Table 8.3.25 Solid Oil Additives

Lubricant type	Temperature range, °F	Source	Identification	Remarks
Colloidal graphite	Up to 1,000	Acheson Colloids Co.	SLA 1275	Good load capacity, excellent temperature resistance
Colloidal MoS_2	Up to 750	Acheson Colloids Co.	SLA 1286	Good antiwear
Colloidal Teflon	Up to 575	Acheson Colloids Co.	SLA 1612	Low coefficient of friction

they will provide long service life if the plastic chosen is correct for the application. Plastics manufacturers and their publications can be consulted for guidance. Alternatively, many plastic gear materials can be molded with internal solid lubricants, such as MoS_2, Teflon, and graphite.

GEAR INSPECTION AND QUALITY CONTROL

Gear performance is not only related to the design, but also depends upon obtaining the specified quality. Details of gear inspection and control of subtle problems relating to quality are given in Michalec, ''Precision Gearing,'' Chap. 11.

COMPUTER MODELING AND CALCULATIONS

A feature of the latest AGMA rating standards is that the graphs, including those presented here, are accompanied by equations which allow application of computer-aided design. Gear design equations and strength and durability rating equations have been computer modeled by many gear manufacturers, users, and university researchers. Numerous software programs, including integrated CAD/CAM, are available from these places, and from computer system suppliers and specialty software houses. It is not necessary for gear designers, purchasers, and fabricators to create their own computer programs.

With regard to gear tooth strength and durability ratings, many custom gear house designers and fabricators offer their own computer modeling which incorporates modifications of AGMA formulas based upon experiences from a wide range of applications.

The following organizations offer software programs for design and gear ratings according to methods outlined in AGMA publications: Fairfield Manufacturing Company Gear Software; Geartech Software, Inc.; PC Gears; Universal Technical Systems, Inc. For details and current listings, refer to AGMA's latest ''Catalog of Technical Publications.''

8.4 FLUID FILM BEARINGS

by Vittorio (Rino) Castelli

REFERENCES: ''General Conference on Lubrication and Lubricants,'' ASME. Fuller, ''Theory and Practice of Lubrication for Engineers,'' 2d ed., Wiley. Booser, ''Handbook of Lubrication, Theory and Design,'' vol. 2, CRC Press. Barwell, ''Bearing Systems, Principles and Practice,'' Oxford Univ. Press. Cameron, ''Principles of Lubrication,'' Longmans Greene. ''Proceedings,'' Second International Symposium on Gas Lubrication, ASME. Gross, ''Fluid-Film Lubrication,'' Wiley. Gunter, ''Dynamic Stability of Rotor-Bearing Systems,'' NASA SP-113, Government Printing Office.

Plain bearings, according to their function, may be

Journal bearings, cylindrical, carrying a rotating shaft and a radial load

Thrust bearings, the function of which is to prevent axial motion of a rotating shaft

Guide bearings, to guide a machine element in its translational motion, usually without rotation of the element

In exceptional cases of design, or with a complete **failure of lubrication,** a bearing may run dry. The coefficient of friction is then between 0.25 and 0.40, depending on the materials of the rubbing surfaces. With the **bearing barely greasy,** or when the bearing is well lubricated but the speed of rotation is very slow, boundary lubrication takes place. The coefficient of friction may vary from 0.08 to 0.14. This condition occurs also in any bearing when the shaft is starting from rest if the bearing is not equipped with an oil lift.

Semifluid, or **mixed,** lubrication exists between the journal and bearing when the conditions are not such as to form a load-carrying fluid film and thus separate the surfaces. Semifluid lubrication takes place at comparatively low speed, with intermittent or oscillating motion, heavy load, insufficient oil supply to the bearing (wick or waste-lubrication, drop-feed lubrication). Semifluid lubrication may also exist in thrust bearings with fixed parallel-thrust collars, in guide bearings of machine tools, in bearings with copious lubrication where the shaft is bent or the bearing is misaligned, or where the bearing surface is interrupted by improperly arranged oil grooves. The coefficient of friction in such bearings may range from 0.02 to 0.08 (Fuller, Mixed Friction Conditions in Lubrication, *Lubrication Eng.*, 1954).

Fluid or **complete lubrication,** when the rubbing surfaces are completely separated by a fluid film, provides the lowest friction losses and prevents wear. A certain amount of oil must be fed to the oil film in order to compensate for end leakage and maintain its carrying capacity. Such lubrication can be provided under pressure from a pump or gravity tank, by automatic lubricating devices in self-contained bearings (oil rings or oil disks), or by submersion in an oil bath (thrust bearings for vertical shafts).

Notation

R = radius of bearing, length
r = radius of journal, length
$c = mr = R - r$ = radial clearance, length
W = bearing load, force
μ = viscosity = force × time/length^2
Z = viscosity, centipoise (cP); 1 cP = 1.45×10^{-7} lb · s/in^2 (0.001 N · s/m^2)
β = angle between load and entering edge of oil film
η = coefficient for side leakage of oil
ν = kinematic viscosity = μ/ρ, length^2/time
R_e = Reynolds number = umr/ν
P_a = absolute ambient pressure, force/area
$P = W/(ld)$ = unit pressure, lb/in^2
N = speed of journal, r/min
m = clearance ratio (diametral clearance/diameter)
F = friction force, force
A = operating characteristic of plain cylindrical bearing
P' = alternate operating characteristic of plain cylindrical bearing
h_0 = minimum film thickness, length
ε = eccentricity ratio, or ratio of eccentricity to radial clearance
e = eccentricity = distance between journal and bearing centers, length
f = coefficient of friction
$f' = F/(\pi rl\rho u^2)$
l = length of bearing, length
$d = 2r$ = diameter of journal, length

K_f = friction factor of plain cylindrical bearing
t_w = temperature of bearing wall
t_0 = temperature of air
t_1 = temperature of oil film
u = surface speed, length/time
ω = angular velocity, rad/time
ρ = mass density, mass/length^3
Λ = bearing compressibility parameter = $6\mu\omega r^2/(P_a c^2)$

INCOMPRESSIBLE AND COMPRESSIBLE LUBRICATION

Depending on the fluid employed and the pressure regime, the fluid density may or may not vary appreciably from the ambient value in the load-carrying film. Typically, oils, water, and liquid metals can be considered incompressible, while gases exhibit compressibility effects even at modest loads. The difference comes from the fact that, in incompressible lubricants, fluid flow rates are linearly proportional to pressure differences, whereas for compressible lubricants the mass flow rates are proportional to the difference of some power of the pressure. This is because the pressure affects the fluid density. The bearing behavior is somewhat dissimilar. In incompressible lubrication, gage pressures can be used and the value of the ambient pressure has no effect on the load-carrying capacity, which is linearly related to viscosity and speed. This is not true in compressible lubrication, where the value of ambient pressure has a direct effect on the load-carrying capacity which, in turn, increases with viscosity and speed, but only up to a limit dependent on the bearing geometry. In what follows, incompressible lubrication is treated first and compressible lubrication second.

Incompressible (Plain Cylindrical Journal Bearings)

Fluid lubrication in plain cylindrical bearings depends on the viscosity of the lubricant, the speed of the bearing components, the geometry of the film, and possible external sources of pressurized lubricant. The oil is entrained by the journal into the film by the action of the viscosity which, if the passage is convergent, causes the creation of a pressure field, resulting in a force sufficient to float the journal and carry the load applied to it.

The **minimum film thickness** h_0 determines the closest approach of the journal and bearing surfaces (Fig. 8.4.1). The allowable closest approach depends on the finish of these surfaces and on the rigidity of the journal and bearing structures. In practice, $h_0 = 0.00075$ in (0.019 mm) is common in electric motors and generators of medium speed, with

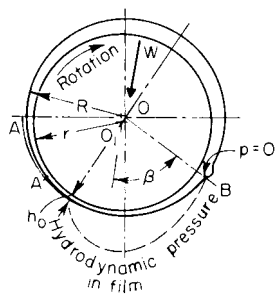


Fig. 8.4.1 Journal bearing with perfect lubrication.

steel shafts in babbitted bearings; $h_0 = 0.003$ in (0.076 mm) to 0.005 in (0.127 mm) for large steel shafts running at high speed in babbitted bearings (turbogenerators, fans), with pressure oil-supply for lubrication; $h_0 = 0.0001$ in (0.0025 mm) to 0.0002 in (0.005 mm) in automotive and aviation engines, with very fine finish of the surfaces.

Figure 8.4.2 gives the relationship between ε and the load-carrying coefficient A for a plain cylindrical journal. The operating characteristic of the bearing is

$$A = (132/\eta)(1{,}000m)^2[P/(ZN)]$$

In Fig. 8.4.1, β is the angle between the direction of the load W and the entering edge of the load-carrying oil film, in degrees. The entering edge is at the place where the hydrodynamic pressure is equal or nearly equal to the atmospheric pressure and may be at the location of the

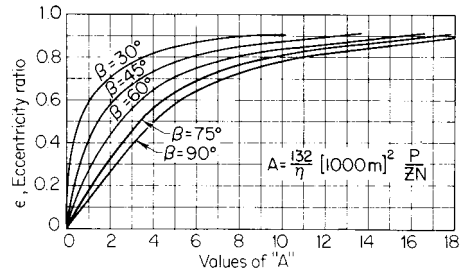


Fig. 8.4.2 Eccentricity ratio for a plain cylindrical journal.

oil-distributing groove B, or at the end of the machined recess pocket as at AA. For **complete bearings,** i.e., when the inner surface of the bearing is not interrupted by grooves, β may be taken as 90°. The reason for this assumption is the fact that, where the film diverges, the bearing pumping action tends to generate negative pressure, which liquids cannot sustain. The film **cavitates;** i.e., it breaks up in regions of fluid intermixed with either air or fluid vapor, while the pressure does not deviate substantially from ambient. For a 120° bearing with a central load, β may be taken as 60°.

The coefficient η corrects for side leakage. There is a loss of load-carrying capacity caused by the drop in the hydrodynamic pressure p in the oil film from the midsection of the bearing toward its ends; $p = 0$ at the ends. The value of η depends on the length-diameter ratio l/d and ε, the eccentricity ratio. Values of η are given in Fig. 8.4.3.

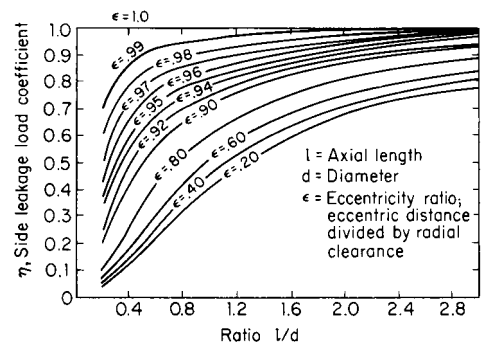


Fig. 8.4.3

EXAMPLE 1. A generator bearing, 6 in diam by 9 in long, carries a vertical downward load of 8,650 lb; $N = 720$ r/min. The diametral clearance of the bearing is 0.012 in; the bearing is split on its horizontal diameter, and the lower half is relieved 40° down on each side, for oil distribution along journal; the bearing arc is therefore 100°; with the load vertical, $\beta = 50°$; bearing temperature 160°F. The absolute viscosity of the oil in the film is 12 centipoises (medium turbine oil). $P = W/ld = 160$ lb/in^2; $\mu = 12 \times 1.45 \times 10^{-7} = 17.4 \times 10^{-7}$ lb · s/in^2. The solution is one of trial and error. By using Fig. 8.4.3 in conjunction with Fig. 8.4.2, only a few trials are necessary to obtain the answer. As a first trial assume $\varepsilon = 0.85$. For an l/d ratio of 1.5 in Fig. 8.4.3, η, the end-leakage factor, will be 0.77. Compute A using this value of η. $m = 0.012/6 = 0.002$.

$$A = \frac{132}{0.77}(2)^2\frac{160}{12 \times 720} = 12.7$$

Enter Fig. 8.4.2 with this value of a and at $\beta = 50°$, and find that $\varepsilon = 0.9$. This value is larger than the initial assumption for ε. As a second trial, $\varepsilon = 0.88$. Then $\eta = 0.8$, $A = 12.2$, and $\varepsilon = 0.89$. This is a sufficiently close check. The minimum film thickness is $h_0 = mr(1 - \varepsilon) = 0.002 \times 3 \times 0.12 = 0.0007$ in (0.01778 mm).

For severe operating conditions the value of A may exceed 18, the limit of Fig. 8.4.2. For complete journal bearings under extreme operating conditions, Fig. 8.4.4 should be used. The ordinate is P', defined as shown. The curves are drawn for various values of l/d instead of values of β as in Fig. 8.4.2. Values of ε may thus be obtained directly (Dennison, Film-Lubrication Theory and Engine-Bearing Design, *Trans. ASME,* **58,** 1936).

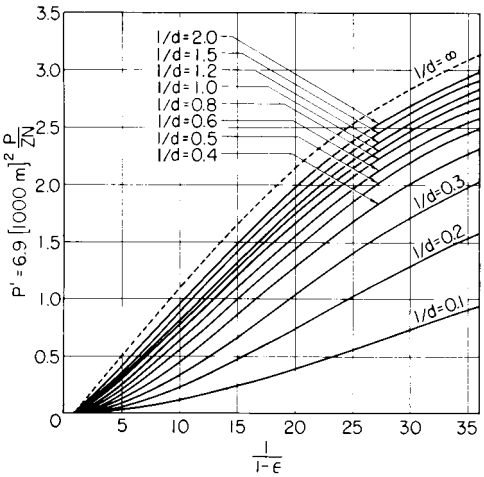


Fig. 8.4.4 Load-carrying parameter in terms of eccentricity.

EXAMPLE 2. A 360° journal bearing 2½ in diam and 3⅞ in long carries a steady load of 3,875 lb. Speed $N = 500$ r/min; diametral clearance, 0.0064 in; average viscosity of the oil in the film, 23.4 centipoises (SAE 20 light motor oil at 105°F). $P = 3{,}875/(2.5 \times 3.875) = 400$ lb/in². Value of $m = 0.0064/2.5 = 0.00256$. Value of $l/d = 1.55$. First, attempt to use Figs. 8.4.2 and 8.4.3 in this solution. Assume eccentricity ratio ε is 0.9. Then, in Fig. 8.4.3, with $l/d = 1.55$, value of η is determined as 0.8. A is calculated as 37. This is completely off scale in Fig. 8.4.2. Consider instead Fig. 8.4.4. Value of P' is computed as

$$P' = 6.9(2.56)^2 \frac{400}{23.4 \times 500} = 1.54$$

In Fig. 8.4.4, enter the curves with $P' = 1.54$, and move left to intersect the curve for $l/d = 1.5$. Drop downward to read a value for $1/(1 - \varepsilon)$ of 16. Then $1/16 = 1 - \varepsilon$, or the eccentricity ratio $\varepsilon = 15/16$, or 0.94. The minimum film thickness, as in Example 1 = $h_0 = mr(1 - \varepsilon)$, or

$$h_0 = 0.00256 \times 1.25(1 - 0.94) = 0.0002 \text{ in } (0.0051 \text{ mm})$$

Allowable mean bearing pressures in bearings with fluid film lubrication are given in Table 8.4.1. If the load maintains the same magnitude and direction when the journal is at rest (heavily loaded shafts, heavy gears), the mean bearing pressure should be somewhat less than when bearings are loaded only when running.

For internal-combustion-engine bearing design, Etchells and Underwood (*Mach. Des.,* Sept. 1942) list the following maximum design pressures for bearing alloys, pounds per square inch of projected area: lead-base babbitt (75 to 85 percent lead, 4 to 10 percent tin, 9 to 15 percent antimony) 600 to 800; tin-base babbitt (0.35 to 0.6 percent lead, 86 to 90 percent tin, 4 to 9 percent antimony, 4 to 6 percent copper) 800 to 1,000; cadmium-base alloy (0.4 to 0.75 percent copper, 97 percent cadmium, 1 to 1.5 percent nickel, 0.5 to 1.0 percent silver) 1,200 to 1,500; copper-lead alloy (45 percent lead, 55 percent copper) 2,000 to 3,000; copper-lead (25 percent lead, 3 percent tin, 72 percent copper) 3,000 to 4,000; silver (0.5 to 1.0 percent lead on surface, 99 percent silver) 5,000 up. The above pressures are based on fatigue life of 500 h at 300°F bearing temperature, and a bearing metal thickness 0.01 to 0.015 in for lead-, tin-, and cadmium-base metals and 0.25 in for copper, lead, and silver. At lower temperatures the life will be greatly extended.

Much higher pressures are encountered in rolling element bearings, such as ball and roller bearings, and gears. In these situations, the formation of fluid films capable of preventing contact between surface asperities is aided by the increase of viscosity with pressure, as exhibited by most lubricating oils. The relation is typically exponential, $\mu = \mu_0 e^{\alpha p}$, where α is the so-called pressure coefficient of viscosity.

Length-diameter ratios are usually chosen between $l/d = 1$ and $l/d = 2$, although many engine bearings are designed with $l/d = 0.5$, or even less. In shorter bearings, the carrying capacity of the oil film is greatly impaired by the effect of side leakage. Longer bearings are used to restrain the shaft from vibration, as in line shafts, or to position the shaft accurately, as in machine tools. In power machines, the tendency is toward shorter bearings. Typical values are as follows: turbogenerators, 0.8 to 1.5; gasoline and diesel engines for main and crankpin bearings, 0.4 to 1.0, with most values between 0.5 and 0.8; generators and motors, 1.5 to 2.0; ordinary shafting, heavy, with fixed bearings, 2 to 3; light, with self-aligning bearings, 3 to 4; machine-tool bearings, 2 to 4; railroad journal bearings, 1.2 to 1.8.

For the **clearance between journal and bearing** see Fits in Sec. 8. Medium fits may be used for journals running at speeds under 600 r/min, and free fits for speeds over 600 r/min. Kingsbury suggests for these journals a diametral clearance = $0.002 + 0.001d$ in. In journals running at high speed, diametral clearance = $0.002d$ should be used in order to lower the friction losses in the bearing. All units are in inches. The most satisfactory clearance should, of course, be based on a complete bearing analysis which includes both load-carrying capacity and heat generation due to friction. For example, a bearing designed to run at the extremely high speed of 50,000 r/min uses a diametral clearance of 0.0025 in for a journal with 0.8-in diameter, giving a clearance ratio, clearance/diameter, of 0.00316.

Table 8.4.1 Current Practice in Mean Bearing Pressures

Type of bearing	Permissible pressure, lb/in², of projected area	Type of bearing	Permissible pressure, lb/in², of projected area
Diesel engines, main bearings	800–1,500	Automotive gasoline engines, main bearings	500–1,000
Crankpin	1,000–2,000	Crankpin	1,500–2,500
Wrist pin	1,800–2,000	Air compressors, main bearings	120– 240
Electric motor bearings	100– 200	Crankpin	240– 400
Marine diesel engines, main bearings	400– 600	Crosshead pin	400– 800
Crankpin	1,000–1,400	Aircraft engine crankpin	700–2,000
Marine line-shaft bearings	25– 35	Centrifugal pumps	80– 100
Steam engines, main bearings	150– 500	Generators, low or medium speed	90– 140
Crankpin	800–1,500	Roll-neck bearings	1,500–2,500
Crosshead pin	1,000–1,800	Locomotive crankpins	1,500–1,900
Flywheel bearings	200– 250	Railway-car axle bearings	300– 350
Marine steam engine, main bearings	275– 500	Miscellaneous ordinary bearings	80– 150
Crankpin	400– 600	Light line shaft	15– 25
Steam turbines and reduction gears	100– 220	Heavy line shaft	100– 150

For high-speed internal-combustion-engine bearings using forced-feed lubrication, medium fits are used. Federal-Mogul recommends the following diametral clearances in inches per inch of shaft diameter for insert-type bearings: tin-base and high-lead babbitts, 0.0005; cadmium-silver-copper, 0.0008; copper-lead, 0.001.

The dependence of the **coefficient of friction** for journal bearings on the bearing clearance, lubricant viscosity, rotational speed, and loading pressure, as reported by McKee and others, is shown in Sec. 3. A plot of the coefficient of friction against the parameter ZN/P is a convenient method for showing this relationship. ZN/P is a parameter based on mixed units. Z is the viscosity in centipoise, N is r/min, P is the mean pressure on the bearing due to the load, pounds per square inch of projected area, and m is the clearance ratio. Values of ZN/P greater than about 30 indicate fluid film conditions in the bearings. If the viscosity of the lubricant becomes lower or if there is a reduction in rotational speed or an increase in load, the value of ZN/P will become smaller until the coefficient of friction reaches a minimum value. Any further reduction in ZN/P will produce breakdown of the oil film, marking the transition from fluid film lubrication with complete separation of the moving surfaces to semifluid or mixed lubrication, where there is partial contact. As soon as semifluid conditions are initiated, there will be a sharp increase in the coefficient of friction. The critical value of ZN/P, where this transition takes place, will be lowest for a rigid bearing and shaft with finely finished surfaces.

Figure 8.4.5 shows a generalization of the relationship between the coefficient of friction for a journal bearing and the parameter ZN/P,

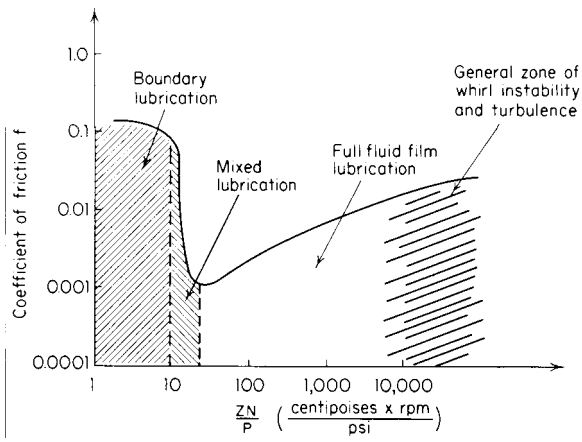


Fig. 8.4.5 Various zones of possible lubrication for a journal bearing.

indicating the various possible lubrication regimes that may be expected. For optimum design, a value of ZN/P somewhere between 30 and 300 would be recommended, but, in any case, the determination of minimum film thickness h_0 should be the deciding parameter. For extremely large values of ZN/P, resulting from high speeds and low loads,

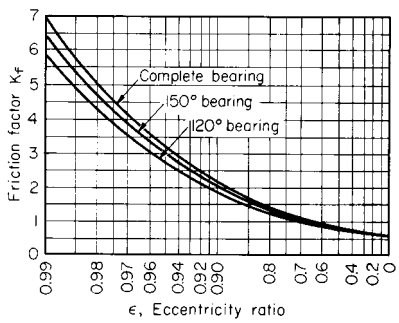


Fig. 8.4.6 Variation of the friction factor of a bearing with eccentricity ratio.

whirl instability may be developed. (See material on gas-lubricated bearings in this section.) With large values of ZN/P and a lubricant having a low kinematic viscosity, turbulent conditions may develop in the bearing clearance.

The friction force in plain journal bearings may be estimated by the use of the expression $F = K_f \mu Nrl/m$, where μ is in lb·s/in² units. The value of K_f depends upon the magnitude of ε and the type of bearing. Figure 8.4.6 shows values of K_f for a complete bearing, a 150° partial bearing, and a 120° partial bearing, assuming that the clearance space is at all times filled with lubricant. Note that F is the friction force at the surface of the bearing. Consequently, the friction torque is obtained by multiplying F by the bearing radius.

EXAMPLE 3. As an illustration of the use of Fig. 8.4.6, determine the friction force in the bearing of Example 2. This is a complete journal bearing 2½-in diam by 3⅞ in. The value of ε was determined as 0.94. From Fig. 8.4.6, $K_f = 2.8$. Then

$$F = \frac{2.8 \times 23.4 \times 1.45 \times 10^{-7} \times 500 \times 1.25 \times 3.875}{0.00256}$$

$$= 8.97 \text{ lb } (4.08 \text{ kg})$$

The coefficient of friction $F/W = 8.97/3875 = 0.00231$. The mechanical loss in the bearing is $FV/33{,}000$ hp, where V is the peripheral velocity of the journal, ft/min.

$$\text{Friction hp} = (8.97 \times 500 \times \pi \times 2.5)/(33{,}000 \times 12)$$
$$= 0.089 \text{ hp } (66.37 \text{ W})$$

Departure from laminarity in the fluid film of a journal bearing will increase the friction loss. Figure 8.4.7 (Smith and Fuller, Journal Bearing Operation at Super-laminar Speeds, *Trans. ASME*, **78**, 1956) shows test results for such bearings, expressed in terms of a Reynolds number for the fluid film, $R_e = umr/\nu$. Laminar conditions hold up to an R_e of about 1,000. Friction may be calculated for laminar flow by using Fig. 8.4.6 or the left branch of the curve in Fig. 8.4.7, where $f' = 2/R_e$, and which applies to low values of the eccentricity ratio ($K_f = 0.66$). The values from Fig. 8.4.7 may be converted to friction torque T by the use of the expression $T = f'\pi\rho u^2 r^2 l$, where ρ is the mass density of the lubricant. In Fig. 8.4.7, a transition region spans values of the Reynolds number from 1,000 to 1,600. Here, two types of flow instability can occur. Usually, the first is due to **Taylor vortices** which are wrapped in

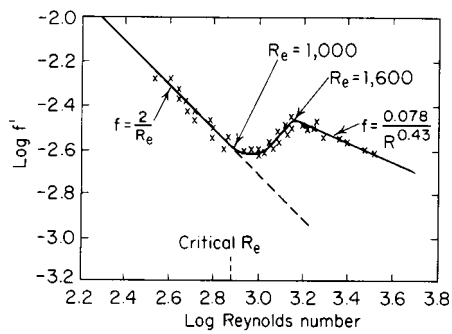


Fig. 8.4.7 Friction f' as a function of the Reynolds number for an unloaded journal bearing with $l/d = 1$. *(Smith and Fuller.)*

regular circumferential structures, each of which occupies the entire clearance. The onset of this phenomenon takes place at a value of the Reynolds number exceeding the threshold $R_e = 41.1(r/c)^{1/2}$. The second instability is due to turbulence, occurring at $R_e > 2{,}000$.

EXAMPLE 4. A journal bearing is 4.5 in diameter by 4.5 in long. Speed 22,000 r/min. $mr = 0.002$ in. Viscosity μ, 1 cP (water) $= 1.45 \times 10^{-7}$ lb·s/in²; mass density $\rho = 62.4/1{,}728 \times 386 = 9.35 \times 10^{-5}$ lb·s²/in⁴; $\nu = \mu/\rho = 1.45 \times 10^{-7}/9.35 \times 10^{-5} = 0.155 \times 10^{-2}$ in²/s; $u = 22{,}000 \times 2\pi \times 2.25/60 = 5{,}180$ in/s; $R_e = 5{,}180 \times 0.002/0.155 \times 10^{-2} = 6{,}680$. This would indicate turbulence in the film. Value of f' is then $0.078/6{,}680^{0.43} = 0.078/44.2 = 1.765 \times 10^{-3}$. Friction torque $T = 1.765 \times 10^{-3} \times \pi \times 9.35 \times 10^{-5} \times 5{,}180^2 \times 2.25^2 \times 4.5$, $T = 317.5$ in·lb. Friction horsepower $= 2\pi TN/12 \times 33{,}000 = 2\pi \times 317.5 \times 22{,}000/12 \times 33{,}000$, FHP = 111 (82.77 kW).

In self-contained bearings (electric motor, line shaft, etc.) without external oil or water cooling, the **heat dissipation** is equal to the heat generated by friction in the bearing.

The heat dissipated from the outside bearing wall to the surrounding air is governed by the laws of heat transfer $Q = hS(t_w - t_0)$, where S is the surface area from which the heat is convected, Q is the rate of energy flow; t_w and t_0 are the temperatures of the wall and ambient air, respectively; and h is the heat convection coefficient, which has values from 2.2 Btu/(h · ft² · °F) for still air to 6.5 Btu/(h · ft² · °F) for air moving at 500 ft/min. Calculations of heat loss are extremely important due to the strong temperature dependence of the viscosity of most oils.

The temperature of the oil film will be higher than the temperature of the bearing wall. Typical ranges of values according to Karelitz (*Trans. ASME*, **64**, 1942), Pearce (*Trans. ASME*, **62**, 1940), and Needs (*Trans. ASME*, **68**, 1948) for self-contained bearings with oil bath, oil ring, and waste-packed lubrication are shown in Fig. 8.4.8.

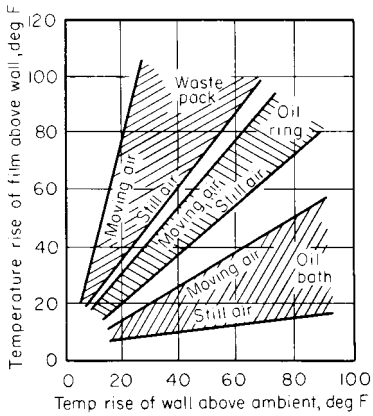


Fig. 8.4.8 Temperature rise of the film.

EXAMPLE 5. The frictional loss for the generator bearing of Example 1, computed by the method outlined in Example 3, is 0.925 hp with $\varepsilon = 0.88$, $K_f = 1.6$, and $F = 27$ lb. Operating in moving air the heat dissipated by the bearing housing will be $L = 6.5S(t_w - t_0)$. Since this is a self-contained bearing, the heat dissipated is also equal to the heat generated by friction in the oil film, or $L = 0.925 \times 2{,}545 = 2{,}355$ Btu/h. With $S = 25 \times 6 \times 9/144 = 9.4$ ft², $t_w = t_0 = 2{,}355/6.5 \times 9.4 = 38.5$°F. This is the temperature rise of the bearing wall above the ambient room temperature. For an 80°F room, the wall temperature of the bearing would be about 118°F. In Fig. 8.4.8 an oil-ring bearing in moving air with a temperature rise of wall over ambient of 38°F should have a film temperature 50°F higher than that of the wall. The film temperature on the basis of Fig. 8.4.8 will then be 80 + 38 + 50, or 168°F. This is close enough to the value of the film temperature of 160°F from Example 1, with which the friction loss in the bearing was computed, to indicate that this bearing can operate without the need for external cooling.

To predict the operating temperature of a self-contained bearing, the cut-and-try method shown above may be used. First, an oil-film temperature is assumed. Viscosity and friction losses are calculated. Then the temperature rise of the wall over ambient is computed so as to dissipate to the atmosphere an amount of heat equal to the friction loss. Lastly from Fig. 8.4.8 the corresponding oil-film temperature is estimated and compared to the value that was originally assumed. A few adjustments of the assumed film temperature will produce satisfactory agreement and indicate the leveling-off temperature of the bearing. Self-contained bearings have been built with diameters of 3, 8, and 24 in (7.62, 20.32, and 60.96 cm) to operate at shaft speeds of 3,600, 1,000, and 200 r/min, respectively. These designs indicate a rough limit for bearings with no external cooling. The highest bearing temperature permissible with normal lubricants is about 210°F (100°C).

The temperature of automotive-type bearings is held within safe limits by using a **pressure-feed oil supply.** Sufficient lubricant is forced through the bearing to act as a coolant and prevent overheating. One widely used practice is to place a circumferential groove at the center of the bearing to which the oil supply is fed. This is effective as far as cooling is concerned but has the disadvantage of interrupting the active length of the bearing and lowering its l/d ratio (see Fig. 8.4.9). The axial flow through each side of the bearing is given by

$$Q_1 = \frac{\Delta P m^3 r^4 \pi}{6\mu b}\left(1 + \frac{3}{2}\varepsilon^2\right)$$

where b is the effective axial length of the half bearing and ΔP is the difference between the oil pressure in the circumferential groove and

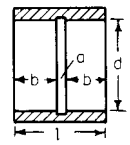


Fig. 8.4.9 Bearing with central circumferential groove.

the pressure at the ends of the bearing. The value of the last term in this equation will vary from 1.0 for a concentric shaft and bearing indicated by $\varepsilon = 0$ to a value of 2.5 for the extreme case of the shaft touching the bearing wall, indicated when $\varepsilon = 1$. Most of the heat caused by friction in the bearing is carried away by the circulating oil. Permissible temperature rises for this type of bearing may range from 15 to 50°F (8 to 28°C). In extreme cases a rise of 100°F (55°C) can be tolerated for high-strength bearing materials. The lower values of temperature rise usually indicate needlessly large oil flow. Such a condition will result in an excessive friction loss in the bearing.

EXAMPLE 6. The bearing of Examples 2 and 3 is lubricated by a circumferential groove with an oil supply pressure of 30 lb/in² and, as before, $\varepsilon = 0.94$, $m = 0.0026$, and $\mu = 23.4 \times 1.45 \times 10^{-7}$ lb · s/in². Length b is about 1.93 in.

$$Q_1 \text{ flow out one side} = \frac{30 \times 0.0026^3 \times 1.25^4 \times \pi}{6 \times 23.4 \times 1.45 \times 10^{-7} \times 1.93}$$

$$\times [1 + 3/2(0.94)^2] = 0.240 \text{ in}^3\text{/s } (3.93 \text{ cm}^3\text{/s})$$

Total flow (two sides) = 0.48 in³/s = 53 lb/h for sp gr = 0.85. The friction loss from Example 3 = 0.089 hp = 226 Btu/h. With a specific heat of 0.5 Btu/(lb · °F) and assuming that all the friction energy is given up to the oil in the form of heat, the temperature rise $\Delta t = 226/0.5 \times 53 = 8.5$°F (4.72°C).

A definite **minimum rate of oil feed** is required to maintain a fluid film in journal bearings. This makes no allowance for the additional flow that may be needed to cool the bearings. However, many industrial bearings run at relatively low speeds with light loads and, as a consequence, additional oil flow to provide cooling is not necessary. But if a fluid film is desired, a definite minimum amount of lubricant is required. If the volume of lubricant fed to the bearing is less than this minimum requirement, there will not be a complete fluid film in the bearing. Friction will rise, wear will become greater, and the satisfactory service life of such a bearing will be reduced. This minimum lubricant supply can be evaluated by using the equation

$$Q_M = K_M urml$$

where Q_M is the flow rate and K_M is approximately 0.006.

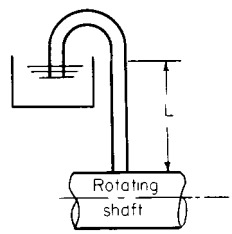


Fig. 8.4.10 Siphon wick.

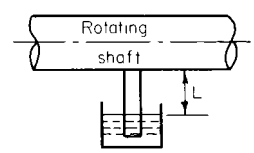


Fig. 8.4.11 Bottom wick.

EXAMPLE 7. The minimum feed rate for a journal bearing 2⅛-in diam by 2⅛ in long will be determined. Diametral clearance is 0.0045 in; speed, 1,230 r/min; load, 40 lb/in² based on projected area. $u = 1{,}230 \times \pi \times 2.125 = 10{,}220$ in/min, $r = 1.062$ in, $m = 0.0045/2.125 = 0.00212$, $l = 2.125$ in. Substituting,

$$Q_M = 0.006 \times 10{,}220 \times 1.062 \times 0.00212 \times 2.125 = 0.28 \text{ in}^3/\text{min}$$

(Fuller and Sternlicht, Preliminary Investigation of Minimum Lubricant Requirements of Journal Bearings, *Trans. ASME*, **78**, 1956.)

Many bearings are supplied with oil at low rates of feed by **felts, wicks,** and **drop-feed oilers.** Wicks can supply substantial rates of feed if they are properly designed. The two basic types of wick feed are siphon wicks, as shown in Fig. 8.4.10, and bottom wicks, as shown in Fig. 8.4.11. Data on oil delivery for these wicks are shown in Figs. 8.4.12 and 8.4.13. The data, from the American Felt Co., are for SAE Fl felts, based on a cross-sectional area of 0.1 in². The flow rate is indicated in drops per minute. One drop equals 0.0026 in³ or 0.043 cm³.

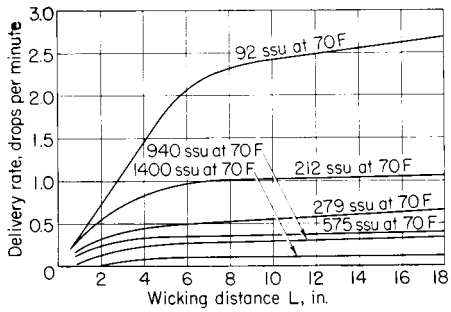


Fig. 8.4.12 Oil delivery with siphon wick (Fig. 8.4.10).

EXAMPLE 8. If it is desired to deliver 12.5 drops/min to a journal bearing, and if the viscosity of the oil is 212 s Saybolt Universal at 70°F, and if *L*, Fig. 8.4.10, is 5 in, what size of round wick would be required? From Fig. 8.4.12, for the stated conditions the delivery rate would be 0.9 drop/min for an area of 0.1 in². If 12.5 drops/min is needed, this would mean an area of 12.5 divided by 0.9 and multiplied by 0.1, or 1.4 in². For a round wick this would mean a diameter of 1⅜ in (3.49 cm).

If a **bottom wick** is considered with $L = 4$ in, Fig. 8.4.11, then in Fig. 8.4.13 the delivery rate using the same oil would be 1.6 drops/min; and if 12.5 drops/min is required, the area would be 12.5 divided by 1.6 and multiplied by 0.1, or 0.78 in². This would mean a bottom wick of 1 in diam if it is round (2.54 cm).

When journal **bearings** are **started, stopped,** or **reversed,** or whenever conditions are such that the operating value of ZN/P falls below the critical value for that bearing, the oil film will be ruptured and metal-to-metal contact will increase friction and cause wear. This condition can be eliminated by using a **hydrostatic oil lift.** High-pressure oil is introduced to the area between the bottom of the journal and the bearing (Fig. 8.4.14). If the pressure and quantity of flow are great enough, the shaft, whether it is rotating or not, will be raised and supported by an oil film. Neglecting axial flow, which is small, the flow up one side is

$$Q_1 = \frac{Wrm^3}{A\mu} \qquad \text{in}^2/\text{s}$$

and the inlet pressure required, $P_o = \mu Q_1 B/(br^2m^3)$, where b is the axial length of the high-pressure recess. Values of A and B are dimensionless factors which represent geometric effects and are given in the following table as a function of ε:

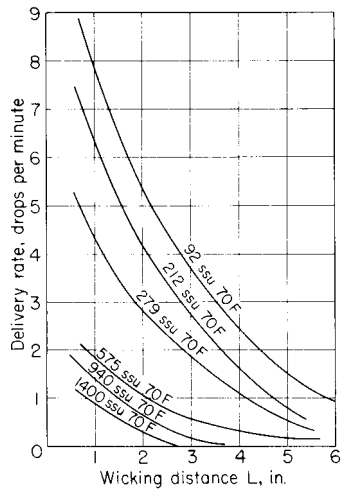


Fig. 8.4.13 Oil delivery with bottom wick (Fig. 8.4.11).

Current practice is to make the total area of the high-pressure recess in a bearing 2½ to 5 percent of the projected area ld of the bearing. It is generally desirable to use a check valve in the supply line to the oil lift so that, when the journal builds up a hydrodynamic oil-film pressure, reverse flow of oil in the supply line will be prevented.

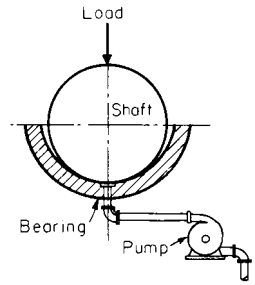


Fig. 8.4.14 Diagram of oil lift.

EXAMPLE 9. A 4,000-in-diam journal rests in a bearing of 4.012-in-diam. SAE 30 oil at 100°F (105 cP) is supplied under pressure to a groove at the lowest point in the bearing. Length of bearing, 6 in, length of groove, 3 in, load on bearing, 3,600 lb. What inlet pressure and oil flow are needed to raise the journal 0.004 in?

$$h_0 = mr(1 - \varepsilon)$$
$$0.004 = 0.006(1 - \varepsilon)$$
$$\varepsilon = 0.333$$

From the table, $A = 44.5$, $B = 42$.

$$Q_1 = \frac{3{,}600 \times 2}{44.5 \times 105 \times 1.45 \times 10^{-7}}(0.003)^3$$
$$= 0.287 \text{ in}^3/\text{s, one side } (4.70 \text{ cm}^3/\text{s})$$

Flow from both sides $= (0.287 \times 2) \times {}^{60}/_{231} = 0.149$ gal/min (0.564 l/min).

Oil supply pressure is

$$P_o = \frac{105 \times 1.45 \times 10^{-7} \times 0.287 \times 42}{3 \times 4} \times \frac{1}{0.003^3} = 566 \text{ lb/in}^2$$

ε	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.75	0.8	0.85	0.9
A	24.0	28.1	33.8	41.6	53.3	72.0	105	173	237	360	613	1,320
B	18.9	23.2	29.0	38.2	52.7	77.9	128	246	344	634	1,260	3,360

ε	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99
A	1,620	2,070	2,620	3,530	5,040	7,800	13,700	30,600	121,000
B	4,340	5,810	8,040	11,800	18,400	32,100	65,300	179,000	348,000

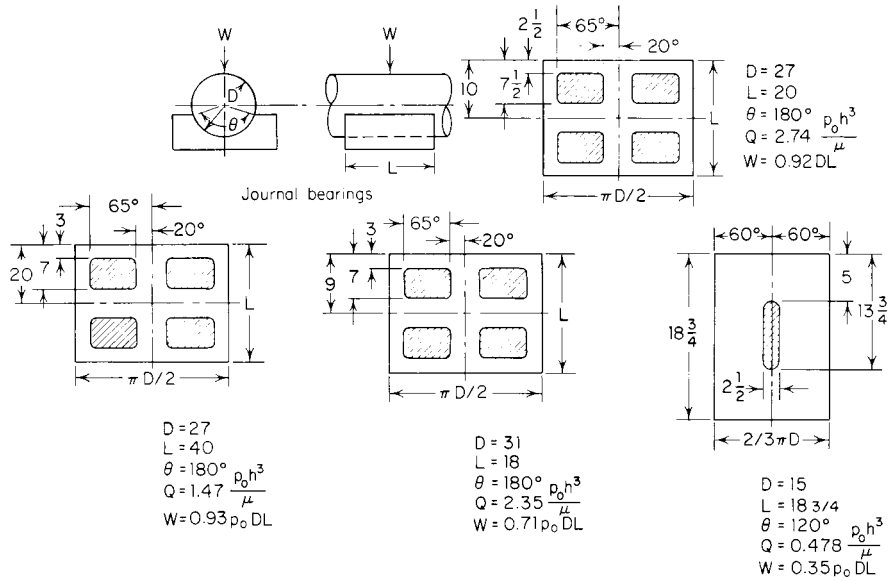


Fig. 8.4.15 Load-carrying capacity and flow for journal bearings *(Loeb)*. Lengths in inches.

An adjustable constant-volume pump or a spur-gear pump with a capacity of about 1,000 lb/in^2 (6.894 kN/m^2) should be used to allow for pressure that may be built up in the line before the journal begins to rise.

Other configurations for hydrostatically lubricated journal bearings are shown in Fig. 8.4.15. These were obtained by means of electric analog solutions (Loeb, Determination of Flow, Film Thickness and Load-Carrying Capacity of Hydrostatic Bearings through the Use of the Electric Analog Field Plotter, *Trans. ASLE*, **1**, 1958). The data from Fig. 8.4.15 are exact for a uniform film thickness corresponding to $\varepsilon = 0$ but may be used with discretion for other values of ε.

Multiple recesses are used in externally pressurized bearings in order to provide local **stiffness**. This term indicates that the bearing resists shaft motions in any direction, and it is achieved by properly arranging the feeding network according to a strategy called **compensation**. Three main types are employed: orifice (and its variant, inherent), capillary, and fixed flow rates. In the first two, the idea is to insert a hydraulic resistance in each of the recess feeding lines and to use a single pump to feed all recesses. The flow rate q through orifices varies with the square root of the pressure drop Δp

$$q \propto \sqrt{\Delta p}$$

while for capillary tubes the relation is linear:

$$q = \frac{\pi \, \Delta p \, d^4}{64 \, l_1 \, \mu}$$

The general rule of thumb in designing orifices or capillary restrictors is to generate a pressure drop approximately equal to that taking place through the bearing, i.e., from the recesses to the ambient. The recess geometry and distribution, on the other hand, are designed so that $W = 0.5 p_{\text{recess}} \, DL$. Thus, the pump supply pressure is 4 times the average bearing pressure. The bearing stiffness is usually equal to $K = 0.5 p_{\text{recess}} \, DL/c$.

The third method of compensation consists of forcing the same amount of flow to reach each recess regardless of clearance distribution. This can be achieved either by using separate pumps for each recess or by using a hydraulic device called a *flow divider*. With recess distributions as indicated above, the pump pressure need only be double the average bearing pressure; thus, this method of compensation leads to half the power dissipation of the other two. It is commonly used in large machinery, where power consumption must be limited. The polar axis bearings of the 200-in Hale telescope on Mount Palomar were the first large-scale demonstration of this technique. The azimuth axis thrust bearing of the 270-ft-diameter Goldstone radio telescope is probably the largest example of this type of bearing.

ELEMENTS OF JOURNAL BEARINGS

Typical dimensions of solid and split **bronze bushings** are given in Table 8.4.2.

Bronze bushings made from hard-drawn sheets and rolled into cylindrical shape are made with a wall thickness of only 1/32 in for bearings up to 1/2 in diam and with a wall thickness of 1/16 in for bearings from 1 in diam up. The wall thickness of these bearings depends chiefly upon the strength of the material which supports them. Bushings of this type are pressed into place, and the bearing surface is finished by burnishing with a slightly tapered bar to a mirror finish. The allowable bearing pressures may exceed those of cast bronze shown in Table 8.4.1 by 10 to 20 percent.

Babbitt linings in larger bearings are generally employed in thickness of 1/8 in or over and must be provided with sufficient anchorage in the

Table 8.4.2 Wall Thickness of Bronze Bushings, in

	Diam of journal, in						
	1/4	1/4–1/2	1/2–1	1–1 1/2	1 1/2–2 1/2	2 1/2–4	4–5 1/2
Solid bushing, normal	1/16	3/32	1/8	3/16	1/4	3/8	1/2
Split bushing, normal	3/32	1/8	5/32	7/32	5/16	15/32	5/8
Solid bushing, thin	1/16	3/32	3/32	1/8	3/16	1/4	3/8
Split bushing, thin	1/16	3/32	1/8	3/16	1/4	3/8	1/2

supporting shell. The anchors take the form of dovetailed grooves or holes drilled in the shell and counterbored from the outside.

Improved conditions are obtained by sweating or bonding the babbitt to the shell by tinning the latter, using potassium chlorate as flux. Tin-base babbitts and other low-strength materials evidence some yielding when subjected to heavy pressures. This tendency may be alleviated by the use of a thinner layer of the bearing material, fused either to a bronze or to a steel shell. This improves the fatigue life of the bearing material. Standard bearing inserts of this type are available in tin-base babbitts, high-lead babbitts, cadmium alloys, and copper-lead mixtures in diameters up to about 6 in (15.24 cm) (Fig. 8.4.16). A few materials can be obtained in sizes up to 8 in (20.32 cm). Some types are available with flanges or with other special features. The bearing lining may vary from about 0.001 in (0.025 mm) to 0.1 in (2.5 mm) in thickness depending upon the size of the bearing.

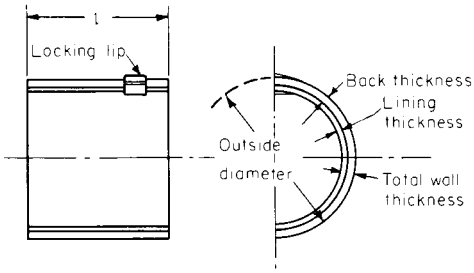


Fig. 8.4.16 Bearing insert.

Figure 8.4.17 shows the principal types of bonded babbitt linings. Figure 8.4.17*a* is for normal operating conditions. Figure 8.4.17*b* is for more severe operating conditions.

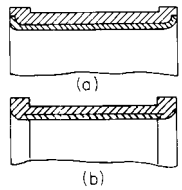


Fig. 8.4.17

General practice for the **thickness of babbitt lining and shells** is as follows: Fig. 8.4.18, $b = \frac{1}{32}d + \frac{1}{8}$ in, $S = 0.18d$ for bronze or steel $= 0.2d$ for cast iron; Fig. 8.4.18*a*, $t = b/2 + \frac{1}{16}$ in, $W = 1.8t$, $W_1 = 2.2t$.

Solid bronze or steel bushings, when pressed into the bearing housing, must be finished after pressing in. Light press fits and securing by

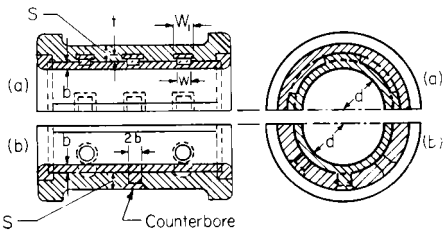


Fig. 8.4.18

setscrews or keys are preferable to heavy press fits and no keying, since heavy pressure, especially in thin-walled bushings, will set up stresses which will release themselves if bearings should run hot in service and will result in closing in on the journal and scoring when cooling.

Uniform Load Distribution Misalignment between journal and bearing should never be so great as to cause metallic contact. The maximum allowable inclination α of the shaft to the bearing is given by $\tan \alpha = md/l$.

Whenever the deflection angle of the bearing installation is greater than α, either the bearing length should be reduced or, if that is not feasible, the bearing should be mounted on a spherical seat to permit self-alignment.

Oil grooves are of two kinds, axial and circumferential; the former distribute the oil lengthwise in the bearing; the latter distribute it around the shaft at the oil hole, and also collect and return oil which would otherwise be forced out at the ends of the bearing. Grooves have often been put into bearings indiscriminatingly, with the result that they scrape off the oil and interrupt the film.

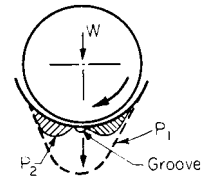


Fig. 8.4.19

In Fig. 8.4.19, W is the resultant force or load, pounds, on the bearing or journal. The radial ordinates P_1, to the dotted curve, show the pressures, lb/in^2, of the journal on the oil film due to the load when there is no axial groove, while the ordinates P_2, to the solid curve, show the pressures with an incorrectly located groove. Since there is no oil pressure near the groove, the permissible load W must be reduced or the film will be ruptured.

Groove dimensions (Fig. 8.4.20) are given by the following relations: $a = \frac{1}{3}$ wall thickness; $W_o = 2.5a$; $W_d = 3a$; $c = 0.5W_d$; $f = \frac{1}{16}$ in to $0.5W_d$.

In order to maintain the oil film, **the axial distributing groove should be placed in the unloaded sector** of the bearing. The location of grooves in a variety of cases is shown in Figs. 8.4.21 to 8.4.30.

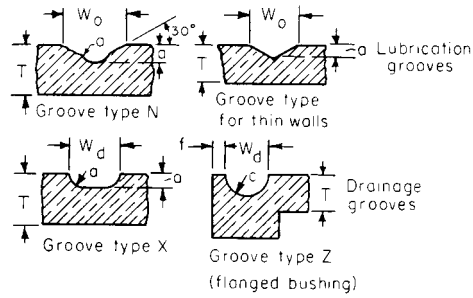


Fig. 8.4.20 Lubrication and drainage grooves.

Horizontal Bearings, Rotational Motion

DIRECTION OF LOAD KNOWN AND CONSTANT

Load downward or inside the lower 60° segment as in the case of ring-oiling bearings (Fig. 8.4.21).

Load at an angle more than 45° to the vertical centerline (Fig. 8.4.22).

In force- or drop-feed oiling, the oil inlet may be anywhere within the no-load sector (Fig. 8.4.23).

Oil can be introduced through the center of the revolving shaft (Fig. 8.4.24).

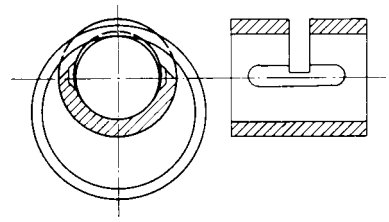


Fig. 8.4.21

Where oil-ring electric-motor bearings will be subjected by the purchaser to belt loads varying from vertical downward to horizontal, a continuous type of oil groove developed by General Electric Co. has proved very successful (Fig. 8.4.25). There are no critical spots with this groove because only a small percentage of the babbitt surface is removed along any axial line.

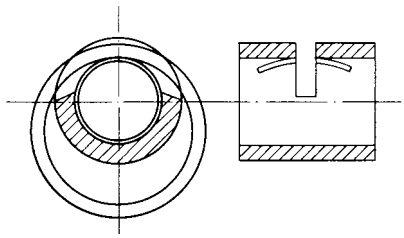


Fig. 8.4.22

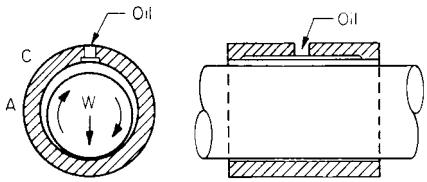


Fig. 8.4.23

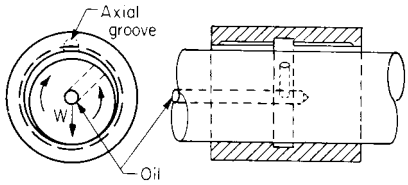


Fig. 8.4.24

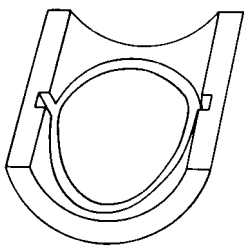


Fig. 8.4.25

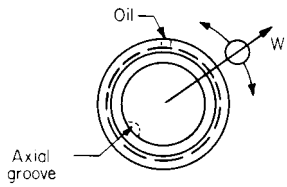


Fig. 8.4.26

ROTATING LOAD

For rotating shafts, a circumferential groove at the middle of the bearing and an axial groove on the no-load side (Fig. 8.4.26).

For stationary shafts and rotating bearings, a circumferential groove in the bearing and an axial groove on the no-load side. The oil hole is in the shaft at the midlength of the bearing (Fig. 8.4.27).

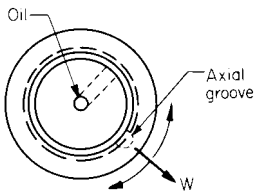


Fig. 8.4.27

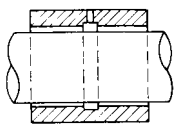


Fig. 8.4.28

LOAD DIRECTION UNCERTAIN

Oil-ring bearings (Figs. 8.4.21 and 8.4.22) may be used, although they have defects under certain load directions. With forced or drop feed, the oil hole enters a circumferential groove at the middle of the bearing and the axial groove is omitted (Fig. 8.4.28). Arrangements for introducing oil through the rotating shaft can be made.

Bearings with Oscillatory Motion

DIRECTION OF LOAD CONSTANT

No oil film can be built up owing to the small sliding velocity, and boundary lubrication will exist. Axial grooves in the loaded sector distribute the lubricant to all parts of the bearing and avoid dry spots (Fig. 8.4.29).

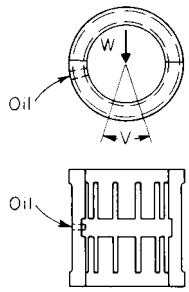


Fig. 8.4.29

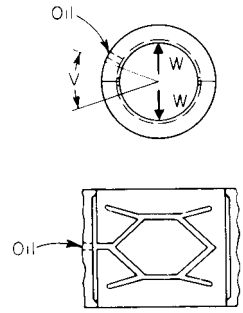


Fig. 8.4.30

LOAD DIRECTION REVERSED DURING OSCILLATION

Fluid film lubrication is possible, at least during part of the motion, owing to the vacuum caused by shaft moving back and forth. Figure 8.4.30 shows grooving which may be modified to suit local conditions. This arrangement is also advisable for bearings under a load which reverses in direction periodically without any rotation of the bearing. The lubrication may then provide an oil cushion to soften shocks.

Bearing seals are used to prevent oil leakage from the bearing housing and to protect the bearing from outside dust, water, vapors, etc. A drainage groove at the end of the bearing is effective to divert the oil passing through the bearing back into the oil well (Fig. 8.4.31*a*). The drain holes at the bottom of the groove must be ample for passage of the oil flow.

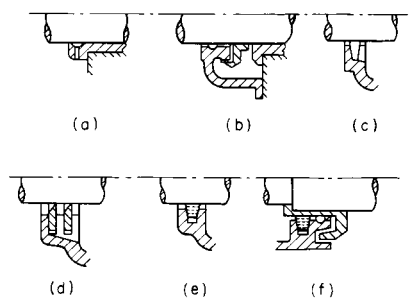


Fig. 8.4.31 Sealing end grooves.

An oil thrower mounted on the shaft is shown in Fig. 8.4.31*b*. The bearing housing may be provided with a single (Fig. 8.4.31*c*) or double collecting groove, or with brass or aluminum strip scrapers (Fig. 8.4.31*d*), to collect the oil creeping along the shaft.

For protection from dust, etc., felt packing rings are often used (Fig. 8.4.31*e*). The felt ring is soaked in oil to prevent charring by friction heat. In severe cases, additional protection by a labyrinth runner is very effective (Fig. 8.4.31*f*).

Standard seals are available for oil and grease retention as shown in

Fig. 8.4.32*a*, *b*, and *c*. The seal material that is pressed against the rotating shaft is typically made of synthetic rubber, which is satisfactory for temperatures as high as about 250°F (121°C). Figure 8.4.32*a* shows the seal material pressed against the shaft by a series of flexible fingers

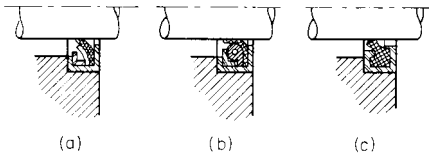


Fig. 8.4.32 Seals for oil and grease retention.

or leaf springs. In Fig. 8.4.32*b* a helical garter spring provides the gripping force. In Fig. 8.4.32*c* the rubber acts as its own spring.

Types of bearings are shown in Figs. 8.4.33 to 8.4.38. They include the principal methods of lubrication and types of construction.

Oiless bearings is the accepted term for self-lubricating bearings containing lubricants in solid or liquid form in their material. Graphite, molybdenum disulfide, and Teflon are used as solid lubricants in one group, and another group consists of porous structures (wood, metal), containing oil, grease, or wax.

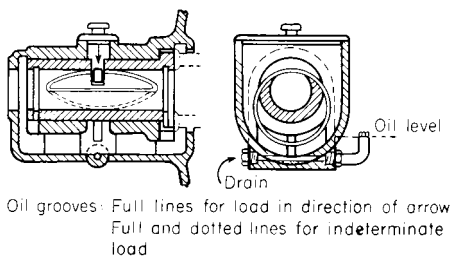


Fig. 8.4.33 Ring-oiled bearing solid bushing.

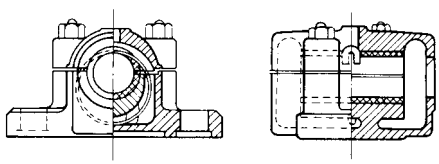


Fig. 8.4.34 Rigid ring-oiling pillow block. *(Link Belt Co.)*

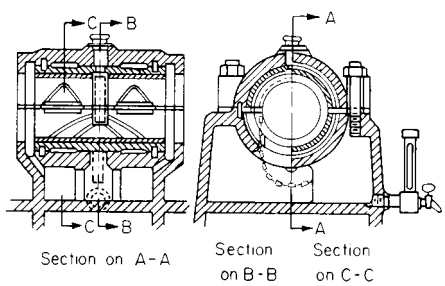


Fig. 8.4.35 Split bearing with one chain. Main crankshaft bearing; vertical oil engine.

Graphite-lubricated bearings (bridge bearings, sheaves, trolley wheels, high-temperature applications) consist generally of cast bearing bronze as a supporting structure containing various overlapping designs of grooves which are filled with graphite. The graphite is mixed with a binder, and the plastic mass is pressed into the cavities to the hardness of a lead pencil; 45 percent of the bearing area may be graphite.

Porous-metal bearings, compressed from metal powders and sintered, contain up to 35 percent of liquid lubricant. See ASTM B202-45T for sintered bronze and iron bearings, and also Army and Navy Specification AN-B-7G. The porous metal generally consists of a 90-10 copper-

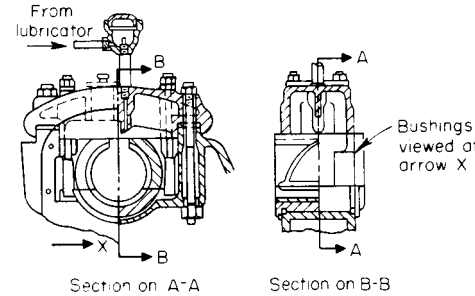


Fig. 8.4.36 Crankshaft main bearing. Horizontal engine with drop-feed lubrication.

tin bronze with 1½ percent graphite. These bearings do not require oil grooves since capillarity distributes the oil and maintains an oil film. If additional lubrication from an oil well should be provided, oil will be absorbed through the porous wall as required. For high temperatures where oil will carburize, a higher percentage of graphite (6 to 15 percent) is used.

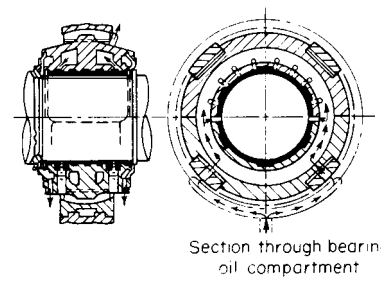


Fig. 8.4.37

Porous-metal bearings are used where plain metal bearings are impractical because of lack of space, cost, or inaccessibility for lubrication, as in automotive generators and motors, hand power tools, vacuum cleaner motors, and the like.

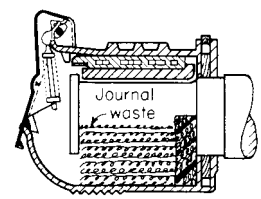


Fig. 8.4.38

THRUST BEARINGS

At low speeds, shaft shoulders or collars bear against flat bearing rings. The lubrication may be semifluid, and the friction is comparatively high.

For hardened-steel collars on bronze rings, with intermittent service, pressures up to 2,000 lb/in^2 (13,790 kN/m^2) are permissible; for continuous low-speed operation, 1,500 lb/in^2 (10,341 kN/m^2); for steel collars on babbitted rings, 200 lb/in^2 (1,378.8 kN/m^2). In multicollar thrust bearings, the values are reduced considerably because of the difficulty in distributing the load evenly between the several collars.

The performance of the bearing thrust rings is much improved by the introduction of **grooves** with tapered lands as shown in Fig. 8.4.39. The lands extend on either side of the groove. The taper angle of the lands is very slight, so that a pressure oil film is formed between the bearing ring

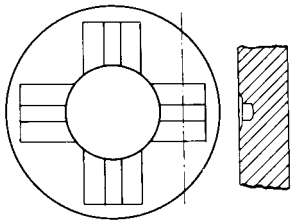


Fig. 8.4.39 Thrust collar with grooves fitted with tapered lands.

and the collar of the shaft. It is generally known that slightly tapered radial grooves will develop a hydrodynamic load-carrying film, when formed in the manner of Fig. 8.4.39. The taper angle should be on the order of 0.5°. Alternatively, a shallow recessed area that is a couple of film thicknesses deep can be used in place of the taper.

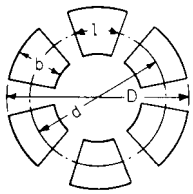


Fig. 8.4.40 Kingsbury thrust bearing with six shoes.

For high speeds or where low friction losses and a low wear rate are essential, **pivoted segmental thrust bearings** are used (Kingsbury thrust bearing, or Michell bearing in Europe). The bearing members in this type are tiltable shoes which rest on hard steel buttons mounted on the bearing housing. The shoes are free to form automatically a wedge-shaped oil film between the shoe surface and the collar of the shaft (Figs. 8.4.40 to 8.4.42).

The **minimum oil-film thickness** h_0, in, between the shoe and the collar, at the trailing edge of the shoe, is approximately

$$h_0 = 0.26\sqrt{\mu u l / P_{\text{avg}}}$$

where μ is the absolute viscosity; u is the velocity of the collar, on the mean diam; l is the length of a shoe, at the mean diam of the collar, in the direction of sliding motion; P_{avg} is the average load on the shoes. As indicated in Fig. 8.4.40, $b = l$, approximately. The standard thrust bearings have six shoes. Load-carrying capacities of Kingsbury thrust bearings are given in Table 8.4.3.

