Power Piping

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ASME Codes and Standards
Chapter I
Scope and Definitions

100 GENERAL

This Power Piping Code is one of several Sections of The American Society of Mechanical Engineers (ASME) Code for Pressure Piping, B31. This Section is published as a separate document for convenience.

Standards and specifications specifically incorporated by reference into this Code are shown in Table 126.1-1. It is not considered practical to refer to a dated edition of each of the standards and specifications in this Code. Instead, the dated edition references are included in Mandatory Appendix F.

100.1 Scope

Rules for this Code Section have been developed considering the needs for applications that include piping typically found in electric power generating stations, industrial and institutional plants, geothermal heating systems, and central and district heating and cooling systems.

100.1.1 This Code prescribes requirements for the design, materials, fabrication, erection, examination, testing, inspection, operation, and maintenance of piping systems. Where service requirements necessitate measures beyond those required by this Code, such measures shall be specified by the engineering design.

Piping as used in this Code includes pipe, flanges, bolting, gaskets, valves, pressure-relieving valves/devices, fittings, and the pressure-containing portions of other piping components, whether manufactured in accordance with standards listed in Table 126.1-1 or specially designed. It also includes hangers and supports and other equipment items necessary to prevent overstressing the pressure-containing components.

Rules governing piping for miscellaneous appurtenances, such as water columns, remote water level indicators, pressure gages, and gage glasses, are included within the scope of this Code, but the requirements for boiler appurtenances shall be in accordance with ASME Boiler and Pressure Vessel Code (BPVC), Section I, PG-60.

The users of this Code are advised that in some areas legislation may establish governmental jurisdiction over the subject matter covered by this Code. However, any such legal requirement shall not relieve the owner of his/her inspection responsibilities specified in para. 136.1.

100.1.2 Power piping systems as covered by this Code (22) apply to all piping and their component parts except as excluded in para. 100.1.3. They include but are not limited to steam, water, oil, gas, and air services.

(a) This Code covers boiler external piping as defined below for power boilers and high-temperature, high-pressure water boilers in which steam or vapor is generated at a pressure of more than 15 psig [100 kPa (gage)]; and high-temperature water is generated at pressures exceeding 160 psig [1103 kPa (gage)] and/or temperatures exceeding 250°F (120°C).

Boiler external piping shall be considered as piping that begins where the boiler proper terminates at

(1) the first circumferential joint for welding end connections; or

(2) the face of the first flange in bolted flanged connections; or

(3) the first threaded joint in that type of connection, and that extends up to and including the valve or valves required by para. 122.1.

The terminal points themselves are considered part of the boiler external piping. The terminal points and piping external to power boilers are illustrated by Figures 100.1.2-1 through 100.1.2-10.

Piping between the terminal points and the valve or valves required by para. 122.1 shall be provided with Data Reports, inspection, and stamping as required by ASME BPVC, Section I. All welding and brazing of this piping shall be performed by manufacturers or contractors authorized to use the ASME Certification Mark and appropriate Designators shown in ASME CA-1, Conformity Assessment Requirements. The installation of boiler external piping by mechanical means may be performed by an organization not holding an ASME Certification Mark. However, the holder of a valid ASME Certification Mark, Certificate of Authorization, with an “S,” “A,” or “PP” Designator shall be responsible for the documentation and hydrostatic test, regardless of the method of assembly. The quality control system requirements of ASME BPVC, Section I; ASME CA-1; and ASME QAI-1, Qualifications for Authorized Inspectors, shall apply.

The valve or valves required by para. 122.1 are part of the boiler external piping, but do not require ASME BPVC, Section I inspection and stamping except for safety, safety
Figure 100.1.2-4

Code Jurisdictional Limits for Piping — Isolable Economizers Located in Feedwater Piping and Isolable Superheaters in Main Steam Piping (Boiler Pressure Relievers, Blowoff, and Miscellaneous Piping for Boiler Proper Not Shown for Clarity)

Administrative Jurisdiction and Technical Responsibility

- **Boiler Proper** — The ASME Boiler and Pressure Vessel Code (ASME BPVC) has total administrative jurisdiction and technical responsibility. Refer to ASME BPVC, Section I, Preamble.

- **Boiler External Piping and Joint (BEP)** — The ASME BPVC has total administrative jurisdiction (mandatory certification by stamping the Certification Mark with the appropriate Designator, ASME Data Forms, and Authorized Inspection) of BEP. The ASME Section Committee B31.1 has been assigned technical responsibility. Refer to ASME BPVC, Section I, Preamble and ASME B31.1 Scope, para. 100.1.2(a). Applicable ASME B31.1 editions are referenced in ASME BPVC, Section I, Table A-360.

- **Nonboiler External Piping and Joint (NBEP)** — The ASME Code Committee for Pressure Piping, B31, has total administrative jurisdiction and technical responsibility.

**NOTE:** (1) With feedwater regulator located between the boiler and economizer, the economizer may be constructed using austenitic stainless steel (see ASME BPVC, Section I, Part PFE).
100.1.3 This Code does not apply to the following:

(a) economizers, heaters, pressure vessels, and components covered by Sections of the ASME BPVC.

(b) building heating and distribution steam and condensate piping designed for 15 psig [100 kPa (gage)] or less, or hot water heating systems designed for 30 psig [200 kPa (gage)] or less.

(c) piping for hydraulic or pneumatic tools and their components downstream of the first block or stop valve off the system distribution header.

(d) piping for marine or other installations under federal control.

(e) towers, building frames, tanks, mechanical equipment, instruments, and foundations.

(f) piping included as part of a shop-assembled packaged equipment assembly within an ASME B31.1 Code piping installation when such equipment piping is constructed to another ASME B31 Code Section (e.g., ASME B31.3 or ASME B31.9) with the owner’s approval. See para. 100.2 for a definition of packaged equipment.

100.1.4 Procedures. This Code does not provide procedures for flushing, cleaning, start-up, operating, or maintenance. Code users are advised, however, that the cleaning and purging of flammable gas systems may be subject to the requirements of NFPA Standard 56.

100.1.5 Units of Measure. This Code states values in both U.S. Customary (USC) and International System (SI, also known as metric) units. Within the text, the SI units are shown in parentheses or in separate tables.
specially designed component: a component designed in accordance with para. 104.7.2.

standard component: a component manufactured in accordance with one or more of the standards listed in Table 126.1-1.

covered piping systems (CPS): piping systems on which condition assessments are to be conducted. As a minimum for electric power generating stations, the CPS are to include NPS 4 (DN 100) and larger of the main steam, hot reheat steam, cold reheat steam, and boiler feedwater piping systems. In addition to the above, CPS also include NPS 4 (DN 100) and larger piping in other systems that have a design temperature greater than 750°F (400°C) or a design pressure greater than 1,025 psi (7.1 MPa).

creep strength enhanced ferritic steel: steel in which the microstructure, consisting of lower transformation products such as martensite and bainite, is stabilized by controlled precipitation of temper-resistant carbides, carbonitrides, and/or nitrides.

defect: a flaw (imperfection or unintentional discontinuity) of such size, shape, orientation, location, or properties as to be rejectable.

discontinuity: a lack of continuity or cohesion; an interruption in the normal physical structure of material or a product.

employer: the owner, manufacturer, fabricator, contractor, assembler, or installer responsible for the welding, brazing, and NDE performed by his/her organization, including procedure and performance qualifications.

engineering design: the detailed design developed from process requirements and conforming to Code requirements, including all necessary drawings and specifications, governing a piping installation.

equipment connection: an integral part of such equipment as pressure vessels, heat exchangers, and pumps, designed for attachment of pipe or piping components.

erection: the complete installation of a piping system, including any field assembly, fabrication, testing, and inspection of the system.

examination: denotes the procedures for all nondestructive examination. Refer to para. 136.3 and the definition for visual examination.

expansion joint: a flexible piping component that absorbs thermal and/or terminal movement.

fabrication: primarily, the joining of piping components into integral pieces ready for assembly. It includes bending, forming, threading, welding, or other operations on these components, if not part of assembly. It may be done in a shop or in the field.

face of weld: the exposed surface of a weld on the side from which the welding was done.

designer: the person or organization in responsible charge of the engineering design.

failure: a physical condition that renders a system or component unable to perform its intended function or functions or meet design and performance requirements, or that is a hazard to personnel safety.

failure analysis: the process of collecting and evaluating data to determine the damage mechanism or mechanisms and cause of a failure.

ferrous material: metals and alloys that contain iron as the principal component.

filler metal: metal to be added in welding, soldering, brazing, or braze welding.

fillet weld: a weld of approximately triangular cross section joining two surfaces approximately at right angles to each other in a lap joint, tee joint, corner joint, or socket weld.

fire hazard: situation in which a material of more than average combustibility or explosibility exists in the presence of a potential ignition source.

flaw: an imperfection or unintentional discontinuity that is detectable by a nondestructive examination.

full fillet weld: a fillet weld whose size is equal to the thickness of the thinner member joined.

fusion: the melting together of filler metal and base metal, or of base metal only, that results in coalescence.

gas blow: a process to clean and remove debris from the gas supply piping by releasing gas (flammable or nonflammable) at a high pressure and velocity through the piping system while venting to atmosphere.

gas purge: a process to purge air from the flammable gas supply piping, typically conducted at a low pressure and velocity.

gas welding: a group of welding processes wherein coalescence is produced by heating with a gas flame or flames, with or without the application of pressure, and with or without the use of filler metal.

groove weld: a weld made in the groove between two members to be joined.

heat-affected zone: portion of the base metal that has not been melted, but whose mechanical properties or microstructure has been altered by the heat of welding or cutting.

heat treatments:

annealing, full: heating a metal or alloy to a temperature above the transformation temperature range for that material and holding above the range for a proper period of time, followed by cooling to below that range. (A softening treatment is often carried out just below the transformation range, which is referred to as a subcritical anneal.)

austenitizing: forming austenite by heating steel above the transformation range.
Pipe: a pressure-tight hollow cylinder used to convey a fluid or to transmit a fluid pressure, ordinarily designated “pipe” in applicable material specifications. Materials designated “tube” or “tubing” may be treated as pipe when intended by the specifications for pressure service.

For operation of a facility, the owner is usually the one who would be granted an operating license by the regulatory authority having jurisdiction or who has the administrative and operational responsibility for the facility. The owner may be either the operating organization (may not be the actual owner of the physical property of the facility) or the organization that owns and operates the plant.

Oxygen cutting: a group of cutting processes wherein the severing of metals is effected by means of the chemical reaction of oxygen with the base metal at elevated temperatures. In the case of oxidation-resistant metals, the reaction is facilitated by use of a flux.

Oxygen gouging: an application of oxygen cutting wherein a chamfer or groove is formed.

Packaged equipment: an assembly of individual components or stages of equipment, complete with its interconnecting piping and connections for piping external to the equipment assembly. The assembly may be mounted on a skid or other structure prior to delivery.

Peening: the mechanical working of metals by means of hammer blows.

Pipe and tube: the fundamental difference between pipe and tube is the dimensional standard to which each is manufactured.

A pipe is a tube with a rounder cross section conforming to the dimensional requirements for nominal pipe size as tabulated in ASME B36.10M and ASME B36.19M. For special pipe having a diameter not listed in these standards, and also for round tube, the nominal diameter corresponds to the outside diameter.

A tube is a hollow product of round or any other cross section having a continuous periphery. Round tube size may be specified with respect to any two, but not all three, of the following: outside diameter, inside diameter, and wall thickness; types K, L, and M copper tube may also be specified by nominal size and type only. Dimensions and permissible variations (tolerances) are specified in the appropriate ASTM or ASME standard specifications.

Types of pipe, according to the method of manufacture, are defined as follows:

(a) Electric resistance welded pipe: pipe produced in individual lengths or in continuous lengths from coiled skelp and subsequently cut into individual lengths, having a longitudinal butt joint wherein coalescence is produced by the heat obtained from resistance of the pipe to the flow of electric current in a circuit of which the pipe is a part, and by the application of pressure.

(b) Furnace butt welded pipe:

(1) Furnace butt welded pipe, bell welded: pipe produced in individual lengths from cut length skelp, having its longitudinal butt joint forge welded by the mechanical pressure developed in drawing the furnace heated skelp through a cone-shaped die (commonly forming and welding die).

(2) Furnace butt welded pipe, continuous welded: pipe produced in continuous lengths from coiled skelp and subsequently cut into individual lengths, having its longitudinal butt joint forge welded by the mechanical pressure developed in rolling the hot formed skelp through a set of round pass welding rolls.

(c) Electric fusion welded pipe: pipe having a longitudinal butt joint wherein coalescence is produced in the preformed tube by manual or automatic electric arc welding. The weld may be single (welded from one side) or double (welded from inside and outside) and may be made with or without the use of filler metal. Spiral welded pipe is also made by the electric fusion welding process with a butt joint, a lap joint, or a lock seam joint.

(d) Electric flash welded pipe: pipe having a longitudinal butt joint wherein coalescence is produced, simultaneously over the entire area of abutting surfaces, by the heat obtained from resistance to the flow of electric current between the two surfaces, and by the application of pressure after heating is substantially completed. Flashing and upsetting are accompanied by expulsion of metal from the joint.

(e) Double submerged arc welded pipe: pipe having a longitudinal butt joint produced by the submerged arc process, with at least two passes, one of which is on the inside of the pipe.

(f) Seamless pipe: pipe produced by one or more of the following processes:

(1) Rolled pipe: pipe produced from a forged billet that is pierced by a conical mandrel between two diametrically opposed rolls. The pierced shell is subsequently rolled and expanded over mandrels of increasingly larger diameter. Where closer dimensional tolerances are desired, the rolled pipe is cold or hot drawn through dies, and machined.

One variation of this process produces the hollow shell by extrusion of the forged billet over a mandrel in a vertical, hydraulic piercing press.

(2) Forged and bored pipe: pipe produced by boring or trepanning of a forged billet.

(3) Extruded pipe: pipe produced from hollow or solid round forgings, usually in a hydraulic extrusion press. In this process the forging is contained in a cylindrical die. Initially a punch at the end of the extrusion plunger pierces the forging. The extrusion plunger then forces the contained billet between the cylindrical die and the punch to form the pipe, the latter acting as a mandrel.

(4) Centrifugally cast pipe: pipe formed from the solidification of molten metal in a rotating mold. Both metal and sand molds are used. After casting, the pipe is machined, to sound metal, on the internal and external
action. In general, solders are lead–tin alloys and may contain antimony, bismuth, silver, and other elements.

