PROBLEMS IN STRENGTH OF MATERIALS

WILLIAM KENT SHEPARD

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PROBLEMS IN STRENGTH OF MATERIALS

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PREFACE

For the average student to obtain a working knowledge of any scientific subject it is necessary that he solve numerous problems. This is especially true in the study of mechanics. In teaching Strength of Materials the author has found that the text-books do not give a sufficient number of examples to completely familiarize the student with the application of the theory.

The aim of this book is to furnish a large variety of problems on each part of the subject, and thus relieve the instructor of tedious dictation in the class room.

A discussion of riveted joints is given for use in the computation and design of such joints as are often found in boiler construction.

No definite notation is adopted in order that the book may be used in connection with a course of lectures or with any text-book on the subject.

Tables at the back of the book give all the data necessary for solving the problems, but answers have been omitted in order to emphasize that the goal is a proper solution and not a mere numerical answer.

I wish to thank Professor C. B. Richards for suggesting numerous examples and for other valuable assistance in compiling this book.

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PROBLEMS IN STRENGTH OF MATERIALS

I. TENSION, COMPRESSION, AND SHEAR

1. Find the breaking unit-stress for a round rod $1\frac{1}{4}$ inches in diameter which breaks with a tensile load of 67,500 pounds.

2. If a wrought-iron bar $2 \times 1\frac{1}{4}$ inches section area breaks under a tensile load of 125,000 pounds, what load will break a wrought-iron rod $1\frac{1}{4}$ inches in diameter?

3. What should be the diameter of a round cast-iron bar which is subjected to a tension of 30,000 pounds, if the unit-stress is 2400 pounds per square inch?

4. Calculate the diameter of a round wrought-iron rod which is under a tension of 85,000 pounds, if the unit-stress is one half the elastic limit.

5. A piece of timber $2\frac{1}{2}$ inches thick is under a tension of 9000 pounds. Find its width if the unit-stress is to be 30 per cent of the elastic limit.

6. A bar of structural steel $1\frac{1}{2}$ inches in diameter ruptures under a tension of 100,000 pounds. Find the ultimate tensile strength of the bar and the tensile force which will rupture a bar of the same steel whose section area is $2\frac{1}{2} \times 3$ inches.

7. Find the greatest tensile force a copper wire 0.2 inch in diameter can stand without breaking.

8. Calculate the size of a square wrought-iron bar to stand a pull of 3000 pounds without breaking.

9. A steel specimen 0.802 inch in diameter and 8 inches long, in an experiment with the testing machine, reached the elastic limit under a tensile force of 24,640 pounds and ruptured under a load of 34,800 pounds. The length of the bar at the elastic limit was 8.0122 inches and at rupture 10.25 inches. Calculate the elastic limit, the ultimate tensile strength, the unit-elongation for the elastic limit and for rupture.

10. A cast-iron bar has an elliptical cross-section with axes 6 and 4 inches. Find the unit-stress under a tensile load of 120,000 pounds, and the factor of safety.

11. A brick column 2 feet square and 8 feet high sustains a load of 50 tons. What is the factor of safety?

12. What load can be borne by a brick pier whose cross-section is $2\frac{1}{2} \times 3\frac{1}{2}$ feet, with a factor of safety of 15?

13. Find the weight of a wrought-iron bar $1\frac{1}{4} \times 2$ inches section and 12 feet long, and of a cast-iron bar of the same size.

14. Find the cross-section area of a wooden beam which weighs 10 pounds per foot. What would be the cross-section area of a steel beam weighing the same per linear foot?

15. What must be the height of a brick tower if the compressive unit-stress on the lowest brick is one third of its ultimate strength?

16. A cast-iron cylindrical rod 1500 feet long is suspended vertically from its upper end. What is the unit-stress at this end, and the factor of safety?

17. Calculate the length of a cast-iron bar, supported vertically at its upper end, that will break under its own weight.

18. The maximum steam pressure in a steam engine is 120 pounds per square inch and the piston area is 200 square inches. Find the diameter of the steel piston-rod for a factor of safety of 8, if lateral bending is prevented.

19. Find the height of a brick wall of uniform thickness for a factor of safety of 15.

20. What must be the diameter of a hard steel piston-rod, if the piston is 18 inches in diameter and the maximum steam pressure is 110 pounds per square inch? Consider length of rod less than ten times its diameter.

21. A short wooden post is 6 inches in diameter. What compressive load can it bear with a factor of safety of 8?

22. A sandstone column bears a load of 6 tons. Find the area of its base for a factor of safety of 20, if the ultimate compressive strength is 3600 pounds per square inch.

23. Find the safe steady load for a short, hollow, cast-iron column, external diameter 10 inches, internal diameter 8 inches.

24. A wrought-iron plate $\frac{5}{8}$ inch thick requires a force of 60,000 pounds to punch a round hole $\frac{3}{4}$ inch in diameter through it. Find the ultimate shearing strength of the plate.

25. Calculate the force required to punch a hole 2 inches square through a cast-iron plate $\frac{3}{4}$ inch thick.

26. What force is necessary to punch a hole 1 inch in diameter through a wrought-iron plate $\frac{5}{8}$ inch thick?

27. What must be the least diameter of a steel bolt which is to safely resist a simple shearing force of 30,000 pounds?

28. Determine the unit shearing stress tending to shear off the head of a $1\frac{1}{2}$-inch wrought-iron bolt under a tension of 12,000 pounds, if the head is $\frac{3}{4}$ inch deep. What is the factor of safety?

29. A wrought-iron bolt $1\frac{1}{2}$ inches in diameter has a head $1\frac{1}{4}$ inches deep and a tension of 30,000 pounds applied longitudinally. Compute the factors of safety against tension and shear.

30. Determine the depth of head for a wrought-iron $1\frac{1}{4}$-inch bolt, if the tensile strength of the bolt is equal to the strength of the head against shearing.

31. The diameter of a wrought-iron bolt is $\frac{3}{4}$ inch. What should be the depth of the bolt head in order that the bolt be equally strong in tension and in shear?

32. A wooden rod 4 inches in diameter and 3 feet long is turned down to 2 inches diameter in the middle so as to leave the enlarged ends each 6 inches long. Will a steady tensile force rupture the rod in the middle or shear off the ends?

33. The head of an engine cylinder, 12 inches inside diameter, is fastened on by 10 wrought-iron bolts. What should be the diameter of the bolts if the steam pressure is 90 pounds per square inch and the allowable unit-stress is 2000 pounds per square inch?

NOTE. The root area should be used in this problem.

34. A cylinder $9\frac{1}{2}$ inches inside diameter contains steam at 180 pounds per square inch pressure. The cylinder-head is held by 6 wrought-iron bolts placed at equal distances from each other on the circumference. Find the diameter and depth of head of the bolts for a factor of safety of 10 against tension and shear.

35. A cubical steel block $\frac{1}{2}$ inch square rests on a wrought-iron plate $\frac{1}{4}$ inch thick and sustains a load of 10,000 pounds. Determine the factor of safety of the plate against being punched through by the block, and of the block against being crushed.

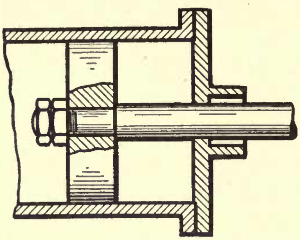


FIG. 1

36. A cylinder $9\frac{1}{2}$ inches inside diameter contains steam whose maximum pressure is 200 pounds per square inch. The steel piston-rod which projects through the piston has a nut on one side of the piston, and a shoulder on the other side, which carries the compressive load on the rod. Find the diameter of the rod through the piston, and that of the shoulder for a factor of safety of 8 against tension and compression.

II. ELASTIC DEFORMATION

37. A bar 1 inch in diameter and 8 feet long elongates 0.05 inch under a tension of 12,000 pounds. How much will a bar of the same material and diameter, 12 feet long, elongate with a pull of 30,000 pounds?

38. Compute the modulus of elasticity for the steel specimen of Problem 9.

39. A copper wire 0.04 inch in diameter and 10 feet long stretches 0.289 inch under a pull of 50 pounds. Find its modulus of elasticity.

40. A wooden specimen 1 inch in diameter and 9 inches long elongates 0.004 inch when the tension is increased from 500 to 1000 pounds, and 0.10 inch when the tension is increased from 1500 to 5000 pounds. Find the modulus of elasticity.

41. Determine the elongation of a $1\frac{1}{4}$-inch round wrought-iron rod 10 feet long, under a tensile load of 24,600 pounds.

42. A wrought-iron rod 2 inches square and 10 feet long lengthened 0.03 inch by suspending a load from its lower end. Determine the load.

43. A wrought-iron bar 10 feet long sustains a load $\frac{1}{5}$ as great as would be required to pull the bar apart. Determine the elongation of the bar, also the load if the bar is $1\frac{1}{2}$ inches square.

44. A wooden post 4 inches square and $2\frac{1}{2}$ feet high sustains a compressive load of 10 tons. How much will the post be shortened? Find the proportion of this shortening to that produced by loading the post to its elastic limit.

45. Determine the length of a $1\frac{1}{4}$-inch round wrought-iron bar, which would elongate 0.1 inch under a load of 8000 pounds suspended from its lower end, and the factor of safety.

46. By what proportion of its own height will a wrought-iron block be shortened if loaded to one half its elastic limit, and what will be the factor of safety?

47. A bar of structural steel 1 inch in diameter is under successive tensions of 25,000, 30,000, and 35,000 pounds. Calculate the unit-elongations in each case, and determine by this means which loads give a stress greater than the elastic limit of the bar.

48. How much will a steel punch 2 inches square and 4 inches long, of uniform size, be shortened by the force required to punch a 2-inch square hole through a wrought-iron plate $\frac{1}{4}$ inch thick?

49. How many 1-inch square rods of wrought-iron would be needed for the suspension of a platform loaded with 20 tons, if the stretching of the rods be limited to one half their elongation at the elastic limit? Each rod bears equal shares of the load.

50. A wrought-iron tie rod is $\frac{3}{4}$ inch diameter. How long must it be to lengthen $\frac{3}{8}$ inch under a steady tension of 5000 pounds?

51. A wooden rod 3 inches in diameter is elongated 0.05 inch by a force of 2000 pounds. What was its original length?

52. How much will a hundred-foot steel tape, $\frac{1}{2}$ inch wide and $\frac{1}{50}$ inch thick, stretch under a pull of 50 pounds?

53. A rectangular timber tie is 12 inches deep and 40 feet long. Find the proper thickness of the tie, so that its elongation under a pull of 270,000 pounds shall not exceed 1.2 inches.

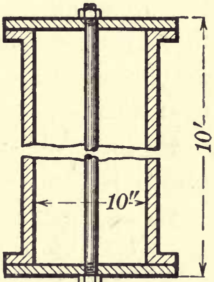


FIG. 2

54. A flanged cylinder 10 inches inside diameter and 10 feet long contains steam at a pressure of 150 pounds per square inch. The heads of the cylinder are held against the flanges by a single wrought-iron bolt 1 inch in diameter, extending through the axis of the cylinder. How much must the bolt be stretched by screwing up the nuts in order that the heads may be held steam-tight against the flanges?

55. Determine the diameter of a steel piston-rod for a piston 20 inches in diameter and a steam pressure 90 pounds per square inch, if the maximum unit-stress in the rod is to be 5000 pounds per square inch. Find the lengthening and shortening of the rod per linear foot under the pull and thrust.

56. A steel piston-rod is 9 feet long and 8 inches in diameter; the diameter of the cylinder is 88 inches, and the maximum effective pressure 40 pounds per square inch. Find the maximum unit-stress in the rod and the total alteration in length during a revolution.

57. A piston-rod of structural steel is 4 inches in diameter and 6 feet long. If the piston diameter is 30 inches, what maximum steam pressure may be used with a factor of safety of 10, and what is the lengthening and shortening of the rod?

58. A tie-rod 100 feet long and 2 square inches in sectional area carries a load of 32,000 pounds, by which it is stretched $\frac{3}{4}$ inch. Find the unit-stress, unit-elongation, and the modulus of elasticity.

59. A beam 12 feet long is suspended horizontally by vertical wrought-iron rods at each end. The rod at left end is 1 inch square and 12 feet long, while the rod at opposite end is $\frac{1}{2}$ inch square and 3 feet long. What concentrated load should be applied to the beam, and how far from the right end must it be placed, in order that each rod shall be stretched to just one half its elastic limit? Weight of beam and rods neglected. What is the elongation of each rod?

60. Calculate the elongation of the rod in Problem 16, due to its own weight.

61. A vertical wooden bar 100 feet long and 6 inches square carries a load of 21,000 pounds at its lower end. Find the unit-stress at the upper end and the elongation of the bar due to combined weight of bar and load.

62. Find the length of a vertical wooden bar 6 × 4 inches cross-section, and having a load of 17,000 pounds at lower end, so that the unit-stress at upper end, due to the combined weight, shall be one fourth the elastic limit. What is the elongation of the bar due to the load and that due to its own weight?

63. A vertical wrought-iron bar 60 feet long and 1 inch in diameter is fixed at the upper end and carries a load of 4000 pounds at the lower end. Find the factors of safety for both ends and the elongation of the bar.

64. Find the length of a vertical wrought-iron rod fixed at its upper end, if the maximum unit-stress in the rod is 8000 pounds per square inch. What will be its elongation?

65. Determine the elongation and factor of safety of a vertical structural steel rod 1 inch in diameter and 50 feet long, under its own weight and a weight of 20,000 pounds suspended from its lower end.

66. A wrought-iron bar 20 feet long and 1 inch square is under a tension of 20,000 pounds. Find the changes in length, section area, and volume.

67. A structural steel cylinder 2 feet high and 2 inches in diameter bears a compressive load of 90,000 pounds. Find the changes in length, diameter, section area, and volume.

68. A bar of structural steel 4 inches square and 20 feet long is under a tension of 216 tons. Calculate the changes in length, section area, and volume.

69. A wrought-iron bar is 20 feet long at 32° F. How long will it be at 90° F.?

70. A wrought-iron bar 18 feet long and $1\frac{1}{2}$ inches in diameter is heated to 400° F.; nuts on its ends are then screwed up so as to bear against the walls of a house which have fallen away from the perpendicular. Find the pull on the walls when the bar has cooled to 300° F.

71. A wrought-iron bar 2 square inches in cross-section has its ends fixed immovably between two walls when the temperature is 60° F. What pressure will be exerted on the walls when the temperature is 100° F.?

72. Steel railroad rails, each 30 feet long, are laid at a temperature of 40° F. What space must be left between them in order that their ends shall just meet at 90° F.? If the rails had been laid with their ends in contact, what would be the unit-stress in them at 90° F.?

73. A wrought-iron tie-rod 20 feet in length and 2 inches in diameter is screwed up to a tension of 10,000 pounds in order to tie together two walls of a building. Find the stress in the rod when the temperature falls 20° F.

74. A cast-iron bar is confined between two immovable walls. Find the unit-stress that will be produced by a rise in temperature of 50°F.

75. A structural steel tie-rod 40 feet in length and 2 inches square is subjected to a steady stress of 40,000 pounds. Find the elongation and the number of foot-pounds of work done.

76. How much work is done in subjecting a cube of 125 cubic inches of wrought-iron to a tensile stress of 10,000 pounds per square inch?

77. Find the work which is done in stressing bars of cast-iron, wrought-iron, and structural steel, each 1 inch in diameter and 2 feet long, up to their elastic limits.

78. Calculate the work which is required to stress a wrought-iron bar 2 inches in diameter and 5 feet long from 6000 to 12,000 pounds per square inch.

79. The work done by a gradually applied force in elongating a 1-inch square wrought-iron rod 25 feet long is 100 foot-pounds. What is the magnitude of the force applied?

80. A structural steel rod is required to support a suddenly applied load of 10,000 pounds. What is the minimum diameter of the rod if a permanent set is avoided?

81. A vertical rod, 2 square inches sectional area, carries a load of 5000 pounds. If an additional load of 2000 pounds is suddenly applied, what is the unit-stress produced?

82. Steam at a pressure of 50 pounds per square inch is suddenly admitted upon a piston 32 inches in diameter. Find the work done upon the steel piston-rod, which is 4 feet in length and 2 inches in diameter.

83. A line of steel rails is 10 miles in length when the temperature is 32° F. Find the length when the temperature is 102° F. and the work stored up in the rails per square inch of section.

84. A wrought-iron bar 25 feet in length and 1 square inch in sectional area has its temperature increased 20°F. Determine the work done.

85. Steam at a pressure of 200 pounds per square inch is suddenly admitted upon a piston 18 inches in diameter. If the steel piston-rod be 3 inches in diameter and 7 feet long, what is the maximum unit-stress and the work done on the rod at the maximum compression?

III. THIN CYLINDERS AND SPHERES

86. What internal pressure will burst a wrought-iron cylinder of 20 inches inside diameter and $\frac{1}{8}$ inch thickness?

87. Determine the diameter of a wrought-iron cylinder $\frac{1}{4}$ inch thick under an internal pressure of 1000 pounds per square inch for a factor of safety of 5.

88. Find the internal pressure for a cast-iron water pipe 24 inches inside diameter and 2 inches thick, for a factor of safety of 10.

89. Determine the thickness of a wrought-iron steam pipe 18 inches inside diameter to resist a pressure of 200 pounds per square inch with a factor of safety of 10.

90. Find the factor of safety for an 8-inch cast-iron water main $\frac{1}{2}$ inch thick, under a water pressure of 300 pounds per square inch.

91. Determine the thickness of a 6-inch cast-iron water pipe to carry a steady pressure of 200 pounds per square inch.

92. Find the factor of safety for a cast-iron water pipe 12 inches inside diameter and $\frac{3}{4}$ inch thick, under a head of 400 feet.

93. Calculate the thickness of a 16-inch cast-iron stand-pipe, which is subjected to a head of water of 300 feet. Assume that the stress is steady.

94. Determine the head of water which can be carried by a wrought-iron pipe 20 inches inside diameter and $\frac{1}{8}$ inch thick, with a factor of safety of 6.