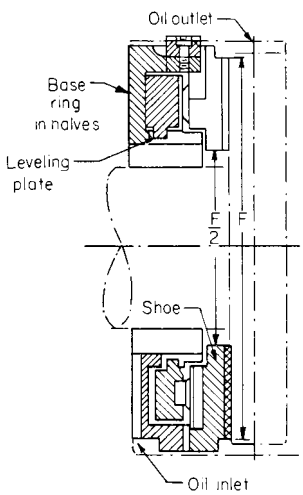


Fig. 8.4.41 Left half of six-shoe self-aligning equalizing horizontal thrust bearing for load in either axial direction.

The coefficient of friction in Kingsbury thrust bearings, referred to the mean diameter of the shoes, is approximately $f = 11.7h_0/l$, where h_0 is computed as shown above. Figures 8.4.41 and 8.4.42 show typical pivoted segmental thrust bearings. They usually embody a system of

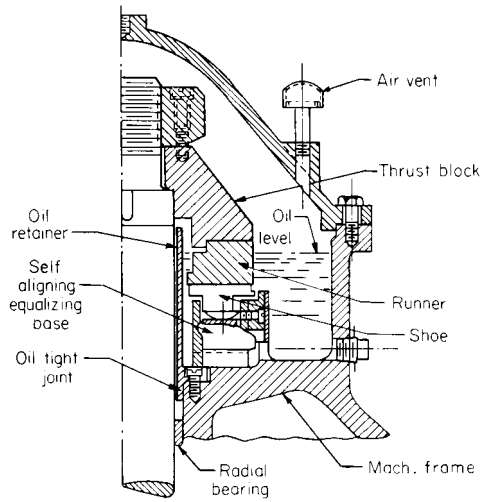


Fig. 8.4.42 Half section of mounting for vertical thrust bearing.

rocking levers which are used for alignment and equalization of load on the several shoes (Fig. 8.4.43).

Thrust may be carried on a hydrostatic step bearing as shown schematically in Fig. 8.4.44, where high-pressure oil at P_o is supplied at the

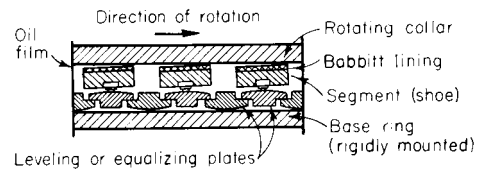


Fig. 8.4.43 Kingsbury thrust bearings. (Developed cylindrical sections.)

center of the bearing from an external pump. The lubricant flows radially outward through the annulus of depth h_0 and escapes at the periphery of the shaft at some pressure P_1 which is usually at atmospheric pressure. An oil film will be present whether the shaft rotates or not. Friction in these bearings can be made to approach zero, depending

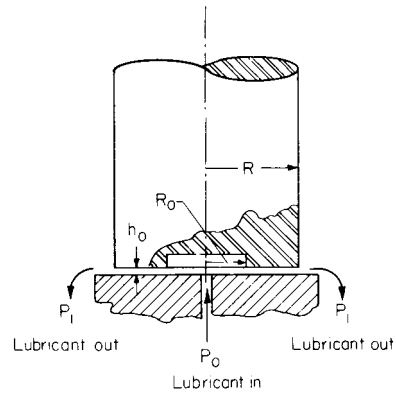


Fig. 8.4.44 Hydrostatic step bearing.

Table 8.4.3 Capacities of Six-Shoe Standard-Duty Horizontal and Vertical Thrust Bearings
(Based on viscosity of 150 s Saybolt at operating temperatures. Capacities given may be increased from 10 to 25% if viscosity is increased in same proportion)

Bearing size, in	Area, in²	Speed, r/min						Bearing size, in	Area, in²	Speed, r/min					
		100	200	400	800	1,800	3,600			100	150	200	300	500	700
		Safe load, 10^3 lb								Safe load, 10^3 lb					
5	12.5	1.44	1.7	2.0	2.4	2.9	3.5	19	180	40.00	44.0	48.0	53.0	60.0	65.0
6	18.0	2.30	2.7	3.2	3.8	4.6	5.5	21	220	51.00	57.0	61.0	68.0	77.0	84.0
7	24.5	3.30	3.9	4.7	5.6	6.8	8.0	23	264	65.00	72.0	77.0	85.0	97.0	105.0
8	32.0	4.60	5.5	6.6	7.8	9.6	11.4	25	312	80.00	88.0	95.0	105.0	119.0	123.0
9	40.5	6.20	7.4	8.8	10.4	13.0	15.0	27	364	97.00	107.0	115.0	127.0	144.0	146.0
10½	55.1	9.20	10.8	13.0	15.4	19.0	22.0	29	420	116.00	128.0	137.0	152.0	168.0	168.0
12	72.0	12.80	15.2	18.0	21.0	26.0	29.0	31	480	137.00	151.0	162.0	180.0	192.0	192.0
13½	91.1	17.20	20.0	24.0	29.0	35.0	36.0	33	544	160.00	177.0	189.0	210.0	220.0	220.0
15	112.5	22.00	26.0	32.0	37.0	45.0		37	684	215.00	235.0	250.0	275.0	275.0	
17	144.5	30.00	36.0	43.0	51.0	58.0		41	840	275.00	305.0	325.0	335.0	335.0	
								45	1012	345.00	385.0	405.0	405.0		

upon the rotational velocity and the viscosity of the lubricant film. Figure 8.4.45 shows the step bearing of a vertical turbogenerator. The load-carrying capacity is

$$W = \frac{P_o \pi}{2} \frac{R^2 - R_o^2}{\ln (R/R_o)}$$

This equation is valid even when the recess is eliminated, in which case R_o becomes the radius of the inlet oil supply pipe. The volume flow rate of lubricant and the clearance are related thus:

$$Q = P_o \pi h_0^3 [6\mu \ln(R/R_o)]$$

The friction power loss in the bearing is

$$H_f = \frac{\pi \mu \omega^2 (R^4 - R_o^4)}{2h_0}$$

The pumping power loss in forcing the lubricant through the bearing is $H_p = Q(P_o - P_1)/\eta$, where η is the efficiency of the pump.

EXAMPLE 10. A typical 5,000-kW vertical turbogenerator has a thrust load of about 101,000 lb; outside diameter of bearing, 16 in; diam of recess, 10 in; pump efficiency, 0.5; speed, 750 r/min. Substituting these values,

$$101{,}000 = \frac{P_o \pi}{2} \left[\frac{8^2 - 5^2}{\ln (8/5)} \right]$$

or

$$P_o = 774 \text{ lb/in}^2$$

In practice, about 825 lb/in² is used on this step bearing to provide some margin of safety. Film thickness in the bearing should be from 0.001 to 0.01 in to protect the surfaces from metal-to-metal contact and allow passage of harmful grit that may find its way into the system. The film thickness determines the oil flow for a given viscosity and pressure. With $h_0 = 0.006$ in (0.1524 mm) and SAE 20 oil at 130°F (29 centipoises), $Q = 8.25 \times \pi \times (0.006)^3/6 \times 29 \times 1.45 \times 10^{-7} \times 0.470 = 46.8$ in³/s (766.91 cm³/s). Flow = $46.8 \times 60/231 = 12.15$ gal/min (45.99 *L*/min). The horsepower lost due to friction, $H_f = 750^2 \times 29 \times 1.45(8^4 - 5^4)/383{,}000 \times 0.006 = 3.58$ hp (2.669 kW). The horsepower lost due to pumping with pump efficiency of 0.5, $H_p = 46.8 \times 825/6{,}600 \times 0.5 = 11.7$ hp (8.725 kW). The total energy lost = 11.7 + 3.58 = 15.28 hp (11.39 kW).

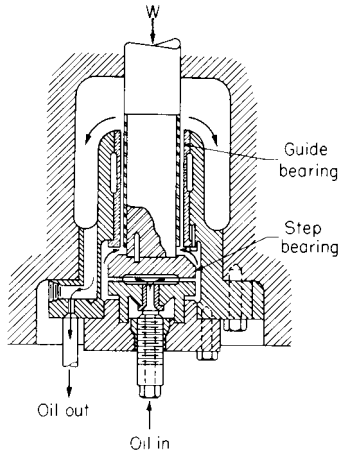


Fig. 8.4.45 Step bearing of a vertical turbogenerator.

Evaluation of these equations for other film thicknesses will show that the minimum lost energy will occur between $h_0 = 0.004$ and $h_0 = 0.006$ in (0.1016 and 0.1524 mm). The coefficient of friction corresponding to an energy loss of 15.28 hp in the above example is 0.002.

Other configurations for hydrostatically lubricated thrust bearings are shown in Fig. 8.4.46 from Loeb. They may be used directly to obtain the value of load-carrying capacity *W* and flow rate *Q*.

LINEAR SLIDING BEARINGS

All sliding bearings (Fig. 8.4.47), to wear true, must have the sliding parts of nearly equal lengths. Bearings made in this way will be found not to wear out of true. Oiling is accomplished in several ways, an acceptable method being that shown in Fig. 8.4.48. Short slides in many machine tools are lubricated by oil pads or direct oil application. The weight of the table and work and thrust of the tool cause wear on the bottom and sides of the guides. To compensate for the wear in both directions, bearings are sometimes made V-shaped, as shown in Fig. 8.4.49.

Simpler sliding bearings in machine tools are made with provision for adjustment (as shown in Fig. 8.4.50) of which there are many modifications. Recent applications involving hydrostatic lubrication on machine-tool ways have been very successful.

GAS-LUBRICATED BEARINGS

The fluid-film calculations included in Examples 1 through 10 have assumed that oil (or, in one case, water) was the lubricant. Actually, almost any **process fluid** may be used if proper recognition is given to the viscosity, corrosive action, change in state (where a liquid is close to its boiling point), toxicity, and in the case of a gas, its compressibility. Fluid-film journal and thrust bearings have run successfully, for example, on water, kerosene, gasoline, acid, liquid refrigerants, mercury, molten metals, and a wide variety of gases.

The previous equations for load-carrying capacity, film thickness, friction, and flow may be used for process liquids, but for gases, proper recognition must be made of the compressibility effects.

Because of the great value of gas-lubricated bearings for special applications, and to demonstrate the methods for handling the compressibility action, an introduction to the **design** of **gas-lubricated bearings** follows.

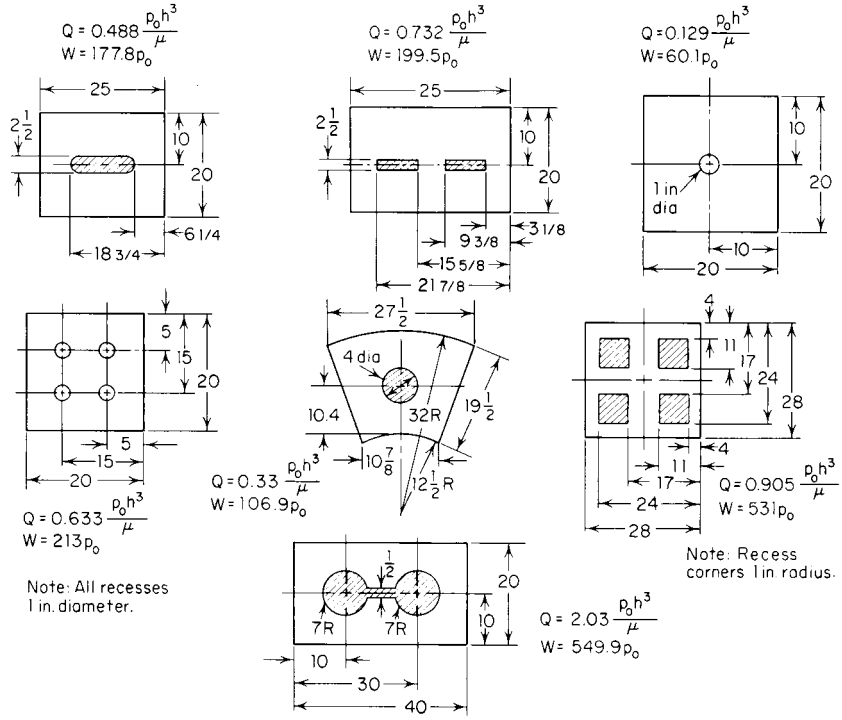


Fig. 8.4.46 Load-carrying capacity and flow for several flat thrust bearings *(Loeb).* Lengths in inches.

Naturally, if the change in pressure within the bearing clearance is small compared to ambient pressure, the compressibility effect will be likewise small, and lubrication equations based on liquids may be used. A **compressibility parameter** Λ indicates the extent of this action. For hydrodynamic journal bearings it has the form $\Lambda = 6\mu\omega/(P_a m^2)$. For values of Λ less than one, the previous equations of this section for journal bearings may be used. For values of Λ greater than one, compressibility effects are included through the use of Figs. 8.4.51 to 8.4.54. (Data from Elrod and Burgdorfer, Proceedings First International Symposium on Gas-lubricated Bearings, 1959, and Raimondi, *Trans. ASLE,* vol. IV, 1961.)

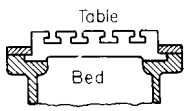


Fig. 8.4.47

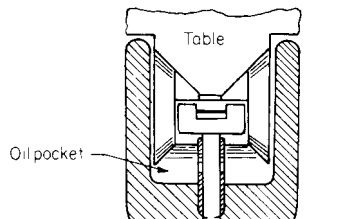


Fig. 8.4.48

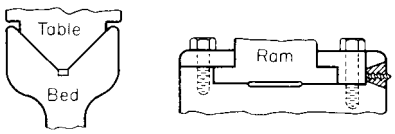


Fig. 8.4.49

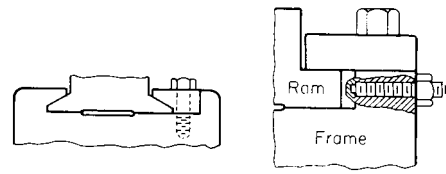


Fig. 8.4.50

EXAMPLE 11. Determine the minimum film thickness for a journal bearing 0.5 in (1.27 cm) diameter by 0.5 in long. Ambient pressure 14.7 lb/in² abs (101.34 kN/m² abs). Speed 12,000 r/min. Load 0.4 lb (0.88 kg). Diametral clearance 0.0005 in (0.0127 mm). Lubricant, air at 100°F and 14.7 lb/in² abs (2.68×10^{-9} lb·s/in² from Fig. 8.4.55). $m = 0.0005/0.5 = 0.001$ in/in. $\omega = 12{,}000 \times 2\pi/60 = 1{,}256$ rad/s, $\Lambda = (6 \times 2.68 \times 10^{-9} \times 1{,}256)/14.7 \times 0.001^2 = 1.37$, and $W/(dlP_a) = 0.4/0.5 \times 0.5 \times 14.7 = 0.109$. Then, in Fig. 8.4.53 ($l/d = 1$), we find that $\varepsilon = 0.22$, and the minimum film thickness $h_0 = 0.00025(1 - 0.22) = 0.000195$ in (0.00495 mm).

Gas-lubricated journal bearings should be checked for **whirl stability.** Figure 8.4.56 is applicable with sufficient accuracy to bearings where l/d is equal to or greater than one. It is used in conjunction with Fig. 8.4.51 for $l/d = \infty$. The stability parameter is ω_1^* which, for a bearing having only gravity loading, has the value $\omega_1^* = \omega\sqrt{mr/g}$.

EXAMPLE 12. To determine whether the bearing of Example 11 is stable at the running speed of 12,000 r/min, we compute ω_1^* as $1{,}256\sqrt{0.00025/386} = 1.015$. The value of eccentricity ratio ε_0 for $l/d = \infty$ is computed from Fig. 8.4.51

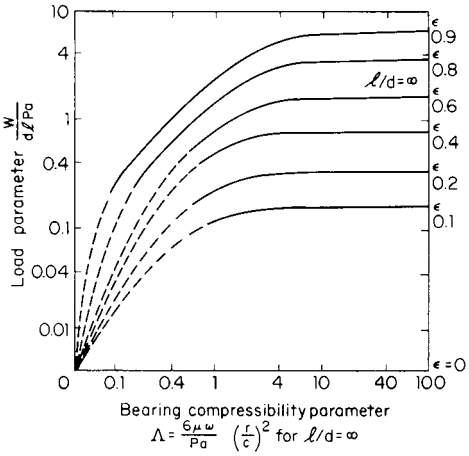


Fig. 8.4.51

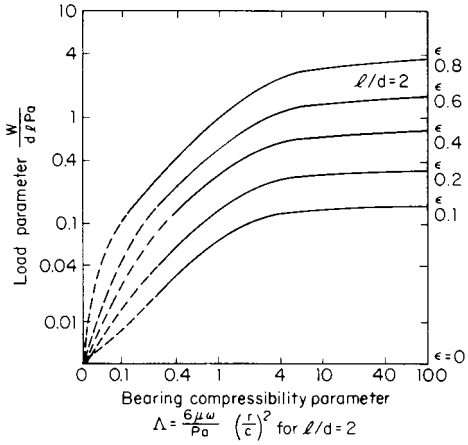


Fig. 8.4.52

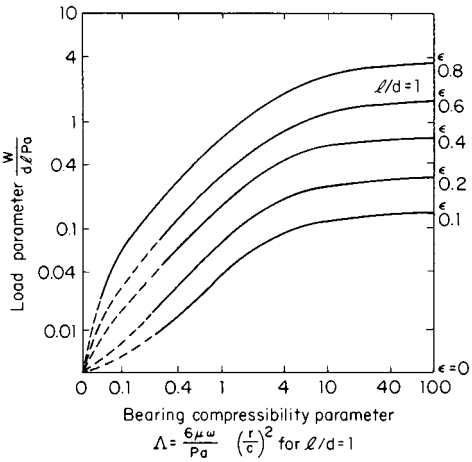


Fig. 8.4.53

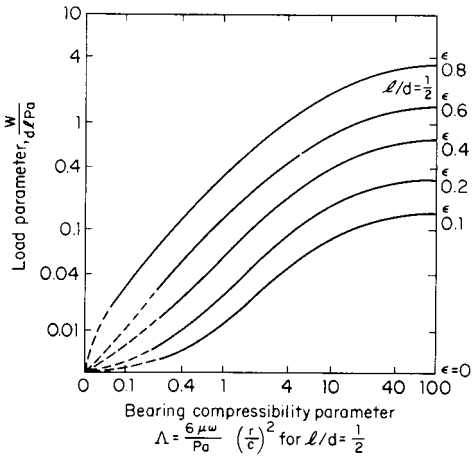


Fig. 8.4.54

Figs. 8.4.51–8.4.54 Theoretical load-carrying parameter vs. compressibility parameter for a full journal bearing: $l/d = \infty$. (Fig. 8.4.51), $l/d = 2$ (Fig. 8.4.52), $l/d = 1$ (Fig. 8.4.53), and $l/d = 0.5$ (Fig. 8.4.54). *(Elrod and Raimondi.)*

on the basis of W being the load per inch of bearing length. Thus W(lb/in) = 0.4/0.5 = 0.8 lb/in. For Fig. 8.4.51, $W/(dlP_a) = 0.218$ and in Fig. 8.4.51, we determine $\varepsilon_0 = 0.18$. Then (in Fig. 8.4.56), for $\omega_1^* = 1.015$ and $\Lambda = 1.37$, we find the intersection at about where a curve for $\varepsilon_0 = 0.18$ would be found. The bearing should just be stable. An intersection point on the ε_0 line or to the left should represent a stable condition. An intersection point to the right of the appropriate ε_0 line would predict an unstable condition.

The plain cylindrical journal bearing (360°) is the least stable of possible bearing designs. Control of ''half-frequency'' whirl has been achieved and the threshold of instability has been raised through modification of the geometry of the plain bearing. The simplest modification is the insertion of axial grooves. Bearings with three or four such grooves have been successful, but lose much stiffness.

A typical three-groove (three-sector) bearing is shown in Fig. 8.4.57.

Half-frequency whirl indicates a dynamic instability in which the journal orbits at approximately one-half of the shaft rotational speed, which coincides with the average speed of the lubricant in the film. If one looked at the bearing geometry from a coordinate system rotating at this whirl speed, one would see the journal attempting to pump lubricant

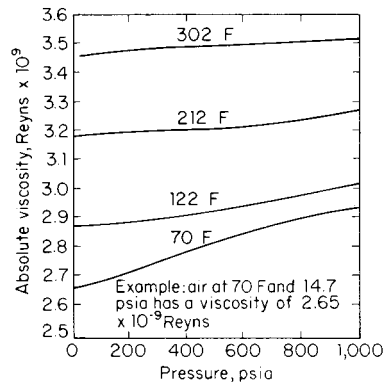


Fig. 8.4.55 Absolute viscosity of air. *(Iwaski, Sci. Rpts., Research Inst., Tohuku Univ., Ser. A; Kestin and Pliarczyk, Trans. ASME,* ***56,*** *1954.)* Reyns = 1.45×10^{-7} cP.

in one direction and the bearing attempting to do the opposite. The capacity of the film to sustain any load is thus greatly diminished, and failure often occurs. Half-frequency whirl can occur when the dynamic system in which the bearing operates has a natural frequency at approximately one-half the speed of rotation. If the energy dissipation rate is

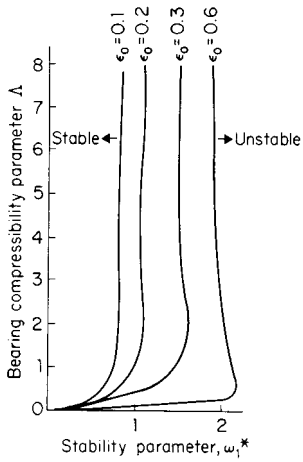


Fig. 8.4.56 Half-frequency translatory whirl threshold for infinite length, 360° journal bearing. *(Castelli and Elrod, Solution for the Stability Problem for 360°, Self Acting Gas Lubricated Bearings, Trans. ASME, **87,** Mar. 1965.)*

not sufficiently large, instability occurs. In the dynamic system mentioned above, the stiffness and damping characteristics of the bearing, or bearings, play a major role. Damping arises from squeezing the lubricant in and out of the bearing by the action of the journal vibrations against the viscous resistance. When the journal moves, gas can compress and act as a capacitance rather than flow and act as a damper. Therefore, gas bearings are much more prone to instability than are liquid-lubricated ones.

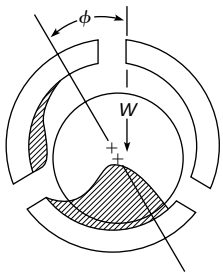


Fig. 8.4.57 Sector sleeve bearing.

Aside from avoiding resonance conditions, two often successful techniques for whirl prevention are shown in Figs. 8.4.58 and 8.4.59. The first depicts a complete journal bearing with a rotating geometric artifact causing a synchronous disturbance. This artifact can be a variation in the clearance or an asymmetric mass leading to dynamic unbalance. The second depicts a bearing geometry with shallow, inward-pumping spiral grooves. The depth of the grooves is approximately twice the radial clearance, their angle is from 25° to 30° to the axis, the land-to-groove ratio is 0.5, and the axial extent of the grooved area is one-half the length of the bearing. The grooves can be on either the stator or the rotor, depending on manufacturing convenience. Etching is a common method for production of the grooves. Design data for this excellent type of self-acting gas bearing can be found in Sec. 4 of Gross's book. (See References.)

The tilting-pad journal bearing in Fig. 8.4.60 is considered to be one of the most stable of all possible designs. The shoes, or pads, are supported on rounded pins and are free to pitch and roll through very small angles. Analysis shows that this freedom to move achieves the stability characteristics of these bearings, and also, of course, permits them to be self-aligning. Three-, four-, and five-shoe configurations are often used. Figure 8.4.60 shows an early design used for machine tool grinding spindles.

When applied to gas lubrication, pressurized gas may be supplied through a drilled pivot (hydrostatic lubrication), as an aid in starting and to provide a reserve of load-carrying capacity (Fig. 8.4.61). See Gunter, Hinkle, and Fuller, Design Guide for Gas-Lubricated, Tilting-Pad Journal and Thrust Bearings, NYO-2512-1, U.S. AEC, I-A 2392-3-1, Nov. 1964, Contract AT 30-1-2512.

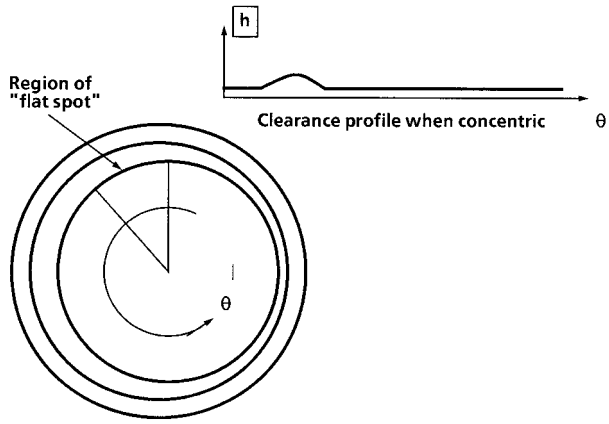


Fig. 8.4.58 Stabilizing rotating geometry. (Clearance greatly exaggerated.)

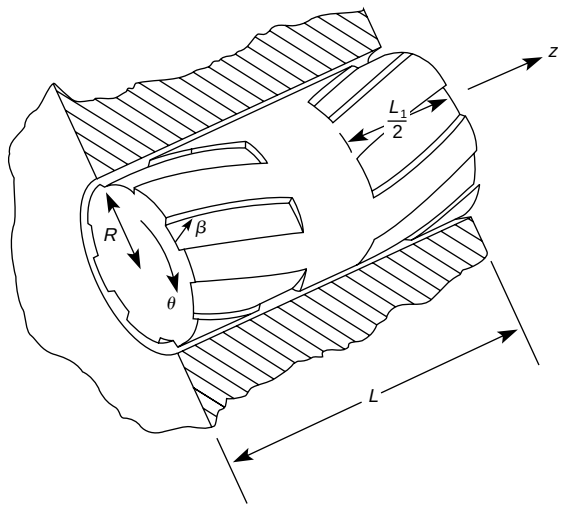


Fig. 8.4.59 Spiral groove bearing shown as outward-pumping. (Clearance is greatly exaggerated.)

A bearing design development that is simple, inexpensive, and very stable is the foil bearing. It is also very tolerant of thermal distortions and possible loss of clearance resulting from elevated temperatures. Probably the most widely used of several designs is shown in Fig. 8.4.62. It consists of overlapping metal shims, anchored at the base end like a cantilever beam. The ''free'' ends deflect and are able to automatically form their own operating clearance. These bearings are widely used in aircraft cabin cooling and for auxiliary power supply systems (Suriano, Dayton, and Woessner, Test Experience with Turbine-end Foil Bearing Equipped Gas Turbine Engines, ASME Paper 83-GT-73, 1983).

Thrust bearings of the tilting-pad variety are less susceptible to compressibility effects and may be considered as liquid-lubricated for values of Λ (suitable for thrust bearings) less than about 30. $\Lambda = 6u\mu l/(h_0^2 P_a)$ where l is the length of the shoe in the direction of sliding and U is the linear velocity at the mean radius. However, the shoes

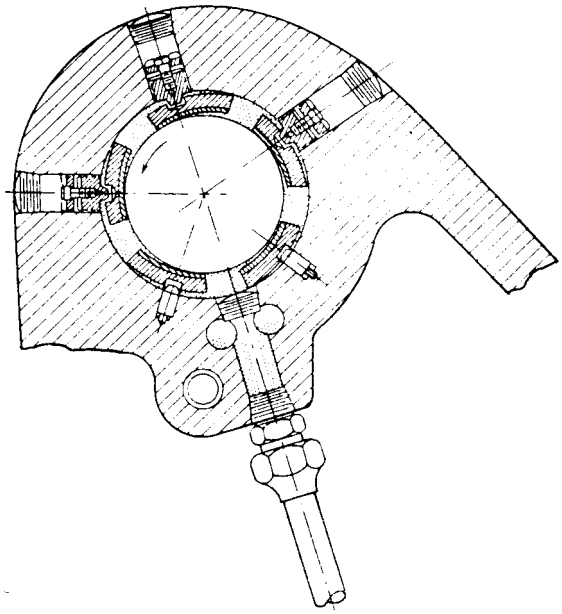


Fig. 8.4.60 Filmatic bearing. *(Courtesy Cincinnati Milacron Corp.)*

should not be made flat for gas operation but should have a crowned contour (see Fig. 8.4.63). (Gross, ''Gas Film Lubrication,'' Wiley.) An approximate value for the crown is to make $\delta = \frac{3}{4}h_0$. The tilting-pad bearing design is probably the most common gas bearing presently in existence. Every hard-disk computer memory since the early 1960s has had its read-write heads supported by self-acting tilting-pad sliders. Hundreds of millions of such units, called *flying heads*, have been manufactured to date. Some designs employ the crown geometry while, most commonly, heads with flat multiple sliders with straight ramps in their forward sections are used. The reason for the multiple thin sliders is the achievement of maximum damping possible. The typical minimum film heights have decreased steadily through the years from 1 μm (40 millionths of an inch) 25 years ago to less than 0.2 μm (8 millionths of an inch) currently (1995). This trend is driven by the achievement of the higher and higher recording densities possible at lower flying heights. Design of these devices is done rather precisely from first principles by means of special simulation programs. At these low clearances, allowance must be made for the finiteness of the **molecular mean free path,** which represents the mean distance that a gas molecule must travel between collisions. This effect manifests itself in a lowering of viscosity and wall shear resistance.

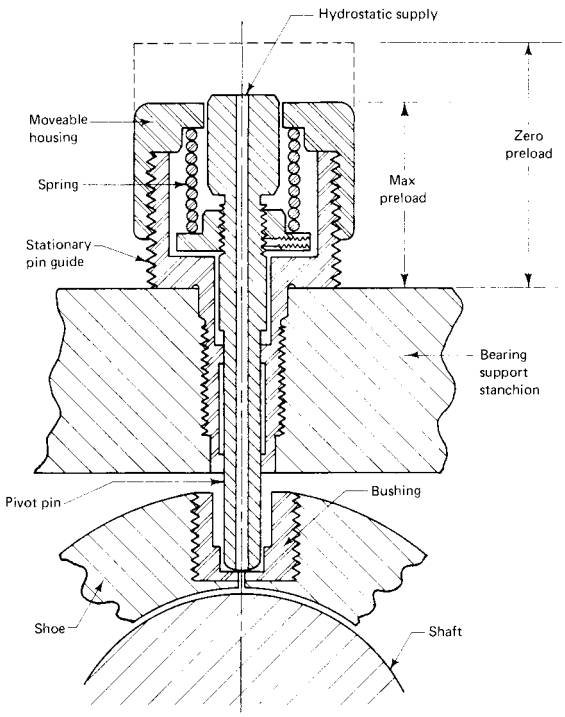


Fig. 8.4.61 Cross-sectional view, spring-mounted pivot assembly. *(Courtesy of The Franklin Institute Research Labs.)*

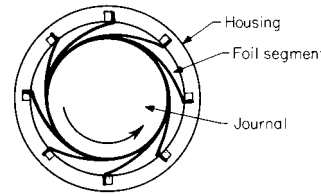


Fig. 8.4.62 Bending-dominated segments foil bearing.

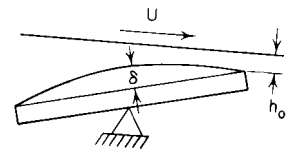


Fig. 8.4.63 Schematic of tilting-pad shoe, showing crown height δ.

Gas-lubricated hydrostatic bearings, unlike liquid-lubricated bearings, cannot be designed on the basis of fixed flow rate. They are designed instead to have a pressure loss produced by an **orifice restrictor** in the supply line. Such throttling enables the bearing to have load-carrying capacity and stiffness. For maximum stiffness the pressure drop in the orifice may be about one-half of the manifold supply pressure. For a circular thrust bearing with a single circular orifice, the load-carrying capacity is given with sufficient accuracy by the equation previously used for liquids (see Fig. 8.4.44). $W = (P_R - P_a/2)[R^2 - R_0^2/\ln (R/R_0)]$, where P_R is the recess pressure, lb/in^2 abs. The flow volume, however, is given by $Q_0 = \pi h_0^3/[6\mu \ln (R/R_0)](P_0^2 - P_1^2)/2P_0$. Q_0 and P_0 refer to recess conditions, and Q_1 and P_1 refer to ambient conditions. Pressures are absolute.

EXAMPLE 13. A circular thrust bearing 6 in (15.24 cm) diameter with a recess 2 in (5.08 cm) diameter has a film thickness of $h_0 = 0.0015$ in (0.0381 mm). $P_0 = 30$ lb/in^2 gage or 44.7 lb/in^2 abs (308.16 kN/m^2). P_1 is room pressure, 14.7 lb/in^2 abs (101.34 kN/m^2 abs). Depth of recess is 0.02 in. Applied load is 375 lb. $Q_0 = (\pi \times 0.0015^3)/(6 \times 2.68 \times 10^{-9} \ln 3)(44.7^2 - 14.7^2)/(2 \times 44.7)$, $Q_0 = 12.3$ in^3/s (201.6 cm^3/s) at recess pressure. Converted to free air, $Q_1 = Q_0(P_0/P_1)$ with isothermal expansion, $Q_1 = 12.3(44.7/14.7) = 37.4$ in^3/s (612.87 cm^3/s), or $Q_1 = 37.4 \times 60 = 2{,}244$ in^3/min (36.77 L/min). Actual measured flow = 2,440 in^3/min (39.98 L/min).

Externally pressurized gas bearings are not as easily designed as liquid-lubricated ones. Whenever a volume larger than approximately that of the film is present between the restrictor and the film, a phenomenon known as **air hammer** or **pneumatic instability** can take place. Therefore, in practical terms, recesses cannot be used and orifice restrictors must be obtained by the smallest flow cross-section at the very entrance to the film; this area is equal to the perimeter of the inlet holes multiplied by the local height of the film. This technique is called **inherent compensation.** Unfortunately, as one can readily see, the area of the restrictors is smaller where the film is smaller; thus, the stiffness is lower than that obtainable by incompressible lubrication. Design data are available in Sec. 5 of Gross's book (see References).

8.5 BEARINGS WITH ROLLING CONTACT

by Michael W. Washo

REFERENCES: Anti-Friction Bearing Manufacturers Association, Inc. (AFBMA), Method of Evaluating Load Ratings. American National Standards Institute (ANSI), Load Ratings for Ball and Roller Bearings. AFBMA, ''Mounting Ball and Roller Bearings.'' Tedric A. Harris, ''Rolling Bearing Analysis.''

COMPONENTS AND SPECIFICATIONS

Rolling-contact bearings are designed to support and locate rotating shafts or parts in machines. They transfer loads between rotating and stationary members and permit relatively free rotation with a minimum of friction. They consist of **rolling elements (balls or rollers)** between an **outer** and **inner ring. Cages** are used to space the rolling elements from each other. Figure 8.5.1 illustrates the common terminology used in describing rolling-contact bearings.

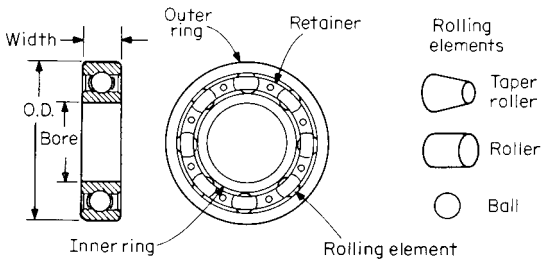


Fig. 8.5.1 Radial contact bearing terminology.

Rings The inner and outer rings of a rolling-contact bearing are normally made of SAE 52100 steel, hardened to Rockwell C 60 to 67. The rolling-element raceways are accurately ground in the rings to a very fine finish (16 μin or less).

Rings are available for special purposes in such materials as stainless steel, ceramics, and plastic. These materials are used in applications where corrosion is a problem.

Rolling Elements Normally the rolling elements, balls or rollers, are made of the same material and finished like the rings. Other rolling-element materials, such as stainless steel, ceramics, Monel, and plastics, are used in conjunction with various ring materials where corrosion is a factor.

Cages Cages, sometimes called separators or retainers, are used to space the rolling elements from each other. Cages are furnished in a wide variety of materials and construction. Pressed-steel cages, riveted or clinched and filled nylon, are most common. Solid machined cages are used where greater strength or higher speeds are required. They are fabricated from bronze or phenolic-type materials. At high speeds, the phenolic type operates more quietly with a minimum amount of friction. Bearings without cages are referred to as full-complement.

A wide variety of rolling-contact bearings are normally manufactured to standard boundary dimensions (bore, outside diameter, width) and tolerances which have been standardized by the AFBMA. All bearing manufacturers conform to these standards, thereby permitting interchangeability. ANSI has for the most part adopted these and published them jointly as AFBMA/ANSI standards as follows:

Title	*Standard*	*Title*	*Standard*
Terminology	1	Ball Standards	10
Gaging Practice	4	Roller Load Ratings	11
Mounting Dimensions	7	Instrument Bearings	12
Mounting Accessories	8.2	Vibration and Noise	13
Ball Load Ratings	9	Basic Boundary Dimensions	20

The Annular Bearing Engineers Committee (ABEC) of the AFBMA has established progressive levels of precision for ball bearings. Designated as ABEC-1, ABEC-5, ABEC-7, and ABEC-9, these standards specify tolerances for bore, outside diameter, width, and radial runout. Similarly, roller bearings have established precision levels as RBEC-1 and RBEC-5.

PRINCIPAL STANDARD BEARING TYPES

The selection of the type of rolling-contact bearing depends upon many considerations, as evidenced by the numerous types available. Furthermore, each basic type of bearing is furnished in several **standard ''series''** as illustrated in Fig. 8.5.2. Although the bore is the same, the outside diameter, width, and ball size are progressively larger. The result is that a wide range of load-carrying capacity is available for a given size shaft, thus giving designers considerable flexibility in selecting standard-size interchangeable bearings. Some of the more common bearings are illustrated below and their characteristics described briefly.

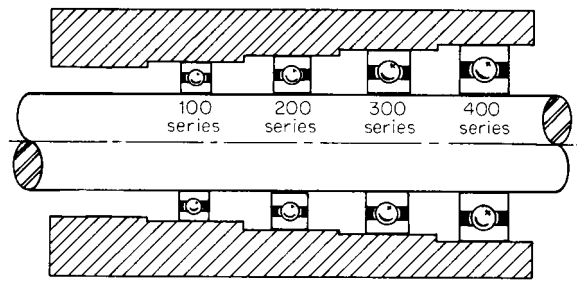


Fig. 8.5.2 Bearing standard series.

Ball Bearings

Single-Row Radial (Fig. 8.5.3) This bearing is often referred to as the **deep groove** or conrad bearing. Available in many variations—single or double shields or seals. Normally used for radial and thrust loads (maximum two-thirds of radial).

Maximum Capacity (Fig. 8.5.4) The geometry is similar to that of a deep-groove bearing except for a **filling slot.** This slot allows more balls in the complement and thus will carry heavier radial loads. However, because of the filling slot, the thrust capacity in both directions is reduced drastically.

Double-Row (Fig. 8.5.5) This bearing provides for heavy radial and light thrust loads without increasing the OD of the bearing. It is approximately 60 to 80 percent wider than a comparable single-row bearing. Because of the filling slot, thrust loads must be light.

Internal Self-Aligning Double-Row (Fig. 8.5.6) This bearing may be used for primarily radial loads where **self-alignment** ($\pm 4°$) is required. The self-aligning feature should not be abused, as excessive misalignment or thrust load (10 percent of radial) causes early failure.

Angular-Contact Bearings (Fig. 8.5.7) These bearings are designed to support **combined radial and thrust** loads or heavy thrust loads depending on the contact-angle magnitude. Bearings having large contact angles can support heavier thrust loads. They may be mounted in pairs (Fig. 8.5.8) which are referred to as **duplex bearings:** back-to-back, tandem, or face-to-face. These bearings (ABEC-7 or ABEC-9) may be preloaded to minimize axial movement and deflection of the shaft.

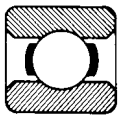


Fig. 8.5.3

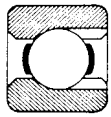


Fig. 8.5.4

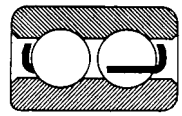


Fig. 8.5.5

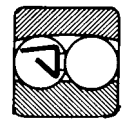


Fig. 8.5.6

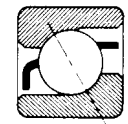


Fig. 8.5.7

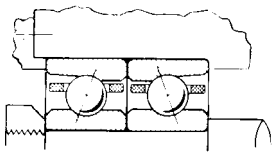


Fig. 8.5.8

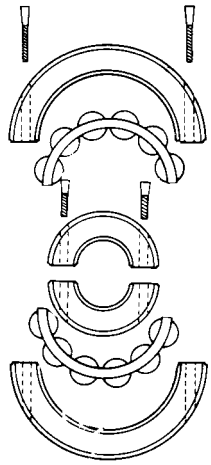


Fig. 8.5.10

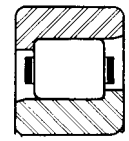


Fig. 8.5.11

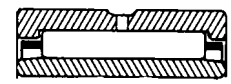


Fig. 8.5.12

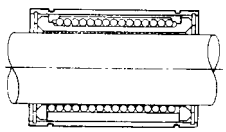


Fig. 8.5.9



Fig. 8.5.13



Fig. 8.5.14

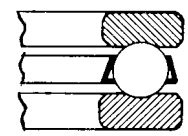


Fig. 8.5.15

Ball Bushings (Fig. 8.5.9) This type of bearing is used for linear motions on hardened shafts (Rockwell C 58 to 64). Some types can be used for linear and rotary motion.

Split-Type Ball Bearing (Fig. 8.5.10) This type of ball or roller bearing has split inner ring, outer ring, and cage. They are assembled by screws. This feature is expensive but useful where it is difficult to install or remove a solid bearing.

Roller Bearings

Cylindrical Roller (Fig. 8.5.11) These bearings utilize cylinders with approximate length/diameter ratio ranging from 1:1 to 1:3 as rolling elements. Normally used for heavy radial loads. Especially useful for free axial movement of the shaft. Highest speed limits for roller bearings.

Needle Bearings (Fig. 8.5.12) These bearings have rollers whose length is at least 4 times their diameter. They are most useful where space is a factor and are available with or without inner race. If shaft is used as inner race, it must be hardened and ground. Full-complement type is used for high loads, oscillating, or slow speeds. Cage type should be used for rotational motion. They cannot support thrust loads.

Tapered-Roller (Fig. 8.5.13) These bearings are used for heavy radial and thrust loads. The bearing is designed so that all elements in the rolling surface and the raceways intersect at a common point on the axis: thus **true rolling** is obtained. Where maximum system rigidity is required, the bearings can be adjusted for a preload. They are available in double row.

Spherical-Roller (Fig. 8.5.14) These bearings are excellent for heavy radial loads and moderate thrust. Their internal self-aligning feature is useful in many applications such as HVAC fans.

Thrust Bearings

Ball Thrust Bearing (Fig. 8.5.15) It may be used for low-speed applications where other bearings carry the radial load. These bearings are made with shields, as well as the open type.

Straight-Roller Thrust Bearing (Fig. 8.5.16) These bearings are made of a series of short rollers to minimize the skidding, which causes twisting, of the rollers. They may be used for moderate speeds and loads.

Tapered-Roller Thrust (Fig. 8.5.17) It eliminates the skidding that takes place with straight rollers but causes a thrust load between the ends of the rollers and the shoulder on the race. Thus speeds are limited because the roller end and race flange are in sliding contact.

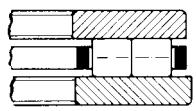


Fig. 8.5.16

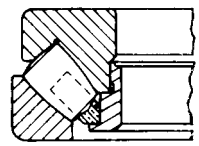


Fig. 8.5.17

Selection of Ball or Roller Bearing

Selection of the type of rolling-element bearing is a function of many factors, such as load, speed, misalignment sensitivity, space limitations, and desire for precise shaft positioning. However, to determine if a ball or roller bearing should be selected, the following **general rules** apply:

1. Ball bearings function on theoretical point contact. Thus they are suited for higher speeds and lighter loads than roller bearings.
2. Roller bearings are generally more expensive except in larger sizes. Since they function theoretically on line contact, they will carry heavy loads, including shock, more satisfactorily, but are limited in speed.

Use Fig. 8.5.18 as a general guide to determine if a ball or roller bearing should be selected. This figure is based on a rated life of 30,000 h.

ROLLING-CONTACT BEARINGS' LIFE, LOAD, AND SPEED RELATIONSHIPS

An accurate knowledge of the load-carrying capacity and expected life is essential in the proper selection of ball and roller bearings. Bearings that are subject to millions of different stress applications fail owing to

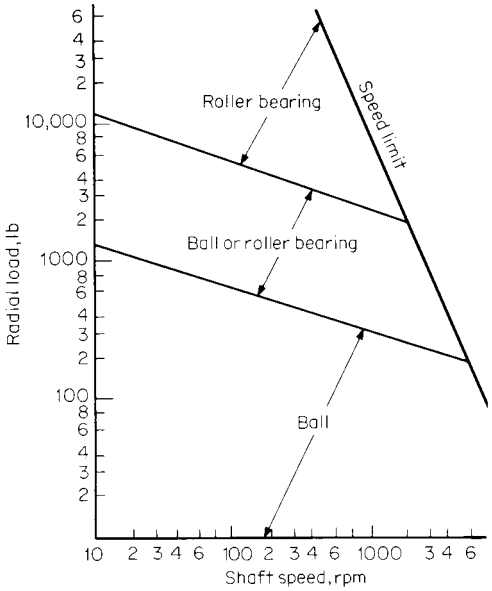


Fig. 8.5.18 Guide to selection of ball or roller bearings.

fatigue. In fact, **fatigue** is the only cause of **failure** if the bearing is properly lubricated, mounted, and sealed against the entrance of dust or dirt and is maintained in this condition. For this reason, the **life** of an individual bearing is defined as the total number of revolutions or hours at a given constant speed at which a bearing runs before the first evidence of fatigue develops.

Definitions

Rated Life L_{10} The number of revolutions or hours at a given constant speed that 90 percent of an apparently identical group of bearings will complete or exceed before the first evidence of fatigue develops; i.e., 10 out of 100 bearings will fail before rated life. The names **Minimum life** and **L_{10} life** are also used to mean rated life.

Basic Load Rating C The radial load that a ball bearing can withstand for one million revolutions of the inner ring. Its value depends on bearing type, bearing geometry, accuracy of fabrication, and bearing material. The basic load rating is also called the **specific dynamic capacity,** the **basic dynamic capacity,** or the **dynamic load rating**.

Equivalent Radial Load P Constant stationary radial load which, if applied to a bearing with rotating inner ring and stationary outer ring, would give the same life as that which the bearing will attain under the actual conditions of load and rotation.

Static Load Rating C_0 Static radial load which produces a maximum contact stress of 580,000 lb/in^2 (4,000 MPa).

Static Equivalent Load P_0 Static radial load, if applied, which produces a maximum contact stress equal in magnitude to the maximum contact stress in the actual condition of loading.

Bearing Rated Life

Standard formulas have been developed to predict the statistical rated life of a bearing under any given set of conditions. These formulas are based on an exponential relationship of load to life which has been established from extensive research and testing.

$$L_{10} = \left(\frac{C}{P}\right)^K \times 10^6 \tag{8.5.1}$$

where L_{10} = rated life, r; C = basic load rating, lb; P = equivalent radial load, lb; K = constant, 3 for ball bearings, 10/3 for roller bearings.

To convert to hours of life L_{10}, this formula becomes

$$L_{10} = \frac{16{,}700}{N}\left(\frac{C}{P}\right)^K \tag{8.5.2}$$

where N = rotational speed, r/min. Table 8.5.1 lists some common design lives vs. the type of application. These may be altered to suit unusual circumstances.

Load Rating

The **load rating** is a function of many parameters, such as number of balls, ball diameter, and contact angle. Two load ratings are associated with a rolling-contact bearing: **basic** and **static** load rating.

Basic Load Rating C This rating is *always* used in determining bearing life for all speeds and load conditions [see Eqs. (8.5.1) and (8.5.2)].

Static Load Rating C_0 This rating is used only as a check to determine if the maximum allowable stress of the rolling elements will be exceeded. It is *never* used to calculate bearing life.

Values for C and C_0 are readily attainable in any bearing manufacturer's catalog as a function of size and bearing type. Table 8.5.2 lists the basic and static load ratings for some common sizes and types of bearings.

Equivalent Load

There are two **equivalent-load** formulas. Bearings operating with some finite speed use the equivalent radial load P in conjunction with C [Eq. (8.5.1)] to calculate bearing life. The static equivalent load is used in comparison with C_0 in applications when a bearing is highly loaded in a static mode.

Equivalent Radial Load P All bearing loads are converted to an equivalent radial load. Equation (8.5.3) is the general formula used for both ball and roller bearings.

$$P = XR + YT \tag{8.5.3}$$

where P = equivalent radial loads, lb; R = radial load, lb; T = thrust (axial) load, lb; X and Y = radial and thrust factors (Table 8.5.3). The empirical X and Y factors in Eq. (8.5.3) depend upon the geometry, loads, and bearing type. Average X and Y factors can be obtained from Table 8.5.3. Two values of X and Y are listed. The set X_1 Y_1 or X_2 Y_2 giving the largest equivalent load should always be used.

Static Equivalent Load P_0 The static equivalent load may be compared directly to the static load rating C_0. If P_0 is greater than the C_0

Table 8.5.1 Design-Life Guide

Application	Design life, h, L_{10}	Application	Design life, h, L_{10}
Agricultural equipment	3,000–6,000	Domestic appliances	1,000–2,000
Aircraft engines	1,000–3,000	Electric motors:	
Aircraft jet engines	1,500–4,000	Domestic	1,000–2,000
Automotive:		Industrial	20,000–30,000
Bus, car	2,000–5,000	Elevator	8,000–15,000
Trucks	1,500–2,500	Fans:	
Blowers:	20,000–30,000	Industrial	8,000–15,000
Continuous 8-h service	20,000–40,000	Mine ventilation	40,000–50,000
Continuous 24-h service	40,000–60,000	Gearing units (multipurpose)	8,000–15,000
Continuous 24-h service (extreme reliability)	100,000–200,000	Intermittent service	8,000–15,000
Compressors	40,000–60,000	Paper machines	50,000–60,000
Conveyors	20,000–40,000	Pumps	40,000–60,000

Table 8.5.2 Approximate Basic and Static Load Ratings vs. Types and Sizes
(Ratings are in pounds) 1 lb = 4,448 N

Bearing bore, mm	Ball single-row 200 series		Ball single-row 300 series		Ball double-row 200 series		Roller cylindrical 300 series		Roller spherical 22200 series	
	C_0	C	C_0	C	C_0	C	C_0	C	C_0	C
10	600	1,040	850	1,430	800	1,210	1,020	1,960		
12	680	1,180	1,040	1,650	1,250	1,820	1,350	2,540		
15	780	1,330	1,220	1,970	1,430	2,030	1,520	2,820		
17	1,000	1,660	1,470	2,340	1,840	2,510	2,070	3,700		
20	1,390	2,220	1,760	2,730	2,540	3,480	2,560	4,490		
25	1,560	2,420	2,350	3,550	2,858	3,780	3,720	6,360		
30	2,250	3,360	3,120	4,600	4,110	5,140	5,070	8,460		
35	3,070	4,430	4,020	5,770	5,600	6,700	6,400	10,400		
40	3,520	5,040	5,020	7,060	6,430	7,680	7,930	12,500	11,800	15,200
45	4,000	5,660	6,130	8,430	7,320	8,620	9,310	14,700	12,600	15,900
50	4,450	6,070	8,010	10,750	8,130	9,220	11,600	17,900	13,600	16,800
55	5,630	7,500	9,400	12,410	10,300	11,400	12,600	19,100	16,500	20,300
60	6,950	9,070	10,902	14,179	12,700	13,800	15,200	22,800	20,800	25,200
65	7,660	9,900	12,516	16,051	14,000	15,000	19,900	29,000	25,500	30,200
70	8,410	10,714	14,240	18,030	15,400	16,300	21,400	30,800	27,500	31,900
75	9,190	11,610	16,080	19,600	16,900	17,300	23,200	32,900	29,100	33,100
80	10,010	12,550	18,020	21,230	18,300	19,100	27,000	38,100	32,100	36,800
85	11,750	14,490	20,080	22,880	19,500	19,700	30,900	43,300	38,200	43,200
90	13,630	16,540	22,250	24,580	22,100	22,600	35,200	48,800	44,500	49,800
95	15,650	18,740	24,530	26,300	28,600	28,600	39,500	54,200	48,800	54,700
100	17,800	21,130	29,430	29,940	32,500	32,100	44,700	60,800	55,700	61,900
110	20,100	23,000	32,040	31,800	30,500	30,700	53,200	70,500	72,000	78,400

rating, permanent deformation of the rolling element will occur. Calculate P_0 as follows:

$$P_0 = X_0R = Y_0T \tag{8.5.4}$$

where P_0 = static equivalent load, lb; X_0 = radial factor (see Table 8.5.4); Y_0 = thrust factor (see Table 8.5.4); R = radial load, lb; T = thrust (axial) load, lb. If a load higher than the basic static load rating is imposed while rotating, the deformation is distributed evenly and no practical impairment occurs until the deformation becomes quite large. Some equipment operates with loads greatly exceeding the static capacity, such as bearings supporting artillery (twice static capacity), or aircraft control pulleys (four times static capacity). The load which will fracture a bearing is approximately eight times the static load rating.

Table 8.5.3 Radial and Thrust Factors

Bearing type	X_1	Y_1	X_2	Y_2
Single-row ball	1.0	0.0	0.56	1.40
Double-row ball	1.0	0.75	0.63	1.25
Cylindrical roller	1.0	0.0	1.0	0.0
Spherical roller	1.0	2.5	0.67	3.7

Table 8.5.4 Radial and Thrust Factors

Type of bearing	X_0	Y_0
Single-row ball	0.6	0.5
Double-row ball	0.6	0.5
Spherical roller, 22200 series	1.0	2.9
Cylindrical roller	1.0	0.0

Oscillating loads, where the motion is such that the rolling element rotates less than half a revolution, approach static load conditions. This type of load is conducive to rapid **false brinelling** and requires special lubrication techniques.

Required Capacity

The basic load rating C is very useful in the selection of the type and size of bearing. By calculating the required capacity needed for a bearing in a certain application and comparing this with known capacities, a bearing can be selected. To calculate the required capacity, the following formula can be used:

$$C_r = \frac{P(L_{10}N)^{1/K}}{Z} \tag{8.5.5}$$

where C = required capacity, lb; L_{10} = rated life, h; P = equivalent radial load, lb; K = constant, 3 for ball bearings, 10/3 for roller bearings; Z = constant, 25.6 for ball bearings, 18.5 for roller bearings; N = rotation speed, r/min.

LIFE ADJUSTMENT FACTORS

Modifications to Eq. (8.5.2) can be made, based on a better understanding of causes of fatigue. Influencing factors include

1. Reliability factors for survival rates greater than 90 percent
2. Improved raw materials and manufacturing processes for ball bearing rings and balls.
3. The beneficial effects of elastrohydrodynamic lubricant films

Equation (8.5.2) can be rewritten to reflect these influencing factors:

$$L_{10}\text{ modified} = A_1A_2A_3\frac{16{,}700}{N}\left(\frac{C}{P}\right)^K \tag{8.5.6}$$

where A_1 = statistical life reliability factor for a chosen survival rate, A_2 = life-modifying factor reflecting bearing material type and condition, and A_3 = elastohydrodynamic lubricant film factor.

Factor A_1

Reliability factors listed in Table 8.5.5 represent rates from 90 to 99 percent. Using rates other than 90 percent will yield larger bearings for equivalent loads and, therefore, will increase costs. Rates higher than 90 percent should be used only when absolutely necessary.

Table 8.5.5 Reliability Factor A_1 for Various Survival Rates

Survival rate, %	Bearing life notation	Reliability factor A_1
90	L_{10}	1.00
95	L_5	0.62
96	L_4	0.53
97	L_3	0.44
98	L_2	0.33
99	L_1	0.21

Factor A_2

While not formally recognized by AFBMA, estimated A_2 factors are commonly used as represented by the values in Table 8.5.6. The main considerations in establishing A_2 values are the material type, melting procedure, mechanical working and grain orientation, and hardness.

Table 8.5.6 Life-Modifying Factor A_2

Material	Factor A_2
A1S1 440C, Air Melted	0.025
SAE 52100, Vacuum Processed	1.0
M50 VIM-VAR Melted	2.0

Factor A_3

This factor is based on elastohydrodynamic lubricant film calculations which relate film thickness and surface finish to fatigue life. A factor of 1 to 3 indicates adequate lubrication, with 1 being the minimum value for which the fatigue formula can still be applied. As A_3 goes from 1 to 3, the life expectancy will increase proportionately, with 3 being the largest value for A_3 that is meaningful. If A_3 is less than 1, poor lubrication conditions are presumed. Calculations for A_3 are beyond the scope of this section.

Speed Limits

Many factors combine to determine the limiting speeds of ball and roller bearings. It depends on several factors, like bearing size, inner- or outer-ring rotation, contacting seals, radial clearance and tolerances, operating loads, type of cage and cage material, temperature, and type of lubrication. A convenient check on speed limits can be made from a *dn* value. The *dn* value is a direct function of size and speed and is dependent on type of lubrication. It is calculated by multiplying the bore in millimeters (mm) by the speed in r/min.

$$dn = \text{bore (mm)} \times \text{speed (r/min)} \qquad (8.5.7)$$

A guide for *dn* values is listed in Table 8.5.7. When these values are exceeded, bearing life is shortened. The values are only a guide for approaching difficulties and can be exceeded by special bearings, lubrication, and application.

Table 8.5.7 *dn* Values vs. Bearing Types

Bearing type	Series	Max *dn* value: Grease	Max *dn* value: Oil
Single-row ball	100, 200, 300, 400, 30, in	200,000	300,000
Double-row ball	200, 300	160,000	220,000
Cylindrical roller	200, 300	150,000	200,000
Spherical roller	22200	120,000	170,000

Friction

One of the assets of rolling-contact bearings is their low friction. The **coefficient of friction** varies appreciably with the type of bearing, load, speed, lubrication, and sealing element. For rough calculations the following coefficients can be used for normal operating conditions and favorable lubrication:

Single-row ball bearings	0.0015
Roller bearings	0.0018

Excess grease, contact seals, etc., will increase these values, and allowances should be made.

PROCEDURE FOR DETERMINING SIZE, LIFE, AND BEARING TYPE

Basically, three common situations may be encountered in the analysis of a bearing system; bearing-size selection, bearing-type selection, and bearing-life determination. Each of these problems requires the following conditions to be known; radial load, thrust load, and speed. The static load capacity is not considered in the following procedures but should be analyzed if the bearing rotational speed is slow or if the bearing is idle for a period of time.

Bearing Size Selection

Known type and series:

1. Select desired design life (Table 8.5.1).
2. Calculate equivalent radial load P [Eq. (8.5.3)].
3. Calculate required capacity C_r [Eq. (8.5.5)].
4. Compare C_r with capacities C in Table 8.5.2. Select first bore size having a capacity C greater than C_r.
5. Check bearing speed limit [Eq. (8.5.7)].

Bearing-Type Selection

Known bore size and life:

1. Select ball or roller bearing (Fig. 8.5.18).
2. Calculate equivalent load P [Eq. (8.5.3)] for various bearing types (conrad, spherical, etc.).
3. Calculate C_r [(Eq. (8.5.5)].
4. Compare C_r with capacities C in Table 8.5.3, and select the type that has a capacity equal to or greater than C_r.
5. Check bearing speed limit [Eq. (8.5.7)].

Bearing-Life Determination

Known bearing size:

1. Select ball or roller bearing (Fig. 8.5.18).
2. Calculate equivalent radial load P [Eq. (8.5.3)].
3. Select basic load rating C from Table 8.5.3.
4. Calculate rated life L_{10} [Eq. (8.5.1) or (8.5.2)].
5. Check calculated life with design life.

BEARING CLOSURES

Rolling-element bearings are made with a wide variety of **closures**. Basically, they are open, shielded, or sealed (Figs. 8.5.19 and 8.5.20). **Shielded bearings** have a small clearance between the stationary shield and rotating ring. This provides reasonable exclusion of dirt without an increase in friction. **Sealed bearings** have a flexible lip (usually synthetic rubber) in contact with the inner ring. Friction is increased, but more effective retention of lubricant and exclusion of dirt is obtained. Seals should not be used to seal a fluid head or at high speeds.

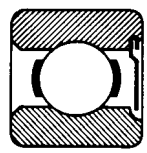


Fig. 8.5.19

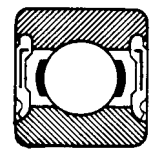


Fig. 8.5.20

BEARING MOUNTING

Correct **mounting** of a rolling-contact bearing is essential to obtain its rated life. Many types of mounting methods are available. The selection of the proper method is a function of the accuracy, speed, load, and cost of the application. The most common and best method of bearing retention is a press fit against a shaft shoulder secured with a locknut. End caps are used to secure the bearing against the housing shoulder (Fig. 8.5.21). Retaining rings are also used to fix a bearing on a shaft or in a housing (Fig. 8.5.22). Each shaft assembly normally must provide for expansion by allowing one end to float. This can be accomplished by

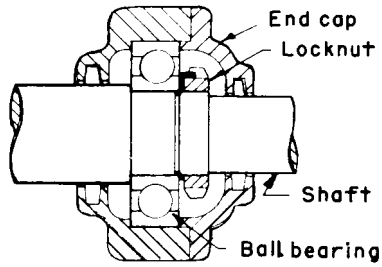


Fig. 8.5.21

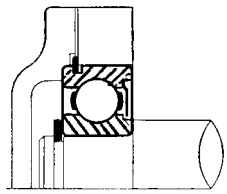


Fig. 8.5.22

allowing the bearing to expand linearly in the housing or by using a straight roller bearing on one end. Care must be exercised when designing a **floating installation** because it requires a slip fit. An excessively loose fit will cause the bearing to spin on the shaft or in the housing.

Table 8.5.8 lists shaft and housing tolerances for press fits with ABEC 1 precision applications (pumps, gear reducers, electric motors, etc.) and ABEC 7 precision applications (grinding spindles, etc.).

Table 8.5.8 Shaft and Housing Tolerances for Press Fit

Bearing bore, mm	Shaft tolerances, in, ABEC 1 precision	Bearing bore, mm	Shaft tolerances, in, ABEC 7 precision
4–6	+0.0000 −0.0002	4–30	+0.00000 −0.00015
7–17	+0.0000 −0.0003	35–50	+0.0000 −0.0002
20–50	+0.0000 −0.0004	55–80	+0.0000 −0.0003
55–80	+0.0000 −0.0005	85–120	+0.00000 −0.00035
85–120	+0.0000 −0.0006		
Bearing OD, mm	**Housing tolerances, in, ABEC 1 precision**	**Bearing OD, mm**	**Housing tolerances, in, ABEC 7 precision**
16–30	+0.0008 −0.0000	16–80	+0.0002 −0.0000
32–47	+0.0010 −0.0000	85–120	+0.0003 −0.0000
52–80	+0.0012 −0.0000	125–225	+0.0004 −0.0000
85–120	+0.0014 −0.0000		
125–180	+0.0016 −0.0000		

Mounted units such as **ball-bearing pillow blocks** (Fig. 8.5.23) are frequently used for fans and conveyors. Three common methods are used to attach the bearing to the shaft; setscrew, eccentric locking collar, and taper-sleeve adapter.

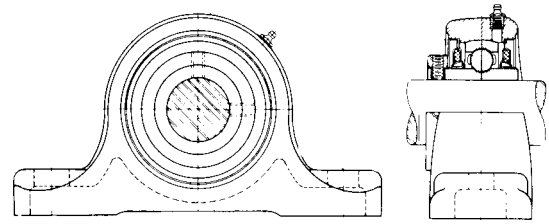


Fig. 8.5.23

Setscrew Figure 8.5.24 illustrates the use of an extended inner-ring bearing held to the shaft with a setscrew. This is a simple method and is suitable only for lightly loaded bearings.