**steel**: an alloy of iron and carbon with no more than 2% carbon by weight. Other alloying elements may include manganese, sulfur, phosphorus, silicon, aluminum, chromium, copper, nickel, molybdenum, and vanadium, depending on the type of steel. For acceptable material specifications for steel, refer to Chapter III.

**stresses**:

- **displacement stress**: a stress developed by the self-constraint of the structure. It must satisfy an imposed strain pattern rather than being in equilibrium with an external load. The basic characteristic of a displacement stress is that it is self-limiting. Local yielding and minor distortions can satisfy the displacement or expansion conditions that cause the stress to occur. Failure from one application of the stress is not to be expected. Further, the displacement stresses calculated in this Code are “effective” stresses and are generally lower than those predicted by theory or measured in strain-gage tests.\(^1\)

- **peak stress**: the highest stress in the region under consideration. The basic characteristic of a peak stress is that it causes no significant distortion and is objectionable only as a possible source of a fatigue crack initiation or a brittle fracture. This Code does not use peak stress as a design basis, but rather uses effective stress values for sustained stress and for displacement stress; the peak stress effect is combined with the displacement stress effect in the displacement stress range calculation.

- **sustained stress**: a stress developed by an imposed loading that is necessary to satisfy the laws of equilibrium between external and internal forces and moments. The basic characteristic of a sustained stress is that it is not self-limiting. If a sustained stress exceeds the yield strength of the material through the entire thickness, the prevention of failure is entirely dependent on the strain-hardening properties of the material. A thermal stress is not classified as a sustained stress. Further, the sustained stresses calculated in this Code are “effective” stresses and are generally lower than those predicted by theory or measured in strain-gage tests.

**stress-relieving**: see heat treatments.

**subcritical heat treatment**: see heat treatments.

**submerged arc welding**: an arc welding process wherein coalescence is produced by heating with an electric arc or arcs between a bare metal electrode or electrodes and the work. The welding is shielded by a blanket of granular, fusible material on the work. Pressure is not used, and filler metal is obtained from the electrode and sometimes from a supplementary welding rod.

**supplementary steel**: steel members installed between existing members to facilitate installation of supports for piping or piping equipment.

**swivel joint**: a component that permits single-plane rotational movement in a piping system.

**tack weld**: a weld made to hold parts of a weldment in proper alignment until the final welds are made.

**tempering**: see heat treatments.

**throat of a fillet weld**:

- **actual**: the shortest distance from the root of a fillet weld to its face.

- **theoretical**: the distance from the beginning of the root of the joint perpendicular to the hypotenuse of the largest right triangle that can be inscribed within the fillet weld cross section.

**throttle valve**: a valve designed to regulate the supply of a fluid, such as steam or gas, to a turbine or other prime mover.

**toe of weld**: the junction between the face of the weld and the base metal.

**tube**: refer to pipe and tube.

**tungsten electrode**: a nonfiller metal electrode used in arc welding, consisting of a tungsten wire.

**undercut**: a groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal.

**visual examination**: the observation of whatever portions of components, joints, and other piping elements that are exposed to such observation before, during, or after manufacture, fabrication, assembly, erection, inspection, or testing. This examination may include verification of the applicable requirements for materials, components, dimensions, joint preparation, alignment, welding or joining, supports, assembly, and erection.

**volumetric examination**: an NDE method used to detect imperfections that may be located anywhere within the examined volume.

**weld**: a localized coalescence of metal that is produced by heating to suitable temperatures, with or without the application of pressure, and with or without the use of filler metal. The filler metal shall have a melting point approximately the same as the base metal.

**welder**: one who is capable of performing a manual or semiautomatic welding operation.

**Welder/Welding Operator Performance Qualification (WPQ)**: demonstration of a welder’s ability to produce welds in a manner described in a Welding Procedure Specification that meets prescribed standards.

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\(^1\) Normally, the most significant displacement stress is encountered in the thermal expansion stress range from ambient to the normal operating condition. This stress range is also the stress range usually considered in a flexibility analysis. However, if other significant stress ranges occur, whether they are displacement stress ranges (such as from other thermal expansion or contraction events, or differential support point movements) or sustained stress ranges (such as from cyclic pressure, steam hammer, or earthquake inertia forces), paras. 102.3.2(b) and 104.8.3 may be used to evaluate their effect on fatigue life.
101.4 Ambient Influences

101.4.1 Cooling Effects on Pressure. Where the cooling of a fluid may reduce the pressure in the piping to below atmospheric, the piping shall be designed to withstand the external pressure or provision shall be made to break the vacuum.

101.4.2 Fluid Expansion Effects. Where the expansion of a fluid may increase the pressure, the piping system shall be designed to withstand the increased pressure or provision shall be made to relieve the excess pressure.

101.4.3 Ambient Temperature. Consideration shall be given to how ambient temperature conditions impact the displacement stress analysis described in paras. 102.3.2(b) and 104.8.3.

101.5 Dynamic Effects

101.5.1 Impact. Impact forces caused by all external and internal conditions shall be considered in the piping design. One form of internal impact force is due to the propagation of pressure waves produced by sudden changes in fluid momentum. This phenomenon is often called water or steam “hammer.” It may be caused by the rapid opening or closing of a valve in the system. The designer should be aware that this is only one example of this phenomenon and that other causes of impact loading exist.

101.5.2 Wind. Exposed piping shall be designed to withstand wind loadings. The analysis considerations and loads may be as described in ASCE/SEI 7, Minimum Design Loads for Buildings and Other Structures. Authoritative local meteorological data may also be used to define or refine the design wind forces. Where local jurisdictional rules covering the design of building structures are in effect and specify wind loadings for piping, these values shall be considered the minimum design values. Wind need not be considered as acting concurrently with earthquakes.

101.5.3 Earthquake. The effect of earthquakes shall be considered in the design of piping, piping supports, and restraints. The analysis considerations and loads may be as described in ASCE/SEI 7. Authoritative local seismological data may also be used to define or refine the design earthquake forces. Where local jurisdictional rules covering the design of building structures are in effect and specify seismic loadings for piping, these values shall be considered the minimum design values. ASME B31E, Standard for the Seismic Design and Retrofit of Above-Ground Piping Systems, may be used as an alternate method of seismic qualification or for guidance in seismic design. Earthquakes need not be considered as acting concurrently with wind.

101.5.4 Vibration. Piping shall be arranged and supported with consideration of vibration [see paras. 120.1(c) and 121.7.5].

101.5.5 Discharge Reactions. Piping shall be designed, arranged, and supported so as to withstand reaction forces due to fluid pressure and momentum effects during normal operations and anticipated transients.

101.6 Weight Effects

101.6.1 Live Load. The live load consists of the weight of the fluid transported. Snow and ice loads shall be considered in localities where such conditions exist.

101.6.2 Dead Load. The dead load consists of the weight of the piping components, insulation, protective lining and coating, and other superimposed permanent loads.

101.6.3 Test or Cleaning Fluid Load. The test or cleaning fluid load consists of the weight of the test or cleaning fluid.

101.7 Thermal Expansion and Contraction Loads

101.7.1 General. The design of piping systems shall take account of the forces and moments resulting from thermal expansion and contraction, and from the effects of expansion joints.

101.7.2 Expansion, Swivel, or Ball Joints, and Flexible Metal Hose Assemblies. Joints of the corrugated bellows, slip, sleeve, ball, or swivel types and flexible metal hose assemblies may be used if their materials conform to this Code, their structural and working parts are of ample proportions, and their design prevents the complete disengagement of working parts while in service. In determining expansion joint design criteria, the designer shall give due consideration to conditions of service, including, but not limited to, temperature, pressure, externally imposed displacements, corrosion/erosion, fatigue, and flow velocity. The design of metallic bellows expansion joints shall be in accordance with Mandatory Appendix P.
101.9 Reduced Ductility Effects

The design rules of this Code are based on material that has adequate ductility to provide sufficient reserve margin so that over-stress conditions will not cause sudden brittle failure and a ductile failure mode occurs. For materials or conditions where reduced ductility is expected, the Code may impose reductions of allowable stress to provide greater margins to failure. Other conditions may result in reduced ductility; for example, ductility reduction may result from welding, heat treatment, forming, bending, or low operating temperatures, including the chilling effect of sudden loss of pressure on highly volatile fluids. When such conditions could occur, the designer should ensure that adequate design margins are incorporated.

102 DESIGN CRITERIA

102.1 General

These criteria cover pressure-temperature ratings for standard and specially designed components, allowable stresses, stress limits, and various allowances to be used in the design of piping and piping components.

102.2 Pressure–Temperature Ratings for Piping Components

102.2.1 Components Having Specific Ratings. Pressure–temperature ratings for certain piping components have been established and are contained in some of the standards listed in Table 126.1-1.

Where piping components have established pressure–temperature ratings that do not extend to the upper material temperature limits permitted by this Code, the pressure–temperature ratings between those established and the upper material temperature limit may be determined in accordance with the rules of this Code, but such extensions are subject to restrictions, if any, imposed by the standards.

Standard components may not be used at conditions of pressure and temperature that exceed the limits imposed by this Code.

102.2.2 Components Not Having Specific Ratings. Some of the standards listed in Table 126.1-1, such as those for butt-welding fittings, specify that components shall be furnished in nominal thicknesses. Unless limited elsewhere in this Code, such components shall be rated for the same allowable pressures as seamless pipe of the same nominal thickness, as determined in paras. 103 and 104 for material having the same allowable stress.

Piping components, such as pipe, for which allowable stresses have been developed in accordance with para. 102.3, but that do not have established pressure ratings, shall be rated by rules for pressure design in para. 104, modified as applicable by other provisions of this Code.

Should it be desired to use methods of manufacture or design of components not covered by this Code or not listed in referenced standards, it is intended that the manufacturer shall comply with the requirements of paras. 103 and 104 and other applicable requirements of this Code for design conditions involved. Where components other than those discussed above, such as pipe or fittings not assigned pressure–temperature ratings in an American National Standard, are used, the manufacturer’s recommended pressure–temperature rating shall not be exceeded.

102.2.3 Ratings: Normal Operating Condition. A piping system shall be considered safe for operation if the maximum sustained operating pressure and temperature that may act on any part or component of the system do not exceed the maximum pressure and temperature allowed by this Code for that particular part or component. The design pressure and temperature shall not exceed the pressure–temperature rating for the particular component and material as defined in the applicable specification or standard listed in Table 126.1-1.

102.2.4 Ratings: Allowance for Variation From Normal Operation. The maximum internal pressure and temperature allowed shall include considerations for occasional loads and transients of pressure and temperature.

It is recognized that variations in pressure and temperature inevitably occur, and therefore the piping system, except as limited by component standards referred to in para. 102.2.1 or by manufacturers of components referred to in para. 102.2.2, shall be considered safe for occasional short operating periods at higher than design pressure or temperature. For such variations, either pressure or temperature, or both, may exceed the design values if the computed circumferential pressure stress does not exceed the maximum allowable stress for the coincident temperature by

(a) 15% if the event duration occurs for no more than 8 hr at any one time and not more than 800 hr/yr, or
(b) 20% if the event duration occurs for not more than 1 hr at any one time and not more than 80 hr/yr

102.2.5 Ratings at Transitions. Where piping systems operating at different design conditions are connected, a division valve shall be provided having a pressure–temperature rating equal to or exceeding the more severe conditions. See para. 122 for design requirements pertaining to specific piping systems.

For components with longitudinal weld joints, the component pressure rating as determined for seamless pipe shall be multiplied by the weld joint strength reduction factor, W, as defined in para. 102.4.7.
102.3 Allowable Stress Values and Other Stress Limits for Piping Components

(22) 102.3.1 Allowable Stress Values

(a) Allowable stress values to be used for the design of power piping systems are given in the tables in Mandatory Appendix A, also referred to in this Code Section as the Allowable Stress Tables. These tables list allowable stress values for commonly used materials at temperatures appropriate to power piping installations. In every case the temperature is understood to be the metal temperature. Where applicable, weld joint efficiency factors and casting quality factors are included in the tabulated values. Thus, the tabulated values are values of $S$, $SE$, or $SF$, as applicable.

(b) Allowable stress values in shear shall not exceed 80% of the values determined in accordance with the rules of (a). Allowable stress values in bearing shall not exceed 160% of the determined values.

(c) The basis for establishing the allowable stress values in this Code Section are the same as those in ASME BPVC, Section II, Part D, Mandatory Appendix 1 and Mandatory Appendix 2, 2-120; except that allowable stresses for cast iron and ductile iron are in accordance with ASME BPVC, Section VIII, Division 1, Nonmandatory Appendix P for Tables UCI-23 and UCD-23, respectively.

(22) 102.3.2 Limits for Sustained Stresses and Displacement Stress Ranges

(a) Sustained Stresses

(1) Internal Pressure Stress. The calculated stress due to internal pressure shall not exceed the allowable stress values. This criterion is satisfied when the wall thickness of the piping component, including any reinforcement, meets the requirements of paras. 104.1 through 104.7, excluding para. 104.1.3 but including the consideration of allowances permitted by paras. 102.2.4, 102.3.3(b), and 102.4.

(2) External Pressure Stress. Piping subject to external pressure shall be considered safe when the wall thickness and means of stiffening meet the requirements of para. 104.1.3. 

(3) Longitudinal Stress. The sum of the longitudinal stresses, $S_L$ (see para. 104.8.1), due to pressure, weight, and other sustained loads shall not exceed the basic material allowable stress in the hot condition, $S_{th}$.

The longitudinal pressure stress, $S_{lp}$, may be determined by either of the following equations:

$$S_{lp} = \frac{PD_n}{4n}$$

or

$$S_{lp} = \frac{Pd_n^2}{D_n^2 - d_n^2}$$

(b) Displacement Stress Ranges

(1) Cyclic Displacement Stress Ranges. The calculated reference displacement stress range, $S_C$ (see paras. 104.8.3 and 119.6.4), shall not exceed the allowable stress range, $S_A$, calculated by eq (1A)

$$S_A = f(1.25S_c + 0.25S_{th})$$

Where $S_{th}$ is greater than $S_c$, the difference between them may be added to the term $0.25S_c$ in eq. (1A). In that case, the allowable stress range, $S_A$, is calculated by eq. (1B)

$$S_A = f(1.25S_c + 1.25S_{th} - S_L)$$

where

$$f = \text{cyclic stress range factor} \quad \text{for the total number of equivalent reference displacement stress range cycles, } N, \text{ determined from eq. (1C)}$$

$$f = 6/N^{0.2} \leq 1.0$$

$N = \text{total number of equivalent reference displacement stress range cycles expected during the service life of the piping.} A \text{ minimum value for } f \text{ is 0.15, which results in an allowable displacement stress range for a total number of equivalent reference displacement stress range cycles greater than } 10^8 \text{ cycles.}$

$S_c = \text{basic material allowable stress at the minimum metal temperature expected during the reference stress range cycle, } 2 \text{ psi (kPa)}$

$S_{th} = \text{basic material allowable stress at the maximum metal temperature expected during the reference stress range cycle, } 4 \text{ psi (kPa)}$

In determining the basic material allowable stresses, $S_c$ and $S_{th}$ for welded pipe, the joint efficiency factor, $E$, need not be applied (see para. 102.4.3). The values of the allowable stresses from Mandatory Appendix A or as calculated per para. 123.1.2(b) may be divided by the joint efficiency factor given for that material. In determining the basic material allowable stresses for castings, the casting quality factor, $F$, shall be applied (see para. 102.4.6).