95. A wrought-iron pipe 10 inches inside diameter and $\frac{1}{4}$ inch thick is subjected to an internal pressure of 500 pounds per square inch. Find the increase in diameter.

96. Compute the thickness of a cast-iron water pipe 18 inches inside diameter, under a head of 200 feet, for a factor of safety of 10. What is the increase in diameter?

97. What head of water can be carried in a cast-iron pipe 2 feet inside diameter and $\frac{3}{4}$ inch thick, with a factor of safety of 10?

98. What internal pressure will burst a cast-iron sphere 24 inches inside diameter and $\frac{5}{8}$ inch thick?

99. A cast-iron sphere 10 inches inside diameter and $\frac{1}{4}$ inch thick sustains an internal pressure of 200 pounds per square inch. Find the factor of safety.

100. What should be the minimum thickness of a cast-iron sphere 8 inches inside diameter to safely withstand a steady internal pressure of 200 pounds per square inch?

101. A force of 500 pounds is applied to the piston-head of a force-pump 1 inch in diameter, which transfers its pressure to a hollow cast-iron sphere 10 inches in diameter. What should be the thickness of the sphere for a factor of safety of 6?

102. Determine the pressure for a factor of safety of 5 in a 60-inch wrought-iron boiler shell $\frac{1}{4}$ inch thick, if the efficiency of the joint is 70 per cent.

103. Find the thickness of plates for a boiler shell 8 feet in diameter to work at a pressure of 160 pounds per square inch, if efficiency of joint is 80 per cent, and stress in plates is 5 tons per square inch.

104. A wrought-iron boiler shell 4 feet in diameter sustains a steam pressure of 120 pounds per square inch. If the efficiency of the riveted joint is 60 per cent and the stress steady, what should be the thickness of the plate?

105. A wrought-iron cylinder 20 inches inside diameter and $\frac{1}{2}$ inch thick has hemispherical ends $\frac{3}{16}$ inch thick. Determine the factor of safety if it is subjected to an internal pressure of 600 pounds per square inch.

106. A wrought-iron pipe 10 inches inside diameter and $\frac{1}{4}$ inch thick is 100 feet long when empty. What will be its length when subjected to an internal pressure of 500 pounds per square inch?

107. A wrought-iron pipe 5 inches inside diameter weighs 12.5 pounds per linear foot. Find its thickness and the internal pressure it can carry with a factor of safety of 8.

108. Find the elongation and factor of safety for a 6-inch wrought-iron pipe $\frac{1}{10}$ inch thick and 50 feet long, under an internal pressure of 200 pounds per square inch.

NOTE. The following problems are to be solved by Stewart's formulæ.*

* *Transactions of the American Society of Mechanical Engineers*, Vol. XXVII.

$$P = 1000\left(1 - \sqrt{1 - 1600\frac{t^2}{d^2}}\right), \qquad (A)$$

$$P = 86{,}670\frac{t}{d} - 1386, \qquad (B)$$

where P = collapsing pressure in pounds per square inch,
d = outside diameter of tube in inches,
t = thickness of wall in inches.

Formula (A) should be used for $P < 581$, or $\frac{t}{d} < 0.023$.

Formula (B) should be used for values greater than these.

109. What external pressure will collapse a steel tube whose outside diameter is 6 inches and thickness of wall 0.180 inch?

110. Find the exterior pressure that will collapse a steel tube $8\frac{5}{8}$ inches outside diameter and thickness of wall 0.180 inch.

111. Determine the internal and external pressures that will respectively rupture and collapse a steel tube 8 inches outside diameter and 0.20 inch thick.

112. What interior and exterior pressures will respectively rupture and collapse a steel tube 0.30 inch thick and 10 inches outside diameter?

113. What thickness of wall should a 4-inch boiler tube have in order to withstand a working pressure of 200 pounds per square inch, with a factor of safety of 6?

114. In a fire-tube boiler the tubes are of steel, 2 inches external diameter and $\frac{1}{8}$ inch thick. What is the factor of safety for a working pressure of 200 pounds per square inch?

115. Find the exterior pressure to collapse a wrought-iron tube 4 inches outside diameter and 0.20 inch thick. What should be the thickness for this tube under a steam pressure of 150 pounds per square inch with a factor of safety of 6?

116. What external pressure can a wrought-iron pipe 3 inches outside diameter and $\frac{1}{4}$ inch thick safely sustain and be secure against shocks?

117. Find the thickness of a boiler tube 3 inches outside diameter and exposed to an external steam pressure of 150 pounds per square inch for a factor of safety of 10.

IV. RIVETED JOINTS

In structural work, as in girders, trusses, etc., and in many forms of receptacles, such as tanks, the shells of steam boilers, etc., composed of plates, the plates are joined together by riveted joints.

When the plates are in tension the rivets transfer the tension from one plate to another. This brings a stress upon each rivet, which tends to shear it across in the plane of the surfaces of contact of the plates. A compressive stress is also brought upon the rounded surface of the rivet, where it bears upon the plate, which tends to crush it against the metal of the plate in front of the rivet. This is called a *bearing stress,* and the exact manner in which this stress acts between the cylindrical surface of the rivet and the hole in the plate through which the rivet passes is not known. Experiment and experience, however, show that for our computations we may suppose this stress to be uniformly distributed over an area which is the projection of the curved surface of the rivet hole up on a plane through its axis. We then compute for this projected area a working unit-stress whose safe value has been determined by experiment.

The general discussion of riveted joints covers their use in all kinds of structures, but we shall limit our attention to their use in uniting plates of pipes and shells which are subjected to internal fluid pressure, and have to be designed for tightness as well as strength. The special case is that of cylindrical boiler shells.

In connecting the plates, the rivets may be arranged in many different ways, but in general they are distributed in rows extending parallel to the edges of the plates that are joined, as is shown in the diagrams of a few forms of joints (see Figs. 3–9).

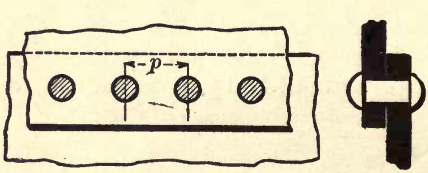


FIG. 3. Single-Riveted Lap Joint

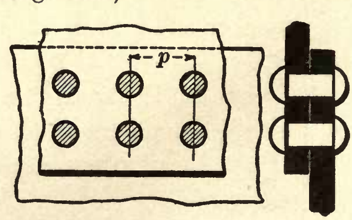


FIG. 4. Double-Chain-Riveted Lap Joint

In each single row the rivets are spaced uniformly, although the uniform spacing in one row may be different from that in another row. The uniform spacing, measured from the center of one rivet to the center of the next one in the same row, parallel to the edge of the plate, and in the row in which the rivets are most widely spaced, is called the *pitch.*

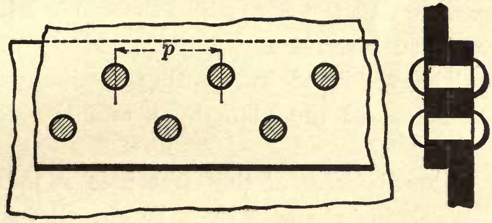


FIG. 5. Staggered Double-Riveted Lap Joint

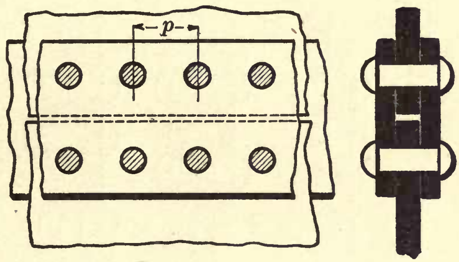


FIG. 6. Single-Riveted Two-Strap Butt Joint

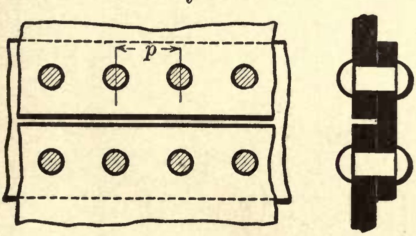


FIG. 7. Single-Riveted Single-Strap Butt Joint

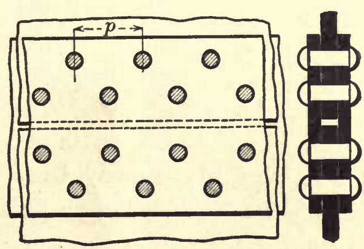


FIG. 8. Double-Riveted Two-Strap Butt Joint

By examining the diagrams it can be seen that there is in every case a repeating uniformity in the grouping of the rivets along the joint, so that the joint may be divided by lines perpendicular to the edge, into sections which are in every respect alike. These are called *repeating sections,* and in computing the strength of the joint we may compute the strength of one repeating section and

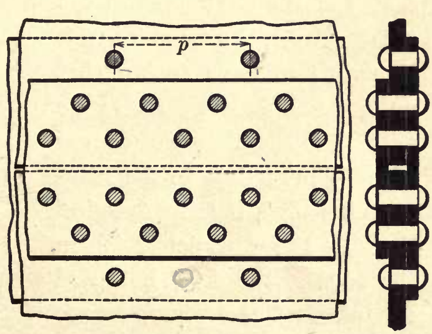


FIG. 9. Triple-Riveted Two-Strap Butt Joint

assume that the strength of the whole joint is that of the aggregate of all such sections.

The width of a repeating section will be denoted by p, the thickness of the plate by t, and the diameter of the rivet holes by d.

The diameter of the rivet hole is taken instead of the original diameter of the cold rivet, because the rivet, when properly driven and headed, completely fills the hole, the size of which therefore determines the effective diameter of the driven rivet. The cold rivet is usually about $\frac{1}{16}$ of an inch smaller than the hole, so that when heated red hot it may be easily and quickly inserted.

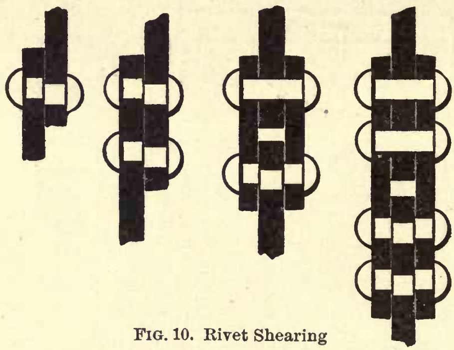


FIG. 10. Rivet Shearing

A riveted joint may fail in one of several ways.

1. The rivets may be sheared, as shown in Fig. 10.

2. The plate in front of the rivet may be sheared out, as in *a* of Fig. 11.

3. The plate may crush in front of the rivet, as in *b* or *c* of Fig. 11.

4. The plate may break along the rivet holes, as in *d*, or along lines from the center of a rivet in one row to the center of the next rivet in the adjacent row, as in *e* of Fig. 11. Experiments have shown that unless the bearing stress be excessive there is no danger of the joint failing in the manner of 2 or 3, if the "margin," that is, the distance between the edge of the rivet hole and the edge of the plate, be made sufficiently great. It should be made at least as great as d.

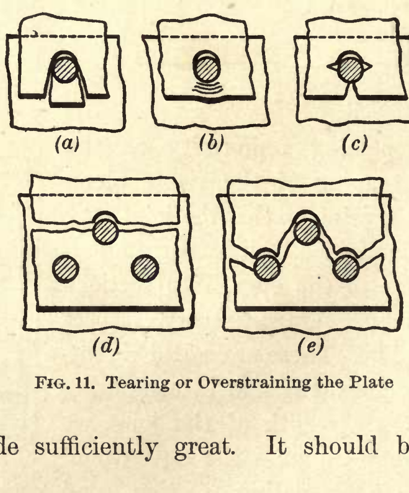


FIG. 11. Tearing or Overstraining the Plate

Let s_t = ultimate tensile unit-stress of the plate,
let s_c = ultimate compressive unit-stress of the rivets,
let s_s = ultimate shearing unit-stress of the rivets.

The *efficiency* of a joint is the ratio between the strength of the joint and the strength of the unriveted plate. Consider a single-riveted lap joint. In a repeating section there is here one rivet to be compressed, one rivet area to be sheared, and the plate is weakened by one rivet hole; hence

$$\left.\begin{aligned} pts_t &= \text{strength of unriveted plate,} \\ (p-d)ts_t &= \text{strength of riveted plate,} \\ tds_c &= \text{compressive strength of rivet,} \\ \frac{\pi d^2}{4}s_s &= \text{shearing strength of rivet.} \end{aligned}\right\} \qquad (A)$$

It is evident that the strength of the repeating section will be represented by the *least* value obtained from these.

We may compute three efficiencies from these expressions, but the smallest one only will give the true efficiency of the joint.

Or consider the following expressions. If the joint is so proportioned that it would fail by the tearing of the plate between the holes, efficiency would be $\frac{p-d}{p}$,

or if by the compression of the rivets, efficiency would be $\frac{ds_c}{ps_t}$; (*B*)

or if by the shearing of the rivets, efficiency would be $\frac{\frac{\pi d^2}{4}s_s}{pts_t}$.

We may therefore compute the efficiency of a joint in two ways: by dividing the smallest value found from equations (*A*), by the strength of the unriveted plate, or by the use of expressions (*B*), where the real efficiency of the joint will be the smallest one of the values thus obtained.

In a repeating section of a staggered double-riveted lap joint there are two rivets to transfer the tension; hence

$$(p-d)\, ts_t = \text{strength of riveted plate},$$

$$2\, tds_c = \text{compressive strength of rivets},$$

$$2\frac{\pi d^2}{4} s_s = \text{shearing strength of rivets}.$$

If the joint fail by tearing the plate, efficiency $= \dfrac{p-d}{p}$;

if by the compression of the rivets, efficiency $= \dfrac{2\, ds_c}{ps_t}$;

if by shearing the rivets, efficiency $= \dfrac{2\dfrac{\pi d^2}{4} s_s}{pts_t}$.

In a butt joint the main plates do not overlap, but cover plates are used to connect them. When tension is applied to the main plates of a butt joint having two cover plates, one half of this applied tension is transferred to each cover plate. Hence, theoretically, the thickness of each cover plate should be one half that of the main plate; but the cover plates, or straps, must be thick enough to remain tight against leakage arising from their flexure between the rivets, and so thick that their edges will admit of effective calking. It is customary, therefore, to make the thickness of each cover plate about five eighths that of the main plates. In the case of a single-strap joint, in which the strap is subject to a bending stress as well as to stress from calking, the strap is made $1\frac{1}{8}$ times the thickness of the main plates. Single-strap joints ought not to be used for the seams of boiler shells.

In a butt joint with single or double riveting, there are twice as many rivet sections to be sheared in a repeating section as in the corresponding case for a lap joint. Hence the strength of the joint against shearing the rivets is twice as great. The effective rivet-bearing surfaces in a butt joint are those surfaces only which are in front of the rivets where they pass through the main plate, and their number, therefore, is equal to the number of rivets in one of the main plates in the repeating section, one surface for each rivet. It must be recognized that in butt joints the number of rivets to be considered in a repeating section is the number on one side only of the line of separation of the main plates. Thus, in Figs. 6 and 7, only one rivet can be considered, in Fig. 8 two rivets are taken, and in Fig. 9 five rivets.

For a single-riveted butt joint with two cover plates

$$(p - d)\,ts_t = \text{strength of riveted plate,}$$
$$tds_c = \text{compressive strength of rivets,}$$
$$2\frac{\pi d^2}{4}s_s = \text{shearing strength of rivets.}$$

For a double-riveted butt joint with two cover plates

$$(p - d)\,ts_t = \text{strength of riveted plate,}$$
$$2\,tds_c = \text{compressive strength of rivets,}$$
$$4\frac{\pi d^2}{4}s_s = \text{shearing strength of rivets.}$$

In any riveted joint let n be the number of rivets and m the number of rivet sections subjected to shearing in a repeating section ; then

$$(p - d)\,ts_t = \text{strength of riveted plate,}$$
$$ntds_c = \text{compressive strength of rivets,}$$
$$m\frac{\pi d^2}{4}s_s = \text{shearing strength of rivets.}$$

The efficiency of the joint will be the least value obtained from these expressions, divided by pts_t, or the strength of the unriveted plate.

In our computations we shall use, for iron or soft steel plates and iron rivets,

$$s_t = 55{,}000 \text{ pounds per square inch,}$$
$$s_c = 80{,}000 \text{ pounds per square inch,}$$
$$s_s = 38{,}000 \text{ pounds per square inch.}$$

If we use a factor of safety of 5, and divide these values just given by this number, we shall have safe working unit-stresses of

11,000 pounds per square inch for tension,
16,000 pounds per square inch for compression,
7,600 pounds per square inch for shearing.

In determining the efficiency of a joint these working unit-stresses may be used in place of the values given for s_t, s_c, and s_s.

Let

$$P_t = \text{strength of riveted plate,}$$
$$P_c = \text{compressive strength of rivets,}$$
$$P_s = \text{shearing strength of rivets,}$$
$$P = \text{force transmitted by a repeating section ;}$$

then $\frac{P_t}{P}$ = factor of safety against tearing the plate,

$\frac{P_c}{P}$ = factor of safety against compressing the rivets,

$\frac{P_s}{P}$ = factor of safety against shearing the rivets.

Design of Riveted Joints

If no other consideration than economy of material in securing the necessary strength were taken into account in designing a joint, the relations between t, d, and p ought to be selected so as to make the values of P_t, P_s, and P_c equal; the efficiency will then be a maximum.

The process would be to first compute d by setting $P_s = P_c$, and then find p by putting $P_t = P_c$.

Practical considerations, however, such as the stanchness required in some joints, convenience of construction, economy of labor, etc., have led to a diversity of custom in proportioning joints so that they may be best adapted to the particular conditions of use.

For present purposes it may be assumed that in good American practice in the design of the joints of steam boiler shells, the diameter of the rivet hole is arbitrarily selected, and corresponds, practically, to a value derived from the expression $d = K\sqrt{t}$, in which $K = 1.5$ for single and double lap joints, and $K = 1.3$ for double-strap butt joints. The dimension p is then computed by using the value of d thus determined, and putting $P_t = P_s$, or $P_t = P_c$, selecting the smaller value of p thus derived as giving the safe dimensions for the pitch. The efficiency of the joint, if otherwise properly proportioned, will be $\frac{p-d}{p}$.