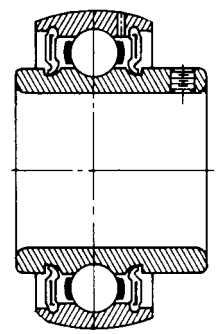


Fig. 8.5.24

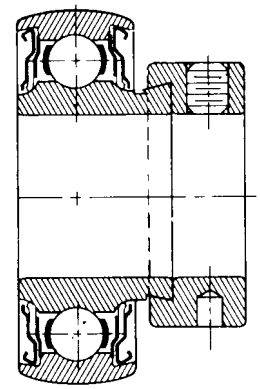


Fig. 8.5.25

Eccentric Locking Collar Figure 8.5.25 illustrates the use of an extended inner-ring bearing held to the shaft with an eccentric collar. This method tends to keep the shaft centered in the bearing more concentrically than the setscrew method. It is suitable for light to moderate loads.

Taper-Sleeve Adapter Figure 8.5.26 illustrates the use of a taper-sleeve adapter to mount the bearing on the shaft. It provides uniform concentric contact between the shaft and bearing bore. However, skill is required to tighten the locking nut enough to keep the sleeve from spinning on the shaft and yet not so tight that the inner race of the bearing is expanded to the point where the clearance is removed from the bearing. It is very difficult to obtain the correct setting with light-series bearings. They are excellent for heavy-duty spherical roller bearings.

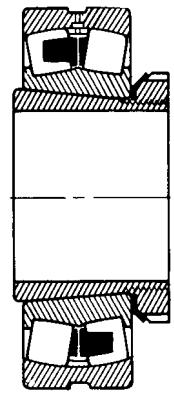


Fig. 8.5.26

LUBRICATION

Rolling-contact bearings need a **fluid lubricant** to obtain or exceed their rated life. In the absence of high-temperature environment, only a small amount of lubricant is required for excellent performance. Excess lubricant will cause heating of the bearing and accelerate the deterioration of the lubricant. Optimum lubrication of rolling-contact bearings can be predicted by

elastohydrodynamic theory (EHD). It has been shown that film thickness is sensitive to bearing speed of operation and lubricant viscosity properties and, moreover, that the film thickness is virtually insensitive to load.

Grease is commonly used for lubrication of rolling-contact bearings because of its convenience and minimum maintenance. A high-quality lithium-based NLGI 2 grease should be used for temperatures up to 180°F (82°C), or polyurea-based grease for temperatures up to 300°F (150°C). In applications involving high speed, oil lubrication is often necessary. Table 8.5.9 can be used as a general guide in selecting oil of the proper viscosity for rolling-contact bearings.

Table 8.5.9 Oil-Lubrication Viscosity
(Viscosity in ISO identification numbers*)

Bearing bore, mm	Bearing speed, r/min				
	10,000	3,600	1,800	600	50
4–7	68	150	220		
10–20	32	68	150	220	460
25–45	10	32	68	150	320
50–70	7	22	68	150	320
75–90	3	10	22	68	220
100	3	7	22	68	220

* ISO identification number = midpoint viscosity in centistokes at 40°C.

Table 8.5.10 Ball-Bearing Grease Relubrication Intervals
(Hours of operation)

Bearing bore, mm	Bearing speed, r/min				
	5,000	3,600	1,750	1,000	200
10	8,700	12,000	25,000	44,000	220,000
20	5,500	8,000	17,000	30,000	150,000
30	4,000	6,000	13,000	24,000	127,000
40	2,800	4,500	11,000	20,000	111,000
50		3,500	9,300	18,000	97,000
60		2,600	8,000	16,000	88,000
70			6,700	14,000	81,000
80			5,700	12,000	75,000
90			4,800	11,000	70,000
100			4,000	10,000	66,000

In applications using grease, it is necessary to replenish the lubricant. Relubrication intervals in hours of operation are dependent on temperature, speed, and bearing size. Table 8.5.10 is a general guide which represents the time after which it is advisable to add a small amount of grease in order to safeguard the bearings. The intervals are valid up to 160°F (71°C) and should be divided by 2 for cylindrical roller bearings and by 10 for spherical roller bearings.

8.6 PACKINGS AND SEALS

by John W. Wood, Jr.

REFERENCES: Staniar, ''Plant Engineering Handbook,'' McGraw-Hill. Thorn, Rubber and Plastic Packings, *Rubber Age*, Jan. 1956. Roberts, Gaskets and Bolted Joints, *Jour. Applied Mechanics*, June 1950. Nonmetallic Gaskets, *Mach. Des.*, Nov. 1954. Elonka, Basic Data on Seals, a *Power* reprint, McGraw-Hill. Fluidtec Engineered Products, Training Manuals.

Packings are materials used to control or stop leakage of fluids (liquids and/or gases) or solid dry products through mechanical clearances when the contained material is under static or dynamic pressure.

Gaskets are compressible materials installed in static clearances which normally exist between parallel flanges or concentric cylinders. Sealing of flat flange gaskets is effected by compressive loading achieved through bolting or other mechanical means. The full face gasket (Fig. 8.6.1) is not recommended because the material outside the bolt holes is ineffective. The simple ring gasket (Fig. 8.6.2) is more efficient and economical. With irregularly contoured flanges, bolt holes may serve to locate the gasket, in which case they should be placed in lobes with full sealing flange width maintained between the inner edge of the holes and the inside of the gasket. **Metal-to-metal** fits require a recess whose volume is greater than that of the gasket to be used. The gasket, such as an O ring (Fig. 8.6.13), either rectangular or round cross section, extends above the groove sufficiently to provide a minimum cross-sectional compression of 15 percent for initial seating. In service, the fluid load automatically provides additional sealing force. **Warped, wavy,** or irregular flanges, often resulting from welding, other fabrication, or as found in glass-lined equipment, require gaskets that are softer or thicker than normal in order to compensate for surface imperfections. Excessive thickness or volume of gasket material, even though the gasket is installed in a groove, must be avoided to prevent distortion or ''mushrooming,'' which will result in inadequate loading. Tongue and groove joints (Fig. 8.6.4) confine the gasket material and may adapt to the extra thickness, within limits.

In addition to the types (Figs. 8.6.5 to 8.6.7) shown, as defined in the table (Fig. 8.6.37), there are the machined metal profile gasket (Fig. 8.6.8) and solid metal designs in flat, round, and either octagonal or oval API ring joint gaskets for extreme pressures and temperatures to seal against steam, oil, and gases. These types have very low compressibilities, and their behavior depends on their cross sections. The envelope gasket (Fig. 8.6.3), usually polytetrafluoroethylene with a variety of cores, is particularly useful for extremely corrosive or noncontaminating service under average pressure.

Cylindrical or **concentric** gasketing uses a retaining gland follower and is mechanically loaded, e.g., the standard mechanical joint for cast-iron pipe (Fig. 8.6.10) or the condenser tube-sheet ferrule (Fig. 8.6.11). Cup-shaped gaskets are designed to be self-tightening under pressure (Fig. 8.6.12). The O ring (Fig. 8.6.13) located in an annular groove and precompressed as in the grooved flange, is a self-energized gasket. A cylindrical ring with internal single lip or double lips, also automatic in action, is quite common in pipe joints.

Beyond these types are many specialty gaskets designed for specific or proprietary use, e.g., a seal for a removable drumhead.

The compressibility of various gasketing materials is shown in Fig. 8.6.37, and their common usage is listed in Table 8.6.1. Beyond rubber are many elastomeric materials generally similar in mechanical behavior but varying as to temperature limits and fluid compatibility (see Sec. 6).

The **proper design** of a gasketed joint requires flange rigidity to avoid distortion, surface finish commensurate with gasket type and good sealing pressure, and adequate bolt loading. The load must seat the gasket, i.e., cause the material to flow into and fill flange irregularities. It must seal sufficiently that the residual fluid pressure on the gasket exceeds the pressure of the fluid being contained. These values, known respectively as the *seating load y* in lb/in^2 and the *gasket factor m*, vary with gasket material and thickness. The ASME Code for Unfired Pressure Vessels, section VIII, gives sufficient detail for typical joint design and tabulates values for *y* and *m* for various gasketing materials.

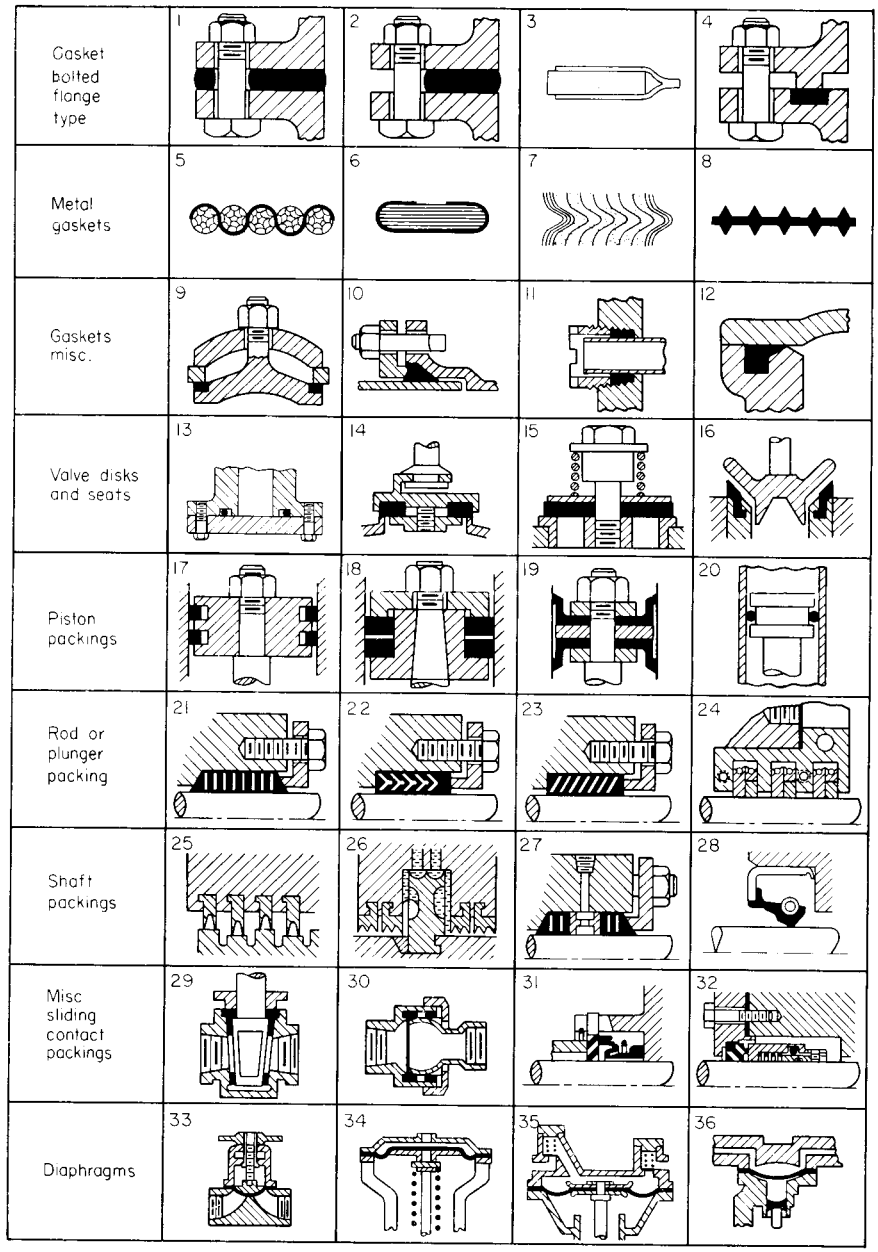


Fig. 8.6.1–8.6.36 Packings.

High bolt loading is desirable for tight and enduring gasket joints, but it must not crush the gasket material. Crushing-strength values, which will vary with thickness and temperature, can be obtained from the gasket manufacturers. Consistent with the condition of the flanges, the thinner the gasket, the more efficient the joint.

Data on the design of **O-ring joints** are available from suppliers. The nominal pressure limit for O rings, based on typical mechanical clearances, is 1,500 lb/in^2 (10 MN/m^2) without backup rings and 3,000 lb/in^2 (20 MN/m^2) with backup rings. If clearances can be eliminated, as in a flanged joint with close metal-to-metal contact, no limit can be set. Other self-energizing joints, such as the boiler hand-hole plate (Fig. 8.6.9), need only sufficient load to effect an initial seal.

Valve disks are specialized gaskets designed for joints that are frequently broken and reseated. Disks for globe valves (Fig. 8.6.14) are usually encased in a disk holder with a swivel mounting, which ensures precise reseating without abrasion during the closing and opening cycles. They are made of firm rubber for bib washers, hard rubber and phenolics for more severe service, and plastics such as nylon and polytetrafluoroethylene. Pump valves (Fig. 8.6.15) are described in Sec. 14. Rubber **valve seats** are used with metal valve disks on some pumps, e.g., the rotary drilling pump valve (Fig. 8.6.16). Plastics are also used for seats, notably in ball valves.

Dynamic packings include all packings that operate on moving surfaces. To retain fluid under pressure, they are subjected to the hydraulic

load. When no pressure exists, as in many oil-seal applications, the packing is mechanically loaded by a spring (Fig. 8.6.28) or by its own resiliency. Dynamic packings operate like bearings, wherein the lubricant serves as both a separating film and a coolant. The film is vital for satisfactory service life, but some leakage will occur. Low-viscosity

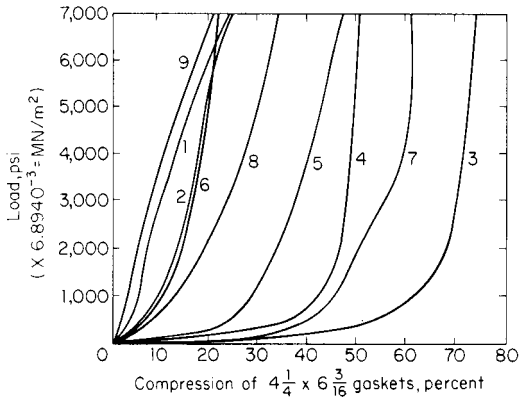


Fig. 8.6.37 Compressibility of gaskets. (See Table 8.6.1.)

fluids and high pressures add to leakage problems, as both require thin films to minimize leakage. This causes higher friction and generates heat, which is the single most detrimental factor in packing life. Deep packings reduce leakage but increase frictional heat, particularly at high speeds. Normally the fluid being sealed serves as the lubricant. Maximum efficiency is attained when oil is the fluid being sealed; in decreasing order of efficiency are clean water, solvents, and fluids containing solids. These are progressively more unsatisfactory unless supplemental lubrication is provided. Lubrication may be provided by using a lantern ring in the center of the packing set through which lubricant is fed to the packings (Fig. 8.6.27). The preferred method of introducing the lubricant is to supply it at a pressure slightly higher than that of the fluid being sealed, say, 5 to 10 lb/in^2 (3.5 to 7 kN/m^2) higher. The choice of lubricant is governed by the fluid being sealed, since the two should be compatible. In cases of extreme contamination, the lantern ring is moved to the bottom of the packing set to introduce clean lubricant and to prevent abrasives from migrating along the dynamic sealing surface. Use of a lantern ring also seals against air being drawn into the system when equipment is operating at negative head or starts under vacuum. Centrifugal pumps equipped in this manner are said to have a **water seal**.

Dynamic packings are classified in three ways:

1. On the basis of shape of the surfaces: cylindrical, conical, spherical, or flat. Cylindrical packings are in turn classified according to whether they pack on the outside perimeter, as in piston packings (Fig. 8.6.17 to 8.6.20) or inside perimeter, as on rods or shafts (Figs. 8.6.21 to 8.6.28). Other examples are: conical, the plug cock lining (Fig. 8.6.29); spherical, the ball joint (Fig. 8.6.30); and flat, the mechanical seals (Figs. 8.6.31 and 8.6.32).
2. On the basis of the type of motion: rotary, oscillating, reciprocating, or helical (as in a rising-stem valve packing).
3. On the basis of being nonautomatic soft or jamb packings/compression packings (tightened by external means, usually a gland follower); or automatic preformed, molded shapes (self-tightening under pressure).

The **selection of a packing** is a matter of economics. In most cases several types are available, some of which, though expensive in the first place, yield exceptional service. A cheaper packing could yield degraded service. Service requirements often dictate the final choice of a packing material, and they must reflect and balance the fluid being sealed, compatibility between fluid and gasket material, operating pressure in the system, and ease of maintenance and replacement.

For **reciprocating elements,** the **O ring** (Fig. 8.6.20) is extremely simple. It is a precision part manufactured to close tolerances, as must be the seat into which it is placed. As an elastomeric material completely exposed to the operating fluid, it is subject to chemical degradation. The O-ring material must be carefully chosen to ensure compatibility with the fluid being sealed; the wrong choice will lead to either shrinkage or swelling, with premature failure of the O ring. It is best suited to medium-pressure service from 1,500 to 3,000 lb/in^2 (10 to 20 MN/m^2) with backup rings and intermittent movement, as in hydraulic cylinder or valve stem service. It is not recommended for pump service. Backup rings are preferably of heavy blocklike cross section in either tetrafluoroethylene or similar material, avoiding the thin spiral type. The split **piston ring** (Fig. 8.6.17), usually cast iron, is widely used in gas, oil, and steam engines and compressors. Large pistons frequently employ segmental rings similar to floating metal rod packings (Fig. 8.6.24) but facing outward. **Floating metal packing rings** are made of numerous radial or tangential segments, making it possible for them to contract on the shaft; they are assembled in sets of two to break the joints and are held together with garter springs. They are used for steam, gas, or air, in either engines or compressors under the most severe operating conditions and at pressures up to 35,000 lb/in^2 (241 MPa). Normally oil lubrication is provided; for less severe service, filled polytetrafluoroethylene (PTFE) rings perform very well in dry gases without auxiliary lubrication. Step-, scarf-, or butt-cut rings of laminated cotton fabric, bonded with an elastomer or phenolic resin, are employed in water pumps, gasoline pumps, etc. They may float similar to cast iron piston rings, or be retained by a gland follower, as in Fig. 8.6.18. **Cups** (Fig. 8.6.19) are fully automatic and very tight; cups in their inverted form, with the lip on the ID, are known as **flange packings** and are also fully automatic and very tight. They are used principally for slow-speed applications. **Nested V and conical rings** (Figs. 8.6.22 and 8.6.23) are automatic, though often provided with a gland follower to effect initial fit. They are made of a wide range of materials from homogeneous elastomers and polymers, through reinforced woven fibers (cotton, aramid, or fiberglass) for severe duty. They range in hardness from soft and

Table 8.6.1 Common Usage of Gasketing Materials*

No.	Type	Service principally for:	Thickness tested, in (× 25.4 = mm)
1	Sheet rubber	Water	1/16
2	Cloth inserted sheet	Water	1/16
3	Cork composition	Oil, low-pressure	1/8
4	Gasket paper	Oil, low-pressure	1/16
5	Rubberized asbestos cloth (Fig. 8.6.9)	Hot water (boiler manholes, etc.)	1/4
6	Compressed asbestos sheet	All services up to 750°F (400°C)	1/16
7	Corrugated sheet metal with filling (Fig. 8.6.5)	Steam, oil at high temperatures	1/4
8	Metal jacket over asbestos center (Fig. 8.6.6)	Steam, oil at high temperatures	1/8
9	Spirally wound steel strip with intervening asbestos layers (Fig. 8.6.7)	Steam, oil at high temperatures	3/16

* Asbestos bearing material is found generally in older equipment; current, new, and/or replacement parts are compounded of other materials suitable to the service application. Fiberglass is a common substitute for asbestos in these applications.

flexible to semirigid. Use of multiple rings allows them to be of the cut or split type for ease of installation and replacement. **Soft or jamb packings** are best suited for rod or plunger service, since an adjustable gland follower (Fig. 8.6.21) is required. They are normally formed in rectangular section with a butt joint staggered from ring to ring at installation. Many materials are employed, such as braided flax saturated with wax or viscous lubricants for water and aqueous solutions; braided fiberglass similarly treated or often impregnated with PTFE/graphite suspensoid for more severe service; laminated rubberized cotton fabric for hot water, low-pressure steam, and ammonia; rolled rubberized fiberglass or aramid fabric for steam; and rolled or twisted metal foil for high-temperature and high-pressure conditions. Packings containing woven or braided fibers are also made from wire-inserted yarns to gain additional strength. For pipe expansion joints, see Sec. 8.

Rotary shafts are generally packed with adjustable soft packings, with the notable exception of the mechanical seals (Figs. 8.6.31 and 8.6.32); where pressures are low, nested V or conical styles may be used. At zero or negligible pressures, the oil seal, a spring-loaded flange packing (Fig. 8.6.28), is very widely used. Where some leakage can be tolerated, the labyrinth (Fig. 8.6.25) and controlled-gap seals are used, particularly on high-speed equipment such as steam and gas turbines. **Soft packings** are of the same general type as those used for reciprocating service, with the fiber braid lubricated with grease and graphite or with polytetrafluoroethylene fibers and suspensoid. Aramid, carbon, and graphite fibers filled with various lubricants and reinforcements are used at higher speeds and fluid pressures. Fiber braid with PTFE suspensoid is widely applied on valve stems operating below 500°F (260°C) and on centrifugal pumps. This material is an insulator, however, and results in high heat buildup on the dynamic surface; a better choice lies in use of a packing with better heat-transfer characteristics, such as one containing carbon or graphite. For continuous rotary service, **automatic packings** are best restricted to low pressure because their tightness under high pressure results in overheating. For intermittent service, as on valve stems, they are excellent.

Oil seals (Fig. 8.6.28) are unique flange packings having an elastomer lip generally bonded to a metal cup which is press-fitted into a smooth cylindrical bore. Basically, an oil seal is a flange packing with a flexible lip and a narrow contact area about 1/16 in (1.6 mm) wide which, under pressure, causes extreme local heating and wear. They are recommended only for nonpressure service and perform best in good lubricating media. To accommodate shaft runout up to 0.020 in (0.5 mm) depending on the rotating speed, the lip is spring-loaded with a coil spring or a finger spring. Coil springs are safer inasmuch as they are molded into the elastomer and are less likely to become dislodged and cause shaft damage. Since the lip is completely exposed to the sealed fluid, particular care should be taken to ensure compatibility between the elastomer and the fluid. Temperature is another operating condition which must be taken into consideration when one is using oil seals.

Mechanical, Rotary, or End Face Seals

The greatest advancements in the design of end face mechanical seals have come about in response to environmental regulations; requirements to minimize energy consumption and operating costs; safety; and concerns over loss of the product which is being sealed. The application of seals to replace packing in rotary equipment has increased dramatically and continues.

All end face mechanical seals (Figs. 8.6.31 and 8.6.32) consist of four parts: a stationary flat face, a rotating flat face, secondary sealing elements (usually elastomeric), and a flexible loading device. The assembled seal is placed and effects proper leak control. The two flat-face seal rings (one stationary, one rotating) rub and create the primary seal. Normally, the flat seal rings have different hardness values, and the soft one is narrower than the hard one. Secondary sealing elements prevent leakage between the rotating shaft and the rotating seal ring, and they block the leakage path around the outside of the stationary seal face. They also serve as gaskets between the assembled parts (i.e., gland plate and housing). The flexible loading device usually consists of one or more springs which press the flat seal rings together. Spring loading ensures a seal when there is little or no hydraulic pressure available to press the faces together and helps maintain constant pressure between the faces as the soft (sacrificial) face wears down. The springs also act as vibration dampers to mitigate against the intrusion of transmitted vibrations, which may affect the efficient operation of the seal assembly.

Types of End Face Mechanical Seals

1. *Inside-mounted.* The seal head is mounted inside the stuffing box (Fig. 8.6.38*a*).

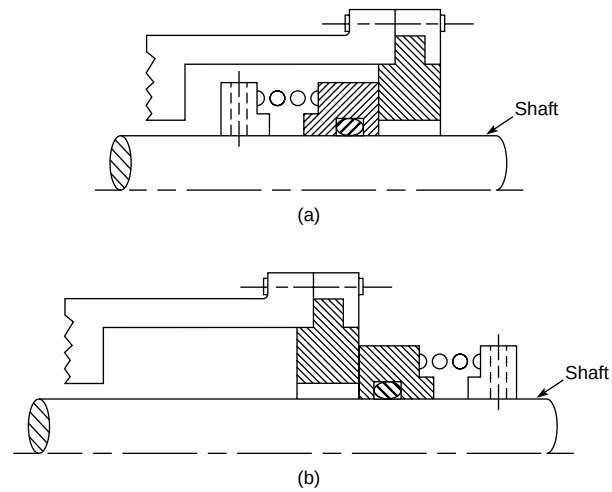


Fig. 8.6.38 Rotary end face seal. (*a*) Inside the seal chamber/stuffing box; (*b*) outside the seal chamber/stuffing box.

2. *Outside-mounted.* The seal head is mounted outside the stuffing box (Fig. 8.6.38*b*).

3. *Unbalanced seal.* The full hydraulic pressure in the seal chamber is transmitted to the seal faces (Fig. 8.6.39*a*).

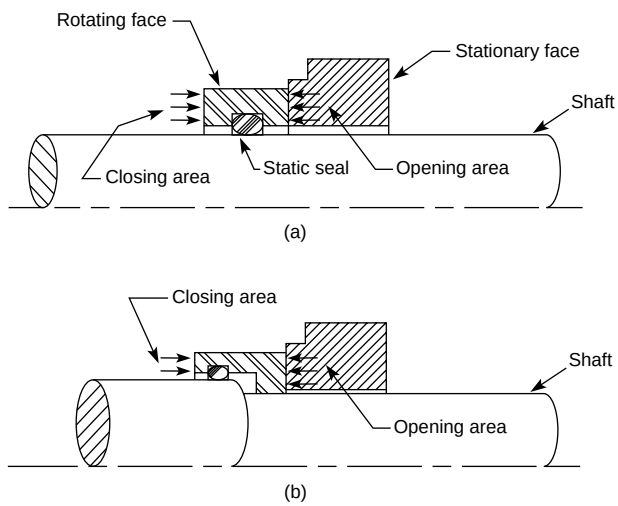


Fig. 8.6.39 Rotary end face seals showing (*a*) unbalanced and (*b*) balanced configurations.

4. *Balanced.* The seal elements are designed to reduce the hydraulic forces transmitted to the seal faces (Fig. 8.6.39*b*). A complete balance is not practical.

5. *Rotary seal.* In this design, the springs rotate with the shaft.

6. *Stationary seal.* In this design, the springs do not rotate with the shaft.

7. *Metal bellows.* Welded or formed metal bellows exert a spring load; there is no dynamic secondary seal element (Fig. 8.6.40).

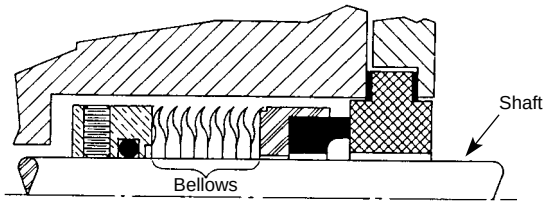


Fig. 8.6.40 Rotary end face seal with metal bellows and ''t'' clamp stationary.

8. *Double seal.* Two mechanical seals are mounted back to back, face to face, or in tandem, between which a barrier fluid (liquid or gas) can be introduced for environmental control (Fig. 8.6.41).

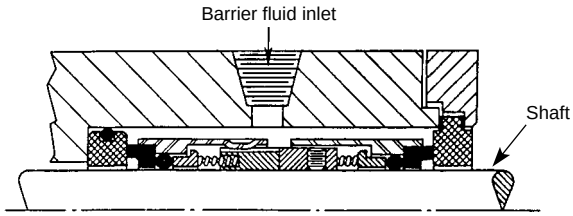


Fig. 8.6.41 Back-to-back double seal. Barrier fluid must have an inlet and an outlet.

End face mechanical seal materials must satisfy a number of design requirements, including chemical compatibility between the sealed fluid and the seal materials, ability of the seal materials to remain serviceable under the worst operating conditions, and ability to provide a reasonably long life in service at the operating conditions. Mating faces of the seals can be made from ordinary materials like bronze and PTFE

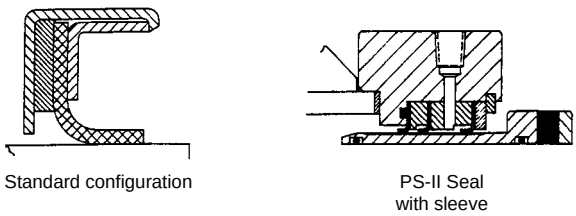


Fig. 8.6.42 High-performance lip seal with modified PTFE elastomer. Illustration shows single and staged elements.

for mild service on up to carbon, carbides, stainless steels, and other exotic alloys as service conditions become more severe. Hard faces can utilize ceramics, tungsten and silicon carbides, and hard coatings over base metals (chromium oxide over stainless steel 316SS, subsequently lapped flat).

Secondary seal materials are usually elastomeric and include these:

Elastomer	*Temperature range*
Nitrile	− 75 to 250°F (− 59 to 121°C)
Neoprene	− 65 to 250°F (− 54 to 121°C)
Viton	− 40 to 450°F (− 40 to 232°C)
Ethylene propylene	− 65 to 300°F (− 59 to 149°C)
Kalrez	32 to 550°F (− 0 to 288°C)

Environmental controls as applied to seals are special techniques used to control the environment in which the seal operates. Some examples include discharge return recirculation, suction return, flush from an outside source, flush, and quench and drain. The controlling techniques often require supplementary equipment such as heaters, coolers, pumping rings, external circulation devices, various special solenoids and valves compatible with the working environment, and so on. Sealed products that solidify, vaporize, abrade, or carry contaminants are successfully sealed with end face seals augmented by environmental controls.

High Performance Lip Seals The nature of some sealed products is such that end face mechanical seals are not applicable. In many difficult instances of that type, sealing can be achieved with high-performance modified PTFE lip seals (Fig. 8.6.42). Gylon is such a material which can serve in seals operating over a wide range of pressures, temperatures, and rotating speeds. It is particularly useful to seal against dry products, viscous resins, heavy slurries, salting solutions, and products which tend to solidify on seal faces. Dry running is possible under some circumstances. Unlike conventional lip seal material, modified PTFE lip seals in multiples can operate from high vacuums (10^{-3} inHg) up to 10 bar (150 lb/in^2), within a temperature range of −130 to + 500°F (− 90 to + 260°C), and exhibit excellent compatibility with a wide range of sealed fluids. Manufacturers' literature will provide data showing the effect of temperature and rotating speed on the permissible operating pressure.

For extremely high speeds, where it is desirable to eliminate all rubbing contact, the **labyrinth** seal (Fig. 8.6.25) is chosen. This seal is not fluid-tight but restricts serious flow by means of a torturous path and induced turbulence. It is widely used on steam turbines (Sec. 9.4). Where no leakage is permissible, a liquid seal based on the U-tube principle (Fig. 8.6.26) may be used. The natural weight of the liquid is amplified by centrifugal force so that under high rotating speed a fair pressure differential can be sealed. Another noncontacting seal is the **controlled gap seal** which is being used on gas turbines where pressure differentials are not excessive and a small amount of leakage can be tolerated. The seal consists of a ring with a shaft clearance in the range of 0.0005 to 0.0015 in (0.013 to 0.038 mm) and is made of exotic heat-resisting materials capable of maintaining that clearance at all operating temperatures. Usually one end of the ring is faced to form an axial seal against the inside of its housing.

Diaphragms are a form of dynamic packing but include the requirements of a gasket where they are gripped or held in position. In service they are leakless, although generally limited in travel. By literally rolling one cylinder inside another, considerable increase in travel is possible. This type is often called a bellows, and a simple application is the mechanical seal suspension shown in Fig. 8.6.31. In the diaphragm valve (Fig. 8.6.33) the diaphragm replaces both the conventional stem packing and valve disk. **Diaphragms** of fabric such as cotton or nylon (except friable materials such as glass) covered with an elastomer suitable for the fluids and temperatures involved are used in pumps (fuel pump, Fig. 8.6.35) and in motors (Fig. 8.6.34) to operate valves, switches, and other controls. Correctly designed diaphragms are made with slack to permit a natural rolling action. Flat sheet stock should be used only where limited travel is desired. An unusual application is shown in Fig. 8.6.36, where the diaphragm is under balanced fluid pressure on both sides and is unstressed. Thin sheet metal, usually with concentric corrugations, is used where movement is limited and long life is desired. Where considerable movement is involved, the possibility of fatigue must be considered.

PTFE and Glyon diaphragms are used with chemically aggressive fluids. Experience shows that PTFE has a tendency toward cold flow, which leads to leaking at the clamp areas; Gylon has proved more dimensionally stable and serviceable.

8.7 PIPE, PIPE FITTINGS, AND VALVES

by Helmut Thielsch

REFERENCES: M. L. Nayyar, ''Piping Handbook,'' McGraw-Hill. ANSI Code for Power Piping. ASTM Specifications. Tube Turns Division, Natural Cylinder Gas Co., catalogs. Crane Co., catalogs and bulletins. Grinnell Co., Inc., ''Piping Design and Engineering.'' M. W. Kellogg Co., ''Design of Piping Systems,'' Wiley. United States Steel Co., catalogs and bulletins.

EDITOR'S NOTE: The several piping standards listed in this section are subject to continuing periodic review and/or modification. It is suggested that the reader make inquiry to the issuing organizations (see Table 8.7.1) as to the currency of a given standard as listed.

PIPING STANDARDS

Codes for various piping services have been developed by nationally recognized engineering societies, standardization bodies, and trade associations. The sound engineering practices incorporated in these codes generally cover minimum safety requirements for the selection of materials, dimensions, design, fabrication, erection, and testing of piping systems. By means of interpretation and revision these codes continually reflect the knowledge gained through experience, testing, and research.

Generally, piping codes form the basis for many state and municipal safety laws. Compliance with a code which has attained this status is mandatory for all systems included within the jurisdiction. Although some of today's piping installations are not within the scope of any mandatory code, it is advisable to comply with the applicable code in the interests of safety and as a basis for contract negotiations. Contracts with various agencies of the federal government are regulated by federal specifications or rules. These often do not have a direct connection with the codes enumerated below.

The reader is cautioned that the **piping standards** are changing more often than in previous years. Although the formulas and other data provided are in accordance with the code rules in effect at the time of publication, it must be recognized that code rules may change, and piping engineering and design work performed in accordance with information contained herein does not provide complete assurance that all extant code requirements have been met. The reader is urged to become familiar with the specific code edition and addenda applicable in a particular project, for they may contain mandatory requirements applicable to the particular project.

The **ASME Boiler and Pressure Vessel Code** is mandatory in many cities, states, and provinces in the United States and Canada. Local application of this code into law is not uniform, making it necessary to investigate the city or state laws which have jurisdiction over the installation in question. Compliance with this code is required in all locations to qualify for insurance approval.

Section I: ''Power Boilers'' concerns all piping connections to power boilers or superheaters including the first stop valve on single boilers, or including the second stop valve for cross-connected multiple-boiler installations. Section I refers to ASME B31.1 which contains rules for design and construction of ''boiler external piping.'' ''Boiler external piping'' is under the jurisdiction of Section I and requires inspection and code stamping in accordance with Section I even though the rules for its design and construction are contained in the ASME Code for Pressure Piping, section B31.1.

Section II ''Material Specifications'' provides detailed specifications of the materials which are acceptable under this code. (These specifications generally are identical to the corresponding ASTM Standards.)

Section III: ''Nuclear Components'' includes all nuclear piping. It is the responsibility of the designer to determine whether or not a particular piping system is ''nuclear'' piping, since Section III makes this determination the responsibility of the designer. In general, piping whose failure could result in the release of radiation which would endanger the public or plant personnel is considered ''nuclear'' piping.

Section VIII: ''Unfired Pressure Vessels'' concerns piping only to the extent of the flanged or threaded connections to the pressure vessel, except that the entire section will apply in those special cases where unfired pressure vessels are made from pipe and fittings.

Section IX: ''Welding and Brazing Qualifications'' establishes the minimum requirements for ASME Code welding.

Section XI: ''Rules for Inservice Inspection of Nuclear Power Plant Components'' contains rules for the examination and repair of components throughout the life of the plant.

The ASME Code for Pressure Piping B31 is, at present, a nonmandatory code in the United States except where U.S. state legislative bodies and Canadian provinces have adopted this code as a legal requirement. The minimum safety requirements of these codes have been accepted by the industry as a standard for all piping outside the jurisdiction of other codes. The piping systems covered by the separate sections of this code are listed below:

Power Piping	B31.1
Fuel Gas Piping	B31.2
Chemical Plant and Petroleum Refinery Piping	B31.3
Liquid Petroleum Transportation Piping Systems	B31.4
Refrigeration Piping	B31.5
Gas Transmission and Distribution Piping Systems	B31.8
Building Service Piping	B31.9

Several other engineering societies and trade associations have also issued standards covering piping. Foremost among these is the American Society for Testing and Materials (ASTM), the American National Standards Institute (ANSI), the American Water Works Association (AWWA), the American Petroleum Institute (API), and the Manufacturers Standardization Society of the Valve and Fitting Industry (MSS).

Additional piping specifications have been issued by the American Welding Society (AWS), the Pipe Fabrication Institute (PFI), the National Fire Protection Association (NFPA), the Copper Development Association (CDA), the Plastics Pipe Institute (PPI), and several others.

The piping standards issued by the ASTM are most commonly referred to in specifications covering piping for power plants, chemical plants, refineries, pulp and paper mills, and other industrial plants. The large majority of ASTM Standards has also been issued by the ASME in Section II of the ASME Boiler and Pressure Vessel Code. The same specification numbers are applied by the ASME as were originally assigned by the ASTM.

The ANSI formerly prepared the various standards of the B31 Code for Pressure Piping. These standards are now issued by the ASME. The ANSI, however, continues to prepare and issue various standards covering pipe fittings, flanges, and other piping components. Note that ASME B16 prepares and issues standards for fittings, flanges, etc.

The AWWA has issued various standards for waterworks applications. The majority of these involve ductile iron pipe, ductile iron and cast iron pipe fittings, etc.

The MSS has prepared various standards for valves, hangers, and fittings, generally involving the lower range of pressures and temperatures.

Table 8.7.1 gives the most **commonly used piping standards** and the organizations from which the standards are available.

Table 8.7.1 Commonly Used Piping Standards

ASTM Specifications
*A 20-82
*A 36-81a
*A 47-77
*A 48-76
*A 53-81a
*A 105-82
*A 106-82
*A 120-82
*A 126-73 (R1980)
*A 134-80
*A 135-79
*A 139-74 (R1980)
*A 167-81a
*A 179-79b
*A 181-81
*A 182-82
*A 193-82
*A 194-82
*A 197-79
*A 202-82
*A 203-82
*A 204-82
*A 211-75a (R1980)
*A 216-82
*A 217-81
*A 225-82
*A 234-82
*A 240-82b
*A 263-82
*A 264-82
*A 265-81a
*A 268-82a
*A 269-82
*A 276-82a
*A 278-75 (R1980)
*A 283-81
*A 285-82
*A 299-82
*A 302-82
*A 307-82a
*A 312-82
*A 320-82
*A 325-82
*A 333-82
*A 334-79
*A 335-81a
*A 338-61 (R1977)
*A 350-81a
*A 351-82
*A 352-82
*A 353-82
*A 354-82b
*A 358-81
*A 369-79a
*A 370-82
*A 376-81
A 377-79
*A 381-81
*A 387-82
*A 395-80
*A 403-82
*A 409-81a
*A 420-81a
*A 426-80
*A 430-79
*A 437-82
*A 451-80
*A 452-79
*A 453-80
*A 494-81
*A 515-82

ASTM Specifications (*Cont.*)
*A 516-82
*A 522-81
*A 524-80
*A 530-82
*A 537-82
*A 553-82
*A 579-79
*A 571-82
*A 587-78
*A 645-82
*A 658-82
*A 671-80
*A 672-81
*A 675-82
*A 691-81
*B 12-76a
*B 21-81
*B 26-82b
*B 42-82
*B 43-80
*B 61-82a
*B 62-82a
*B 68-80
*B 75-81a
*B 88-81
*B 96-82
*B 98-82
*B 127-80a
*B 148-82
*B 150-82a
*B 152-82
*B 160-81
*B 161-81
*B 162-80
*B 164-81
*B 165-81
*B 166-81
*B 167-81
*B 168-80a
*B 169-82
*B 209-82b
*B 210-82a
*B 211-82b
*B 221-82a
*B 241-82a
*B 247-82a
*B 283-81
*B 333-77
*B 335-77
*B 337-78
*B 345-82
*B 361-81
*B 366-81
*B 402-81
*B 407-77
*B 443-82
*B 444-82
*B 446-82
*B 466-82a
*B 467-82
*B 574-77
*B 575-77
*B 581-81
*B 582-81
*B 584-82
*B 619-81
*B 620-77
*B 621-77
*C 14-78
*C 296-78
*C 301-79

ASTM Specifications (*Cont.*)
*C 361-78
*C 582-68 (R1974)
*C 599-70 (R1977)
*D 1503-73 (R1978)
*D 1527-77
D 1600-80
D 1694-79
*D 1785-76
*D 2104-74
*D 2235-81
*D 2239-74
*D 2241-80
*D 2282-77
*D 2310-80
*D 2412-77
*D 2446-73 (R1978)
*D 2447-74
*D 2464-76
*D 2465-73 (R1979)
*D 2466-78
*D 2467-76a
*D 2468-80
*D 2469-76
*D 2513-80a
D 2517-81
*D 2560-80
*D 2564-80
*D 2609-74
*D 2657-79
*D 2662-81
*D 2666-81a
*D 2672-80
*D 2683-80
D 2737-74
*D 2740-80
*D 2837-76
*D 2846-80
*D 2855-80
*D 2992-71 (R1977)
*D 2996-81
*D 2997-71 (R1977)
D 3000-73
D 3035-74
D 3036-73
D 3139-77
*D 3140-72 (R1977)
D 3197-73
*D 3261-81
D 3287-73
*D 3309-80a
*E 112-82
*E 114-75 (R1981)
*E 125-63 (R1980)
*E 142-77
*E 155-79
*E 165-80
*E 186-81
*E 272-75 (R1979)
*E 280-81
*E 310-75 (R1979)
*E 446-81
*E 709-80
*F 336-78
F 423-75
*F 437-77
*F 438-77
*F 439-77
*F 441-77
*F 442-77
*F 443-77
*F 491-77

ASTM Specifications (*Cont.*)
*F 492-77
*F 493-80
*F 546-77
*F 599-78
SAE Specifications
*J 513f-1977
*J 514j-1980
*J 518c-1972
ASNT Standard
SNT TC-1A-1980
*A3.0-1980
*A5.1-1981
*A5.4-1981
*A5.5-1981
Copper Development Assn.
Copper Tube Handbook
EJMA Standards, Current
***American National Standards**
A21.14-1979
A21.52-1981
A58.1-1972
B1.1-1974
B1.20.3-1976
B1.20.1-1983
B1.20.7-1966 (R1983)
B16.1-1975
B16.3-1977
B16.4-1977
B16.5-1981
B16.9-1978
B16.9a-1981
B16.10-1973
B16.11-1980
B16.14-1977
B16.15-1978
B16.18-1978
B16.20-1973
B16.21-1978
B16.22-1980
B16.24-1979
B16.25-1979
B16.26-1975
B16.28-1978
B16.33-1981
B16.34-1981
B16.36-1975 (A1979)
B16.38-1978
B16.39-1977
B16.42-1979
B18.2.1-1981
B18.2.2-1972
B36.10-1979
B36.19-1976
B46.1-1978
B93.11-1981
PPI Technical Reports
TR-21-1973
Pipe Fabrication Institute
ES-7-1962 (R1980)
Federal Specification
WW-P-421D. Sept. 1976

NOTE: Footnotes appear at the end of the table.

Table 8.7.1 Commonly Used Piping Standards (*Continued*)

API Standards†
5B, 10th ed., 1979 (A1982)
5L, 32d ed., 1982
5LE, 2d ed., 1976
5LP, 4th ed., 1976
5LR, 4th ed., 1976
5LS, 12th ed., 1982
5LX, 24th ed., 1982
*526, 2d ed., 1969 (R1977)
593, 2d ed., 1981
594, 2d ed., 1977
595, 2d ed., 1979
597, 3d ed., 1981
599, 2d ed., 1978
600, 8th ed., 1981
601, 5th ed., 1982
602, 4th ed., 1978
603, 3d ed., 1977
604, 4th ed., 1981
*605, 3d ed., 1980
606, 1st ed., 1976
609, 2d ed., 1978
*C101-1967 (R1977)
*C110-1977
*C111-1980
*C115-1975
*C150-1976

API Standards (*Cont.*)
*C151-1976
*C200-1980
*C207-1978
C208-1959
C300-1974
*C301-1972 (A1974)
C302-1974
C400-1977
*C402-1977
*C500-1980
*C504-1980
*C600-1982
C900-1975
ASME Codes
*ASME Boiler and Pressure Vessel Code, 1980 ed.
*Section V, incl. addenda through W82
*Section VIII, Division 1
*Section VIII, Division 2
*Section IX, incl. addenda through W82
MSS Standard Practices
SP-6-1985

MSS Standard Practices (*Cont.*)
SP-9-1984
SP-25-1978 (R83)
SP-42-1985
SP-43-1982
SP-44-1985
SP-45-1982
SP-51-1982
SP-53-1985
SP-55-1985
*SP-58-1983
SP-60-1982
SP-61-1985
SP-65-1983
SP-67-1985
SP-68-1984
SP-69-1983
SP-70-1984
SP-71-1984
SP-72-1970
SP-73-1982
SP-75-1983
SP-77-1984
SP-78-1977
SP-79-1980
SP-80-1979
SP-81-1981

MSS Standard Practices (*Cont.*)
SP-82-1976 (R81)
SP-83-1976
SP-85-1985
SP-86-1981
SP-87-1987
SP-88-1978
SP-89-1985
SP-90-1980
SP-91-1984
SP-92-1982
SP-93-1982
SP-94-1983
CGA
G-4.1-1977
NACE
Corrosion Data Survey
NBS
PS 15-69
NFPA Specifications, current
Uniform Building Code, current
Aluminum Assn.

The referenced standards are available from the listed organizations:

Standards sources

Alum. Assn.	Aluminum Association 900 19th St., NW, Washington, DC 20006 202 862-5100
ANSI	American National Standards Institute, Inc. 11 West 42d St., New York, NY 10036 212 642-4900
API	American Petroleum Institute 1220 L Street, NW, Washington, DC 20005-8029 202 682-8000
ASME	The American Society of Mechanical Engineers 345 East 47th Street, New York, NY 10017 212 705-7722
ASNT	American Society for Nondestructive Testing 3200 Riverside Drive, Columbus, OH 43221 614 488-7921
ASTM	American Society for Testing and Materials 1916 Race Street, Philadelphia, PA 19103 215 299-5400
AWWA	American Water Works Association 6666 W. Quincy Avenue, Denver, CO 80235 303 794-7711
AWS	American Welding Society 2501 N.W. 7th Street, Miami, FL 33125 305 642-7090
CDA	Copper Development Association 260 Madison Avenue, New York, NY 10016 212 251-7234
(a) CGA	Compressed Gas Association 1235 Jefferson Davis Highway Arlington, VA 22202
(a) EJMA	Expansion Joint Manufacturers Association 25 North Broadway, North Tarrytown, NY 10591 914 382-0040
Fed. Spec.	Federal Specification: Superintendent of Documents United States Government Printing Office Washington, DC 20402 202 541-3000
MSS	Manufacturers Standardization Society of the Valve and Fittings Industry 127 Park Street, NE, Vienna, VA 22180 703 281-6613
NACE	National Association of Corrosion Engineers P.O. Box 986 Katy, TX 77450 713 492-0535
NIST	National Institute of Standards and Technology (U.S. Dept. of Commerce): Publications available from Superintendent of Documents United States Government Printing Office Washington, DC 20402 202 541-3000
NFPA	National Fire Protection Association P.O. Box 9101 1 Batterymarch Park, Quincy, MA 02269-9101 617 770-3000
PFI	Pipe Fabrication Institute Box 173, Lenore Avenue, Springdale, PA 15144-1518 412 274-4722
PPI	Plastics Pipe Institute 65 Madison Avenue, Morristown, NJ 07960-6078 No telephone listed
SAE	Society of Automotive Engineers 400 Commonwealth Drive Warrendale, PA 15096 412 776-4841
UBC	Uniform Building Code International Conference of Building Officials 5360 South Workman Mill Road Whittier, CA 90601 213 699-0541

* Indicates that the standard has been approved as an American National Standard by the American National Standards Institute.

† Including supplements to these API Standards through spring 1981.

NOTE: The issue date shown immediately following the hyphen after the number of the standard (e.g., B16.9-1978, C207-1978, and A 47-77) is the effective date of the issue (edition) of the Standard. Any additional number shown following the issue date and prefixed by the letter R is the latest date of reaffirmation [e.g., C101-1967 (R1977)]. Any edition number prefixed by the letter A is the date of the latest addenda accepted [e.g., B16.36-1975 (A1979)].

PIPING, PIPE, AND TUBING

The term **piping** generally is broadly applied to pipe, fittings, valves, and other components that convey liquids, gases, slurries, etc.

The term **pipe** is applied to tubular products of dimensions and materials commonly used for pipelines and connections, formerly designated as **iron pipe size (IPS)**. The outside diameter of all weights and kinds of IPS pipe is of necessity the same for a given pipe size on account of threading. Nevertheless, the large majority of pipe is furnished unthreaded with butt-weld ends.

The word **tube** (or **tubing**) is generally applied to tubular products as utilized in boilers, heat exchangers, instrumentation, and in the machine, aircraft, automotive, and related industries.

Pipe and Tube Products—General

Commercial pipe and tube products are grouped into various classifications generally based on the application or use and not on the manufacturing method. Most tubular products fall into one of three very broad classifications: (1) pipe, (2) pressure tubes, and (3) mechanical tubes. Each classification falls into various subgroupings, which may have been defined and standardized differently by the different trade or user groups. The same standard materials specifications may apply to several of the (user) classifications. For example, ASTM A120 or A53 pipe may be used for applications representing refrigeration, pressure, and nipple service.

Cost considerations enter into the selection of specific piping materials. In some sizes, prices of pipe made to different materials specifications may vary, whereas in other sizes, they may be identical.

Within the broad **use classifications** listed above, the **production method classifications** are also recognized. These are primarily (1) seamless wrought pipe, (2) seamless cast pipe, and (3) seam-welded pipe or tubes. The large variety of single and combination pipe- or tube-forming methods can produce different characteristics and properties in essentially identical pipe materials. In addition, the final finishing can result in hot-finished or cold-finished products. Cold-finishing may be accomplished by reducing or by expanding. Heat treatments may also affect the properties of the finished product.

Piping

On the basis of user classification, the more commonly used types of pipe are tabulated in Table 8.7.2. This listing ignores method of manufacture, size range, wall thickness, and finish, for which the different user groups may have developed different standard requirements.

Table 8.7.2 Major Pipe Classification and Examples of Applications

Identification of pipe	Uses
Standard	Mechanical (structural) service pipe, low-pressure service pipe, refrigeration (ice-machine) pipe, ice-rink pipe, dry-kiln pipe
Pressure	Liquid, gas, or vapor service pipe, service for elevated temperature or pressure, or both
Line	Threaded or plain end, gas, oil, and steam pipe
Water well	Reamed and drifted, water-well casing, drive pipe, driven well pipe, pump pipe, turbine-pump pipe
Oil country tubular goods	Casing, well tubing, drill pipe
Other pipe	Conduit, piles, nipple pipe, sprinkler pipe, bedstead tubing

Standard Pipe Mechanical service pipe is produced in three classes of wall thickness—standard weight, extra strong, and double extra strong. It is available as welded or seamless pipe of ordinary finish and dimensional tolerances, produced in sizes up to 12-in nominal OD. This pipe is used for structural and mechanical purposes. Certain applications have other requirements for size, surface finish, or straightness.

Refrigeration Pipe This pipe is also known as ice-machine pipe or ammonia pipe. It may be butt-welded, lap-welded, electric-resistance-welded, or seamless and is intended for use as a conveyor of refrigerants. This pipe is suitable for coiling, bending, and welding. The sizes commonly used range from ¾ to 2 in. The piping is produced in random and double random lengths in standard line pipe sizes and weights. Double random lengths are used as ice-rink pipe. It can be produced with plain ends, with threaded ends only, or with threaded ends and line pipe couplings, as desired.

Dry-Kiln Pipe This pipe is butt-welded, electric-resistance-welded, or seamless pipe for use in the lumber industry. It is produced in standard-weight pipe sizes of ¾, 1, and 1¼ in. Joints are designed to permit subsequent ''makeup'' after expansion has occurred. Dry-kiln pipe is commonly produced with threaded ends and couplings and in random lengths.

Pressure Pipe Pressure pipe is used for conveying fluids or gases at normal, subzero, or elevated temperatures and/or pressures. It generally is not subjected to external heat application. The range of sizes is ⅛-in nominal size to 36-in actual OD. It is produced in various wall thicknesses. Pressure piping is furnished in random lengths, with threaded or plain ends, as required. Pressure pipe generally is hydrostatically tested at the mill.

Line Pipe Line pipe is seamless or welded pipe produced in sizes from ⅛-in nominal OD to 48-in actual OD. It is used principally for conveying gas, oil, or water. Line pipe is produced with ends which are plain, threaded, beveled, grooved, flanged, or expanded, as required for various types of mechanical couplers, or for welded joints. When threaded ends and couplings are required, recessed couplings are normally supplied.

Water-Well Pipe Water-well pipe is welded or seamless steel pipe used for conveying water for municipal and industrial applications. Pipelines for such purposes involve flow mains, transmission mains, force mains, water mains, or distribution mains. The mains are generally laid underground. Sizes range from ⅛- to 106-in OD in a variety of wall thicknesses. Pipe is produced with ends suitably prepared for mechanical couplers, with plain ends beveled for welding, with ends fitted with butt straps for field welding, or with bell-and-spigot joints with rubber gaskets for field joining. Pipe is produced in double random lengths of about 40 ft, single random lengths of about 20 ft, or in definite cut lengths, as specified. Wall thicknesses vary from 0.068 in for ⅛-in nominal OD to 1.00 in for 106-in actual OD.

When required, water-well pipe is produced with a specified coating or lining or both. For example, cement-mortar lining and coatings are extensively used.

Oil Country Goods Casing is used as a structural retainer for the walls of oil or gas wells. It is also used to exclude undesirable fluids, and to confine and conduct oil or gas from productive subsurface strata to the ground level. Casing is produced in sizes 4½- to 20-in OD. Size designations refer to actual outside diameter and weight per foot. Ends are commonly threaded and furnished with couplings. When required, the ends are prepared to accommodate other types of joints.

Drill Pipe Drill pipe is used to transmit power by rotary motion from ground level to a rotary drilling tool below the surface and also to convey flushing media to the cutting face of the tool. Drill pipe is produced in sizes 2⅜- to 6⅝-in OD. Size designations refer to actual outside diameter and weight per foot. Drill pipe is generally upset, either internally or externally, or both, and is furnished with threaded ends and couplings, threaded only, or prepared to accommodate other types of joints.

Tubing is used within the casing of oil wells to conduct oil to ground level. It is produced in sizes 1.050- to 4.500-in OD in several weights per foot. Ends are threaded and fitted with couplings and may or may not be upset externally.

Other Pipe Classifications **Rigid conduit pipe** is welded or seamless pipe intended especially for the protection of electrical wiring systems. Conduit pipe is not subjected to hydrostatic tests unless so specified. It is furnished in standard-weight pipe sizes from ¼- to 6-in OD in 10-ft

lengths,* with plain ends or with threaded ends and couplings, as specified.

Piling pipe is welded or seamless pipe for use as piles, where the cylinder section acts as a permanent load-carrying member or where it acts as a shell to form cast-in-place concrete piles. Specifications provide for the choice of three grades by minimum tensile strength, in which the sizes listed are 8⅝- to 24-in OD in a variety of wall thicknesses and in two length ranges. Ends are plain or beveled for welding.

Nipple pipe is standard-weight, extra-strong, or double-extra-strong welded or seamless pipe produced for the manufacture of pipe nipples. Standard-weight pipe with threaded ends is also used in sprinkler systems. Nipple pipe is commonly produced in random lengths with plain ends in nominal sizes ⅛- to 12-in OD. Close OD tolerances, sound welds, good threading properties, and surface cleanliness are essential in this product. It is commonly coated with oil or zinc and well protected in shipment. When reference is made to ASTM Specifications for this application, Specification A120 is generally used for diameters to 5-in OD and A53 for diameters of 5 in and over.

Standard Pipe Sizes Standard pressure, line, and other pipe with plain ends for welding or with threaded ends is standardized in two ranges. Diameters of 12 in and less have a nominal size which represents approximately that of the inside diameter of standard-weight pipe. The nominal outside diameter is standard, regardless of weight. Increase in wall thickness results in a decrease of the inside diameter.

The standardization of pipe sizes over 12 in is based on the actual outside diameter, the wall thickness, and the weight per foot.

The principal dimensions, weights, and characteristics of commercial piping materials are summarized in Table 8.7.3.

The weights of butt-welding elbows, tees, and laterals and flanges are given in Tables 8.7.4 to 8.7.9 for several common pipe sizes. The weights of reducing fittings are approximately the same as for full-size fittings.

The weights of welding reducers are for one size reduction and are thus only approximately correct for other reductions.

Hot-finished or cold-drawn seamless low-alloy steel tubes generally are process-annealed at temperatures between 1,200 and 1,350°F.

Austenitic stainless-steel tubes are usually annealed at temperatures between 1,800 and 2,100°F, with specific temperatures varying somewhat with each grade. This is generally followed by pickling, unless bright-annealing was done.

Mechanical Tubing

Unlike pipe and pressure tubes, mechanical tubing is generally classified by the method of manufacture and the degree of finish. Examples of classifications are ''seamless hot-finished,'' ''cold-drawn welded,'' ''flash-in-grade,'' etc.

Seamless Tubes Seamless tubes are available as either hot- or cold-finished. They are normally made in sizes from 0.187-in OD to 10.750-in OD.

Dimensions for hot-finished mechanical tubes are provided in Table 8.7.11. Dimensions for cold-finished tubes are listed in Table 8.7.12.

Welded Tubes Welded tubes generally are produced by electric resistance methods. Where required, the welding flash is removed with a cutting tool. Industry practice normally recognizes a number of finish conditions which are summarized in Table 8.7.13.

Flash-in Type Tubing This tubing is generally limited to applications where nothing is inserted in the tube.

Flash-Controlled Tubing This tubing is used where moderate control of the inside diameter is required. Generally, the outside and inside diameters are specified.

For special materials, the equations listed below for weights of tubes and weights of contents of tubes are helpful.

$$\text{Weight of tube, lb/ft} = F \times 10.68 \times T \times D - T$$

* Although some specifications of rigid conduit pipe list lengths to 20 ft, the National Electric Code, 1965, limits lengths to 10 ft.

where T = wall thickness, in; D = outside diameter, in; F = relative weight factor.

The weight of tube calculation is based on low-carbon steel weighing 0.2833 lb/in^3 and is extended to other materials through the factor F.

Relative weight factor F

Aluminum	0.35
Brass	1.12
Cast-iron	0.91
Copper	1.14
Ferritic stainless steel	1.02
Steel	1.00
Wrought iron	0.98

$$\text{Weight of contents of tube, lb/ft} = G \times 0.3405 \times (D - 2T)^2$$

where G = specific gravity of contents; T = tube wall thickness, in; D = tube outside diameter, in.

The weight per foot of steel pipe is subject to the tolerances listed in Table 8.7.10.

The designation *sink-draw tubes* is specified where close control over the outer diameter is required with normal tolerance applying to the wall thickness. Smoothness of the inside surface is not controlled, except that the flash is generally controlled to a height of 0.005 or 0.010 in maximum.

Mandrel-drawn tubes usually are normalized after welding by passing the tubes through a continuous atmosphere-controlled furnace. After descaling, the tubes are cold-drawn through a die with a mandrel on the inside of the tube. These tubes provide maximum control over surface finish, outside or inside diameters, and wall thickness. The normalizing heat treatment removes the effects of welding and provides a uniform microstructure around the tube circumference.

The different finish classifications may result in substantial differences in the mechanical properties of the steel material.

Typical examples for low-carbon steel material are given in Table 8.7.14. Differences in carbon content and other chemistry, heat treatment, etc., may significantly change these typical values.

Other Tubing Types Among other tube classifications are sanitary tubing usually made of 18% Cr-8% Ni stainless steel and available as seamless or welded tubing. This tubing is used extensively in the dairy, beverage, and food industries. Sanitary tubing is generally available in sizes from 1- to 4-in OD. It may be furnished either hot- or cold-finished. The tubes are normally annealed at temperatures above 1,900°F.

Some welded tube is also produced by fusion-welding methods utilizing either the inert-gas tungsten-arc-welding or gas-shielded consumable metal-arc-welding process. This tubing is generally more expensive than the resistance-welded types.

The butt-welded cold-finished tubes are made from hot-rolled or cold-rolled strip and fusion-welded. This tubing is usually furnished as sink-drawn or mandrel-drawn.

Butt-welded tubing is made in heavier wall thicknesses than the resistance-welded tube.

Several tubing materials used in the automobile industry are covered by specifications of the Society of Automotive Engineers, ''SAE Handbook.''

Pressure Tubing

Pressure-tube applications commonly involve external heat applications, as in boilers or superheaters.

Pressure tubing is produced to the actual outside diameter and minimum wall or average wall thickness specified by the purchaser. Pressure tubing may be hot- or cold-finished.

The wall thickness is normally given in decimal parts of an inch rather than as a fraction or gage number. When gage numbers are given without reference to a gage system, Birmingham wire gage (BWG) is implied.

Pressure tubing is usually made from steel produced by the open-hearth, basic oxygen, or electric-furnace processes.