When considering more than a single displacement stress range, whether from thermal expansion or other cyclic conditions, each significant stress range shall be computed. The reference displacement stress range, $S_{dp}$

1 Applies to essentially noncorroded piping. Corrosion can sharply decrease cyclic life; therefore, corrosion-resistant materials should be considered where a large number of significant stress range cycles is anticipated. The designer is also cautioned that the fatigue life of materials operated at elevated temperatures may be reduced.

2 For materials with a minimum tensile strength of over 70 ksi (480 MPa), eqs. (1A) and (1B) shall be calculated using $S_c$ or $S_{th}$ values no greater than 20 ksi (140 MPa), unless otherwise justified.
is defined as the greatest computed displacement stress range. The total number of equivalent reference displacement stress range cycles, \( N \), may then be calculated by eq. (2)

\[
N = N_E + \sum (q_i S_i) \quad \text{for } i = 1, 2, ..., n
\]  

(2) Noncyclic Displacement Stress Ranges. Stress ranges caused by noncyclic movements such as those due to settlement or uplift of pipe-supporting structures or components such as buildings, pipe racks, pipe anchors, or rigid supports will not significantly influence fatigue life. Stress ranges caused by such movements may be calculated using Figure 104.8-1, eq. (17), replacing \( S_{A} \) with an allowable stress range of 3.0 \( S_{C} \) and replacing \( M_{C} \) with the moment range due to the noncyclic movement. The stress ranges due to noncyclic displacements need not be combined with cyclic stress ranges in accordance with (1).

102.3.3 Limits of Calculated Stresses Due to Occasional Loads

(a) During Operation. The sum of the longitudinal stresses produced by internal pressure, live and dead loads, and such occasional loads as the temporary supporting of extra weight may exceed the allowable stress values given in the Allowable Stress Tables by the amounts and durations of time given in para. 104.8.2.

(b) During Test. During pressure tests performed in accordance with para. 137, the circumferential (hoop) stress shall not exceed 90% of the yield strength (0.2% offset) at test temperature. In addition, the sum of longitudinal stresses due to test pressure and live and dead loads at the time of test, excluding occasional loads, shall not exceed 90% of the yield strength at test temperature.

102.4 Allowances

102.4.1 Corrosion or Erosion. When corrosion or erosion is expected, an increase in wall thickness of the piping shall be provided over that required by other design requirements. This allowance in the judgment of the designer shall be consistent with the expected life of the piping.

102.4.2 Threading and Grooving. The calculated minimum thickness of piping (or tubing) that is to be threaded shall be increased by an allowance equal to thread depth; dimension \( h \) of ASME B1.20.1 or equivalent shall apply. For machined surfaces or grooves, where the tolerance is not specified, the tolerance shall be assumed to be \( \frac{1}{64} \) in. (0.40 mm) in addition to the specified depth of cut. The requirements of para. 104.1.2(c) shall also apply.

102.4.3 Weld Joint Efficiency Factors. The use of joint efficiency factors for welded pipe is required by this Code. The factors in Table 102.4.3-1 are based on full penetration welds. These factors are included in the allowable stress values given in Mandatory Appendix A. The factors in Table 102.4.3-1 apply to both straight seam and spiral seam welded pipe.

102.4.4 Mechanical Strength. Where necessary for mechanical strength to prevent damage, collapse, excessive sag, or buckling of pipe due to superimposed loads from supports or other causes, the wall thickness of the pipe should be increased; or, if this is impractical or would cause excessive local stresses, the superimposed loads or other causes shall be reduced or eliminated by other design methods. The requirements of para. 104.1.2(c) shall also apply.

102.4.5 Bending. The minimum wall thickness at any point on the bend shall conform to (a) or (b).

(a) The minimum wall thickness at any point in a completed bend shall not be less than required by eq. (7) or eq. (8) of para. 104.1.2(a).

(1) Table 102.4.5-1 is a guide to the designer who must specify wall thickness for ordering pipe. In general, it has been the experience that when good shop practices are employed, the minimum thicknesses of straight pipe shown in Table 102.4.5-1 should be sufficient for bending and still meet the minimum thickness requirements of para. 104.1.2(a).

(2) The bend thinning allowance in Table 102.4.5-1 may be provided in all parts of the cross section of the pipe circumference without any detrimental effects being produced.

(b) The minimum required thickness, \( t_m \), of a bend, after bending, in its finished form shall be determined in accordance with eq. (3) or eq. (4)  

\[
t_m = \frac{PD_b}{2(SEW/1 + Py)} + A 
\]  

or  

\[
t_m = \frac{Pd + 2SEWA/1 + 2(PA)}{2(SEW/1 + Py - P)} 
\]  

where at the intrados (inside of bend)  

\[
l = \frac{4(R/D_o) - 1}{4(R/D_o) - 2}
\]
Table 102.4.5-1
Longitudinal Weld Joint Efficiency Factors

<table>
<thead>
<tr>
<th>No.</th>
<th>Type of Joint</th>
<th>Type of Seam</th>
<th>Examination</th>
<th>Factor $E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Furnace butt weld, continuous weld</td>
<td>Straight</td>
<td>As required by listed specification</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Electric resistance weld</td>
<td>Straight or spiral</td>
<td>As required by listed specification</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Electric fusion weld</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(a) Single butt weld (without filler metal)</td>
<td>Straight or spiral</td>
<td>As required by listed specification Additionally 100% volumetric examination (RT or UT)</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>(b) Single butt weld (with filler metal)</td>
<td>Straight or spiral</td>
<td>As required by listed specification Additionally 100% volumetric examination (RT or UT)</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>(c) Double butt weld (without filler metal)</td>
<td>Straight or spiral</td>
<td>As required by listed specification Additionally 100% volumetric examination (RT or UT)</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td>(d) Double butt weld (with filler metal)</td>
<td>Straight or spiral</td>
<td>As required by listed specification Additionally 100% volumetric examination (RT or UT)</td>
<td>0.90</td>
</tr>
<tr>
<td>4</td>
<td>API 5L</td>
<td></td>
<td></td>
<td>0.90</td>
</tr>
</tbody>
</table>

NOTES:
(1) It is not permitted to increase the longitudinal weld joint efficiency factor by additional examination for joint 1 or joint 2.
(2) RT (radiographic examination) shall be in accordance with the requirements of para. 136.4.5 or the material specification, as applicable. UT (ultrasonic examination) shall be in accordance with the requirements of para. 136.4.6 or the material specification, as applicable.

Table 102.4.5-1
Bend Thinning Allowance

<table>
<thead>
<tr>
<th>Radius of Bends</th>
<th>Minimum Thickness Recommended Prior to Bending</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 pipe diameters or greater</td>
<td>$1.06t_m$</td>
</tr>
<tr>
<td>5 pipe diameters</td>
<td>$1.08t_m$</td>
</tr>
<tr>
<td>4 pipe diameters</td>
<td>$1.14t_m$</td>
</tr>
<tr>
<td>3 pipe diameters</td>
<td>$1.25t_m$</td>
</tr>
</tbody>
</table>

GENERAL NOTES:
(a) Interpolation is permissible for bending to intermediate radii.
(b) $t_m$ is determined by eq. (7) or eq. (8) of para. 104.1.2(a).
(c) Pipe diameter is the nominal diameter as tabulated in ASME B36.10M, Table 1 and ASME B36.19M, Table 1. For piping with a diameter not listed in these tables, and also for tubing, the nominal diameter corresponds with the outside diameter.
and at the extrados (outside of bend)

\[ I = \frac{4(R/D)}{4(R/D)} + 1 \]

and at the sidewall on the bend centerline

\[ I = 1.0 \]

where

\[ R = \text{bend radius of pipe bend} \]

See para. 104.1.2 for the other nomenclature used above.

\[ W \] equals 1 for seamless pipe or for seam-welded pipe operating below the creep range and for parts of the bend that do not contain a weld.

Thickness variations from the intrados to the extrados and at the ends of the bend shall be gradual. The thickness requirements apply at the center of the bend arc and at the intrados, extrados, and bend centerline (see Figure 102.4.5-1). The minimum thickness at the ends of the bends shall not be less than the requirements of para. 104.1.2 for straight pipe. For bends to conform to this paragraph, all thickness requirements must be met.

102.4.6 Casting Quality Factors

(a) General. Except for gray iron castings, the use of a casting quality factor is required for all cast components that use the allowable stress values of Mandatory Appendix A as the design basis. This factor, 0.80 for castings and 0.85 for centrifugally cast pipe, is included in the allowable stress values given in Mandatory Appendix A.

This required factor does not apply to component standards listed in Table 126.1-1, if such standards define allowable pressure-temperature ratings or provide the allowable stresses to be used as the design basis for the component.

(b) For steel materials, a casting quality factor not exceeding 1.0 may be applied when the following requirements are met:

1. All steel castings having a nominal body thickness of 4\(\frac{1}{2}\) in. (114 mm) or less (other than pipe flanges, flanged valves and fittings, and butt welding end valves, all complying with ASME B16.5 or ASME B16.34) shall be inspected visually (MSS SP-55 may be used for guidance) as follows:

   (a) All critical areas, including the junctions of all gates, risers, and abrupt changes in section or direction and area of weld end preparation, shall be volumetrically examined in accordance with ASME BPVC, Section V. Radiographs shall conform to the requirements of ASTM E446, Reference Radiographs for Steel Castings up to 2 in. (50 mm) in Thickness, or ASTM E186, Reference Radiographs for Heavy Walled (2 to 4\(\frac{1}{2}\) in. [50 to 114 mm]) Steel Castings, depending on the section thickness. MSS SP-54 may be used for guidance. The maximum acceptable severity level for a 1.0 quality factor shall be as listed in Table 102.4.6-1. Where appropriate, radiographic examination (RT) of castings may be supplemented or replaced with ultrasonic examination (UT), provided it is performed in accordance with MSS SP-94.

   (b) All surfaces of each casting, including machined gasket seating surfaces, shall be examined by the magnetic particle or dye penetrant method after heat treatment. The examination techniques shall be in accordance with ASME BPVC, Section V, Article 6 or Article 7, as applicable, and Article 9. MSS SP-53 and MSS SP-93 may be used for guidance. Magnetic particle or dye penetrant indications exceeding degree 1 of Type I, degree 2 of Type II, and degree 3 of Type III, and exceeding degree 1 of Types IV and V of ASTM E125, Standard Reference Photographs for Magnetic

<table>
<thead>
<tr>
<th>Table 102.4.6-1</th>
<th>Maximum Severity Level for Casting Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discontinuity Category Designation</td>
<td>Severity Level</td>
</tr>
<tr>
<td>For E446 [Castings up to 2 in. (50 mm) Thickness]</td>
<td></td>
</tr>
<tr>
<td>Type A</td>
<td>1</td>
</tr>
<tr>
<td>Type B</td>
<td>2</td>
</tr>
<tr>
<td>Types 1, 2, 3, and 4 of C</td>
<td>1</td>
</tr>
<tr>
<td>D, E, F, and G, of C</td>
<td>None acceptable</td>
</tr>
<tr>
<td>For E186 [Castings 2 in. to 4(\frac{1}{2}) in. (50 mm to 114 mm) Thickness]</td>
<td></td>
</tr>
<tr>
<td>Type A, B, and Types 1 and 2 of C</td>
<td>2</td>
</tr>
<tr>
<td>Type 3 of C</td>
<td>3</td>
</tr>
<tr>
<td>D, E, and F</td>
<td>None acceptable</td>
</tr>
</tbody>
</table>
104 PRESSURE DESIGN OF COMPONENTS

104.1 Straight Pipe

104.1.1 Straight Pipe Under Internal Pressure.
Straight pipe under internal pressure shall have a minimum wall thickness calculated per para. 104.1.2.

104.1.2 Straight Pipe Under Internal Pressure — Seamless, Longitudinal Welded, or Spiral Welded

(a) Minimum Wall Thickness. The minimum thickness of pipe wall required for design pressures within the prescribed temperature limits for materials permitted by para. 123.1, including allowances for mechanical strength, shall not be less than that determined by eq. (7) or eq. (8), as follows:

\[ t_m = \frac{P D_o}{2(SEW + P_y)} + A \]  

\[ t_m = \frac{P_d + 2SEWA + 2yPA}{2(SEW + P_y - P)} \]

Design pressure shall not exceed

\[ P = \frac{2SEW(t_m - A)}{D_o - 2y(t_m - A)} \]  

\[ P = \frac{2SEW(t_m - A)}{d - 2y(t_m - A) + 2t_m} \]

where

\[ A = \text{additional thickness, in. (mm)} \]

(1) To compensate for material removed in threading, grooving, etc., required to make a mechanical joint, refer to para. 102.4.2.

(2) To provide for mechanical efficiency of the pipe, refer to para. 102.4.4 (not intended to provide for extreme conditions of misapplied external loads or for mechanical abuse).

(3) To provide for corrosion and/or erosion, refer to para. 102.4.1.

\[ d = \text{inside diameter of pipe, in. (mm). For design calculations, the inside diameter of pipe is the maximum possible value allowable under the purchase specification. When calculating the allowable working pressure of pipe on hand or in stock, the actual measured inside diameter and actual measured minimum wall thickness at the thinner end of the pipe may be used to calculate this pressure.} \]

\[ D_o = \text{outside diameter of pipe, in. (mm). For design calculations, the outside diameter of pipe as given in tables of standards and specifications shall be used in obtaining the value of } t_m \text{. When calculating the allowable working pressure of pipe on hand or in stock, the actual measured outside diameter and actual measured minimum wall thickness at the thinner end of the pipe may be used to calculate this pressure.} \]

\[ SE \text{ or } SF = \text{maximum allowable stress in material due to internal pressure and joint efficiency (or casting quality factor) at the design temperature, psi (MPa). The value of } SE \text{ or } SF \text{ shall not exceed that given in Mandatory Appendix A for listed materials or as determined per para. 123.1.2(b) for unlisted materials, for the respective material and design temperature. These values include the weld joint efficiency, } E, \text{ or the casting factor, } F. \]

\[ t_m = \text{minimum required wall thickness, in. (mm)} \]

(1) If pipe is ordered by its nominal wall thickness, the manufacturing tolerance on wall thickness shall be taken into account. After the minimum pipe wall thickness, \( t_m \) is determined by eq. (7) or eq. (8), this minimum thickness shall be increased by an amount sufficient to provide the manufacturing tolerance allowed in the applicable pipe specification or required by the process. The next heavier commercial wall thickness shall then be selected from thickness schedules such as contained in ASME B36.10M or from manufacturers’ schedules for other than standard thickness.