In staggered double-riveted joints the distance between the two rows of holes should be determined by making the diagonal pitch p'' (see Figs. 5 and 8), such that $p'' - d = 0.6\ (p - d)$. Experiment has shown this proportion to be a good one.

For an example we will design a triple-riveted, two-strap butt joint for $\frac{3}{8}$-inch plates (Fig. 9).

$t = \frac{3}{8}$ inch, $d = 1.3\sqrt{t} = .796$; selecting d to the nearest sixteenth of an inch, we have $d = \frac{13}{16}$ inch, $n = 5$, and $m = 9$.

$$P_t = (p - d)ts_t = (p - \tfrac{13}{16})\tfrac{3}{8} \cdot 55{,}000,$$

$$P_s = m\frac{\pi d^2}{4}s_s = 9\,(.518)\;38{,}000 = 177{,}666.7,$$

$$P_c = ntds_c = 5 \cdot \tfrac{3}{8} \cdot \tfrac{13}{16} \cdot 80{,}000 = 121{,}875.$$

$$\therefore \quad (p - \tfrac{13}{16})\tfrac{3}{8} \cdot 55{,}000 = 121{,}875.$$

Solving $p = 6.71$, we will then take

$p = 6\frac{3}{4}$ inches;

$$\frac{p-d}{p} = \frac{95}{108} = .88.$$

The joint then has an efficiency of 88 per cent, and the inner rows of rivets will have a spacing of $3\frac{3}{8}$ inches.

The present discussion of riveted joints is not given with the intention of completing the subject in regard to all forms and methods of construction, but for use in computations and design of such joints as are often found in boiler construction.

118. Determine the efficiency of a single-riveted lap joint if $t = \frac{3}{16}$ inch, $d = \frac{5}{8}$ inch, and $p = 1\frac{3}{4}$ inches.

119. Find the efficiency of a single-riveted lap joint if $t = \frac{3}{8}$ inch, $d = \frac{15}{16}$ inch, and $p = 2\frac{3}{16}$ inches.

120. Calculate the efficiency of a single-riveted lap joint if $t = \frac{5}{8}$ inch, $d = 1\frac{3}{16}$ inches, and $p = 2\frac{7}{16}$ inches.

121. Determine the efficiency of a single-riveted lap joint if $t = \frac{1}{2}$ inch, $d = 1\frac{1}{16}$ inches, and $p = 2\frac{5}{16}$ inches.

122. Calculate the efficiency of a single-riveted lap joint if $t = \frac{5}{16}$ inch, $d = \frac{13}{16}$ inch, and $p = 2\frac{1}{16}$ inches.

123. A single-riveted lap joint, with $t = \frac{7}{16}$ inch, $d = 1$ inch, and $p = 2\frac{1}{4}$ inches, sustains a tension of 5000 pounds on each repeating section. Compute the efficiency of the joint and the factors of safety.

124. Determine the pitch of a single-riveted lap joint where $t = \frac{1}{8}$ inch, and $d = \frac{1}{2}$ inch, so that the strength of the joint against tearing the plate between the rivet holes shall equal the shearing strength of the rivets. Calculate also the efficiency of the joint.

125. Determine the efficiency of a double-riveted lap joint where $t = \frac{3}{8}$ inch, $d = \frac{15}{16}$ inch, and $p = 3\frac{7}{16}$ inches.

126. Calculate the efficiency of a double-riveted lap joint if $t = \frac{7}{16}$ inch, $d = 1$ inch, and $p = 3\frac{5}{8}$ inches.

127. In a double-riveted lap joint $t = \frac{1}{2}$ inch, $d = 1\frac{1}{16}$ inches, and $p = 3\frac{9}{16}$ inches. Find its efficiency.

128. Find the efficiency of a double-riveted lap joint if $t = \frac{1}{4}$ inch, $d = \frac{3}{4}$ inch, and $p = 2\frac{7}{8}$ inches.

129. Determine the efficiency of a double-riveted lap joint if $t = \frac{5}{16}$ inch, $d = \frac{13}{16}$ inch, and $p = 2\frac{7}{8}$ inches.

130. Each repeating section of the riveted joint of Problem 129 sustains a tension of 7000 pounds. Find the factors of safety.

131. Find the pitch of a double-riveted lap joint in which $t = \frac{1}{4}$ inch and $d = \frac{3}{4}$ inch, so that the strength of the joint against tearing the plates between the rivet holes shall equal the shearing strength of the rivets. Find also the efficiency of the joint.

132. Determine the efficiency of a single-riveted, two-strap butt joint if $t = \frac{3}{8}$ inch, $d = \frac{13}{16}$ inch, and $p = 2$ inches.

133. Find the efficiency of a single-riveted, two-strap butt joint if $t = \frac{1}{2}$ inch, $d = \frac{15}{16}$ inch, and $p = 2\frac{1}{4}$ inches.

134. Determine p for a single-riveted, two-strap butt joint in which $t = \frac{5}{8}$ inch and $d = 1\frac{1}{16}$ inches, so that the strength of the joint against tearing the plates between the rivet holes shall equal the compressive strength of the rivets. Determine also the efficiency of the joint.

135. Determine the efficiency of a double-riveted, two-strap butt joint if $t = \frac{3}{8}$ inch, $d = \frac{13}{16}$ inch, and $p = 3\frac{1}{8}$ inches.

136. Find the efficiency of a double-riveted, two-strap butt joint if $t = \frac{5}{8}$ inch, $d = 1$ inch, and $p = 3\frac{7}{8}$ inches.

137. Determine the pitch for a double-riveted, two-strap butt joint in which $t = \frac{1}{2}$ inch, and $d = \frac{15}{16}$ inch, so that the strength of the joint against tearing the plates between the rivet holes shall equal the compressive strength of the rivets. What is the efficiency of this joint?

138. Each repeating section of the riveted joint of Problem 135 sustains a tension of 9000 pounds. Find the factors of safety.

139. Design a single-riveted lap joint for $\frac{1}{4}$-inch plates and find its efficiency.

140. Design a single-riveted lap joint for $\frac{3}{4}$-inch plates and find its efficiency.

141. Design a double-riveted lap joint for $\frac{9}{16}$-inch plates and find its efficiency.

142. Design a double-riveted lap joint for $\frac{5}{8}$-inch plates and find its efficiency.

143. Design a single-riveted, two-strap butt joint for $\frac{5}{16}$-inch plates and find its efficiency.

144. Design a single-riveted, two-strap butt joint for $\frac{7}{16}$-inch plates and find its efficiency.

145. Design a double-riveted, two-strap butt joint for $\frac{5}{16}$-inch plates and find its efficiency.

146. Design a double-riveted, two-strap butt joint for $\frac{7}{16}$-inch plates and find its efficiency.

147. Determine the efficiency of a triple-riveted, two-strap butt joint in which $t = \frac{5}{16}$ inch, $d = \frac{3}{4}$ inch, and $p = 6\frac{1}{4}$ inches.

148. Find the efficiency of a triple-riveted, two-strap butt joint in which $t = \frac{1}{2}$ inch, $d = 1$ inch, and $p = 7\frac{1}{2}$ inches.

149. Calculate the efficiency of a triple-riveted, two-strap butt joint in which $t = \frac{9}{16}$ inch, $d = 1\frac{1}{16}$ inches, and $p = 7\frac{3}{4}$ inches.

150. Design a triple-riveted, two-strap butt joint for $\frac{7}{16}$-inch plates and find its efficiency.

151. Design a triple-riveted, two-strap butt joint for $\frac{5}{8}$-inch plates and find its efficiency.

152. Show that when s_t, s_s, and s_c have values as given above, if $m = n$ and $K = 1.5$ for $t \lesseqgtr 0.313$ inch, then $P_c \lesseqgtr P_s$.

153. Show that if $5\,m = 9\,n$ (Fig. 9), and $K = 1.3$,

$$\text{for } t \lesseqgtr 0.76 \text{ inch, then } P_c \lesseqgtr P_s.$$

154. Show that if $m = 2\,n$ and $K = 1.3$

$$\text{for } t \lesseqgtr 0.94 \text{ inch, then } P_c \lesseqgtr P_s.$$

155. A boiler shell 4 feet in diameter has longitudinal single-riveted lap joints for which $t = \frac{5}{16}$ inch, $d = \frac{13}{16}$ inch, and $p = 2\frac{1}{16}$ inches. Determine the maximum steam pressure which can be used with a factor of safety of 5.

156. A boiler shell 60 inches in diameter has longitudinal single-riveted lap joints for which $t = \frac{3}{8}$ inch, $d = \frac{15}{16}$ inch, and $p = 2\frac{3}{16}$ inches. Calculate the maximum steam pressure which can be used with a factor of safety of 5.

157. A boiler 48 inches in diameter carries a steam pressure of 65 pounds per square inch. It has single-riveted longitudinal lap joints for which $t=\frac{1}{4}$ inch, $d=\frac{3}{4}$ inch, and $p=2$ inches. Find the factor of safety.

158. Determine the steam pressure which will rupture a boiler shell 5 feet in diameter, with single-riveted longitudinal lap joints for which $t=\frac{1}{4}$ inch, $d=\frac{3}{4}$ inch, and $p=2$ inches.

159. A boiler shell 60 inches in diameter, with single-riveted longitudinal lap joints, is to carry a steam pressure of 78 pounds per square inch, with a factor of safety of 5. Determine the thickness of the shell and the pitch of the rivets if the efficiency of the joint is 0.572.

160. Determine the factor of safety when a steam pressure of 80 pounds per square inch is used in a 60-inch boiler, with double-riveted, longitudinal lap joints for which $t=\frac{3}{8}$ inch, $d=\frac{15}{16}$ inch, and $p=3\frac{7}{16}$ inches.

161. What steam pressure will burst a boiler 4 feet in diameter, with double-riveted, longitudinal lap joints for which $t=\frac{1}{4}$ inch, $d=\frac{3}{4}$ inch, and $p=3\frac{1}{8}$ inches?

162. A boiler shell 5 feet in diameter has single-riveted, two-strap butt joints for the longitudinal seams, for which $t=\frac{1}{2}$ inch, $d=\frac{15}{16}$ inch, and $p=2\frac{1}{4}$ inches. What steam pressure can it carry with a factor of safety of 5?

163. A boiler 36 inches in diameter has double-riveted, two-strap butt joints for the longitudinal seams, for which $t=\frac{5}{8}$ inch, $d=1$ inch, and $p=3\frac{7}{8}$ inches. Find the factor of safety for a steam pressure of 250 pounds per square inch.

164. A boiler 5 feet in diameter, with longitudinal, double-riveted, two-strap butt joints, is to carry a steam pressure of 103 pounds per square inch, with a factor of safety of 5. Find the thickness of the shell and the pitch of the rivets if the efficiency of the joints is 75 per cent.

165. A cylindrical stand-pipe, 100 feet high, inside diameter 18 feet, has longitudinal, double-riveted two-strap butt joints at the lowest part of the pipe, for which $t=\frac{5}{8}$ inch, $d=1$ inch, and $p=3\frac{7}{8}$ inches. Compute the factor of safety when the pipe is full of water.

166. A boiler 66 inches in diameter, with longitudinal, triple-riveted, two-strap butt joints, is to carry a steam pressure of 100 pounds per square inch, with a factor of safety of 5. Find the thickness of the shell and the pitch of the rivets if the efficiency of the joints is 80 per cent.

V. CANTILEVER AND SIMPLE BEAMS

Shear and Moment Diagrams

Construct the shear and moment diagrams and find the maximum shear and moment for the following cases.

167. A cantilever beam of length l, with a uniform load of w pounds per linear foot.

168. A cantilever beam of length l, with a concentrated load P at the free end.

169. A cantilever beam of length l, with a uniform load of w pounds per linear foot, and a concentrated load P at the free end.

170. A simple beam of length l, with a uniform load of w pounds per linear foot.

171. A simple beam of length l, with a concentrated load P at the middle.

172. A simple beam of length l, with a uniform load of w pounds per linear foot, and a concentrated load P at the middle.

173. A cantilever beam of length 12 feet, with a total uniform load of 240 pounds.

174. A cantilever beam of length 10 feet, with a concentrated load of 100 pounds at the free end.

175. A wooden cantilever beam, 9 inches deep, 8 inches broad, and 15 feet long, with a concentrated load of 1000 pounds at the free end.

176. A simple beam 20 feet in length, with a uniform load of 30 pounds per linear foot.

177. A simple beam 12 feet in length, with a concentrated load of 1000 pounds at the middle.

178. A simple beam 18 feet in length, with a total uniform load of 180 pounds, and a concentrated load of 800 pounds at the middle.

179. A cantilever beam 10 feet long and weighing 12 pounds per linear foot, with a concentrated load of 80 pounds, 2 feet from the free end.

180. A cantilever beam 12 feet long, weighing 10 pounds per linear foot, with concentrated loads of 100 and 150 pounds at distances of 4 and 8 feet respectively from the free end.

181. A cantilever beam 10 feet long, with a uniform load of 50 pounds per linear foot, and concentrated loads of 100, 300, and

500 pounds at distances of 2, 5, and 8 feet respectively from the fixed end.

182. Show analytically that the maximum moment occurs in a cantilever beam and in a simple beam at that section where the shear passes through zero.

In the following problems find also the position of the danger section.

183. A simple beam of length l, with two equal concentrated loads at the quarter points. Neglect weight of beam.

184. A simple beam of length l, with two equal concentrated loads at the quarter points, and a uniform load of w pounds per linear foot.

185. A simple beam of length 10 feet, with 200 pounds 4 feet from the left end. Weight of beam neglected.

186. A simple beam 12 feet in length, with 300 pounds 4 feet from the left end, and a uniform load of 20 pounds per linear foot.

187. A simple beam 20 feet long, weighing 12 pounds per linear foot, with a load of 240 pounds 5 feet from the left end.

188. A simple beam 8 feet in length, with a concentrated load of 1000 pounds 2 feet from the left end, and a uniform load of 500 pounds per linear foot.

189. A simple beam 6 feet long, with concentrated loads of 1000 pounds 2 feet from each end, if weight of beam is neglected.

190. A simple beam 12 feet long, with a uniform load of 40 pounds per linear foot, and concentrated loads of 2000 pounds at 3 feet from each end.

191. A simple beam 12 feet in length, with 240 pounds 3 feet from the left end, and 360 pounds 4 feet from the right end, if weight of beam is neglected.

192. The beam of Problem 191 has in addition to the concentrated loads a uniform load of 60 pounds per linear foot.

193. A simple beam 20 feet long, with concentrated loads of 2000 pounds 4 feet from the left end, and 1000 pounds 2 feet from the right end, and also a uniform load of 100 pounds per linear foot.

194. A simple beam 6 feet in length, there being concentrated loads of 4000 and 1000 pounds 1 and 2 feet respectively from the left end, and no uniform load.

195. A simple beam 5 feet long, with a uniform load of 50 pounds per linear foot, and concentrated loads of 50 pounds 2 feet from the left end, and 75 pounds 1 foot from the right end.

196. A simple beam 16 feet in length, carrying a uniform load of 40 pounds per linear foot, and two concentrated loads, one of 240 pounds 3 feet from the left support, and one of 180 pounds 4 feet from the right support.

197. A simple beam 12 feet long, there being concentrated loads of 90 and 60 pounds 4 and 7 feet respectively from the left end, and a uniformly distributed load of 20 pounds per linear foot.

198. A simple beam 30 feet in length, bearing a uniform load of 40 pounds per linear foot, and concentrated loads of 1 and 1.5 tons at 9 and 20 feet respectively from the left end.

199. A simple beam 12 feet long, there being concentrated loads of 240, 90, and 120 pounds at 3, 4, and 8 feet respectively from the left end, but no uniform load.

200. The beam of Problem 199 has, in addition to the concentrated loads, a uniform load of 100 pounds per linear foot.

201. A simple beam of 12 feet span, weighing 35 pounds per linear foot, with concentrated loads of 300, 60, and 150 pounds at 3, 5, and 8 feet respectively from the left support.

202. A simple beam 100 feet between the supports, with three concentrated loads of 1200 pounds each at distances from the left support of 40, 60, and 80 feet. Neglect weight of beam.

203. A simple beam 12 feet long, bearing concentrated loads of 1, $\frac{1}{2}$, and 3 tons at distances of 3, 6, and 7 feet respectively from the left support, and a uniform load of $\frac{3}{5}$ ton.

204. A simple beam 20 feet in length, there being a uniform load of 20 pounds per linear foot, and concentrated loads of 200, 100, 400, and 200 pounds at 4, 6, 8, and 12 feet respectively from the left end.

205. The simple beam of Problem 204, with the same concentrated loads, but no uniform load.

206. A simple beam 20 feet long, with concentrated loads of 200, 100, 400, and 200 pounds at 4, 6, 8, and 12 feet respectively from the left end, and a uniform load of 100 pounds per linear foot.