Table 8.7.3 Properties of Commercial Steel Pipe

Nominal pipe size, outside diameter, in	Schedule number* a	Schedule number* b	Schedule number* c	Wall thickness, in	Inside diameter, in	Inside area, in^2	Metal area, in^2	Outside surface, ft^2/ft	Inside surface, ft^2/ft	Weight, lb/ft†	Weight of water, lb/ft	Moment of inertia, in^4	Section modulus, in^3	Radius of gyration, in
⅛			10S	0.049	0.307	0.0740	0.0548	0.106	0.0804	0.186	0.0321	0.00088	0.00437	0.1271
0.405	40	Std	40S	0.068	0.269	0.0568	0.0720	0.106	0.0705	0.245	0.0246	0.00106	0.00525	0.1215
	80	XS	80S	0.095	0.215	0.0364	0.0925	0.106	0.0563	0.315	0.0157	0.00122	0.00600	0.1146
¼			10S	0.065	0.410	0.1320	0.0970	0.141	0.1073	0.330	0.0572	0.00279	0.01032	0.1694
0.540	40	Std	40S	0.088	0.364	0.1041	0.1250	0.141	0.0955	0.425	0.0451	0.00331	0.01230	0.1628
	80	XS	80S	0.119	0.302	0.0716	0.1574	0.141	0.0794	0.535	0.0310	0.00378	0.01395	0.1547
⅜			5S	0.065	0.710	0.396	0.1582	0.220	0.1859	0.538	0.1716	0.01197	0.0285	0.2750
0.675			10S	0.065	0.545	0.2333	0.1246	0.177	0.1427	0.423	0.1011	0.00586	0.01737	0.2169
	40	Std	40S	0.091	0.493	0.1910	0.1670	0.177	0.1295	0.568	0.0827	0.00730	0.02160	0.2090
	80	XS	80S	0.126	0.423	0.1405	0.2173	0.177	0.1106	0.739	0.0609	0.00862	0.02554	0.1991
½			5S	0.065	0.710	0.3959	0.1583	0.220	0.1859	0.538	0.171	0.0120	0.0285	0.2750
0.840			10S	0.083	0.674	0.357	0.1974	0.220	0.1765	0.671	0.1547	0.01431	0.0341	0.2692
	40	Std	40S	0.109	0.622	0.304	0.2503	0.220	0.1628	0.851	0.1316	0.01710	0.0407	0.2613
	80	XS	80S	0.147	0.546	0.2340	0.320	0.220	0.1433	1.088	0.1013	0.02010	0.0478	0.2505
	160			0.187	0.466	0.1706	0.383	0.220	0.1220	1.304	0.0740	0.02213	0.0527	0.2402
		XXS		0.294	0.252	0.0499	0.504	0.220	0.0660	1.714	0.0216	0.02425	0.0577	0.2192
¾			5S	0.065	0.920	0.655	0.2011	0.275	0.2409	0.684	0.2882	0.02451	0.0467	0.349
1.050			10S	0.083	0.884	0.614	0.2521	0.275	0.2314	0.857	0.2661	0.02970	0.0566	0.343
	40	Std	40S	0.113	0.824	0.533	0.333	0.275	0.2157	1.131	0.2301	0.0370	0.0706	0.334
	80	XS	80S	0.154	0.742	0.432	0.435	0.275	0.1943	1.474	0.1875	0.0448	0.0853	0.321
	160			0.218	0.614	0.2961	0.570	0.275	0.1607	1.937	0.1284	0.0527	0.1004	0.304
		XXS		0.308	0.434	0.1479	0.718	0.275	0.1137	2.441	0.0641	0.0579	0.1104	0.2840
1			5S	0.065	1.185	1.103	0.2553	0.344	0.310	0.868	0.478	0.0500	0.0760	0.443
1.315			10S	0.109	1.097	0.945	0.413	0.344	0.2872	1.404	0.409	0.0757	0.1151	0.428
	40	Std	40S	0.133	1.049	0.864	0.494	0.344	0.2746	1.679	0.374	0.0874	0.1329	0.421
	80	XS	80S	0.179	0.957	0.719	0.639	0.344	0.2520	2.172	0.311	0.1056	0.1606	0.407
	160			0.250	0.815	0.522	0.836	0.344	0.2134	2.844	0.2261	0.1252	0.1903	0.387
		XXS		0.358	0.599	0.2818	1.076	0.344	0.1570	3.659	0.1221	0.1405	0.2137	0.361
1¼			5S	0.065	1.530	1.839	0.326	0.434	0.401	1.107	0.797	0.1038	0.1250	0.564
1.660			10S	0.109	1.442	1.633	0.531	0.434	0.378	1.805	0.707	0.1605	0.1934	0.550
	40	Std	40S	0.140	1.380	1.496	0.669	0.434	0.361	2.273	0.648	0.1948	0.2346	0.540
	80	XS	80S	0.191	1.278	1.283	0.881	0.434	0.335	2.997	0.555	0.2418	0.2913	0.524
	160			0.250	1.160	1.057	1.107	0.434	0.304	3.765	0.458	0.2839	0.342	0.506
		XXS		0.382	0.896	0.631	1.534	0.434	0.2346	5.214	0.2732	0.341	0.411	0.472
1½			5S	0.065	1.770	2.461	0.375	0.497	0.463	1.274	1.067	0.1580	0.1663	0.649
1.900			10S	0.109	1.682	2.222	0.613	0.497	0.440	2.085	0.962	0.2469	0.2599	0.634
	40	Std	40S	0.145	1.610	2.036	0.799	0.497	0.421	2.718	0.882	0.320	0.326	0.623
	80	XS	80S	0.200	1.500	1.767	1.068	0.497	0.393	3.631	0.765	0.391	0.412	0.605
	160			0.281	1.338	1.406	1.429	0.497	0.350	4.859	0.608	0.483	0.508	0.581
		XXS		0.400	1.100	0.950	1.855	0.497	0.288	6.408	0.412	0.568	0.598	0.549
				0.525	0.850	0.567	2.267	0.497	0.223	7.710	0.246	0.6140	0.6470	0.5200
				0.650	0.600	0.283	2.551	0.497	0.157	8.678	0.123	0.6340	0.6670	0.4980

Table 8.7.3 Properties of Commercial Steel Pipe (*Continued*)

Nominal pipe size, outside diameter, in	Schedule number*			Wall thickness, in	Inside diameter, in	Inside area, in^2	Metal area, in^2	Outside surface, ft^2/ft	Inside surface, ft^2/ft	Weight, lb/ft†	Weight of water, lb/ft	Moment of inertia, in^4	Section modulus, in^3	Radius of gyration, in
	a	b	c											
2			5S	0.065	2.245	3.96	0.472	0.622	0.588	1.604	1.716	0.315	0.2652	0.817
2.375			10S	0.109	2.157	3.65	0.776	0.622	0.565	2.638	1.582	0.499	0.420	0.802
	40	Std	40S	0.154	2.067	3.36	1.075	0.622	0.541	3.653	1.455	0.666	0.561	0.787
	80	XS	80S	0.218	1.939	2.953	1.477	0.622	0.508	5.022	1.280	0.868	0.731	0.766
	160			0.343	1.689	2.240	2.190	0.622	0.442	7.444	0.971	1.163	0.979	0.729
		XXS		0.436	1.503	1.774	2.656	0.622	0.393	9.029	0.769	1.312	1.104	0.703
				0.562	1.251	1.229	3.199	0.622	0.328	10.882	0.533	1.442	1.2140	0.6710
				0.687	1.001	0.787	3.641	0.622	0.262	12.385	0.341	1.5130	1.2740	0.6440
2½			5S	0.083	2.709	5.76	0.728	0.753	0.709	2.475	2.499	0.710	0.494	0.988
2.875			10S	0.120	2.635	5.45	1.039	0.753	0.690	3.531	2.361	0.988	0.687	0.975
	40	Std	40S	0.203	2.469	4.79	1.704	0.753	0.646	5.793	2.076	1.530	1.064	0.947
	80	XS	80S	0.276	2.323	4.24	2.254	0.753	0.608	7.661	1.837	1.925	1.339	0.924
	160			0.375	2.125	3.55	2.945	0.753	0.556	10.01	1.535	2.353	1.637	0.894
		XXS		0.552	1.771	2.464	4.03	0.753	0.464	13.70	1.067	2.872	1.998	0.844
				0.675	1.525	1.826	4.663	0.753	0.399	15.860	0.792	3.0890	2.1490	0.8140
				0.800	1.275	1.276	5.212	0.753	0.334	17.729	0.554	3.2250	2.2430	0.7860
3			5S	0.083	3.334	8.73	0.891	0.916	0.873	3.03	3.78	1.301	0.744	1.208
3.500			10S	0.120	3.260	8.35	1.274	0.916	0.853	4.33	3.61	1.822	1.041	1.196
	40	Std	40S	0.216	3.068	7.39	2.228	0.916	0.803	7.58	3.20	3.02	1.724	1.164
	80	XS	80S	0.300	2.900	6.61	3.02	0.916	0.759	10.25	2.864	3.90	2.226	1.136
	160			0.437	2.626	5.42	4.21	0.916	0.687	14.32	2.348	5.03	2.876	1.094
		XXS		0.600	2.300	4.15	5.47	0.916	0.602	18.58	1.801	5.99	3.43	1.047
				0.725	2.050	3.299	6.317	0.916	0.537	21.487	1.431	6.5010	3.7150	1.0140
				0.850	1.800	2.543	7.073	0.916	0.471	24.057	1.103	6.8530	3.9160	0.9840
3½			5S	0.083	3.834	11.55	1.021	1.047	1.004	3.47	5.01	1.960	0.980	1.385
4.000			10S	0.120	3.760	11.10	1.463	1.047	0.984	4.97	4.81	2.756	1.378	1.372
	40	Std	40S	0.226	3.548	9.89	2.680	1.047	0.929	9.11	4.28	4.79	2.394	1.337
	80	XS	80S	0.318	3.364	8.89	3.68	1.047	0.881	12.51	3.85	6.28	3.14	1.307
		XXS		0.636	2.728	5.845	6.721	1.047	0.716	22.850	2.530	9.8480	4.9240	1.2100
4			5S	0.083	4.334	14.75	1.152	1.178	1.135	3.92	6.40	2.811	1.249	1.562
4.500			10S	0.120	4.260	14.25	1.651	1.178	1.115	5.61	6.17	3.96	1.762	1.549
				0.188	4.124	13.357	2.547	1.178	1.082	8.560	5.800	5.8500	2.6000	1.5250
	40	Std	40S	0.237	4.026	12.73	3.17	1.178	1.054	10.79	5.51	7.23	3.21	1.510
	80	XS	80S	0.337	3.826	11.50	4.41	1.178	1.002	14.98	4.98	9.61	4.27	1.477
	120			0.437	3.626	10.33	5.58	1.178	0.949	18.96	4.48	11.65	5.18	1.445
				0.500	3.500	9.621	6.283	1.178	0.916	21.360	4.160	12.7710	5.6760	1.4250
	160			0.531	3.438	9.28	6.62	1.178	0.900	22.51	4.02	13.27	5.90	1.416
		XXS		0.674	3.152	7.80	8.10	1.178	0.825	27.54	3.38	15.29	6.79	1.374
				0.800	2.900	6.602	9.294	1.178	0.759	31.613	2.864	16.6610	7.4050	1.3380
				0.925	2.650	5.513	10.384	1.178	0.694	35.318	2.391	17.7130	7.8720	1.3060
5			5S	0.109	5.345	22.44	1.868	1.456	1.399	6.35	9.73	6.95	2.498	1.929
5.563			10S	0.134	5.295	22.02	2.285	1.456	1.386	7.77	9.53	8.43	3.03	1.920
	40	Std	40S	0.258	5.047	20.01	4.30	1.456	1.321	14.62	8.66	15.17	5.45	1.878
	80	XS	80S	0.375	4.813	18.19	6.11	1.456	1.260	20.78	7.89	20.68	7.43	1.839
	120			0.500	4.563	16.35	7.95	1.456	1.195	27.04	7.09	25.74	9.25	1.799
	160			0.625	4.313	14.61	9.70	1.456	1.129	32.96	6.33	30.0	10.80	1.760
		XXS		0.750	4.063	12.97	11.34	1.456	1.064	38.55	5.62	33.6	12.10	1.722
				0.875	3.813	11.413	12.880	1.456	0.998	43.810	4.951	36.6450	13.1750	1.6860
				1.000	3.563	9.966	14.328	1.456	0.933	47.734	4.232	39.1110	14.0610	1.6520

NOTE: See footnotes at end of table.

Table 8.7.3 Properties of Commercial Steel Pipe (*Continued*)

Nominal pipe size, outside diameter, in	Schedule number*			Wall thick-ness, in	Inside diameter, in	Inside area, in^2	Metal area, in^2	Outside surface, ft^2/ft	Inside surface, ft^2/ft	Weight, lb/ft†	Weight of water, lb/ft	Moment of inertia, in^4	Section modulus, in^3	Radius of gyration, in
	a	b	c											
6			5S	0.109	6.407	32.2	2.231	1.734	1.677	5.37	13.98	11.85	3.58	2.304
6.625			10S	0.134	6.357	31.7	2.733	1.734	1.664	9.29	13.74	14.40	4.35	2.295
				0.219	6.187	30.100	4.410	1.734	1.620	15.020	13.100	22.6600	6.8400	2.2700
	40	Std	40S	0.280	6.065	28.89	5.58	1.734	1.588	18.97	12.51	28.14	8.50	2.245
	80	XS	80S	0.432	5.761	26.07	8.40	1.734	1.508	28.57	11.29	40.5	12.23	2.195
	120			0.562	5.501	23.77	10.70	1.734	1.440	36.39	10.30	49.6	14.98	2.153
	160			0.718	5.189	21.15	13.33	1.734	1.358	45.30	9.16	59.0	17.81	2.104
		XXS		0.864	4.897	18.83	15.64	1.734	1.282	53.16	8.17	66.3	20.03	2.060
				1.000	4.625	16.792	17.662	1.734	1.211	60.076	7.284	72.1190	21.7720	2.0200
				1.125	4.375	15.025	19.429	1.734	1.145	66.084	6.517	76.5970	23.1240	1.9850
8			5S	0.109	8.407	55.5	2.916	2.258	2.201	9.91	24.07	26.45	6.13	3.01
8.625			10S	0.148	8.329	54.5	3.94	2.258	2.180	13.40	23.59	35.4	8.21	3.00
				0.219	8.187	52.630	5.800	2.258	2.150	19.640	22.900	51.3200	11.9000	2.9700
	20			0.250	8.125	51.8	6.58	2.258	2.127	22.36	22.48	57.7	13.39	2.962
	30			0.277	8.071	51.2	7.26	2.258	2.113	24.70	22.18	63.4	14.69	2.953
	40	Std	40S	0.322	7.981	50.0	8.40	2.258	2.089	28.55	21.69	72.5	16.81	2.938
	60			0.406	7.813	47.9	10.48	2.258	2.045	35.64	20.79	88.8	20.58	2.909
	80	XS	80S	0.500	7.625	45.7	12.76	2.258	1.996	43.39	19.80	105.7	24.52	2.878
	100			0.593	7.439	43.5	14.96	2.258	1.948	50.87	18.84	121.4	28.14	2.847
	120			0.718	7.189	40.6	17.84	2.258	1.882	60.63	17.60	140.6	32.6	2.807
	140			0.812	7.001	38.5	19.93	2.258	1.833	67.76	16.69	153.8	35.7	2.777
		XXS		0.875	6.875	37.1	21.30	2.258	1.800	72.42	16.09	162.0	37.6	2.757
	160			0.906	6.813	36.5	21.97	2.258	1.784	74.69	15.80	165.9	38.5	2.748
				1.000	6.625	34.454	23.942	2.258	1.734	81.437	14.945	177.1320	41.0740	2.7190
				1.125	6.375	31.903	26.494	2.258	1.669	90.114	13.838	190.6210	44.2020	2.6810
10			5S	0.134	10.482	86.3	4.52	2.815	2.744	15.15	37.4	63.7	11.85	3.75
10.750			10S	0.165	10.420	85.3	5.49	2.815	2.728	18.70	36.9	76.9	14.30	3.74
				0.219	10.312	83.52	7.24	2.815	2.70	24.63	36.2	100.46	18.69	3.72
	20			0.250	10.250	82.5	8.26	2.815	2.683	28.04	35.8	113.7	21.16	3.71
	30			0.307	10.136	80.7	10.07	2.815	2.654	34.24	35.0	137.5	25.57	3.69
	40	Std	40S	0.365	10.020	78.9	11.91	2.185	2.623	40.48	34.1	160.8	29.90	3.67
	60	XS	80S	0.500	9.750	74.7	16.10	2.815	2.553	54.74	32.3	212.0	39.4	3.63
	80			0.593	9.564	71.8	18.92	2.815	2.504	64.33	31.1	244.9	45.6	3.60
	100			0.718	9.314	68.1	22.63	2.815	2.438	76.93	29.5	286.2	53.2	3.56
	120			0.843	0.064	64.5	26.24	2.815	2.373	89.20	28.0	324	60.3	3.52
				0.875	9.000	63.62	27.14	2/815	2.36	92.28	27.6	333.46	62.04	3.50
	140			1.000	8.750	60.1	30.6	2.815	2.091	104.13	26.1	368	68.4	3.47
	160			1.125	8.500	56.7	34.0	2.815	2.225	115.65	24.6	399	74.3	3.43
				1.250	8.250	53.45	37.31	2.815	2.16	126.832	23.2	428.17	79.66	3.39
				1.500	7.750	47.15	43.57	2.815	2.03	148.19	20.5	478.59	89.04	3.31

Table 8.7.3 Properties of Commercial Steel Pipe (*Continued*)

Nominal pipe size, outside diameter, in	Schedule number*			Wall thick-ness, in	Inside diameter, in	Inside area, in^2	Metal area, in^2	Outside surface, ft^2/ft	Inside surface, ft^2/ft	Weight, lb/ft†	Weight of water, lb/ft	Moment of inertia, in^4	Section modulus, in^3	Radius of gyration, in
	a	b	c											
12			5S	0.156	12.438	121.4	6.17	3.34	3.26	20.99	52.7	122.2	19.20	4.45
12.750			10S	0.180	12.390	120.6	7.11	3.34	3.24	24.20	52.2	140.5	22.03	4.44
	20			0.250	12.250	117.9	9.84	3.34	3.21	33.38	51.1	191.9	30.1	4.42
	30			0.330	12.090	114.8	12.88	3.34	3.17	43.77	49.7	248.5	39.0	4.39
		Std	40S	0.375	12.000	113.1	14.58	3.34	3.14	49.56	49.0	279.3	43.8	4.38
	40			0.406	11.938	111.9	15.74	3.34	3.13	53.53	48.5	300	47.1	4.37
		XS	80S	0.500	11.750	108.4	19.24	3.34	3.08	65.42	47.0	362	56.7	4.33
	60			0.562	11.626	106.2	21.52	3.34	3.04	73.16	46.0	401	62.8	4.31
	80			0.687	11.376	101.6	26.04	3.34	2.978	88.51	44.0	475	74.5	4.27
				0.750	11.250	99.40	28.27	3.34	2.94	96.2	43.1	510.7	80.1	4.25
	100			0.843	11.064	96.1	31.5	3.34	2.897	107.20	41.6	562	88.1	4.22
				0.875	11.000	95.00	32.64	3.34	2.88	110.9	41.1	578.5	90.7	4.21
	120			1.000	10.750	90.8	36.9	3.34	2.814	125.49	39.3	642	100.7	4.17
	140			1.125	10.500	86.6	41.1	3.34	2.749	139.68	37.5	701	109.9	4.13
				1.250	10.250	82.50	45.16	3.34	2.68	153.6	35.8	755.5	118.5	4.09
	160			1.312	10.126	80.5	47.1	3.34	2.651	160.27	34.9	781	122.6	4.07
14			5S	0.156	13.688	147.20	6.78	3.67	3.58	23.0	63.7	162.6	23.2	4.90
14.000			10S	0.188	13.624	145.80	8.16	3.67	3.57	27.7	63.1	194.6	27.8	4.88
				0.210	13.580	144.80	9.10	3.67	3.55	30.9	62.8	216.2	30.9	4.87
				0.219	13.562	144.50	9.48	3.67	3.55	32.2	62.6	225.1	32.2	4.87
	10			0.250	13.500	143.1	10.80	3.67	3.53	36.71	62.1	255.4	36.5	4.86
				0.281	13.438	141.80	12.11	3.67	3.52	41.2	61.5	285.2	40.7	4.85
	20			0.312	13.376	140.5	13.42	3.67	3.50	45.68	60.9	314	44.9	4.84
				0.344	13.312	139.20	14.76	3.67	3.48	50.2	60.3	344.3	49.2	4.83
	30	Std		0.375	13.250	137.9	16.05	3.67	3.47	54.57	59.7	373	53.3	4.82
	40			0.437	13.126	135.3	18.62	3.67	3.44	63.37	58.7	429	61.2	4.80
				0.469	13.062	134.00	19.94	3.67	3.42	67.8	58.0	456.8	64.3	4.79
		XS		0.500	13.000	132.7	21.21	3.67	3.40	72.09	57.5	484	69.1	4.78
	60			0.593	12.814	129.0	24.98	3.67	3.35	84.91	55.9	562	80.3	4.74
		XXS		0.625	12.750	127.7	26.26	3.67	3.34	89.28	55.3	589	84.1	4.73
	80			0.750	12.500	122.7	31.2	3.67	3.27	106.13	53.2	687	98.2	4.69
	100			0.937	12.126	115.5	38.5	3.67	3.17	130.73	50.0	825	117.8	4.63
	120			1.093	11.814	109.6	44.3	3.67	3.09	150.67	47.5	930	132.8	4.58
	140			1.250	11.500	103.9	50.1	3.67	3.01	170.22	45.0	1017	146.8	4.53
	160			1.406	11.188	98.3	55.6	3.67	2.929	189.12	42.6	1127	159.6	4.48
16			5S	0.165	15.670	192.90	8.21	4.19	4.10	28	83.5	257	32.2	5.60
16.000			10S	0.188	15.624	191.70	9.34	4.19	4.09	32	83.0	292	36.5	5.59
	10			0.250	15.500	188.7	12.37	4.19	4.06	42.05	81.8	384	48.0	5.57
	20			0.312	15.376	185.7	15.38	4.19	4.03	52.36	80.5	473	59.2	5.55
	30	Std		0.375	15.250	182.6	18.41	4.19	3.99	62.58	79.1	562	70.3	5.53
	40	XS		0.500	15.000	176.7	24.35	4.19	3.93	82.77	76.5	732	91.5	5.48
	60			0.656	14.688	169.4	31.6	4.19	3.85	107.50	73.4	933	116.6	5.43
	80			0.843	14.314	160.9	40.1	4.19	3.75	136.46	69.7	1157	144.6	5.37
	100			1.031	13.938	152.6	48.5	4.19	3.65	164.83	66.1	1365	170.6	5.30
	120			1.218	13.564	144.5	56.6	4.19	3.55	192.29	62.6	1556	194.5	5.24
	140			1.437	13.126	135.3	65.7	4.19	3.44	223.64	58.6	1760	220.0	5.17
	160			1.593	12.814	129.0	72.1	4.19	3.35	245.11	55.9	1894	236.7	5.12

Table 8.7.3 Properties of Commercial Steel Pipe (*Continued*)

Nominal pipe size, outside diameter, in	Schedule number* a	b	c	Wall thick-ness, in	Inside diameter, in	Inside area, in^2	Metal area, in^2	Outside surface, ft^2/ft	Inside surface, ft^2/ft	Weight, lb/ft†	Weight of water, lb/ft	Moment of inertia, in^4	Section modulus, in^3	Radius of gyration, in
18			5S	0.165	17.670	245.20	9.24	4.71	4.63	31	106.2	368	40.8	6.31
18.000			10S	0.188	17.624	243.90	10.52	4.71	4.61	36	105.7	417	46.4	6.30
	10			0.250	17.500	240.5	13.94	4.71	4.58	47.39	104.3	549	61.0	6.28
	20			0.312	17.376	237.1	17.34	4.71	4.55	59.03	102.8	678	75.5	6.25
		Std		0.375	17.250	233.7	20.76	4.71	4.52	70.59	101.2	807	89.6	6.23
	30			0.437	17.126	230.4	24.11	4.71	4.48	82.06	99.9	931	103.4	6.21
		XS		0.500	17.00	227.0	27.49	4.71	4.45	93.45	98.4	1053	117.0	6.19
	40			0.562	16.876	223.7	30.8	4.71	4.42	104.75	97.0	1172	130.2	6.17
	60			0.750	16.500	213.8	40.6	4.71	4.32	138.17	92.7	1515	168.3	6.10
	80			0.937	16.126	204.2	50.2	4.71	4.22	170.75	88.5	1834	203.8	6.04
	100			1.156	15.688	193.3	61.2	4.71	4.11	207.96	83.7	2180	242.2	5.97
	120			1.375	15.250	182.6	71.8	4.71	3.99	244.14	79.2	2499	277.6	5.90
	140			1.562	14.876	173.8	80.7	4.71	3.89	274.23	75.3	2750	306	5.84
	160			1.781	14.438	163.7	90.7	4.71	3.78	308.51	71.0	3020	336	5.77
20			5S	0.188	19.634	302.40	11.70	5.24	5.14	40	131.0	574	57.4	7.00
20.000			10S	0.218	19.564	300.60	13.55	5.24	5.12	46	130.2	663	66.3	6.99
	10			0.250	19.500	298.6	15.51	5.24	5.11	52.73	129.5	757	75.7	6.98
	20	Std		0.375	19.250	291.0	23.12	5.24	5.04	78.60	126.0	1114	111.4	6.94
	30	XS		0.500	19.000	283.5	30.6	5.24	4.97	104.13	122.8	1457	145.7	6.90
	40			0.593	18.814	278.0	36.2	5.24	4.93	122.91	120.4	1704	170.4	6.86
	60			0.812	18.376	265.2	48.9	5.24	4.81	166.40	115.0	2257	225.7	6.79
				0.875	18.250	261.6	52.6	5.24	4.78	178.73	113.4	2409	240.9	6.77
	80			1.031	17.938	252.7	61.4	5.24	4.70	208.87	109.4	2772	277.2	6.72
	100			1.281	17.438	238.8	75.3	5.24	4.57	256.10	103.4	3320	332	6.63
	120			1.500	17.00	227.0	87.2	5.24	4.45	296.37	98.3	3760	376	6.56
	140			1.750	16.500	213.8	100.3	5.24	4.32	341	92.6	4200	422	6.48
	160			1.968	16.064	202.7	111.5	5.24	4.21	379.01	87.9	1490	459	6.41
22			5S	0.188	21.624	367.3	12.88	5.76	5.66	44	159.1	766	69.7	7.71
22.000			10S	0.218	21.564	365.2	14.92	5.76	5.65	51	158.2	885	80.4	7.70
	10			0.250	21.500	363.1	17.18	5.76	5.63	58	157.4	1010	91.8	7.69
	20	Std		0.375	21.250	354.7	25.48	5.76	5.56	87	153.7	1490	135.4	7.65
	30	XS		0.500	21.000	364.4	33.77	5.76	5.50	115	150.2	1953	177.5	7.61
				0.625	20.750	338.2	41.97	5.76	5.43	143	146.6	2400	218.2	7.56
				0.750	20.500	330.1	50.07	5.76	5.37	170	143.1	2829	257.2	7.52
	60			0.875	20.250	322.1	58.07	5.76	5.30	197	139.6	3245	295.0	7.47
	80			1.125	19.750	306.4	73.78	5.76	5.17	251	132.8	4029	366.3	7.39
	100			1.375	19.250	291.0	89.09	5.76	5.04	303	126.2	4758	432.6	7.31
	120			1.625	18.750	276.1	104.02	5.76	4.91	354	119.6	5432	493.8	7.23
	140			1.875	18.250	261.6	118.55	5.76	4.78	403	113.3	6054	550.3	7.15
	160			2.125	17.750	247.4	132.68	5.76	4.65	451	107.2	6626	602.4	7.07

Table 8.7.3 Properties of Commercial Steel Pipe (*Continued*)

Nominal pipe size, outside diameter, in	Schedule number* a	b	c	Wall thick-ness, in	Inside diameter, in	Inside area, in^2	Metal area, in^2	Outside surface, ft^2/ft	Inside surface, ft^2/ft	Weight, lb/ft†	Weight of water, lb/ft	Moment of inertia, in^4	Section modulus, in^3	Radius of gyration, in
24			5S	0.218	23.564	436.1	16.29	6.28	6.17	55	188.9	1152	96.0	8.41
24.000	10			0.250	23.500	434	18.65	6.28	6.15	63.41	188.0	1316	109.6	8.40
	20	Std		0.375	23.250	425	27.83	6.28	6.09	94.62	183.8	1943	161.9	8.35
		XS		0.500	23.000	415	36.9	6.28	6.02	125.49	180.1	2550	212.5	8.31
	30			0.562	22.876	411	41.4	6.28	5.99	140.80	178.1	2840	237.0	8.29
				0.625	22.750	406	45.9	6.28	5.96	156.03	176.2	3140	261.4	8.27
	40			0.687	22.626	402	50.3	6.28	5.92	171.17	174.3	3420	285.2	8.25
				0.750	22.500	398	54.8	6.28	5.89	186.24	172.4	3710	309	8.22
				0.875	22.250	388.6	63.54	6.28	5.83	216	168.6	4256	354.7	8.18
	60			0.968	22.064	382	70.0	6.28	5.78	238.11	165.8	4650	388	8.15
	80			1.218	21.564	365	87.2	6.28	5.65	296.36	158.3	5670	473	8.07
	100			1.531	20.938	344	108.1	6.28	5.48	367.40	149.3	6850	571	7.96
	120			1.812	20.376	326	126.3	6.28	5.33	429.39	141.4	7830	652	7.87
	140			2.062	19.876	310	142.1	6.28	5.20	483.13	134.5	8630	719	7.79
	160			2.343	19.314	293	159.4	6.28	5.06	541.94	127.0	9460	788	7.70
26				0.250	25.500	510.7	19.85	6.81	6.68	67	221.4	1646	126.6	9.10
26.000	10			0.312	25.376	505.8	25.18	6.81	6.64	86	219.2	2076	159.7	9.08
		Std		0.375	25.250	500.7	30.19	6.81	6.61	103	217.1	2478	190.6	9.06
	20	XS		0.500	25.000	490.9	40.06	6.81	6.54	136	212.8	3259	250.7	9.02
				0.625	24.750	481.1	49.82	6.81	6.48	169	208.6	4013	308.7	8.98
				0.750	24.500	471.4	59.49	6.81	6.41	202	204.4	4744	364.9	8.93
				0.875	24.250	461.9	69.07	6.81	6.35	235	200.2	5458	419.9	8.89
				1.000	24.000	452.4	78.54	6.81	6.28	267	196.1	6149	473.0	8.85
				1.125	23.750	443.0	87.91	6.81	6.22	299	192.1	6813	524.1	8.80
28				0.250	27.500	594.0	21.80	7.33	7.20	74	257.3	2098	149.8	9.81
28.000	10			0.312	27.376	588.6	27.14	7.33	7.17	92	255.0	2601	185.8	9.79
		Std		0.375	27.250	583.2	32.54	7.33	7.13	111	252.6	3105	221.8	9.77
	20	XS		0.500	27.000	572.6	43.20	7.33	7.07	147	248.0	4085	291.8	9.72
	30			0.625	26.750	562.0	53.75	7.33	7.00	183	243.4	5038	359.8	9.68
				0.750	26.500	551.6	64.21	7.33	6.94	218	238.9	5964	426.0	9.64
				0.875	26.250	541.2	74.56	7.33	6.87	253	234.4	6865	490.3	9.60
				1.000	26.000	530.9	84.82	7.33	6.81	288	230.0	7740	552.8	9.55
				1.125	25.750	520.8	94.98	7.33	6.74	323	225.6	8590	613.6	9.51
30			5S	0.250	29.500	683.4	23.37	7.85	7.72	79	296.3	2585	172.3	10.52
30.000	10		10S	0.312	29.376	677.8	29.19	7.85	7.69	99	293.7	3201	213.4	10.50
		Std		0.375	29.250	672.0	34.90	7.85	7.66	119	291.2	3823	254.8	10.48
	20	XS		0.500	29.000	660.5	46.34	7.85	7.59	158	286.2	5033	335.5	10.43
	30			0.625	28.750	649.2	57.68	7.85	7.53	196	281.3	6213	414.2	10.39
	40			0.750	28.500	637.9	68.92	7.85	7.46	234	276.6	7371	491.4	10.34
				0.875	28.250	620.7	80.06	7.85	7.39	272	271.8	8494	466.2	40.30
				1.000	28.000	615.7	91.11	7.85	7.33	310	267.0	9591	639.4	10.26
				1.125	27.750	604.7	102.05	7.85	7.26	347	262.2	10653	710.2	10.22
32				0.250	31.500	779.2	24.93	8.38	8.25	85	337.8	3141	196.3	11.22
32.000	10			0.312	31.376	773.2	31.02	8.38	8.21	106	335.2	3891	243.2	11.20
		Std		0.375	31.250	766.9	37.25	8.38	8.18	127	332.5	4656	291.0	11.18
	20	XS		0.500	31.000	754.7	49.48	8.38	8.11	168	327.2	6140	383.8	11.14
	30			0.625	30.750	742.5	61.59	8.38	8.05	209	321.9	7578	473.6	11.09
	40			0.688	30.624	736.6	67.68	8.38	8.02	230	319.0	8298	518.6	11.07
				0.750	30.500	730.5	73.63	8.38	7.98	250	316.7	8990	561.9	11.05
				0.875	30.250	718.3	85.52	8.38	7.92	291	311.6	10372	648.2	11.01
				1.000	30.000	706.8	97.38	8.38	7.85	331	306.4	11680	730.0	10.95
				1.125	29.750	694.7	109.0	8.38	7.79	371	301.3	13023	814.0	10.92

NOTE: See footnotes at end of table.

Table 8.7.3 Properties of Commercial Steel Pipe (*Continued*)

Nominal pipe size, outside diameter, in	Schedule number*			Wall thick-ness, in	Inside diameter, in	Inside area, in^2	Metal area, in^2	Outside surface, ft^2/ft	Inside surface, ft^2/ft	Weight, lb/ft†	Weight of water, lb/ft	Moment of inertia, in^4	Section modulus, in^3	Radius of gyration, in
	a	b	c											
34				0.250	33.500	881.2	26.50	8.90	8.77	90	382.0	3773	221.9	11.93
34.000	10			0.312	33.376	874.9	32.99	8.90	8.74	112	379.3	4680	275.3	11.91
		Std		0.375	33.250	867.8	39.61	8.90	8.70	135	376.2	5597	329.2	11.89
	20	XS		0.500	33.000	855.3	52.62	8.90	8.64	179	370.8	7385	434.4	11.85
	30			0.625	32.750	841.9	65.53	8.90	8.57	223	365.0	9124	536.7	11.80
	40			0.688	32.624	835.9	72.00	8.90	8.54	245	362.1	9992	587.8	11.78
				0.750	32.500	829.3	78.34	8.90	8.51	266	359.5	10829	637.0	11.76
				0.875	32.250	816.4	91.01	8.90	8.44	310	354.1	12501	735.4	11.72
				1.000	32.000	804.2	103.67	8.90	8.38	353	348.6	14114	830.2	11.67
				1.125	31.750	791.3	116.13	8.90	8.31	395	343.2	15719	924.7	11.63
36				0.250	35.500	989.7	28.11	9.42	9.29	96	429.1	4491	249.5	12.64
36.000	10			0.312	35.376	982.2	34.95	9.42	9.26	119	426.1	5565	309.1	12.62
		Std		0.375	35.250	975.8	42.01	9.42	9.23	143	423.1	6664	370.2	12.59
	20	XS		0.500	35.000	962.1	55.76	9.42	9.16	190	417.1	8785	488.1	12.55
	30			0.625	34.750	948.3	69.50	9.42	9.10	236	411.1	10872	604.0	12.51
	40			0.750	34.500	934.7	83.01	9.42	9.03	282	405.3	12898	716.5	12.46
				0.875	34.250	920.6	96.50	9.42	8.97	328	399.4	14903	827.9	12.42
				1.000	34.000	907.9	109.96	9.42	8.90	374	393.6	16851	936.2	12.38
				1.125	33.750	894.2	123.19	9.42	8.89	419	387.9	18763	1042.4	12.34
42				0.250	41.500	1352.6	32.82	10.99	10.86	112	586.4	7126	339.3	14.73
42.000		Std		0.375	41.250	1336.3	49.08	10.99	10.80	167	579.3	10627	506.1	14.71
	20	XS		0.500	41.000	1320.2	65.18	10.99	10.73	222	572.3	14037	668.4	14.67
	30			0.625	40.750	1304.1	81.28	10.99	10.67	276	565.4	17373	827.3	14.62
	40			0.750	40.500	1288.2	97.23	10.99	10.60	330	558.4	20689	985.2	14.59
				1.000	40.000	1256.6	128.81	10.99	10.47	438	544.8	27080	1289.5	14.50
				1.250	39.500	1225.3	160.03	10.99	10.34	544	531.2	33233	1582.5	14.41
				1.500	39.000	1194.5	190.85	10.99	10.21	649	517.9	39181	1865.7	14.33

NOTE: The following formulas are used in the computation of the values shown in the table:

$$\begin{aligned}
&\text{Weight of pipe per foot (pounds)} &&= 10.6802t(D - t)\\
&\text{Weight of water per foot (pounds)} &&= 0.3405d^2\\
&\text{Square feet outside surface per foot} &&= 0.2618D\\
&\text{Square feet inside surface per foot} &&= 0.2618d\\
&\text{Inside area (square inches)} &&= 0.785d^2\\
&\text{Area of metal (square inches)} &&= 0.785(D^2 - d^2)\\
&\text{Moment of inertia (inches}^4\text{)} &&= 0.0491(D^4 - d^4)\\
& &&= A_m R_g^2\\
&\text{Section modulus (inches}^3\text{)} &&= \frac{0.0982(D^4 - d^4)}{D}\\
&\text{Radius of gyration (inches)} &&= 0.25\sqrt{D^2 + d^2}
\end{aligned}$$

where A_m = area of metal, in^2; d = inside diameter, in; D = outside diameter, in; R_g = radius of gyration, in; t = pipe wall thickness, in.

* Schedule numbers: Standard-weight pipe and schedule 40 are the same in all sizes through 10 in; from 12 in through 24 in, standard weight pipe has a wall thickness of ⅜ in. Extra-strong-weight pipe and schedule 80 are the same in all sizes through 8 in; from 8 in through 24 in, extra-strong-weight pipe has a wall thickness of ½ in. Double-extra-strong-weight pipe has no corresponding schedule number.

a: ANSI B36.10 steel pipe schedule numbers
b: ANSI B36.10 steel pipe nominal wall thickness designation
c: ANSI B36.19 stainless steel pipe schedule numbers

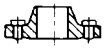
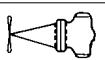
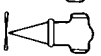
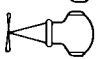
† The ferritic steels may be about 5% less and the austenitic stainless steels about 2% greater than the values shown in this table, which are based on weights for carbon steel.

Table 8.7.4 Weight of Standard Pipe Fittings and Materials, 3-in Size (3.500-in OD)

	Schedule no.	40	80	160	
	Wall designation	Std	XS		XXS
	Thickness, in	0.216	0.300	0.438	0.600
	Pipe, lb/ft	7.58	10.25	14.32	18.58
	Water, lb/ft	3.20	2.86	2.35	1.80
Welding fittings	L.R. 90° elbow	**4.6** 0.8	**6.1** 0.8	**8.4** 0.8	**10.7** 0.8
	S.R. 90° elbow	**3** 0.5	**4** 0.5		
	L.R. 45° elbow	**2.4** 0.3	**3.2** 0.3	**4.4** 0.3	**5.4** 0.3
	Tee	**7.4** 0.8	**9.5** 0.8	**12.2** 0.8	**14.8** 0.8
	Lateral	**13** 1.8	**19** 1.8		
	Reducer	**2.2** 0.3	**2.9** 0.3	**3.7** 0.3	**4.7** 0.3
	Cap	**1.4** 0.5	**1.8** 0.5	**3.5** 0.5	**3.7** 0.5

Temperature range, °F		100–199	200–299	300–399	400–499	500–599	600–699	700–799	800–899	900–999	1,000–1,099	1,100–1,200
Insulation												
85% magnesia calcium silicate	Nom. thick., in	1	1	1½	2	2	2½	3	3	3	3½	3½
	lb/ft	1.25	1.25	2.08	3.01	3.01	4.07	5.24	5.24	5.24	6.65	6.65
Combination	Nom. thick., in						2½	3	3	3	3½	3½
	lb/ft						5.07	6.94	6.94	6.94	9.17	9.17
*Asbestos fiber-sodium silicate	Nom. thick., in	1	1	1	1½	1½	2	2	3	3	3½	3½
	lb/ft	1.61	1.61	1.61	2.74	2.74	3.98	3.98	6.99	6.99	8.99	8.99

Table 8.7.4 Weight of Standard Pipe Fittings and Materials, 3-in Size (3.500-in OD) (*Continued*)

			Pressure rating, lb/in²								
			Cast iron		Steel						
			125	250	150	300	400	600	900	1,500	2,500
Flanges		Screwed or slip-on	**9** 1.5	**17** 1.5	**9** 1.5	**17** 1.5	**20** 1.5	**20** 1.5	**37** 1.5	**61** 1.5	**102** 1.5
		Welding neck			**11** 1.5	**19** 1.5	**27** 1.5	**27** 1.5	**38** 1.5	**61** 1.5	**113** 1.5
		Lap joint			**9** 1.5	**17** 1.5	**19** 1.5	**19** 1.5	**36** 1.5	**60** 1.5	**99** 1.5
		Blind	**10** 1.5	**19** 1.5	**10** 1.5	**20** 1.5	**24** 1.5	**24** 1.5	**38** 1.5	**61** 1.5	**105** 1.5
Flanged fittings		S.R. 90° elbow	**26** 3.9	**46** 4	**32** 3.9	**53** 4		**67** 4.1	**98** 4.3	**150** 4.6	
		L.R. 90° elbow	**30** 4.3	**50** 4.3	**40** 4.3	**63** 4.3					
		45° elbow	**22** 3.5	**41** 3.6	**28** 3.5	**46** 3.6		**60** 3.8	**93** 3.9	**135** 4	
		Tee	**39** 5.9	**67** 6	**52** 5.9	**81** 6		**102** 6.2	**151** 6.5	**238** 6.9	
Valves		Flanged bonnet gate	**66** 7	**112** 7.4	**70** 4	**125** 4.4		**155** 4.8	**260** 5	**410** 5.5	
		Flanged bonnet globe or angle	**56** 7.2	**121** 7.6	**60** 4.3	**95** 4.5		**155** 4.8	**225** 5	**495** 5.5	
		Flanged bonnet check	**46** 7.2	**100** 7.6	**60** 4.3	**70** 4.4		**120** 4.8	**150** 4.9	**440** 5.8	
		Pressure seal bonnet–gate							**208** 3	**235** 3.2	
		Pressure seal bonnet–globe							**135** 2.5	**180** 3	

NOTES: Boldface type is weight in pounds. Lightface type beneath weight is weight factor for insulation.

Insulation thicknesses and weights are based on average conditions and do not constitute a recommendation for specific thicknesses of materials. Insulation weights are based on 85% magnesia and hydrous calcium silicate at 11 lb/ft³. The listed thicknesses and weights of combination covering are the sums of the inner layer of diatomaceous earth at 21 lb/ft³ and the outer layer at 11 lb/ft³.

Insulation weights include allowances for wire, cement, canvas, bands and paint, but no special surface finishes.

To find the weight of covering on flanges, valves or fittings, multiply the weight factor by the weight per foot of covering used on straight pipe.

Valve weights are approximate. When possible, obtain weights from the manufacturer.

Cast-iron valve weights are for flanged end valves; steel weights for welding end valves.

All flanged fitting, flanged valve and flange weights include the proportional weight of bolts or studs to make up all joints.

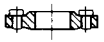
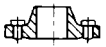
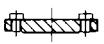
* 16 lb/ft³ density. (Existing installations only.)

Table 8.7.5 Weights of Standard Pipe Fittings and Materials, 4-in Size (4.500-in OD)

	Schedule no.	40	80	120	160	
	Wall designation	Std	XS			XXS
	Thickness, in	0.237	0.337	0.438	0.531	0.674
	Pipe, lb/ft	10.79	14.98	18.96	22.51	27.54
	Water, lb/ft	5.51	4.98	4.48	4.02	3.38
Welding fittings	L.R. 90° elbow	**8.7** 1	**11.9** 1		**17.6** 1	**21** 1
	S.R. 90° elbow	**5.8** 0.7	**7.9** 0.7			
	L.R. 45° elbow	**4.3** 0.4	**5.9** 0.4		**8.5** 0.4	**10.1** 0.4
	Tee	**12.6** 1	**16.4** 1		**23** 1	**27** 1
	Lateral	**21** 2.1	**33** 2.1			
	Reducer	**3.6** 0.3	**4.9** .3		**6.6** .3	**8.2** 0.3
	Cap	**2.6** 0.6	**3.4** 0.6		**6.5** 0.6	**6.7** 0.6

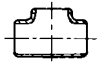
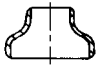
Temperature range, °F		100–199	200–299	300–399	400–499	500–599	600–699	700–799	800–899	900–999	1,000–1,099	1,100–1,200
Insulation												
85% magnesia calcium silicate	Nom. thick., in	1	1	1½	2	2½	2½	3	3	3½	3½	4
	lb/ft	1.62	1.62	2.55	3.61	4.66	4.66	6.07	6.07	7.48	7.48	9.10
Combination	Nom. thick., in						2½	3	3	3½	3½	3½
	lb/ft						6.07	8.30	8.30	10.6	10.6	10.6
Asbestos fiber-sodium silicate	Nom. thick., in	1	1	1	1½	1½	2	2	3	3	3½	3½
	lb/ft	2.04	2.04	2.04	3.28	3.28	4.70	4.70	8.29	8.29	10.25	10.25

Table 8.7.5 Weights of Standard Pipe Fittings and Materials, 4-in Size (4.500-in OD) (*Continued*)

			Pressure rating, lb/in²								
			Cast iron		Steel						
			125	250	150	300	400	600	900	1,500	2,500
Flanges		Screwed or slip-on	**16** 1.5	**26** 1.5	**15** 1.5	**26** 1.5	**32** 1.5	**43** 1.5	**66** 1.5	**90** 1.5	**158** 1.5
		Welding neck			**17** 1.5	**29** 1.5	**41** 1.5	**48** 1.5	**64** 1.5	**90** 1.5	**177** 1.5
		Lap joint			**15** 1.5	**26** 1.5	**31** 1.5	**42** 1.5	**64** 1.5	**92** 1.5	**153** 1.5
		Blind	**18** 1.5	**29** 1.5	**19** 1.5	**31** 1.5	**39** 1.5	**47** 1.5	**67** 1.5	**90** 1.5	**164** 1.5
Flanged fittings		S.R. 90° elbow	**45** 4.1	**72** 4.2	**59** 4.1	**85** 4.2	**99** 4.3	**128** 4.4	**185** 4.5	**254** 4.8	
		L.R. 90° elbow	**52** 4.5	**79** 4.5	**72** 4.5	**98** 4.5					
		45° elbow	**40** 3.7	**65** 3.8	**51** 3.7	**78** 3.8	**82** 3.9	**119** 4	**170** 4.1	**214** 4.2	
		Tee	**70** 6.1	**109** 6.2	**86** 6.1	**121** 6.3	**153** 6.4	**187** 6.6	**262** 6.8	**386** 7.2	
Valves		Flanged bonnet gate	**109** 7.2	**188** 7.5	**100** 4.2	**175** 4.5	**195** 5	**255** 5.1	**455** 5.4	**735** 6	
		Flanged bonnet globe or angle	**97** 7.4	**177** 7.8	**95** 4.3	**145** 4.8	**215** 5	**230** 5.1	**415** 5.5	**800** 6	
		Flanged bonnet check	**80** 7.4	**146** 7.8	**80** 4.3	**105** 4.5	**160** 4.8	**195** 5	**320** 5.6	**780** 6	
		Pressure seal bonnet–gate						**215** 2.8	**380** 3	**520** 4	
		Pressure seal bonnet–globe							**240** 2.7	**290** 3	

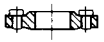
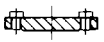
NOTE: See footnotes to Table 8.7.4.

Table 8.7.6 Weights of Standard Pipe Fittings and Materials, 8-in Size (8.625-in OD)

	Schedule no.	20	30	40	60	80	100	120	140		160	
	Wall designation			Std		XS				XXS		
	Thickness, in	0.250	0.277	0.322	0.406	0.500	0.598	0.718	0.812	0.875	0.906	
	Pipe, lb/ft	22.36	24.70	28.55	35.64	43.4	50.9	60.6	67.8	72.4	74.7	
	Water, lb/ft	22.48	22.18	21.69	20.79	19.8	18.8	17.6	16.7	16.1	15.8	
Welding fittings	 L.R. 90° elbow			**46** 2		**69** 2				**114** 2	**117** 2	
	 S.R. 90° elbow			**31** 1.3		**46** 1.3						
	 L.R. 45° elbow			**23** 0.8		**34** 0.8				**55** 0.8	**56** 0.8	
	 Tee			**54** 1.8		**76** 1.8				**118** 1.8	**120** 1.8	
	 Lateral			**76** 3.8		**140** 3.8						
	 Reducer			**13.9** 0.5		**20** 0.5				**32** 0.5	**33** 0.5	
	 Cap			**11.3** 1		**16.3** 1				**31** 1	**32** 1	

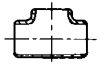
Temperature range, °F		100–199	200–299	300–399	400–499	500–599	600–699	700–799	800–899	900–999	1,000–1,099	1,100–1,200
Insulation	85% magnesia calcium silicate	Nom. thick., in	1½	1½	2	2	2½	3	3½	3½	4	4	4½
		lb/ft	4.13	4.13	5.64	5.64	7.85	9.48	11.5	11.5	13.8	13.8	16.0
	Combination	Nom. thick., in						3	3½	3½	4	4	4½
		lb/ft						12.9	16.2	16.2	20.4	20.4	23.8
	Asbestos fiber-sodium silicate	Nom. thick., in	1½	1½	1½	1½	1½	2½	2½	3½	3½	4½	4½
		lb/ft	5.38	5.38	5.38	5.38	5.38	10.60	10.60	15.85	15.85	20.85	20.85

Table 8.7.6 Weights of Standard Pipe Fittings and Materials, 8-in Size (8.625-in OD) (*Continued*)

			Pressure rating, lb/in²								
			Cast iron		Steel						
			125	250	150	300	400	600	900	1,500	2,500
Flanges		Screwed or slip-on	**34** 1.5	**64** 1.5	**33** 1.5	**67** 1.5	**82** 1.5	**135** 1.5	**207** 1.5	**319** 1.5	**601** 1.5
		Welding neck			**42** 1.5	**76** 1.5	**104** 1.5	**137** 1.5	**222** 1.5	**334** 1.5	**692** 1.5
		Lap joint	 1.5	 1.5	**33** 1.5	**67** 1.5	**79** 1.5	**132** 1.5	**223** 1.5	**347** 1.5	**587** 1.5
		Blind	**45** 1.5	**83** 1.5	**48** 1.5	**90** 1.5	**115** 1.5	**159** 1.5	**232** 1.5	**363** 1.5	**649** 1.5
Flanged fittings		S.R. 90° elbow	**117** 4.5	**201** 4.7	**157** 4.5	**238** 4.7	**310** 5	**435** 5.2	**639** 5.4	**995** 5.7	
		L.R. 90° elbow	**152** 5.3	**236** 5.3	**202** 5.3	**283** 5.3					
		45° elbow	**101** 3.9	**171** 4	**127** 3.9	**203** 4	**215** 4.1	**360** 4.4	**507** 4.5	**870** 4.8	
		Tee	**175** 6.8	**304** 7.1	**230** 6.8	**337** 7.1	**445** 7.5	**610** 7.8	**978** 8.1	**1,465** 8.6	
Valves		Flanged bonnet gate	**251** 7.5	**583** 8.1	**305** 4.5	**505** 5.1	**730** 6	**960** 6.3	**1,180** 6.6	**2,740** 7	
		Flanged bonnet globe or angle	**317** 8.4	**554** 8.6	**475** 5.4	**505** 5.5	**610** 5.9	**1,130** 6.3	**1,160** 6.3	**2,865** 7	
		Flanged bonnet check	**302** 8.4	**454** 8.6	**235** 5.2	**310** 5.3	**475** 5.6	**725** 6	**1,140** 6.4	**2,075** 7	
		Pressure seal bonnet–gate						**925** 4.5	**1,185** 4.7	**2,345** 5.5	
		Pressure seal bonnet–globe							**1,550** 4	**1,680** 5	

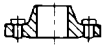
NOTE: See footnotes to Table 8.7.4.

Table 8.7.7 Weights of Standard Pipe Fittings and Materials, 12-in Size (12.750-in OD)

	Schedule no.	20	30		40		60	80	100	120	140	160
	Wall designation			Std		XS						
	Thickness, in	0.250	0.330	0.375	0.406	0.500	0.562	0.687	0.843	1.000	1.125	1.312
	Pipe, lb/ft	33.38	43.8	49.6	53.5	65.4	73.2	88.5	107.2	125.5	139.7	160.3
	Water, lb/ft	51.10	49.7	49.0	48.5	47.0	46.0	44.0	41.6	39.3	37.5	34.9
Welding fittings	 L.R. 90° elbow			**119** 3		**157** 3						**375** 3
	 S.R. 90° elbow			**80** 2		**104** 2						
	 L.R. 45° elbow			**60** 1.3		**78** 1.3						**181** 1.3
	 Tee			**132** 2.5		**167** 2.5						**360** 2.5
	 Lateral			**180** 5.4		**273** 5.4						
	 Reducer			**33** 0.7		**44** 0.7						**94** 0.7
	 Cap			**30** 1.5		**38** 1.5						**89** 1.5

	Temperature range, °F		100–199	200–299	300–399	400–499	500–599	600–699	700–799	800–899	900–999	1,000–1,099	1,100–1,200
Insulation	85% magnesia calcium silicate	Nom. thick., in	1½	1½	2	2½	3	3	3½	4	4	4½	4½
		lb/ft	6.04	6.04	8.13	10.5	12.7	12.7	15.1	17.9	17.9	20.4	20.4
	Combination	Nom. thick., in						3	3½	4	4	4½	4½
		lb/ft						17.7	21.9	26.7	26.7	31.1	31.1
	Asbestos fiber-sodium silicate	Nom. thick., in	1½	1½	1½	1½	1½	2½	2½	4	4	5	5
		lb/ft	5.22	5.22	5.22	5.22	5.22	14.20	14.20	24.64	24.64	32.40	32.40

Table 8.7.7 Weights of Standard Pipe Fittings and Materials, 12-in Size (12.750-in OD) (*Continued*)

			Pressure rating, lb/in²								
			Cast iron		Steel						
			125	250	150	300	400	600	900	1,500	2,500
Flanges		Screwed or slip-on	**71** 1.5	**137** 1.5	**72** 1.5	**140** 1.5	**164** 1.5	**261** 1.5	**388** 1.5	**820** 1.5	**1,611** 1.5
		Welding neck			**88** 1.5	**163** 1.5	**212** 1.5	**272** 1.5	**434** 1.5	**843** 1.5	**1,919** 1.5
		Lap joint			**72** 1.5	**164** 1.5	**187** 1.5	**286** 1.5	**433** 1.5	**902** 1.5	**1,573** 1.5
		Blind	**96** 1.5	**177** 1.5	**118** 1.5	**209** 1.5	**261** 1.5	**341** 1.5	**475** 1.5	**928** 1.5	**1,755** 1.5
Flanged fittings		S.R. 90° elbow	**265** 5	**453** 5.2	**345** 5	**509** 5.2	**669** 5.5	**815** 5.8	**1,474** 6.2		
		L.R. 90° elbow	**375** 6.2	**553** 6.2	**485** 6.2	**624** 6.2			**1,598** 6.2		
		45° elbow	**235** 4.3	**383** 4.3	**282** 4.3	**414** 4.3	**469** 4.5	**705** 4.7	**1,124** 4.8		
		Tee	**403** 7.5	**684** 7.8	**513** 7.5	**754** 7.8	**943** 8.3	**1,361** 8.7	**1,928** 9.3		
Valves		Flanged bonnet gate	**687** 7.8	**1,298** 8.5	**635** 4	**1,015** 5	**1,420** 5.5	**2,155** 7	**2,770** 7.2	**4,650** 8	
		Flanged bonnet globe or angle	**808** 9.4	**1,200** 9.5	**710** 5	**1,410** 5.5					
		Flanged bonnet check	**674** 9.4	**1,160** 9.5	**560** 6	**720** 6.5		**1,410** 7.2	**2,600** 8	**3,370** 8	
		Pressure seal bonnet–gate						**1,975** 5.5	**2,560** 6	**4,515** 7	
		Pressure seal bonnet–globe									

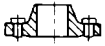
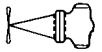
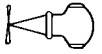
NOTE: See footnotes to Table 8.7.4.

Table 8.7.8 Weights of Standard Pipe Fittings and Materials, 24-in Size (24-in OD)

		Schedule no.	10	20		30	40	60	80	100	120	140	160
		Wall designation		Std	XS								
		Thickness, in	0.250	0.375	0.500	0.562	0.687	0.968	1.218	1.531	1.812	2.062	2.343
		Pipe, lb/ft	63.4	94.6	125.5	140.8	171.2	238.1	296.4	267.4	429.4	483.1	541.9
		Water, lb/ft	188.0	183.8	180.1	178.1	174.3	165.8	158.3	149.3	141.4	134.5	127.0
Welding fittings		L.R. 90° elbow		**458** 6	**606** 6								
		S.R. 90° elbow		**305** 3.7	**404** 3.7								
		L.R. 45° elbow		**229** 2.5	**302** 2.5								
		Tee		**445** 4.9	**563** 4.9								
		Lateral		**544** 10	**882** 10								
		Reducer		**167** 1.7	**220** 1.7								
		Cap		**102** 2.8	**134** 2.8								

Temperature range, °F			100–199	200–299	300–399	400–499	500–599	600–699	700–799	800–899	900–999	1,000–1,099	1,100–1,200
Insulation	85% magnesia calcium silicate	Nom. thick., in	1½	1½	2	2½	3	3	3½	4	4	4½	4½
		lb/ft	10.0	10.0	13.4	17.0	21.0	21.0	24.8	28.7	28.7	32.9	32.9
	Combination	Nom. thick., in						30	3½	4	4	4½	4½
		lb/ft						29.2	36.0	43.1	43.1	50.6	50.6
	Asbestos fiber-sodium silicate	Nom. thick., in	1½	1½	1½	2	2	3	3	4½	4½	5	5
		lb/ft	13.55	13.55	13.55	18.44	18.44	28.38	28.38	45.06	45.06	50.97	50.97

Table 8.7.8 Weights of Standard Pipe Fittings and Materials, 24-in Size (24-in OD) (*Continued*)

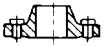
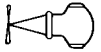
		Pressure rating, lb/in²								
		Cast iron		Steel						
		125	250	150	300	400	600	900	1,500	2,500
Flanges	 Screwed or slip-on	**255** 1.5		**245** 1.5	**577** 1.5	**676** 1.5	**1,056** 1.5	**1,823** 1.5	**3,378** 1.5	
	 Welding neck			**295** 1.5	**632** 1.5	**777** 1.5	**1,157** 1.5	**2,450** 1.5	**4,153** 1.5	
	 Lap joint			**295** 1.5	**617** 1.5	**752** 1.5	**1,046** 1.5	**2,002** 1.5	**3,478** 1.5	
	 Blind	**405** 1.5	**757** 1.5	**446** 1.5	**841** 1.5	**1,073** 1.5	**1,355** 1.5	**2,442** 1.5		
Flanged fittings	 S.R. 90° elbow	**1,231** 6.7	**2,014** 6.8	**1,671** 6.7	**2,174** 6.8	**2,474** 7.1	**3,506** 7.6	**6,155** 8.1		
	 L.R. 90° elbow	**1,711** 8.7	**2,644** 8.7	**1,821** 8.7	**2,874** 8.7					
	 45° elbow	**871** 4.8	**1,604** 5	**1,121** 4.8	**1,634** 5	**1,974** 5.1	**2,831** 5.5	**5,124** 6		
	 Tee	**1,836** 10	**3,061** 10.2	**2,276** 10	**3,161** 10.2	**3,811** 10.6	**5,184** 11.4	**9,387** 12.1		
Valves	 Flanged bonnet gate	**3,062** 8.5	**6,484** 9.8	**2,500** 5	**4,675** 7	**6,995** 8.7	**8,020** 9.5			
	 Flanged bonnet globe or angle									
	 Flanged bonnet check	**2,956** 12								
	 Pressure seal bonnet–gate									
	 Pressure seal bonnet–globe									

NOTE: See footnotes to Table 8.7.4.

Table 8.7.9 Weights of Standard Pipe Fittings and Materials, 36-in Size (36-in OD)

	Schedule no.	10		20	30	40							
	Wall designation		Std	XS									
	Thickness, in	0.312	0.375	0.500	0.625	0.750							
	Pipe, lb/ft	119.1	142.7	189.6	236.1	282.4							
	Water, lb/ft	425.9	422.6	416.6	411.0	405.1							
Welding fittings	 L.R. 90° elbow		**1,040** 12	**1,380** 12									
	 S.R. 90° elbow		**692** 5	**913** 5									
	 L.R. 45° elbow		**518** 4.8	**686** 4.8									
	 Tee		**1,294** 9.5	**1,610** 9.5									
	 Lateral												
	 Reducer		**340** 3.6	**360** 3.6									
	 Cap		**175** 6	**235** 6									
	Temperature range, °F		100–199	200–299	300–399	400–499	500–599	600–699	700–799	800–899	900–999	1,000–1,099	1,100–1,200
Insulation	85% magnesia calcium silicate	Nom. thick., in	1½	1½	2	2½	3	3½	4	4½	5	5	6
		lb/ft	14.2	14.2	19.2	24.2	29.5	34.8	40.3	45.9	51.7	51.7	63.5
	Combination	Nom. thick., in						3½	4½	5½	6	6½	7
		lb/ft						49.8	69.3	89.7	100.2	111.0	122.0
	Asbestos fiber-sodium silicate	Nom. thick., in	3	3	3	3	3	3	3	4½	4½	5	5
		lb/ft	40.84	40.84	40.84	40.84	40.84	40.84	40.84	55.83	55.83	71.48	71.48

Table 8.7.9 Weights of Standard Pipe Fittings and Materials, 36-in Size (36-in OD) (*Continued*)

			Pressure rating, lb/in^2								
			Cast iron		Steel						
			125	250	150	300	400	600	900	1,500	2,500
Flanges		Screwed or slip-on			**480** 1.5	**1,200** 1.5	**1,325** 1.5	**1,699** 1.5	**3,350** 1.5		
		Welding neck			**520** 1.5	**1,300** 1.5	**1,475** 1.5	**1,750** 1.5	**3,450** 1.5		
		Lap joint									
		Blind			**1,125** 1.5	**2,275** 1.5	**2,525** 1.5	**2,950** 1.5	**4,900** 1.5		
Flanged fittings		S.R. 90° elbow									
		L.R. 90° elbow									
		45° elbow									
		Tee									
Valves		Flanged bonnet gate									
		Flanged bonnet globe or angle									
		Flanged bonnet check									
		Pressure seal bonnet–gate									
		Pressure seal bonnet–globe									

NOTE: See footnotes to Table 8.7.4.

Table 8.7.10 Weight Tolerances of Steel Piping

Specification	Size	Tolerance, %	
ASTM A53	Std wt	+5	−5
	XS wt	+5	−5
ASTM A120	XXS wt	+10	−10
ASTM A106	Sch 10–120	+6.5	−3.5
	Sch 140–160	+10	−3.5
ASTM A335	12 in and under	+6.5	−3.5
	Over 12 in	+10	−5
ASTM A312 ASTM A376	12 in and under	+6.5	−3.5
API 5L	Std. wt Reg wt XS wt XXS wt	+10	−3.5
	Spec. plain end pipe	+10	−5

Seamless pressure tubing may be either hot-finished or cold-drawn. Cold-drawn steel tubing is frequently process-annealed at temperatures above 1,200°F. To ensure quality, maximum hardness values are frequently specified. For example, in ASME Specification SA192,* Specification for Seamless Carbon Steel Boiler Tubes for High-Pressure Service, the following maximum hardness values are given.

Boiler tubes	Brinell hardness no. (tubes 0.200 in and over in wall thickness)	Rockwell hardness no. (tubes less than 0.200 in in wall thickness)
Hot-finished tubes	137	B77
Cold-drawn (normalized) tubes	125	B72

Piping Fabrication Methods Commercial steel pipe is furnished most commonly as seamless pipe. Seamless pipe can be produced by (1) piercing, (2) hollow forging, and (3) forging, turning, and boring. Commercial pipe is also produced by welding involving (1) electric resistance welding, (2) electric fusion welding, or (3) submerged arc welding. Some mills are prepared to extrude small-diameter pipe and tubing in a variety of geometric shapes or to cast large-diameter steel pipe.

Electric-Fusion Welding Flat plate, known as **skelp,** is prepared in proper width and thickness for the desired pipe inside and outside diameters. It is then charged into an electric furnace and, when the proper welding temperature has been reached, is drawn through a funnel-shaped die so shaped that the plate is gradually formed into the shape of a tube, with the edges of the plate being forced squarely together and fused. The formed pipe then passes through a series of rolls in which it is sized or drawn to final dimensions.

Electric-Resistance Welding For pipes or tubes sized 4-in (10.2-cm) OD and under, strip is fed onto a set of forming rolls which consists of horizontal and vertical rollers so placed as to gradually form the flat strip into a tube. The tube form then passes to the welding electrodes. The electrodes are copper disks connected to the secondary of a revolving transformer assembly. The copper-disk electrodes make contact on each side of the seam of the tube form; a flow of current takes place across the seam, and temperature is raised to the welding point. Outside flash is removed by a cutting tool as the tube leaves the electrodes; inside flash is removed either by an air hammer or by passing a mandrel through the welded tube after the tube has been cooled.