(2) To compensate for thinning in bends, refer to para. 102.4.5.

(3) For cast piping components, refer to para. 102.4.6.

(4) Where ends are subject to forming or machining for jointing, the wall thickness of the pipe, tube, or component after such forming or machining shall
104.2.3 Mitters. Miter joints, and the terminology related thereto, are described in ASME B31J. A widely spaced miter with

\[ \theta < 9 \frac{r}{R} \text{ deg} \]

shall be considered to be equivalent to a girth butt-welded joint, and the rules of this paragraph do not apply. Miter joints, and fabricated pipe bends consisting of segments of straight pipe welded together, with \( \theta \) equal to or greater than this calculated value may be used within the limitations described below.

(a) Pressure shall be limited to 10 psi (70 kPa) under the following conditions:

1. The assembly includes a miter weld with \( \theta > 22.5 \) deg, or contains a segment that has a dimension

\[ B < 6t_n \]

2. The thickness of each segment of the miter is not less than that determined in accordance with para. 104.1.

3. The contained fluid is nonflammable, nontoxic, and incompressible, except for gaseous vents to atmosphere.

4. The number of full pressure cycles is less than 7,000 during the expected lifetime of the piping system.

5. Full penetration welds are used in joining miter segments.

(b) Pressure shall be limited to 100 psi (700 kPa) under the conditions defined in (a)(2) through (a)(5), in addition to the following:

1. The angle \( \theta \) does not exceed 22.5 deg

2. The assembly does not contain any segment that has a dimension

\[ B < 6t_n \]

(c) Mitters to be used in other services or at design pressures above 100 psi (700 kPa) shall meet the requirements of para. 104.7.

1. When justification under para. 104.7 is based on comparable service conditions, such conditions must be established as comparable with respect to cyclic as well as static loadings.

2. When justification under para. 104.7 is based on an analysis, that analysis and substantiating tests shall consider the discontinuity stresses that exist at the juncture between segments, both for static (including brittle fracture) and cyclic internal pressure.

3. The wall thickness, \( t_s \), of a segment of a miter shall not be less than specified in (a) or (b), depending on the spacing.

   (a) For closely spaced miter bends (see ASME B31J for definition)

\[ t_s = t_m \frac{2 - r/R}{2(1 - r/R)} \]

(b) For widely spaced mitters (see ASME B31J for definition)

\[ t_s = t_m (1 + 0.64 \sqrt{r/t_s \tan \theta}) \]

(The above equation requires an iterative or quadratic solution for \( t_s \).

104.3 Intersections and Attachments

104.3.1 Branch Connections

(a) This paragraph gives rules governing the design of branch connections to sustain internal and external pressure in cases where the axes of the branch and the run intersect, and the angle between the axes of the branch and of the run is between 45 deg and 90 deg, inclusive.

Branch connections in which the smaller angle between the axes of the branch and the run is less than 45 deg or branch connections where the axes of the branch and the run do not intersect impose special design and fabrication problems. The rules given herein may be used as a guide, but sufficient additional strength must be provided to ensure safe service. Such branch connections shall be designed to meet the requirements of para. 104.7.

(b) Branch connections in piping may be made from materials listed in Mandatory Appendix A by the use of the following:

1. Fittings, such as tees, laterals, and crosses made in accordance with the applicable standards listed in Table 126.1-1 where the attachment of the branch pipe to the fitting is by butt welding, socket welding, brazing, soldering, threading, or a flanged connection.

2. Weld outlet fittings, such as cast or forged nozzles, couplings and adaptors, or similar items where the attachment of the branch pipe to the fitting is by butt welding, socket welding, threading, or a flanged connection. Such weld outlet fittings are attached to the run by welding similar to that shown in Figure 127.4.8-5 or Figure 127.4.8-6, as applicable. The minimum thickness of the weld attaching a branch weld-on fitting to the run pipe shall be the greater of

   (a) the nominal wall thickness of the attached branch pipe

   (b) the weld thickness required to fill the joint to the manufacturer's fitting weld line (or the weld thickness required to fill the joint to the edge of the first bevel of the branch weld-on fitting where a weld line is not provided)

MSSSP-97 may be used for design and manufacturing standards for integrally reinforced forged branch outlet fittings. Couplings are restricted to a maximum of NPS 3 (DN 80).

3. Extruded outlets at right angles to the run pipe, in accordance with (g), where the attachment of the branch pipe is by butt welding.
(4) piping directly attached to the run pipe by welding in accordance with para. 127.4.8 or by socket welding or threading as stipulated below.

(-a) socket welded right angle branch connections may be made by attaching the branch pipe directly to the run pipe provided

(-1) the nominal size of the branch does not exceed NPS 2 (DN 50) or one-fourth of the nominal size of the run, whichever is smaller.

(-2) the depth of the socket measured at its minimum depth in the run pipe is at least equal to that shown in ASME B16.11. If the run pipe wall does not have sufficient thickness to provide the proper depth of socket, an alternate type of construction shall be used.

(-3) the clearance between the bottom of the socket and the end of the inserted branch pipe is in accordance with Figure 127.4.4-3.

(-4) the size of the fillet weld is not less than 1.09 times the nominal wall thickness of the branch pipe.

(-b) threaded right angle branch connections may be made by attaching the branch pipe directly to the run pipe provided

(-1) the nominal size of the branch does not exceed NPS 2 (DN 50) or one-fourth of the nominal size of the run, whichever is smaller.

(-2) the minimum thread engagement is six full threads for NPS 1/2 (DN 15) and NPS 3/4 (DN 20) branches; seven for NPS 1 (DN 25), NPS 1 1/4 (DN 32), and NPS 1 1/2 (DN 40) branches; and eight for NPS 2 (DN 50) branches. If the run pipe wall does not have sufficient thickness to provide the proper depth for thread engagement, an alternative type of construction shall be used.

(c) Branch Connections Not Requiring Reinforcement. A pipe having a branch connection is weakened by the opening that must be made in it. Unless the wall thickness of the branch and/or run pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide additional material to meet the reinforcement requirements of (d) and (e). However, there are certain branch connections for which supporting calculations are not required. These are as follows:

(1) branch connections made by the use of a fitting (tee, lateral, cross, or branch weld-on fitting), manufactured in accordance with a standard listed in Table 126.1-1, and used within the limits of pressure-temperature ratings specified in that standard.

(2) branch connections made by welding a coupling or half coupling directly to the run pipe in accordance with Figure 127.4.8-6, provided the nominal diameter of the branch does not exceed NPS 2 (DN 50) or one-fourth the nominal diameter of the run, whichever is less. The minimum wall thickness of the coupling anywhere in the reinforcement zone (if threads are in the zone, wall thickness is measured from the root of the thread to the minimum O.D.) shall not be less than that of the unthreaded branch pipe. In no case shall the thickness of the coupling be less than that of ASME B16.11, Class 3000.

(3) integrally reinforced fittings welded directly to the run pipe when the reinforcements provided by the fitting and the deposited weld metal meet the requirements of (d).

(4) integrally reinforced extruded outlets in the run pipe. The reinforcement requirements shall be in accordance with (g).

(5) partial penetration welded branch connections NPS 2 (DN 50) and smaller, as shown in Figure 127.4.8-7, illustration (a), provided \( t_w \) is not less than the nominal wall thickness of Schedule 160 pipe of the branch size.

(6) partial penetration welded instrument connections NPS 2 (DN 50) and smaller, as shown in Figure 127.4.8-7, illustration (b), provided \( t_w \) is not less than \( P_d/1.6S_h \), where \( P \) is the design pressure [psi (kPa)], \( d \) is the nominal diameter [in. (mm)] of the hole into which the instrumentation is inserted, and \( S_h \) is the allowable stress [psi (kPa)] of either the run pipe or branch at the design temperature, whichever is lower. In addition, for welds made to instruments inserted into the flow stream, the designer shall consider the fluid flow static, dynamic, and vibration loads to which they will be subjected.

(d) Branch Connections Subject to Internal Pressure Requiring Reinforcement

(1) Reinforcement is required when it is not provided inherently in the components of the branch connection. This subparagraph gives rules covering the design of branch connections to sustain internal pressure in cases where the angle between the axes of the branch and of the run is between 45 deg and 90 deg. Subparagraph (e) gives rules covering the design of connections to sustain external pressure.

(2) Figure 104.3.1-1 illustrates the notations used in the pressure–temperature design conditions of branch connections. These notations are as follows:

\[ b = \text{subscript referring to branch} \]
\[ d_1 = \text{inside centerline longitudinal dimension of the finished branch opening in the run of the pipe, in. (mm)} \]
\[ d_2 = \text{“half width” of reinforcing zone, in. (mm)} \]
\[ d_3 = \text{or } 2(Th - A), \text{if } (Tb - A) > 2.5(Tb - A) + t_r \]
\[ d_4 = \text{or } 2.5(Tb - A) + t_r \]

\[ D_{ob} = \text{outside diameter of branch, in. (mm)} \]
\[ D_{oh} = \text{outside diameter of header, in. (mm)} \]
\[ h = \text{subscript referring to run or header} \]
\[ L_4 = \text{altitude of reinforcement zone outside of run, in. (mm)} \]

\[ P_d \]
\[ T_p, T_h = \text{actual wall thickness (by measurement) or the minimum wall thickness permissible under the purchase specification of the branch or header pipe, in. (mm)} \]
\[ t_{mb}, t_{mh} = \text{required minimum wall thickness, in. (mm), of the branch or header pipe as determined by use of eq.(7) or eq.(8) in para. 104.1.2(a)} \]
\[ t_r = \text{thickness of attached reinforcing pad, in Example A, in. (mm); or height of the largest 60 deg right triangle supported by the run and branch outside diameter projected surfaces and lying completely within the area of integral reinforcement, in Example B, in. (mm)} \]
\[ \alpha = \text{angle between axes of branch and run, deg} \]

(-a) If the run pipe contains a longitudinal seam that is not intersected by the branch, the stress value of seamless pipe of comparable grade may be used to determine the value of \( t_{mh} \) for reinforcement calculations only. If the branch intersects a longitudinal weld in the run, or if the branch contains a weld, the weld joint efficiency for either or both shall enter the calculations. If the branch and run both contain longitudinal welds, care shall be taken to ensure that the two welds do not intersect each other.

(-b) The required reinforcement area in square inches (square millimeters) for branch connections shall be the quantity

\[ A_7 = A_6(2 - \sin \alpha) = (t_{mh} - A)d_1(2 - \sin \alpha) \]

For right angle connections, the required reinforcement becomes

\[ A_7 = A_6 = (t_{mh} - A)d_1 \]

The required reinforcement must be within the limits of the reinforcement zone as defined in (-d).

(-c) The reinforcement required by (2) shall be that provided by any combination of areas \( A_1, A_2, A_3, A_4 \) and \( A_5 \) as defined below and illustrated in Figure 104.3.1-1 where

- \( A_1 \) = area provided by excess pipe wall in the run
  \[ = (2d_2 - d_1)(T_h - t_{mh}) \]
- \( A_2 \) = area, in.\(^2\) (mm\(^2\)), provided by excess pipe wall in the branch for a distance, \( L_4 \), above the run
  \[ = 2L_4(T_h - t_{mh})/\sin \alpha \]
- \( A_3 \) = area provided by deposited weld metal beyond the outside diameter of the run and branch, and for fillet weld attachments of rings, pads, and saddles
- \( A_4 \) = area provided by a reinforcing ring, pad, or integral reinforcement. The value of \( A_4 \) may be taken in the same manner in which excess header metal is considered, provided the weld completely fuses the branch pipe, run pipe, and ring or pad, or inte-

\[ T_h = \text{required minimum wall thickness, in. (mm), of the branch or header pipe as determined by use of eq.(7) or eq.(8) in para. 104.1.2(a)} \]

\[ t_{mh} = \text{required minimum wall thickness, in. (mm), of the branch or header pipe as determined by use of eq.(7) or eq.(8) in para. 104.1.2(a)} \]

\[ t_r = \text{thickness of attached reinforcing pad, in Example A, in. (mm); or height of the largest 60 deg right triangle supported by the run and branch outside diameter projected surfaces and lying completely within the area of integral reinforcement, in Example B, in. (mm)} \]

\[ \alpha = \text{angle between axes of branch and run, deg} \]

\[ A_7 = A_6(2 - \sin \alpha) = (t_{mh} - A)d_1(2 - \sin \alpha) \]

\[ A_7 = A_6 = (t_{mh} - A)d_1 \]

\[ A_7 = A_6 = (t_{mh} - A)d_1 \]

(-d) Reinforcement Zone. The reinforcement zone is a parallelogram whose width shall extend a distance, \( d_2 \), on each side of the centerline of the branch pipe, and whose altitude shall start at the inside surface of the run pipe and extend to a distance, \( L_4 \), from the outside surface of the run pipe.

(-e) Reinforcement of Multiple Openings. It is preferred that multiple branch openings be spaced so that their reinforcement zones do not overlap. If closer spacing is necessary, the following requirement shall be met. The two or more openings shall be reinforced in accordance with (2), with a combined reinforcement that has a strength equal to the combined strength of the reinforcement that would be required for the separate openings. No portion of the cross section shall be considered as applying to more than one opening, or be evaluated more than once in a combined area.

When more than two adjacent openings are provided with a combined reinforcement, the minimum distance between centers of any two of these openings should preferably be at least 1\( \frac{1}{2} \) times their average diameter, and the area of reinforcement between them shall be at least equal to 50% of the total required for these two openings.

(-f) Rings, Pads, and Saddles. Reinforcement provided in the form of rings, pads, or saddles shall not be appreciably narrower at the side than at the crotch. A vent hole shall be provided at the ring, pad, or saddle to provide venting during welding and heat treatment. Refer to para. 127.4.8(e).

Rings, pads, or saddles may be made in more than one piece, provided the joints between pieces have full thickness welds, and each piece has a vent hole.

