear of 25 ksi. Determine the overall factor of safety for the links CF and the pins connecting them to the horizontal members.

![Fig. P1.53](image)

1.54 Solve Prob. 1.53, assuming that the pins at C and F have been replaced by pins with a ½-in. diameter.

1.55 In the structure shown, an 8-mm-diameter pin is used at A, and a 12-mm-diameter pin is used at B and D. Knowing that the ultimate shearing stress is 100 MPa at all connections and that the ultimate normal stress is 250 MPa in each of the two links joining B and D, determine the allowable load \( P \) if an overall factor of safety of 3.0 is desired.

![Fig. P1.55](image)

1.56 In an alternative design for the structure shown in Prob. 1.55, a pin of 10-mm diameter is to be used at A. Assuming that all other specifications remain unchanged, determine the allowable load \( P \) if an overall factor of safety of 3.0 is desired.

1.57 The Load and Resistance Factor Design method is to be used to select the two cables that will raise and lower a platform supporting two window washers. The platform weighs 160 lb and each of the window washers is assumed to weigh 100 lb with equipment. Since these workers are free to move on the platform, 75% of their total weight and the weight of their equipment will be used as the design live load of each cable. (a) Assuming a resistance factor \( \phi = 0.95 \) and load factors \( \gamma_L = 1.25 \) and \( \gamma_C = 1.5 \), determine the required minimum ultimate load of one cable. (b) What is the conventional factor of safety for the selected cables?

1.58 A 40-kg platform is attached to the end B of a 50-kg wooden beam AB, which is supported as shown by a pin at A and by a slender steel rod BC with a 12-kN ultimate load. (a) Using the Load and Resistance Factor Design method with a resistance factor \( \phi = 0.00 \) and load factors \( \gamma_L = 1.25 \) and \( \gamma_C = 1.6 \), determine the largest load that can be safely placed on the platform. (b) What is the corresponding conventional factor of safety for rod BC?

![Fig. P1.57](image)

![Fig. P1.58](image)
1.62 In the marine crane shown, link CD is known to have a uniform cross section of $90 \times 150$ mm. For the loading shown, determine the normal stress in the central portion of that link.

![Diagram](image)

Fig. P1.62

1.63 Two wooden planks, each $\frac{1}{2}$ in. thick and 9 in. wide, are joined by the dry mortise joint shown. Knowing that the wood used shears off along its grain when the average shear stress reaches 1.20 ksi, determine the magnitude $P$ of the axial load that will cause the joint to fail.

![Diagram](image)

Fig. P1.63

1.64 Two wooden members of uniform rectangular cross section of sides $a = 100$ mm and $b = 60$ mm are joined by a simple glued joint as shown. Knowing that the ultimate stresses the joint are $\sigma_t = 1.20$ MPa in tension and $\tau_{ij} = 1.50$ MPa in shear and that $P = 6$ kN, determine the factor of safety for the joint when (a) $\alpha = 30^\circ$, (b) $\alpha = 35^\circ$, (c) $\alpha = 40^\circ$. For each of these values of $\alpha$, also determine whether the joint will fail in tension or in shear if $P$ is increased until rupture occurs.

![Diagram](image)

Fig. P1.64

1.65 Member ABC, which is supported by a pin and bracket at C and a cable BD was designed to support the 16-kN load $P$ as shown. Knowing that the ultimate load for cable BD is 100 kN, determine the factor of safety with respect to cable failure.

![Diagram](image)

Fig. P1.65

1.66 The 2000-lb load may be moved along the beam BD to any position between stops at E and F. Knowing that $\sigma_{tu} = 6$ ksi for the steel used in rods AB and CD, determine where the stops should be placed if the permitted motion of the load is to be as large as possible.

![Diagram](image)

Fig. P1.66

1.67 Knowing that a force $P$ of magnitude 750 N is applied to the pedal shown, determine (a) the diameter of the pin at C for which the average shearing stress in the pin is 40 MPa, (b) the corresponding bearing stress in the pedal at C, (c) the corresponding bearing stress in each support bracket at C.