Submerged-Arc Electric Welding This process is used for pipes from 24-in to 36-in (61.0- to 9.1.4-cm) OD. Flat plate is first pressed into a U and later into an O shape. The O shape is placed in an automatic welder and backed up on the inside by a water-cooled copper shoe. Two electrodes in close proximity are used. The electrodes are not in actual contact with the pipe. The current passes from one electrode through a granular flux and across the gap in the pipe to the second electrode. The high temperature of the arc heats the edges of the plate; a welding rod placed just over the seam is thereby melted and metal is deposited in the groove. After the outside weld has been made, the pipe is conveyed to an inside welder where a similar operation is carried on, except that no backup shoe is needed.

Seamless Tubing and Pipe A heated billet is brought into contact with tapered revolving rolls in such a way that the billet is pulled into the space allowed between the rolls. A piercing mandrel is placed in this space; the soft center of the billet makes it possible for the rolls to draw the billet over the mandrel, producing a hollow shell. When the billet has entirely passed over the mandrel, it is in the form of a thick-walled seamless tube. The heavy-walled tube is then passed to a rolling mill which reduces the tube to pipe of proper outside diameter and wall thickness.

The method of fabrication described above is limited as to diameter and thickness. For seamless alloy tubes and for heavy-wall carbon-steel tubes or pipe, a process known as **cupping and drawing** is frequently used. A circular flat plate of proper diameter and thickness is heated, placed in a hydraulic press, and pressed by a ram through a die. The cup so formed is reheated and pressed through a smaller die, thus elongating the cup so that it becomes a short cylinder with one closed end. This short cylinder is then placed in a horizontal drawbench, and with reheating as necessary, is pushed by a ram through dies of successively smaller diameters until the desired outer diameter is reached.

Forged, Turned, and Bored Tubing In this process, the ingot is heated and forged to a rough cylindrical shape, oversize in both diameter and length. The forging is then placed in a lathe and the outside turned down to the desired outer diameter. Rough ends are then removed so that the finally desired length is obtained. The cylinder is then placed in a boring mill, and the inside bored out until the desired wall

* Specifications for boiler tubes generally reference the ASME Standards such as SA178, SA192, SA210, etc.

Table 8.7.11 Diameter and Wall-Thickness Tolerances for Seamless Hot-finished Mechanical Tubing of Carbon and Alloy Steel (AISI)*

Specified size, OD, in	Ratio of wall thickness to OD	OD tolerance		Wall thicknesses tolerance, %							
				0.109 in and under		Over 0.109 to 0.172 in, incl.		Over 0.172 to 0.203 in, incl.		Over 0.203 in	
		Over	Under	Over	Under	Over	Under	Over	Under	Over	Under
Under 3	All wall thicknesses	0.023	0.023	16.5	16.5	15	15	14	14	12.5	12.5
3–5½, excl.	All wall thicknesses	0.031	0.031	16.5	16.5	15	15	14	14	12.5	12.5
5½–8 excl.	All wall thicknesses	0.047	0.047					14	14	12.5	12.5
8–10¾, incl	5% and over	0.047	0.047							12.5	12.5
8–10¾, incl.	Under 5%	0.063	0.063							12.5	12.5

* The common range of sizes of hot-finished tubes is 1½ to and including 10¾ in outside diameter with wall thickness not less than 0.095 in (no. 13 BWG) or 3% or more of the outside diameter. For sizes under 1½ or over 10¾ in outside diameter, the tolerances are commonly negotiated between the purchaser and producer.

SOURCE: AISI, ''Steel Products Manual.''

Table 8.7.12 Diameter and Wall-Thickness Tolerances for Seamless Cold-Worked Mechanical Tubing of Carbon and Alloy Steel (AISI)*

	Unannealed or finish-annealed				Soft annealed or normalized				Quenched and tempered				Wall thickness all conditions, %	
	OD, in		ID, in		OD, in		ID, in		OD, in		ID, in			
Size, OD, in	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under
3/16–1/2, excl.†‡	0.004	0			0.006	0.002			0.010	0.010			15	15
1/2–1 1/2, excl.†‡§¶	0.005	0	0	0.005	0.008	0.002	0.002	0.008	0.015	0.015	0.015	0.015	10	10
1 1/2–3 1/2, excl.†‡§¶	0.010	0	0	0.010	0.015	0.005	0.005	0.015	0.030	0.030	0.030	0.030	10	10
3 1/2–5 1/2, excl.§¶	0.015	0	0.005	0.015	0.023	0.007	0.015	0.025	0.045	0.045	0.045	0.045	10	10
5 1/2–8, excl.,¶ wall less than 5% OD	0.030	0.030	0.035	0.035	0.060	0.060	0.070	0.070					10	10
5 1/2–8, excl., wall from 5 to 7.5% OD	0.020	0.020	0.025	0.025	0.040	0.040	0.050	0.050					10	10
5 1/2–8, excl.,§ wall over 7.5% OD	0.030	0	0.015	0.030	0.045	0.015	0.037	0.053					10	10
8–10 3/4, incl.,¶ wall less than 5% OD	0.045	0.045	0.050	0.050									10	10
8–10 3/4, incl., wall from 5 to 75% OD	0.035	0.035	0.040	0.040									10	10
8–10 3/4, incl.,§ wall over 7.5% OD	0.045	0	0.015	0.040									10	10

* For tolerances closer than those indicated, availability, and applicable tolerances for tubing less than 3/16 in OD or larger than 10 3/4-in OD, the producer should be consulted.

† For those tubes with inside diameter less than 1/2 in (or less than 5/8 in when the wall thickness is more than 20% of the outside diameter), which are not commonly drawn over a mandrel. Note § is not applicable. Unless otherwise agreed upon by the purchaser and producer, the wall thickness may vary 15% over and under that specified, and the inside diameter is governed by the outside diameter and wall-thickness tolerances shown.

‡ For tubes with inside diameter less than 1/2 in (or less than 5/8 in when the wall thickness is more than 20% of the outside diameter), which can be produced by the rod or bar mandrel process, the tolerances are as shown in the above table except that the wall-thickness tolerances are 10% over and under the specified wall thickness.

§ Many tubes with inside diameter less than 50% of outside diameter, or with wall thickness more than 25% of outside diameter, or with wall thickness over 1 1/4 in, or weighing more than 90 lb/ft are difficult to draw over a mandrel. Unless otherwise agreed upon by the purchaser and producer the inside diameter may vary over or under by an amount equal to 10% of the wall thickness and the wall thickness may vary 12 1/2% over and under that specified.

¶ Tubing having a wall thickness less than 3% of the outside diameter cannot be straightened properly without a certain amount of distortion. Consequently, such tubes, while having an average outside diameter and inside diameter within the tolerances shown in the above table, require an ovality tolerance of 0.5% over and under nominal outside diameter, this being in addition to the tolerances indicated in the above table.

SOURCE: AISI, ''Steel Products Manual.''

Table 8.7.13 Finish Classifications Normally Recognized as Welded Mechanical Tubing

	Type	Condition
A	Flash-in, hot-rolled	Made by longitudinally forming and welding hot-rolled strip; the interior welding flash remains in place
B	Flash-in, cold-rolled	Made by longitudinally forming and welding cold-rolled strip; the interior flash remains in place
C	Flash controlled–0.010 in max, hot-rolled	Same as A, except that the interior flash is partially removed so that the height remaining does not exceed 0.010 in
D	Flash controlled–0.010 in max, cold-rolled	Same as C, except that cold-rolled strip has been used
E	Flash controlled–0.005 in max, hot-rolled	Same as C, except that flash height on tube inside does not exceed 0.005 in
F	Flash controlled–0.005 in max, cold-rolled	Same as E, except that cold-rolled strip has been used
G	Sink-drawn, hot-rolled	Tubing with flash controlled to 0.010 in max, which has been descaled and cold-drawn through a die to cold-finish the exterior surface
H	Sink-drawn, cold-rolled	Tubing with flash controlled to 0.010 in max, which has been cold-drawn through a die to cold-finish the exterior surface
I	Mandrel-drawn	Cold-rolled tubing with the interior flash removed and drawn through a die and over a mandrel to cold-finish the exterior and interior surfaces

thickness is secured. Because of the relatively high cost, this process is now rarely used.

Hollow-Forged Pipe and Tubing In this process, ingots are cast and their ends cropped; then they are placed in a furnace and heated to a specified temperature. The heated ingot is placed in a press where it is pierced. This hollow cylinder, open at one end, is then descaled and drawn over a mandrel on a horizontal drawbench. The closed end is then burned off, and the hollow forging is chemically descaled. Following this, the forging is straightened, placed in a lathe, and the outer diameter machined to a true dimension. The inside is dressed to remove scale, but no machining is done on the inside.

Carbon-steel piping is most frequently used as manufactured in accordance with ASTM Specifications A106 and A53 (or ASME Specifications SA106 and SA53). The chemical compositions of these two materials are identical except for the deoxidation practice which applies to the A106 pipe. Both are subjected to physical tests, but those for A106 are more rigorous. A53 and A106 are made in grades A and B; grade B has higher strength properties but is less ductile and, for this reason, grade A is permitted only for cold bending or close coiling. When carbon steel is intended for use in welded construction at temperatures in excess of 775°F (413°C), consideration should be given to the possibility of graphite formation.

Chromium-molybdenum steel has been used for temperatures up to 1,100°F (593°C). In the small diameters, the material is usually available in the seamless construction; because of the inability of the seamless mills to fabricate large-diameter and heavy-walled pipe, it may be necessary to resort to the more expensive hollow-forged or forged-and-bored piping for higher pressures and temperatures. The material for a high-temperature piping system should be selected after a careful review of technical and economic considerations; the following is intended only as being indicative of recent and current practice.

For temperatures up to 1,000°F, 1¼% Cr-½% Mo (A335, grade Pll) is used. For temperatures from 950 to 1050°F, 2¼% Cr-1% Mo (A335, P22) generally is used. Where there is a combination of high temperatures and erosive action, 5% Cr-½% Mo (A335, grade 5) or other more highly chromium-molybdenum or chromium stainless steels have been used.

Stainless-steel piping is available in a variety of compositions, most popular of which are ASTM A213, grade TP304 (16% Cr–8% Ni), and ASTM A213, grade TP316 (18% Cr–12% Ni and 3% Mo). For high-temperature service, type 34 stainless steels are used (18% Cr–8% Ni and stabilized with columbium). This material may be used up to 1,200°F (649°C); particular care must be given to choice of welding filler metal to avoid brittleness in the welds.

The permissible stress values for a large variety of piping materials at low and elevated temperatures are provided in Table 8.7.15.

PIPE FITTINGS

The various major piping materials are also produced in the form of standard fittings. Among the more widely used are wrought-steel fittings, welded-steel fittings, cast-steel fittings, cast-iron fittings, ductile-iron fittings, malleable-iron fittings, brass and copper fittings, aluminum fittings, etc. Other major nonferrous piping materials are also produced in the form of cast and wrought fittings.

Cast-iron, ductile-iron, and malleable-iron fittings are made by conventional founding methods for a variety of joints including bell-and-spigot, flanged, and mechanical (gland-type), or other proprietary joint designs.

Schedule Designations Over 100 years ago piping was designated as standard, extra-strong, and double extra-strong. There was no provision for thin-walled pipe, and no intervening standard thicknesses between the three schedules, which covered too great a spread to be economical without intermediate weights. Table 8.7.3 lists piping as a function of the schedule number which is given, approximately, by the following relationship: Schedule no. = 1,000 $P/(SE)$, where P is operating pressure, lb/in² gage, S is allowable stress, lb/in² (Table 8.7.15), and E is the quality factor (Tables 8.7.16 and 8.7.17).

Commercial sizes of steel pipe are known by their nominal inside diameter (ID) from ⅛ in (0.3175 cm) to 12 in (30.5 cm). Above 12-in ID, pipe is usually known by its outside diameter (OD). All classes of pipe of a given nominal size have the same OD, the extra thickness for different weights being on the inside.

Thickness of Pipe The following notes, covering power piping systems, have been abstracted from Part 2 of the Code for Power Piping (ASME B31.1).

For inspection purposes, the minimum thickness of pipe wall to be used for piping at different pressures and for temperatures not exceeding those for the various materials listed in Table 8.7.15 shall be determined by the formula

$$t_m = \frac{PD}{2(SE + Py)} + A \qquad (8.7.1)$$

where t_m = minimum pipe-wall thickness, in, allowable on inspection; P = maximum internal service pressure, lb/in² gage (plus water-

Table 8.7.14 Typical Mechanical Properties of Resistance-Welded Mechanical Carbon-Steel Tubing

Type	Yield strength, lb/in²	Tensile strength, lb/in²	Elongation, %	Hardness, Rockwell B
Flash-in or flash-controlled, hot-rolled	48,000	58,000	29	68
Flash-in or flash-controlled, cold-rolled	68,000	76,000	17	84
Normalized	34,000	52,000	39	61
Sink-drawn	73,000	76,000	20	84
Mandrel-drawn	80,000	83,000	15	86

Table 8.7.15 Basic Allowable Stresses in Tension for Metals

Material	Spec. no.	P no. (5)†	Grade	Notes	Min temp. (6)
Iron					
Centrifugally cast pipe	A 377			(8) (9) (48)	− 20
Castings					
Gray	A 48		20	(8) (9) (48)	− 20
Gray	A 48		25	(8) (9) (48)	− 20
Gray	A 48		30	(8) (9) (48)	− 20
Gray	A 48		35	(8) (9) (48)	− 20
Gray	A 48		40	(8) (9) (48)	− 20
Gray	A 48		45	(8) (9) (48)	− 20
Gray	A 48		50	(8) (9) (48)	− 20
Gray	A 48		55	(8) (9) (48)	− 20
Gray	A 48		60	(8) (9) (48)	− 20
Gray	A 278		70	(8) (9) (53)	− 20
Gray	A 278		80	(8) (9) (53)	− 20
Cupola malleable	A 197			(8) (9)	− 20
Malleable	A 47		32510	(8) (9)	− 20
Malleable	A 47		35018	(8) (9)	− 20
Ductile	A 395			(8) (9)	− 20
Ferritic ductile	A 395			(8) (9)	− 20
Austenitic ductile	A 571		Type D-2M	(9)	− 20

Materials	Spec. no.	P no. (5)	Grade	Notes	Min temp. (6)	SMTS, ksi	SMYS, ksi
Carbon steel							
Pipes and tubes							
	A 120	1		(8)	− 20		
A 285 gr. A	A 672	1	A45	(57) (59) (67)	− 20	45	24
	A53	1	Type F	(8)	− 20	45	25
Butt weld	API 5L	1	A25				
Smls & ERW	API 5L	1	A25	(57) (59)	− 20	45	25
	A 179	1		(57) (59)	− 20	47	26
	A 135	1	A	(57) (59)	− 20	48	30
A 285 gr. B	A 672	1	A50	(57) (59) (67)	− 20	50	27
A 285 gr. C	A 134	1		(8) (57)	− 20	55	30
A 285 gr. C	A 671	1	CA55	(59) (67)	− 20	55	30
A 516 gr. 60	A 671	1	CC60	(57) (67)	− 20	60	32
A 515 gr. 60	A 672	1	B60	(57) (67)	− 20	60	32
	A 135	1	B	(57) (59)	− 20	60	35
	A 53	1	B	(57) (59)	− 20		
	A 106	1	B	(57)	− 20	60	35
	A 139	1	D	(8)	− 20	60	46
(> ⅜ in thick)	A 381	SP3	Y48	(51)	− 20	62	48
(> ⅜ in thick)	A 381	SP3	Y50	(51)	− 20	64	50
A 515 gr. 65	A 672	1	B65	(57) (67)	− 20	65	35
(> ⅜ in thick)	A 381	SP3	Y52	(51)	− 20	66	52
(≤ ⅜ in thick)	A 381	SP3	Y48	(51)	− 20	67	48
A 516 gr. 70	A 671	1	CC70	(57) (67)	− 20	70	38
	A 106	1	C	(57)	− 20	70	40
(≤ ⅜ in thick)	A 381	SP3	Y52	(51)	− 20	72	52
A 299 (> 1 in thick)	A 672	1	N75	(57) (67)	− 20	75	40
A 299 (≤ 1 in thick)	A 672	1	N75	(57) (67)	− 20	75	42

NOTE: Footnotes appear at the end of the table.

SMTS,‡ ksi	SMYS,‡ ksi	Basic allowable stress *S*, ksi (1), at metal temperature, °F (7)						
		Min temp. to 100	200	300	400	500	600	650
		4.0	4.0	4.0	4.0			
20		2.0	2.0	2.0	2.0			
25		2.5	2.5	2.5	2.5			
30		3.0	3.0	3.0	3.0			
35		3.5	3.5	3.5	3.5			
40		4.0	4.0	4.0	4.0			
45		4.5	4.5	4.5	4.5			
50		5.0	5.0	5.0	5.0			
55		5.5	5.5	5.5	5.5			
60		6.0	6.0	6.0	6.0			
70		7.0	7.0	7.0	7.0	7.0	7.0	7.0
80		8.0	8.0	8.0	8.0	8.0	8.0	8.0
40	30	8.0	8.0	8.0	8.0	8.0	8.0	8.0
50	32	10.0	10.0	10.0	10.0	10.0	10.0	10.0
53	35	10.6	10.6	10.6	10.6	10.6	10.6	10.6
60	40	20.0	19.0	17.9	16.9	15.9	14.9	14.1
65	30	20.0						

Basic allowable stress *S*, ksi (1), at metal temperature, °F (7)															
Min temp. to 100	200	300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100
12.0	11.4														
15.0	14.6	14.2	13.7	13.0	11.8	11.6	11.5	10.3	9.0	7.8	6.5	4.5	2.5	1.6	1.0
15.0	15.0	14.5	13.8												
15.0	15.0	14.5	13.8												
15.7	15.0	14.2	13.5	12.8	12.1	11.8	11.5	10.6	9.2	7.9	6.5	4.5	2.5	1.6	1.0
16.0	16.0	16.0	16.0	16.0	14.8	14.5	14.4	10.7	9.3	7.9	6.5	4.5	2.5	1.6	1.0
16.7	16.4	16.0	15.4	14.6	13.3	13.1	13.0	11.2	9.6	8.1	6.5	4.5	2.5	1.6	1.0
18.3	18.3	17.7	17.2	16.2	14.8	14.5	14.4	12.0	10.2	8.3	6.5				
18.3	18.3	17.7	17.2	16.2	14.8	14.5	14.4	12.1	10.2	8.4	6.5	4.5	2.5	1.6	1.0
20.0	19.5	18.9	18.3	17.3	15.8	15.5	15.4	13.0	10.8	8.7	6.5	4.5	2.5		
20.0	19.5	18.9	18.3	17.3	15.8	15.5	15.4	13.0	10.8	8.7	6.5	4.5	2.5	1.6	1.0
20.0	20.0	20.0	20.0	18.9	17.3	17.0	16.5	13.0	10.8	8.7	6.5	4.5	2.5		
20.0	20.0	20.0	20.0	18.9	17.3	17.0	16.5	13.0	10.8	8.7	6.5	4.5	2.5	1.6	1.0
20.0	20.0	20.0													
20.6	19.7	18.7	17.8	16.9	16.0	15.5									
21.3	20.3	19.3	18.4	17.4	16.5	16.0									
21.7	21.3	20.7	20.0	18.9	17.3	17.0	16.8	13.9	11.4	9.0	6.5	4.5	2.5	1.6	1.0
22.0	21.0	19.9	18.9	17.9	17.0	16.5									
22.3	21.3	20.2	19.2	18.2	17.3	16.7									
23.3	23.1	22.5	21.7	20.5	18.7	18.4	18.3	14.8	12.0	9.3	6.5	4.5	2.5		
23.3	23.3	23.3	22.9	21.6	19.7	19.4	19.2	14.8	12.0						
24.0	22.9	21.7	20.7	19.6	18.6	18.0									
25.0	24.4	23.7	22.9	21.6	19.7	19.4	19.2	15.7	12.6	9.5	6.5	4.5	2.5	1.6	1.0
25.0	25.0	24.8	24.0	22.7	20.7	20.4	20.2								

Table 8.7.15 Basic Allowable Stresses in Tension for Metals (*Continued*)

Materials	Spec. no.	P no. (5)	Grade	Notes	Min temp. (6)	SMTS, ksi	SMYS, ksi
Carbon steel (*Cont.*)							
Pipes (structural grade)							
A 283 gr. A	A 134	1		(8)	−20	45	24
A 570 gr. 30	A 134	1		(8)	−20	49	30
A 283 gr. B	A 134	1		(8)	−20	50	27
A 570 gr. 33	A 134	1		(8)	−20	52	33
A 570 gr. 36	A 134	1		(8)	−20	53	36
A 570 gr. 40	A 134	1		(8)	−20	55	40
A 36	A 134	1		(8)	−20	58	36
A 570 gr. 45	A 134	1		(8)	−20	60	45
A 570 gr. 50	A 134	1		(8)	−20	65	50
Forgings and fittings							
	A 350	1	LF-1	(9) (57) (59)	−20	60	30
	A 105	1		(9) (57) (59)	−20	70	36
Castings							
	A 216	1	WCA	(9) (57)	−20	60	30
	A 352	1	LCB	(9) (57)	−50	65	35
	A 216	1	WCC	(9) (57)	−20	70	40

Material	Spec. no.	P no. (5)	Grade	Notes	Min temp. (6)
Low and intermediate alloy steel					
Pipes					
C–½Mo	A 335	3	P1	(58)	−20
½Cr–½Mo	A 691	3	½Cr	(11) (67)	−20
A 387 gr. 2 cl. 1					
1Cr–½Mo	A 691	4	1Cr	(11) (67)	−20
A 387 gr. 12 cl. 1					
1½Si–½Mo	A 335	3	P15		−20
7Cr–½Mo	A 426	5	CP7	(10)	−20
3Cr–Mo	A 426	5	CP21	(10)	−20
¾C–¾Ni–Cu–Al	A 333	4	4		−150
2Cr–½Mo	A 369	4	FP3b		−20
7Cr–½Mo	A 335	5	P7		−20
1¼Cr–½Mo	A 335	4	P11		−20
5Cr–½Mo	A 691	5	5Cr	(11) (67)	
A 387 gr. 5 cl. 1					
5Cr–½Mo–Si	A 335	5	P5b		−20
9Cr–1Mo	A 335	5	F9		−20
3Cr–1Mo	A 335	5	P21		−20
2¼Cr–1Mo	A 691	5	2¼Cr	(11) (67)	−20
A 387 gr. 22 cl. 1					
2¼Cr–1Mo	A 335	5	P22		−20
2Ni–1Cu	A 333	9A	9		−100
C–Mo A 204 gr. B	A 672	3	L65	(11) (58) (67)	−20
2¼Ni	A 333	9A	7		−100
3½Ni	A 333	9B	3		−150
2¼Ni A 203 gr. B	A 671	9A	CF70	(11) (65) (67)	−20
C–Mo A 204 gr. B	A 672	3	L70	(11) (58) (67)	−20
1¼Cr–½Mo	A 426	4	CP11	(10)	−20
C–Mo A 204 gr. C	A 672	3	L75	(11) (58) (67)	−20
12¾Cr	A 426	6	CPCA-15	(10)	−20
5Cr–½Mo	A 426	5	CP5	(10)	−20
9Ni	A 333	11A-SG1	8	(47)	−320
Forgings and fittings					
C–½Mo	A 234	3	WP1	(58)	−20
1Cr–½Mo	A 234	4	WP12		−20
1¼Cr–½Mo	A 234	4	WP11		−20

Basic allowable stress *S*, ksi (1), at metal temperature, °F (7)															
Min temp. to 100	200	300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100
13.7	13.0	12.4													
15.0	15.0	15.0	15.0												
15.3	14.4	13.9													
15.9	15.9	15.9	15.9												
16.3	16.3	16.3	16.3												
16.9	16.9	16.9	16.9												
17.6	16.8	16.8	16.8												
18.4	18.4	18.4	18.4												
19.9	19.9	19.9	19.9												
20.0	18.3	17.7	17.2	16.2	14.8	14.5	14.4	12.9	10.8	8.6	6.5	4.5	2.5	1.6	1.0
23.3	21.9	21.3	20.6	19.4	17.8	17.4	17.3	14.8	12.0	9.3	6.5	4.5	2.5	1.6	1.0
20.0	18.3	17.7	17.2	16.2	14.8	14.5	14.4	13.0	10.8	8.6	6.5	4.5	2.5	1.6	1.0
21.7	21.3	20.7	20.0	18.9	17.3	17.0	16.8	13.8	11.4	8.9	6.5	4.5	2.5	1.6	1.0
23.3	23.3	23.3	22.9	21.6	19.7	19.4	19.2	14.8	12.0	9.3	6.5	4.5	2.5		

		Basic allowable stress *S*, ksi (1), at metal temperature, °F (7)							
SMTS, ksi	SMYS ksi	Min temp. to 100	200	400	600	800	1,000	1,100	1,200
55	30	18.3	18.3	16.9	15.7	13.5	4.8		
55	33	18.5	18.3	18.3	17.3	13.8	5.9		
55	33	18.3	18.3	18.3	17.3	15.9	6.6	2.6	1.0
60	30	18.8	18.2	17.0	15.9	14.4	6.3	2.4	
60	30	18.8	17.9	16.2	14.5	12.5	5.0	2.5	1.2
60	30	18.8	18.1	16.8	15.5	13.9	7.0	4.0	1.5
60	35	20.0	19.1	17.3	15.5				
60	30	20.0	18.5	16.4	15.7	13.5	6.2	2.6	1.0
60	30	20.0	18.1	17.2	16.8	12.8	5.8	2.9	1.2
60	30	20.0	18.7	17.5	16.7	15.0	7.8	4.0	1.2
60	30	20.0	18.1	17.2	16.8	12.8	5.8	2.9	1.3
60	30	20.0	18.1	17.2	16.8	12.8	7.4	3.3	1.5
60	30	20.0	18.7	17.5	16.7	15.0	7.0	4.0	1.5
60	30	20.0	18.5	17.9	17.9	15.2	7.8	4.2	1.6
60	30	20.0	18.5	17.9	17.9	15.2	7.8	4.2	2.0
63	46	21.0							
65	37	21.7	21.7	20.7	19.3	15.8	4.8		
65	35	21.7	19.6	18.7	16.8	11.4	2.5	1.0	
65	35	21.7	19.6	18.7	16.8	11.4	2.5	1.0	
70	40	23.3							
70	40	23.3	23.3	22.5	20.9	17.5	4.8		
70	40	23.3	23.3	23.3	22.3	15.0	7.8	4.0	1.2
75	43	25.0	25.0	24.1	22.5	18.8	4.8		
90	65	30.0							
90	60	30.0	28.0	24.1	20.1	14.5	5.6	3.1	1.3
100	75	31.7	31.7						
55	30	18.3	18.3	16.9	15.7	13.5	4.8		
60	30	20.0	18.7	17.5	16.7	15.0	7.5	2.8	1.0
60	30	20.0	18.7	17.5	16.7	15.0	7.8	4.0	1.2

Table 8.7.15 Basic Allowable Stresses in Tension for Metals (*Continued*)

Material	Spec. no.	P no. (5)†	Grade	Notes	Min temp. (6)
Low and intermediate alloy steel (*Cont.*)					
Forgings and fittings (*Cont.*)					
5Cr–½Mo	A 234	5	WP5		−20
9Cr–½Mo	A 234	5	WP9		−20
3½Ni	A 350	9B	LF3	(9)	−150
C–½Mo	A 182	3	F1	(9) (58)	−20
½Cr–½Mo	A 182	3	F2	(9)	−20
1¼Cr–½Mo	A 182	4	F11	(9)	−20
5Cr–½Mo	A 182	5	F5	(9)	−20
13Cr	A 182	6	F6a Cl.1		−20
3Cr–1Mo	A 182	5	F21	(9)	−20
13Cr	A 182		F6a Cl.2		−20
5Cr–½Mo	A 182	5	F5a	(9)	−20
9Ni	A 420	11A-SG1	WPL8	(47)	−320
13Cr	A 182		F6a Cl.3		−20
13Cr–½Mo	A 182		F6b		
Castings					
C–½Mo	A 217	3	WC1	(9) (58)	−20
2½ Ni	A 352	9A	LC2	(9)	−100
Ni–Cr–1Mo	A 217	4	WC5	(9)	−20
2¼Cr–1Mo	A 217	5	WC9	(9)	−20
12Cr	A 217	6	CA15	(9) (35)	−20
5Cr–½Mo	A 217	5	C5	(9)	−20

Material	Spec. no.	P no. (5)	Grade	Notes	Min temp. (6)	SMTS, ksi	SMYS, ksi
Stainless steel (4) (40)							
Pipes and tubes							
18CR–8Ni pipe	A 312	8	TP304L		−425	70	25
Type 304L A 240	A 358	8	304L	(36)	−425		
16Cr–12Ni–2Mo pipe	A 312	8	TP316L		−325	70	25
23Cr–13Ni	A 451	8	CPH8	(26) (28) (35)	−325	65	28
18Cr–Ti tube	A 268	7	TP430TI	(35) (49)	−20	60	40
16Cr–8Ni–2Mo pipe	A 376	8	16–8–2H	(26) (31) (35)	−325	75	30
12Cr–Al tube	A 268	7	TP405	(35)	−20	60	30
16Cr tube	A 268	7	TP430	(35) (49)	−20	60	35
Type 310S A 240	A 358	8	310S	(28) (31) (35) (36)	−325	75	30
18Cr–10Ni–Ti	A 312	8	TP321	(28)	−325	75	30
Type 321 A 240	A 358	8	321	(28) (30) (36)	−325		
Type 309S A 240	A 358	8	309S	(28) (31) (35) (36)	−325	75	30
18Cr–8Ni	A 451	8	CPF8	(26) (28)	−425	70	30
Type 347 A 240	A 358	8	347	(28) (30) (36)	−425	75	30
Type 348 A 240	A 358	8	348	(28) (30) (36)	−325		
18 Cr–10Ni–Cb pipe	A 409	8	TP348	(28) (30) (36)	−325		
Type 310S A 240	A 358	8	310S	(28) (29) (31) (35) (36)	−325	75	30
18Cr–10Ni–Ti pipe	A 312	8	TP321H		−325	75	30
Type 316 A 240	A 358	8	316	(26) (28) (31) (36)	−325		
16Cr–12Ni–2Mo pipe	A 376	8	TP316	(26) (28) (31) (35)	−325	75	30
18Cr–13Ni–3Mo pipe	A 312	8	TP317	(26) (28)	−325		
16Cr–12Ni–2Mo pipe	A 430	8	FP316H	(26) (31) (36)	−325	70	30
16Cr–12Ni–2Mo pipe	A 312	8	TP316H	(26)	−325	75	30
18Cr–10Ni–Cb pipe	A 430	8	FP347H	(30) (36)	−325	70	30
18Cr–10Ni–Cb pipe	A 312	8	TP348H		−325	75	30
18Cr–8Ni pipe	A 430	8	FP304	(26) (31) (36)	−425	70	30
Type 304 A 240	A 358	8	304	(26) (28) (31) (36)	−425	75	30
						70	30
18Cr–8Ni pipe	A 312	8	TP304H	(26)	−325	75	30
18Cr–8Ni	A 452	8	TP304H	(26)	−325	75	30

SMTS, ksi	SMYS, ksi	Basic allowable stress *S*, ksi (1), at metal temperature, °F (7)							
		Min temp. to 100	200	400	600	800	1,000	1,100	1,200
60	30	20.0	18.1	17.2	16.8	12.8	5.8	2.9	1.3
60	30	20.0	18.1	17.2	16.8	12.8	7.4	3.3	1.5
70	37.5	23.3							
70	40	23.3	23.3	22.5	20.9	17.5	4.8		
70	40	23.3	23.3	22.5	20.9	17.5	5.9		
70	40	23.3	23.3	22.5	20.9	19.2	6.9	2.8	1.2
70	40	23.3	23.3	22.4	22.0	14.8	5.8	2.9	1.3
70	40								
75	45	25.0	25.0	24.1	23.8	22.5	6.8	3.2	1.3
85	55	28.3	28.3	27.2	26.1	23.2			
90	65	30.0	29.9	28.9	28.3	19.1	5.8	2.9	1.3
110	75	31.7	31.7						
110	85								
110–135	90								
65	35	21.7	21.5	19.7	18.3	15.8	4.8		
70	40	23.3	17.5	17.5	17.5				
70	40	23.3	23.3	22.5	20.9	17.5	6.9	2.8	
70	40	23.3	23.3	22.5	22.4	21.0	7.6	4.4	1.3
90	65	30.0	21.5	20.0	18.8	16.8	5.0	2.3	1.0
90	60	30.0	29.9	28.9	28.3	19.1	5.8	2.9	1.3

Basic allowable stress *S*, ksi (1), at metal temperature, °F (7)								
Min temp. to 100	200	400	600	800	1,000	1,200	1,400	1,500
16.7	16.7	15.8	14.0	13.0	7.8	3.2	1.1	0.9
16.7	16.7	15.5	13.5	12.4	11.2	6.4	1.8	1.0
18.7	18	18.7	18.0	16.3	10.4	3.7	1.3	0.8
20.0								
20.0								
20.0	18.4	17.4	16.8	11.1	4.0			
20.0	20.0	19.2	18.5	11.1	6.5	1.7		
20.0	20.0	20.0	19.2	17.5	11.0	2.5	0.4	0.2
20.0	20.0	18.6	16.4	15.5	13.8	3.6	0.8	0.3
20.0	20.0	20.0	19.2	17.5	10.5	3.8	1.3	0.7
20.0	20.0	17.5	15.7	14.8	10.8	4.4	1.3	0.8
20.0	20.0	20.0	19.3	18.3	14.0	4.4	1.2	0.8
20.0	20.0	20.0	19.2	17.5	11.0	6.0	1.6	0.8
20.0	20.0	18.6	16.4	15.5	14.0	5.4	1.9	1.1
20.0	20.0	19.3	17.0	15.9	15.3	7.4	2.3	1.3
20.0	20.0	19.3	17.0	15.9	15.3	7.4	2.3	1.3
20.0	20.0	19.2	18.3	18.2	18.0	7.9	2.5	1.3
20.0	20.0	20.0	19.3	18.3	18.0	7.9	2.5	1.3
20.0	20.0	18.7	16.4	15.2	13.8	6.0	2.3	1.4
20.0	20.0	18.7	16.4	15.2	13.8	6.0	2.3	1.4
20.0	20.0	18.7	16.5	15.1	13.8	6.0	2.2	1.4

Table 8.7.15 Basic Allowable Stresses in Tension for Metals (*Continued*)

Material	Spec. no.	P no. (5)	Grade	Notes	Min temp. (6)	SMTS, ksi	SMYS, ksi
Stainless steel (4) (40) (*Cont.*)							
Pipes and tubes (*Cont.*)							
18Cr–10Ni–Mo	A 451	8	CPF8M	(26) (28)	−425	70	30
27Cr tube	A 268	10E	TP446	(35)	−20	70	40
26Cr–3Ni–1Mo tube	A 268	10E	TP329	(35)	−20	90	70
Forgings and Fittings							
18Cr–8Ni	A 182	8	F304L	(9)	−425	65	25
16Cr–12Ni–2Mo	A 182	8	F316L	(9)	−325	65	25
20Ni–8Cr	A 182	8	F10	(9) (26) (28) (39)	−325	80	30
25Cr–20Ni	A 182	8	F310	(9) (28) (35) (39)	−425	75	30
18Cr–10Ni–Ti	A 182	8	F321	(9) (21) (28)	−325	75	30
25Cr–20Ni	A 182	8	F310	(9) (28) (29) (35) (39)	−425	75	30
18Cr–10Ni–Cb	A 182	8	F347	(9) (21) (28)	−425	75	30
18Cr–10Ni–Ti	A 182	8	F321H	(9) (21)	−325	75	30
16Cr–12Ni–2Mo	A 182	8	F316H	(9) (21) (26)	−325	75	30
18Cr–10Ni–Cb	A 182	8	F347H	(9) (21)	−325	75	30
16Cr–12Ni–2Mo	A 403	8	WP316	(26) (28) (31) (32) (37)	−325	75	30
18Cr–8Ni	A 182	8	F304	(9) (21) (26) (28)	−425	75	30
18Cr–8Ni	A 403	8	WP304H	(26) (31) (32) (37)	−325	75	30
Castings							
28Ni–20Cr–2Mo–3Cb	A 351	8	CN7M	(9) (30)	−325	62	25
35Ni–15Cr–Mo	A 351	8	HT30	(36) (39)	−325	65	28
15Cr–15Ni–2Mo–Cb	A 351	8	CF10MC	(9) (30)	−325	70	30
18Cr–8Ni	A 351	8	CF3	(9)	−425	70	30
18Cr–8Ni	A 351	8	CF8	(9) (26) (27) (31)	−425	70	30
25Cr–13Ni	A 351	8	CH10	(9) (27) (31) (35)	−325	70	30
18Cr–10Ni–2Mo	A 351	8	CF8M	(9) (26) (27) (30)	−425	70	30
25Cr–20Ni	A 351	8	HK40	(35) (36) (39)	−325	62	35
18Cr–8Ni	A 351	8	CF3A	(9) (26)	−425	70	35

Material	Spec. no.	P no. (5)	Grade	Class§	Notes	Size range, in	Min temp. (6)
Nickel and nickel alloy (4)							
Pipes and tubes							
Low C Ni	B 161	41	201 (N02201)	Ann.		>5 OD	−325
Ni	B 161	41	200 (N02200)	Ann.		>5 OD	−325
Ni–Cu	B 165	42	400 (N04400)	Ann.		>5 OD	−325
Ni–Cr–Fe	B 167	43	600 (N06600)	H.F. or H.F. Ann.		>5 OD	−325
Ni–Cu	B 165	42	400 (N04400)	Ann.		≤5 OD	−325
Ni–Cr–Fe	B 167	43	600 (N06600)	H.F. or H.F. Ann.		≤5 OD	−325
Ni–Fe–Cr	B 407	45	800 (N08800)	C.D. Ann.	(61)		−325
Ni–Cr–Fe–Mo–Cu	B 619	45	G1 (N06007)	Sol. Ann.			−325
Cr–Ni–Fe–Mo–Cu–Cb	B 464	45	20Cb (N08020)	Ann.			−325
Ni–Cr–Fe–Mo–Cu	B 622	45	G (N06007)	Sol. Ann.			−325
Ni–Cr–Mo–Fe	B 619		X (N06002)	Sol. Ann.			−325
Ni–Mo–Cr	B 619	44	C-276 (N10276)	Sol. Ann.			−325
Ni–Mo–Cr	B 622	44	C-276 (N10276)	Sol. Ann.			−325
Ni–Mo	B 619	44	B-2 (N10665)	Sol. Ann.			−325
Ni–Mo	B 619		B (N10001)	Sol. Ann.			−325
Ni–Cr–Mo–Cb	B 444	43	625 (N06625)	Ann.	(64)		−325
Ni–Mo	B 622	44	B-2 (N10655)	Sol. Ann.			−325
Forgings and fittings							
Low C Ni	B 160	41	201 (N02201)	Ann.	(9)	All	−325
Ni	B 160	41	200 (N02200)	H.F.	(9)	All	−325
Ni–Cu	B 164	42	400 (N04400)	Ann. Forg.	(9) (13)	All	−325
	B 366	43	WPNC1 (N06600)		(32)	All	−325

Basic allowable stress *S*, ksi (1), at metal temperature, °F (7)								
Min temp. to 100	200	400	600	800	1,000	1,200	1,400	1,500
20.0	20.0	19.4	17.1	15.5	15.4	6.8	2.3	1.4
23.3	23.3	20.4	18.4	16.2	4.5			
30.0								
16.7	16.7	15.8	14.0	13.0	7.8	3.2	1.1	0.9
16.7	16.7	15.5	13.5	12.4	11.2	6.4	1.8	1.0
20.0								
20.0	20.0	20.0	19.2	17.5	11.0	2.5	0.4	0.2
20.0	20.0	18.6	16.4	15.5	13.8	3.6	0.8	0.3
20.0	20.0	20.0	19.2	17.5	11.0	6.0	1.6	0.8
20.0	20.0	20.0	19.3	18.3	14.0	4.4	1.2	0.8
20.0	20.0	18.6	16.4	15.5	14.0	5.4	1.9	1.1
20.0	20.0	19.3	17.0	15.9	15.3	7.4	2.3	1.3
20.0	20.0	20.0	19.3	18.3	18.0	7.9	2.5	1.3
20.0	20.0	19.3	17.0	15.9	15.3	7.4	2.3	1.3
20.0	20.0	18.7	16.4	15.2	13.8	6.0	2.3	1.4
20.0	20.0	18.7	16.4	15.2	13.8	6.0	2.3	1.4
16.6								
18.6								
20.0								
20.0	20.0	17.6	15.6	14.7				
20.0	20.0	17.6	15.6	14.7	10.7	4.5	1.4	0.7
20.0	20.0	20.0	19.2	17.5	10.5	3.7	1.2	0.7
20.0	20.0	19.4	17.1	15.6	13.1	6.7	2.4	1.5
20.6								
23.2								

		Basic allowable stress *S*, ksi (1), at metal temperature, °F (7)								
SMTS, ksi	SMYS, ksi	Min temp. to 100	200	400	600	800	1,000	1,200	1,400	1,500
50	10	6.7	6.4	6.2	6.2	5.9	3.0	1.2		
55	12	8.0	8.0	8.0	8.0					
70	25	16.7	14.7	13.2	13.2	12.7				
75	25	16.7	16.7	16.7	16.7	16.7	7.0	2.0		
70	28	18.7	16.4	14.8	14.8	14.2				
80	30	20.0	20.0	20.0	20.0	20.0	7.0	2.0		
75	30	20.0	20.0	20.0	20.0	20.0	17.6	6.6	1.1	0.8
90	35	22.5	22.5	21.9	21.1	20.5	18.9			
85	35	23.3	21.3	20.6	20.3	19.2				
90	35	23.5	23.3	23.3	22.7	21.8				
100	40	26.6	24.1	22.9	21.1	19.8	18.6	11.3		
100	41	27.3	27.3	27.3	25.4	22.9	21.8			
100	41	27.5	27.3	27.3	25.4	23.0				
110	51	29.1	28.9	28.9	28.9	28.9				
100	45	30.0	30.0	30.0	30.0	27.6				
120	60	30.0	30.0	28.2	26.4	26.0	26.0	13.2		
110	51	34.2	34.0	34.0	34.0	34.0				
50	10	6.6	6.4	6.2	6.2	5.9	3.0	1.2		
60	15	10.0	10.0	10.0	8.3					
70	25	16.6	14.6	13.2	13.1	12.7				
75	25	16.7	16.7	16.7	16.7	16.7	7.0	2.0		

Table 8.7.15 Basic Allowable Stresses in Tension for Metals (*Continued*)

Material	Spec. no.	P no. (5)	Grade	Class§	Notes	Size range, in	Min temp. (6)
Nickel and nickel alloy (4) (*Cont.*)							
Forgings and fittings (*Cont.*)							
Ni–Cr–Fe	B 166	43	600 (N06600) WPHX	H.F.	(9) (13)	All	−325
Ni–Cr–Mo–Fe	B 366		(N06002)		(32)		−325
Castings							
Ni–Mo–Cr	A 494		CW-12M-1		(9) (44)		−325
Ni–Mo–Cr	A 494		CW-12M-2		(9) (44)		−325

Material	Spec. no.	P no. (5)	Grade	Notes	Min temp. (6)
Unalloyed titanium					
Pipes and tubes					
C.P.	B 337	51	1	(17)	−75
C.P.	B 337	51	2	(17)	−75
C.P.	B 337	52	3	(17)	−75

Material	Spec. no.	P no. (5) (46)	Class	Temper	Size range, in	Notes
Copper and copper alloy						
Pipes and tubes						
Cu tube	B 75	31	C10200, C12000, C12200, C14200	Annealed		(14)
Cu tube	B 88	31	C10200, C12000, C12200	Annealed		(14) (24)
Red brass	B 43	32	C23000	Annealed		(14)
Cu–Ni 90/10	B 467	34	C70600	Annealed	>4.5 OD	(14)
Cu–Ni 90/10	B 467	34	C70600	Annealed	≤4.5 OD	(14)
Cu–Ni 70/30	B 467	34	C71500	Annealed	>4.5 OD	(14)
Cu	B 42	31	C10200, C1200, C12200	Drawn	NPS 2½ thru 12	(14) (34)
Cu tube	B 88	31	C10200, C12000, C12200	Drawn		(14) (24) (34)
Cu–Ni 70/30	B 466	34	C71500	Annealed		(14)
Forgings						
Cu	B 283	a	C11000			(9) (14)
High Si bronze (A)	B 283	33	C65500			(9) (14)
Forging brass	B 283	a	C37700			(9) (14)
Leaded naval brass	B 283	a	C48500			(9) (14)
Naval brass	B 283	32	C46400			(9) (14)
Mn–bronze (A)	B 283	32	C67500			(9) (14)
Al–Si bronze	B 283	35	C63900			(9) (14)
Castings						
Composition bronze	B 62	a	C83600			(9)
Leaded Ni–bronze	B 584	a	C97600			(9)
Leaded Sn–bronze	B 584	a	C92200			(9)
Steam bronze	B 61	a	C92200			(9)
Sn–bronze	B 584	b	C90300			(9)
Leaded Mn–bronze	B 584	a	C86400			(9)
No. 1 Mn–bronze	B 584	b	C86500			(9)
Al–bronze	B 584	b	C95200			(9)
Si–Al–bronze	B 584	b	C95600			(9)

SMTS, ksi	SMYS, ksi	Basic allowable stress *S*, ksi (1), at metal temperature, °F (7)								
		Min temp. to 100	200	400	600	800	1,000	1,200	1,400	1,500
85	35	23.3	21.2	21.2	21.2	20.4	14.5	5.5		
95	35	23.3	23.3	22.9	21.1	19.8	19.3	11.3		
72	46	24.0	16.4	16.4	16.4					
72	46	24.0	16.4	16.4	16.4	15.5	14.6			

SMTS, ksi	SMYS, ksi	Basic allowable stress *S*, ksi (1), at metal temperature, °F (7)					
		Min temp. to 100	200	300	400	500	600
35	25	11.7	9.7	7.7	6.4	5.3	4.2
50	40	16.7	16.7	12.3	9.8	8.0	7.3
65	55	21.7	19.0	15.6	12.3	9.9	8.0

Min temp. (6)	Specified min strength, ksi		Basic allowable stress *S*, ksi (1), at metal temperature, °F (7)						
	Tensile	Yield	Min temp. to 100	200	300	400	500	600	700
−325	30	9	6.0	4.8	4.7	3.0	0.8		
−325	30	9	6.0	5.9	5.0	2.5	0.8		
−325	40	12	8.0	8.0	8.0	5.0			
−325	38	13	8.7	8.1	7.8	7.5	7.2	6.0	
−325	40	15	10.0	9.5	8.9	8.5	8.0	6.0	
−325	45	15	10.0	9.5	9.1	8.6	8.2	8.0	7.8
−325	36	30	12.0	9.0	8.7	8.2			
−325	36	30	12.0	8.7	8.0	2.5	0.8		
−325	50	18	12.0	11.3	10.8	10.3	9.9	9.6	9.4
−325	33	11	7.3	6.5	5.0	2.5	0.8		
−325	52	18	12.0	10.0	10.0	2.0			
−325	58	23	15.3	12.0	10.5	2.0			
−325	62	24	16.0	15.0	13.0	2.0			
−325	64	26	17.3	15.3	13.0	2.0			
−325	72	34	22.7	12.0	10.5	2.0			
−325	83	41	27.3	17.3	17.1	16.8			
−325	30	14	9.4	9.4	9.1	8.6			
−325	40	17	10.0	7.3	6.3				
−325	34	16	10.6	10.6	10.6	10.3			
−325	34	16	10.6	10.6	10.6	10.3	9.0		
−325	40	18	12.0	9.5	8.5	7.0			
−325	60	20	13.3	12.0	10.5				
−325	65	25	16.6	13.4	10.5				
−325	65	25	16.6	16.1	15.5	14.5	10.0		
−325	60	28	18.8						

Table 8.7.15 Basic Allowable Stresses in Tension for Metals (*Continued*)

Material	Spec. no.	P no. (5) (46)	Class	Temper	Size range, in	Notes
Copper and copper alloy (*Cont.*)						
Al–bronze	B 584	b	C95400			(9)
Mn–bronze	B 584	a	C86700			(9)
High-strength Mn–bronze	B 584	b	C86300			(9)

Material	Spec. no.	P no. (5)	Grade	Temper	Notes	Size or thickness limitations, in
Aluminum alloy						
Seamless pipes and tubes						
	B 210, B 241, B 345	21	1060	0, H112	(14) (33)	
	B 241	21	1100	0, H112	(14) (33)	
	B 210, B 241, B 345	21	3003	H18	(14) (33)	
	B 210, B 241, B 345	21	Alclad 3002	0, H112	(14) (33)	
	B 210	21	Alclad 3003	H18	(14) (33)	
	B 210, B 241	22	5052	0	(14)	
	B 210, B 241, B 345	25	5083	0, H112	(33)	
	B 210, B 241, B 345	25	5086	0, H112	(33)	
	B 210	25	5086	H34	(33)	
	B 210	22	5154	H34	(33)	
	B 241	22	5454	0, H112	(33)	
	B 210, B 241	25	5456	0, H112	(33)	
	B 241	22	5652	0, H112	(33)	
	B 210	23	6061	T4	(33)	
	B 241, B 345	23	6061	T4	(33) (63)	
	B 241, B 345	23	6061	T6	(33)	Pipe $<$ NPS 1
	B 241, B 345	23	6061	T6	(33) (63)	Pipe $\geq$ NPS 1 all tube
	B 241, B 345	23	6063	T4	(33)	$\leq$ 0.500
	B 241, B 345	23	6063	T5	(33)	$\leq$ 0.500
	B 241, B 345	23	6063	T6	(33)	
	B 210, B 241, B 345	23	6063	T4, T5, T6 Wld.		
Structural tubes						
	B 221	21	1100	0, H112	(14) (33)	
	B 221	21	3003	0, H112	(14) (33)	
	B 221	22	5052	0	(14)	
	B 221	25	5083	0		
	B 221	25	5086	0		
	B 221	22	5454	0		
	B 221	23	6061	T4	(33) (63)	
	B 221	23	6061	T4, T6 Wld.	(22) (63)	
	B 221	23	6063	T4	(33)	$\leq$ 0.500
	B 221	23	6063	T5	(33)	$\leq$ 0.500
	B 221	23	6063	T6	(33)	
	B 221	23	6063	T4, T5, T6 Wld.		
Forgings and fittings						
	B 247	25	5083	0, H112	(9) (33)	
	B 247	23	6061	T6	(9) (33) (45)	
	B 361	21	WP3003	0, H112	(13) (14) (23) (32) (33)	
	B 361	22	WP5154	0, H112	(14) (23) (32) (33)	
	B 361	23	WP6061	T4	(13) (14) (23) (32) (33)	
	B 361	23	WP6061	T4, T6 Wld.	(22) (23) (32)	
	B 361	23	WP6063	T4	(13) (14) (23) (32) (33)	
	B 361	23	WP6063	T4, T6 Wld.	(23) (32)	
Castings						
	B 26		443.0	F	(9) (43)	
	B 26		356.0	T6	(9) (43)	

SOURCE: Adapted from ASME B31.3-1984 with permission.

† Numbers in parentheses refer to notes at end of table. All specifications are ASTM unless noted otherwise.

‡ In the table, SMTS = standard minimum tensile stress, SMYS = standard minimum yield stress.

§ Abbreviations in class column: Ann. = annealed, C.D. = cold drawn, Forg. = forged, H.F. = hot-finished, H.R. = hot-rolled, Plt. = plate, R. = Rolled, Rel. = relieved, Sol. = solution, and Str. = stress.

Min temp. (6)	Specified min strength, ksi		Basic allowable stress *S*, ksi (1), at metal temperature, °F (7)						
	Tensile	Yield	Min temp. to 100	200	300	400	500	600	700
− 325	75	30	20.0	18.0	16.3	14.8	11.0		
− 325	80	32	21.3	15.3	10.5				
− 325	110	60	36.6	19.0	10.5				

Min temp. (6)	SMTS, ksi	SMYS, ksi	Basic allowable stress *S*, ksi (1), at metal temperature, °F (7)						
			Min temp. to 100	150	200	250	300	350	400
− 452	8.5	2	1.7	1.7	1.6	1.5	1.3	1.1	0.8
− 452	11	3	2.0	2.0	2.0	1.9	1.7	1.3	1.0
− 452	27	24	9.0	9.0	8.9	6.3	5.4	3.5	2.5
− 452	13.5	4.5	3.0	3.0	3.0	2.8	2.2	1.6	1.3
− 452	26	23	8.1	8.1	8.0	5.7	4.9	3.2	2.2
− 452	25	10	6.7	6.7	6.7	6.2	5.6	4.1	2.3
− 452	39	16	10.7	10.7					
− 452	35	14	9.3	9.3					
− 452	44	34	14.7	14.7					
− 452	39	29	13.0	13.0					
− 452	31	12	8.0	8.0	8.0	7.4	5.5	4.1	3.0
− 452	41	19	12.7	12.7					
− 452	25	10	6.7	6.7	6.7	6.2	5.6	4.1	2.3
− 452	30	16	10.0	10.0	10.0	9.8	9.2	7.9	5.6
− 452	26	16	8.7	8.7	8.7	8.5	8.0	7.9	5.6
− 452	42	35							
− 452	38	35	12.7	12.7	12.7	12.1	10.6	7.9	5.6
− 452	19	10	6.7	6.7	6.7	6.7	6.7	3.4	2.0
− 452	22	16	7.3	7.3	7.2	6.8	6.1	3.4	2.0
− 452	30	25	10.0	10.0	9.8	9.0	6.6	3.4	2.0
− 452	17		5.7	5.7	5.7	5.6	5.2	3.0	2.0
− 452	11	3	2.0	2.0	2.0	1.9	1.7	1.3	1.0
− 452	14	5	3.3	3.3	3.3	3.1	2.4	1.8	1.4
− 452	25	10	6.7	6.7	6.7	6.2	5.6	4.1	2.3
− 452	39	16	10.7	10.7					
− 452	35	14	9.3	9.3					
− 452	31	12	8.0	8.0	8.0	7.4	5.5	4.1	3.0
− 452	26	16	8.7	8.7	8.7	8.5	8.0	7.7	5.3
− 452	24		8.0	8.0	8.0	7.9	7.4	6.1	4.3
− 452	19	10	6.4	6.4	6.4	6.4	6.4	3.4	2.0
− 452	22	16	7.3	7.3	7.2	6.8	6.1	3.4	2.0
− 452	30	25	10.0	10.0	9.8	9.0	6.6	3.4	2.0
− 452	17		5.7	5.7	5.7	5.6	5.2	3.0	2.0
− 452	39	16	10.7	10.7					
− 452	38	35	12.7	12.7	12.7	12.1	10.6	7.9	5.6
− 452	14	5	3.3	3.3	3.3	3.1	2.4	1.8	1.4
− 452	30	11	7.3	7.3					
− 452	26	16	8.7	8.7	8.7	8.5	8.0	7.7	5.6
− 452	24		8.0	8.0	8.0	7.9	7.4	6.1	4.3
− 452	18	9	6.0	6.0	6.0	6.0	6.0	3.4	2.0
− 452	17		5.7	5.7	5.7	5.6	5.2	3.0	2.0
− 452	17	6	4.0	4.0	4.0	4.0	4.0	4.0	3.0
− 452	30	20	10.0	10.0	10.0	8.4			

Table 8.7.15 Basic Allowable Stresses in Tension for Metals (*Continued*)

NOTES: These notes are requirements of the Code. Those marked with an asterisk (*) restate requirements found in the text of the Code. The other notes are limitations or special requirements applicable to particular materials. At this time, metric equivalents have not been provided in the stress tables for metals. (P-number groupings, tables, and appendixes cited in these notes for Table 8.7.15 will be found in the basic reference ASME B31.3.)

(1)* The stress values in Table A-1 and the design stress values in Table A-2 are basic allowable stresses in tension in accordance with 302.3.1(a). For pressure design, the stress values from Table A-1 are multiplied by the appropriate quality factor E (E_c from Table A-1A, or E_j from Table A-1B). Stress values in shear and bearing are stated in 302.3.1(b); those in compression in 302.3.1(c).

(2)* The quality factors for castings E_c in Table A-1A are basic factors in accordance with 302.3.3(b). The quality factors for longitudinal weld joints E_j in Table A-1B are basic factors in accordance with 302.3.4(a). See 302.3.3(c) and 302.3.4(b) for enhancement of quality factors. See also 302.3.1(a), footnote 9.

(3)* This casting quality factor can be enhanced by supplementary examination in accordance with 302.3.3(c) and Table 302.3.3C. The higher factor from Table 302.3.3C may be substituted for this factor in pressure design equations.

(4)* In shaded areas, stress values printed in *italics* exceed two-thirds of the expected yield strength at temperature. All other stress values in shaded areas are equal to 90% of expected yield strength at temperature. See 302.3.2(d)(4) and 302.3.2(d) [Note (3)].

(5)* See 327.5.2 for description of P-number groupings.

(6)* The minimum temperature shown is that design minimum temperature for which the material is normally suitable without impact testing other than that required by the material specification. However, the use of a material at a design minimum temperature below − 20°F (− 29°C) is established by rules elsewhere in this Code, including any necessary impact test requirements.

(7)* A single bar (|) in these stress tables indicates there are conditions other than stress which affect usage above or below the temperature, as described in other referenced notes. A double bar (‖) after a tabled stress indicates that use of the material is prohibited above that temperature. A double bar (‖) before the stress value for ''Min. temp. to 100°F'' indicates that the use of the material is prohibited below the listed minimum temperature. At temperatures where there are no stress values, the material may be used in accordance with 323.2 unless prohibited by a double bar (‖).

(8)* There are restrictions on the use of this material in the text of the Code.

(9)* Pressure-temperature ratings of cast and forged parts as published in standards referenced in this Code section may be used for parts meeting requirements of these standards. Allowable stresses for castings and forgings, where listed, are for use in design of special components not furnished in accordance with such standards.

(10)* These casting quality factors are applicable only when proper supplementary examination has been specified (see 302.3.3).

(11) For use under this Code, radiography shall be performed after heat treatment.

(12)* Certain forms of this material, as stated in Table 323.2.2, must be impact-tested to qualify for service below − 20°F (− 29°C). Alternatively, if provisions for impact testing are included in the material specification as supplementary requirements and are invoked, the material may be used down to the temperature at which the test was conducted in accordance with the specification.

(13) Properties of this material vary with thickness or size. Stresses are based on minimum properties for the thickness listed.

(14) For use in Code piping at the stated stress values, the required minimum tensile and yield properties must be verified by tensile test at the mill. If such tests are not required by the material specification, they shall be specified in the purchase order.

(15) These stress values are established from a consideration of strength only and will be satisfactory for average service. For bolted joints where freedom from leakage over a long period of time without retightening is required, lower stress values may be necessary as determined from the flexibility of the flange and bolts and corresponding relaxation properties.

(16) This joint factor shall be applied to stress values in Table A-1 unless the longitudinal welded joint has been 100% radiographed as required by the specification for fabricated welds.

(17)* Filler metal shall not be used in the manufacture of this pipe or tube.

(18)* This specification does not include requirements for 100% radiographic inspection. If this higher joint factor is to be used, the material shall be purchased to the special requirements of Table 327.4.1A for longitudinal butt welds with 100% radiography in accordance with Table 302.3.4.

(19)* This specification includes requirements for random radiographic inspection for mill quality control. If the 0.90 joint factor is to be used, the welds shall meet the requirements of Table 327.4.1A for longitudinal butt welds with spot radiography in accordance with Table 302.3.4. This shall be a matter of special agreement between purchaser and manufacturer.

(20) For pipe sizes NPS 8 and larger and for wall thicknesses of Schedule 140 or heavier, the minimum specified tensile strength is 70.0 ksi (483 MPa).

(21) For material thickness greater than 5 in (125 mm), the minimum specified tensile strength shall be 70.0 ksi (483 MPa).

(22) The minimum tensile strength for weld (qualification) and stress values shown shall be multiplied by 0.90 for pipe having an outside diameter less than 2 in (51 mm) and a D/t value less than 15. This requirement may be waived if it can be shown that the welding procedure to be used will consistently produce welds that meet the listed minimum tensile strengths of 24.0 ksi (165 MPa).

(23) Stress values apply only to fittings made from seamless material conforming to ASTM B 210 or B 241. Otherwise, the value of factor E_j shall be selected from Table 302.3.4 for the appropriate construction.

(24) Yield strengths listed are not included in the material specifications. The value shown is based on yield strengths of materials with similar characteristics.

(26) These unstabilized grades of stainless steel have increasing tendency to intergranular carbide precipitation as the carbon content increases above 0.03%.

(27) For temperatures above 800°F (425°C), these stress values apply only when the carbon content is 0.04% or higher.

(28) For temperatures above 1,000°F (538°C), these stress values apply only when the carbon content is 0.04% or higher.

(29) The higher stress values at 1,050°F (566°C) and above for this material shall be used only when the steel has an austenitic micrograin size no. 6 or less (coarser grain) as defined in ASTM E 112. Otherwise, the lower stress values shall be used.

(30) For temperatures above 1,000°F (538°C), these stress values may be used only if the material has been heat-treated at a temperature of 2,000°F (1,090°C) minimum.

(31) For temperatures above 1,000°F (538°C), these stress values may be used only if the material has been heat-treated by heating to a minimum temperature of 1,000°F (1,040°C) and quenching in water or rapidly cooling by other means.

(32) Stress values shown are for the lowest-strength base material permitted by the specification to be used in the manufacture of this grade of fitting. If a higher strength base material is used, the higher stress values for that material may be used in design.

(33) For welded construction with work-hardened grades, use the stress values for annealed material; for welded construction with precipitation hardened grades, use the special stress values for welded construction given in the table.

(34) After use above the temperature indicated by a single bar (|), use at a lower temperature shall be based on the stress values allowed for the annealed condition of the material.

(35) These steels are intended for use at high temperatures; however, they may have low ductility and/or low impact properties at room temperature after being used above the temperature indicated by the single bar (|).

(36) The specification permits this material to be furnished without solution heat treatment or with other than a solution heat treatment. When the material has not been solution heat-treated, the minimum temperature shall be − 20°F (− 29°C) unless the material is impact tested per 323.3.

(37) Impact requirements for seamless fittings shall be governed by those listed in this table for the particular basic material specification in the grades permitted (A 312, A 240, and A 182). When A 276 materials are used in the manufacture of these fittings, the notes, minimum temperatures, and allowable stresses for comparable grades of A 240 materials shall apply.

(38) For use at temperatures below − 20°F through − 50°F (− 29°C through − 45°C), this material must be quenched and tempered.

(39) This material when used below − 20°F (− 29°C) requires impact testing if the carbon content is above 0.10%.

(40) The stress values for austenitic stainless steels in this table may not be applicable if the material has been given a final heat treatment other than that required by the material specification and any overriding requirements of this Code called for by note (30) or (31).

(41) Design stresses for the cold-drawn temper are based on hot-rolled properties until required data on cold-drawn are submitted.

(42) This is a product specification. No design stresses are necessary. Limitations on metal temperature for materials covered by this specification are:

	°F	°C		°F	°C
Grades 1 and 2	− 20 to 900	− 29 to 480	Grade 6	− 20 to 800	− 29 to 425
Grade 2H	− 50 to 1,100	− 45 to 595	Grade 8FA [see note (39)]	− 20 to 800	− 29 to 425
Grade 3	− 20 to 1,100	− 29 to 595	Grades 8MA and 8TA	− 325 to 1,500	− 198 to 815
Grade 4	− 150 to 1,100	− 100 to 595	Grades 8A and 8CA	− 425 to 1,500	− 254 to 815

(43)* The stress values given for this material are not applicable when either welding or thermal cutting is employed [see 323.4.2(c)].