(-g) Other Designs. The adequacy of designs to which the reinforcement requirements of para. 104.3 cannot be applied shall be proven by burst or proof tests on scale models or on full-size structures, or by
Calculations previously substantiated by successful service of similar design.

(e) Branch Connections Subject to External Pressure Requiring Reinforcement. The reinforcement area in square inches (square millimeters) required for branch connections subject to external pressure shall be

$$0.5t_{mh}(2 - \sin \alpha)$$

where $t_{mh}$ is the required header wall thickness determined for straight pipe under external pressure, using procedures outlined in ASME BPVC, Section VIII, Division 1, UG-28, UG-29, UG-30, and UG-31.

Procedures established heretofore for connections subject to internal pressure shall apply for connections subject to external pressure provided that $D_{ob}$, $D_{oh}$, and $t_r$ are reduced to compensate for external corrosion, if required by design conditions.

(f) Branch Connections Subject to External Forces and Moments. The requirements of the preceding paragraphs are intended to ensure safe performance of a branch connection subjected to pressure. However, when external forces and moments are applied to a branch connection by thermal expansion and contraction; by dead weight of piping, valves, and fittings, covering and contents; or by earth settlement, the branch connection shall be analyzed considering the stress intensification factors as specified in ASME B31J. Use of ribs, gussets, and clamps designed in accordance with para. 104.3.2 is permissible to stiffen the branch connection, but their areas cannot be counted as contributing to the required reinforcement area of the branch connection.

(g) Extruded Outlets Integrally Reinforced

(1) The following definitions, modifications, notations, and requirements are specifically applicable to extruded outlets. The designer shall make proper wall thickness allowances in order that the required minimum reinforcement is ensured over the design life of the system.

(2) Definition. An extruded outlet header is defined as a header in which the extruded lip at the outlet has an altitude above the surface of the run that is equal to or greater than the radius of curvature of the external contoured portion of the outlet; i.e., $h_o \geq r_o$. See nomenclature and Figure 104.3.1-2.

(3) These rules apply only to cases where the axis of the outlet intersects and is perpendicular to the axis of the run. These rules do not apply to any nozzle in which additional nonintegral material is applied in the form of rings, pads, or saddles.

(4) The notation used herein is illustrated in Figure 104.3.1-2. All dimensions are in inches (millimeters).

- $D_{ob}$ = outside diameter of branch pipe
- $D_{oh}$ = outside diameter of run
- $d_r$ = corroded internal diameter of run
- $h_o$ = height of the extruded lip. This must be equal to or greater than $r_o$, except as shown in (b) under the definition of $r_o$
- $L_\theta$ = altitude of reinforcement zone
- $r_1$ = half width of reinforcement zone (equal to $d_r$
- $r_o$ = radius of curvature of external contoured portion of outlet measured in the plane containing the axes of the run and branch. This is subject to the following limitations:
  - (a) Minimum Radius. This dimension shall not be less than $0.05D_{ob}$ except that on branch diameters larger than NPS 30 (DN 750), it need not exceed 1.50 in. (38 mm)
  - (b) Maximum Radius. For outlet pipe sizes 6 in. (150 mm) nominal and larger, this dimension shall not exceed $0.10D_{ob} + 0.50$ in. $(0.10D_{ob} + 12.7$ mm). For outlet pipe sizes less than NPS 6 (DN 150), this dimension shall not exceed $1.25$ in. (32 mm).
  - (c) When the external contour contains more than one radius, the radius of any arc sector of approximately 45 deg shall meet the requirements of (a) and (b). When the external contour has a continuously varying radius, the radius of curvature at every point on the contour shall meet the requirements of (a) and (b).
  - (d) Machining other than grinding for weld cleanup shall not be employed to meet the above requirements.

$$T_h - A = \text{actual wall thickness (by measurement)}$$

- $T_h - A = \text{actual wall thickness (by measurement)}$
- $t_{mb} - A = \text{required thickness of branch pipe according to wall thickness eq. (7) or eq. (8) in para. 104.1.2(a), but not including any thickness for corrosion}$
- $t_{mb} - A = \text{required thickness of the run according to eq. (7) or eq. (8) in para. 104.1.2(a), but not including any allowance for corrosion}$
To = corroded finished thickness of extruded outlet measured at a height equal to ro above the outside surface of the run.

(5) The required area is defined as

\[ A = K(t_{mh} - A)d_c \]

where K shall be taken as follows:

For \( D_{ob}/D_{oh} \) greater than 0.60,

\[ K = 1.00 \]

For \( D_{ob}/D_{oh} \) greater than 0.15 and not exceeding 0.60,

\[ K = 0.6 + \frac{2}{3} \frac{D_{ob}}{D_{oh}} \]

For \( D_{ob}/D_{oh} \) equal to or less than 0.15,

\[ K = 0.70 \]

The design must meet criteria that the reinforcement area defined in (6) is not less than the required area.

(6) Reinforcement Area. The reinforcement area shall be the sum of areas

\[ A_1 + A_2 + A_4 \]

as defined below.

(-a) Area \( A_1 \) is the area lying within the reinforcement zone resulting from any excess thickness available in the run wall.

\[ A_1 = d_c(T_h - t_{mh}) \]

(-b) Area \( A_2 \) is the area lying within the reinforcement zone resulting from any excess thickness available in the branch pipe wall.

\[ A_2 = 2L_3(T_b - t_{mh}) \]

(-c) Area \( A_4 \) is the area lying within the reinforcement zone resulting from excess thickness available in the extruded outlet lip.

\[ A_4 = 2r_4(T_b - (T_b - A)) \]

(7) Reinforcement of Multiple Openings. It is preferred that multiple branch openings be spaced so that their reinforcement zones do not overlap. If closer spacing is necessary, the following requirements shall be met. The two or more openings shall be reinforced in accordance with (g) with a combined reinforcement that has a strength equal to the combined strength of the reinforcement that would be required for separate openings. No portion of the cross section shall be considered as applying to more than one opening, or be evaluated more than once in a combined area.

(8) In addition to the above, the manufacturer shall be responsible for establishing and marking on the section containing extruded outlets the design pressure and temperature. The manufacturer's name or trademarks shall be marked on the section.

104.3.2 Attachments. External and internal attachments to piping shall be designed so as not to cause flattening of the pipe, excessive localized bending stresses, or harmful thermal gradients in the pipe wall. It is important that such attachments be designed to minimize stress concentrations in applications where the number of stress cycles, due to either pressure or thermal effect, is relatively large for the expected life of the equipment.

104.4 Closures

104.4.1 General. Closures for power piping systems shall meet the applicable requirements of this Code and shall comply with the requirements described in (a) or (b). Closures may be made

(a) by use of closure fittings, such as threaded or welded plugs, caps, or blind flanges, manufactured in accordance with standards listed in Table 126.1-1, and used within the specified pressure-temperature ratings, or

(b) in accordance with the rules contained in ASME BPVC, Section I, PG-31 or Section VIII, Division 1, UG-34 and UW-13, calculated from

\[ t_m = t + A \]

where

\[ t = \text{pressure design thickness, calculated for the given closure shape and direction of loading using appropriate equations and procedures in ASME BPVC, Section I or Section VIII, Division 1} \]

The symbol A and the symbols used in determining t shall have the definitions shown herein, instead of those given in the ASME BPVC.
104.8 Analysis of Piping Components

To validate a design under the rules in this paragraph, the complete piping system must be analyzed for conditions and criteria dealing with the effects of thermal expansion, including movements of equipment, anchors, guides, and restraints, weight and other sustained loads, and applicable occasional loads such as those described in para. 101. Each component in the system must meet the limits in this paragraph. For pipe and fittings, the pressure term in Figure 104.8-1, eqs. (15) and (16) may be replaced with the alternative term for $S_{lp}$ as defined in para. 102.3.2(a)(3). The pressure term in eqs. (15) and (16) may not apply for bellows and expansion joints. When evaluating stresses in the vicinity of expansion joints, consideration must be given to actual cross-sectional areas that exist at the expansion joint.

104.8.1 Stress Due to Sustained Loads. The effects of pressure, weight, and other sustained mechanical loads shall meet the requirements of Figure 104.8-1, eq. (15). The nomenclature for the equation is as follows:

- $A_p$ = cross-sectional material area of the pipe
- $D_o$ = nominal outside diameter of the pipe
- $F_a$ = longitudinal force due to weight and other sustained loads (excluding pressure)

*NOTE:* Compressive forces are negative values.

- $I_a$ = sustained longitudinal force index. In the absence of more applicable data, $I_a$ is taken as 1.00.
- $I_l$ = sustained in-plane moment index. In the absence of more applicable data, $I_l$ is taken as the greater of 0.75$i_i$ and 1.00 ($i_i$ taken from ASME B31J, Table 1-1).
- $I_o$ = sustained out-of-plane moment index. In the absence of more applicable data, $I_o$ is taken as the greater of 0.75$i_o$ and 1.00 ($i_o$ taken from ASME B31J, Table 1-1).
- $I_t$ = sustained torsional moment index. In the absence of more applicable data, $I_t$ is taken as the greater of 0.75$i_t$ and 1.00 ($i_t$ taken from ASME B31J, Table 1-1).

$M_{ib}$, $M_{ob}$, $M_{tb} = \text{in-plane, out-of-plane, or torsional moment, respectively, due to sustained loads plus occasional loads [see para. 104.8.4(b)]}$

$P_o = \text{pressure coincident with the occasional load being evaluated}$

$S_o = \text{stresses due to pressure, weight, sustained loads, and occasional loads}$

104.8.2 Stress Due to Occasional Loads. The effects of pressure, weight, other sustained loads, and occasional loads shall meet the requirements of Figure 104.8-1, eq. (16). The loads described in para. 101.5 may be considered as occasional loads if the time limitations of the term $k$ are met.

Terms for eq. (16) are as defined in para. 104.8.1, except

- $F_b$ = longitudinal force due to weight, other sustained loads (excluding pressure), and occasional loads [see para. 104.8.4(b)]

*NOTE:* Compressive forces are negative values.

- $k = 1.15$ for occasional loads acting for no more than 8 hr at any one time and no more than 800 hr/yr [see para. 102.3.3(a)]
- $k = 1.2$ for occasional loads acting for no more than 1 hr at any one time and no more than 80 hr/yr [see para. 102.3.3(a)]

$M_{ib}$, $M_{ob}$, $M_{tb} = \text{in-plane, out-of-plane, or torsional moment, respectively, due to sustained loads plus occasional loads [see para. 104.8.4(b)]}$

104.8.3 Stress Due to Displacement Load Ranges. The effects of thermal expansion and other cyclic loads shall meet the requirements of Figure 104.8-1, eq. (17). The terms are as defined in para. 104.8.1, except

- $F_c$ = axial force range due to reference displacement load range

*NOTE:* Compressive forces are negative values.

- $i_a = \text{axial force stress intensification factor. In the absence of more applicable data, } i_a = 1.0$ for elbows, pipe bends, and miter bends (single, closely spaced, and widely spaced), and $i_o = \text{(or } i_{o} \text{ when listed) in ASME B31J for other components}$

- $i_b$, $i_o$, $i_t = \text{in-plane, out-of-plane, and torsional stress intensification factors, respectively, for piping component as defined by ASME B31J, Table 1-1}$

$M_{ib}$, $M_{ob}$, $M_{tb} = \text{in-plane, out-of-plane, or torsional moment, respectively, due to sustained loads}$

$P_o = \text{pressure coincident with the occasional load being evaluated}$

$S_o = \text{stresses due to pressure, weight, sustained loads, and occasional loads}$

$S_{lp} = \text{longitudinal pressure stress as defined in para 102.3.2(a)(3).}$
104.8.4 Application of Forces and Moments

(a) For Figure 104.8-1, eqs. (15) through (17), for moment convention to calculate stresses, the designer may refer to ASME B31J, Figure 1-1 for moments in branch connections and ASME B31J, Figure 1-2 for pipe bends or welding elbows.

(b) When combining forces and moments due to weight, other sustained loads and forces, and occasional loads, if the method of analysis for occasional loads, such as earthquake or other dynamic loads, is such that only the force and moment magnitudes without relative algebraic signs are obtained, the most conservative combination of the signed and unsigned forces and moments shall be used.

(c) Figure 104.8-1, eq. (17) shall be used to calculate $S_I$ when computing the total number of equivalent reference displacement stress range cycles, $N$ [see para. 102.3.2(b)(1), eq. (2)]. When calculating $S_I$, the force and moments associated with the $i$ displacement range cycle should be used rather than the reference displacement range cycle.

$S_L = \sqrt{\frac{I_a P_o}{4t_n} + \frac{F_a}{A_p} \left( \sqrt{\frac{(I_i M_{iA})^2 + (I_o M_{oA})^2}{Z}} \right)^2 + \left( \frac{I_t M_{tA}}{Z} \right)^2} \leq S_h$

$S_O = \sqrt{\frac{I_a P_o}{4t_n} + \frac{F_b}{A_p} + \sqrt{\frac{(I_i M_{iB})^2 + (I_o M_{oB})^2}{Z}} \right)^2 + \left( \frac{I_t M_{tB}}{Z} \right)^2} \leq k S_h$

$S_E = \sqrt{\frac{I_a F_c}{A_p} + \sqrt{\frac{(I_i M_{iC})^2 + (I_o M_{oC})^2}{Z}} \right)^2 + \left( \frac{I_t M_{tC}}{Z} \right)^2} \leq S_A$

$S_E = \text{reference displacement stress range [see para. 104.8.4(c)]}$

PART 3
SELECTION AND LIMITATIONS OF PIPING COMPONENTS

105 PIPE

105.1 General

Pipe conforming to the standards and specifications listed in Mandatory Appendix A shall be used within the range of temperatures for which allowable stresses are given within the limitations specified herein.

105.2 Metallic Pipe

105.2.1 Ferrous Pipe

(a) Furnace butt welded steel pipe shall not be used for flammable, combustible, or toxic fluids.

(b) Ductile iron pipe may be used for design pressures within the ratings established by the standards and specifications listed in Tables 126.1-1 and A-5 and Notes thereto, and the limitations herein and in para. 124.6. Ductile iron pipe shall not be used for flammable, combustible, or toxic fluids. Temperature limits for the use of ductile iron pipe are often determined by the type of elastomeric gasket used in the pipe joints, or the lining material used on the internal surface of the pipe. It is the responsibility of the designer to determine whether these components are suitable for use in the particular application being considered. See para. 106.1(e).
In many cases a supporting element may be a combination of both of these.