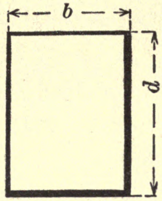


FIG. 12

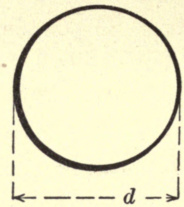


FIG. 13

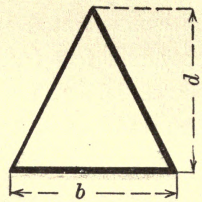


FIG. 14

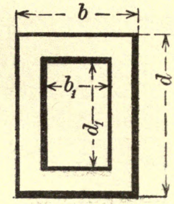


FIG. 15

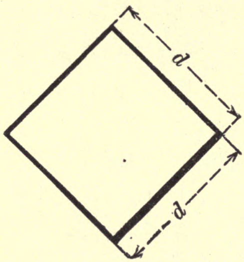


FIG. 16

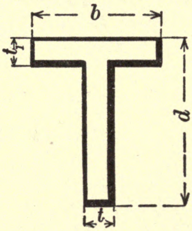


FIG. 17

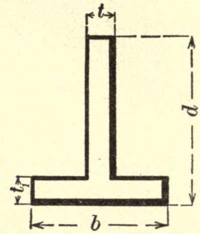


FIG. 18

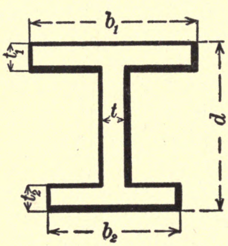


FIG. 19

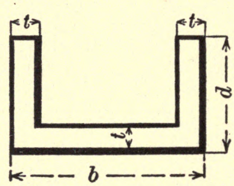


FIG. 20

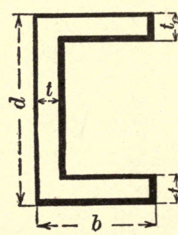


FIG. 21

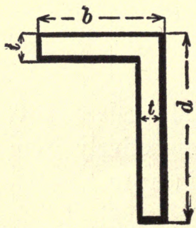


FIG. 22

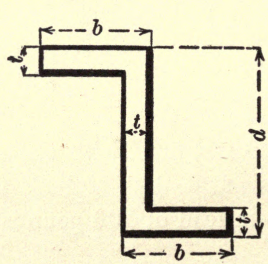


FIG. 23

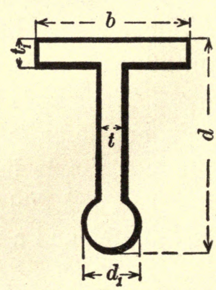


FIG. 24

Neutral Axis and Moments of Inertia

Determine the position of the neutral axis and the moments of inertia in respect to this axis for the following beam-sections.

207. The rectangular section shown in Fig. 12.

208. The circular section shown in Fig. 13.

209. The triangular section shown in Fig. 14.

210. The hollow rectangular section shown in Fig. 15.

211. The square section shown in Fig. 16.

212. The T-section shown in Fig. 17, if $b = 3$, $t_1 = 2$, $t = 1$, and $d = 8$ inches.

213. The T-section shown in Fig. 17, if $d = 12$, $b = 5$, $t = 1$, and $t_1 = 2$ inches.

214. The T-section shown in Fig. 17, if $t_1 = t = 1$, $d = 9$, and $b = 4$ inches.

215. The section of Fig. 15, if $d = 6$, $b = 4$, $d_1 = 4$, and $b_1 = 2$ inches.

216. The section of Fig. 19, if $d = 6$, $t_1 = t_2 = t = 1$, and $b_1 = b_2 = 4$ inches.

217. The section of Fig. 19, if $d = 8$, $t_1 = t_2 = t = \frac{1}{2}$, and $b_1 = b_2 = 4$ inches.

218. The section of Fig. 19, if $d = 12$, $t_1 = t_2 = t = \frac{1}{2}$, and $b_1 = b_2 = 5$ inches.

219. A section like Fig. 19, if $d = 12$, $b_1 = 4$, $b_2 = 2$, $t = 1$, and $t_1 = t_2 = 2$ inches.

220. A section like Fig. 19, if $d = 10$, $t = \frac{1}{2}$, $t_1 = t_2 = 1$, $b_1 = 4$, and $b_2 = 2$ inches.

221. The section of Fig. 20, if $t = \frac{1}{2}$, $b = 8$, and $d = 2$ inches.

222. The section of Fig. 20, if $t = 1$, $b = 8$, and $d = 6$ inches.

223. The section of Fig. 20, if $t = 1$, $b = 12$, and $d = 4$ inches.

224. A section like Fig. 21, if $d = 12$, $b = 4$, $t = 1$, and $t_1 = 2$ inches.

225. A section like Fig. 21, if $d = 15$, $b = 3\frac{1}{2}$, and $t = t_1 = \frac{1}{2}$ inch.

226. The section of Fig. 22, if $b = d = 6$, and $t = \frac{1}{2}$ inch.

227. The section of Fig. 22, if $d = 6$, $b = 4$, and $t = \frac{1}{2}$ inch.

228. A section like Fig. 23, if $d = 6$, $b = 4$, and $t = 1$ inch.

229. A section like Fig. 23, if $d = 8$, $b = 3$, and $t = \frac{1}{2}$ inch.

230. The section of Fig. 24, if $d = 6$, $b = 4$, $d_1 = t_1 = 1$, and $t = \frac{1}{2}$ inch.

231. A trapezoidal section, if the depth is 8 inches, the longer base 6 inches, and the shorter base 4 inches.

232. A section like Fig. 25, if $d = 12$ inches, $t = \frac{1}{2}$ inch, and each angle section $4 \times 3 \times \frac{1}{2}$ inches, with the longer leg horizontal.

233. A section like Fig. 25, if $d = 10$ inches, $t = \frac{1}{2}$ inch, and each angle section $3 \times 2\frac{1}{2} \times \frac{1}{2}$ inches, with the longer leg horizontal.

234. A section like Fig. 25, if $d = 10$ inches, $t = \frac{3}{4}$ inch, and each angle section $5 \times 3\frac{1}{2} \times \frac{3}{4}$ inches, with the longer leg horizontal.

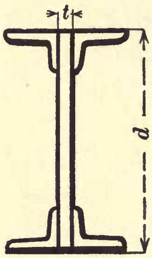


FIG. 25

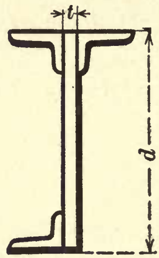


FIG. 26

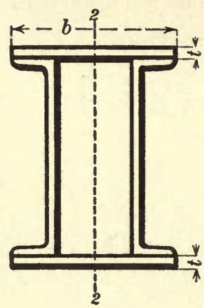


FIG. 27

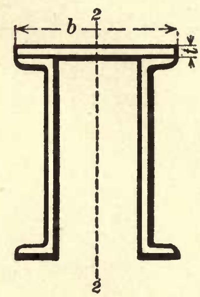


FIG. 28

235. The section of Fig. 26, if $d = 14$ inches, $t = \frac{1}{2}$ inch, and each angle section $3\frac{1}{2} \times 3\frac{1}{2} \times \frac{1}{2}$ inches.

236. The section of Fig. 26, if $d = 12$ inches, $t = \frac{1}{2}$ inch, and each angle section $4 \times 4 \times \frac{1}{2}$ inches.

237. A section like Fig. 27, if $b = 8$ inches, $t = \frac{1}{2}$ inch, and each channel is 6 inches deep and weighs 8 pounds per foot. Find also the moment of inertia in respect to the axis 2–2.

238. A section like Fig. 27, if $b = 10$ inches, $t = \frac{1}{2}$ inch, and each channel is 8 inches deep and weighs 11.25 pounds per foot. Find also the moment of inertia in respect to the axis 2–2.

239. A section like Fig. 27, if $b = 12$ inches, $t = \frac{1}{2}$ inch, and each channel is 10 inches deep and weighs 30 pounds per foot. Find also the moment of inertia in respect to the axis 2–2.

240. The section of Fig. 28, if $b = 12$ inches, $t = \frac{1}{2}$ inch, and each channel is 12 inches deep and weighs 20.5 pounds per foot. Find also the moment of inertia in respect to the axis 2–2.

Investigation

241. A rectangular, wooden cantilever beam 12 feet long, 4 inches broad, and 8 inches deep bears a total uniform load of 50 pounds per linear foot. Find the factor of safety.

242. A wooden cantilever beam 5 feet in length has a rectangular section 2 inches broad and 3 inches deep. Find the total uniform load it can carry with a factor of safety of 8.

243. Find the factor of safety for a rectangular, wooden cantilever beam 12 feet long, 4 inches broad, and 8 inches deep there being a concentrated load of 300 pounds at the free end. Neglect the weight of the beam.

244. Determine the factor of safety for the beam in Problem 243, if the weight of the beam is considered.

245. A cast-iron bar 1 inch in diameter and 2 feet long is supported at its middle, and loads of 50 pounds are hung at each end. Find the factor of safety if the weight of the bar is neglected.

246. A rectangular, wooden cantilever beam 10 feet long and 6 inches deep is to support a load of 200 pounds at the free end. What should be its width for steady stress if weight of cantilever is neglected?

247. A rectangular, wooden cantilever beam 8 feet long, 6 inches broad, and 8 inches deep carries a load of 300 pounds at the free end and a total uniform load of 160 pounds. What is the factor of safety?

248. A rectangular, wooden cantilever beam 8 feet in length, 6 inches broad, and 8 inches deep has a load of 200 pounds at the free end. What total uniform load can it also carry with a factor of safety of 10?

249. A simple wooden beam of rectangular section 8×12 inches and 16 feet long sustains a total uniform load of 500 pounds per linear foot. Find the factor of safety if the short side is horizontal.

250. Would the beam of Problem 249 be safe if the long side were horizontal?

251. A piece of timber 20 feet long, supported at its ends, is to carry a total uniform load of 4 tons. What should be the size of its square cross-section for a factor of safety of 10?

252. What should be the depth of a rectangular wooden girder 20 feet long and 4 inches broad to sustain a total uniformly distributed load of 1600 pounds, with a factor of safety for varying stress?

253. Find the total uniform load that a wooden floor beam 2×10 inches in rectangular section and 16 feet long will carry with a factor of safety of 8.

254. Solve Problem 253 with the 10-inch side horizontal.

255. A simple wooden beam 3 inches wide, 4 inches deep, and 16 feet long bears a concentrated load of 140 pounds at the middle. Determine the factor of safety if the weight of the beam is neglected.

256. Find the factor of safety for the beam of Problem 255, taking into account the weight of the beam.

257. A piece of scantling 2 inches square and 8 feet long is supported at its ends, and sustains a load of 150 pounds at its middle. Is it safe? Neglect weight of beam.

258. A wooden beam 4 inches square, resting on end supports, is to carry a uniform load of 40 pounds per linear foot, including its own weight. Find the maximum safe distance between supports.

259. A wooden beam 4 inches broad, 6 inches deep, and 10 feet long is supported at its ends. Calculate the load it can carry at its middle point with a factor of safety of 8, if weight of beam is neglected.

260. Solve Problem 259, considering weight of beam.

261. The piston of a steam engine is 14 inches in diameter, and the steam pressure 80 pounds per square inch. Assuming that the total pressure on the piston comes on the crank pin at the dead points, and that the crank pin is a cantilever uniformly loaded, what should be its diameter if 4 inches long and made of wrought-iron? Use a factor of safety of 10.

262. A steel engine shaft resting on bearings 5 feet apart carries a 3-ton fly-wheel midway between the bearings. Find the diameter of the shaft to carry this load with a factor of safety of 10.

263. A wooden cantilever 8 feet in length and 4 inches broad bears a total uniform load of 80 pounds per linear foot, and concentrated loads of 600 and 200 pounds at 3 and 8 feet respectively from the support. Determine the depth of the beam, using a factor of safety for steady stress.

264. Find the factor of safety for a structural steel engine shaft 12 inches in diameter, resting in bearings 54 inches apart and carrying a fly-wheel of 40 tons midway between the bearings. Neglect weight of shaft.

265. A hollow, circular, cast-iron beam, inside diameter 5 inches, outside diameter 6 inches, rests upon end supports 8 feet apart. With a factor of safety for varying stress, what is the maximum safe load that may be concentrated at its center? Neglect weight of beam.

266. A rectangular wooden beam 14 feet long, 4 inches wide, and 9 inches deep rests on end supports. Find the factor of safety if it bears a uniform load of 100 pounds per linear foot in addition to its own weight.

267. Design a rectangular wooden cantilever to project 4 feet from a wall and bear a load of 500 pounds at its free end, the factor of safety being 8, and weight of beam neglected.

268. A wooden beam of circular cross-section rests on end supports 10 feet apart. What load may be hung at the middle, if the radius of beam is 4 inches? Use factor of safety for steady stress, and neglect weight of beam.

269. A wooden beam resting on end supports 10 feet apart has a cross-section which is an isosceles triangle with a 6-inch horizontal base. It carries a uniform load, including its own weight, of 120 pounds per linear foot. What must be the altitude of its cross-section for a factor of safety of 8?

270. Find the uniform load per linear foot which a wooden cantilever 6 feet in length, rectangular section 2 inches broad and 3 inches deep, can carry with a maximum fiber-stress of 800 pounds per square inch.

271. Wooden beams 18 feet between supports, 6 inches deep, and 2 inches broad support a floor weighing 100 pounds per square foot. Neglecting the weight of the beams and using a factor of safety for varying stress, how far apart should they be spaced?

272. A balcony projecting 6 feet from a wall is supported by wooden beams 4 inches broad and spaced 3 feet apart. Find the depth of the beams if the total uniform load is 120 pounds per square foot and the maximum fiber-stress is 800 pounds per square inch.

273. A rectangular, wooden simple beam 9 inches deep and 3 inches wide supports a load of $\frac{1}{2}$ ton concentrated at the middle of an 8-foot span. Find the maximum fiber-stress, considering the weight of the beam.

274. A wrought-iron beam 14 feet long, supported at its ends and of circular section, is loaded with a total uniform load of 200 pounds per linear foot. Find its diameter for a factor of safety of 4.

275. A simple wooden beam 20 feet long and 12 inches square supports a load of 2 tons at the middle. Find the factor of safety, considering the weight of the beam.

276. A cast-iron rectangular beam resting upon end supports 12 feet apart carries a load of 2000 pounds at the center. If the breadth is one half the depth, find the area of cross-section for a factor of safety of 4. Neglect weight of beam.

277. Round and square beams of the same material are equal in length and have the same loading. Find the ratio of the diameter to the side of the square so that the two beams may be of equal strength.

278. Compare the relative strengths of a square beam and a circular beam which is the inscribed cylinder.

279. Compare the strength of a square beam with a side vertical, to that of the same beam with a diagonal vertical.

280. Compare the relative strengths of a cylindrical beam and the strongest rectangular beam that can be cut from it.

281. A wrought-iron beam 8 feet in length and supported at its ends bears a total uniform load of 2000 pounds per linear foot. Its section is like Fig. 19, where $b_1 = b_2 = 4$, $t_1 = t_2 = t = 1$, and $d = 6$ inches. Find the factor of safety.

282. Find the factor of safety for the beam of Problem 281, if its section is like Fig. 15, with $b = 4$, $d = 6$, $b_1 = 2$, and $d_1 = 4$ inches.

283. The beam of Problem 281 has a section like Fig. 21, with $b = 4$, $t_1 = t = 1$, and $d = 8$ inches. Find the factor of safety.

284. Determine the factor of safety for a wrought-iron beam 8 feet in length and supported at its ends, with a concentrated load of 8000 pounds 3 feet from the left end. Its section is like Fig. 19, with $b_1 = b_2 = 4$, $t_1 = t_2 = t = 1$, and $d = 6$ inches. Neglect weight of beam.

285. The beam of Problem 284 has a section like Fig. 15, with $b = 4$, $d = 6$, $b_1 = 2$, and $d_1 = 4$ inches. Find the factor of safety.

286. Find the factor of safety for a circular wrought-iron simple beam 3 inches in diameter and 6 feet in length, with concentrated loads of 1000 pounds 2 feet from each end. Neglect weight of beam.

287. A wrought-iron simple beam 6 feet in length, with cross-section 3 inches square, has concentrated loads of 1000 pounds 2 feet from each end. Neglecting the weight of the beam, find the factor of safety.

288. Solve Problem 287, considering the weight of the beam.

289. Solve Problem 287, if the diagonal is vertical.

290. Determine the factor of safety for a wrought-iron beam 8 feet in length, supported at its ends, with a total uniform load of 1000 pounds per linear foot and a concentrated load of 1000 pounds at the middle. Its section is like Fig. 19, with $b_1 = b_2 = 4$, $t_1 = t_2 = t = 1$, and $d = 6$ inches.

291. A wrought-iron, circular simple beam 6 feet in length has concentrated loads of 4000 and 1000 pounds at 1 and 2 feet respectively from the left end. Is it safe if the diameter is 3 inches?

292. Find the factor of safety for the beam of Problem 291, if its section is 3 inches square and a side vertical.

293. A wrought-iron beam 8 feet span and supported at its ends has an **I**-section, with $b_1 = b_2 = 4$, $t_1 = t_2 = t = 1$, and $d = 6$ inches. What concentrated load can it carry at its middle point with a factor of safety of 6? Neglect weight of beam.

294. A simple wooden beam 12 feet span, 9 inches deep and 8 inches wide, carries two equal loads, each 3 feet from the middle, but on opposite sides. Find these loads for a factor of safety of 10, neglecting the weight of the beam.

295. Solve Problem 294, considering the weight of the beam.

296. Determine the total uniform load for a cast-iron beam 12 feet span and supported at its ends for a factor of safety of 6, if the section is like Fig. 18, with $b = 5$, $d = 12$, $t = 1$, and $t_1 = 2$ inches.

297. A cast-iron simple beam 10 feet span has a section like Fig. 18, with $b = 3$, $d = 8$, $t = 1$, and $t_1 = 2$ inches. What concentrated load can it carry at the middle with a factor of safety of 8? Neglect weight of beam.

298. A 12-inch steel **I**-beam, weighing 35 pounds per linear foot, of 10 feet span and supported at the ends sustains a total uniform load of 20 tons. Find the factor of safety.

299. Determine the total uniform load for a 10-inch steel **I**-beam, 30 pounds per foot, 12 feet span and supported at the ends, for a factor of safety of 6.

300. Find the factor of safety for a 15-inch steel **I**-beam, 42 pounds per foot, 16 feet span and supported at the ends, if it bears a concentrated load of 15,000 pounds at the middle. Neglect weight of beam.

301. Solve Problem 300, considering the weight of the beam.

302. Find the concentrated load at the middle of a 9-inch steel **I**-beam, 25 pounds per foot, 14 feet span and supported at the ends, for a factor of safety of 4. Neglect weight of beam.

303. A cast-iron simple beam of 12 feet span has a section like Fig. 19 with $t_1 = t_2 = t = 1$, $d = 10$, and $b_1 = b_2 = 6$ inches. Find the concentrated load it can carry at its middle with a factor of safety of 6. Neglect weight of beam.