(44) This material shall not be welded.

(45) Stress values shown are applicable for ''die'' forgings only.

(46) The letter ''a'' indicates alloys which are not recommended for welding and which, if welded, must be individually qualified. The letter ''b'' indicates copper-base alloys which must be individually qualified.

(47) If no welding is employed in fabrication of piping from these materials, the stress values may be increased to 33.3 ksi (230 MPa).

(48) The stress value to be used for this gray cast iron material at its upper temperature limit of 450°F (232°C) is the same as that shown in the 400°F (204°C) column.

(49) If the chemical composition of this grade is such as to render it hardenable, qualification under P no. 6 is required.

(50) This material is grouped in P no. 7 because its hardenability is low.

(51) Special P-numbers SP-1, SP-2, and SP-3 of carbon steels are not included in P no. 1 because of possible high-carbon, high-manganese combination which would require special consideration in qualification. Qualification of any high carbon, high manganese grade may be extended to other grades in its group.

(52) Copper-silicon alloys are not always suitable when exposed to certain media and high temperature, particularly above 212°F (100°C). The user should satisfy himself that the alloy selected is satisfactory for the service for which it is to be used.

(53) Stress relief heat treatment is required for service above 450°F (232°C).

Table 8.7.15 Basic Allowable Stresses in Tension for Metals (*Continued*)

(54) The maximum operating temperature is arbitrarily set at 500°F (260°C) because harder temper adversely affects design stress in the creep rupture temperature ranges.
(55) Pipe produced to this specification is not intended for high-temperature service. The stress values apply to either nonexpanded or cold-expanded material in the as-rolled, normalized, or normalized and tempered condition.
(56) Because of thermal instability, this material is not recommended for service above 800°F (425°C).
(57)* Conversion of carbides to graphite may occur after prolonged exposure to temperatures over 800°F (425°C) (see App. F).
(58)* Conversion of carbides to graphite may occur after prolonged exposure to temperatures over 875°F (468°C) (see App. F).
(59)* For temperatures above 900°F (480°C), consider the advantages of killed steel (see App. F).
(60) For all design temperatures, the maximum hardness shall be Rockwell C35 immediately under the thread roots. The hardness shall be taken on a flat area at least ⅛ in (3 mm) across, prepared by removing threads. No more material than necessary shall be removed to prepare the area. Hardness determination shall be made at the same frequency as tensile tests.
(61) Annealed at approximately 1,800°F (980°C).
(62) Annealed at approximately 2,000°F (1,150°C).
(63) For stress-relieved tempers (T351, T3510, T3511, T451, T4510, T4511, T651, T6510, T6511), stress values for material in the listed temper shall be used.
(64) The minimum tensile strength of the reduced section tensile specimen in accordance with QW-462.1 of BPV Code, Section IX, shall not be less than 110.0 ksi (758 MPa).
(65) The minimum temperature shown is for the heaviest wall permissible by the specification. The minimum temperature for lighter walls shall be as shown in the following tabulation:

Spec. and grade	Temp. for plate thicknesses shown					
	°F			°C		
	1 in max	2 in max	Over 2 to 3 in	25 mm max	50 mm max	Over 50 to 76 mm
A 203, A	−90	−90	−75	−68	−68	−60
A 203, B	−90	−90	−75	−68	−68	−60
A 203, D	−150	−150	−125	−101	−101	−87
A 203, E	−150	−150	−125	−101	−101	−87

(66) Stress values shown are 90% of those for the corresponding core material.
(67) For use under this Code, the heat treatment requirements for pipe manufactured to ASTM A 671, A 672, and A 691 shall be as required by 331 for the particular material being used. In some cases, 331 does not require heat treatment. In these cases, if the user requires no radiography, the designation shall be class 13. If 100% radiography is required, it shall be class 12. If heat treatment is required by the plate thickness or by the engineering design, the designation shall be class 23 (no radiography) or class 22 (100% radiography).
(68) The tension test specimen from plate 0.500 in (12.7 mm) and thicker is machined from the core and does not include the cladding alloy; therefore, the stress values listed are those for materials less than 0.500 in (12.7 mm).

Table 8.7.16 Basic Casting Quality Factors E_c
Abstracted from ASME B31.3 (1984) with permission

Spec. no.	Description	E_c (2)*	Notes*
Iron			
FS-WW-P421c	Centrifugally cast pipe	1.00	
A 377	Centrifugally cast pipe	1.00	
A 47	Malleable iron castings	1.00	
A 48	Gray iron castings	1.00	
A 126	Gray iron castings	1.00	
A 197	Cupola malleable iron castings	1.00	
A 278	Gray iron castings	1.00	
A 338	Malleable iron castings	1.00	
A 395	Ductile and ferritic ductile iron castings	0.80	(3)
A 571	Austenitic ductile iron castings	0.80	(3)
Carbon steel			
A 216	Carbon steel castings	0.80	(3)
A 352	Ferritic steel castings	0.80	(3)
Low and intermediate alloy steel			
A 426	Centrifugally cast pipe	1.00	(10)
A 217	Martensitic stainless and alloy castings	0.80	(3)
A 352	Ferritic steel castings	0.80	(3)
Stainless steel			
A 451	Centrifugally cast pipe	0.90	(3) (10)
A 452	Centrifugally cast pipe	0.85	(3)
A 351	Austenitic steel castings	0.80	(3)
Copper and copper alloy			
B 61	Steam bronze castings	0.80	(3)
B 62	Composition bronze castings	0.80	(3)
B 148	Al–bronze and Si–Al–bronze castings	0.80	(3)
B 584	Copper alloy castings	0.80	(3)
Nickel and nickel alloy			
A 494	Nickel and nickel alloy castings	0.80	(3)
Aluminum alloy			
B 26, temper F	Aluminum alloy castings	1.00	(10)
B 26, temper T6, T71	Aluminum alloy castings	0.80	(3)

* See Notes at end of Table 8.7.15.

Table 8.7.17 Basic Quality Factors for Longitudinal Weld Joints in Pipes, Tubes, and Fittings, E_j

Spec. no.	Class material	Description	E_j (2)*	Notes*
Carbon steel				
API 5L		Seamless	1.00	
		Electric resistance welded	0.85	
		Electric fusion welded, double butt, straight or spiral	0.85	
		Furnace butt welded	0.60	
A 53	Type S	Seamless	1.00	
	Type E	Electric resistance welded	0.85	
	Type F	Furnace butt welded	0.60	
A 105		Forgings and fittings	1.00	
A 106		Seamless	1.00	
A 120		Seamless	1.00	
		Electric resistance welded	0.85	
		Furnace butt welded	0.60	
A 134		Electric fusion welded, single butt, straight or spiral	0.80	
A 135		Electric resistance welded	0.85	
A 139		Electric fusion welded, straight or spiral	0.80	
A 179		Seamless	1.00	
A 181		Forgings and fittings	1.00	
A 211		Spiral welded	0.75	
A 234		Seamless and welded fittings	1.00	
A 333		Seamless	1.00	
		Electric resistance welded	0.85	
A 334		Seamless	1.00	
A 350		Forgings and fittings	1.00	
A 369		Seamless	1.00	
A 381		Electric fusion welded, 100% radiograph	1.00	(18)
		Electric fusion welded, spot radiograph	0.90	(19)
		Electric fusion welded, as manufactured	0.85	
A 420		Welded fittings, 100% radiograph	1.00	
A 524		Seamless	1.00	
A 587		Electric resistance welded	0.85	
A 671	12, 22	Electric fusion welded, 100% radiograph	1.00	
	13, 23	Electric fusion welded, double butt	0.85	

Table 8.7.17 Basic Quality Factors for Longitudinal Weld Joints in Pipes, Tubes, and Fittings, E_j (*Continued*)

Spec. no.	Class material	Description	E_j (2)*	Notes*
A 672	12, 22	Electric fusion welded, 100% radiograph	1.00	
	13, 23	Electric fusion welded, double butt	0.85	
A 691	12, 22	Electric fusion welded, 100% radiograph	1.00	
	13, 23	Electric fusion welded, double butt	0.85	
Low and intermediate alloy steel				
A 182		Forgings and fittings	1.00	
A 234		Seamless and welded fittings	1.00	
A 333		Seamless	1.00	
		Electric resistance welded	0.85	
A 334		Seamless	1.00	
A 335		Seamless	1.00	
A 350		Forgings and fittings	1.00	
A 369		Seamless	1.00	
A 420		Welded fittings, 100% radiograph	1.00	
A 671	12, 22	Electric fusion welded, 100% radiograph	1.00	
	13, 23	Electric fusion welded, double butt	0.85	
A 672	12, 22	Electric fusion welded, 100% radiograph	1.00	
	13, 23	Electric fusion welded, double butt	0.85	
A 691	12, 22	Electric fusion welded, 100% radiograph	1.00	
	13, 23	Electric fusion welded, double butt	0.85	
Stainless steel				
A 182		Forgings and fittings	1.00	
A 268		Seamless	1.00	
		Electric fusion welded, double butt	0.85	
		Electric fusion welded, single butt	0.80	
A 269		Seamless	1.00	
		Electric fusion welded, double butt	0.85	
		Electric fusion welded, single butt	0.80	
A 312		Seamless	1.00	
		Electric fusion welded, double butt	0.85	
		Electric fusion welded, single butt	0.80	
A 358	1, 3, 4	Electric fusion welded, 100% radiograph	1.00	
	5	Electric fusion welded, spot radiograph	0.90	
	2	Electric fusion welded, double butt	0.85	
A 376		Seamless	1.00	
A 403		Seamless fitting	1.00	
		Welded fitting, 100% radiograph	1.00	(16)
		Welded fitting, double butt	0.85	
		Welded fitting, single butt	0.80	
A 409		Electric fusion welded, double butt	0.85	
		Electric fusion welded, single butt	0.80	
A 430		Seamless	1.00	
Copper and copper alloy				
B 42		Seamless	1.00	
B 43		Seamless	1.00	
B 68		Seamless	1.00	
B 75		Seamless	1.00	
B 88		Seamless	1.00	
B 466		Seamless	1.00	
B 467		Electric resistance welded	0.85	
		Electric fusion welded, double butt	0.85	(16)
		Electric fusion welded, single butt	0.80	(16)
Nickel and nickel alloy				
B 160		Forgings and fittings	1.00	
B 161		Seamless	1.00	
B 164		Forgings and fittings	1.00	
B 165		Seamless	1.00	
B 166		Forgings and fittings	1.00	
B 167		Seamless	1.00	
B 366		Seamless and welded fittings	1.00	(16)
B 407		Seamless	1.00	
B 444		Seamless	1.00	
B 619		Electric resistance welded	0.85	
		Electric fusion welded, double butt	0.85	
		Electric fusion welded, single butt	0.80	
Unalloyed titanium				
B 337		Seamless	1.00	
		Electric fusion welded, double butt	0.85	
Aluminum alloy				
B 210		Seamless	1.00	
B 241		Seamless	1.00	
B 247		Forgings and fittings	1.00	
B 345		Seamless	1.00	
B 361		Seamless fittings	1.00	

* See Notes at end of Table 8.7.15.
SOURCE: Abstracted from ASME B31.3 (1984) with permission

hammer allowance in case of cast-iron conveying liquids); D = OD of pipe, in; S = maximum allowable stress in material due to internal pressure, lb/in^2; E = quality factor, y = a coefficient, values for which are listed in Table 8.7.18; A = allowance for threading, mechanical strength, and corrosion, in, with values of A listed in Table 8.7.19.

The thickness of ductile-iron pipe conveying liquid may be taken from Table 8.7.24, using the pressure class next higher than the maximum internal service pressure in pounds per square inch. Where

Table 8.7.18 Values of *y*
(Interpolate for intermediate values) (ASME B31.1)

	Temp, °F (°C)					
	900 (482) and below	950 (510)	1,000 (538)	1,050 (566)	1,100 (593)	1,150 (621) and above
Ferritic steels	0.4	0.5	0.7	0.7	0.7	0.7
Austenitic steels	0.4	0.4	0.4	0.4	0.5	0.7

Table 8.7.19 Values of *A*
(ASME B31.1)

Type of pipe	*A*, in
Cast-iron pipe, centrifugally cast	0.14
Cast-iron, pit-cast	0.18
Threaded-steel, wrought-iron, or nonferrous pipe:	
⅜ in and smaller	0.05
½ in and larger	Depth of thread
Grooved-steel, wrought-iron or nonferrous pipe	Depth of groove
Plain-end steel, wrought-iron or tube:	
1 in and smaller	0.05
1¼ in and larger	0.065
Plain-end nonferrous pipe or tube	0.000

ductile-iron pipe is used for steam service, the thickness should be calculated by Eq. (8.7.1).

Plain-end pipe includes pipe joined by flared compression couplings, lapped joints, and by welding, i.e., by any method that does not reduce the wall thickness of the pipe at the joint.

Physical and Chemical Properties of Pipes, Tubes, etc. The design of piping for operation above 750°F (399°C) presents many problems not encountered at lower temperatures. For the properties of steel applicable to high-temperature service (as well as to ordinary service) for pipes, tubes, fittings, bolting material, etc., see Sec. 6. For a discussion of creep properties, see Sec. 5.

Piping of thickness designed in accordance with Eq. (8.7.1) may be used for any combination of pressure and temperature for which S and E values are listed in Tables 8.7.15 to 8.7.17. The following summarizes piping industry practice.

Steam Pressures above 250 lb/in² (1,724 kPa), and Not above 2,500 lb/in² (17,238 kPa), Temperatures Not above 1,100°F (593°C) For pressures in excess of 100 lb/in² (690 kPa), the pipe may be seamless steel (A106), (A312), (A335), or (A376); or electric-fusion-welded steel (A691); or forged-and-bored steel (A369); or automatic-welded steel (A312). For pressures between 250 and 600 lb/in² (9,224 and 22,137 N/m²) the pipe may be seamless steel (A106) or (A53); electric-fusion-welded steel (A155); electric-resistance-welded steel (A135) or (A53). For pressures of 250 lb/in² (1,724 kPa) and lower and for service up to 750°F (399°C), any of the following may be used: electric-fusion-welded steel (A134) or (A139); electric-resistance-welded steel (A135); seamless or welded steel (A53). Grade A seamless pipe (A106) or (A53); or grade A electric-welded pipe (A53), (A135), or (A139) is used for close coiling or cold bending. Pipe permissible for services specified may be used for temperatures higher than 750°F (399°C), unless otherwise prohibited, if the S and E values of Tables 8.7.15 to 8.7.17 are used when calculating the required wall thickness.

Because of several failures in seam-welded 1¼% Cr–½% Mo or 2¼% Cr–1% Mo piping produced to ASTM Specification A155 operating at temperatures above 950°F, a preference has developed for seamless piping in these applications. Nevertheless, in general, seam-welded piping has provided entirely satisfactory service in high-temperature applications above 950°F.

Valves and fittings must have flange openings or welded ends, and valves must have external stem threads. Valves must be of cast or forged steel or may be fabricated from plate and pipe. Valves of nonferrous materials are generally cast or forged. Forged and cast-steel threaded valves and fittings may be used up to 300 lb/in² and 500°F for 3 (2) [1½] in pipe, and pressure from 250 to 400 (400 to 600) [600 to 2,500] lb/in². Malleable-iron threaded fittings (300 lb/in²) may be used for pressures not greater than 300 lb/in² and temperatures not over 500°F. Valves 8 in and larger should have the bypass of at least ¾ in, commercial size.* Welded fittings may be used of the same material and thickness as the pipe to which they are to be connected.

Steam Pressures from 125 to 250 lb/in² (862 to 1,724 kPa), Temperature Not above 450°F (232°C) Pipe may be electric-fusion-welded steel (A134 or A139). Copper and brass may be used if the temperature does not exceed 406°F. Cast iron may also be used. For close coiling or cold bending, grade A seamless steel (A53); or grade A electric-welded steel (A53), (A135), or (A139) is suitable. Pipe permissible for this service may be used for temperatures above 450°F (232°C) if the proper S and E are used in calculating the pipe-wall thickness.

Valves below 3 in may have inside stem screws. Stop valves 8 in and over must be bypassed. Bodies, bonnets, and yokes are of cast iron, malleable iron, steel, bronze, brass, or Monel. Flanged-steel fittings must conform to the class 300 ANSI Standard B16.5; if of cast iron, to the class 250 ANSI Standard B16.1; or, for threaded fittings, to the ANSI Standard B16.4. Malleable-iron threaded fittings must conform to the class 300 ANSI B16.3 standard, except that the class 150 ANSI Standard B16.3 may be used for pressures not greater than 150 lb/in². Welded fittings may be used.

Steam Pressures from 25 to 125 lb/in² (172 to 802 kPa) Temperatures Not above 450°F Pipe may be of steel, ductile iron, copper, or brass; valve bodies of cast iron, malleable iron, ductile iron, steel, or brass. Fittings are of class 125 or class 150 American Standard cast iron with screwed or flanged ends, or of ductile or malleable iron with screwed ends.

Steam Pressures 25 lb/in² (172 kPa) and Less, Temperature up to 450°F Pipe may be of steel, brass, copper, or cast iron. Flanged fittings conform to the class 25 ANSI Standard B16.1. Screwed fittings are of the class 125 ANSI Standard B16.4 or of the class 150 ANSI Standard B16.3 for malleable iron, or conform to B16.15 for cast bronze. Welded-steel fittings are extensively used.

Pipe coils are made from any of the commercial sizes of iron, steel, brass, and copper pipe and tubing. Limiting center-to-center dimensions, to which pipe coils can be fabricated in sizes ¾ to 2 in, are given in Table 8.7.20. Steel tubing cannot be bent to the absolute limits of brass or copper.

Table 8.7.20 Center-to-Center Dimensions of Pipe Coils

Nominal pipe size, in	Recommended and advisable minimum, in	
	Schedule 40	Schedule 80
¾	3½	2½
1	4	3
1¼	5	4
1½	6	5
2	8	6

Seamless mechanical tubing is obtainable in outside diameters ranging from ¼ to 10¾ in and in wall thickness from 20 gage to 2 in (0.091 to 5.08 cm). Oval, square, rectangular, and other special shapes can be obtained in various sizes and wall thicknesses. Mechanical tubing is available either hot-finished or cold-drawn, but is furnished principally cold-drawn. It is readily adaptable to varied treatment by expansion, cupping, tapering, swaging, flanging, coiling, welding, and similar manipulations. Typical of the many uses are aircraft tubing, automobile axle housings, driveshafts, drive-shaft housings, tie rods, steering columns, piston rods and pins, gear rings, roller-bearing cases and cones, cylinders for various purposes, machine parts, sleeves, bushings, spacers, surgical instruments, and hypodermic needles. Table 8.7.21 lists weights and dimensions of round seamless-steel tubing for sizes that have by common usage become standard. Detailed information on mechanical tubing for any particular applications can be obtained from manufacturers.

Dimensions and weights of **condenser** and **heat-exchanger tubes** are given in Table 8.7.22 and of **boiler** tubes in Table 8.7.23.

Spiral Pipe Spiral pipe is strong lightweight steel pipe with a single continuous welded helical seam from end to end stiffening it throughout. It is listed in sizes 6- to 42-in ID (15.24- to 106.7-cm), in various thicknesses, and in lengths up to 40 ft (12.19 m). It is used for high- and low-pressure water lines, vacuum lines, exhaust-steam lines, low-pressure air lines, sand and gravel slurry conveying and similar services. It is also used extensively by the petroleum industry, for oil and gas lines, for low-pressure steam lines, etc.

Spiral pipe may be asphalt-coated or galvanized. The pipe is designed for special joints, flanges, and lightweight fittings, but the ANSI flanges and fittings can be furnished, if desired.

The **sleeve-type coupling** illustrated in Fig. 8.7.1 is particularly suitable for plain-end pipe and is widely used. A gasket is used to make a tight joint. Advantages of this coupling are low cost, the use of unskilled labor in making the connections, and the fact that small changes in alignment and grade can be made with regular straight lengths of pipe by a movement in the coupling. This type of coupling is used extensively in long oil lines.

* See Manufacturers Standardization Society SP-45 for recommended size of bypass valves.

Table 8.7.21 Approx Weight of Round Seamless Cold-Finished Carbon-Steel Mechanical Tubing, lb/ft*
(Carbon 0.25% max. Standard sizes for warehouse stocks random lengths. United States Steel Corporation)

Wall thickness		OD, in																	
in	g or in	⅜	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2	2⅛	2¼	2⅜	2½
0.035	20 g	0.127	0.174	0.221	0.267	0.314	0.361	0.407	0.454	—	0.548								
0.049	18 g	0.171	0.236	0.301	0.367	0.432	0.498	0.563	0.629	0.694	0.759	0.825	0.890	—	1.02				
0.058	17 g	—	0.274	0.351	0.429	—	0.584												
0.065	16 g	0.215	0.302	0.389	0.476	0.562	0.649	0.736	0.823	0.909	0.996	1.08	1.17	1.26	1.34	1.43	1.52	1.60	1.69
0.083	14 g	—	0.370	0.480	0.591	0.702	0.813	0.924	1.03	1.15	1.26	—	—	—	1.70				
0.095	13 g	—	0.411	0.538	0.665	0.791	0.918	1.05	1.17	1.30	1.43	1.55	1.68	1.81	1.93	2.06	2.19	2.31	2.44
0.109	12 g	—	0.455	0.601	0.746	0.892	1.04	1.18	1.33	—	1.62								
0.120	11 g	—	0.487	0.647	0.807	0.968	1.13	1.29	1.45	1.61	1.77	1.93	2.09	2.25	2.41	2.57	2.73	2.89	3.05
0.134	10 g	—	—	0.703	0.882	—	1.24	1.42	1.60	1.78	1.96	2.13	2.31	—	2.67				
0.156	5/32	—	—	0.781	0.990	1.20	1.41	1.61	1.82	2.03	2.24	2.45	2.66	2.86	3.07	3.28	3.49	3.70	3.91
0.188	3/16	—	—	—	1.13	1.38	1.63	1.88	2.13	2.38	2.63	2.89	3.14	3.39	3.64	3.89	4.14	4.39	4.64
0.219	7/32	—	—	—	—	1.53	1.83	2.12	2.41	2.70	3.00	3.29	3.58	3.87	4.17	4.46	4.75	5.04	5.34
0.250	¼	—	—	—	1.34	1.67	2.00	2.34	2.67	3.00	3.34	3.67	4.01	4.34	4.67	5.01	5.34	5.67	6.01
0.281	9/32	—	—	—	—	—	—	—	2.91	—	3.66	4.03	4.41	4.78	5.16	—	5.91	6.28	6.66
0.313	5/16	—	—	—	—	—	—	—	3.13	3.55	3.97	4.39	4.80	5.22	5.64	6.06	6.48	6.89	7.31
0.375	⅜	—	—	—	—	—	—	—	3.50	4.01	4.51	5.01	5.51	6.01	6.51	7.01	7.51	8.01	8.51
0.438	7/16	—	—	—	—	—	—	—	—	—	4.97	5.53	6.14	6.72	7.31	7.89	8.48	9.06	9.65
0.500	½	—	—	—	—	—	—	—	—	—	5.34	6.01	6.68	7.34	8.01	8.68	9.35	10.0	10.7
0.625	⅝	—	—	—	—	—	—	—	—	—	—	—	—	—	9.18	—	10.8	11.7	12.5

* Other standard sizes, in certain standard wall thicknesses, vary by ⅛-in increments for 2½ to 3½ in; by ¼-in increments from 3½ to 7½ in; ½-in increments from 7½ to 10½ in OD. There are also standard sizes for every 1/16 in from ⅜ to 1⅜ in OD.

To obtain weights in kg/m, multiply tabular values shown by 1.42.

Table 8.7.22 Steel Condenser and Heat-Exchanger Tubes
(Dimensions and weights. United States Steel Corporation)

		Avg wall			Min wall		
OD, in	Thickness, in	ID, in	Area of metal, in²*	Weight per ft, lb†	ID, in	Area of metal, in²*	Weight per ft, lb†
½	0.035	0.430	0.0511	0.1738	0.423	0.0558	0.1898
	0.050	0.400	0.0707	0.2403	0.390	0.0769	0.2614
	0.065	0.370	0.0888	0.3020	0.357	0.0963	0.3272
⅝	0.035	0.555	0.0649	0.2205	0.548	0.0709	0.2412
	0.050	0.525	0.0903	0.3071	0.515	0.0985	0.3348
	0.065	0.495	0.1144	0.3888	0.482	0.1243	0.4227
	0.085	0.455	0.1442	0.4902	0.438	0.1561	0.5308
¾	0.050	0.650	0.1100	0.3738	0.640	0.1201	0.4082
	0.065	0.620	0.1399	0.4755	0.607	0.1524	0.5181
	0.085	0.580	0.1776	0.6037	0.563	0.1928	0.6556
	0.095	0.560	0.1955	0.6646	0.541	0.2119	0.7204
⅞	0.050	0.775	0.1296	0.4406	0.765	0.1417	0.4817
	0.065	0.745	0.1654	0.5623	0.732	0.1805	0.6136
	0.085	0.705	0.2110	0.7172	0.688	0.2296	0.7804
	0.095	0.685	0.2328	0.7914	0.666	0.2530	0.8599
1	0.050	0.900	0.1492	0.5073	0.890	0.1633	0.5551
	0.065	0.870	0.1909	0.6491	0.857	0.2086	0.7090
	0.085	0.830	0.2443	0.8306	0.813	0.2663	0.9052
	0.095	0.810	0.2701	0.9182	0.791	0.2940	0.9994
1¼	0.050	1.150	0.1885	0.6408	1.140	0.2065	0.7020
	0.065	1.120	0.2420	0.8226	1.107	0.2647	0.8999
	0.085	1.080	0.3111	1.058	1.163	0.3397	1.155
	0.095	1.060	0.3447	1.172	1.041	0.3761	1.278
	0.105	1.040	0.3777	1.284	1.019	0.4117	1.399
1½	0.050	1.400	0.2278	0.7743	1.390	0.2497	0.8488
	0.065	1.370	0.2930	0.9962	1.357	0.3209	1.091
	0.085	1.330	0.3779	1.285	1.313	0.4053	1.378
	0.095	1.310	0.4193	1.426	1.291	0.4581	1.557
	0.105	1.290	0.4602	1.564	1.269	0.5024	1.708
1¾	0.065	1.620	0.3441	1.170	1.606	0.3803	1.293
	0.085	1.580	0.4446	1.512	1.561	0.4907	1.668
	0.095	1.560	0.4939	1.679	1.539	0.5448	1.852
	0.105	1.540	0.5426	1.845	1.517	0.5902	2.007
	0.120	1.510	0.6145	2.089	1.484	0.6766	2.300
2	0.065	1.870	0.3951	1.343	1.856	0.4370	1.486
	0.085	1.830	0.5114	1.738	1.811	0.5649	1.920
	0.095	1.810	0.5685	1.933	1.789	0.6275	2.133
	0.105	1.790	0.6251	2.125	1.767	0.6896	2.344
	0.120	1.760	0.7087	2.409	1.734	0.7812	2.656

* Multiply values shown by 0.0645 to obtain areas in cm².
† Multiply values shown by 1.42 to obtain weights in kg/m.

Table 8.7.23 Seamless-Steel Boiler Tubes

Outside diam, in	Thickness BWG	Thickness in	Mfg.* wt, lb/ft	Outside diam, in	Thickness BWG	Thickness in	Mfg.* wt, lb/ft	Outside diam, in	Thickness BWG	Thickness in	Mfg.* wt, lb/ft
1	13	0.095	1.037	2½	12	0.109	3.171	4½	10	0.134	7.103
	12	0.109	1.168		11	0.120	3.457		9	0.148	7.817
	11	0.120	1.263		10	0.134	3.835		8	0.165	8.702
	10	0.134	1.384		9	0.148	4.207		7	0.180	9.447
1¼	13	0.095	1.323	2¾	12	0.109	3.504	5	9	0.148	8.720
	12	0.109	1.502		11	0.120	3.823		8	0.165	9.711
	11	0.120	1.628		10	0.134	4.244		7	0.180	10.550
	10	0.134	1.793		9	0.148	4.658		6	0.203	11.810
1½	13	0.095	1.619	3	12	0.109	3.838	5½	9	0.148	9.622
	12	0.109	1.836		11	0.120	4.189		8	0.165	10.720
	11	0.120	1.994		10	0.134	4.652		7	0.180	11.650
	10	0.134	2.201		9	0.148	5.110		6	0.203	13.050
1¾	13	0.095	1.910	3¼	11	0.120	4.555	6	7	0.180	12.750
	12	0.109	2.169		10	0.134	5.061		6	0.203	14.290
	11	0.120	2.360		9	0.148	5.061		5	0.220	15.410
	10	0.134	2.610		8	0.165	6.179		4	0.238	16.640
2	13	0.095	2.201	3½	11	0.120	4.921				
	12	0.109	2.503		10	0.134	5.469				
	11	0.120	2.726		9	0.148	6.012				
	10	0.034	3.018		8	0.065	6.683				
2¼	13	0.095	2.492	4	10	0.134	6.286				
	12	0.109	2.837		9	0.148	6.915				
	11	0.120	3.092		8	0.165	7.693				
	10	0.134	3.427		7	0.180	8.347				

* Multiply values shown by 1.42 to obtain weights in kg/m.
SOURCE: United States Steel Corporation.

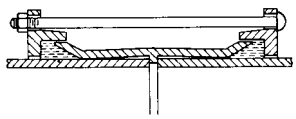


Fig. 8.7.1 Sleeve type, plain end coupling.

CAST-IRON AND DUCTILE-IRON PIPE

Cast-iron pipe was extensively produced since before the turn of the century until approximately 1960. Even though cast-iron pipe generally has given excellent service, the manufacture of cast-iron pipe was discontinued at that time.

Since then, **ductile-iron pipe** has replaced cast-iron pipe because of its improved ductility. Ductile-iron pipe is now extensively utilized for water, gas, sewage, culverts, drains, etc. It is produced in a wide range of sizes for varying pressures. Ductile-iron pipe is particularly adaptable to underground and submerged service because of its comparatively superior corrosion resistance compared to steel pipe. Nevertheless, steel pipe, when properly coated and wrapped, can also provide adequate resistance to corrosion when placed in certain soils.

Pipe fittings are available as cast-iron pipe fittings and ductile-iron pipe fittings. Both types of fittings are used with ductile-iron pipe.

Ductile-iron pipe may be obtained in various thicknesses and weights with (1) flanges cast on, (2) ends threaded for screwed-on flanges, (3) ends prepared for mechanical joint, (4) ends grooved or shouldered for patented coupling, (5) one end bell, other end spigot, and (6) one end hub, other end spigot. **Bell-and-spigot** ends are most popular for underground work; hub-and-spigot ends are most frequently used for sewage systems in enclosed spaces. Spigot-end joints are prepared by tightly tamping in hemp or jute at the bottom of the recess with a yarning iron and then pouring in molten lead; the lead, when cooled, is caulked in tightly with a caulking iron and makes a gastight joint. For exposed piping, flanged ends are used, the joints being made up with gaskets. Flanged pipe has superior strength and tightness of the joint and is used where pipelines can be well supported. The bell-and-spigot joint possesses greater flexibility and provides for expansion and contraction. It is therefore suitable for water pipe and is largely used for that purpose. Figure 8.7.2 shows a typical form of this joint for ordinary pressures. Figure 8.7.3 shows one form of this joint for ordinary pressures. Figure 8.7.3 shows one form of **mechanical joint** suitable for water, gas, or oil. Other forms of joint, plain-end pipe with couplings, and threaded pipe also are manufactured. Cast-iron and ductile-iron pipe, fittings, and valves have been found unsuitable for superheated steam service. The Code for Pressure Piping, B31.1 (Power Piping), states that cast iron or ductile-iron pipe may be used for steam service not over 250 lb/in^2 or 406°F (1,724 kPa or 208°C) provided that it meets the requirements as dictated by Eq. (8.7.1).



Fig. 8.7.2 Standard bell-and-spigot joint.

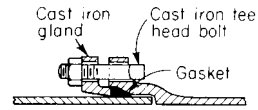


Fig. 8.7.3 Mechanical joint.

Wall thicknesses for the various conditions which ductile-iron pipe is designed to meet are determined in accordance with the requirements of ANSI 21.50 (AWWA C150).

Ductile-iron pipe is made by **centrifugal casting,** in which molten iron is admitted to the interior of a sand-lined or metal-lined mold, the mold being rotated at high speeds so that the molten metal is thrown by centrifugal force against the lining. ANSI specifications have been prepared for the various combinations of fabrication procedure and intended end use.

Table 8.7.24 lists thicknesses and weight data for centrifugally cast ductile-iron pipe intended for use with water or other liquids.

The employment of ductile-iron pipe for gas supply and distribution is second in importance only to its use for carrying water. Bell-and-spigot gas pipe is similar in design to bell-and-spigot water pipe (Fig. 8.7.2). For flanged gas pipe, the class 25 ANSI B16.1 Standard flanges are approved for maximum gas pressures of 25 lb/in^2 (172 kPa). The class 125 ANSI B16.1 Standard flanges are approved for gas pressures of 125 lb/in^2 (862 kPa), up to 4 in nominal pipe size; 100 lb/in^2 (689 kPa), 6 to 12 in; and 80 lb/in^2 (552 kPa), 16 to 48 in. The type of joint shown in Fig. 8.7.2 is also widely used for gas.

Table 8.7.24 Standard Weights and Thicknesses of Ductile-Iron Bell-and-Spigot Pipe for Water

Nominal size, in	Class 50, 50 lb/in² (345 kPa) 115-ft (35.05-m) head			Class 100, 100 lb/in² (690 kPa) 231-ft (70.41-m) head			Class 150, 150 lb/in² (1,034 kPa) 346-ft (105.5-m) head			Approx lb lead per joint 2 in thick	Approx lb hemp or jute per joint
	Thickness, in	OD, in	Wt, lb per avg ft	Thickness, in	OD, in	Wt, lb per avg ft	Thickness, in	OD, in	Wt, lb per avg ft		
3	0.32	3.96	12.4	0.32	3.96	12.4	0.32	3.96	12.4	6.2	0.17
4	0.35	4.80	16.5	0.35	4.80	16.5	0.35	4.80	16.5	7.5	0.21
6	0.38	6.90	25.9	0.38	6.90	25.9	0.38	6.90	25.9	10.3	0.31
8	0.41	9.05	37.0	0.41	9.05	37.0	0.41	9.05	37.0	13.3	0.44
10	0.44	11.10	49.1	0.44	11.10	49.1	0.44	11.10	49.1	16.0	0.53
12	0.48	13.20	63.7	0.48	13.20	63.7	0.48	13.20	63.7	19.0	0.61
14	0.48	15.30	74.6	0.51	15.30	78.8	0.51	15.65	80.7	22.0	0.81
16	0.54	17.40	95.2	0.54	17.40	95.2	0.54	17.80	97.5	30.0	0.94
18	0.54	19.50	107.6	0.58	19.50	114.8	0.58	19.92	117.2	33.8	1.00
20	0.57	21.60	125.9	0.62	21.60	135.9	0.62	22.06	138.9	37.0	1.25
24	0.63	25.80	166.0	0.68	25.80	178.1	0.73	26.32	194.0	44.0	1.50
30	0.79	32.00	257.6	0.79	32.00	257.6	0.85	32.00	275.4	54.3	2.06
36	0.87	38.30	340.9	0.87	38.30	340.9	0.94	38.30	365.9	64.8	3.00
42	0.97	44.50	442.0	0.97	44.50	442.0	1.05	44.50	475.3	75.3	3.62
48	1.06	50.80	551.6	1.06	50.80	551.6	1.14	50.80	589.6	85.5	4.37

Pipe weights indicated are approximate and include allowance for bell based on a 16-ft laying length. Calculations are for pipe laid without blocks, on flat-bottom trench, with tamped backfill under 5 ft of cover. Thicknesses given above include allowance for water hammer and factory tolerance.
To obtain weights in kg/m, multiply values shown in lb per avg ft by 1.42.
SOURCE: Condensed from Table 8.2 of Specification AWWA C 108-70.

Flexible-Joint Pipe The necessity for crossing streams and other waterways and of laying pipelines into them has led to the development of various forms of flexible-joint pipe adapted to laying under water, which are capable of motion through several degrees without leakage. Figure 8.7.4 shows one style of such joint which has an adjustment of about 15° in standard sizes.

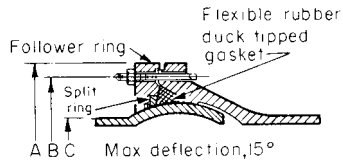


Fig. 8.7.4 Flexible joint. (See Table 8.7.25 for dimensions.)

In selecting the thickness of a pipe for a submerged line, the internal-service pressure is seldom the determining factor, as ample allowance should be made to minimize the risk of breakage in laying and to withstand external shocks from floating ice or other objects. The dimensions and weights given in Table 8.7.25 are typical of those listed by several manufacturers.

"Universal" pipe (Fig. 8.7.5) is ductile-iron pipe with hub-and-spigot ends, the contact surfaces of which are machined on a taper, giving an iron-to-iron joint, By making the tapers of slightly different pitch, the joint provides for flexibility while remaining tight. Two bolts to the

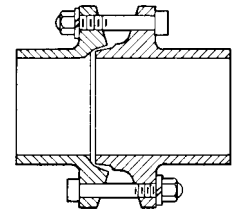


Fig. 8.7.5 Universal ductile-iron pipe and joint.

Table 8.7.25 Dimensions and Weights of Flexible-Joint Pipe*
(Dimensions refer to Fig. 8.7.4)

Nominal diam, in	Class	Dimensions, in			Bolts			Average metal thickness, in	Weight† of pipe, incl. bell, lb per 12-ft length
		A	*B*	*C*	No. required	Size, in	Length, in		
4	B	12.13	9.75	5.00	8	0.75	4.50	0.45	290
4	C	12.13	9.75	5.00	8	0.75	4.50	0.48	305
4	D	12.13	9.75	5.00	8	0.75	4.50	0.52	325
6	B	14.25	11.75	7.10	12	0.75	4.50	0.48	440
6	C	14.25	11.75	7.10	12	0.75	4.50	0.51	460
6	D	14.25	11.75	7.10	12	0.75	4.50	0.55	490
8	B	17.25	14.75	9.30	12	0.75	5.25	0.51	635
8	C	17.25	14.75	9.30	12	0.75	5.25	0.56	680
8	D	17.25	14.75	9.30	12	0.75	5.25	0.60	720
10	B	20.56	18.00	11.40	16	0.75	5.25	0.57	905
10	C	20.56	18.00	11.40	16	0.75	5.25	0.62	965
10	D	20.56	18.00	11.40	16	0.75	5.25	0.68	1,035
12	B	23.75	21.00	13.50	16	0.75	6.25	0.62	1,200
12	C	23.75	21.00	13.50	16	0.75	6.25	0.68	1,280
12	D	23.75	21.00	13.50	16	0.75	6.25	0.75	1,375

* United States Pipe and Foundry Co.
† Weights do not include follower rings, bolts, or gaskets. For sizes above 12 in, see manufacturers' catalogs. Multiply weights shown by 38.7 to obtain weight in kg per m or by 0.4536 to obtain weight in kg per 12-ft length.

Table 8.7.26 Standard Weights and Thicknesses of Universal Ductile-Iron Pipe
(Central Foundry Co.)

Nominal ID, in	Class 150, 150 lb/in² (1,034 kPa)			Class 250, 250 lb/in² (1,724 kPa)		
	Approx thickness, in	Estimated wt, lb per*		Approx thickness, in	Estimated wt, lb per*	
		ft	6-ft length		ft	6-ft length
2	0.25	7	42	0.31	8	48
3	0.30	11¼	67½	0.34	12½	75
4	0.32	16½	99	0.37	18	108
6	0.36	26.6	160	0.43	30	180
8	0.39	38½	231	0.47	44¼	265½
10	0.43	53½	321	0.50	60½	363
12	0.47	69	414	0.53	77½	465
14	0.50	87	522	0.565	98½	591
16	0.53	106	636	0.60	121	726

ID, in	2	3	4	6	8	10	12	14	16
Bolt sizes, in	½ × 4	½ × 4¼	⅝ × 5	¾ × 6	⅞ × 6¾	1 × 7½	1 × 8	1⅛ × 9	1¼ × 9½

* Multiply wts. by 0.4536 to obtain wt. in kilograms.

joint are sufficient, except for pressures above 175 lb/in² (1,207 kPa). Universal ductile-iron pipe is used largely for carrying gas and water and is suitable for all pressures and services. The pipe is tested with hydrostatic pressure of 300 to 500 lb/in² (2,067 to 3,448 kPa). All universal pipe and special castings of a given diameter and of any class are interchangeable with those of a different class. Standard laying lengths are 6 ft (1.83 m). Thicknesses and weights of standard types up to 16 in are given in Table 8.7.26. Information on other types and sizes and on fittings may be obtained from pipe producers.

Fittings for Ductile-Iron Water Pipe Flanged fittings of the dimensions of the ANSI standard for steam are not often used with ductile-iron water pipe. The longer fittings of the AWWA are generally preferred because of low friction loss. The dimensions of the flanged fittings of this class conform very closely to the dimensions of the bell-and-spigot fittings of the AWWA. The flange thicknesses and drillings conform to those of the ANSI standards. These fittings, both flange and bell-and-spigot type, are made in a great variety of forms known as ''standard special fittings.'' For dimensions and weights, see manufacturers' catalogs or standard specifications of the AWWA.

Cast-iron soil pipe and fittings are of the hub-and-spigot form, similar in design to the pipe shown in Fig. 8.7.2. Tapped openings and pipe plugs are threaded in accordance with the taper pipe thread requirements of ANSI B1.20.1-1983.

The ANSI standard, Threaded Cast-Iron Pipe for Drainage, Vent, and Waste Services, ANSI A40.5-1943, covers two types of pipes having threaded joints in nominal pipe sizes 1¼ to 12 in and in lengths 5 to 27 ft. One type has external threads on both ends; the other type has external threads on one end and an internal threaded drainage hub on the other end.

PIPES AND TUBES OF NONFERROUS MATERIALS

Brass tubing is commercially available in the form known as yellow brass, an alloy consisting of approximately 65 percent copper and 35

Table 8.7.27 Sizes and Weights of SPS Copper and 85 Red Brass Pipe*

Standard size, in	Nominal dimensions, in			Theoretical areas based on nominal dimensions			Theoretical weight, lb/ft	Allowable internal pressure, lb/in²			
	Outside diameter	Inside diameter	Wall thickness	Cross-sectional area of bore, in²	External surface, ft²/lin. ft	Internal surface ft²/lin. ft		100°F, S = 6,000	200°F, S = 4,800	300°F, S = 4,700	400°F, S = 3,000
¼	0.540	0.410	0.065	0.132	0.141	0.107	0.376	1,500	1,200	1,180	740
⅜	0.675	0.545	0.065	0.233	0.177	0.143	0.483	1,170	940	910	580
½	0.840	0.710	0.065	0.396	0.220	0.186	0.613	920	740	720	460
¾	1.050	0.920	0.065	0.665	0.275	0.241	0.780	730	580	560	360
1	1.315	1.185	0.065	1.10	0.344	0.310	0.989	580	460	450	290
1¼	1.660	1.530	0.065	1.84	0.435	0.401	1.26	450	360	350	220
1½	1.900	1.770	0.065	2.46	0.497	0.464	1.45	400	310	300	190
2	2.375	2.245	0.065	3.96	0.622	0.588	1.83	300	240	240	140
2½	2.875	2.745	0.065	5.92	0.753	0.719	2.22	250	200	190	120
3	3.500	3.334	0.083	8.73	0.916	0.874	3.45	260	210	210	130
3½	4.000	3.810	0.095	11.4	1.05	0.998	4.52	270	210	210	130
4	4.500	4.286	0.107	14.4	1.18	1.12	5.72	270	210	210	130
5	5.562	5.298	0.132	22.0	1.46	1.39	8.73	270	210	210	130
6	6.625	6.309	0.158	31.3	1.73	1.65	12.4	270	210	210	130
8	8.625	8.215	0.205	53.0	2.26	2.15	21.0	270	210	210	130
10	10.750	10.238	0.256	82.3	2.81	2.68	32.7	270	210	210	130
12	12.750	12.124	0.313	115.	3.34	3.18	47.4	280	220	220	130

* The values in the table above are based on the formula in The Code for Pressure Piping, ANSI B31:

$$t_m = \frac{PD}{2S + 0.8P} + C \qquad \text{or when } C \text{ is } O \qquad P = \frac{2St_m}{D - 0.8t_m}$$

where t_m = minimum pipe wall thickness, in; P = maximum rated internal working pressure, lb/in²; D = outside diameter of pipe, in; S = allowable stress in material due to internal pressure, at operating temperature, lb/in²; C = allowance for threading, mechanical strength and/or corrosion, in. The allowable internal pressures apply to the pipe itself after brazing.

SOURCE: Copper Development Association.

Table 8.7.28 Allowable Internal Pressures, lb/in², for Temperatures up to 400°F for Red Brass and Copper Pipe*

	Pipe with threaded ends								Pipe with plain ends for use with welded, brazed, or soldered fittings							
	Red brass				Copper				Red brass				Copper			
Standard size, in	100°F S = 8,000	200°F S = 8,000	300°F S = 8,000	400°F S = 5,000	100°F S = 6,000	200°F S = 4,800	300°F S = 4,700	400°F S = 3,000	100°F S = 8,000	200°F S = 8,000	300°F S = 8,000	400°F S = 5,000	100°F S = 6,000	200°F S = 4,800	300°F S = 4,700	400°F S = 3,000
Regular																
⅛	370	370	370	230	280	210	210	130	2,640	2,640	2,640	1,650	1,980	1,570	1,540	980
¼	870	870	870	550	650	510	510	320	2,610	2,610	2,610	1,640	1,960	1,560	1,530	970
⅜	890	890	890	570	670	530	510	320	2,280	2,280	2,280	1,440	1,710	1,350	1,330	840
½	900	900	900	570	670	530	520	320	2,160	2,160	2,160	1,350	1,620	1,280	1,260	800
¾	810	810	810	520	610	480	470	300	1,800	1,800	1,800	1,130	1,350	1,070	1,050	670
1	630	630	630	400	480	370	370	230	1,580	1,580	1,580	1,000	1,190	940	920	590
1¼	690	690	690	430	520	410	400	250	1,440	1,440	1,440	900	1,080	890	840	530
1½	630	630	630	400	480	370	370	230	1,280	1,280	1,280	800	960	750	740	470
2	540	540	540	350	410	320	310	190	1,050	1,050	1,050	670	790	620	610	380
2½	450	450	450	280	340	260	250	160	1,040	1,040	1,040	650	780	620	610	380
3	510	510	510	320	380	300	290	180	1,000	1,000	1,000	630	750	590	580	370
3½	570	570	570	370	430	330	330	200	1,000	1,000	1,000	630	750	590	580	370
4	510	510	510	320	380	300	290	180	880	880	880	550	660	530	520	320
5	410	410	410	270	310	230	240	140	710	710	710	450	540	420	410	260
6	340	340	340	220	260	190	200	120	600	600	600	380	450	350	340	220
8	360	360	360	230	270	270	210	130	560	560	560	350	420	320	320	200
10	360	360	360	230	270	210	210	130	520	520	520	330	390	300	300	190
12	320	320	320	200	240	190	200	120	450	450	450	280	340	260	250	160
Extra-Strong																
⅛	1,960	1,960	1,960	1,240	1,470	1,160	1,140	720	4,630	4,630	4,630	2,900	3,470	2,750	2,710	1,730
¼	2,210	2,210	2,210	1,340	1,660	1,310	1,290	820	4,200	4,200	4,200	2,640	3,150	2,500	2,460	1,570
⅜	1,840	1,840	1,840	1,150	1,380	1,090	1,070	680	3,360	3,360	3,360	2,100	2,520	2,000	1,960	1,250
½	1,760	1,760	1,760	1,100	1,320	1,040	1,030	660	3,130	3,130	3,130	1,970	2,350	1,860	1,830	1,160
¾	1,510	1,510	1,510	950	1,130	900	880	560	2,560	2,560	2,560	1,600	1,920	1,520	1,500	960
1	1,340	1,340	1,340	850	1,010	790	780	490	2,360	2,360	2,360	1,490	1,770	1,400	1,370	880
1¼	1,160	1,160	1,160	730	880	730	680	430	1,950	1,950	1,950	1,220	1,460	1,160	1,140	720
1½	1,090	1,090	1,090	680	820	660	640	410	1,770	1,770	1,770	1,120	1,330	1,050	1,030	660
2	1,000	1,000	1,000	630	750	590	570	360	1,520	1,520	1,520	950	1,140	910	890	560
2½	970	970	970	620	730	580	560	360	1,600	1,600	1,600	1,000	1,200	950	930	590
3	910	910	910	570	680	530	530	340	1,420	1,420	1,420	900	1,070	840	830	530
3½	860	860	860	550	650	510	500	310	1,300	1,300	1,300	820	980	790	760	480
4	840	840	840	530	630	490	480	300	1,230	1,230	1,230	770	920	730	710	460
5	770	770	770	480	580	450	440	340	1,080	1,080	1,080	680	810	640	630	400
6	800	800	800	500	600	470	460	290	1,060	1,060	1,060	670	800	620	610	380
8	710	710	710	450	530	430	410	260	910	910	910	570	680	540	540	340
10	550	550	550	350	420	340	330	200	710	710	710	450	540	440	420	240

* The values above are based on the formula in The Code for Pressure Piping, ANSI B31:

$$t_m = \frac{PD}{2S + 0.8P} + C \qquad \text{or} \qquad P = \frac{2S(t_m - C)}{D - 0.8(t_m - C)} \qquad \text{or when } C \text{ is O} \quad P = \frac{2St_m}{D - 0.8t_m}$$

where t_m = minimum pipe wall thickness, in; P = maximum rated internal working pressure, lb/in²; D = outside diameter of pipe, in; S = allowable stress in annealed material due to internal pressure, at operating temperature, lb/in²; C = allowance for threading, mechanical strength and/or corrosion, in. C equals 0.05 for sizes ⅜ in and smaller and the depth of the thread for all other sizes, and equals O for pipe with plain ends. These allowable internal pressures apply to the pipe itself and do not take into account the limitations which may be imposed by the type of joint and the joining material.

SOURCE: Copper Development Association.

percent zinc, and is used principally for ornamental work and hand railings, It has a density of approximately 0.3 lb/in^3 (8.31 g/cm^3), the exact density being dependent upon the specific chemical composition. **Brass piping** is most frequently furnished as red brass, an alloy consisting of approximately 85 percent copper and 15 percent zinc. This alloy, having a density of about 0.32 lb/in^3 (8.86 g/cm^3), has been found to be structurally superior to the yellow brasses and is used where the fluid being conveyed has corrosive properties.

Copper is available either as pipe or as tubing. In the form of piping, it has the same outer diameter as that of standard steel pipe (Tables 8.7.27 and 8.7.28). As tubing, it is used for a variety of purposes, such as for compressed-air instrumentation lines, hydraulic control lines around machinery, domestic oil-burner and heating systems, and for general plumbing purposes. **Copper tubing** (Table 8.7.29) is furnished in 12-ft (3.7-m) and 20-ft (6.1-m) straight lengths or in coils of 100-ft (30.5-m) length. **Type K** tubing, in coils, is used for underground work where the minimum number of joints, combined with greater thickness of type K tubing, is of distinct advantage. **Type L** tubing, usually in straight lengths, is used as a principal piping material for plumbing systems in homes and buildings; this is largely due to the economy of installation made possible by the use of soldered fittings. Copper deteriorates rapidly under high temperatures and repeated stresses. At a temperature of 360°F (182°C) its strength is reduced 15 percent, and on this account it should never be used for high steam pressures and temperatures.

Commercial sizes of **aluminum tubing** are listed by the manufacturers in even outside diameters and in wall thicknesses conforming to Stubs gage. Aluminum pipe is available as listed in Table 8.7.30. To obtain the approximate weight per foot of aluminum pipe or tubing, a weight of 0.098 lb/in^3 (2.71 g/cm^3) may be used.

Lead pipe is supplied in straight lengths, in coils, or in reels.

Block tin is a term used in the metal trade to refer to products made wholly from strictly pure high-grade tin. While tin pipe has many and varied uses, its most important applications are in types of equipment handling liquids intended for human consumption. Tin pipe does not corrode, and therefore does not contaminate most of the liquids passing through it.

Plastic pipes and **tubes** are available in a wide range of diameters and thicknesses, with Table 8.7.31 generally representative. The plastic used is resistant to attack by many chemicals, light in weight, flexible, and available in coiled form so that installation time is low. It is used for a variety of purposes including drainage, irrigation, sewage, and for conveying chemical solutions or waters that would attack metal piping. Plastic pipe used in gas service is listed in Table 8.7.32. Caution should be used in selection of plastic piping insofar as service temperature is concerned: e.g., polyethylene is suitable for a maximum temperature of 120°F (49°C). Table 8.7.33 lists corrosion-resistance data for polyethylene plastic piping.

Pipes with Special Linings For use in lines through which are passed solutions containing more or less free acid or other corrosive agents, standard pipe, valves, and fittings may be **lead-lined, tin-lined,** or **rubber-lined,** to resist corrosive action. This lining prolongs the life of the pipe and also gives it additional strength. For mine service in coal districts where the drainage water is more or less impregnated with sulfur or free sulfuric acid, **wood-lined pipe** and fittings are sometimes used. For special service, **seamless-copper-lined pipe** is also used. The **cement lining** of ductile-iron and steel pipe for water and other services is advantageous because of its protection against unusual destructive agencies and its ability to prevent tuberculation. Standard **hard-rubber pipe** and fittings have been developed for working pressures of 50 lb/in^2 (345 kPa) at normal temperatures. Standard sizes run from ¼- to 4-in diam (0.635- to 10.2-cm), in 10-ft (3.05-m) lengths. For temperature above 120°F (49°C), the use of hard-rubber-lined steel pipe is recommended. This pipe is suitable for conveying strong acids and chemicals.

VITRIFIED, WOODEN-STAVE, AND CONCRETE PIPE

Vitrified pipe is used extensively for drains and sewerage systems. Burnt-clay tile, being rendered impervious to water by glazing, is by far the best material for sewage purposes as it is not attacked by acids. Dimensions are given in Table 8.7.34 (see also Fig. 8.7.6). For sizes larger than 36 in (91.4 cm) and other data, refer to the publications of the Clay Products Assoc., Chicago (see ASTM Standard C-700).

Wood-stave pipe (Fig. 8.7.7) is used to a large extent for municipal water supply, outfall sewers, mining, irrigation, and various other uses providing for the transportation of water. The water carried may be hot, cold, or acid. It is made either untreated or creosoted by a vacuum and pressure process. This process uses 8 lb of creosote per cubic foot of wood treated. The untreated pipe is most used where the pipe is constantly full of water, and the wood therefore completely saturated, although in many such instances the creosoted wood is used to give assurance of permanence. (See also Sec. 6.)

Wood-stave pipe is made in two types: machine-banded pipe and continuous-stave pipe. **Machine-banded pipe** is banded with wire and is

Table 8.7.29 Sizes and Weights of Copper Tubes

Nominal size, in	OD, in, types* K, L	ID, in		Wall thickness, in		Permissible variation of mean OD, in, Types K, L		Weight,† lb/ft	
		Type K	Type L	Type K	Type L	Annealed	Hard-drawn	Type K	Type L
⅜	0.500	0.402	0.430	0.049	0.035	0.0025	0.001	0.269	0.198
½	0.625	0.527	0.545	0.049	0.040	0.0025	0.001	0.344	0.285
⅝	0.750	0.652	0.666	0.049	0.042	0.0025	0.001	0.418	0.362
¾	0.875	0.745	0.785	0.065	0.045	0.003	0.001	0.641	0.455
1	1.125	0.995	1.025	0.065	0.050	0.0035	0.0015	0.839	0.655
1¼	1.375	1.245	1.265	0.065	0.055	0.004	0.0015	1.04	0.884
1½	1.625	1.481	1.505	0.072	0.060	0.0045	0.002	1.36	1.14
2	2.125	1.959	1.985	0.083	0.070	0.005	0.002	2.06	1.75
2½	2.625	2.435	2.465	0.095	0.080	0.005	0.002	2.93	2.48
3	3.125	2.907	2.945	0.109	0.090	0.005	0.002	4.00	3.33
3½	3.625	3.385	3.425	0.120	0.100	0.005	0.002	5.12	4.29
4	4.125	3.857	3.905	0.134	0.110	0.005	0.002	6.51	5.38
5	5.125	4.805	4.875	0.160	0.125	0.005	0.002	9.67	7.61
6	6.125	5.741	5.845	0.192	0.140	0.005	0.002	13.9	10.2
8	8.125	7.583	7.725	0.271	0.200	0.006	0.003	25.9	19.3
10	10.125	9.449	9.625	0.338	0.250	0.008	0.004	40.3	30.1
12	12.125	11.315	11.565	0.405	0.280	0.008	0.004	57.8	40.4

* Type K recommended for underground service and general plumbing. Type L suitable for interior plumbing and other services.
† Multiply these values by 1.48 to obtain weight in kg/m.
SOURCE: American Brass Co.

Table 8.7.30 Aluminum Piping

Nominal pipe size, in	Schedule no.	OD, in	ID, in	Wall thickness, in	Weight per linear foot, lb, plain ends†	Cross-sectional wall area, in^2	Inside cross-sectional area, in^2	Moment of inertia, in^4	Section modulus, in^3	Radius of gyration, in
⅛	40‡	0.405	0.269	0.068	0.085	0.0720	0.0568	0.0011	0.0053	0.1215
	80§	0.405	0.215	0.095	0.109	0.0925	0.0363	0.0012	0.0060	0.1146
¼	40‡	0.540	0.364	0.088	0.147	0.1250	0.1041	0.0033	0.0123	0.1628
	80§	0.540	0.302	0.119	0.185	0.1574	0.0716	0.0038	0.0139	0.1547
⅜	40‡	0.675	0.493	0.091	0.196	0.1670	0.1909	0.0073	0.0216	0.2090
	80§	0.675	0.423	0.126	0.256	0.2173	0.1405	0.0086	0.0255	0.1991
½	40‡	0.840	0.622	0.109	0.294	0.2503	0.3039	0.0171	0.0407	0.2613
	80§	0.840	0.546	0.147	0.376	0.3200	0.2341	0.0201	0.0478	0.2505
¾	10	1.050	0.884	0.083	0.297	0.2521	0.6138	0.0297	0.0566	0.3432
	40‡	1.050	0.824	0.113	0.391	0.3326	0.5333	0.0370	0.0705	0.3337
	80§	1.050	0.742	0.154	0.510	0.4335	0.4324	0.0448	0.0853	0.3214
1	5	1.315	1.185	0.065	0.300	0.2553	1.103	0.0500	0.0760	0.4425
	10	1.315	1.097	0.109	0.486	0.4130	0.9452	0.0757	0.1151	0.4382
	40‡	1.315	1.049	0.133	0.581	0.4939	0.8643	0.0873	0.1328	0.4205
	80§	1.315	0.957	0.179	0.751	0.6388	0.7193	0.1056	0.1606	0.4066
1¼	5	1.660	1.530	0.065	0.383	0.3257	1.839	0.1037	0.1250	0.5644
	10	1.660	1.442	0.109	0.625	0.5311	1.633	0.1605	0.1934	0.5497
	40‡	1.660	1.380	0.140	0.786	0.6685	1.496	0.1947	0.2346	0.5397
	80§	1.660	1.278	0.191	1.037	0.8815	1.283	0.2418	0.2913	0.5238
1½	5	1.900	1.770	0.065	0.441	0.3747	2.461	0.1579	0.1662	0.6492
	10	1.900	1.682	0.109	0.721	0.6133	2.222	0.2468	0.2598	0.6344
	40‡	1.900	1.610	0.145	0.940	0.7995	2.036	0.3099	0.3262	0.6226
	80§	1.900	1.500	0.200	1.256	1.068	1.767	0.3912	0.4118	0.6052
2	5	2.375	2.245	0.065	0.555	0.4717	3.958	0.3149	0.2652	0.8170
	10	2.375	2.157	0.109	0.913	0.7760	3.654	0.4992	0.4204	0.8021
	40‡	2.375	2.067	0.154	1.264	1.074	3.356	0.6657	0.5606	0.7871
	80§	2.375	1.939	0.218	1.737	1.477	2.953	0.8679	0.7309	0.7665
2½	5	2.875	2.709	0.083	0.856	0.7280	5.764	0.7100	0.4939	0.9876
	10	2.875	2.635	0.120	1.221	1.039	5.453	0.9873	0.6868	0.9750
	40‡	2.875	2.469	0.203	2.004	1.704	4.788	1.530	1.064	0.9474
	80§	2.875	2.323	0.276	2.650	2.254	4.238	1.924	1.339	0.9241
3	5	3.500	3.334	0.083	1.048	0.8910	8.730	1.301	0.7435	1.208
	10	3.500	3.260	0.120	1.498	1.274	8.346	1.822	1.041	1.196
	40‡	3.500	3.068	0.216	2.621	2.228	7.393	3.017	1.724	1.164
	80§	3.500	2.900	0.300	3.547	3.016	6.605	3.894	2.225	1.136
3½	5	4.000	3.834	0.083	1.201	1.021	11.55	1.960	0.9799	1.385
	10	4.000	3.760	0.120	1.720	1.463	11.10	2.755	1.378	1.372
	40‡	4.000	3.548	0.226	3.151	2.680	9.887	4.788	2.394	1.337
	80§	4.000	3.364	0.318	4.326	3.678	8.888	6.281	3.140	1.307
4	5	4.500	4.334	0.083	1.354	1.152	14.75	2.810	1.249	1.562
	10	4.500	4.260	0.120	1.942	1.651	14.25	3.963	1.761	1.549
	40‡	4.500	4.026	0.237	3.733	3.174	12.73	7.232	3.214	1.510
	80§	4.500	3.826	0.337	5.183	4.407	11.50	9.611	4.272	1.477
5	40‡	5.563	5.047	0.258	5.057	4.300	20.01	15.16	5.451	1.878
	80§	5.563	4.813	0.375	7.188	6.112	18.19	20.67	7.432	1.839
6	40‡	6.625	6.065	0.280	6.564	5.581	28.89	28.14	8.496	2.246
	80§	6.625	5.761	0.432	9.884	8.405	26.07	40.49	12.22	2.195
8	30	8.625	8.071	0.277	8.543	7.265	51.16	63.35	14.69	2.953
	40‡	8.625	7.981	0.322	9.878	8.399	50.03	72.49	16.81	2.938
	80§	8.625	7.625	0.500	15.01	12.76	45.66	105.7	24.51	2.878
10		10.750	10.192	0.279	10.79	9.178	81.59	125.9	23.42	3.704
	30	10.750	10.136	0.307	11.84	10.07	80.69	137.4	25.57	3.694
	40‡	10.750	10.020	0.365	14.00	11.91	78.85	160.7	29.90	3.674
	80§	10.750	9.750	0.500	18.93	16.10	74.66	211.9	39.43	3.628
12	30	12.750	12.090	0.330	15.14	12.88	114.8	248.5	38.97	4.393
	‡	12.750	12.000	0.375	17.14	14.58	113.1	279.3	43.81	4.377
	§	12.750	11.750	0.500	22.63	19.24	108.4	361.5	56.71	4.335
					Construction pipe					
		2.00	1.900	0.050	0.3602	0.3063	2.835	0.1457	0.1457	0.6897
		3.00	2.900	0.050	0.5449	0.4634	6.605	0.5042	0.3361	1.043
		4.00	3.900	0.050	0.7297	0.6205	11.95	1.210	0.6051	1.397
		5.00	4.896	0.052	0.9506	0.8083	18.83	2.474	0.9896	1.749
		6.00	5.876	0.062	1.360	1.157	2.712	5.098	1.699	2.100
		7.00	6.856	0.072	1.843	1.567	36.92	9.403	2.687	2.450
		8.00	7.812	0.094	2.745	2.335	47.93	18.24	4.561	2.795

* Aluminum Co. of America.
† Weights calculated for 6061 and 6063. For 3003 multiply by 1.010.
‡ Also designated as standard pipe.
§ Also designated as extra-heavy or extra-strong pipe. All calculations based on nominal dimensions.