(b) In addition to the weight effects of piping components, consideration shall be given in the design of pipe supports to other load effects introduced by service pressure, wind, earthquake, etc., as defined in para. 101. Hangers and supporting elements shall be fabricated and assembled to permit the free movement of piping caused by thermal expansion and contraction. The design of elements for supporting or restraining piping systems, or components thereof, shall be based on all the concurrently acting loads transmitted into the supporting elements.

(c) Where the resonance with imposed vibration and/or shock occurs during operation, suitable dampeners, restraints, anchors, etc., shall be added to remove these effects.

120.2 Supports, Anchors, and Guides

120.2.1 Rigid-Type Supports

(a) The required strength of all supporting elements shall be based on the loadings as given in para. 120.1, including the weight of the fluid transported or the fluid used for testing, whichever is heavier. The allowable stress in supporting equipment shall be as specified in para. 121.2.

(b) Exceptions may be made in the case of supporting elements for large size gas or air piping, exhaust steam, and relief or safety valve relief piping, but only under the conditions where the possibility of the line becoming full of water or other liquid is very remote.

120.2.2 Variable and Constant Supports. Load calculations for variable and constant supports, such as springs or counterweights, should be based on the design operating conditions of the piping. They shall not include the weight of the hydrostatic test fluid. However, the support shall be capable of carrying the total load under test conditions, unless additional support is provided during the test period.

120.2.3 Anchors or Guides. Where anchors or guides are provided to restrain, direct, or absorb piping movements, their design shall take into account the forces and moments at these elements caused by internal pressure and thermal expansion.

120.2.4 Supplementary Steel. Where it is necessary to frame structural members between existing steel members, such supplementary steel shall be designed in accordance with American Institute of Steel Construction specifications, or similar recognized structural design standards. Increases of allowable stress values shall be in accordance with the structural design standard being used. Additional increases of allowable stress values, such as allowed in para. 121.2(j), are not permitted.

121 DESIGN OF PIPE-SUPPORTING ELEMENTS

121.1 General

Design of standard pipe-supporting elements shall be in accordance with the rules of MSS SP-58. Allowable stress values and other design criteria shall be in accordance with this paragraph. Supporting elements shall be capable of carrying the sum of all concurrently acting loads as listed in para. 120. They shall be designed to provide the required supporting effort and allow pipeline movement with thermal changes without causing overstress. The design shall also prevent complete release of the piping load in the event of spring failure or misalignment. All parts of the supporting equipment shall be fabricated and assembled so that they will not be disengaged by movement of the supported piping. The maximum safe loads for bolts, threaded hanger rods, and all other threaded members shall be based on the root area of the threads. MSS SP-58 may be used for guidance with respect to selection and application of pipe hangers and supports.

121.2 Allowable Stress Values

(a) Allowable stress values tabulated in MSS SP-58 or in Mandatory Appendix A of this Code Section may be used for the base materials of all parts of pipe-supporting elements.

(b) Where allowable stress values for a material specification listed in Table 126.1-1 are not tabulated in Mandatory Appendix A or in MSS SP-58, allowable stress values from ASME BPVC, Section II, Part D, Tables 1A and 1B may be used, provided the requirements of para. 102.3.1(b) are met. Where there are no stress values given in ASME BPVC, Section II, Part D, Tables 1A and 1B, an allowable stress value of 25% of the minimum tensile strength given in the material specification may be used, for temperatures not exceeding 650°F (345°C).

(c) For a steel material of unknown specification, or of a specification not listed in Table 126.1-1 or MSS SP-58, an allowable stress value of 30% of yield strength (0.2% offset) at room temperature may be used at temperatures not exceeding 650°F (345°C). The yield strength shall be determined through a tensile test of a specimen of the material and shall be the value corresponding to 0.2% permanent strain (offset) of the specimen. The allowable stress values for such materials shall not exceed 9,500 psi (65.5 MPa).

(d) The allowable shear stress shall not exceed 80% of the values determined in accordance with the rules of (a) through (c).

(e) The allowable compressive stress shall not exceed the values as determined in accordance with the rules of (a), (b), or (c). In addition, consideration shall be given to structural stability.
Parts PMB and PEB. Manual quarter-turn valves shall be provided with a handle or other position indicator to indicate from a distance whether the valve is open or closed.

(2) In the case of a single boiler and prime mover installation, the stop valve required herein may be omitted provided the prime mover throttle valve is equipped with an indicator to show whether it is open or closed, and it is designed to withstand the required boiler hydrostatic test. The limit of boiler external piping ends at the connection of such prime mover valves and does not include the connection; the connection between the boiler external piping and prime mover valves is nonboiler external piping.

(3) When two or more boilers are connected to a common header, or when a single boiler is connected to a header having another steam source, the connection from each boiler having a manhole opening shall be fitted with two stop valves having an ample free-blow drain between them. The preferred arrangement consists of one stop-check valve (located closest to the boiler) and one valve of the style and design described in (1). Alternatively, both valves may be of the style and design described in (1).

When a second stop valve is required, it shall have a pressure rating at least equal to that required for the expected steam pressure and temperature at the valve, or a pressure rating at least equal to 85% of the lowest set pressure of any safety valve on the boiler drum at the expected temperature of the steam at the valve, whichever is greater.

(4) All valves and fittings on steam lines shall have a pressure rating of at least 100 psig [690 kPa (gage)] in accordance with the applicable ASME standard.

(b) Feedwater Valves

(1) The feedwater piping for all boilers, except for high-temperature water boilers complying with the requirements of (8) and forced-flow steam generators with no fixed steam and waterline complying with the requirements of (9), shall be provided with a check valve and a stop valve or cock between the check valve and the boiler. The stop valve or cock shall comply with the requirements of (c)(5).

(2) The relative locations of the check and stop (or cock) valves, as required in (1), may be reversed on a single boiler-turbine unit installation.

(3) If a boiler is equipped with a duplicate feed arrangement, each such arrangement shall be equipped as required by these rules.

(4) When the supply line to a boiler is divided into branch feed connections and all such connections are equipped with stop and check valves, the stop and check valves in the common source may be omitted.

(5) When two or more boilers are fed from a common source, there shall also be a globe or regulating valve in the branch to each boiler located between the check valve and the source of supply. A typical arrangement is shown in Figure 100.1.2-3.

When there is a regulating valve located downstream of the economizer as shown in Figure 100.1.2-4, illustration (2), an additional globe or regulating valve upstream of the check valve is not required.

(6) A combination stop and check valve in which there is only one seat and disk, and in which a valve stem is provided to close the valve, shall be considered only as a stop valve, and a check valve shall be installed as otherwise provided.

(7) Where an economizer or other feedwater heating device is connected directly to the boiler without intervening valves, the feed valves and check valves required shall be placed on the inlet of the economizer or feedwater heating device.

(8) The recirculating return line for a high-temperature water boiler shall be provided with the same stop valve, or valves, required by (1) and (3). The use of a check valve in the recirculating return line is optional. A check valve shall not be a substitute for a stop valve.

(9) The feedwater boiler external piping for a forced-flow steam generator with no fixed steam and waterline may terminate up to and including the stop valve or valves and omitting check valves, provided that a check valve having a pressure rating no less than the boiler inlet design pressure is installed at the discharge of each boiler feed pump or elsewhere in the feedline between the feed pump and stop valves.

(10) Wherever globe valves are used within BEP feedwater piping for either isolation or regulation, the inlet shall be under the disk of the valve.

(c) Blowoff Valves

(1) Ordinary globe valves as shown in Figure 122.1.7-1, illustration (a), and other types of valves that have dams or pockets where sediment can collect shall not be used on blowoff connections.

(2) Y-type globe valves as shown in Figure 122.1.7-1, illustration (b), or angle valves may be used in vertical pipes, or they may be used in horizontal runs of piping provided they are so constructed or installed that the lowest edge of the opening through the seat is at least 25% of the inside diameter below the centerline of the valve.

(3) The blowoff valve or valves, the pipe between them, and the boiler connection shall be of the same size except that a larger pipe for the return of condensate may be used.

(4) For all boilers [except electric steam boilers having a normal water content not exceeding 100 gal (380 L), traction-purpose, and portable steam boilers; see (11) and (12)] with allowable working pressure in excess of 100 psig [690 kPa (gage)], each bottom blowoff pipe shall have two slow-opening valves, or one quick-opening valve or cock, at the boiler nozzle.
(4) impingement of gases on nearby objects
(5) foreign objects propelled by venting
(6) chilling effect from the venting operation
(7) protection of people by evacuation, by use of
appropriate personal protective equipment, or by
other means

The chilling effect from venting is a factor for deter-
mining the lowest expected service temperature relative
to the possibility of brittle fracture of materials.

(b) Materials. Steel piping, subject to the limitations in
para. 105, shall be used for all flammable gases, except as
otherwise permitted in (2) through (4).

(1) Welded joints shall be used between steel
components where practicable. Where bolted flanged
joints are necessary, the gasket material shall be suitable
for the service. Where threaded joints and compression
fittings are unavoidable, the following requirements shall
be met:

(a) For threaded joints, the pipe thickness shall be
not less than extra strong regardless of pressure or type of
material.

(b) Threaded joints and compression fittings may
be used subject to the limitations of para. 122.8(b).

(c) Threaded joints and compression fittings shall
be assembled carefully to ensure leak tightness. Threaded
joints shall meet the requirements of para. 135.5.
Compression fittings shall meet the requirements of
paras. 115 and 135.6. A thread sealant, suitable for the
service, shall be used in threaded joints unless the
joint is to be seal welded or a gasket or O-ring is used
to provide sealing at a surface other than the threads.

(2) For hydrogen systems, the following alternative
materials may be used:

(a) seamless steel tubing with welded joints.

(b) seamless copper or brass pipe or tubing with
brazed, threaded, or compression fitting joints.
Threaded fittings shall not exceed NPS 3/4 (DN 20).
For protection against damage, tubing shall be installed in a guarded
manner that will prevent damage during construction,
operation, or service. Valves with suitable packing,
gages, regulators, and other equipment may also
consist of copper alloy materials. Safety relief devices
shall be vented individually, and connected vent piping
shall be designed to convey the fluid, without pockets,
to the outside atmosphere; and then directed away
from equipment ventilation systems and vents from
other systems.

(3) For fuel gas instrumentation and control, seamless copper tubing subject to the following restrictions
may be used:

(a) The design pressure shall not exceed 100 psi
(690 kPa).

(b) Tubing shall not exceed 5/8 in. (15.9 mm)
nominal outside diameter.

(c) All joints shall be made with compression or
flared fittings.

(d) Copper tubing shall not be used if the fuel gas
contains more than 0.3 grains (19.4 mg) of hydrogen
sulfide per 100 ft³/min (47 L/s) of gas at standard
conditions.

(e) Consideration shall be given in the design to
the lower strength and melting point of copper compared
to steel. Adequate support and protection from high
ambient temperatures and vibration shall be provided.

(f) Tubing shall be installed in a guarded manner
that will prevent damage during construction, operation,
and service.

(4) Polyethylene (PE) pipe may be used for natural
gas service, in buried installations only, in accordance with
Mandatory Appendix N.

(c) Valves and Specialties. Valves, strainers, meters, and
other specialties shall be of steel or nickel alloy construc-
tion. As an alternative, ductile iron or copper alloy valves
and specialties may be used, subject to the restrictions in
paras. 124.6 and 124.7, where metal temperatures do not
exceed 400°F (204°C).

(4) For in-plant fuel gas distribution systems where the
use of a full-relieving-capacity safety or safety relief valve
as described in para. 107.8.3(b) could create an undue
venting hazard, an alternative pressure-limiting design
may be substituted. The alternative design shall
include the provisions in (1) through (3).

(1) Tandem Gas Pressure-Reducing Valves. To protect
the low pressure system, two gas pressure-reducing
valves capable of independent operation shall be installed
in series. Each shall have the capability of closing off
against the maximum upstream pressure, and of control-
ling the pressure on the low pressure side at or below
the design pressure of the low pressure system, if the other
valve fails open. Control lines must be suitably protected,
designed, and installed so that damage to any one control
line will not result in overpressurizing the downstream
piping.

(2) Trip Stop Valve. A fail-safe trip stop valve shall be
installed to automatically close, in less than 1 sec, at or
below the design pressure of the downstream piping.
It shall be a manually reset design. The pressure
switch for initiating closure of the trip stop valve shall
be hardwired directly to the valve tripping circuit. The
pressure switch shall be mounted directly on the low pres-
sure piping without an intervening isolation valve. The
trip stop valve shall be located so that it is accessible
and protected from mechanical damage and from
weather or other ambient conditions that could impair
its proper functioning. It may be located upstream or
downstream of the tandem gas pressure-reducing
valves. The trip stop valve and all upstream piping
shall be designed for the maximum upstream supply pres-
sure. The trip stop valve may also serve as the upstream
isolation valve of a double-block and vent gas supply isolation
system. Provision shall be made to safely bleed off the
pressure downstream of the trip stop valve.
Chapter III

Materials

123 GENERAL REQUIREMENTS

Chapter III contains limitations and required qualifications for materials based on their inherent properties. Use of these materials in piping systems is also subject to requirements and limitations in other parts of this Code.

123.1 Materials and Specifications

(22) 123.1.1 Listed Materials. Material meeting the following requirements shall be considered listed and acceptable material:

(a) Materials for which allowable stress values are listed in Mandatory Appendix A or that have been approved by the procedure established by (c).

(b) A material conforming to a specification for which allowable stresses are not listed in Mandatory Appendix A is acceptable provided its use is not specifically prohibited by this Code Section and it satisfies one of the following requirements:

(1) It is referenced in a standard listed in Table 126.1-1. Such a material shall be used only within the scope of and in the product form covered by the referencing standard listed in Table 126.1-1.

(2) It is referenced in other parts of this Code Section and shall be used only within the scope of and in the product form permitted by the referencing text.

(c) The ASME B31.1 Committee considers requests for adoption of new materials desired by the owner/user or fabricator, manufacturer, installer, or assembler of piping or piping components constructed to the Code. Where it is desired to use materials that are not currently acceptable under the rules of this Code Section, written application shall be made to the Committee fully describing the proposed material, the user need, and the contemplated use.

(1) Details of information that should be included in such applications are given in ASME BPVC, Section II, Part D, Mandatory Appendix 5.