304. Select the proper steel **I**-beam of 12 feet span, supported at its ends, to carry two loads of 5000 pounds each, one at the middle and the other 2 feet from the left end, with a factor of safety of 4. Neglect weight of beam.

305. A floor designed to carry a total uniform load of 180 pounds per square foot is supported by steel **I**-beams of 20 feet span and 4 feet apart from center to center. Find the proper beam that should be used for a factor of safety of 5.

306. A floor which is to carry a total uniform load of 150 pounds per square foot is supported by 9-inch steel **I**-beams, 35 pounds per foot and 15 feet span. Find their distance apart from center to center, if the factor of safety is 4.

307. A cylindrical wrought-iron simple beam resting on end supports 24 feet apart sustains three concentrated loads of 400 pounds each at distances of 4, 12, and 16 feet respectively from the left support. What should be the diameter of the beam for varying stress? Neglect weight of beam.

308. A 10-inch steel **I**-beam, 40 pounds per foot, 15 feet span and supported at its ends, bears a concentrated load of 5 tons at its center. Is it safe?

309. Select a steel **I**-beam 10 feet long and supported at its ends to bear a total uniform load of 1500 pounds per linear foot with varying stress.

310. A simple beam 16 feet span is loaded with 8000 pounds at the middle and has a section like Fig. 18, with $t = t_1 = 1$, $d = 10$, and $b = 6$ inches. Neglecting the weight of the beam, determine the maximum fiber-stress, both tensile and compressive.

311. A floor is supported by wooden beams, 2 × 10 inches section and 12 feet span, spaced 16 inches between centers. Find the safe load per square foot of floor area if the maximum fiber-stress is 800 pounds per square inch.

312. A floor is to support a total load of 200 pounds per square foot of floor area. Determine the proper size for the steel **I**-beams, 12 feet span and spaced 5 feet apart between centers, to support this floor with a factor of safety of 4.

313. A beam has a section like Fig. 19, with $b_1 = b_2 = 6$, $t_1 = t_2 = 1$, $t = \frac{3}{4}$, and $d = 10$ inches. Compare its strength to resist bending when placed like this: **I**; and like this: ⊢⊣ .

314. A cast-iron simple beam of 12 feet span has a section like Fig. 20, with $t = 1$, $d = 6$, and $b = 8$ inches. Find the factors of safety against tension and compression under a total uniform load of 5000 pounds.

315. Select the proper steel **I**-beam for Problem 193 for a factor of safety of 6.

316. Select the proper steel **I**-beam for Problem 203 for a factor of safety of 6.

Rupture

317. Find the length of a cast-iron cantilever beam 2 inches square that will break under its own weight.

318. A cast-iron cantilever beam 2 × 4 inches section area and 12 feet long, carries a concentrated load at its free end. Find this load to break the beam, considering the weight of the beam itself.

319. Calculate the length of a wooden cantilever beam 1 × 2 inches section area that will break under its own weight.

320. Determine the total uniform load to rupture a cast-iron cantilever beam 2 inches square and 10 feet long.

321. Compute the size of a square wooden simple beam 9 feet span that will break under its own weight.

322. Determine the concentrated load placed at the middle that will rupture a wooden simple beam 2 × 4 inches cross-section and 12 feet span. Neglect weight of beam.

323. A cast-iron simple beam 12 feet long and 3 inches square carries two equal loads at quarter points. Find the loads that will rupture the beam, neglecting its own weight.

324. Determine the total uniform load that will rupture a wooden simple beam 8 feet span and 2×6 inches cross-section.

325. Find the load placed at the middle that will break a round cast-iron bar 16 feet long and 4 inches in diameter supported at the ends. Neglect weight of bar.

326. Determine the greatest length of a round cast-iron bar 1 inch in diameter that can just carry its own weight when supported at the ends.

327. A simple beam 6 feet long, 2 inches broad, and 3 inches deep is broken by a weight of 1200 pounds placed at the center. What uniformly distributed load will break a simple beam of the same length and material, if breadth is 3 inches and depth 4 inches?

Moving Loads

328. A load of 500 pounds is rolled over a simple beam 20 feet long, whose weight is 40 pounds per linear foot. Find the position of this load for the maximum bending moment and compute its value.

329. Two loads each of 3000 pounds, 5 feet apart, roll over a simple beam of 15 feet span. Find the position of these loads for the maximum bending moment and find its value.

330. Two wagon-wheels, 8 feet apart, roll over a simple beam 24 feet long. If the load on each wheel is 2000 pounds, find their position for the maximum bending moment and determine its value.

331. Solve Problem 330, if the load on one wheel is 3000 pounds and on the other 2000 pounds.

332. Three loads of 3000 pounds each, 4 feet apart, roll over a simple beam of 20 feet span. Find the position of these loads for the maximum bending moment and compute its value.

333. Three loads 4 feet apart, one being 3000 pounds and the others 1500 pounds each, roll over a simple beam 19 feet long. Find their position for the maximum bending moment, and find its value.

Deflection

334. Find the maximum deflection of a wooden cantilever beam 6 inches wide, 8 inches deep, and 10 feet long, due to a total uniform load of 100 pounds per linear foot.

335. A wooden cantilever beam 6 inches wide, 8 inches deep, and 10 feet long supports a weight of 1000 pounds at the free end. Find the maximum deflection due to this load.

336. Find the maximum deflection for the beam of Problem 334, if it has a concentrated load of 1000 pounds at the free end in addition to the uniform load.

337. A cast-iron bar 2 inches wide, 4 inches deep, and 6 feet long is balanced upon a support at its middle point, and a weight of 5000 pounds hung at each end. Find the end deflections.

338. Find the maximum deflection of a simple wooden beam 16 feet long, 2 inches wide, and 4 inches deep, due to a load of 120 pounds at the middle.

339. Calculate the maximum deflection of a steel bar, supported at its ends, 1 inch square and 6 feet long, due to a load of 100 pounds at its center.

340. A steel engine shaft 12 inches in diameter, resting in bearings 4 feet apart, carries a fly-wheel weighing 30 tons midway between the bearings. Considering the shaft as a simple beam, find its maximum deflection.

341. A wooden floor beam 2 × 10 inches cross-section and 16 feet long sustains a total uniform load of 80 pounds per linear foot. Find the maximum deflection.

342. Determine the maximum deflection of a wooden girder 10 feet long, 8 inches wide, and 10 inches deep, supported at its ends, if it carries a total uniform load of 10,000 pounds.

343. A simple wooden beam 8 × 14 inches cross-section and 16 feet long bears a total uniform load of 100 pounds per linear foot. How much greater will be the maximum deflection when the short side is vertical than when the long side is vertical?

344. A cast-iron rod supported at both ends, 5 feet span, 2 inches wide and $\frac{1}{2}$ inch deep, has a maximum deflection of $\frac{1}{4}$ inch due to a weight of 18 pounds at its center. Find its modulus of elasticity.

345. Find the maximum deflection of a simple wooden beam 9 feet long, due to a concentrated load of 1000 pounds at the middle. Cross-section is an ellipse having axes 6 and 4 inches, with short axis vertical.

346. Solve Problem 345 if the long axis is vertical.

347. A hollow circular cast-iron beam 8 feet long, inside diameter 5 inches and outside diameter 6 inches, rests upon end supports. Calculate the maximum deflection due to a load of 4000 pounds at the middle.

348. A beam is 4 × 12 inches section area and 16 feet long. Another beam of the same material is 6 × 8 inches section area and 10 feet long. What is the ratio between the maximum deflections, if the longer side is vertical in each beam, and the manner of loading and supporting is the same?

349. A beam 16 feet long, 2 inches wide, and 6 inches deep has a maximum deflection of 0.3 inch. Determine the maximum deflection of a beam of the same material 12 feet long, 3 inches wide, and 8 inches deep, with the same loading and manner of support.

350. Find the maximum deflection of a 12-inch steel **I**-beam, 40 pounds per foot, resting on end supports 20 feet apart, and bearing a total uniform load of 900 pounds per linear foot.

351. A 9-inch steel **I**-beam, 21 pounds per foot, supported at its ends and 10 feet long, bears a concentrated load of 25 tons at its center. Determine the maximum deflection due to this load.

352. Find the deflection at a point 4 feet from the left end of the beam in Problem 351.

353. A floor is to support a total uniform load of 100 pounds per square foot. The 10-inch steel **I**-beams, 25 pounds per foot, have a span of 20 feet and are spaced 6.5 feet apart between centers. Does the maximum deflection of the beams exceed $\frac{1}{360}$ of the span?

354. Determine the proper distance from center to center of 12-inch steel **I**-beams, 35 pounds per foot, 24 feet span, to support a total uniform load of 100 pounds per square foot of floor area, with a maximum deflection of $\frac{1}{360}$ of the span.

355. Solve Problem 354 for 15-inch steel **I**-beams, 50 pounds per foot and 26 feet span.

356. Find the distance between supports for 9-inch steel **I**-beams, 30 pounds per foot, spaced 7.5 feet from center to center, to support a total uniform load of 100 pounds per square foot of floor area, with a maximum deflection of $\frac{1}{360}$ of the span.

357. Solve Problem 356 for 8-inch steel **I**-beams, 18 pounds per foot, spaced 9 feet apart from center to center.

358. For the case of 10-inch steel I-beams, 30 pounds per foot, supported at both ends, and loaded uniformly, determine the span for which the maximum stress shall be 16,000 pounds per square inch and the maximum deflection $\frac{1}{360}$ of the span.

359. Solve Problem 358 for 12-inch steel I-beams, 35 pounds per foot.

360. Find the total uniform load for a 6-inch steel I-beam, 14.75 pounds per foot, resting on end supports 20 feet apart, if the maximum deflection is $\frac{1}{360}$ of the span and the maximum stress not greater than 16,000 pounds per square inch.

361. Solve Problem 360 for a 7-inch steel I-beam, 20 pounds per foot.

362. A wooden cantilever 15 feet long, 3 inches wide, and 4 inches deep carries a load of 100 pounds 5 feet from the free end. Find the deflection at the end due to this load.

363. The wooden cantilever of Problem 362 carries a load of 100 pounds 5 feet from the free end, and another load of 100 pounds 10 feet from the free end. Calculate the end deflection.

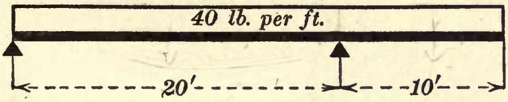
364. A beam of length l rests on end supports and bears a total uniform load W. Another support just touches under the middle of the beam. How much must this middle support be raised in order that the end supports shall just touch the beam?

365. Solve Problem 364 for a wooden beam 12 feet long, 3 inches wide, and 4 inches deep, bearing a total uniform load of 400 pounds.

VI. OVERHANGING BEAMS

Draw the shear and moment diagrams, determine the maximum shear, maximum moment, danger sections, and points of inflection in the following cases:

366.



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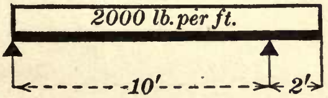

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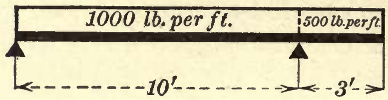

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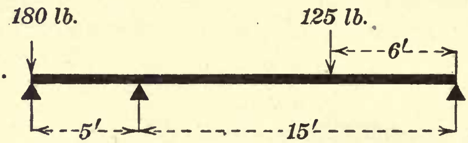

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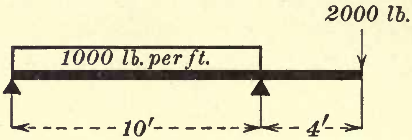
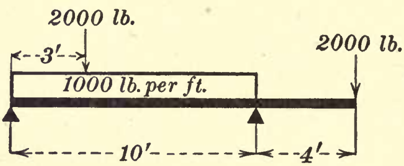
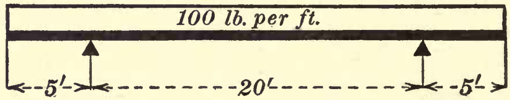


371.

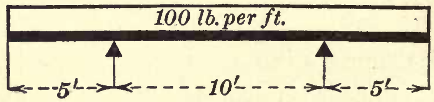


372. A piece of timber is supported at one end and at one other point. Find the position of this point if the reaction is double that at the end.

373.



374.



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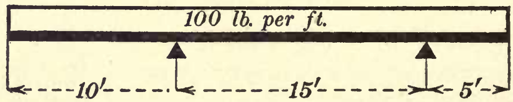
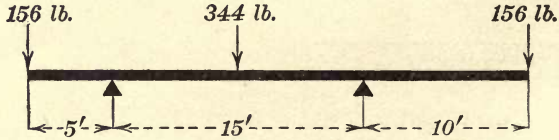
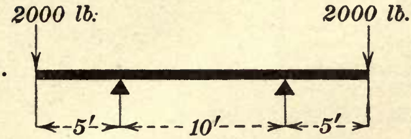
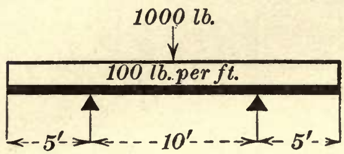
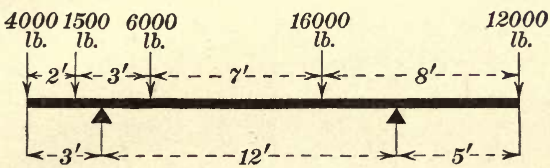


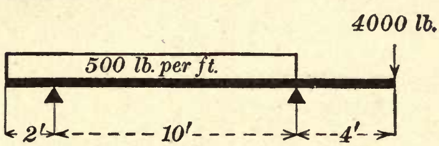
376.



377. 

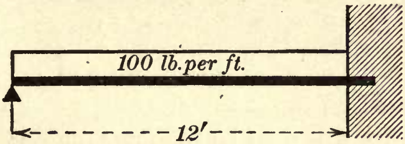
378. 

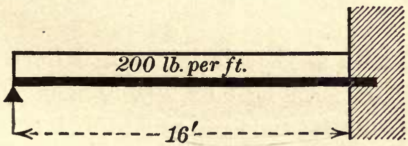
379. 

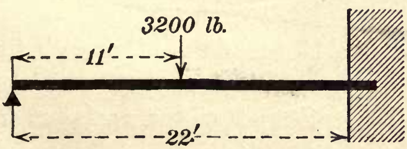
380. 

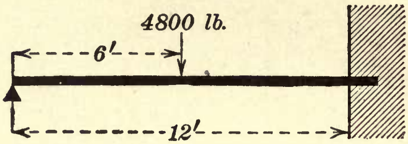
VII. FIXED BEAMS

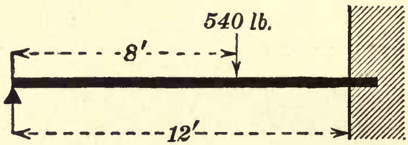
Draw the shear and moment diagrams, determine the maximum shear, maximum moment, danger sections, and points of inflection in the following cases:

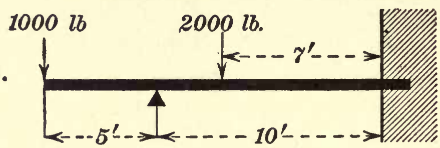
381. 

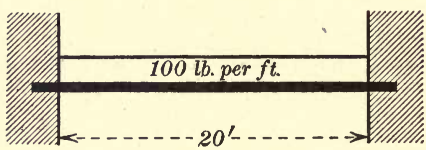
382. 

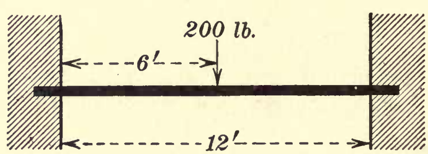
383. 

384. 

385. 

386. 

387. 

388. 

389. A cast-iron hollow cylindrical beam 30 feet long and fixed at both ends has an external diameter of 10 inches and an internal diameter of 10 inches. What load can it support at the middle with a factor of safety of 6, and what will then be the maximum deflection? Neglect weight of beam.

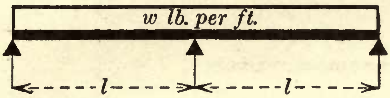
390. What steel **I**-beam with fixed ends is required for a span of 20 feet to support a total uniform load of 20,000 pounds, with a maximum unit-stress of 15,000 pounds per square inch? Find also the maximum deflection.

391. An 8-inch steel **I**-beam, 18 pounds per foot, with fixed ends and 8 feet span, is loaded at the middle so that the maximum unit-stress is 16,000 pounds per square inch. Find the maximum deflection.

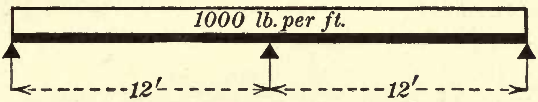
VIII. CONTINUOUS BEAMS

Draw the shear and moment diagrams, determine the maximum shear, maximum moment, danger sections, and points of inflection in the following cases:

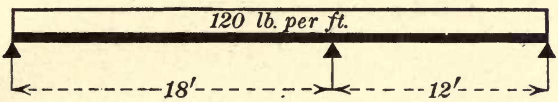
392.



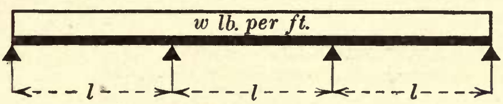
393.



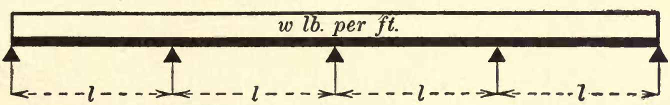
394.



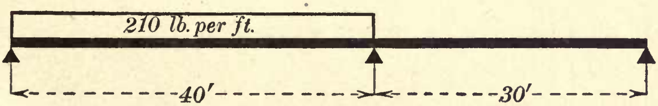
395.



396.



397.