Table 8.7.31 Commerical Sizes (IPS) and Weights of Polyvinyl Chloride (PVC) Pipe*

Nominal size, in	Schedule	Wall thickness,* in	OD, in	ID, in	Theoretical weight,† lb/ft	Calculated min bursting pressure, lb/in²	
						Note 1	Note 2
¼	40	0.088	0.540	0.364	0.076	2,490	1,950
	80	0.119	0.540	0.302	0.096	3,620	2,830
½	40	0.109	0.840	0.622	0.153	1,910	1,490
	80	0.147	0.840	0.546	0.185	2,720	2,120
¾	40	0.113	1.050	0.824	0.203	1,540	1,210
	80	0.154	1.050	0.742	0.265	2,200	1,720
1	40	0.133	1.315	1.049	0.305	1,440	1,130
	80	0.179	1.315	0.957	0.385	2,020	1,580
1¼	40	0.140	1.660	1.380	0.409	1,180	920
	80	0.191	1.660	1.278	0.550	1,660	1,300
1½	40	0.145	1.900	1.610	0.489	1,060	830
	80	0.200	1.900	1.500	0.653	1,510	1,180
2	40	0.154	2.375	2.067	0.640	890	690
	80	0.218	2.375	1.939	0.910	1,290	1,010
3	40	0.216	3.500	3.068	1.380	840	660
	80	0.300	3.500	2.900	1.845	1,200	940
4	40	0.237	4.500	4.026	1.965	710	560
	80	0.337	4.500	3.826	2.710	1,040	810

* Thicknesses listed are minimum values. Tolerance is generally − 0 + 10%.
† These representative values are not specified in ASTM D1785-85.
NOTES:
1. Materials are PVC 1120, 1220, and 4116. A fiber stress of 6,400 lb/in² was used in bursting pressure calculations.
2. Materials are PVC 2112, 2116, and 2120. A fiber stress of 5,000 lb/in² was used in bursting pressure calculations.
SOURCE: Abstracted from ASTM Specification D1785-85.

Table 8.7.32 Dimensions of Plastic Pipe for Gas Service (AGA Requirements)

Nominal size, in	Nominal OD, in	Nominal ID, in	Sleeved weight, lb	Max working pressure at 73°F, lb/in²
½	0.625	0.500	0.054	250
¾	0.875	0.750	0.079	175
1	1.125	1.000	0.103	125
1¼	1.375	1.250	0.127	110
1½	1.625	1.500	0.152	90
1¾	1.875	1.750	0.177	80
2	2.125	2.000	0.200	75
2½	2.660	2.500	0.320	75
3	3.190	3.000	0.457	75
4	4.250	4.000	0.800	75

made with wood or metal collars, or with inserted joints. **Continuous-stave pipe** is manufactured in units consisting of staves, bands, and shoes, shipped in knocked-down form, and constructed in the trench. In building this type of pipe, the staves are laid so as to break joints and the completed pipe is without joints. Continuous-stave pipe is banded with individual bands, ranging in size from ⅜ to 1 in (0.95 to 2.54 cm), depending upon the size of the pipe. A factor of safety of 4 is maintained in the band, based on an ultimate strength of 60,000 lb/in² (414 MPa) of cross section. The maximum pressure to which a continuous-stave pipe may be subjected depends upon the size of the pipe. The head for small pipes may run as high as 400 ft (121.9 m) while in the largest sizes the head would be less than 200 ft (61 m).

Machine-banded pipe is made for pressures of 50 to 400 ft (15.2 to 121.9 m). The staves are made from redwood or Douglas-fir lumber, dried and carefully selected. The inside and outside of the staves are dressed to conform to the circumferential lines, and the edges of the staves dressed to conform to the radial lines.

Wooden pipe is largely built in western sections of the United States, close to the natural lumber market. The sizes of machine-banded pipe range from 2 to 24 in (5.08 to 61 cm), and of the continuous-stave pipe from 6- to 20-ft (15.2-cm to 6.1-m) inside diameter.

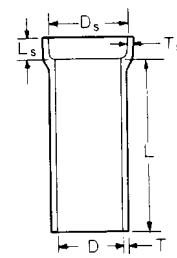


Fig. 8.7.6 Joint for vitrified pipe.

Pipe made from **plywood** is molded in lengths up to 11 ft (3.35 m) in diameters 3 in (7.62 cm) and up, and in wall thicknesses to specifications. Tubes made from fiber, by a molding process, are obtainable in a variety of sizes and lengths.

Concrete pipe is an important factor in sewer, conduit, railroad, culvert, and water-pipe construction. The pipe, as usually made, is constructed of concrete reinforced longitudinally with bars and transversely with wire mesh or steel bands. It is made in sections of definite length, with the longitudinal reinforcement so disposed as to provide for the interlocking of one section with another, and so formed that when these are locked together and cemented they form a continuous line of pipe free from leakage or seepage. Various forms of joints are used, all capable of taking care of expansion. Figure 8.7.8 shows one type of construction. Concrete pipe is manufactured in a great variety of diameters, thicknesses, and lengths to suit almost any requirement arising in practice. (See also Sec. 6.)

Table 8.7.33 Corrosion-Resistance Data, Polyethylene Pipe

Reagent	Performance at: 75°F (24°C)	120°F (49°C)	Reagent	Performance at: 75°F (24°C)	120°F (49°C)	Reagent	Performance at: 75° (24°C)	120°F (49°C)
Acetic acid, glacial*	F	NG	Ferrous sulfate, 15 percent aq.	E	E	Potassium chloride, saturated	E	E
Acetic acid, 10 percent*	E	E	Fluorine	E	NG	Potassium dichromate	E	E
Acetone	NG	NG	Fluosilicic acid, concentrated	E	F	Potassium hydroxide	E	E
Ammonia, dry gas	E	E	Formaldehyde, 40 percent	E	E	Potassium nitrate	E	E
Ammonium hydroxide, 10 percent	E	E	Formic acid, 50 percent	E	E	Potassium permanganate	E	E
Ammonium hydroxide, 28 percent	E	E	Furfuryl alcohol	NG	NG	Silicic acid	E	E
Amyl acetate	NG	NG	Gasoline	NG	NG	Silver nitrate	E	E
Aniline	E	F	Hydrobromic acid	E	E	Sodium benzoate	E	E
Benzene	NG	NG	Hydrochloric acid, 10 percent	E	E	Sodium bisulfite	E	E
Bromine	NG	NG	Hydrochloric acid, 37 percent	E	E	Sodium carbonate, concentrated	E	E
Butyraldehyde	E	G	Hydrofluoric acid, 48 percent	E	E	Sodium chloride, saturated solution	E	E
Calcium chloride, saturated	E	E	Hydrofluoric acid, 75 percent	E	F	Sodium hydroxide, 10 percent	E	E
Calcium hydroxide	E	E	Hydrogen peroxide, 30 percent	E	G	Sodium hydroxide, 50 percent	E	E
Calcium hypochlorite	E	E	Hydrogen peroxide, 90 percent	G	NG	Sodium sulfate	E	E
Carbon disulfide	NG	NG	Lactic acid, 90 percent	E	E	Stannic chloride, saturated	E	E
Carbon tetrachloride	NG	NG	Linseed oil	E	E	Stearic acid, 100 percent	E	E
Carbonic acid	E	E	Lubricating oil	NG	NG	Sulfuric acid, 10 percent	E	E
Chlorine, dry gas	F	NG	Magnesium chloride	E	E	Sulfuric acid, 30 percent	E	E
Chlorine, liquid	NG	NG	Magnesium sulfate	E	E	Sulfuric acid, 60 percent	E	F
Chlorosulfonic acid	NG	NG	Methyl bromide	NG		Sulfuric acid, 98 percent	F	NG
Citric acid, saturated	E	E	Methyl isobutyl ketone	F	NG	Tannic acid	E	E
Copper sulfate	E	E	Nitric acid, 10 percent	E	E	Toluene	NG	NG
Cyclohexanone	NG	NG	Nitric acid, 30–50 percent	E	E	Trichlorobenzene	F	NF
Diethylene glycol	E	E	Nitric acid, 70 percent	E	E	Trichloroethylene	NG	NG
Dioxane	E	G	Oleic acid	F	NG	Vinegar	E	E
Ethyl acetate	F	NG	Phosphoric acid, 30 percent	E	E	Xylene	NG	NG
Ethyl alcohol, 35 percent	NG	NG	Phosphoric acid, 90 percent	E	NG	Zinc chloride	E	E
Ethyl butyrate	F	NG	Photographic developer	E	E	Zinc sulfate	E	E
Ethylene dichloride	NG	NG	Potassium borate	E	E			
Ferric chloride	E	E	Potassium carbonate	E	E			

Corrosion-resistance data given in this table based on laboratory tests conducted by the manufacturers of the materials covered, and are indicative only of the conditions under which the tests were made. This information may be considered as a basis for recommendation, but not as a guarantee. Materials should be tested under actual service to determine suitability for a particular purpose.
E = excellent, G = good, F = fair, NG = not good.
* Polyethylene is permeable to acetic acid.

Asbestos-cement pipe, known by the trade name **Transite** pipe in this country, was developed initially in Europe. It was widely used in the United States for many years in a large variety of services. It was made of a mixture of portland cement and asbestos fiber, was highly resistant to corrosion, and provided outstanding service in mine drainage systems, waterworks systems, gas lines, and sewerage systems. It was manufactured in diameters from 3 to 36 in (7.6 to 91 cm), in stock lengths of 13 ft (4 m), and in pressure classes of 50, 100, 150, and 200 lb/in^2 (349, 689, 1,034, and 1,379 kPa). While it is no longer manufactured, it is still in place in some of the above-cited applications. Repairs to existing Transite piping generally devolves into replacing it with pipe made of a material compatible with its service, often with fiberglass-reinforced pipe, plastic pipe, or some form of metal pipe.

Table 8.7.34 Standard-Strength Vitrified Clay Pipe
(Dimensions refer to Fig. 8.7.6)

Size D, in	Laying length L: Nominal, ft	Laying length L: Limit of minus variation,* in/ft length	Max difference in length of two opposite sides, in	OD of barrel, in: Min	OD of barrel, in: Max	ID of socket ½ in above base D_s, in: Min	ID of socket ½ in above base D_s, in: Max	Depth of socket L_s, in: Nominal	Depth of socket L_s, in: Min	Thickness of barrel T, in: Nominal	Thickness of barrel T, in: Min	Thickness of socket at ½ in from outer end T_s, in: Nominal	Thickness of socket at ½ in from outer end T_s, in: Min
4	2, 2½, 3	¼	5/16	4 7/8	5 1/8	5 3/4	6 1/8	1 3/4	1½	½	7/16	7/16	3/8
6	2, 2½, 3	¼	3/8	7 1/16	7 7/16	8 3/16	8 5/8	2½	2	5/8	9/16	½	7/16
8	2, 2½, 3	¼	7/16	9¼	9¾	10½	11	2½	2¼	¾	11/16	9/16	½
10	2, 2½, 3	¼	7/16	11½	12	12¾	13¼	2 5/8	2 3/8	7/8	13/16	5/8	9/16
12	2, 2½, 3	¼	7/16	13¾	14 5/16	15⅛	15¾	2¾	2½	1	15/16	¾	11/16
15	3, 4	¼	½	17 3/16	17 13/16	18 5/8	19¼	2 7/8	2 5/8	1¼	1⅛	15/16	7/8
18	3, 4	¼	½	20 5/8	21 7/16	22¼	23	3	2¾	1½	1⅜	1⅛	1 1/16
21	3, 4	¼	9/16	24⅛	25	25 7/8	26¾	3¼	3	1¾	1⅝	1 5/16	1 3/16
24	3, 4	⅜	9/16	27½	28½	29⅜	30⅜	3⅜	3⅛	2	1⅞	1½	1⅜
27	3, 4	⅜	9/16	31	32⅛	33	34⅛	3½	3¼	2¼	2⅛	1 11/16	1 9/16
30	3, 4	⅜	5/8	34⅜	35 5/8	36½	37¾	3 5/8	3⅜	2½	2⅜	1⅞	1¾
33	3, 4	⅜	5/8	37 5/8	38 15/16	39⅞	41¼	3¾	3½	2 5/8	2½	2	1 13/16
36	3, 4	⅜	11/16	40¾	42¼	43¼	44¾	4	3¾	2¾	2 5/8	2 1/16	1⅞

When ordering standard-strength vitrified-clay pipe, give the size of pipe (ID) and the laying strength wanted, and refer to ASTM Specification C-700. Standard lengths of pipe shown meet normal practice in various sections of the country. Manufacturers' stocks include those lengths conforming to local practice.
* There is no limit for plus variation.

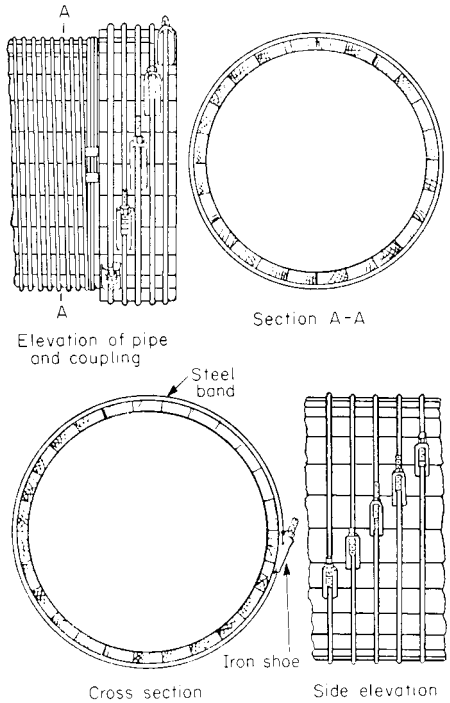


Fig. 8.7.7 Wood-stave pipes.

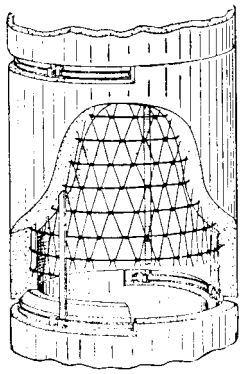


Fig. 8.7.8 Reinforced-concrete pipe.

FITTINGS FOR STEEL PIPE

American National Standard Cast-Iron Pipe Flanges and Flanged Fittings for Maximum Working Saturated Steam Pressure of 25, 125, and 250 lb/in² (172, 862, and 1,724 kPa)

INTRODUCTORY NOTES

Sizes The sizes of the fittings in the following tables are nominal pipe sizes. In the class 25 standard, the nominal pipe size is the same as the port diameter of the fittings, for *all* sizes. In the class 125 and class 250 standards the nominal pipe size is the same as the port diameter of fittings for pipe having inside diameters of 12 in (30.5 cm) and smaller. For pipe 14 in (35.6 cm) and larger, the corresponding outside diameter of the pipe is given, and consequently the fittings will have a smaller port diameter.

Pressure Rating In the class 25 standard the sizes 36 in (91.4 cm) and smaller may also be used for maximum nonshock working hydraulic pressures of 43 lb/in² gage (296 kPa) or a maximum gas pressure of 25 lb/in² gage (172 kPa), at or near the ordinary range of air temperatures. In the class 125 standard, the sizes 12 in (30.5 cm) and smaller may also be used for maximum nonshock working hydraulic pressure of 175 lb/in² gage (1,207 kPa) at or near the ordinary range of air temperatures. In the class 250 standard, the sizes 12 in and smaller may be used for maximum nonshock working hydraulic pressures of 400 lb/in² gage (2,758 kPa) at or near the ordinary range of air temperatures.

Facing All class 25 and class 125 cast-iron flanges and flanged fittings are plain faced, i.e., without projection or raised face. All class 250 cast-iron flanges and flanged fittings have a raised face 1/16 (0.16 cm) high, of the diameters given in Table 8.7.35. The raised face is included in the minimum flange thickness and center-to-face dimensions.

An **inspection limit** of ± 1/32 in (0.08 cm) is allowed on all center-to-contact-surface dimensions for sizes up to and including 10 in (25.4 cm) and ± 1/8 in on sizes larger than 10 in.

Dimensions In the class 25 standard, the flange diameters, bolt circles, and number of bolts are the same as in the class 125 ANSI Standard B16.1-1975, with a reduction in the thickness of flanges and bolt diameters, thereby maintaining interchangeability between the two standards.

The center-to-face and face-to-face dimensions of class 25 standard fittings are the same as for the class 125 standard.

Bolting Drilling templates are in multiples of four, so that fittings may be made to face in any quarter. **Bolt-holes** straddle the centerline. For bolts smaller than 1¾ in (4.45 cm) the bolt-holes are drilled 1/8 in larger in diameter than the nominal size of the bolt. Holes for bolts 1¾ in and larger are drilled ¼ in (0.64 cm) larger than nominal diameter of bolts. **Bolts** of steel are with standard ''rough square heads'' and the nuts are of steel with standard ''rough hexagonal'' dimensions; all as given in the American Standard on Wrench Head Bolts and Nuts and Wrench Openings of the National Screw Thread Commission. For bolts, 1¾-in (4.45-cm) diam and larger, bolt studs with a nut on each end are recommended.

Hexagonal nuts for pipe sizes 1 to 48 in (2.54 to 122 cm) in the class 125 standard and 1 to 16 in (40.6 cm) in the class 250 standard can be conveniently pulled up with open wrenches of minimum design of heads. Hexagonal nuts for pipe sizes 48 to 96 in (244 cm) in the class 125 standard and 18 to 48 in (45.7 to 122 cm) in the class 250 standard can be conveniently pulled up with box wrenches.

Spot Facing The bolt-holes of classes 25, 125, and 250 cast-iron flanges and flanged fittings are not spot-faced for ordinary service. When required, the flanges and fittings in sizes 30 in (76.2 cm) and larger may be spot-faced or back-faced to the minimum thickness of flange with a plus tolerance of 1/8 in (0.32 cm).

Reducing Fittings Reducing elbows and side-outlet elbows carry same dimensions center to face as straight-size elbows corresponding to the size of the larger opening.

Tees, side-outlet tees, crosses, and laterals sizes 16 in (40.6 cm) and smaller, reducing on the outlet or branch, have the same dimension center to face and face to face as straight-size fittings corresponding to the size of the larger opening. Sizes 18 in (45.7 cm) and larger, reducing on the outlet or branch, are made in two lengths depending on the size of the outlet as given in the tables of dimensions.

Tees, crosses, and laterals, reducing on the run only, have the same dimensions center to face and face to face as straight-size fittings corresponding to the size of the larger opening.

Reducers and eccentric reducers for all reduction have the same face-to-face dimensions for the larger opening.

Special double-branch elbows whether straight or reducing have the same dimension center to face as straight-size elbows corresponding to the size of the larger opening.

Side-outlet elbows and side-outlet tees have all openings on intersecting centerlines.

Table 8.7.35 Templates for Drilling Cast-Iron Pipe Flanges, Flanged Valves, and Fittings*

Nominal pipe size, in	Diameter of flange, in	Thickness of flange (minimum), in	Diameter of raised face, in	Diameter of bolt circle, in	Number of bolts	Diameter of bolts, in	Diameter of drilled bolt-holes, in	Length of bolts, in	Length of bolt stud with two nuts, in	Total effective area bolt metal, in^2	Stress in bolt metal, lb/in^2†	Size of ring gasket, in
					Class 25 standard (922 N/m^2)							
4	9	¾		7½	8	⅝	¾	2¼		1.616	570	4 × 6⅞
5	10	¾		8½	8	⅝	¾	2¼		1.616	750	5 × 7⅞
6	11	¾		9½	8	⅝	¾	2¼		1.616	930	6 × 8¾
8	13½	¾		11¾	8	⅝	¾	2¼		1.616	1470	8 × 11
10	16	⅞		14¼	12	⅝	¾	2½		2.424	1440	10 × 13⅜
12	19	1		17	12	⅝	¾	2¾		2.424	2195	12 × 16⅛
14	21	1⅛		18¾	12	¾	⅞	3¼		3.620	1750	14 × 18
16	23½	1⅛		21¼	16	¾	⅞	3¼		4.830	1710	16 × 20½
18	25	1¼		22¾	16	¾	⅞	3½		4.830	1965	18 × 22
20	27½	1¼		25	20	¾	⅞	3½		6.040	1920	20 × 24½
24	32	1⅜		29½	20	¾	⅞	3¾		6.040	2690	24 × 28¾
30	38¾	1½		36	28	⅞	1	4¼		11.760	2030	30 × 35⅛
36	46	1⅝		42¾	32	⅞	1	5		13.440	2610	36 × 41⅞
42	53	1¾		49½	36	1	1⅛	5¼		19.800	2315	42 × 48½
48	59½	2		56	44	1	1⅛	5½		24.200	2475	48 × 55
54	66¼	2¼		62¾	44	1	1⅛	5¾		24.200	3195	54 × 61¾
60	73	2¼		69¼	52	1⅛	1¼	6		36.020	2515	60 × 68⅛
72	86½	2½		82½	60	1⅛	1¼	6¼		41.570	3120	72 × 81⅜
84	99¾	2¾		95½	64	1¼	1⅜	7¼		57.140	3005	84 × 94¼
96	113¼	3		108½	68	1¼	1⅜	7¾		60.570	3705	96 × 107¼
					Class 125 standard (4,612 N/m^2)							
1	4¼	7⁄16		3⅛	4	½	⅝	1¾				1 × 2⅝
1¼	4⅝	½		3½	4	½	⅝	2				1¼ × 3
1½	5	9⁄16		3⅞	4	½	⅝	2				1½ × 3⅜
2	6	⅝		4¾	4	⅝	¾	2¼				2 × 4⅛
2½	7	11⁄16		5½	4	⅝	¾	2½				2½ × 4⅞
3	7½	¾		6	4	⅝	¾	2½				3 × 5⅜
3½	8½	13⁄16		7	8	⅝	¾	2¾				3½ × 6⅜
4	9	15⁄16		7½	8	⅝	¾	3				4 × 6⅞
5	10	15⁄16		8½	8	¾	⅞	3				5 × 7¾
6	11	1		9½	8	¾	⅞	3¼				6 × 8¾
8	13½	1⅛		11¾	8	¾	⅞	3½				8 × 11
10	16	1 3⁄16		14¼	12	⅞	1	3¼				10 × 13⅜
12	19	1¼		17	12	⅞	1	3¾				12 × 16⅛
14 OD	21	1⅜		18¾	12	1	1⅛	4¼				14 × 17¾
16 OD	23½	1 7⁄16		21¼	16	1	1⅛	4½				16 × 20¼
18 OD	25	1 9⁄16		22¾	16	1⅛	1¼	4¾				18 × 21⅝
20 OD	27½	1 11⁄16		25	20	1⅛	1¼	5				20 × 23⅞
24 OD	32	1⅞		29½	20	1¼	1⅜	5½				24 × 28¼
30 OD	38¾	2⅛		36	28	1¼	1⅜	6¼				30 × 34⅝
36 OD	46	2⅜		42¾	32	1½	1⅝	7				36 × 41¼
42 OD	53	2⅝		49½	36	1½	1⅝	7½				42 × 48
48 OD	59½	2¾		56	44	1½	1⅝	7¾				48 × 54½
54 OD	66¼	3		62¾	44	1¾	2	8½	10½			54 × 61
60 OD	73	3⅛		69¼	52	1¾	2	8¾	11			60 × 67½
72 OD	86½	3½		82½	60	1¾	2	9½	12			72 × 80¾
84 OD	99¾	3⅞		95½	64	2	2¼	10½	13			84 × 93½
96 OD	113¼	4¼		108½	68	2¼	2½	11½	14½			96 × 106¼
					Class 250 standard (9,224 N/m^2)							
1	4⅞	1 1⁄16	2 11⁄16	3½	4	⅝	¾	2¼				1 × 2⅞
1¼	5¼	¾	3 1⁄16	3⅞	4	⅝	¾	2½				1¼ × 3¼
1½	6⅛	1 3⁄16	3 9⁄16	4½	4	¾	⅞	2½				1½ × 3¾
2	6½	⅞	4 3⁄16	5	8	⅝	¾	2½				2 × 4⅜
2½	7½	1	4 15⁄16	5⅞	8	¾	⅞	3				2½ × 5⅛
3	8¼	1⅛	5 1 1⁄16	6⅝	8	¾	⅞	3¼				3 × 5⅞
3½	9	1 3⁄16	6 5⁄16	7¼	8	¾	⅞	3¼				3½ × 6½
4	10	1¼	6 15⁄16	7⅞	8	¾	⅞	3½				4 × 7⅛
5	11	1⅜	8 5⁄16	9¼	8	¾	⅞	3¾				5 × 8½
6	12½	1 7⁄16	9 11⁄16	10⅝	12	¾	⅞	3¾				6 × 9⅞
8	15	1⅝	11 15⁄16	13	12	⅞	1	4¼				8 × 12⅛
10	17½	1⅞	14 1⁄16	15¼	16	1	1⅛	5				10 × 14¼
12	20½	2	16 7⁄16	17¾	16	1⅛	1¼	5½				12 × 16⅝
14 OD	23	2⅛	18 15⁄16	20¼	20	1⅛	1¼	5¾				13¼ × 19⅛
16 OD	25½	2¼	21 1⁄16	22½	20	1¼	1⅜	6				15¼ × 21¼
18 OD	28	2⅜	23 5⁄16	24¾	24	1¼	1⅜	6¼				17 × 23½
20 OD	30½	2½	25 9⁄16	27	24	1¼	1⅜	6½				19 × 25¾
24 OD	36	2¾	30 5⁄16	32	24	1½	1⅝	7½	9½			23 × 30½
30 OD	43	3	37 3⁄16	39¼	28	1¾	2	8¼	10½			29 × 37½
36 OD	50	3⅜	43 1 1⁄16	46	32	2	2¼	9¼	11½			34½ × 44
42 OD	57	3 1 1⁄16	50 7⁄16	52¾	36	2	2¼	9¾	12			40¼ × 50¾
48 OD	65	4	58 7⁄16	60¾	40	2	2¼	10½	13			46 × 58¾

* To obtain linear dimensions in cm, multiply tabular values in in by 2.54. To obtain areas in cm^2, multiply tabular values in in^2 by 6.45. To obtain stress in N/m^2, multiply values in lb/in^2 by 36.895.

† The stress shown is that of internal pressure assumed to act only on a circular area equal in diameter to the outside diameter of the ring gasket covering the flange to the inside of the bolts for the 25-lb standard.

SOURCE: ANSI B16.1-1975.

Elbows Special degree elbows ranging from 1 to 45° have the same center-to-face dimensions given for 45° elbows, and those over 45° and up to 90° have the same center-to-face dimensions given for 90° elbows. The angle designation of an elbow is its deflection from straight-line flow and is the angle between its flange faces.

Threaded Companion Flanges Threaded companion flanges in the class 25 standard should not be thinner than those in the class 125 standard on sizes 24 in (61 cm) and smaller. Other types of flanges may have thicknesses as given in Table 8.7.35.

Laterals Laterals (Y branches) both straight and reducing sizes 8 in and larger are reinforced to compensate for the inherent weakness in the casting design.

The American National Standard B16.1-1975 covers also dimensions (not included in the tables) of base elbows and base tees and anchorage bases for straight tees and reducing tees.

American National Standard cast-iron pipe flanges and flanged fittings are available for maximum nonshock working hydraulic pressure of 800 lb/in² gage (5,516 kPa) at ordinary air temperatures.

Assembly of Flanged Joints The optimum degree of tightening occurs when a stress of 30,000 lb/in² (207 MPa) is uniformly reached in each flange stud or bolt. For a modulus of elasticity of 30,000,000 lb/in² (207 GPa) a stress of 30,000,000 lb/in² occurs when the elongation, determined with a dial indicator or micrometer, is 0.001 in/in of stud length measured between centers of nuts. Uniform tension in flange bolts may also be obtained by use of a torque wrench; bearing surfaces of nuts must have a good machine finish, and threads must be properly lubricated for reliable results with a torque wrench. The following torque values have been found to give 30,000 lb/in² stress in studs:

Study diam, in	*Threads per inch*	*Torque, lb · ft**
⅝	11	89
¾	10	107
⅞	9	162
1	8	244
1⅛	8	322
1¼	8	410
1⅜	8	510
1½	8	615

* Multiply by 0.149 to obtain torque in kilogram-metres.

American National Standard Steel Pipe Flanges and Flanged Fittings

INTRODUCTORY NOTES

Pressure Ratings and Tests These standards are known as ''American Class 150, 300, 400, 600, 900, 1,500, and 2,500 Steel Flange Standards'' (ANSI B16.5-1981), said pressure designation being the recommended rating at the temperatures given in Table 8.7.35. This table shows recommended ratings for various temperatures. For other tables, refer to ANSI B16.5-1981.

Sizes The size of the fittings and companion flanges in the tables is identified by the corresponding nominal pipe size. For pipe NPS 14 (35.6 cm) and larger, the corresponding outside diameter of the pipe is given.

Materials The flanged fittings and flanges should be either steel castings or steel forgings of the grade complying with the ASTM specifications recommended under these standards for the various pressure-

Table 8.7.36 Pressure-Temperature Ratings for Carbon-Steel Flanges and Flanged Fittings, Working Pressure in lb/in² Gage

	Class 150			Class 300			Class 1500		
	Material group*			Material group*			Material group*		
	1.1	1.2	1.4	1.1	1.2	1.4	1.1	1.2	1.4
Temperature,	Carbon steel			Carbon steel			Carbon steel		
°F	Norm.	High	Low	Norm.	High	Low	Norm.	High	Low
−20–100	285	290	235	740	750	620	3,705	3,750	3,085
200	260	260	215	675	750	560	3,375	3,750	2,810
300	230	230	210	655	730	550	3,280	3,640	2,735
400				635	705	530	3,170	3,530	2,645
500				600	665	500	2,995	3,325	2,490
600				550	605	455	2,735	3,025	2,285
650				535	590	450	2,685	2,940	2,245
700				535	570	450	2,665	2,840	2,245
750				505	505	445	2,520	2,520	2,210
800				410	410	370	2,060	2,060	1,850
850					270			1,340	
900					170			860	
950					105			515	
1,000					50			260	

Material group	Materials (spec. grade)	See notes
1.1	A105, A181-II, A216-WCB, A515-70	†, ¶
	A516-70	†, §
	A350-LF2, A537-C1.1	‡
1.2	A203-B, A203-E, A216-WCC	†, ¶
	A350-LF3, A352-LC2, A352-LC3	‡
1.4	A181-I, A515-60	†, ¶
	A516-60	†, §
	A350-LF1	‡

* Ratings shown apply to other material groups where columns dividing lines are omitted.
† Permissible but not recommended for prolonged use above about 800°F.
‡ Not to be used over 650°F.
§ Not to be used over 850°F.
¶ Not to be used over 1,000°F.
SOURCE: Abstracted from ASME B16.5-81 with permission.

temperature ratings for which these standards are designed. A few of these characteristics from ANSI B16.5-1981 are given in Table 8.7.36.

Bolting material including nuts and washers are based on a high-grade product equal to that given in ASTM Standard Specifications for Alloy-Steel Bolting Material for High Temperature Service (Table 8.7.37) and with physical and chemical requirements in accordance with the tables given under ANSI B16.5-1981. **Commercial steel bolts should not be used at steam pressures over 250** lb/in^2 (1,724 kPa) and temperatures over 450°F (232°C). Nuts should be of carbon or alloy steel. Washers when used under nuts should be of forged or rolled carbon steel.

Bolting Drilling templates are in multiples of four, so that fittings may be made to face in any quarter. Bolt-holes straddle the centerlines. Bolt-holes are drilled ⅛ in (0.32 cm) larger in diameter than the nominal size of bolt. Bolts or bolt studs threaded at both ends may be used and should be equipped with cold-punched or cold-pressed semifinished nuts of American National Standard rough dimensions, chamfered and trimmed.

All bolts and bolt studs having diameters 1 in and smaller, and the corresponding nuts are threaded with the American National Standard screw thread, coarse thread series, medium fit, class 3, while those bolts and bolt studs whose diameters are 1⅛ in (2.86 cm) and larger have special threads of the American National form whose pitch is ⅛ in (8 threads per inch). It is recommended that these special threads be allowed a pitch-diameter tolerance of -0.006 in and a lead tolerance of ± 0.002 in.

Bolt studs with a nut at each end are recommended for high-temperature service.

The allowable working fiber stress, considering internal allowable working pressure only, in bolting material for valve bonnet flanges, cleanout flanges, etc., is not to exceed 9,000 lb/in^2 (62 MPa) assuming the pressure to act upon an area circumscribed by the periphery of the outside of the contact surface.

Metal Thickness Minimum metal thicknesses specified in the tables are based on an allowable fiber stress of 7,000 lb/in^2 (48 MPa), using the modified Barlow formula of the ASME Boiler Construction Code for cylindrical sections and adding 50 percent to the thickness thus determined to compensate for the shape of the fittings. The minimum commercial casting thickness is considered to be ¼ in; therefore, the standards do not show thicknesses less than this. The minimum thickness in these standards means the minimum thickness in any part of the finished casting.

The modified Barlow formula is as follows: For pipes having nominal diameters of ¼ to 5 in, $P + 125 = 2S(t - 0.065)/D$. For pipes of nominal diameters over 5 in, $P = 2S(t - 0.1)/D$, where P is the working pressure, lb/in^2, t is the thickness of wall of pipe, in; D is the actual outside diameter of pipe, in; and S is 7,000 lb/in^2 (48 MPa).

Ring Joints The dimensions used for ring and groove joint facings were developed by a committee of the API. The corresponding dimensions and ring numbers incorporated in the ANSI Standard are identical with those given in API Standard 5G. The dimension for the depth of groove is added to the basic flange thickness, which makes it necessary to include separate tables of dimensions for fittings having the ring joint facing.

Fitting Dimensions An inspection limit of $\pm$ 1/32 in is allowed on all center-to-contact surface dimensions for sizes up to and including 10 in, and $\pm$ 1/16 in on sizes larger than NPS 10. An inspection limit of $\pm$ 1/16 in is allowed on all contact-surface to contact-surface dimensions for sizes up to and including NPS 10, and $\pm$ ⅛ in, on sizes larger than NPS 10.

When elbows having longer radii than specified in the standards are required, the use of pipe bends is recommended.

Laterals The 45° laterals of the larger sizes may require additional reinforcement to compensate for the inherent weakness in this shape of casting.

Valve Dimensions Face-to-face and end-to-end dimensions of ferrous valves for the various pressures are in accordance with the requirements of ANSI B16.10-1973 for ferrous flanged valves.

Reducing Fittings Reducing fittings have the same center-to-flange edge dimensions as those of straight-size fittings of the largest opening.

Side-Outlet Fittings All side-outlet fittings have all openings on the intersecting centerlines.

Welding Neck Flanges The materials, facings, spot facings, etc., conform to the requirements given for other flanges, with the additional provision that the carbon content of the steel shall not exceed 0.35 percent.

Templates for drilling and center to contact-surface dimensions of the American Standard class 150 steel flanges and flanged fittings are the same as for the American Standard class 125 cast-iron flanged fitting standard.

Templates for drilling and center to contact-surface dimensions of the ANSI class 300 steel flanges and flanged fittings are the same as for the ANSI class 600 steel flanged fitting standard for sizes NPS ½ to 1½ (Table 8.7.38); and the same as for the ANSI class 250 cast-iron flanged fitting standard for sizes NPS 2 to NPS 24.

Flanged Pipe Joints

The usual form of pipe joint is that made up by bolting together flanges cast or forged integral with the pipe or fitting, threaded flanges, loose flanges on pipes with lapped ends, and flanges arranged for welding. These forms are illustrated in Tables 8.7.39 and 8.7.40 and in Fig. 8.7.9. The threaded joint is satisfactory for low and medium steam pressures. The lapped joint is permitted in the same sizes and service ratings as for joints with integral flanges. It is extensively used in high-class work. With the ring joint a higher pressure can be maintained with the same total bolt stress than is possible with the flat gasket type of joint. The welded joint eliminates possibility of leakage between flange and pipe. It is very successful in lines subject to high temperatures and pressures and heavy expansion strains. The welding-neck flange is available in the various pipe sizes. Specific requirements covering the application of all the types of joints in common use are outlined in the Code for Power Piping (ASME B31.1 and B31.3).

Facing of Flanges Various styles of finish are used on the faces of flanges, for the purpose of the retention of the gasket used to make a tight joint. Those in general use are as follows (see Table 8.7.39): plain straight face, plain face corrugated or scored, male and female, tongue and groove, and raised face.

The **plain straight face** has the entire face of the flange faced straight across and may be used with either a full face or ring gasket. The **plain face, serrated or V-grooved,** is a plain face upon which concentric grooves have been cut with either a round-nose or V-shaped tool. This finish is sometimes of advantage when the service demands an exceptionally thick, loosely woven fibrous or soft metallic gasket, because the roughening of the faces of the flanges tends to keep the gasket from blowing out. The **male-and-female** facing consists of a recess in one flange and a corresponding raised face or projection on the other mating flange extending from the inside of the pipe nearly to the inside of the bolt holes. In the **tongue-and-groove** facing, the tongue or raised face and the groove or recess are narrow rings located between the bolt holes and the port. The male-and-female and the tongue-and-groove facing have been extensively used, particularly on hydraulic lines. To a more limited extent they have been used also on high-pressure steam lines. Both these types, however, have in common several objectionable features from the standpoint of manufacture, erection, and maintenance. These objections are removed by the use of the **raised-face** facing, which consists of a high narrow raised ring on each of the mating flanges, whose inside diameters is the same as that of the pipe or port. It is particularly recommended for high-pressure steam and hydraulic lines. **Gaskets** used in this type of joint are either soft fibrous material or soft metal and extend from the inside of the pipe to the bolt holes. Only the small portion in contact with the narrow raised face is subjected to the compressive effect of the bolts.

The following advantages are claimed for the raised-face type of facing: all mating of flanges has been eliminated; any valve or fitting may be removed from the line without springing the line apart; the gasket is automatically centered by its outer edge coming in contact with the bolts; the outside edges of the flanges are far enough apart to make it possible to determine whether the joint has been properly made.

Table 8.7.37 Mechanical Properties of Alloy Steel Bolting Material for High-Temperature Service

Ferritic steels

Grade	Diameter, in (mm)	Minimum tempering temperature,* °F (°C)	Tensile strength, min ksi (MPa)	Yield strength, min 0.2% offset, ksi (MPa)	Elongation in 2 in (50.8 mm), min. %	Reduction of area, min %	Hardness, max
B5, 4 to 6% chromium	Up to 4 (101.6), incl.	1,100 (593)	100 (690)	80 (550)	16	50	
B6, 13% chromium	Up to 4 (101.6), incl.	1,100 (593)	110 (760)	85 (585)	15	50	
B6X, 13% chromium	Up to 4 (101.6), incl.	1,100 (593)	90 (620)	70 (485)	16	50	26 HRC
B7, chromium-molybdenum	2½ (63.5) and under	1,100 (593)	125 (860)	105 (720)	16	50	
	Over 2½ to 4 (63.5 to 101.6)	1,100 (593)	115 (790)	95 (655)	16	50	
	Over 4 to 7 (101.6 to 117.8)	1,100 (593)	100 (690)	75 (515)	18	50	
B7M,† chromium-molybdenum	2½ (63.5) and under	1,150 (620)	100 (690)	80 (550)	18	50	235 HB or 99 HRB
B16, chromium-molybdenum-vanadium	2½ (63.5) and under	1,200 (650)	125 (860)	105 (720)	18	50	
	Over 2½ to 4 (63.5 to 101.6)	1,200 (650)	110 (760)	95 (655)	17	45	
	Over 4 to 7 (101.6 to 177.8)	1,200 (650)	100 (690)	85 (585)	16	45	

Austenitic steels

Class and grade, diameter, in (mm)	Heat treatment‡	Tensile strength, min ksi (MPa)	Yield strength, min 0.2% offset, ksi (MPa)	Elongation in 2 in (50.8 mm), min %	Reduction of area, min %	Hardness, max
Class 1: B8, B8C, B8M, B8P, B8T, B8LN, B8MLN, all diameters	Carbide solution treated	75 (515)	30 (205)	30	50	223 HB or 96 HRB
Class 1A: B8A, B8CA, B8MA, B8PA, B8TA, B8LNA, B8MLNA, B8NA, B8MNA, all diameters	Carbide solution treated in finished condition	75 (515)	30 (205)	30	50	192 HB or 90 HRB
Class 1B: B8N, B8MN, all diameters	Carbide solution treated	80 (550)	35 (240)	30	40	223 HB or 96 HRB
Class 1C: B8R, all diameters	Carbide solution treated	100 (690)	55 (380)	35	55	271 HB or 28 HRC
B8RA, all diameters	Carbide solution treated in finished condition	100 (690)	55 (380)	35	55	271 HB or 28 HRC
B8S, all diameters	Carbide solution treated	95 (655)	50 (345)	35	55	271 HB or 28 HRC
B8SA, all diameters	Carbide solution treated in finished condition	95 (655)	50 (345)	35	55	271 HB or 28 HRC
Class 2: B8, B8C, B8P, B8T, B8N, ¾ (19.05) and under	Carbide solution treated and strain-hardened	125 (860)	100 (690)	12	35	321 HB or 35 HRC
Over ¾ to 1 (19.05 to 25.4) incl.		115 (790)	80 (550)	15	35	321 HB or 35 HRC
Over 1 to 1¼ (25.4 to 31.6) incl.		105 (720)	65 (450)	20	35	321 HB or 35 HRC
Over 1¼ to 1½ (31.6 to 37.9) incl.		100 (690)	50 (345)	28	45	321 HB or 35 HRC
Class 2: B8M, B8MN, ¾ (19.05) and under	Carbide solution treated and strain-hardened	110 (760)	95 (655)	15	45	321 HB or 35 HRC
Over ¾ to 1 (19.05 to 25.4) incl.		100 (690)	80 (550)	20	45	321 HB or 35 HRC
Over 1 to 1¼ (25.4 to 31.6) incl.		95 (655)	65 (450)	25	45	321 HB or 35 HRC
Over 1¼ to 1½ (31.6 to 37.9) incl.		90 (620)	50 (345)	30	45	321 HB or 35 HRC

* For sizes ¾ in. in diameter and smaller, a maximum hardness of 241 HB (100 HRB) is permitted.

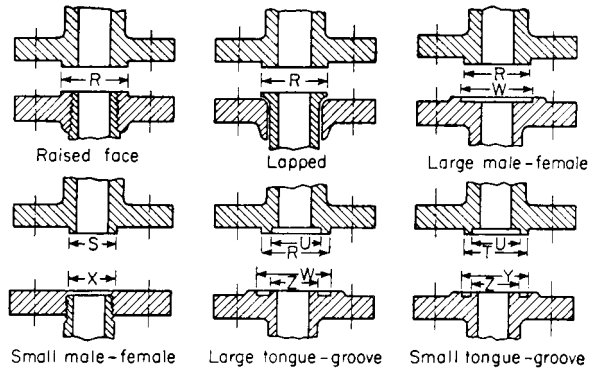
† To meet the tensile requirements, the Brinell hardness shall be over 201 HB (94 HRB).

‡ Class 1 is solution treated. Class 1A is solution treated in the finished condition for corrosion resistance: heat treatment is critical due to physical property requirement. Class 2 is solution-treated and strain-hardened. Austenitic steels in the strain-hardened condition may not show uniform properties throughout the section particularly in sizes over ¾ in (19.05 mm) in diameter.

Table 8.7.38 Templates for Drilling, American National Standard Steel Pipe Flanges and Flanged Fittings (ANSI B16.5-1981)
(All dimensions in inches)

	Class 400 standard					Class 600 standard					Class 900 standard					Class 1,500 standard				
Nominal pipe size	Outside diam of flange	Thickness of flange, minimum	Diam of bolt circle	Number of bolts	Size of bolts	Outside diam of flange	Thickness of flange, minimum	Diam of bolt circle	Number of bolts	Size of bolts	Outside diam of flange	Thickness of flange, minimum	Diam of bolt circle	Number of bolts	Size of bolts	Outside diam of flange	Thickness of flange, minimum	Diam of bolt circle	Number of bolts	Size of bolts
½	For sizes below 4 in use dimensions of 600-lb fittings					3¾	9/16	2⅝	4	½	For sizes below 3 in use dimensions of 1,500-lb fittings					4¾	⅞	3¼	4	¾
¾						4⅝	⅝	3¼	4	⅝						5⅛	1	3½	4	¾
1						4⅞	11/16	3½	4	⅝						5⅞	1⅛	4	4	1⅞
1¼	—	—	—	—	—	5¼	13/16	3⅞	4	⅝	—	—	—	—	—	6¼	1⅛	4⅜	4	⅞
1½	—	—	—	—	—	6⅛	⅞	4½	4	¾	—	—	—	—	—	7	1¼	4⅞	4	1
2	—	—	—	—	—	6½	1	5	8	⅝	—	—	—	—	—	8½	1½	6½	8	⅞
2½	—	—	—	—	—	7½	1⅛	5⅞	8	¾	—	—	—	—	—	9⅝	1⅝	7½	8	1
3	—	—	—	—	—	8¼	1¼	6⅝	8	¾	9½	1½	7½	8	⅞	10½	1⅞	8	8	1⅛
3½	—	—	—	—	—	9	1⅜	7¼	8	⅞										
4	10	1⅜	7⅞	8	⅞	10¾	1½	8½	8	⅞	11½	1¾	9¼	8	1⅛	12¼	2⅛	9½	8	1¼
5	11	1½	9¼	8	⅞	13	1¾	10½	8	1	13¾	2	11	8	1¼	14¾	2⅞	11½	8	1½
6	12½	1⅝	10⅝	12	⅞	14	1⅞	11½	12	1	15	2 3/16	12½	12	1⅛	15½	3¼	12½	12	1⅜
8	15	1⅞	13	12	1	16½	2 3/16	13¾	12	1⅛	18½	2½	15½	12	1⅜	19	3⅝	15½	12	1⅝
10	17½	2⅛	15¼	16	1⅛	20	2½	17	16	1¼	21½	2¾	18½	16	1⅜	23	4¼	19	12	1⅞
12	20½	2¼	17¾	16	1¼	22	2⅝	19¼	20	1¼	24	3⅛	21	20	1⅜	26½	4⅞	22½	16	2
14 OD	23	2⅜	20¼	20	1¼	23¾	2¾	20¾	20	1⅜	25¼	3⅜	22	20	1½	29½	5¼	25	16	2¼
16 OD	25½	2½	22½	20	1⅜	27	3	23¾	20	1½	27¾	3½	24¼	20	1⅝	32½	5¾	27¾	16	2½
18 OD	28	2⅝	24¾	24	1⅜	29¼	3¼	25¾	20	1⅝	31	4	27	20	1⅞	36	6⅜	30½	16	2¾
20 OD	30½	2¾	27	24	1½	32	3½	28½	24	1⅝	33¾	4¼	29½	20	2	38¾	7	32¾	16	3
24 OD	36	3	32	24	1¾	37	4	33	24	1⅞	41	5½	35½	20	2½	46	8	39	16	3½

Table 8.7.39 Facing Dimensions for the American Class 150, 300, 400, 600, 900, 1,500, and 2,500 Steel Flanges (ANSI B16.5-1981)



Nominal pipe size, in	Outside diameter, in: Raised face, lapped, large male, and large tongue, *R*	Outside diameter, in: Small male, *S*	Outside diameter, in: Small tongue, *T*	ID of large and small tongue, *U*	Outside diameter, in: Large female and large groove, *W*	Outside diameter, in: Small female, *X*	Outside diameter, in: Small groove, *Y*	ID of large and small groove, *Z*	Height, in: Raised face, 150 and 300 lb std*	Height, in: Raised face, large and small male and tongue 400-, 600-, 900-, 1,500- and 2,500-lb studs	Depth of groove or female companion flanges
½	1⅜	2³⁄₃₂	1⅜	1	1⁷⁄₁₆	²⁵⁄₃₂	1⁷⁄₁₆	¹⁵⁄₁₆	⅛	¼	³⁄₁₆
¾	1¹¹⁄₁₆	¹⁵⁄₁₆	1¹¹⁄₁₆	1⁵⁄₁₆	1¾	1	1¾	1¼	⅛	¼	³⁄₁₆
1	2	1⅜	1⅞	1½	2¹⁄₁₆	1¼	1¹⁵⁄₁₆	1⁷⁄₁₆	⅛	¼	³⁄₁₆
1¼	2½	1½	2¼	1⅞	2⁹⁄₁₆	1⁹⁄₁₆	2⁵⁄₁₆	1¹³⁄₁₆	⅛	¼	³⁄₁₆
1½	2⅞	1¾	2½	2⅛	2¹⁵⁄₁₆	1¹³⁄₁₆	2⁹⁄₁₆	2¹⁄₁₆	⅛	¼	³⁄₁₆
2	3⅝	2¼	3¼	2⅞	3¹¹⁄₁₆	2⁵⁄₁₆	3⅝	2¹³⁄₁₆	⅛	¼	³⁄₁₂
2½	4⅛	2¹¹⁄₁₆	3¾	3⅜	4³⁄₁₆	2¾	3¹³⁄₁₂	3⁵⁄₁₆	⅛	¼	³⁄₁₆
3	5	3⅝	4⅝	4¼	5¹⁄₁₆	3⅜	4¹¹⁄₁₆	4³⁄₁₆	⅛	¼	³⁄₁₆
3½	5½	3¹³⁄₁₆	5⅛	4¾	5⁹⁄₁₆	3⅞	5³⁄₁₆	4¹¹⁄₁₆	⅛	¼	³⁄₁₆
4	6³⁄₁₆	4⅝	5¹¹⁄₁₆	5³⁄₁₆	6¼	4⅜	5¾	5⅛	⅛	¼	³⁄₁₆
5	7⁵⁄₁₆	5⅜	6¹³⁄₁₆	6⁵⁄₁₆	7⅜	5⁷⁄₁₆	6⅞	6¼	⅛	¼	³⁄₁₆
6	8½	6⅜	8	7½	8⁹⁄₁₆	6⁷⁄₁₆	8¹⁄₁₆	7⁷⁄₁₆	⅛	¼	³⁄₁₆
8	10⅝	8⅜	10	9⅜	10¹¹⁄₁₆	8⁷⁄₁₆	10¹⁄₁₆	9⁵⁄₁₆	⅛	¼	³⁄₁₆
10	12¾	10½	12	11¼	12¹³⁄₁₆	10⁹⁄₁₆	12¹⁄₁₆	11³⁄₁₆	⅛	¼	³⁄₁₆
12	15	12½	14¼	13½	15¹⁄₁₆	12⁹⁄₁₆	14⁵⁄₁₆	13⁷⁄₁₆	⅛	¼	³⁄₁₆
14 OD	16¼	13¾	15½	14¾	16⁵⁄₁₆	13¹³⁄₁₆	15⁹⁄₁₆	14¹¹⁄₁₆	⅛	¼	³⁄₁₆
16 OD	18½	15¾	17⅝	16¾	18⁹⁄₁₆	15¹³⁄₁₆	17¹¹⁄₁₆	16¹¹⁄₁₆	⅛	¼	³⁄₁₆
18 OD	21	17¾	20⅛	19¼	21¹⁄₁₆	17¹³⁄₁₆	20³⁄₁₆	19³⁄₁₆	⅛	¼	³⁄₁₆
20 OD	23	19¾	22	21	23¹⁄₁₆	19¹³⁄₁₆	22¹⁄₁₆	20¹⁵⁄₁₆	⅛	¼	³⁄₁₆
24 OD	27¼	23¾	26¼	25¼	27⁵⁄₁₆	23¹³⁄₁₆	26⁵⁄₁₆	25³⁄₁₆	⅛	¼	³⁄₁₆

* Included in the minimum flange thickness dimensions. A ⅛-in raised face is also permitted on the class 400, 600, 900, 1,500, and 2,500 flange standards, but it must be added to the minimum flange thicknesses. Regular facing for class 400, 600, 900, 1,500, and 2,500 flange standards is a ¼-in raised face not included in minimum flange thickness dimensions.

A tolerance of ⅛₄ in is allowed on the inside and outside diameters of all facings.

Gaskets for male-female and tongue-groove joints should cover the bottom of the recess with minimum clearance taking into account the tolerances stated above.

Unions may be classified as **screw** and **flange**. Typical designs are shown in Fig. 8.7.10, where at the top left is represented a female screw union of the gasket type, at the top right a female screw union having a brass to iron seat that is noncorrosive and a ground joint that eliminates the need for a gasket, and at the bottom a flange union of the gasket type. As in the case of other pipe fittings, unions and union fittings are available in the various pipe sizes and in materials and designs suitable for any service conditions. Very large flange unions can be made by bolting together two screwed companion flanges.

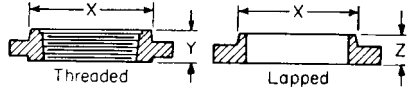
Threaded Fittings

Threaded fittings are made of cast iron, malleable iron, cast steel, forged steel, or brass. Plain standard fittings are generally used for low-pressure gas and water, as in house plumbing and railing work, while the beaded fitting is the standard steam, air, gas, or oil fitting. Screwed fittings are supplied with a large factor of safety. The questions of strength involve much more than the pressure from within the pipe which induces a comparatively low stress in the material. The greater strains come from expansion, contraction, weight of piping, settling, water hammer, etc. Dimensions of cast-iron and malleable-iron screwed fittings of the American National Standard are given in Tables 8.7.41 and 8.7.42.

The dimensions of ferrous plugs, bushings, locknuts, and caps with pipe threads are covered by ANSI B16.14-1983. The dimensions of pipe plugs from this standard are given in Table 8.7.43.

The normal **amount of thread engagement** necessary to make a tight

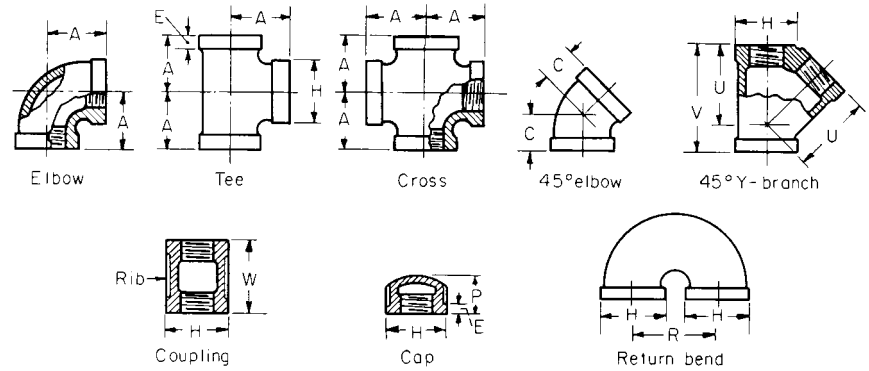
Table 8.7.40 Dimensions of American National Standard Companion Flanges (ANSI B16.5-1981)*



Nominal pipe size	Class 150			Class 300			Class 400			Class 600			Class 900			Class 1,500		
	X	*Y*	*Z*	*X*	*Y*	*Z*	*X*	*Y*	*Z*	*X*	*Y*	*Z*	*X*	*Y*	*Z*	*X*	*Y*	*Z*
½	1 3/16	5/8	5/8	1½	7/8	7/8	For sizes below 4 in, use dimensions of 600-lb flanges			1½	7/8	7/8	For sizes below 3 in, use dimensions of 1,500-lb flanges			1½	1¼	1¼
¾	1½	5/8	5/8	1 7/8	1	1				1 7/8	1	1				1¾	1 3/8	1 3/8
1	1 15/16	1 1/16	1 1/16	2 1/8	1 1/16	1 1/16				2 1/8	1 1/16	1 1/16				2 1/16	1 5/8	1 5/8
1¼	2 5/16	1 3/16	1 3/16	2½	1 1/16	1 1/16	—	—	—	2½	1 1/8	1 1/8	—	—	—	2½	1 5/8	1 5/8
1½	2 9/16	7/8	7/8	2¾	1 3/16	1 3/16	—	—	—	2¾	1¼	1¼	—	—	—	2¾	1¾	1¾
2	3 1/16	1	1	3 5/16	1 5/16	1 5/16	—	—	—	3 5/16	1 7/16	1 7/16	—	—	—	4 1/8	2¼	2¼
2½	3 9/16	1 1/8	1 1/8	3 15/16	1½	1½	—	—	—	3 15/16	1 5/8	1 5/8	—	—	—	4 7/8	2½	2½
3	4¼	1 3/16	1 3/16	4 5/8	1 11/16	1 11/16	—	—	—	4 5/8	1 13/16	1 13/16	5	2 1/8	2 1/8	5¼	2 7/8	2 7/8
3½	4 13/16	1¼	1¼	5¼	1¾	1¾	—	—	—	5¼	1 15/16	1 15/16						
4	5 5/16	1 5/16	1 5/16	5¾	1 7/8	1 7/8	5¾	2	2	6	2 1/8	2 1/8	6¼	2¾	2¾	6 3/8	3 9/16	3 9/16
5	6 7/16	1 7/16	1 7/16	7	2	2	7	2 1/8	2 1/8	7 7/16	2 3/8	2 3/8	7½	3 1/8	3 1/8	7¾	4 1/8	4 1/8
6	7 9/16	1 9/16	1 9/16	8 1/8	2 1/16	2 1/16	8 1/8	2¼	2¼	8¾	2 5/8	2 5/8	9¼	3 3/8	3 3/8	9	4 11/16	4 11/16
8	9 11/16	1¾	1¾	10¼	2 7/16	2 7/16	10¼	2 11/16	2 11/16	10¾	3	3	11¾	4	4½	11½	5 5/8	5 5/8
10	12	1 15/16	1 15/16	12 5/8	2 5/8	3¾	12 5/8	2 7/8	4	13½	3 3/8	4 3/8	14½	4¼	5	14½	6¼	7
12	14 3/8	2 3/16	2 3/16	14¾	2 7/8	4	14¾	3 1/8	4¼	15¾	3 5/8	4 5/8	16½	4 5/8	5 5/8	17¾	7 1/8	8 5/8
14 OD	15¾	2¼	3 1/8	16¾	3	4 3/8	16¾	3 5/16	4 5/8	17	3 11/16	5	17¾	5 1/8	6 1/8	19½	—	9½
16 OD	18	2½	3 7/16	19	3¼	4¾	19	3 11/16	5	19½	4 3/16	5½	20	5¼	6½	21¾	—	10¼
18 OD	19 7/8	2 11/16	3 13/16	21	3½	5 1/8	21	3 7/8	5 3/8	21½	4 5/8	6	22¼	6	7½	23½	—	10 7/8
20 OD	22	2 7/8	4 1/16	23 1/8	3¾	5½	23 1/8	4	5¾	24	5	6¼	24½	6½	8¼	25¼	—	11½
24 OD	26 1/8	3¼	4 3/8	27 5/8	4 3/16	6	27 5/8	4½	6¼	28¼	5½	7¼	29½	8	10½	30	—	13

* Other dimensions are given in Tables 8.7.38 and 8.7.39. Finished bore on lapped flange to be such as method of attachment of pipe requires.

Table 8.7.41 Dimensions of ANSI Class 150 Standard Malleable-Iron Threaded Fittings*
(All dimensions in inches)



Size	*A*	*H*	*E*	*C*	*V*	*U*	*W*	*P*	*R* Close	*R* Medium	*R* Open
⅛	0.69	0.693	0.200				0.96				
¼	0.81	0.844	0.215	0.73			1.06				
⅜	0.95	1.015	0.230	0.80	1.93	1.43	1.16				
½	1.12	1.197	0.249	0.88	2.32	1.71	1.34	0.87	1.000	1.25	1.50
¾	1.31	1.458	0.273	0.98	2.77	2.05	1.52	0.97	1.250	1.50	2.00
1	1.50	1.771	0.302	1.12	3.28	2.43	1.67	1.16	1.500	1.875	2.50
1¼	1.75	2.153	0.341	1.29	3.94	2.92	1.93	1.28	1.750	2.25	3.00
1½	1.94	2.427	0.368	1.43	4.38	3.28	2.15	1.33	2.188	2.50	3.50
2	2.25	2.963	0.422	1.68	5.17	3.93	2.53	1.45	2.625	3.00	4.00
2½	2.70	3.589	0.478	1.95	6.25	4.73	2.88	1.70			4.50
3	3.08	4.285	0.548	2.17	7.26	5.55	3.18	1.80			5.00
3½	3.42	4.843	0.604	2.39			3.43	1.90			
4	3.79	5.401	0.661	2.61	8.98	6.97	3.69	2.08			
5	4.50	6.583	0.780	3.05				2.32			
6	5.13	7.767	0.900	3.46				2.55			

* The complete standard (ANSI B16.3-1977) covers also reducing couplings, elbows, tees, crosses, and service or street elbows and tees.
SOURCE: ANSI B16.3-1977.

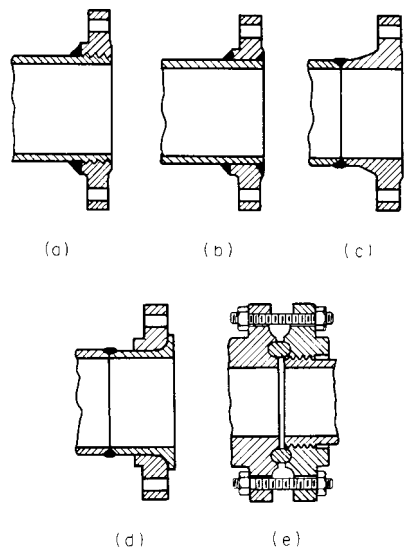


Fig. 8.7.9 Welded flange joints and ring joint. (*a*) Forged steel, screwed flange, back-welded and refaced; (*b*) forged steel, slip-on welding flange, welded front and back, refaced; (*c*) forged steel, welding neck flange, butt-welded to pipe; (*d*) lap-welding nipple, butt-welded to pipe; (*e*) ring joint.

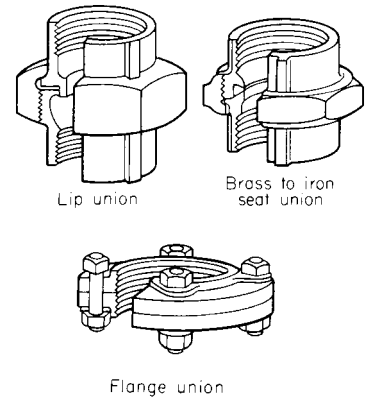


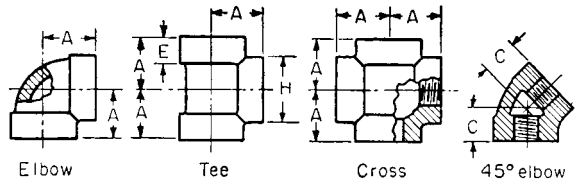
Fig. 8.7.10 Types of pipe unions.

joint for ANSI Standard pipe thread joints as recommended by Crane Co. is as follows:

Size of pipe, in	⅛	¼	⅜	½	¾	1	1¼	1½	2
Length of thread, in	¼	⅜	⅜	½	9⁄16	11⁄16	11⁄16	11⁄16	¾

Size of pipe, in	2½	3	3½	4	5	6	8	10	12
Length of thread, in	15⁄16	1	1 1⁄16	1 ⅛	1 ¼	1 5⁄16	1 7⁄16	1 ⅝	1 ¾

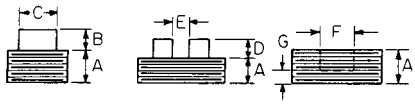
Table 8.7.42 Dimensions of Class 125 and Class 250 Standard Cast-Iron Threaded Fittings*
(All dimensions in inches)



	Class 125				Class 250			
Size	*A*	*H*	*E*	*C*	*A*	*H*	*E*	*C*
¼	0.81	0.93	0.38	0.73	0.94	1.17	0.49	0.81
⅜	0.95	1.12	0.44	0.80	1.06	1.36	0.55	0.88
½	1.12	1.34	0.50	0.88	1.25	1.59	0.60	1.00
¾	1.13	1.63	0.56	0.98	1.44	1.88	0.68	1.13
1	1.50	1.95	0.62	1.12	1.63	2.24	0.76	1.31
1¼	1.75	2.39	0.69	1.29	1.94	2.73	0.88	1.50
1½	1.94	2.68	0.75	1.43	2.13	3.07	0.97	1.69
2	2.25	3.28	0.84	1.68	2.50	3.74	1.12	2.00
2½	2.70	3.86	0.94	1.95	2.94	4.60	1.30	2.25
3	3.08	4.62	1.00	2.17	3.38	5.36	1.40	2.50
3½	3.42	5.20	1.06	2.39	3.75	5.98	1.49	2.63
4	3.79	5.79	1.12	2.61	4.13	6.61	1.57	2.81
5	4.50	7.05	1.18	3.05	4.88	7.92	1.74	3.19
6	5.13	8.28	1.28	3.46	5.63	9.24	1.91	3.50
8	6.56	10.63	1.47	4.28	7.00	11.73	2.24	4.31
10	8.08	13.12	1.68	5.16	8.63	14.37	2.58	5.19
12	9.50	15.47	1.88	5.97	10.00	16.84	2.91	6.00

* This applies to elbows and tees only.
The class 125 standard covers also reducing elbows and tees. The class 250 standard covers only the straight sizes.
SOURCE: ANSI B16.4-1971.