(2) If it is desired that the material be permitted for use in Boiler External Piping (BEP), this should be noted in the request. The request should indicate whether the material is currently permitted for use by ASME BPVC, Section I or an ASME BPVC, Section I Code Case and whether a request has been made or will be made to the Section I Committee to consider permitting the use of the material. The request shall indicate the intended application and range of service temperatures for the material. In determining whether a material should be permitted to be used in BEP, the ASME B31.1 Committee will consider the following and other pertinent factors:

(-a) whether the material is permitted to be used by ASME BPVC, Section I

(-b) whether the material is essentially the same as a material permitted to be used by ASME BPVC, Section I

(-c) the experience base for the use of the material

(-d) whether the material is seam welded with filler metal added (seam-welded pipe with filler metal added is generally not permitted)

(-e) whether the material is intended for use in water-wetted service and is austenitic stainless steel (austenitic stainless steels are generally not permitted in water-wetted service)

(3) Such material shall not be considered listed and not be used as a listed material until it has been approved by the Committee and allowable stress values have been published in Mandatory Appendix A.

(d) Materials conforming to ASME SA or ASME SB specifications may be used interchangeably with material specified to the listed ASTM A or ASTM B specifications of the same number, except where the requirements of para. 123.2.2 apply.

(e) The tabulated stress values in Mandatory Appendix A that are shown in italics are at temperatures in the range where creep and stress rupture strength govern the selection of stresses.

123.1.2 Unlisted Materials. Materials other than those meeting the requirements of para. 123.1.1 shall be considered unlisted materials. Such unlisted materials may only be used for nonboiler external piping provided they satisfy all of the following requirements:

(a) Unlisted materials are certified by the material manufacturer to satisfy the requirements of a specification listed in any Code Section of ASME B31 Code for Pressure Piping; ASME BPVC, Section II, Part D; or to a published specification covering chemistry, physical and mechanical properties, method and process of manufacture, heat treatment, and quality control.

(b) The allowable stresses of the unlisted materials shall be determined in accordance with the rules of para. 102.3.1(c).
used at design temperatures above those for which stress values are given except as permitted by para. 122.6.2(g).

124.1.2 Lower Temperature Limits

(a) The designer shall give consideration to the possibility of brittle fracture at low service temperature.

(b) The requirements of ASME B31T, Standard Toughness Requirements for Piping, shall be met.

(1) For materials listed in ASME B31T, see Nonmandatory Appendix VIII for guidelines to determine if low-temperature service requirements apply.

(2) For materials not listed in ASME B31T, the designer shall establish the T-number group using the guidelines provided in ASME B31T, Nonmandatory Appendix B, and the requirements of ASME B31T for that T-number group shall be met. To confirm the T-number group assignment, impact tests shall be run on three heats of the material. The test shall be in accordance with the requirements of section 4 of ASME B31T, and the test temperature shall be at or below the “Material Minimum Temperature Without Impacts” listed for the T-number group in Table 3.1-1 of ASME B31T.

124.2 Steel

(a) Upon prolonged exposure to temperatures above 800°F (427°C), the carbide phase of plain carbon steel, carbon–molybdenum steel, plain nickel alloy steel, carbon–manganese alloy steel, manganese–vanadium alloy steel, and carbon–silicon steel may be converted to graphite.

(b) Upon prolonged exposure to temperatures above 875°F (468°C), the carbide phase of alloy steels, such as manganese–molybdenum–vanadium, manganese–chromium–vanadium, and chromium–vanadium, may be converted to graphite.

(c) Carbon or alloy steel having carbon content of more than 0.35% shall not be used in welded construction or be shaped by an oxygen cutting process or other thermal cutting processes.

(d) Where low alloy 2 1/4% chromium steels are used at temperatures above 850°F (454°C), the carbon content of the base material and weld filler metal shall be 0.05% or higher.

(e) Carbon and low alloy steels may be susceptible to flow-accelerated corrosion (FAC, also referred to as flow-assisted corrosion) under certain conditions, which might include rapid or turbulent single- or two-phase flow, low pH, low oxygen concentration, and temperatures in the range of approximately 200°F (93°C) to 500°F (260°C). Materials containing at least 0.1% chromium are considered to be less susceptible to FAC, and these steels will exhibit increasing resistance to FAC as chromium content is increased. Additional information regarding FAC is provided in Nonmandatory Appendix IV.

124.4 Gray Cast Iron

The low ductility of cast gray iron may result in sudden failure if shock loading (pressure, temperature, or mechanical) should occur. Possible shock loadings and consequences of failure must be considered before specifying the use of such material. Cast iron components may be used within the nonshock pressure–temperature ratings established by the standards and specifications herein and in para. 105.2.1(b). Castings to ASME SA-278 and ASTM A278 shall have maximum limits of 250 psig [1725 kPa (gage)] and 450°F (232°C).

The following referenced paragraphs prohibit or restrict the use of gray cast iron for certain applications or to certain pressure–temperature ratings:

Pipe supports 121.7.2(c)
BEP blowoff 122.1.4(a)(3)
BEP blowdown 122.1.4(b)(3)
BEP valves and fittings 122.1.7
Blowoff valves 122.1.7(c)(5), 1221.7(c)(6)
Non-BEP blowoff 122.2(a)(1)
Non-BEP blowdown 122.2(a)(2)
Flammable or combustible liquids 122.7.2(a), 122.7.2(b), 122.7.4
Flammable gases 122.8.1(b), 122.8.1(c)
Toxic gases or liquids 122.8.2(b), 122.8.2(d)

124.5 Malleable Iron

Certain types of malleable iron have low ductility characteristics and may be subject to brittle fracture. Malleable iron may be used for design conditions not to exceed 350 psig [2 415 kPa (gage)] or 450°F (232°C).

The following referenced paragraphs prohibit or restrict the use of malleable iron for certain applications or to certain pressure–temperature ratings:

Pipe supports 121.7.2(d)
BEP blowoff 122.1.4(a)(3)
BEP blowdown 122.1.4(b)(3)
Non-BEP blowoff 122.2(a)(1)
Non-BEP blowdown 122.2(a)(2)
Flammable or combustible liquids 122.7.2(a), 122.7.2(b), 122.7.4
Flammable gases 122.8.1(b), 122.8.1(c)
Toxic gases or liquids 122.8.2(b), 122.8.2(d)

124.6 Ductile (Nodular) Iron

Ductile iron components complying with ANSI/AWWA C110/A21.10, ANSI/AWWA C115/A21.15, ANSI/AWWA C151/A21.51, or ANSI/AWWA C153/A21.53 may be used for water and other nontoxic, nonflammable service, with pressure limits as specified in those standards and temperature limits as specified in
para. 106.1(e). These components may not be used for boiler external piping.

Ductile (nodular) iron components conforming to ASME B16.42 may be used for services including boiler external piping under the following conditions:

(a) Components for boiler external piping shall be used only within the following limitations:
   (1) Only ASME SA-395 material may be used.
   (2) Design pressure shall not exceed 350 psig [2415 kPa (gage)].
   (3) Design temperature shall not exceed 450°F (232°C).
(b) Welding shall not be used, either in fabrication of the components or in their assembly as a part of a piping system.
(c) The following referenced paragraphs prohibit or restrict the use of ductile iron for certain applications or to certain pressure–temperature ratings:

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<td>BEP blowdown</td>
<td>1221.4(b)(3)</td>
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<tr>
<td>BEP blowoff valves</td>
<td>1221.7(c)(5), 1221.7(c)(6)</td>
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<tr>
<td>Toxic gases or liquids</td>
<td>1228.2(b), 1228.2(d)</td>
</tr>
<tr>
<td>Pipe supports</td>
<td>123.3</td>
</tr>
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</table>

124.7 Nonferrous Metals

Nonferrous metals may be used in piping systems under the following conditions:
(a) The melting points of copper, copper alloys, aluminum, and aluminum alloys must be considered, particularly where there is a fire hazard.
(b) The designer shall consider the possibility of galvanic corrosion when combinations of dissimilar metals, such as copper, aluminum, and their alloys, are used in conjunction with each other or with steel or other metals in the presence of an electrolyte.
(c) Threaded Connections. A suitable thread compound shall be used in making up threaded joints in aluminum pipe to prevent seizing that might cause leakage and perhaps prevent disassembly. Pipe in the annealed temper should not be threaded.

124.8 Cladding and Lining Materials

Materials with cladding or lining may be used, provided that
(a) the base material is an approved Code material. The allowable stress used shall be that of the base metal at the design temperature.
(b) the cladding or lining is a material that in the judgment of the user is suitable for the intended service, and the cladding/lining and its method of application do not detract from the serviceability of the base material.
(c) bending procedures are such that damaging or detrimental thinning of the cladding material is prevented.
(d) welding and the inspection of welds is in accordance with the provisions of Chapters V and VI of this Code.
(e) the thickness of the cladding is not credited for structural strength in the piping design.

124.9 Nonmetallic Pipe

This Code recognizes the existence of a wide variety of nonmetallic piping materials that may be used in corrosive (either internal or external) or other specialized applications. Extreme care must be taken in their selection, as their design properties vary greatly and depend on the material, type, and grade. Particular consideration shall be given to
(a) possible destruction where fire hazard is involved
(b) possible decrease in tensile strength at slight increase in temperature
(c) effects of toxicity
(d) requirements for providing adequate support for flexible pipe

Rules and service limitations for plastic and elastomer-based piping materials, including thermoplastics and reinforced thermosetting resins, are given in Mandatory Appendix N.

124.10 Deterioration of Materials in Service

It is the responsibility of the designer to select materials suitable for the intended application. Guidelines and information related to corrosion, corrosion protection, and potential damage mechanisms other than corrosion are provided in Nonmandatory Appendices IV and V.

124.11 Gaskets

Limitations on gasket materials are covered in para. 108.4.

124.12 Bolting

Limitations on bolting materials are covered in para. 108.5.

125 CREEP STRENGTH ENHANCED FERRITIC MATERIALS

125.1 Requirements for ASTM A217, Grade C12A and ASTM A1091, Grade C91 Castings

125.1.1 Required Examinations. The casting shall be examined in accordance with the requirements of para. 1024.6(b).
Alternatively, castings for valves may be examined in accordance with the requirements of ASME B16.34 for special class valves.

### 125.1.2 Heat Treatment Requirements

(a) The material shall be austenitized within the temperature range of 1,900°F to 1,975°F (1040°C to 1080°C), followed by air or accelerated cooling to a temperature of 200°F (95°C) or below, followed by tempering within a range of 1,350°F to 1,470°F (730°C to 800°C). However, if a major weld repair, as defined in ASTM A217, para. 9.4 or ASTM A1091, para. 10.3.4, as applicable, is made after the austenitizing and tempering heat treatment, then a new austenitizing and tempering heat treatment in accordance with the requirements of this subparagraph shall be carried out.

(b) When heat treating single castings, compliance with the specified temperature range shall be verified by thermocouples placed directly on the casting. For castings that are heat treated in batches, compliance with the specified temperature range shall be verified by thermocouples placed on selected castings in each heat treatment batch. The number and location of thermocouples to be placed on each casting, or on each heat treatment batch of castings, for verification of heat treatment shall be as agreed between the purchaser and the producer. A record of the final austenitizing and tempering heat treatment, and any subsequent subcritical heat treatment, shall be prepared and made available to the purchaser. In addition, all heat treatment temperatures and cycle times for the final austenitizing and tempering heat treatment, and any subsequent subcritical heat treatment, shall be shown on the certification report.

(c) The hardness of the cast material after the final heat treatment (including PWHT) shall be Brinell hardness number 185 to 248 or Rockwell B90 to C25. Hardness testing shall be in accordance with Supplementary Requirement S13 of ASTM A217 or ASTM A1091, as applicable.

### 125.1.3 Weld Repair Requirements

(a) Weld repairs to castings shall be made with one of the following welding processes and consumables:

1. SMAW, ASME SFA-5.5/SFA-5.5M E90XX-B9
2. SAW, ASME SFA-5.23/SFA-5.23M EB9 + neutral flux
3. GTAW, ASME SFA-5.28/SFA-5.28M ER90S-B9
4. FCAW, ASME SFA-5.29/SFA-5.29M E91T1-B9

In addition, the Ni + Mn content of all welding consumables shall not exceed 1.0%.

(b) Weld repairs to castings as part of material manufacture shall be made with welding procedures and welders qualified in accordance with ASME BPVC, Section IX.

(c) All weld repairs shall be recorded with respect to their location on the casting. For all major weld repairs, as defined in ASTM A217, para. 9.4 or ASTM A1091, para. 10.3.4, as applicable, the record shall include a description of the length, width, and depth of the repair. Supplementary Requirement S12 of ASTM A703 shall apply. For weld repairs performed as part of material manufacture, the documentation shall be included with the Material Test Report. For weld repairs performed on components for boiler external piping by the Manufacturer, documentation shall be included with the Manufacturer's Data Report.

### 125.1.4 Overheating Requirements

If, during the manufacturing, any portion of the component is heated to a temperature greater than 1,470°F (800°C), then the component shall be reaustenitized and retempered in its entirety in accordance with para. 125.1.2, or that portion of the component heated above 1,470°F (800°C), including the heat-affected zone created by the local heating, shall be replaced or shall be removed, reaustenitized, retempered, and then replaced in the component.

### 125.1.5 Certification Requirements

A manufacturer’s test report meeting certification requirements of ASTM A703 shall be provided.

### 125.2 Grade 91 Welding Consumables

With the exception of repair welds to castings [see para. 125.1.3(a)], the Ni + Mn content of Grade 91 welding consumables (AWS B9, EV CrMo91, etc.) shall not exceed 1.2% when used toweld P-No. 15E, Group 1 materials. Nickel-based welding consumables (AWS ERNiCr-3, ENiCrFe-2, etc.) are not required to meet the Ni + Mn content limitation and may be used in conjunction with the PWHT limits listed in Note 7 of Table 132.1.1-1.