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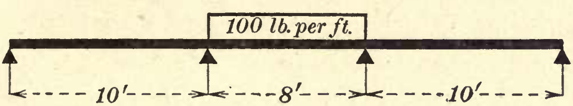

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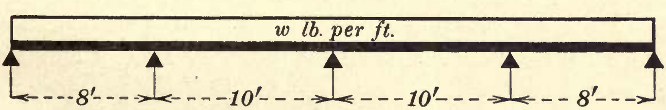
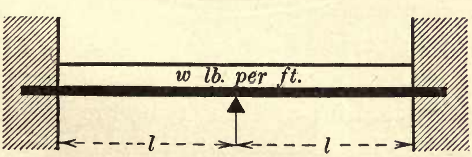
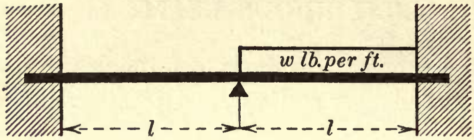
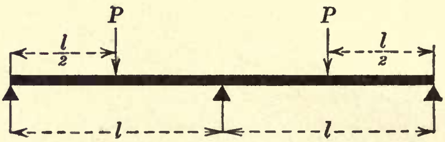


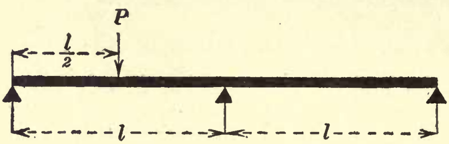
A 12-inch steel I-beam, 40 pounds per foot, extends over these supports. Find w for a factor of safety of 4.

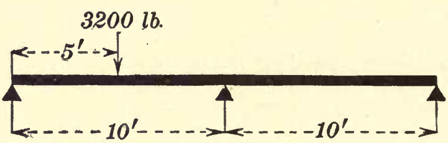
400.



401. 

402. 

403. 

404. 

IX. COLUMNS AND STRUTS

405. Find the load to rupture a cast-iron cylindrical column with flat ends, 15 feet long and 6 inches in diameter, both by Euler's and Rankine's formulas.

406. A cylindrical steel column with round ends is 36 feet long and 6 inches in diameter. Calculate by Euler's formula the axial load for rupture.

407. Find the buckling load for a steel strut with rounded ends, 3 inches square and $2\frac{1}{2}$ feet long, both by Euler's and Rankine's formulas.

408. Solve Problem 407 for a length of 9 feet.

409. Solve Problem 407 for a length of 15 feet.

410. A square wooden column with fixed ends is 20 feet long and sustains a load of 10,000 pounds. Find its size by Euler's formula, with a factor of safety for steady load.

411. Find the breaking load for a solid round wrought-iron pillar 2 inches in diameter and 10 feet in length, with fixed ends.

412. Calculate the breaking load for a wrought-iron column with fixed ends, 9 × 4 inches section area and 20 feet long.

413. Find the loads to rupture a round wrought-iron and a round cast-iron column each 9 feet in length and 6 inches in diameter, with flat ends.

414. Determine the buckling load for a cast-iron strut with rounded ends, 2 × 1 inches section area and 16 inches long.

415. Find the breaking load for a cylindrical strut of wrought-iron, 3 inches in diameter and 10 feet long, with rounded ends.

416. What load can be sustained by a cast-iron column with flat ends, 14 feet long and 6 inches in diameter, with a factor of safety of 8?

417. A wooden stick 3 × 4 inches cross-section and 10 feet long is used as a column with flat ends. Find the factor of safety under a load of 2000 pounds.

418. Determine the load for a fixed-end timber column, 3 × 4 inches cross-section and 10 feet long, for a factor of safety of 10. What would it be for a length of less than 2 feet?

419. Find the breaking load for a hollow cast-iron pillar with fixed ends, 9 feet in length and 6 inches square, the metal being 1 inch thick.

420. Find the safe steady load for a hollow cast-iron column with fixed ends, outside dimensions 8 × 6 inches, inside dimensions 6 × 4 inches, and 10 feet long.

421. Solve Problem 420 for a length of 20 feet.

422. Find the safe steady load for a hollow cast-iron column with fixed ends, length 20 feet, outside dimensions 4 × 5 inches, inside dimensions 3 × 4 inches.

423. Solve Problem 422 for a length less than 3 feet.

424. A hollow wooden column of rectangular section, 4 × 5 inches outside dimensions, 3 × 4 inches inside dimensions, has fixed ends and a length of 16 feet. Find the factor of safety for an axial load of 1200 pounds.

425. A wrought-iron pipe 10 feet long, 4 inches external and 3 inches internal diameter, sustains a load of 14 tons. What is the factor of safety?

426. What safe steady load will a hollow cast-iron column with flat ends support if it is 14 feet long, outside diameter 10 inches and inside diameter 8 inches? Compare the load it could support for a length less than 8 feet with the result obtained.

427. Determine the load on a hollow, round, cast-iron column with flat ends, external diameter 12 inches, thickness 1 inch, and length 14 feet, for a factor of safety of 8.

428. A cylindrical, wrought-iron column with fixed ends is 10 feet long, 6.4 inches outside diameter, 6 inches inside diameter, and carries a load of 50,000 pounds. Find its factor of safety.

429. Determine the size of a square, wooden column 30 feet long with flat ends to safely sustain a steady load of 20 tons.

430. Solve Problem 429 for a steady load of 7 tons.

431. A square, wooden post 12 feet high is to support a load of 16 tons. What must be the size of the post for a factor of safety of 10?

432. Find the size of a square steel strut 8 feet long with round ends to safely transmit a steady compressive load of 5 tons.

433. A round, solid, wrought-iron pillar 10 feet in height is to support a load of 40,000 pounds. Find its diameter for a factor of safety of 5.

434. Determine the diameter of a round, solid, steel pillar 16 feet high to safely support a steady load of 29,000 pounds.

435. A round, solid, cast-iron strut 15 feet long with rounded ends bears a compressive load of 10 tons. Find its diameter for a factor of safety of 6.

436. A hollow, square, wooden column with flat ends is to safely support a steady load of 12,000 pounds. If the thickness of each side is $1\frac{1}{2}$ inches and length of column 20 feet, what should be the outside and inside dimensions?

437. A cylindrical, structural steel connecting-rod $7\frac{1}{2}$ feet long is subjected to a maximum compressive load of 21,000 pounds. Considering it to be a column with both ends hinged, determine its diameter for a factor of safety of 10.

438. A wrought-iron piston-rod has a diameter of 2 inches and a length of 4 feet. Considering it to be a column with one end flat and the other round, what is the allowable diameter of the piston, if the steam pressure is 60 pounds per square inch, for a factor of safety of 10?

439. The diameter of a piston is 18 inches and the maximum steam pressure 130 pounds per square inch. Find the proper diameter for the structural steel piston-rod if it is 5 feet long and subject to shocks.

440. The diameter of a piston is 40 inches and the maximum steam pressure 110 pounds per square inch. The wrought-iron connecting-rod has a rectangular cross-section and a length of $12\frac{1}{2}$ feet. Find the dimensions for the cross-section of the rod for a factor of safety of 10.

441. A hollow, circular, steel column 28 feet long with fixed ends is to support a steady load of 30 tons. If the external diameter is 6 inches, determine the thickness of the metal for a factor of safety of 4.

442. A steel I-beam 15 inches deep, 50 pounds per foot, is used as a column 10 feet long with fixed ends. Find the load it can bear with a factor of safety of 4.

443. A column 20 feet long with fixed ends is formed by joining the legs of two 10-inch steel channels, 30 pounds per foot, by two plates 10 inches wide and $\frac{1}{2}$ inch thick, section as shown in Fig. 27. Find the load for a factor of safety of 4.

444. A steel column 20 feet long with fixed ends is used in a bridge under an axial compression of 240,000 pounds. The section is like Fig. 28, the 12-inch channels weigh 20.5 pounds per foot, $b = 16$, and $t = \frac{3}{4}$ inch. Determine the factor of safety.

445. Two 8-inch steel I-beams, 25.25 pounds per foot, are joined by lattice work to form a column 20 feet long with fixed ends. How far apart must the beams be placed, center to center, in order that the column shall be of equal strength to resist buckling in either axial plane? What load can the column then stand with a factor of safety of 5?

446. Solve Problem 445 with two 9-inch steel I-beams, 21 pounds per foot.

447. A steel column 14 feet long with square ends is formed by two 12-inch steel channels, 20.5 pounds per foot, placed back to back. Determine the proper spacing of the channels and the load the column will then carry with a factor of safety of 4.

448. Find the load for a hollow cast-iron column with fixed ends, 16 feet long, outside dimensions 4×5 inches, inside dimensions 3×4 inches, if the eccentricity of the load is $1\frac{1}{4}$ inches and the factor of safety is 6.

449. Determine the size of a square wooden column, 10 feet long, with fixed ends, to carry an eccentric load of 15 tons, eccentricity 2 inches, with a factor of safety of 10.

450. A hollow, cylindrical, cast-iron column with fixed ends, 10 inches external diameter, 8 inches internal diameter, and 10 feet long, is loaded with 80,000 pounds 2 inches out of center. Determine the factor of safety.

X. TORSION

451. Find the horse-power that can be transmitted by a cast-iron shaft 3 inches in diameter and making 10 R.P.M., with a factor of safety of 10.

452. Find the diameter of a solid, wrought-iron, circular shaft to safely transmit 150 H.P. at a speed of 60 R.P.M.

453. Calculate the diameter of a structural steel shaft to transmit 300 H.P. at a speed of 200 R.P.M., with a factor of safety of 6.

454. Find the H.P. that can be safely transmitted by a cast-iron, circular shaft 7 inches in diameter and making 80 R.P.M.

455. What should be the diameter of a structural steel shaft to safely transmit 500 H.P. at 200 R.P.M.?

456. Calculate the H.P. that a round, wrought-iron shaft 8 inches in diameter and making 150 R.P.M. will transmit with a factor of safety of 6.

457. Find the diameter of a wrought-iron shaft to transmit 5000 H.P. at 100 R.P.M., with a factor of safety of 10.

458. Calculate the diameter of a structural steel engine-shaft to transmit 4000 H.P. at 50 R.P.M., with a factor of safety of 10.

459. Find the factor of safety for a wrought-iron shaft 3 inches in diameter when transmitting 40 H.P. at 100 R.P.M.

460. Determine the factor of safety for a structural steel shaft 2 inches in diameter and transmitting 25 H.P. at 100 R.P.M.

461. What H.P. can be transmitted, with a factor of safety of 6, by a hollow, wrought-iron shaft, external diameter 12 inches, internal diameter 10 inches, and making 60 R.P.M.

462. Find the speed for a hollow, cast-iron shaft, 10 inches outside diameter, 6 inches inside diameter, to transmit 750 H.P. with a factor of safety of 10.

463. Find the H.P. that can be safely transmitted by a hollow, wrought-iron shaft making 100 R.P.M., if the outside diameter is 8 inches and the inside diameter 5 inches.

464. Find the ratio of the strength of a hollow circular shaft to that of a solid circular one of the same material and the same section area.

465. A solid shaft has a diameter of 12 inches and a hollow shaft of the same material has an external diameter of 20 inches. Find the internal diameter of the hollow shaft for the same section area, and the ratio of their strengths.

466. A hollow and a solid shaft are of the same material and same section area. If the outside diameter of the hollow shaft is twice its inside diameter, find the ratio of the strengths of the shafts.

467. A solid shaft of structural steel is to transmit 300 H.P. at 200 R.P.M. If the maximum moment is 30 per cent greater than the average, find the diameter of the shaft for a factor of safety of 6.

468. A hollow, structural steel shaft, outside diameter 6 inches, transmits 300 H.P. at 200 R.P.M. Find the inside diameter for a factor of safety of 6.

469. Find the H.P. that can be transmitted by a hollow, structural steel shaft, 15 inches external diameter and 11 inches internal diameter, at a speed of 50 R.P.M., with a factor of safety of 4.

470. A steel wire 0.18 inch in diameter and 20 inches long is twisted through an angle of 18.5° by a moment of 20 inch-pounds. Determine the shearing modulus of elasticity of the wire.

471. Find the shearing modulus of elasticity of a cast-iron bar 10 inches long and 0.82 inch in diameter, if twisted through an angle of 1.3° by a twisting moment of 50 pound-feet.

472. A shaft 15 feet long and 4.5 inches in diameter is twisted through an angle of 2° by a moment of 2000 pound-feet. Find the moment which will twist a shaft of the same material, 20 feet long and 7 inches in diameter, through an angle of 2.5°.

473. A round, cast-iron shaft 15 feet in length is acted upon by a weight of 2000 pounds applied at the circumference of a wheel on the shaft, whose diameter is 2 feet. Determine the diameter of the shaft so that the angle of torsion shall not exceed 2°.

474. A steel shaft 20 feet in length and 3 inches in diameter transmits 50 H.P. at 200 R.P.M. Through what angle is the shaft twisted?

475. A wrought-iron shaft 20 feet long and 5 inches in diameter is twisted through an angle of 2°. Find the maximum unit-stress in the metal.

476. Find the diameter and angle of twist of a 12-foot wrought-iron shaft transmitting 20 H.P. at 25 R.P.M., with a factor of safety of 6.

477. A structural steel shaft 120 feet long and 16 inches in diameter transmits 8000 H.P. at 20 R.P.M. Find the angle of twist and the factor of safety.

478. A turbine transmits 92 H.P. at 114 R.P.M. through a wrought-iron shaft 8.5 feet in length. Determine the diameter of the shaft so that the angle of torsion shall not exceed 1°.

479. A structural steel shaft 20 feet in length and 3 inches in diameter transmits 50 H.P. at 200 R.P.M. Through what angle is the shaft twisted and what is the factor of safety?

480. A structural steel shaft 2 inches in diameter transmits 25 H.P. at 100 R.P.M. Find the factor of safety and the angle of twist per linear foot.

481. A cast-iron shaft in a spinning mill is 84 feet long and transmits 270 H.P. at 50 R.P.M. Find its diameter if the stress in the metal is not to exceed 5000 pounds per square inch and the angle of torsion is not to exceed 0.1° per linear foot.

482. Determine the diameter and angle of twist of a solid steel shaft 20 feet long, to transmit 6000 H.P. at 116 R.P.M., the maximum twisting moment being 30 per cent greater than the mean and the maximum allowable stress 10,000 pounds per square inch.

483. Find the size of a hollow steel shaft to replace the one of Problem 482, if the inside diameter is $\frac{5}{8}$ of the outside diameter. What is the saving in weight in 50 feet of shafting?

484. Find the diameter and angle of twist per linear foot of a hollow steel shaft transmitting 5000 H.P. at 70 R.P.M., if the external diameter is twice the internal and the maximum stress is 7500 pounds per square inch.

485. Find the ratio of the strengths of two solid circular shafts of the same material, and the ratio of their stiffness for the same length.

486. Solve Problem 485, if one diameter is twice the other.

487. The external diameter of a hollow shaft is n times the internal. Compare its torsional strength with that of a solid circular shaft of the same material and same section area, in terms of n. Find also their stiffness ratio for the same length.

488. Solve Problem 487, if the external diameter of the hollow shaft is twice its internal diameter.

489. A solid shaft 10 inches in diameter is of the same material and section area as a hollow shaft whose internal diameter is 5 inches. Determine the external diameter of the hollow shaft and compare their torsional strengths and stiffness for the same length.

490. A hollow steel shaft has an external diameter d and an internal diameter $\frac{d}{2}\cdot$ Compare its torsional strength and stiffness with a solid steel shaft of the same length and of diameter d.

491. A solid shaft 6 inches in diameter is coupled by bolts 1 inch in diameter on a flange coupling. The centers of the bolts are 5 inches from the axis. Find the number of bolts in order that their torsional strength shall equal that of the shaft.

492. What H.P. can be transmitted with a factor of safety of 6 by a wrought-iron shaft 4 inches square and making 110 R.P.M.?

493. Find the H.P. that can be transmitted by a 7-inch cast-iron square shaft making 80 R.P.M., with a factor of safety of 10.

494. A wooden beam 6 inches square projects 4 feet from a wall, and is acted upon at the free end by a twisting moment of 20,000 pound-feet. Find the angle of twist.

495. What torsional moment can a wrought-iron shaft 10 feet long and 5 inches square withstand, with the angle of torsion less than $\frac{1}{4}^\circ$?

496. A round wrought-iron shaft 3 inches in diameter and 20 feet long transmits 20 H.P. at 100 R.P.M. Find the size of a square wrought-iron shaft of equal strength, and the angle of twist for each shaft.

497. A square wooden shaft 8 feet in length is acted upon by a force of 200 pounds applied at the circumference of an 8-foot wheel on the shaft. Find the size of the shaft in order that the angle of torsion shall not exceed 2°.

498. Determine the factor of safety and the angle of twist per foot of length for a wooden shaft 12 inches square when transmitting 24 H.P. at 12 R.P.M.

499. Compare the strength and stiffness of a square shaft with that of a round shaft of the same material when a side of the square shaft is equal to the diameter of the round shaft.

500. Compare the strength and stiffness of a round shaft with that of a square one of the same material and having the same area of cross-section.

XI. COMBINED STRESSES

501. A 12-inch steel I-beam, 40 pounds per foot, 6 feet span, carries in addition to its own weight a uniform load of 1200 pounds, and is subjected to an axial compression of 60,000 pounds. Find the factor of safety.

502. Find the size of a square, wooden simple beam of 12 feet span to carry a load of 400 pounds at the middle, when it is also subject to an axial compression of 3000 pounds, the maximum allowable compressive stress being 1000 pounds per square inch. Neglect weight of beam.

503. Determine the factor of safety for a simple wooden beam 8 feet long, 10 inches wide, and 9 inches deep, under an axial compression of 40,000 pounds, and bearing a total uniform load of 4200 pounds.

504. A wooden cantilever beam 3 feet long, 3 inches wide, and 4 inches deep has a load of 300 pounds at the free end, and is under an axial compression of 4500 pounds. Determine the maximum compressive unit-stress, neglecting weight of beam.

505. A wooden cantilever beam 8 inches wide and 4 feet long carries a total uniform load of 400 pounds per linear foot, and is subjected to an axial compression of 40,000 pounds. Find the depth of the beam so that the maximum compressive unit-stress shall be 1000 pounds per square inch.