![Diagram](image)

Fig. P1.67
1.68 A force $P$ is applied as shown to a steel reinforcing bar that has been embedded in a block of concrete. Determine the smallest length $L$ for which the full allowable normal stress in the bar can be developed. Express the result in terms of the diameter $d$ of the bar, the allowable normal stress $a_{n}$ in the steel, and the average allowable bond stress $a_{b}$ between the concrete and the cylindrical surface of the bar. (Neglect the normal stresses between the concrete and the end of the bar.)

![Fig. P1.68](image)

1.69 The two portions of member $AB$ are glued together along a plane forming an angle $\theta$ with the horizontal. Knowing that the ultimate stress for the glued joint is 2.5 ksi in tension and 1.3 ksi in shear, determine the range of values of $\theta$ for which the factor of safety of the members is at least 3.0.

![Fig. P1.69 and P1.70](image)

1.70 The two portions of member $AB$ are glued together along a plane forming an angle $\theta$ with the horizontal. Knowing that the ultimate stress for the glued joint is 2.5 ksi in tension and 1.3 ksi in shear, determine (a) the value of $\theta$ for which the factor of safety of the member is maximum, (b) the corresponding value of the factor of safety. (Hint: Equate the expressions obtained for the factors of safety with respect to normal stress and shear.)

![Fig. P1.71](image)

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**COMPUTER PROBLEMS**

The following problems are designed to be solved with a computer.

1.61 A solid steel rod consisting of a cylindrical elements welded together is subjected to the loading shown. The diameter of element $i$ is denoted by $d_{i}$ and the load applied to its lower end by $P_{i}$, with the magnitude $P_{i}$ of this load being assumed positive if $P_{i}$ is directed downward as shown and negative otherwise. (a) Write a computer program that can used with either SI or U.S. customary units to determine the average stress in each element of the rod. (b) Use this program to solve Probs. 1.2 and 1.4.

1.62 A 20kN load is applied as shown to the horizontal member $ABC$. Member $ABC$ has a $10 \times 50$-mm uniform rectangular cross section and is supported by four vertical links, each of $5 \times 36$-mm uniform rectangular cross section. Each of the four pins at $A$, $B$, $C$, and $D$ has the same diameter $d$ and is in double shear. (a) Write a computer program to calculate for values of $d$ from 10 to 30 mm, using 1-mm increments, (i) the maximum value of the average normal stress in the links connecting pins $B$ and $D$, (ii) the average normal stress in the links connecting pins $C$ and $E$, (iii) the average shear stress in pin $B$, (iv) the average shear stress in pin $C$, (v) the average bearing stress at pin $E$ in member $ABC$. (b) Check your program by comparing the values obtained for $d = 10$ mm with the answers given for Probs. 1.7 and 1.27. (c) Use this program to find the permissible values of the diameter $d$ of the pins, knowing that the allowable values of the normal, shearing, and bearing stresses for the steel used are, respectively, 150 MPa, 90 MPa, and 230 MPa. (d) Solve part (c), assuming that the thickness of member $ABC$ has been reduced from 10 to 8 mm.

![Fig. P1.61](image)

1.63 Two horizontal 5-kip forces are applied to pin $B$ of the assembly shown below. Each of the three pins at $A$, $B$, and $C$ has the same diameter $d$ and double shear. (a) Write a computer program to calculate for values of $d$ from 0.50 to 1.50 in., using 0.05-in. increments, (i) the maximum value of the average normal stress in member $ABC$, (ii) the average normal stress in member $ABC$. (b) Check the values of $d$ from 0.50 to 1.50 in., using 0.05-in. increments, (i) the maximum value of the average normal stress in member $ABC$, (ii) the average normal stress in member $ABC$. (c) Use this program to find the permissible values of the diameter $d$ of the pins, knowing that the allowable values of the normal, shearing, and bearing stresses for the steel used are, respectively, 150 MPa, 90 MPa, and 230 MPa. (d) Solve part (c), assuming that the thickness of member $ABC$ has been reduced from 10 to 8 mm.

![Fig. P1.62](image)