Table 8.7.43 Dimensions of Class 125, 150, and 250 Pipe Plugs*
(All dimensions in inches)



Nominal pipe size	Square-head pattern			Slotted pattern			Countersunk pattern† (square sockets)		
	A	*B*	*C*	*A*	*D*	*E*	*A*	*F*	*G*
⅛	0.37	0.24	9/32						
¼	0.44	0.28	⅜						
⅜	0.48	0.31	7/16						
½	0.56	0.38	9/16				0.56	⅜	0.16
¾	0.63	0.44	⅝				0.63	½	0.18
1	0.75	0.50	13/16				0.75	½	0.20
1¼	0.80	0.56	15/16				0.80	¾	0.22
1½	0.83	0.62	1⅛				0.83	¾	0.24
2	0.88	0.68	1 5/16				0.88	⅞	0.26
2½	1.07	0.74	1½				1.07	1⅛	0.29
3	1.13	0.80	1 11/16				1.13	1⅜	0.31
3½	1.18	0.86	1⅞				1.18	1½	0.34
4				1.22	1.00	0.88	1.22	2	0.37
5				1.31	1.00	0.88	1.31	2¼	0.46
6				1.40	1.25	1.25	1.40	2½	0.52
8				1.57	1.38	1.50			

* The material of (ANSI B16.14-1983) is to be cast iron, malleable iron, or steel, for use in connection with fittings covered by the American National Standard class 125 cast-iron threaded fittings (ANSI B16.4) and the American National Standard class 150 malleable-iron screwed fittings (ANSI B16.3).
† Hexagon sockets (sizes ⅛ to 1 in) have dimensions to fit regular wrenches used with hexagon socket setscrews.
SOURCE: ANSI B16.14-1983.

The Manufacturers' Standardization Society of Valve and Fitting Industry (MSS) has standardized malleable-iron and brass threaded fittings for several pressures.

Cast-bronze threaded fittings are made in both the class 125 and 250 standards. They are used for any water pipe where bad water makes steel pipe undesirable. Bronze fittings may be had in iron pipe sizes. Forged-steel threaded fittings are made for cold water or oil-working pressures up to 6,000 lb/in^2 (41.4 MPa) hydrostatic. The ANSI has approved standard B16.26-1983 for cast copper alloy fittings for flared copper tubes for maximum cold-water service pressure of 175 lb/in^2 (1,207 kPa).

Railing Fittings Fittings of special construction and of tighter weight than standard steam, gas, and water pipe fittings are widely used for hand railings around areaways, on stairs, for office enclosures with gates, and for permanent ladders. Railing fittings are made in various styles, generally globe-shaped in body, with ends reduced to take thread and recessed to cover all threads. They are furnished in malleable iron, black and galvanized, and in brass.

Special railing-fitting joints are available, such as the slip-and-screwed joint, where the post connection is screwed and the rim of the fitting is so made that the rail will slip into the fitting and allow for an angular variation of several degrees, being fastened by pins which are riveted over and filed smooth. The flush-joint stair-rail fitting is another special style of fitting which provides a hand rail with even surfaces at the joints.

Drainage fittings, as shown in the figures accompanying Table 8.7.44, have no pockets for the lodgment of solids, and the length of the thread chamber is such that when the pipe is threaded to the American National Standard dimensions, the end of the pipe will practically touch the shoulder when screwed in. They are especially adapted to plumbing work and vacuum-cleaning pipe installations. Dimensions in Table 8.7.44 conform to ANSI Standard B16.12-1983, Cast-Iron Threaded Drainage Fittings.

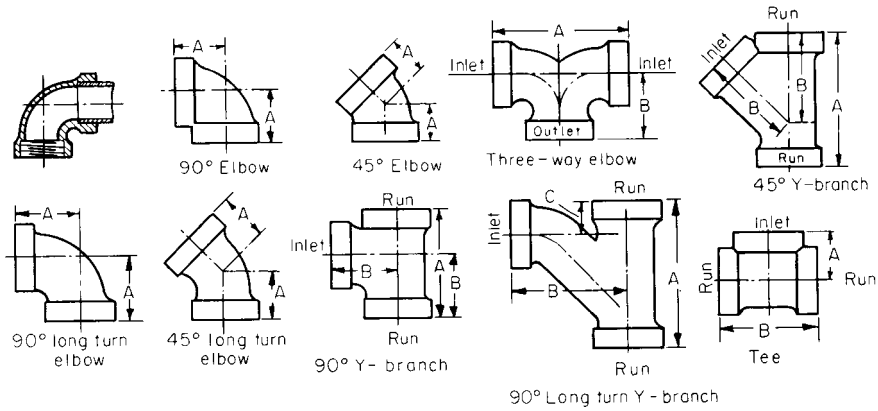
The development of standards for **cast-iron long-turn sprinkler fittings** was begun by the National Fire Protection Assoc. in 1914 with a study of the peculiar needs of fittings intended for fire-protection purposes. These fittings (screwed and flanged) are rated at 175 and 250 lb/in^2 (1,207 and 1,724 kPa).

American National Standard Air Gaps and Backflow Preventers in Plumbing Systems, ANSI A40.4-1942 and A40.6-1943, was prepared to establish minimum requirements for plumbing, including water-supply distributing systems, drainage and venting systems, fixtures, apparatus, and devices, and the standardization of plumbing equipment in general.

Ammonia valves and fittings must provide a high margin of safety against accidents. Flanged valves and fittings have tongue-and-groove faces to assure tightness at the joints and against blowing out gaskets. Gaskets are compressed asbestos sheet. Threaded valves and fittings have long threads and are recessed so that the joints may be soldered. These valves and fittings are made of malleable iron, ductile iron, ferrosteel, or forged steel; depending on the size and style. Valves are all iron, with steel stems, and have special lead disk faces or steel disks. Copper or brass must not be used in their construction. Flanged valves are generally interchangeable with flanged fittings. All valves and fittings for ammonia are tested to 300 lb/in^2 (2,069 kPa) air pressure under water. For dimensions of valves, fittings, and specialties for ammonia, refer to manufacturers' catalogs.

Soldered-Joint Fittings The American standard for these fittings

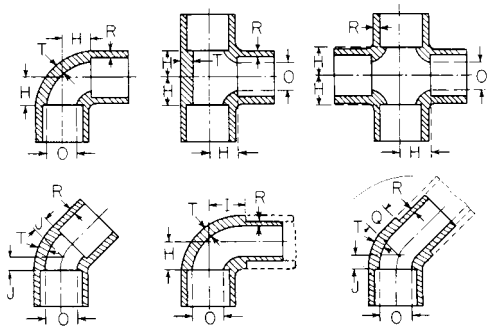
Table 8.7.44 Dimensions of American National Standard Cast-Iron Threaded Drainage Fittings
(All dimensions in inches)



Size, in	90° elbows*	45° elbows*	90° long-turn elbows	45° long-turn elbows	Three-way elbows†		Tees*		90° Y branches		90° long-turn *Y* branches			45° Y branches*	
	A	*A*	*A*	*A*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*C*	*A*	*B*
1¼	1¾	1 5/16	2¼	1¾	4½	2¼	1¾	3½	3¾	2¼	4¾	3⅝	1⅛	5	3¼
1½	1 5/16	1 7/16	2½	1⅞	5	2½	1 5/16	3⅞	4¼	2½	5⅜	4⅛	1¼	5½	3⅝
2	2¼	1 11/16	3 1/16	2¼	6⅛	3 1/16	2¼	4½	5 3/16	3 1/16	7	5¼	1¾	6½	4⅜
2½	2 11/16	1 15/16	3 11/16	2⅝	7⅝	3 11/16	2 11/16	5⅜	6 5/16	3 11/16	8¼	6¼	2	7⅞	5⅜
3	3 1/16	2 3/16	4¼	2 15/16	8½	4¼	3 1/16	6⅛	7¼	4¼	9⅞	7½	2⅜	9	6 3/16
4	3 13/16	2⅝	5 3/16	3½	10⅜	5 3/16	3 13/16	7⅝	8¾	5 3/16	13	9⅞	3⅛	10⅞	7 11/16
5	4½	3 1/16	6⅛	4⅛	12¼	6⅛	4½	9	10 5/16	6⅛	15¾	12¼	3½	12 15/16	9¾
6	5⅛	3 7/16	7⅛	4⅞	14¼	7⅛	5⅛	10¼	11 15/16	7⅛	18¾	14⅝	4⅛	14⅞	10¾

* Same as adopted for Class 125 Cast-iron Threaded Fittings, ANSI B16.4-1983.
† Three-way elbows have same dimensions as 90° long-radius elbows.
Double Y branches have the same dimensions as single Y branches.
Other fittings which are available are as follows: 5⅝, 11¼, and 60° elbows; basin tees and crosses; double 90° Y branches; double 90° long-turn Y branches; 45° double Y branches; S traps; half S traps; offsets, couplings, increasers, and reducing sizes.
SOURCE: ANSI B16.2-1983.

Table 8.7.45 Soldered-Joint Fittings—Dimensions of Elbows, Tees, and Crosses
(All dimensions in inches)



Nominal size	Cast brass†							Wrought metal
	*H**	*I*	*J*	*Q*	*O*‡	*T*	*R*	(*T* and *R*)§,¶
¼	¼	⅜	3⁄16	¼	0.31	0.08	0.048	0.030
⅜	5⁄16	7⁄16	3⁄16	5⁄16	0.43	0.08	0.048	0.035
½	7⁄16	9⁄16	3⁄16	5⁄16	0.54	0.09	0.054	0.040
¾	9⁄16	11⁄16	¼	⅜	0.78	0.10	0.060	0.045
1	¾	⅞	5⁄16	7⁄16	1.02	0.11	0.066	0.050
1¼	⅞	1	7⁄16	9⁄16	1.26	0.12	0.072	0.055
1½	1	1⅛	½	⅝	1.50	0.13	0.078	0.060
2	1¼	1⅜	9⁄16	¾	1.98	0.15	0.090	0.070
2½	1½	1⅝	⅝	⅞	2.46	0.17	0.102	0.080
3	1¾	1⅞	¾	1	2.94	0.19	0.114	0.090
3½	2	2⅛	⅞	1⅛	3.42	0.20	0.120	0.100
4	2¼	2⅜	15⁄16	1¼	3.90	0.22	0.132	0.110
5	3⅛		1 7⁄16		4.87	0.28	0.168	0.125
6	3⅝		1⅝		5.84	0.34	0.204	0.140

Wrought fittings as well as cast fittings, must be provided with a shoulder or stop at the bottom end of socket.

* Dimensions for reducing elbows, reducing crosses, reducing tees, couplings, caps, bushings, adapters, and fittings with pipe thread on one end are also included in this standard.

† These dimensions may be used for wrought metal fittings as well as for cast brass fittings at manufacturer's option.

‡ This dimension is the same as the inside diameter class L tubing (ASTM B88-1983).

§ This dimension has the same thickness as class L tubing.

¶ These dimensions are minimum, but in every case the thickness of wrought fittings should be at least as heavy as the tubing with which it is to be used.

SOURCE: ANSI B16.18-1984.

(ANSI B16.18-1984) covers certain dimensions of soldered-joint wrought metal and cast brass fittings for copper water tubing including (1) detailed dimensions of the bore, (2) minimum specifications for materials, (3) minimum inside diameter of the fitting, (4) metal thickness for both wrought metal and cast brass fittings, and (5) general dimensions for cast brass fittings including center-to-shoulder dimensions for both straight and reducing cast fittings. Pressure and temperature ratings are also given. Sizes of the fittings are identified by the nominal tubing size as covered by the Specifications for Copper Water Tube (ASTM B88-1983). Dimensions of some of the fittings from this standard are given in Table 8.7.45.

Valves

The face-to-face dimensions of ferrous flanged and welding end valves are given in ANSI B16.10-1973. The types covered are:

Wedge-Gate Valves Cast iron, for 125-, 175-, and 250-lb/in^2 (862, 1,207, and 1,724 kPa) steam service pressure and 800-lb/in^2 (5,516 kPa) hydraulic pressure, and steel, for 150-, 300-, 400-, 600-, 900-, and 1,500-lb/in^2 (1,034-, 2,068-, 2,758-, 4,137-, 6,206-, and 10,343-kPa) steam service pressures (see Fig. 8.7.11).

Double-Disk Gate Valves Cast iron, for 125- and 250-lb/in^2 (862- and 1,724-kPa) steam service pressure and 800-lb/in^2 (5,516-kPa) hydraulic pressure.

Globe and Angle Valves Cast iron, for 125- and 250-lb/in^2 (862- and 1,724-kPa) steam service pressure, and steel, for 150-, 300-, 400-, 600-, 900-, 1,500-, and 2,500-lb/in^2 (862-, 2,068-, 2,758-, 4,137-, 6,206-, 10,343-, and 17,238-kPa) steam service pressures (see Fig. 8.7.12).

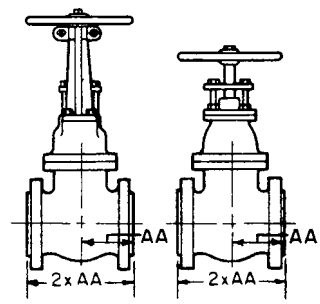


Fig. 8.7.11 Wedge gate valves.

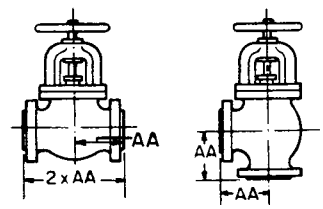


Fig. 8.7.12 Globe valve and angle valve.

Swing-Check Valves Cast iron, for 125- and 250-lb/in² (862- and 1,724-kPa) steam service pressure and 800-lb/in² (5,516-kPa) hydraulic pressure, and steel, for 150-, 300-, 400-, and 600-lb/in² (1,034-, 2,068-, 2,758-, and 4,137-kPa) steam service pressures.

Except for ring-joint facings to the face-to-face dimension for flanged valves is the distance between the faces of the connecting end flanges upon which the gaskets are actually compressed, i.e., the ''contact surfaces.''

All flanges for class 125 cast-iron valves are plain-faced. The facings of the class 250 cast-iron, and the class 150 and 300 steel valves have a 1⁄16-in raised face which is included in the contact-surface to contact-surface dimensions. The contact-surface to contact-surface dimensions of steel valves for class 400 and higher pressures and for cast-iron valves for class 800 hydraulic pressure include a ¼-in raised face.

The end-to-end dimensions for **welding-end** valves for sizes NPS 1 to 8 are the same as the contact-surface to contact-surface dimensions given in the tables for steel valves. For details of welding bevel see ANSI B16.10-1973 and Fig. 8.7.15.

A plus or minus **tolerance** of 1⁄16 in is allowed on all face-to-face dimensions of valves NPS 10 and smaller, and a tolerance of ⅛ on sizes NPS 12 and larger.

Cocks The ordinary plug cock operated by a handle or wrench is a form of valve in comparatively small sizes suitable for ordinary service only. The ASME Code for Pressure Piping requires that where cocks are used for high-temperature service they shall be so designed as to prevent galling, either by making the plugs of different material from the body of the cock or by treating the plugs to ensure different physical properties. By means of special design features that eliminate the tendency to leak and stick, the plug-cock type of valve has become available in large sizes and for severe service conditions. Sizes are listed as high as 30 in and are gear-operated in the larger sizes. For further details, refer to manufacturers' catalogs.

Expansion and Flexibility

Piping systems must be designed so that they (1) will not fail because of excessive stresses, (2) will not produce excessive thrusts or moments at connected equipment, or (3) will not leak at joints because of expansion of the pipe. Flexibility is provided by changes of direction in the piping through the use of bends or loops, or provision may be made to absorb thermal strains by use of expansion joints. All, or portions, of the pipe may be corrugated to improve flexibility; in many systems, however, sufficient change is provided by the geometry of the layout to make unnecessary the use of either expansion joints or corrugated sections of piping. Proper cold springing is beneficial in assisting the piping system to attain its most favorable condition. Because of plastic flow of the piping material, hot stresses tend to decrease with time while cold stresses tend to increase with time; their sum, called the stress range, remains substantially constant. For this reason no credit is warranted with regard to stresses; for calculation of forces and moments, the effect of cold spring is recognized by use of a cold-spring factor varying from 0 to 1 for cold spring varying from 0 to 100 percent.

The allowable stress range S_A is calculated by

$$S_A = f(1.25S_c + 0.25S_h)$$

where S_c and S_h are the S values for the minimum cold and maximum hot conditions, respectively, as given in Table 8.7.15. The stress-reduction factor f is a function of the number of hot-to-cold-to-hot (full) temperature cycles anticipated over the life of the plant, as follows:

Total no. of full temp cycles over expected life	*Stress-reduction factor*
7,000 and less	1.0
14,000 and less	0.9
22,000 and less	0.8
45,000 and less	0.7
100,000 and less	0.6
Over 100,000	0.5

The bending and torsional stresses calculated (see paragraph 119.6.4 of ANSI B31.1.0-1983) are used to determine the maximum computed expansion stress $S_E = \sqrt{S_b^2 + 4S_t^2}$, where S_b and S_t are bending and torsional stresses, respectively. S_E must not exceed the allowable stress range S_A.

In recent years, many principal high-temperature steam lines have either been analyzed, tested in a model-testing machine, or both. No rigid rule is stipulated for the requirement of analysis or model test; however, the Code for Pressure Piping suggests that when the following criterion is not satisfied, need for an analysis is indicated: $DY/(L - U)^2 \leq 0.03$, where D is the nominal pipe size, in; Y is the resultant of movements to be absorbed by pipeline, in; U is the length of straight line joining the anchor points, ft; and L is the length of the developed line axis, ft.

Expansion Joints for Steam Pipelines In many instances it may be economical to care for thermal expansion by use of expansion joints. For low-pressure steam lines, the use of packed expansion joints may be feasible; experience has indicated that packed joints are difficult to maintain when used on high-pressure lines. Figure 8.7.13 shows a type of joint that has been successfully used for high-pressure, high-temperature service. The bellows is designed to take either axial, lateral, or combined axial and lateral deflections. The internal sleeve guides movement of the joint and also protects the flexible bellows from direct contact with the fluid being handled. Face-to-face dimensions, as well as permissible axial and lateral deflections, are indicated in Table 8.7.46.

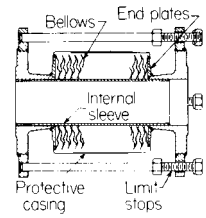


Fig. 8.7.13 Expansion joint for steam line. *(Croll-Reynolds, Inc.)*

Where large lateral deflections are to be absorbed, two expansion joints separated by a length of pipe as shown in Fig. 8.7.14 may be used. With such an arrangement, the lateral deflection permissible with one joint only may be increased many times. Tie rods, as shown, should always be installed to protect the joint against overtravel and externally to guide movement of the joint.

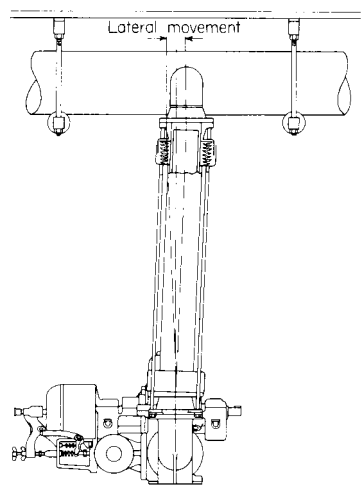


Fig. 8.7.14 Arrangement of expansion joints for large lateral deflection. *(Croll-Reynolds, Inc.)*

Table 8.7.46 Dimensions of Expansion Joints*

Pipe size	Pressure series, lb/in² gage	Face-to-face dimensions,† axial movements of			Lateral movements‡ equivalent to axial movements of		
		1 in	2 in	3 in	1 in	2 in	3 in
4	150	8½	11	15½	1/16	1/4	9/16
	300	12	17	24	1/8	1/2	1
	600	17½	26½		1/4	1	
	900	31½			11/16		
6	150	9½	12	16½	1/16	3/16	3/8
	300	13	18	25	3/32	13/32	15/16
	600	18½	27½		7/32	27/32	
	900	33½			1/2		
8	150	10½	13	17½	1/32	3/16	3/8
	300	14	19	26	3/32	3/8	27/32
	600	20	29		3/16	3/4	
	900	35½			15/32		
10	150	10½	13	17½	1/32	1/8	5/16
	300	14	19	26	1/16	5/16	23/32
	600	21½	30½		5/32	5/8	
	900	37			3/8		
12	150	22½	14	18½	1/32	1/8	1/4
	300	15	20	27	1/16	1/4	19/32
	600	21½	30½		1/8	1/2	
	900	38½			5/16		
14	100	12½	15½		1/32	1/8	
	150	15	20		1/16	7/32	
	300	20½			3/32		
16	100	12½	15½		1/32	3/32	
	150	15	20		1/32	3/16	
	300	20½			3/32		
18	100	13½	16½		1/32	3/32	
	150	16	21		1/32	3/16	
	300	21½			3/32		
20	100	14½	16½			3/32	
	150	16	21		1/32	3/16	
	300	21½			3/32		
24	100	14½	17½			1/16	
	150	17	22		1/32	5/32	
	300	22½			1/16		
30	100	9½	12½			1/16	
	150	12	17		1/32	1/8	
	300	19½			1/16		

* Croll-Reynolds, Inc.
† For welding ends, add 4 in to face-to-face dimension shown.
‡ Consult manufacturer for permissible combined axial and lateral deflection.

Table 8.7.47 Thermal Expansion Data

Material	Coef-ficient	Temp range: 70°F (21°C) to: 70 (21)	200 (93)	300 (149)	400 (205)	500 (260)	600 (316)	700 (371)	800 (427)	900 (482)	1,000 (538)	1,100 (593)	1,200 (649)	1,300 (705)	1,400 (760)
Carbon steel: carbon-moly steel low-chrome steels (through 3% Cr)	*A*		6.38	6.60	6.82	7.02	7.23	7.44	7.65	7.84	7.97	8.12	8.19	8.28	8.36
	B	0	0.99	1.82	2.70	3.62	4.60	5.63	6.70	7.81	8.89	10.04	11.10	12.22	13.34
Intermediate alloy steels: 5 Cr Mo-9 Cr Mo	*A*		6.04	6.19	6.34	6.50	6.66	6.80	6.96	7.10	7.22	7.32	7.41	7.49	7.55
	B	0	0.94	1.71	2.50	3.35	4.24	5.14	6.10	7.07	8.06	9.05	10.00	11.06	12.05
Austenitic stainless steels	*A*		9.34	9.47	9.59	9.70	9.82	9.92	10.05	10.16	10.29	10.39	10.48	10.54	10.60
	B	0	1.46	2.61	3.80	5.01	6.24	7.50	8.80	10.12	11.48	12.84	14.20	15.56	16.92
Straight chromium stainless steels: 12 Cr, 17 Cr, and 27 Cr	*A*		5.50	5.66	5.81	5.96	6.13	6.26	6.39	6.52	6.63	6.72	6.78	6.85	6.90
	B	0	0.86	1.56	2.30	3.08	3.90	4.73	5.60	6.49	7.40	8.31	9.20	10.11	11.01
25 Cr-20 Ni	*A*		7.76	7.92	8.08	8.22	8.38	8.52	8.68	8.81	8.02	9.00	9.08	9.12	9.18
	B	0	1.21	2.18	3.20	4.24	5.33	6.44	7.60	8.78	9.95	11.12	12.31	13.46	14.65
Monel 67: Ni-30 Cu	*A*		7.84	8.02	8.20	8.40	8.58	8.78	8.96	9.16	9.34	9.52	9.70	9.88	10.04
	B	0	1.22	2.21	3.25	4.33	5.46	6.64	7.85	9.12	10.42	11.77	13.15	14.58	16.02
Monel 66: Ni-29 CuAl	*A*		7.48	7.68	7.90	8.09	8.30	8.50	8.70	8.90	9.10	9.30	9.50	9.70	9.89
	B	0	1.17	2.12	3.13	4.17	5.28	6.43	7.62	8.86	10.16	11.50	13.00	14.32	15.78
Aluminum	*A*		12.95	13.28	13.60	13.90	14.20								
	B	0	2.00	3.66	5.39	7.17	9.03								
Gray cast iron	*A*		5.75	5.93	6.10	6.28	6.47	6.65	6.83	7.00	7.19				
	B	0	0.90	1.64	2.42	3.24	4.11	5.03	5.98	6.97	8.02				
Bronze	*A*		10.03	10.12	10.23	10.32	10.44	10.52	10.62	10.72	10.80	10.90	11.00		
	B	0	1.56	2.79	4.05	5.33	6.64	7.95	9.30	10.68	12.05	13.47	14.92		
Brass	*A*		9.76	10.00	10.23	10.47	10.69	10.92	11.16	11.40	11.63	11.85	12.09		
	B	0	1.52	2.76	4.05	5.40	6.80	8.26	9.78	11.35	12.98	14.65	16.39		
Wrought iron	*A*		7.32	7.48	7.61	7.73	7.88	8.01	8.13	8.29	8.39				
	B	0	1.14	2.06	3.01	3.99	5.01	6.06	7.12	8.26	9.36				
Copper-nickel (70/30)	*A*		8.54	8.71	8.90										
	B	0	1.33	2.40	3.52										

A = mean coefficient of thermal expansion × 10^6, in/(in · °F) in going from 70°F (21°C) to indicated temperature.
B = linear thermal expansion, in/100 ft in going from 70°F (21°C) to indicated temperature.
Multiply values of *A* shown by 1.8 to obtain coefficient of expansions in cm/(cm · °C).
Multiply values of *B* shown by 8.33 to obtain linear expansion in cm per 100 m.
SOURCE: ANSI B31.1-1983.

Table 8.7.47, extracted from the Code for Pressure Piping, lists thermal-expansion data for both ferrous and nonferrous piping. For expansion at temperatures intermediate between those shown, straight-line interpolation is permitted.

The **rubber expansion joint** has become an established part of pipeline equipment. Its special field of application is on low-pressure and vacuum lines in condenser applications, etc., and it is recommended for pressures up to 25 lb/in^2 (172 kPa) gage where the maximum temperature does not exceed 250°F. Standard joints for pressure installations are reinforced to withstand working pressures up to 125 lb/in^2 (862 kPa) gage and temperatures up to 200°F. Joints are available in all standard pipe sizes.

Welding in Power-Plant Piping

(For dimensions of welding fittings see Tables 8.7.48 to 8.7.51; for welding techniques see also Sec. 13.3.)

The majority of main-cycle and service steel piping in modern steam power plants is of welded construction. Steel pipe of NPS 2 and smaller is generally socket-welded; larger-size piping is usually butt-welded. Frequently, depending on location and scheduling, piping larger than NPS 2 is prefabricated; smaller piping is shipped to the construction site in random lengths and is fabricated concurrently with installation. Small-sized chromium-molybdenum piping requiring bending is frequently also shop-fabricated so as to avoid high field preheat, welding, and stress-relieving costs. It is desirable to schedule shipment of

Table 8.7.48 Dimensions of Long-Radius 90° Butt-Welding Elbows
(Standard weight—ANSI B16.9-1978, ASTM A234)
(All dimensions in inches)

Nominal pipe size	OD	ID	Wall thickness	Center to face	Pipe schedule numbers	Approx wt, lb
2½	2.875	2.469	0.203	3¾	40	2.92
3	3.500	3.068	0.216	4½	40	4.58
3½	4.000	3.548	0.226	5¼	40	6.43
4	4.500	4.026	0.237	6	40	8.70
5	5.563	5.047	0.258	7½	40	14.7
6	6.625	6.065	0.280	9	40	22.9
8	8.625	7.981	0.322	12	40	46.0
10	10.750	10.020	0.365	15	40	81.5
12	12.750	12.000	0.375	18	ST*	119
14	14.000	13.250	0.375	21	30	154
16	16.000	15.250	0.375	24	30	201
18	18.000	17.250	0.375	27	ST*	256
20	20.000	19.250	0.375	30	20	317
22	22.000	21.250	0.375	33	ST*	385
24	24.000	23.250	0.375	36	20	458
26	26.000	25.250	0.375	39	ST*	539
30	30.000	29.250	0.375	45	ST*	720
34	34.000	33.250	0.375	51	ST*	926
36	36.000	35.250	0.375	54	ST*	1,040
42	42.000	41.250	0.375	63	ST*	1,420

* Standard weight.

Table 8.7.49 Dimensions of Straight Butt-Welding Tees
(Standard weight—ANSI B16.9-1978, ASTM A234)
(Dimensions in inches)

Nominal pipe size	OD	ID	Wall thickness	Center to end	Pipe schedule numbers	Approx wt, lb
2½	2.875	2.469	0.203	3	40	5.21
3	3.500	3.068	0.216	3⅜	40	7.44
3½	4.000	3.548	0.226	3¾	40	9.85
4	4.500	4.026	0.237	4⅛	40	12.6
5	5.563	5.047	0.258	4⅞	40	19.8
6	6.625	6.065	0.280	5⅝	40	29.3
8	8.625	7.981	0.322	7	40	53.7
10	10.750	10.020	0.365	8½	40	91.2
12	12.750	12.000	0.375	10	ST*	132
14	14.000	13.250	0.375	11	30	172
16	16.000	15.250	0.375	12	30	219
18	18.000	17.250	0.375	13½	ST*	282
20	20.000	19.250	0.375	15	20	354
22	22.000	21.250	0.375	16½	ST*	437
24	24.000	23.250	0.375	17	20	493
26	26.000	25.250	0.375	19½	ST*	634
30	30.000	29.250	0.375	22	ST*	855
34	34.000	33.250	0.375	25	ST*	1,136
36	36.000	35.250	0.375	26½	ST*	1,294

* Standard weight.

Table 8.7.50 Dimensions of Long-Radius 45° Butt-Welding Elbows
(Standard weight—ANSI B16.9-1978, ASTM A234)
(Dimensions in inches)

Nominal pipe size	OD	ID	Wall thickness	Center to face	Radius	Pipe schedule numbers	Approx wt, lb
2½	2.875	2.469	0.203	1¾	3¾	40	1.64
3	3.500	3.068	0.216	2	4½	40	2.43
3½	4.000	3.548	0.226	2¼	5¼	40	3.29
4	4.500	4.026	0.237	2½	6	40	4.31
5	5.563	5.047	0.258	3⅛	7½	40	7.30
6	6.625	6.065	0.280	3¾	9	40	11.3
8	8.625	7.981	0.322	5	12	40	22.8
10	10.750	10.020	0.365	6¼	15	40	40.4
12	12.750	12.000	0.375	7½	18	ST*	59.5
14	14.000	13.250	0.375	8¾	21	30	76.5
16	16.000	15.250	0.375	10	24	30	100
18	18.000	17.250	0.375	11¼	27	ST*	128
20	20.000	19.250	0.375	12½	30	20	158
22	22.000	21.250	0.375	13½	33	ST*	192
24	24.000	23.250	0.375	15	36	20	229
26	26.000	25.250	0.375	16	39	ST*	269
30	30.000	29.250	0.375	18½	45	ST*	358
34	34.000	33.250	0.375	21	51	ST*	463
36	36.000	35.250	0.375	22¼	54	ST*	518
42	42.000	41.250	0.375	26	63	ST*	707

* Standard weight.

hangers so that they will be available at the job site upon arrival of the prefabricated piping; this avoids the expense of providing, installing, and later removing temporary hangers and supports. Aside from the economy of welded construction, it is a virtual necessity in high-pressure, high-temperature work because of danger of leakage if joints are flanged.

Shop welds are frequently made by automatic or semiautomatic submerged-arc or inert-gas shielded-arc processes; field welds are gener-

Table 8.7.51 Dimensions of Concentric and Eccentric Butt-Welding Reducers
(Standard weight—ANSI B16.9-1978, ASTM A234)
(Dimensions in inches)

Nominal pipe size	Length	Approx wt, lb	Nominal pipe size	Length	Approx wt, lb	Nominal pipe size	Length	Approx wt, lb	
2½ × 1	3½	1.30	8 × 6	6	13.4	22 × 20	20	157	
2½ × 1¼	3½	1.47	8 × 6	6	13.9	24 × 16	20	160	
2½ × 1½	3½	1.51	10 × 4	7	21.1	24 × 18	20	163	
2½ × 2	3½	1.60	10 × 5	7	21.8	24 × 20	20	167	
3 × 1¼	3½	1.70	10 × 6	7	22.3	26 × 18	24	200	
3 × 1½	3½	1.89	10 × 8	7	23.2	26 × 20	24	200	
3 × 2	3½	2.00	12 × 5	8	30.5	26 × 22	24	200	
3 × 2½	3½	2.16	12 × 6	8	31.1	26 × 24	24	200	
3½ × 1¼	4	2.35	12 × 8	8	32.1	30 × 20	24	220	
3½ × 1½	4	2.52	12 × 10	8	33.4	30 × 24	24	220	
3½ × 2	4	2.71	14 × 6	13	55.8	30 × 26	24	220	
3½ × 2½	4	2.96	14 × 8	13	57.2	30 × 28	24	220	
3½ × 3	4	3.05	14 × 10	13	60.4				
4 × 1½	4	2.73	14 × 12	13	63.4			Conc.	Ecc.
4 × 2	4	3.17	16 × 8	14	70.2	34 × 24	24	270	229
4 × 2½	4	3.34	16 × 10	14	72.9	34 × 26	24	270	237
4 × 3	4	3.50	16 × 12	14	75.6	34 × 30	24	270	253
4 × 3½	4	3.61	16 × 14	14	77.5	34 × 32	24	270	261
5 × 2	5	5.05	18 × 10	15	86.9	36 × 24	24	340	237
5 × 2½	5	5.52	18 × 12	15	89.2	36 × 26	24	340	245
5 × 3	5	5.73	18 × 14	15	90.9	36 × 30	24	340	261
5 × 3½	5	5.86	18 × 16	15	94.0	36 × 32	24	340	269
5 × 4	5	5.99	20 × 12	20	134	36 × 34	24	340	277
6 × 2½	5½	7.61	20 × 14	20	135	42 × 24	24	260	
6 × 3	5½	8.00	20 × 16	20	138	42 × 26	24	270	
6 × 3½	5½	8.14	20 × 18	20	142	42 × 30	24	285	
6 × 4	5½	8.19	22 × 14	20	148	42 × 32	24	295	
6 × 5	5½	8.65	22 × 16	20	151	42 × 34	24	300	
8 × 3½	6	12.8	22 × 18	20	154	42 × 36	24	310	
8 × 4	6	13.1							

ally of the manual type and may be done by the shielded metal-arc and/or inert-gas metal-arc processes. Welding in power piping systems, whether in the shop or at the job site, must be done by welders who have qualified under provisions of the Code for Pressure Piping or the ASME Boiler and Pressure Vessel Code.

End Preparation for Butt Welds Figure 8.7.15 shows the end preparation recommended (not required) for piping whose wall thickness is ¾ in or less, and Fig. 8.7.16 shows that required for piping with wall thickness above ¾ in. During the welding process, to avoid entrance of welding material into the pipe, backing rings may be used as shown in Fig. 8.7.17*a*, *b*, and *c*.* Note that thick-walled pipes (over ¾ in) are taper-bored on the inside in order that they may receive a tapered, machined backing ring.

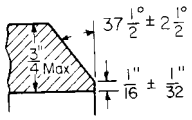


Fig. 8.7.15 Recommended end preparation for pipe wall thickness of ¾ in or less.

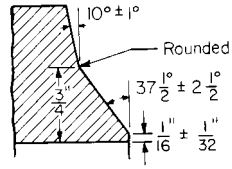


Fig. 8.7.16 Recommended end preparation for pipe wall thickness greater than ¾ in.

Preheating Prior to start of welding, many materials require preheat to a specified temperature: preheat may be done by electrical-resistance or induction heating or by ring-type gas burners placed concentrically with the pipe. The preheat temperature is measured by indicating crayons or by thermocouple pyrometers and must be maintained during the welding operation. Table 1, Appendix D, of the Code for Pressure Piping lists materials used in piping systems and the appropriate temperatures for preheat. In general, the following is indicative of the intent only; for specific instances, the Code must be consulted.

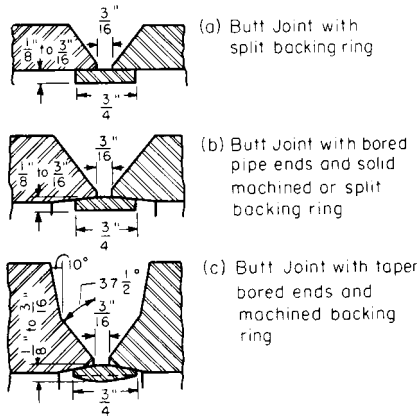


Fig. 8.7.17 Recommended backing ring types. (*a*) Butt joint with split backing ring; (*b*) butt joint with bored pipe ends and solid machined or split backing ring; (*c*) butt joint with taper-bore ends and machined backing ring.

Carbon steel and **wrought iron** should be preheated to a ''hand-hot'' condition if the ambient temperature at time of field installation is 32°F (0°C) or less: carbon steels which have minimum tensile properties of 70,000 lb/in^2 (483 MPa) or higher should be preheated to 250°F (121°C); under other conditions, preheat is not mandatory, but some purchasers insist that the contractor preheat heavy-walled piping such as boiler feed.

* Consumable inserts are also available. They are recommended for installation in piping systems which require a smooth, unobstructed interior surface.

Low-alloy steels with a chromium content not exceeding ¾ percent and low-alloy steels with a total alloy content not exceeding 2 percent are required to be preheated to a minimum temperature of 300°F (149°C).

Alloy steels with a chromium content between ¾ and 2 percent and low-alloy steels with a total alloy content not exceeding 2¾ percent require preheating to 375°F (191°C) minimum. Those with a total alloy content greater than 2¾ percent but not exceeding 10 percent require preheating to a temperature of 450°F (232°C) minimum.

High-alloy steels containing the martensitic phase require preheating to 450°F (232°C) minimum; preheating is a matter of agreement between the purchaser and contractor in the case of welding high-alloy ferritic steels (ASTM A240 and A268). The possible advantages of preheat have not been established in the case of welding high-alloy austenitic steels, and for this reason the Code for Pressure Piping states that preheat is optional for these materials.

Welding procedure varies with material and welding process. In general, the pipe ends must be cleaned of oil or grease, and excessive amounts of scale or rust should be removed. The size and type of welding rod must be stated; the number of layers or passes is determined by the thickness of the pieces being joined. All slag or flux remaining on any bead of welding must be removed before laying down the next successive bead; any cracks or blowholes that appear on the surface of any bead must be chipped or ground away before the next bead of weld material is deposited. Throughout the welding process, it is essential that the minimum specified preheat temperature be maintained.

Stress Relieving Welded joints in all carbon-steel material whose thickness is ¾ in (1.91 cm) or greater must be stress-relieved at a temperature of 1,100°F (593°C) or over for a period of time proportioned on the basis of at least 1 h/in of pipe-wall thickness (but in no case less than ½ h) and then allowed to cool slowly (generally under a blanket) and uniformly. No stress relief is required for joints in carbon-steel piping whose wall thickness is less than ¾ in.

Welded joints in alloy steels with a wall thickness of ½ in (1.27 cm) or greater, having a chromium content not exceeding ¾ percent, and low-alloy steels with a total alloy content not exceeding 2 percent require stress-relieving at a temperature of 1,200°F (649°C) or over for a period of time proportioned on the basis of at least 1 h/in (0.4 h/cm) of wall thickness, but in no case less than ½ h.

Welded joints in alloy steels having a chromium content exceeding ¾ percent, or a total alloy content exceeding 2 percent, except high-alloy ferritic (ASTM A240, A268) and austenitic steels, regardless of wall thickness, require stress relief at a temperature of 1,200°F or over for a period of time proportioned on the basis of at least 1 h/in of wall thickness, but in no case less than ½ h. Stress relief of high-alloy ferritic steel (A240, A268) and austenitic steels is not required but may be performed as agreed upon by purchaser and contractor. In welds between austenitic and ferritic materials, stress relieving is optional and, if used, shall be a matter of agreement between the purchaser and contractor. Because of the difference between the coefficients of thermal expansion of the two dissimilar materials, careful consideration should be given to the selection of a heat treatment, if any, that will be beneficial to the welded joint.

Graphitization is precipitation of carbon at the grain boundaries in the heat-affected zone during the welding process. Such a phenomenon occurs when some metals operate at high temperatures for extended periods. It has been observed particularly in carbon-molybdenum steels that operate at 900°F (482°C) or higher.

Graphitization does not generally occur in carbon-molybdenum steels with over 1 percent molybdenum. It also has generally not occurred in the chromium-molybdenum low-alloy steels operated at temperatures between 900°F (482°C) and 1,050°F (566°C). Where graphitization has occurred, the two most commonly used methods for rehabilitation of the pipe are (1) gouging out the heat-affected zone of the weld deposit and rewelding the area with electrodes depositing carbon-molybdenum weld metal, followed by a stabilization heat treatment at 1,300°F (704°C) for 4 h, or (2) solution annealing the weld joints at 1,800°F (982°C), followed by a stabilization heat treatment.

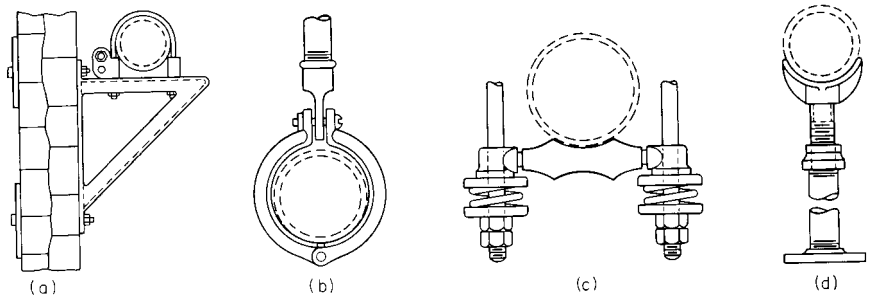


Fig. 8.7.18 Methods of supporting pipes.

Pipe Supports

The Code for Pressure Piping includes many types of supports and gives directions for their application. A proper pipe support must have a strong rigid base properly supported, and an adjustable roll construction which will maintain the alignment in any direction. It is important to avoid friction caused by the movement of the pipe in the support and to have all parts of sufficient strength to maintain alignment at all times. Wire hangers, band iron hangers, wooden hangers, hangers made from small pipe, and hangers having one vertical pipe support do not maintain alignment.

The direction of expansion in a pipe run can be predetermined by anchoring one end, both ends, or the middle. **Anchors** must be firmly fastened to a rigid and heavy part of the power-plant structure, and must also be securely fastened to the pipe; otherwise the equipment for absorbing expansion is useless, and severe stresses may be thrown on parts of the piping system. Some methods of support are shown in Figs. 8.7.18 and 8.7.19. Welded steel brackets (Fig. 8.7.18*a*) are available in light, medium, and heavy weights. Many types of supports can be mounted on these brackets, such as the anchor chair shown on the bracket at (*a*), pipe roller supports of the type at (*c*), pipe roll stands of various types such as shown in Fig. 8.7.19, pipe seats, etc. Figure 8.7.18*b* illustrates one of the many types of adjustable ring hangers in use. The split ring hanger can be applied after the pipeline is in place. At (*c*) in Fig. 8.7.18 is shown a spring cushion pipe roll hanger recommended for service where constant support* is required and compensation must be made for movement of the piping. The springs provide an efficient means of absorbing the vibration. Figure 8.7.18*d* shows one of the many types of pipe saddle supports available. Figure 8.7.19 shows a cast-iron pipe roll stand designed for cases where vertical adjustment is not necessary but where provision must be made for expansion and contraction of the pipeline. Several designs of such stands with provision for vertical adjustment and of the same general dimensions are also available. One type of cast-iron roll and plate, illustrated in Fig. 8.7.19, provides for expansion and contraction where vertical adjustment is not necessary. If necessary, the baseplate can be raised or lowered by use of shims. Detailed information and dimensions of a great variety of pipe supports can be found in manufacturers' catalogs.

In supporting a high-temperature piping system, it is necessary to provide for expansion and contraction due to cyclic changes. It is often possible to find a point of zero movement along the run of a long line and to support a considerable portion of the total load by a rigid hanger or support of the type shown in Figs. 8.7.18 and 8.7.19. However, for other portions of the run, some form of spring support is often indicated. For relatively light lines, which are not subjected to excessive movements from hot to cold positions, a variable spring hanger will frequently suffice; for heavy lines, or those in which expansion movements are great, it is advisable to use constant support of counterweighted hangers so that transfer of weight to other hangers or equipment connections is prevented. Parts (*a*) and (*b*) of Fig. 8.7.20 indicate, respectively, a horizontal and vertical run of piping supported by a **constant-support hanger**. Figure 8.7.20*c* and 8.7.21*a* indicate horizontal runs supported by **variable-spring hangers**. Figure 8.7.21*b* shows a riser supported by a variable spring beneath a base elbow. Figure 8.7.21*c* indicates a **sway brace** that is used to control vibration and undesirable movement in a piping system.

The principal supports utilized for the support of critical piping in-

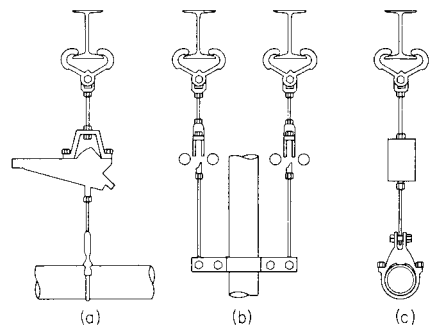


Fig. 8.7.20 Constant support and variable-spring hangers.

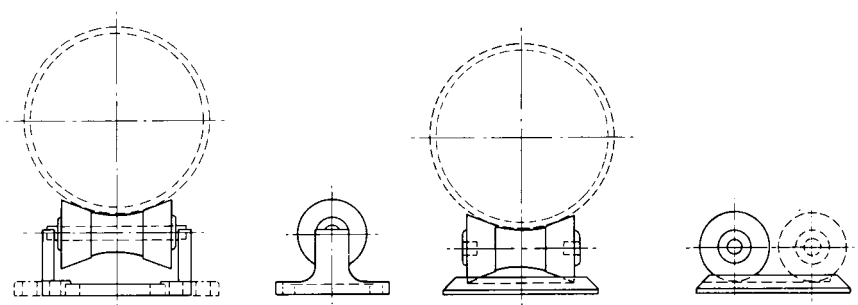


Fig. 8.7.19 Pipe supports on cast-iron rolls.

* The support afforded by the hanger of Fig. 8.7.18*c* is constant only in the sense that some degree of support is always present. It might be more appropriately termed a variable-support device.

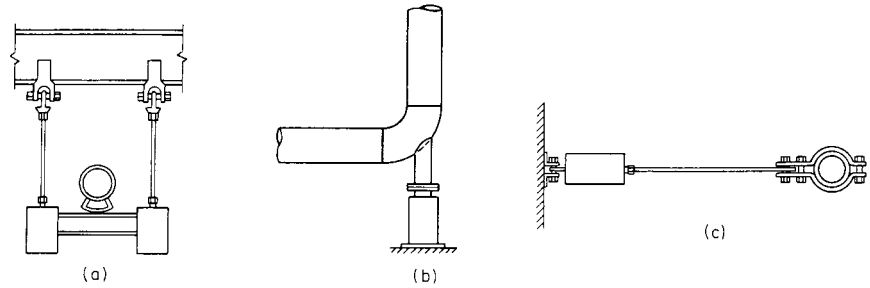


Fig. 8.7.21 Spring hangers and sway brace.

volve constant-support hangers, variable-spring hangers, rigid hangers, and restraints.

Constant-Support Hangers This type of hanger provides a constant supporting force for the piping system throughout its full range of vertical pipe movement. This is accomplished through use of a spring coil working in conjunction with a lever in such a way that the spring force times its distance to the lever pivot is always equal to the pipe load times its distance to the lever pivot. This type of support is ''thermally invisible,'' as the supporting force equals the pipe weight throughout its entire expansion or contraction cycles.

These hangers are used on systems or at locations where stresses are considered critical. Pipe weight reactions or transfer of loads are not imposed in the system or connections with this type of device.

As the load is considered constant with the unit in travel, readings from inspections are based on travel. The readings are taken from the position of an indicator and its relation to the numbers on the travel scale. The scale is divided into 10 divisions. H or high on the scale is equal to (0.0), M or midway on the scale is equal to (5.0), and L or low on the scale is equal to 10.

The design settings were obtained from the position of the factory-installed buttons that are placed adjacent to the travel scale.

''Perfect'' readings would be if the indicator were to line up with the white button (cold) and the red (hot); however, this is rarely the case. Generally, readings are considered acceptable and not noteworthy as long as they reflect movement consistent with design in both direction and length. A general rule is that when the hot setting is higher than the cold setting, then movement is down from cold to hot. If the cold setting is higher, movement is up.

The following terms are normally applied to these devices:

Actual travel: Anticipated movement of the pipe from design. The hot and cold position stickers are a function of this movement.

Total travel: The maximum movement a support can accept without danger of topping or bottoming out. The scale from H (0.0) to L (10.0) is a function of this.

Topped out: The indicator is above the high point and in contact with the end of the slot. This condition means the support is unloaded or is in the process of unloading.

Bottomed out: The indicator is below the (10.0) point and in contact with the end of the travel slot; the support is overloaded.

Variable-Spring Hangers These devices are installed at locations where stresses are not considered to be critical or where movement and economics permit their use.

The inherent characteristics of a variable are such that the supporting force varies with the spring's deflection. Movement of the pipe causes the spring to extend or compress. This results in a change or variance in the supporting force. Since the weight of the pipe is the same in either condition, hot or cold, the variation results in pipe weight transfer to equipment and adjacent hangers and consequently additional stresses in the piping system. The effects of this variation are usually considered during the original design.

In addition, as it is desirable to support the actual weight of the pipe when the system is hot, when the stresses tend to become most critical, the hot load is the dead weight of the pipe. The cold load is actually under- or oversupporting the pipe, depending on the movement from cold to hot.

The general rule for determining movement is similar to that of constant supports. If the hot load is higher than the cold, then pipe movement is down from cold to hot. If the cold load is higher, then movement is up.

Unlike constant supports, the readings from variables are measured in pounds. The readings are taken by noting the position of the indicator relative to a load scale that is adjacent to the travel slot.

The **distance between supports** will vary with the kind of piping and the number of valves and fittings. Supports should be provided near changes in direction, branch lines, and particularly near valves. The weight of piping must not be carried through valve bodies. In establishing the location of pipe supports, the designer should be guided by two requirements: (1) the horizontal span must not be so long that sag in the pipe will impose an excessive stress in the pipe wall and (2) the pipeline must be pitched downward so that the outlet of each span is lower than maximum sag in the span. Otherwise entrapped water can result in severe water hammer and pipe swings, particularly during plant start-up of steam piping.

Fabrication and installation practices are provided in MSS Standard Practice SP-89. Table 8.7.52 lists spacing for standard-weight pipe supports.

Pipe Insulation

(see Secs. 4 and 6 for heat-transmission data.)

The value of a steam-pipe covering is measured by its ability to reduce heat losses. This might range from 50 percent for small, low-temperature lines to 90 percent for large, high-temperature lines. Many **pipe-insulating materials** are available: 85 percent magnesia, foam glass, calcium silicate, and various forms of diatomaceous earths. Some of these materials are suited for relatively low temperatures only, others are best suited for high temperatures, and still others are suitable over a considerable temperature range.

Pipe insulation is applied in molded sections 3 ft long. For high-temperature work, the insulation is applied in at least two layers with the

Table 8.7.52 Maximum Spacing of Pipe Supports at 750°F (399°C)*

Nominal pipe size, in	1	1½	2	3	4	6	8	10	12	14	16	18	20	24
Maximum span, ft	7	9	10	12	14	17	19	22	23	25	27	28	30	32
Maximum span, m	2.13	2.74	3.05	3.66	4.27	5.18	5.79	6.71	7.01	7.62	8.23	8.53	9.14	9.75

* This tabulation assumes that concentrated loads, such as valves and flanges, are separately supported. Spacing is based on a combined bending and shear stress of 1,500 lb/in^2 when pipe is filled with water; under this condition, sag in pipeline between supports will be approximately 0.1 in.

joints staggered so as to prevent a direct channel for heat loss. Because of its maximum-temperature limitation of about 600°F (316°C), 85 percent magnesia is used as the second layer with a high-temperature-resistant material placed in direct contact with the pipe. The molded insulation is fastened securely in place with copper or galvanized wire and is then given a surface finish; indoor pipes are first sheathed with resin paper and covered with canvas, either pasted or sewed; outdoor pipes may be weather-protected by a coating of asphaltic-type waterproofing compound, they may be sheathed and canvased and then given a weatherproof surface, so they may be encased in metallic (steel or aluminum) jackets.

The heat loss from an insulated pipe appears in three phases: heat passes by *conduction* through the metallic pipe walls and through the insulating material; it then is dissipated from the outdoor surface of the insulation by *convection* and by *radiation.* Extremely accurate calculations must also take into account the temperature drop by convection through the film on the inside surface of the pipe. The task of accurately calculating heat losses is somewhat tedious, since the convection and radiation losses are related to the surface temperature (outside of insulation), which is unknown until conduction losses are balanced against surface losses.

For combined convection and radiation coefficients for bare pipes, and all necessary formulas to permit trial-and-error calculations, see Sec. 4. Insulation manufacturers publish data which give heat losses for wide ranges of pipe size and temperature.

Identification of Piping

The American National Standards Institute has approved a **Scheme for the Identification of Piping Systems** (ANSI A13.1-1981). This scheme is limited to the identification of piping systems in industrial plants, not including pipes buried in the ground, and electric conduits. Fittings, valves, and pipe coverings are included, but not supports, brackets, or other accessories.

Classification by Color All piping systems are classified by the nature of the material carried. Each piping system is placed, by the nature of its contents, in the following classifications:

Class	*Color*
F—Fire-protection equipment	Red
D—Dangerous materials	Yellow (or orange)
S—Safe materials	Green (or the achromatic colors, white, black, gray, or aluminum)
P—Protective materials	Bright blue
V—Extra valuable materials	Deep purple

Method of Identification At conspicuous places throughout a piping system, color bands should be painted on the pipes to designate to which one of the five main classes it belongs. If desired, the entire length of the piping system may be painted the main classification color.

Further, the actual contents of a piping system may be indicated by, preferably, a stenciled legend of standard size giving the name of the contents in full or abbreviated form. These legends should be placed on the color bands. The identification scheme may be extended by the use of colored stripes placed at the edges of the colored bands.

The bands, legends, and stripes should be placed at intervals throughout the piping system, preferably adjacent to valves and fittings to ensure ready recognition during operation, repairs, and at times of emergency.

A recommended classification, under this color scheme of materials carried in pipes, includes, as dangerous, combustible gases and oils, hot water and steam above atmospheric pressure; as safe, compressed air, cold water, and steam under vacuum.

Pressure Hose

Hose with durable rubber lining may be obtained to withstand any needed pressure. If the rubber compound is properly made, the life of a hose will be 7 to 10 years, while a cheaper hose, lined with inferior material, will probably not last more than 3 or 4 years. See also Secs. 3 and 12.

American National Fire-Hose Coupling Screw Thread (ANSI B1.20-7-1966) This standard is intended to cover the threaded part of fire-hose couplings, hydrant outlets, standpipe connections, and at other special fittings on fire lines, where fittings of the nominal diameters given in Table 8.7.53 are used. It also includes the limiting dimensions of the field inspection gages. The American National Standard form of thread must be used.

Table 8.7.53 Dimensions of Standard Fire-Hose Couplings
(All dimensions in inches. Letters refer to Fig. 8.7.22)

Inside diam, *C*	Diam of thread, *D*	No. of threads per inch	*L*	*I*	*H*	*J*	*T*
2½	3 1/16	7½	1	¼	15/16	3/16	11/16
3	3 5/8	6	1⅛	5/16	1 1/16	¼	13/16
3½	4¼	6	1⅛	5/16	1 1/16	¼	13/16
4½	5¾	4	1¼	7/16	1 3/16	⅜	15/16

SOURCE: ANSI B1.20.7-1966.

American National Standard Hose-Coupling Screw Threads (ANSI B1.20.7-1966) These standards apply to the threaded parts of hose couplings, valves, nozzles, and all other fittings used in direct connection with hose intended for fire protection or for domestic, industrial, or general service in nominal sizes given in Table 8.7.54. The American

Table 8.7.54 Dimensions of Standard Hose Couplings
(All dimensions in inches. Letters refer to Fig. 8.7.22)

Service and nominal size	Inside diam, *C*	Diam of thread, *D*	No. of threads per inch	*L*	*I*	*H*	*T*
Garden:							
½, ⅝, ¾	25/32	1 1/16	11½	9/16	⅛	17/32	⅜
Chemical:							
¾, 1	1 1/32	1⅜	8	⅝	5/32	19/32	15/32
Fire:							
1½	1 17/32	2	9	⅝	5/32	19/32	15/32
Other connections:							
½	17/32	13/16	14	½	⅛	15/32	5/32
¾	25/32	1 1/32	14	9/16	⅛	17/32	⅜
1	1 1/32	1 9/32	11½	9/16	5/32	17/32	⅜
1¼	1 9/32	1⅝	11½	⅝	5/32	19/32	15/32
1½	1 17/32	1⅞	11½	⅝	5/32	19/32	15/32
2	2 1/32	2 11/32	11½	¾	3/16	23/32	19/32

SOURCE: ANSI B1.20.7-1966.

National Standard thread form is used. This coupling is similar in design to the fire-hose couplings illustrated in Fig. 8.7.22.

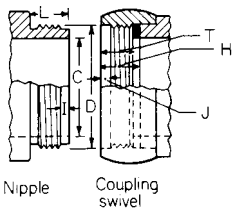


Fig. 8.7.22 Typical form of standard coupling.

Flexible metal hose and tubing are available for a wide range of conditions of temperature, pressure, vibration, and corrosion, and are made in two basic constructions, corrugated or interlocked, and in either bronze or steel.

The corrugated type (Fig. 8.7.23) may have either annular or helical corrugated formations, usually covered with metal braid, and is adapted to high-pressure high-temperature leak-proof service. Some typical applications include diesel-engine exhaust hose, reciprocating flexible connections, loading and unloading hose, saturated and superheated steam lines, lubricating lines, gas and oil lines, vibration connections, etc.

The interlocked type is made in several ways; the fully interlocked type is illustrated in Fig. 8.7.24. Typical applications include wiring conduit, cable armor, decorative wiring covering, dust-collective tubing, grease and oil connections, flexible spouts, and moderate-pressure oil lines.

Standard couplings and fittings can be attached to flexible metal hose or tubing by various methods such as brazing or welding. Each type of hose construction has limits of service use and proved application usages. Information and recommendations as to the type and size to use under any given conditions should be obtained from the manufacturers.

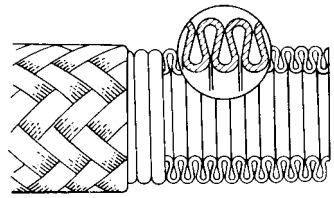


Fig. 8.7.23 Flexible metal hose.

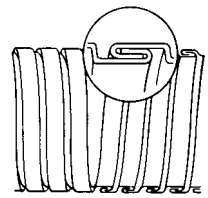


Fig. 8.7.24 Interlocked flexible metal hose.

8.8 PREFERRED NUMBERS

by C. H. Berry

REFERENCES: Hirshfeld and Berry, Size Standardization by Preferred Numbers, *Mech. Eng.*, Dec. 1922. Schlink, A New Tool for Standardizers, *Am. Mach.*, July 12, 1923. ANSI Standard Z17.1.

Many manufactured articles are made in several sizes which may be designated by some dimension, speed, capacity, or other feature. Each such series of products may be paralleled by a series of numbers.

It is generally agreed that such number series should be **geometric progressions;** i.e., each term should be a fixed percentage larger than the preceding. A geometric series provides small steps for small numbers, large steps for large numbers, and this best meets most requirements. The small steps in the diameter of the numbered twist drills would be absurd in drills of 1 in diameter and larger.

In the case of sized objects that are used principally as raw material, e.g., steel rod, an arithmetic progression may be preferable because it tends to reduce the cost of machining. It is desirable to be able to buy raw material a fixed amount (rather than a fixed percentage) larger than the finished article.

Preferred numbers is the name given to various series proposed for general use. These are either geometric progressions or approximations thereto. A geometric series is defined by one term and the ratio of each term to the preceding one. On the choice of these elements for a preferred number series, there is as yet no general agreement. The same value would hardly be satisfactory for all cases. The idea of preferred numbers is to provide a master series from which terms can be chosen to suit any needs. This would ultimately lead to a comprehensive plan in all fields of manufacture, so that, for example, the sizes of shafting would be in accord with the sizes of bearings, and indeed with all manner of cylindrical machine elements.

An advantage of a geometric series is that if linear dimensions are chosen in the series, areas, volumes, and other functions of powers of dimensions are also members of the same series.

In one of the most carefully considered systems of preferred numbers the base term is 1, and the ratio is $\sqrt[80]{10}$. In this series, the 81st term is 10, and accordingly the series from 10 to 100 or from 0.01 to 0.1, or, in general, from 10^n to 10^{n+1} is identical with the series from 1 to 10 with the decimal point shifted. This series will rarely be used in full; some will choose alternate terms, some every fourth, fifth, tenth, or twentieth

Table 8.8.1 Basic Series of Preferred Numbers: R 80 Series

1.00	1.80	3.15	5.60
1.03	1.85	3.25	5.80
1.06	1.90	3.35	6.00
1.09	1.95	3.45	6.15
1.12	2.00	3.55	6.30
1.15	2.06	3.65	6.50
1.18	2.12	3.75	6.70
1.22	2.18	3.87	6.90
1.25	2.24	4.00	7.10
1.28	2.30	4.12	7.30
1.32	2.36	4.25	7.50
1.36	2.43	4.37	7.75
1.40	2.50	4.50	8.00
1.45	2.58	4.62	8.25
1.50	2.65	4.75	8.50
1.55	2.72	4.87	8.75
1.60	2.80	5.00	9.00
1.65	2.90	5.15	9.25
1.70	3.00	5.30	9.50
1.75	3.07	5.45	9.75

SOURCE: American National Standard Preferred Numbers Z17.1, reproduced with permission of ANSI.

term. The index of the root, 80, has as factors, 2^4 and 5, so that the series readily yields subseries having as ratios the roots of 10 with indices 2, 4, 8, 16, 5, 10, 20, 40, thus giving a wide range of choice. See Table 8.8.1.

The strict logic of this series has been somewhat impaired by the adoption of rounded values that are slightly different in the 1-to-10 and 10-to-100 intervals. For the United States, ANSI has adopted a Table of Preferred Numbers (ANSI Z17.1) which differs slightly from the system described in the preceding paragraph.

Another type of series is the **semigeometric series** consisting of a basic geometric series with 1 as the base term and a ratio of 2, giving a series . . . ⅛, ¼, ½, 1, 2, 4, ... Between consecutive terms are inserted arithmetic series of 2, 4, 8, or 16 terms, in general using different numbers of terms in different intervals.

A similar procedure is used to establish the numbers of teeth in a prescribed number of gears that are intended for use in a gear train to provide a stepped gradation of rotational speeds within an upper and lower bound.