506. Solve Problem 501 for an axial tension of 60,000 pounds instead of the axial compression.

507. Find the size of a square, wooden simple beam of 12 feet span to carry a load of 400 pounds at the middle, when it is also subject to an axial tension of 3000 pounds, the maximum allowable tensile stress being 1000 pounds per square inch. Neglect weight of beam.

508. Determine the factor of safety for a simple wooden beam 8 feet long, 10 inches wide, and 9 inches deep, under an axial tension of 40,000 pounds, and bearing a total uniform load of 4200 pounds.

509. A wooden cantilever beam 3 feet long, 3 inches wide, and 4 inches deep has a load of 300 pounds at the free end, and is under an axial tension of 4500 pounds. Compute the maximum tensile and compressive unit-stresses, neglecting the weight of the beam.

510. Find the size of a square, wooden simple beam of 12 feet span, which bears a total uniform load of 50 pounds per linear foot, and at the same time is under an axial tension of 2000 pounds, the maximum allowable unit-stress being 1000 pounds per square inch.

511. A bolt 1 inch in diameter is subjected to a longitudinal tension of 5000 pounds, and at the same time to a cross-shear of 3000 pounds. Determine the maximum combined tensile and shearing unit-stresses, and the angles they make with the axis of the bolt.

512. Find the maximum unit-stresses in a circular steel shaft 6 inches in diameter, resting on supports 10 feet apart, and transmitting 50 H.P. at 225 R.P.M., due to the combined bending and torsional moments.

513. Determine the diameter of a solid wrought-iron shaft 12 feet between bearings and transmitting 50 H.P. at 130 R.P.M., if pulleys are placed so as to produce a maximum bending moment of 600 pound-feet at the middle, and the maximum combined unit-stress is 10,000 pounds per square inch.

514. A bar of iron is under a direct tensile stress of 5000 pounds per square inch and a shearing stress of 3500 pounds per square inch. Find the maximum tensile and shearing unit-stresses.

515. A wrought-iron shaft is subjected simultaneously to a bending moment of 8000 pound-inches and a twisting moment of 15,000 pound-inches. Determine the least diameter of the shaft if the maximum tensile strength is not to exceed 10,000 pounds per square inch, and the shearing stress 8000 pounds per square inch.

516. Find the diameter of a wrought-iron shaft to transmit 90 H.P. at 130 R.P.M., with a factor of safety of 5, if there is also a bending moment equal to the twisting moment.

517. A wrought-iron shaft 3 inches in diameter and making 140 R.P.M. is supported in bearings 16 feet apart. If a load of 210 pounds is brought by a belt and pulley at the middle, what H.P. can be transmitted with a maximum shearing stress of 8000 pounds per square inch?

518. Compute the maximum unit-stresses for a steel shaft 3 inches in diameter, in fixed bearings 12 feet apart, which transmits 40 H.P. at 120 R.P.M., and upon which a load of 800 pounds is brought by a belt and pulley at the middle.

519. Find the diameter of a steel shaft, in fixed bearings 8 feet apart, to transmit 90 H.P. at 250 R.P.M., if there is a load of 480 pounds at the middle and the maximum allowable unit-stress is 7000 pounds per square inch.

520. Determine the factor of safety for a wrought-iron shaft 3 inches in diameter, resting in bearings 12 feet apart, when transmitting 25 H.P. at 100 R.P.M., and bearing a load of 200 pounds at the middle.

521. A hollow structural steel shaft, 17 inches outside diameter and 11 inches inside diameter, with ends fixed in bearings 18 feet apart, is to transmit 15,000 H.P. at 50 R.P.M. Find the maximum unit-stresses, considering the weight of the shaft.

522. A steel shaft 4 inches in diameter, with ends fixed in bearings 10 feet apart, carries a pulley 14 inches in diameter at its center. If the tension in the belt on this pulley is 250 pounds, and the shaft makes 80 R.P.M., how many H.P. is it transmitting, and what is the maximum unit-stress in the shaft?

523. Find the factor of safety for a vertical wrought-iron shaft 4 feet long and 2 inches in diameter, if it weighs with its loads 6000 pounds, and is subjected to a twisting moment of 1200 pound-feet.

524. Find the maximum horizontal shearing unit-stress in a cantilever beam 6 inches wide, 8 inches deep, and 10 feet long, if it supports a weight of 1000 pounds at its free end.

525. A simple wooden beam 4 inches wide, 12 inches deep, and 14 feet span bears a load of 12,500 pounds at the middle. Find the maximum horizontal shearing unit-stress.

526. A wooden, built-up simple beam 6 inches wide, 12 inches deep, and 10 feet long is formed by bolting together three 4×6 inch beams. When the beam supports a load of 2000 pounds at its middle point, find the maximum unit-shear in the planes of contact and the total horizontal shear on the bolts.

527. A 10-inch steel I-beam, 30 pounds per foot, resting on supports 20 feet apart, carries a load of 6000 pounds at its middle point. Determine the maximum horizontal unit-shear if the center of gravity of each half section is 4.5 inches from the neutral axis.

528. An 8-inch steel I-beam, 18 pounds per foot, resting on supports 15 feet apart, carries a load of 5000 pounds at its middle point. Determine the maximum horizontal unit-shear, if the center of gravity of each half section is 3.6 inches from the neutral axis.

XII. COMPOUND COLUMNS AND BEAMS

529. A vertical bar 10 feet long and 1 inch square is compounded by fastening together rigidly at the two ends a bar of steel and a bar of copper of equal size. When a load of 12,000 pounds is applied at the lower end of the compound bar, how much of this load will be sustained by each of the component bars, and what will be the elongation of the compound bar?

530. A compound column 4 feet in length is formed by bolting two $\frac{1}{2}$-inch steel plates, 8 inches wide, to the 8-inch sides of a piece of timber 6×8 inches in section area. When the column sustains an axial load of 120,000 pounds what is the compressive unit-stress in the steel and in the timber?

531. A flitched timber beam 15 feet long, supported at its ends, has a timber section 8×12 inches, with two steel plates $\frac{1}{2} \times 9$ inches bolted to the 12-inch sides. When the beam supports a total uniform load of 16,000 pounds, find the factors of safety for the timber and the steel.

532. A flitched beam consists of two timbers, each 10 inches wide and 14 inches deep, with a steel plate $\frac{3}{4}$ inch thick and 7 inches wide bolted between them on the 14-inch sides. Find the unit-stress in the steel when the unit-stress in the timber is 900 pounds per square inch.

533. A concrete column 12 feet high and 12×12 inches in section area has four vertical steel rods, each $1\frac{1}{2}$ inches in diameter, placed near the corners. Compute the unit-stresses in the concrete and steel due to their own weight and to an axial load of 30,000 pounds.

534. Find the load that a short concrete column 24 inches square, reinforced with 4 round, vertical, steel rods $2\frac{1}{2}$ inches in diameter, can safely carry if the compression in the concrete is limited to 450 pounds per square inch. What is then the unit-stress in the steel rods?

535. What percentage of reinforcement must be introduced into a concrete column designed to sustain a load of 650 pounds per square inch, when the compressive unit-stress in the concrete is limited to 500 pounds per square inch?

536. Find the safe bending moment for a reinforced concrete beam 16 inches deep and 4 inches wide, having one steel rod $\frac{7}{8}$ inch in diameter, with its center $1\frac{1}{2}$ inches above the bottom of the concrete, if the tensile resistance of the concrete is neglected and the maximum compressive stress in the concrete is 600 pounds per square inch.

537. Find the safe bending moment for the beam of Problem 536, if the concrete is to resist part of the tensile stresses with a maximum tensile stress of 100 pounds per square inch.

538. Determine the maximum bending moment for a reinforced concrete beam 8 inches wide and 17 inches deep, with a 1-inch-square steel rod placed with its center 2 inches above the bottom, if the concrete offers no tensile resistance and the maximum compressive stress in the concrete is limited to 600 pounds per square inch.

539. Solve Problem 538, if the maximum compressive stress in the concrete is limited to 500 pounds per square inch.

540. The beam of Problem 538 is supported at the ends of a 20-foot span and bears a total uniform load of 5200 pounds. Determine the unit-stresses in the concrete and in the steel, assuming that the concrete sustains none of the tensile load.

541. A reinforced concrete beam 5 inches deep, 48 inches wide, and 6 feet span has 2 square inches of steel placed 1 inch above the bottom of the concrete and sustains a total uniform load of 6000 pounds. If the beam is supported at the ends and the concrete offers no tensile resistance, determine the position of the neutral surface and the maximum unit-stresses in the concrete and in the steel.

542. A concrete-steel beam 12 inches wide, $13\frac{1}{2}$ inches deep, and 14 feet span, with supported ends, has 1 per cent of steel embedded $1\frac{1}{2}$ inches above the bottom of the concrete and bears two loads of 1300 pounds each at the third points of the span. Assuming that the concrete offers no tensile resistance, find the maximum unit-stresses in the steel and in the concrete. Consider weight of beam.

543. A concrete beam 14 inches deep, 8 inches wide, and 10 feet span, with supported ends, has two $\frac{3}{4}$-inch square steel rods placed 1 inch from the bottom. Supposing that the concrete offers no tensile resistance, find the total uniform load for the beam if the maximum compressive unit-stress in the concrete is 500 pounds per square inch. What is then the tensile unit-stress in the steel?

544. Solve Problem 543 for a concrete beam 8 inches broad, 10 inches deep, and 15 feet span, which is reinforced on the tensile side by six $\frac{1}{2}$-inch steel rounds with their centers 2 inches from the bottom of the beam.

545. A concrete beam 8 inches broad and 10 inches deep is reinforced by steel rods placed with their centers 2 inches from the bottom of the beam. Neglecting the tensile strength of the concrete, find the area of the steel reinforcement necessary to make the beam equally strong in tension and compression. What is then the safe bending moment for a factor of safety of 6?

XIII. THICK CYLINDERS AND GUNS

546. A cylinder 1 foot inside and 2 feet outside diameter is subjected to an internal pressure of 600 pounds per square inch and an external pressure of 15 pounds per square inch. Determine the tangential unit-stresses at the inside and outside surfaces of the cylinder.

547. The steel cylinder of an hydraulic press has an internal diameter of 5 inches and an external diameter of 7 inches. How great an internal pressure can the cylinder withstand with a factor of safety of 4?

548. Find the internal pressure to burst a cast-iron cylinder 10 inches inside diameter and 5 inches thick. Compare the result with that obtained when considering it a thin cylinder.

549. Determine the internal pressure for a cast-iron pipe 10 inches inside diameter and 2 inches thick, for a factor of safety of 8. Consider it first as a thick and then as a thin cylinder.

550. If a gun of 3 inches bore has an internal pressure of 2000 pounds per square inch, what should be its thickness so that the greatest stress in the material shall not exceed 3000 pounds per square inch?

551. The cylinder of an hydraulic press has an internal diameter of 6 inches. Find its thickness to resist an interior hydrostatic pressure of 1200 pounds per square inch, with a maximum stress in the material of 2000 pounds per square inch.

552. Determine the thickness for a steel locomotive cylinder 22 inches internal diameter, to withstand a maximum steam pressure of 200 pounds per square inch, with a factor of safety of 10.

553. What inside pressure will produce a maximum stress of 20,000 pounds per square inch in a gun-tube 6 inches inside diameter and 3 inches thick?

554. A pipe 6 inches inside diameter is to withstand an internal pressure of 1000 pounds per square inch. Find its outside diameter, if the maximum tensile stress in the metal is 3000 pounds per square inch.

555. A wrought-iron cylinder, inside radius 2 inches and outside radius 3 inches, has no inside pressure but an external pressure of 4200 pounds per square inch. Find the stresses at the inside and outside surfaces of the cylinder.

556. A gun-tube 3 inches inside radius and 5 inches outside radius is hooped so that the tangential compression at the bore is 14,400 pounds per square inch. The inside pressure caused by an explosion is 25,000 pounds per square inch. Determine the resultant tangential tension at the bore during the explosion.

557. A gun-tube 4 inches inside diameter and 6 inches outside diameter is hooped so that the tangential compression at the inside surface is 18,000 pounds per square inch. Find the resultant tangential stress at the bore during an explosion which causes a pressure of 25,000 pounds per square inch.

558. A gun-tube 4 inches inside diameter and 2 inches thick is hooped so that the tangential compression on the inside surface is 30,000 pounds per square inch. What powder pressure will produce a resultant tangential tension on the inside surface of 30,000 pounds per square inch?

559. A steel hoop whose thickness is 2 inches is shrunk upon a steel tube whose inside radius is 3 inches and outside radius 5 inches. Find the stresses produced at the inside and outside surfaces of the hoop and tube, if the original difference between the outside radius of the tube and inside radius of the hoop is 0.004 inch.

560. A steel tube, outside radius 4 inches and inside radius 2.9984 inches, is shrunk upon another tube, outside radius 3.00098 inches and inside radius 2 inches. Find the stresses produced in the tubes at the outside and inside surfaces.

XIV. FLAT PLATES

561. Find the thickness of a fixed cast-iron cylinder-head 36 inches in diameter, to sustain a uniform pressure of 250 pounds per square inch, with a maximum tensile stress of 4000 pounds per square inch.

562. Determine the thickness of a fixed steel cylinder-head 36 inches in diameter to sustain a uniform pressure of 300 pounds per square inch, with a factor of safety of 5.

563. The cylinder of a locomotive is 20 inches inside diameter. Find the thickness of the steel end-plate to withstand a pressure of 160 pounds per square inch, with a maximum tensile stress of 10,000 pounds per square inch.

564. A circular cast-iron valve-gate $\frac{1}{2}$ inch thick closes an opening 6 inches in diameter. Find the maximum unit-stress in the gate if the pressure against it is 65 pounds per square inch.

565. Find the maximum unit-stress in a circular steel plate $1\frac{1}{2}$ inches thick and 24 inches in diameter, bearing a load of 4000 pounds at its center, if this load is distributed over a circle 3 inches in diameter.

566. Determine the uniform pressure, with a factor of safety of 4 for an elliptical cast-iron manhole cover 3 feet long, 18 inches wide, and 1 inch thick.

567. Find the proper thickness for an elliptical cast-iron manhole cover 24 inches long and 16 inches wide, when used in a stand-pipe under a head of water of 60 feet, with a factor of safety of 6.

568. Determine the safe uniform pressure for a cast-iron elliptical manhole cover 20 inches long, 13 inches wide, and $1\frac{1}{4}$ inches thick, if the maximum unit-stress is limited to 3000 pounds per square inch.

TABLES

AVERAGE PHYSICAL CONSTANTS

Material	Ultimate Tensile Strength	Ultimate Compressive Strength	Ultimate Shearing Strength	Modulus of Elasticity	Shearing Modulus of Elasticity
	Pounds per Square Inch	Pounds per Square Inch	Pounds per Square Inch	Pounds per Square Inch	Pounds per Square Inch
Hard steel	100 000	120 000	80 000	30 000 000	12 000 000
Structural steel . .	60 000	60 000	50 000	30 000 000	12 000 000
Wrought-iron . .	50 000	50 000	40 000	25 000 000	10 000 000
Cast-iron	20 000	90 000	20 000	15 000 000	6 000 000
Copper	30 000			15 000 000	6 000 000
Timber, with grain .	10 000	8 000	600	1 500 000	
Timber, across grain			3 000		400 000
Concrete	300	3 000	1 000	3 000 000	
Stone		6 000	1 500	6 000 000	
Brick		3 000	1 000	2 000 000	

Material	Elastic Limit	Ultimate Flexural Strength	Weight	Coefficient of Linear Expansion	Unit Elongation at Elastic Limit
	Pounds per Square Inch	Pounds per Square Inch	Pounds per Cubic Foot	For 1° Fahrenheit	Inch
Hard steel	60 000	110 000	490	0.000 0065	0.0012
Structural steel. . .	35 000		490	0.000 0065	0.0012
Wrought-iron . . .	25 000		480	0.000 0067	0.0010
Cast-iron (tension) .	6 000	35 000	450	0.000 0062	0.0004
Cast-iron (compression)	20 000				
Timber	3 000	9 000	40	0.000 0028	0.0020
Concrete (compression)	1 000	700	150	0.000 0055	
Stone (compression) .	2 000	2 000	160	0.000 0050	
Brick (compression) .	1 000	800	125	0.000 0050	

DIMENSIONS OF BOLTS

Diameter of Bolt	Diameter of Bolt	Threads per Inch	Diameter at Root	Area of Body	Area of Root
Inches	Inches	Number	Inches	Square Inches	Square Inches
$\frac{1}{8}$	.125	40		.0122	
$\frac{3}{16}$	.1875	30		.0276	
$\frac{1}{4}$	.25	20	.185	.0491	026
$\frac{5}{16}$	.3125	18	.24	.0767	.045
$\frac{3}{8}$	.375	16	.294	.1104	.068
$\frac{7}{16}$	.4375	14	.345	.150	.093
$\frac{1}{2}$	.50	13	.400	.196	.125
$\frac{9}{16}$	.5625	12	.454	.249	.162
$\frac{5}{8}$	.625	11	.507	.307	.202
$\frac{11}{16}$	.6875			.372	
$\frac{3}{4}$	.75	10	.620	.442	.302
$\frac{13}{16}$	.8125			.518	
$\frac{7}{8}$	.875	9	.731	.601	.420
$\frac{15}{16}$	.9375			.690	
1	1.0	8	.837	.785	.550
$1\frac{1}{16}$	1.0625			.882	
$1\frac{1}{8}$	1.125	7	.940	.994	.694
$1\frac{3}{16}$	1.1875			1.110	
$1\frac{1}{4}$	1.25	7	1.065	1.227	.893
$1\frac{5}{16}$	1.3125			1.348	
$1\frac{3}{8}$	1.375	6	1.160	1.485	1.057
$1\frac{1}{2}$	1.50	6	1.284	1.767	1.295
$1\frac{5}{8}$	1.625	$5\frac{1}{2}$	1.389	2.074	1.515
$1\frac{3}{4}$	1.75	5	1.491	2.405	1.744
$1\frac{7}{8}$	1.875	5	1.615	2.761	2.048
2	2.0	$4\frac{1}{2}$	1.712	3.142	2.302
$2\frac{1}{4}$	2.25	$4\frac{1}{2}$	1.962	3.976	3.023
$2\frac{1}{2}$	2.50	4	2.175	4.909	3.715
$2\frac{3}{4}$	2.75	4	2.425	5.940	4.619
3	3.0	$3\frac{1}{2}$	2.629	7.069	5.428
$3\frac{1}{4}$	3.25	$3\frac{1}{2}$	2.879	8.296	6.510
$3\frac{1}{2}$	3.50	$3\frac{1}{4}$	3.100	9.621	7.548
$3\frac{3}{4}$	3.75	3	3.317	11.045	8.641
4	4.0	3	3.567	12.566	9.993

FACTORS OF SAFETY

Material	For Steady Stress (Buildings)	For Varying Stress (Bridges)	For Shocks (Machines)
Hard Steel	5	8	15
Structural Steel . .	4	6	10
Wrought-Iron . . .	4	6	10
Cast-Iron	6	10	20
Timber	8	10	15
Brick and Stone . .	15	25	30

POISSON'S RATIO

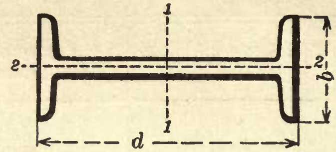
Steel	.295	Copper	.340
Iron	.277	Lead	.375
Brass	.357	Zinc	.205

RANKINE'S COLUMN FORMULA

Values of Constant

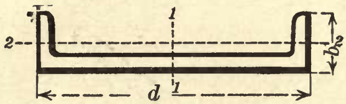
Material	Both Ends Fixed	Fixed and Round	Both Ends Round
Steel	$\frac{1}{25000}$	$\frac{1}{14060}$	$\frac{1}{6250}$
Wrought-Iron . . .	$\frac{1}{36000}$	$\frac{1}{20250}$	$\frac{1}{9000}$
Cast-Iron	$\frac{1}{5000}$	$\frac{1}{2810}$	$\frac{1}{1250}$
Timber	$\frac{1}{3000}$	$\frac{1}{1690}$	$\frac{1}{750}$

PROPERTIES OF STANDARD I-BEAMS



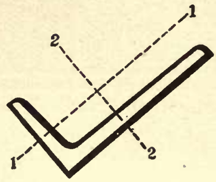
Depth of Beam	Weight per Foot	Area of Section	Width of Flange	Moment of Inertia Axis 1–1	Section Modulus Axis 1–1	Radius of Gyration Axis 1–1	Moment of Inertia Axis 2–2	Radius of Gyration Axis 2–2
Inches	Pounds	Square Inches	Inches	Inches^4	Inches^3	Inches	Inches^4	Inches
3	5.50	1.63	2.33	2.5	1.7	1.23	.46	.53
3	6.50	1.91	2.42	2.7	1.8	1.19	.53	.52
3	7.50	2.21	2.52	2.9	1.9	1.15	.60	.52
4	7.50	2.21	2.66	6.0	3.0	1.64	.77	.59
4	8.50	2.50	2.73	6.4	3.2	1.59	.85	.58
4	9.50	2.79	2.81	6.7	3.4	1.54	.93	.58
4	10.50	3.09	2.88	7.1	3.6	1.52	1.01	.57
5	9.75	2.87	3.00	12.1	4.8	2.05	1.23	.65
5	12.25	3.60	3.15	13.6	5.4	1.94	1.45	.63
5	14.75	4.34	3.29	15.1	6.1	1.87	1.70	.63
6	12.25	3.61	3.33	21.8	7.3	2.46	1.85	.72
6	14.75	4.34	3.45	24.0	8.0	2.35	2.09	.69
6	17.25	5.07	3.57	26.2	8.7	2.27	2.36	.68
7	15.00	4.42	3.66	36.2	10.4	2.86	2.67	.78
7	17.50	5.15	3.76	39.2	11.2	2.76	2.94	.76
7	20.00	5.88	3.87	42.2	12.1	2.68	3.24	.74
8	18.00	5.33	4.00	56.9	14.2	3.27	3.78	.84
8	20.25	5.96	4.08	60.2	15.0	3.18	4.04	.82
8	22.75	6.69	4.17	64.1	16.0	3.10	4.36	.81
8	25.25	7.43	4.26	68.0	17.0	3.03	4.71	.80
9	21.00	6.31	4.33	84.9	18.9	3.67	5.16	.90
9	25.00	7.35	4.45	91.9	20.4	3.54	5.65	.88
9	30.00	8.82	4.61	101.9	22.6	3.40	6.42	.85
9	35.00	10.29	4.77	111.8	24.8	3.30	7.31	.84
10	25.00	7.37	4.66	122.1	24.4	4.07	6.89	.97
10	30.00	8.82	4.80	134.2	26.8	3.90	7.65	.93
10	35.00	10.29	4.95	146.4	29.3	3.77	8.52	.91
10	40.00	11.76	5.10	158.7	31.7	3.67	9.50	.90
12	31.50	9.26	5.00	215.8	36.0	4.83	9.50	1.01
12	35.00	10.29	5.09	228.3	38.0	4.71	10.07	.99
12	40.00	11.76	5.21	245.9	41.0	4.57	10.95	.96
15	42.00	12.48	5.50	441.8	58.9	5.95	14.62	1.08
15	45.00	13.24	5.55	455.8	60.8	5.87	15.09	1.07
15	50.00	14.71	5.65	483.4	64.5	5.73	16.04	1.04
15	55.00	16.18	5.75	511.0	68.1	5.62	17.06	1.03
15	60.00	17.65	5.84	538.6	71.8	5.52	18.17	1.01
18	55.00	15.93	6.00	795.6	88.4	7.07	21.19	1.15
18	60.00	17.65	6.10	841.8	93.5	6.91	22.38	1.13
18	70.00	20.59	6.26	921.2	102.4	6.69	24.62	1.09
20	65.00	19.08	6.25	1169.5	117.0	7.83	27.86	1.21
20	75.00	22.06	6.40	1268.8	126.9	7.58	30.25	1.17
24	80.00	23.32	7.00	2087.2	173.9	9.46	42.86	1.36
24	90.00	26.47	7.13	2238.4	186.5	9.20	45.70	1.31
24	100.00	29.41	7.25	2379.6	198.3	8.99	48.55	1.28

PROPERTIES OF STANDARD CHANNELS



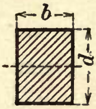
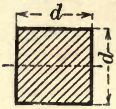
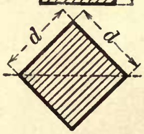
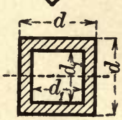
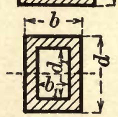
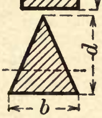
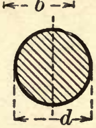
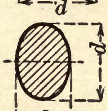
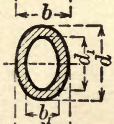
Depth of Channel	Weight per Foot	Area of Section	Width of Flange	Moment of Inertia Axis 1 – 1	Radius of Gyration Axis 1 – 1	Moment of Inertia Axis 2 – 2	Radius of Gyration Axis 2 – 2	Outside of Web to Center of Gravity
Inches	Pounds	Square Inches	Inches	$Inches^4$	Inches	$Inches^4$	Inches	Inches
3	4.00	1.19	1.41	1.6	1.17	0.20	.41	.44
3	6.00	1.76	1.60	2.1	1.08	0.31	.42	.46
4	5.25	1.55	1.58	3.8	1.56	0.32	.45	.46
4	7.25	2.13	1.73	4.6	1.46	0.44	.46	.46
5	6.50	1.95	1.75	7.4	1.95	0.48	.50	.49
5	11.50	3.38	2.04	10.4	1.75	0.82	.49	.51
6	8.00	2.38	1.92	13.0	2.34	0.70	.54	.52
6	13.00	3.82	2.16	17.3	2.13	1.07	.53	.52
6	15.50	4.56	2.28	19.5	2.07	1.28	.53	.55
7	9.75	2.85	2.09	21.1	2.72	0.98	.59	.55
7	14.75	4.34	2.30	27.2	2.50	1.40	.57	.53
7	19.75	5.81	2.51	33.2	2.39	1.85	.56	.58
8	11.25	3.35	2.26	32.3	3.10	1.33	.63	.58
8	16.25	4.78	2.44	39.9	2.89	1.78	.61	.56
8	21.25	6.25	2.62	47.8	2.76	2.25	.60	.59
9	13.25	3.89	2.43	47.3	3.49	1.77	.67	.61
9	20.00	5.88	2.65	60.8	3.21	2.45	.65	.58
9	25.00	7.35	2.81	70.7	3.10	2.98	.64	.62
10	15.00	4.46	2.60	66.9	3.87	2.30	.72	.64
10	30.00	8.82	3.04	103.2	3.42	3.99	.67	.65
10	35.00	10.29	3.18	115.5	3.35	4.66	.67	.69
12	20.50	6.03	2.94	128.1	4.61	3.91	.81	.70
12	25.00	7.35	3.05	144.0	4.43	4.53	.78	.68
12	35.00	10.29	3.30	179.3	4.17	5.90	.76	.69
12	40.00	11.76	3.42	196.9	4.09	6.63	.75	.72
15	33.00	9.90	3.40	312.6	5.62	8.23	.91	.79
15	40.00	11.76	3.52	347.5	5.44	9.39	.89	.78
15	50.00	14.71	3.72	402.7	5.23	11.22	.87	.80
15	55.00	16.18	3.82	430.2	5.16	12.19	.87	.82

PROPERTIES OF STANDARD ANGLES

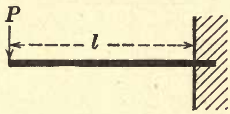
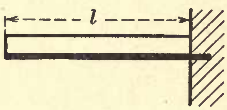
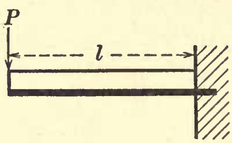
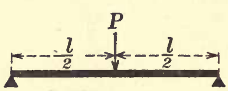
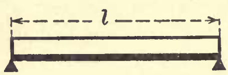
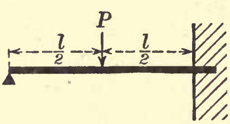
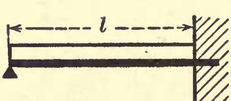
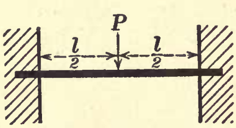
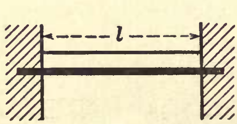


Dimensions	Weight per Foot	Area of Section	Distance of Center of Gravity from Back of Longer Leg	Moment of Inertia Axis 1–1	Radius of Gyration Axis 1–1	Distance of Center of Gravity from Back of Shorter Leg	Moment of Inertia Axis 2–2	Radius of Gyration Axis 2–2
Inches	Pounds	Square Inches	Inches	Inches^4	Inches	Inches	Inches^4	Inches
$2\frac{1}{2} \times 2 \times \frac{1}{2}$	6.8	2.00	.63	.64	.56	.88	1.14	.75
$3 \times 2\frac{1}{2} \times \frac{1}{2}$	8.5	2.50	.75	1.30	.72	1.00	2.08	.91
$3\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{2}$	9.4	2.75	.70	1.36	.70	1.20	3.24	1.09
$3\frac{1}{2} \times 3 \times \frac{1}{2}$	10.2	3.00	.88	2.33	.88	1.13	3.45	1.07
$4 \times 3 \times \frac{1}{2}$	11.1	3.25	.83	2.42	.86	1.33	5.05	1.25
$4 \times 3 \times \frac{3}{4}$	16.0	4.69	.92	3.28	.84	1.42	6.93	1.22
$5 \times 3 \times \frac{1}{2}$	12.8	3.75	.75	2.58	.83	1.75	9.45	1.59
$5 \times 3 \times \frac{3}{4}$	18.5	5.44	.84	3.51	.80	1.84	13.15	1.55
$5 \times 3\frac{1}{2} \times \frac{1}{2}$	13.6	4.00	.91	4.05	1.01	1.66	9.99	1.58
$5 \times 3\frac{1}{2} \times \frac{3}{4}$	19.8	5.82	1.00	5.55	.98	1.75	13.92	1.55
$6 \times 3\frac{1}{2} \times \frac{1}{2}$	15.3	4.50	.83	4.25	.97	2.08	16.59	1.92
$6 \times 3\frac{1}{2} \times \frac{3}{4}$	22.4	6.57	.93	5.84	.94	2.18	23.34	1.89
$6 \times 4 \times \frac{1}{2}$	16.2	4.75	.99	6.27	1.15	1.99	17.40	1.91
$6 \times 4 \times \frac{3}{4}$	23.6	6.94	1.08	8.68	1.12	2.08	24.51	1.88
Equal legs								
$2 \times 2 \times \frac{1}{2}$	6.0	1.75	.68	.59	.58			
$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{2}$	7.7	2.25	.81	1.23	.74			
$3 \times 3 \times \frac{1}{2}$	9.4	2.75	.93	2.22	.90			
$3\frac{1}{2} \times 3\frac{1}{2} \times \frac{1}{2}$	11.1	3.25	1.06	3.64	1.04			
$3\frac{1}{2} \times 3\frac{1}{2} \times \frac{3}{4}$	16.0	4.69	1.15	4.96	1.02			
$4 \times 4 \times \frac{1}{2}$	12.8	3.75	1.18	5.56	1.20			
$4 \times 4 \times \frac{3}{4}$	18.5	5.44	1.27	7.66	1.17			
$6 \times 6 \times \frac{1}{2}$	19.6	5.75	1.68	19.91	1.84			
$6 \times 6 \times \frac{3}{4}$	28.7	8.44	1.78	28.15	1.81			
$8 \times 8 \times \frac{1}{2}$	26.4	7.75	2.19	48.65	2.49			
$8 \times 8 \times \frac{3}{4}$	38.9	11.44	2.28	69.74	2.45			

PROBLEMS OF VARIOUS SECTIONS

Sections	Area of Section	Distance from Extreme Fiber to Neutral Axis	Moment of Inertia	Section Modulus	Radius of Gyration
	bd	$\frac{d}{2}$	$\frac{bd^3}{12}$	$\frac{bd^2}{6}$	$\frac{d}{\sqrt{12}} = .289\,d$
	d^2	$\frac{d}{2}$	$\frac{d^4}{12}$	$\frac{d^3}{6}$	$\frac{d}{\sqrt{12}} = .289\,d$
	d^2	$\frac{d}{\sqrt{2}} = .707\,d$	$\frac{d^4}{12}$	$\frac{d^3}{6\sqrt{2}} = .118d^3$	$\frac{d}{\sqrt{12}} = .289\,d$
	$d^2 - d_1^2$	$\frac{d}{2}$	$\frac{d^4 - d_1^4}{12}$	$\frac{d^4 - d_1^4}{6\,d}$	$\sqrt{\frac{d^2 + d_1^2}{12}}$
	$bd - b_1d_1$	$\frac{d}{2}$	$\frac{bd^3 - b_1d_1^3}{12}$	$\frac{bd^3 - b_1d_1^3}{6\,d}$	$\sqrt{\frac{bd^3 - b_1d_1^3}{12(bd - b_1d_1)}}$
	$\frac{1}{2}\,bd$	$\frac{2\,d}{3}$	$\frac{bd^3}{36}$	$\frac{bd^3}{24}$	$\frac{d}{\sqrt{18}} = .236\,d$
	$\frac{\pi d^2}{4}$	$\frac{d}{2}$	$\frac{\pi d^4}{64} = .049\,d^4$	$\frac{\pi d^3}{32} = .098\,d^3$	$\frac{d}{4}$
	$\frac{\pi(d^2 - d_1^2)}{4}$	$\frac{d}{2}$	$\frac{\pi(d^4 - d_1^4)}{64}$	$\frac{\pi(d^4 - d_1^4)}{32\,d}$	$\frac{\sqrt{d^2 + d_1^2}}{4}$
	$\frac{\pi bd}{4}$	$\frac{d}{2}$	$\frac{\pi bd^3}{64}$	$\frac{\pi bd^3}{32}$	$\frac{d}{4}$
	$\frac{\pi(bd - b_1d_1)}{4}$	$\frac{d}{2}$	$\frac{\pi(bd^3 - b_1d_1^3)}{64}$	$\frac{\pi(bd^3 - b_1d_1^3)}{32\,d}$	$\frac{1}{4}\sqrt{\frac{bd^3 - b_1d_1^3}{bd - b_1d_1}}$

BENDING MOMENTS AND DEFLECTIONS

Method of Loading and Supporting	Maximum Bending Moment	Maximum Deflection	Remarks
	Pl	$\frac{1}{3}\frac{Pl^3}{EI}$	Cantilever, load at free end.
	$\frac{Wl}{2}$	$\frac{1}{8}\frac{Wl^3}{EI}$	Cantilever, uniform load W.
	$Pl + \frac{Wl}{2}$	$\frac{1}{3}\frac{Pl^3}{EI} + \frac{1}{8}\frac{Wl^3}{EI}$	Cantilever, load at free end and uniform load W.
	$\frac{Pl}{4}$	$\frac{1}{48}\frac{Pl^3}{EI}$	Simple beam, load at middle.
	$\frac{Wl}{8}$	$\frac{5}{384}\frac{Wl^3}{EI}$	Simple beam, uniform load W.
	$\frac{3}{16}Pl$	$\frac{1}{108}\frac{Pl^3}{EI}$	One end fixed, other end supported, load at middle.
	$\frac{Wl}{8}$	$\frac{1}{185}\frac{Wl^3}{EI}$	One end fixed, other end supported.
	$\frac{Pl}{8}$	$\frac{1}{192}\frac{Pl^3}{EI}$	Both ends fixed, load at middle.
	$\frac{Wl}{12}$	$\frac{1}{384}\frac{Wl^3}{EI}$	Both ends fixed, uniform load W.