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1. To facilitate complete transformation to martensite after the austenitizing, cooling should be as uniform as possible.
### Table 126.1-1
Specifications and Standards

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**Note**

[Note to Editor - Move these three specifications to the end of the ASTM listings.]
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- B247, B247M: Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings
- B283/B283M: Copper and Copper-Alloy Die Forgings (Hot Pressed)
- B381: Titanium and Titanium Alloy Forgings
- B462: Forged or Rolled UNS N06030, N06022, N06035, N06200, N06059, N10362, N06686, N08020, N08024, N08026, N08367, N10276, N10665, N10675, N10629, N08031, and N06045 Pipe Flanges, Forged Fittings, and Valves and Parts for Corrosive High-Temperature Service
- B564: Nickel Alloy Forgings

#### Seamless Pipe and Tube

- B42: Seamless Copper Pipe, Standard Sizes
- B43: Seamless Red Brass Pipe, Standard Sizes
- B68/B68M: Seamless Copper Tube, Bright Annealed
- B75: Seamless Copper Tube
- B88/B88M: Seamless Copper Water Tube
- B111/B111M: Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock
- B161: Nickel Seamless Pipe and Tube
- B163: Seamless Nickel and Nickel-Alloy (UNS N06845) Condenser and Heat-Exchanger Tubes
- B165: Nickel-Copper Alloy (UNS N04400) Seamless Pipe and Tube
- B210/B210M: Aluminum and Aluminum Alloy Drawn Seamless Tubes
- B234/B234M: Aluminum and Aluminum-Alloy Drawn Seamless Tubes for Surface Condensers, Evaporators, and Heat Exchangers
- B241/B241M: Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube
- B251/B251M: General Requirements for Wrought Seamless Copper and Copper-Alloy Tube
- B280: Seamless Copper Tube for Air Conditioning and Refrigeration Field Service
- B302: Threadless Copper Pipe, Standard Sizes
- B315: Seamless Copper Alloy Pipe and Tube
- B407: Nickel-Iron-Chromium Alloy Seamless Pipe and Tube
- B423: Nickel-Chromium-Molybdenum-Copper Alloy (UNS N08825, N08821, and N06845) Seamless Pipe and Tube
- B466/B466M: Seamless Copper-Nickel Pipe and Tube
- B622: Seamless Nickel and Nickel-Cobalt Alloy Pipe and Tube
- B677: UNS N08925, UNS N08354, and UNS N08926 Seamless Pipe and Tube
- B690: Iron-Nickel-Chromium-Molybdenum Alloys (UNS N08366 and UNS N08367) Seamless Pipe and Tube
- B729: Seamless UNS N08020, UNS N08026, and UNS N08024 Nickel-Alloy Pipe and Tube
- B861: Titanium and Titanium Alloy Seamless Pipe

#### Seamless and Welded Pipe and Tube

- B338: Seamless and Welded Titanium and Titanium Alloy Tubes for Condensers and Heat Exchangers
- B444: Nickel-Chromium-Molybdenum-Columbium Alloy (UNS N06625 and UNS N06852) and Nickel-Chromium-Molybdenum-Silicon Alloy (UNS N06219) Pipe and Tube

#### Welded Pipe and Tube

- B464: Welded (UNS N08020, N08024, and N08026) Alloy Pipe
- B467: Welded Copper-Nickel Pipe
- B468: Welded (UNS N08020, N08024, and N08026) Alloy Tubes

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B706: Standard Specification for Seamless Copper Alloy (UNS No. C69100) Pipe and Tube
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GENERAL NOTES:
(a) For boiler external piping application, see para. 123.2.2.
(b) For all other piping, materials conforming to an ASME SA or ASME SB specification may be used interchangeably with material specified to an ASTM A or ASTM B specification of the same number listed in this table.
(c) The approved year of issue of the specifications and standards is not given in this table. This information is given in Mandatory Appendix F of this Code.
(d) The addresses and phone numbers of organizations whose specifications and standards are listed in this table are given at the end of Mandatory Appendix F.

NOTES:
(1) ANSI B18.22.1 is nonmetric.
(2) This standard requires testing of couplings with bending moments applied that are equivalent to support spacings shorter than those recommended in para. 121.5. Couplings should be tested with bending moments applied that correspond to support spacings equal to or greater than those to be used in the piping installation.
(3) See para. 107.1(d) for valve stem retention requirements.

SAE Standard

SAE J429 Mechanical and Material Requirements for Externally Threaded Fasteners
Chapter V
Fabrication, Assembly, and Erection

127 WELDING

127.1 General

Piping systems shall be constructed in accordance with the requirements of this Chapter and of materials that have been manufactured in accordance with the requirements of Chapter IV. These requirements apply to all fabrication, assembly, and erection operations, whether performed in a shop or at a construction site. The following applies essentially to the welding of ferrous materials. The welding of aluminum, copper, etc., requires different preparations and procedures.

127.1.1 The welding processes that are to be used under this part of this Code shall meet all the test requirements of ASME BPVC, Section IX.

127.2 Material

127.2.1 Electrodes and Filler Metal. Welding electrodes and filler metal, including consumable inserts, shall conform to the requirements of ASME BPVC, Section II, Part C. An electrode or filler metal not conforming to the above may be used provided the WPS and the welders and welding operators who will follow the WPS have been qualified as required by ASME BPVC, Section IX. Unless otherwise specified by the designer, welding electrodes and filler metals used shall produce weld metal that complies with the following:

(a) The nominal tensile strength of the weld metal shall equal or exceed the minimum specified tensile strength of the base metals being joined.

(b) If base metals of different tensile strengths are to be joined, the nominal tensile strength of the weld metal shall equal or exceed the minimum specified tensile strength of the weaker of the two.

(c) The nominal chemical analysis of the weld metal shall be similar to the nominal chemical analysis of the base metal, including consideration of both major and essential minor alloying elements [e.g., 2 1/4% Cr, 1% Mo steels should be joined using 2 1/4% Cr, 1% Mo filler metals; see also para. 124.2(d)].

(d) If base metals of different chemical analysis are being joined, the nominal chemical analysis of the weld metal shall be similar to either base metal or an intermediate composition, except as specified in (e) for austenitic steels joined to ferritic steels.

(e) When austenitic steels are joined to ferritic steels, the weld metal shall have an austenitic structure.

(f) For nonferrous metals, the weld metal shall be that recommended by the manufacturer of the nonferrous metal or by industry associations for that metal.

(g) Filler metals not meeting the requirements of (a) through (f) may be accepted by agreement between the fabricator/erector and the designer. Examples of conditions where this may apply include (but may not be limited to) where unusual materials or combinations of materials are used, where highly corrosive environments may require a more electrochemically noble weld metal, where dissimilar materials are welded, or where it is desired to achieve a weld with different mechanical properties from the base material.

127.2.2 Backing Rings. Backing rings, when used, shall conform to the following requirements:

(a) Ferrous Rings. Ferrous metal backing rings that become a permanent part of the weld shall be made from material of weldable quality, compatible with the base material and the sulfur content shall not exceed 0.05%.

(b) Nonferrous and Nonmetallic Rings. Backing rings of nonferrous or nonmetallic materials may be used for backing provided they are included in a WPS as required in para. 127.5. Nonmetallic or nonfusing rings shall be removed.

127.2.3 Consumable Inserts. Consumable inserts may be used provided they are made from material compatible with the chemical and physical properties of the base material. Qualification of the WPS shall be as required by para. 127.5.
127.3 Preparation for Welding

(a) End Preparation

(1) Oxygen or arc cutting is acceptable only if the cut is reasonably smooth and true, and all slag is cleaned from the flame cut surfaces. Discoloration that may remain on the flame cut surface is not considered to be detrimental oxidation.

(2) Butt-welding end preparation dimensions contained in ASME B16.25 or dimensions of any other end preparation that meets the WPS are acceptable.

(3) If piping component ends are bored, such boring shall not result in finished wall thickness, after welding, less than the minimum design thickness. Where necessary, weld metal of the appropriate analysis may be deposited on the inside or outside of the piping component to provide sufficient material for machining to ensure satisfactory fitting of rings.

(4) If the piping component ends are upset, they may be bored to allow for a completely recessed backing ring, provided the remaining net thickness of the finished ends is not less than the minimum design thickness.

(b) Cleaning. Surfaces for welding shall be clean and shall be free from paint, oil, rust, scale, or other material that is detrimental to welding.

(c) Alignment. The inside diameters of piping components to be butt welded shall be aligned as accurately as is practicable within existing commercial tolerances on diameters, wall thicknesses, and out-of-roundness. Alignment shall be preserved during welding. The internal misalignment of the ends to be joined shall not exceed \(\frac{1}{16}\) in. (1.5 mm) unless the piping design specifically states a different allowable misalignment.

127.4 Procedure

127.4.1 General

(a) Qualification of the WPS to be used, and of the performance of welders and operators, is required and shall comply with the requirements of para. 127.5.

(b) No welding shall be done if there is impingement of rain, snow, sleet, or high wind on the weld area.

(c) Tack welds permitted to remain in the finished weld shall be made by a qualified welder. Tack welds made by an unqualified welder shall be removed. Tack welds that remain shall be made with an electrode and WPS that is the same as or equivalent to the electrode and WPS to be used for the first pass. The stopping and starting ends shall be prepared by grinding or other means so that they can be satisfactorily incorporated into the final weld. Tack welds that have cracked shall be removed.

(d) Arc strikes outside the area of the intended weld should be avoided on any base metal. Arc strikes made outside of the weld joint area shall be removed and the surface visually examined. The surface shall also be examined by the liquid penetrant or magnetic particle method when the material is P-No. 4, P-No. 5A, P-No. 5B, or P-No. 15E.

127.4.2 Girth Butt Welds

(a) Girth butt welds shall be complete penetration welds and shall be made with a single vee, double vee, or other suitable type of groove, with or without backing rings or consumable inserts. The depth of the weld measured between the inside surface of the weld...
136.4.1-1. For repairs to welds, the minimum examination shall be the same method that revealed the defect in the original weld. For repairs to base material, the minimum examination shall be the same as required for butt welds.

127.5 Qualification

127.5.1 General. Qualification of the WPS to be used, and of the performance of welders and welding operators, is required and shall comply with the requirements of ASME BPVC, Section IX, as modified herein.

Certain materials listed in Mandatory Appendix A do not appear in ASME BPVC, Section IX P-Number groups. Where these materials have been assigned P-Numbers in Mandatory Appendix A, they may be welded under this Code for nonboiler external piping only without separate qualification as if they were listed in ASME BPVC, Section IX.

127.5.2 Welding Responsibility. Each employer (see para. 100.2) shall be responsible for the welding performed by his own organization and the performance of welders or welding operators employed by that organization.

127.5.3 Qualification Responsibility

(a) Procedures. Each employer shall be responsible for qualifying any WPS that he/she intends to have used by personnel of his/her organization. However, to avoid duplication of effort, and subject to approval of the owner of the WPS qualified by a technically competent group or agency may be used,

(1) if the group or agency qualifying the WPS meets all of the procedure qualification requirements of this Code
(2) if the owner accepts the WPS thus qualified
(3) if the owner of the WPS has qualified at least one welder using the WPS

(4) if the user of the WPS assumes specific responsibility for the procedure qualification work done by another.

All of the conditions in (1) through (4) shall be met before a WPS thus qualified may be used.

(b) Welders and Welding Operators. Each employer shall be responsible for qualifying all the welders and welding operators employed by him/her.

However, to avoid duplication of effort, he/she may accept a Welder/Welding Operator Performance Qualification (WPQ) made by a previous employer (subject to the approval of the owner or agent) on piping using the same or an equivalent procedure wherein the essential variables are within the limits established in ASME BPVC, Section IX. An employer accepting such qualification tests by a previous employer shall obtain a copy of the original WPQ, showing the name of the employer by whom the welders or welding operators were qualified, the dates of such qualification, and evidence that the welder or welding operator has maintained qualification in accordance with ASME BPVC, Section IX, QW-522. The evidence of process usage to maintain continuity may be obtained from employers other than the original qualifying employer. The employer shall then prepare and sign the record required in para. 127.6 accepting responsibility for the ability of the welder or welding operator.

127.5.4 Standard Welding Procedure Specifications. Standard Welding Procedure Specifications published by the American Welding Society and listed in ASME BPVC, Section IX, Mandatory Appendix E, are permitted for Code construction within the limitations established by ASME BPVC, Section IX, Article V.

127.6 Welding Records

The employer shall maintain a record [WPS and/or WPQ] signed by himself, and available to the purchaser or agent, of the WPQ used and the welders and/or welding operators employed by himself, showing the dates and results of procedure and performance qualification.

The WPQ shall also show the identification symbol assigned to the welder or welding operator employed by himself, and the employer shall put this symbol to identify the welding performed by the welder or welding operator. This may be accomplished by the application of the symbol on the weld joint in a manner specified by the employer. Alternatively, the employer shall maintain records that identify welds made by the welder or welding operator.
128 BRAZING AND SOLDERING

128.1 General

128.1.1 The brazing processes that are to be used under this part of the Code shall meet all the test requirements of ASME BPVC, Section IX.

128.1.2 Soldering. Solderers shall follow the procedure in ASTM B829, Standard Practice for Making and Cutting Joints by Soldering of Copper and Copper Alloy Tube and Fittings.

128.2 Materials

128.2.1 Filler Metal. The brazing alloy or solder shall melt and flow freely within the specified or desired temperature range and, in conjunction with a suitable flux or controlled atmosphere, shall wet and adhere to the surfaces to be joined.

128.2.2 Flux. A flux that is fluid and chemically active at brazing or soldering temperature shall be used when necessary to eliminate oxidation of the filler metal and the surfaces to be joined, and to promote free flow of the brazing alloy or solder.

128.3 Preparation

128.3.1 Surface Preparation. The surfaces to be brazed or soldered shall be clean and free from grease, oxides, paint, scale, dirt, or other material that is detrimental to brazing. A suitable chemical or mechanical cleaning method shall be used if necessary to provide a clean wettable surface.

128.3.2 Joint Clearance. The clearance between surfaces to be joined by brazing or soldering shall be no larger than is necessary to allow complete capillary distribution of the brazing alloy or solder.

128.4 Procedure

128.4.1 General

(a) Qualification of the brazing procedures to be used and of the performance of the brazers and brazing operators is required and shall comply with the requirements of para. 128.5.

(b) No brazing shall be done if there is impingement of rain, snow, sleet, or high wind on the area to be brazed.

128.4.2 Heating. To minimize oxidation, the joint shall be brought to brazing or soldering temperature in as short a time as possible without localized underheating or overheating.

128.4.3 Flux Removal. Residual flux shall be removed if detrimental.

128.5 Brazing Qualification

128.5.1 General. The qualification of the brazing procedure and of the performance of brazers and brazing operators shall be in accordance with the requirements of ASME BPVC, Section IX, Part QB, except as modified herein.

128.5.2 Brazing Responsibility. Each employer (see para. 100.2) shall be responsible for the brazing performed by the brazers employed by that organization and the performance of brazers employed by that organization.

128.5.3 Qualification Responsibility

(c) Procedures. Each employer shall be responsible for qualifying any Brazing Procedure Specification (BPS) that it intends to have used by personnel employed by that organization. However, to avoid duplication of effort, and subject to approval of the owner, a BPS qualified by a technically competent group or agency may be used.
by the employer

the employer's organization.

the owner's

the purchaser's

by the employer
Figure 127.4.8-7
Typical Partial Penetration Weld Branch and Instrument Connections for NPS 2 (DN 50) and Smaller Fittings

(a) Branch Connection Typical Partial Penetration Weld

(b) Instrument Connection Typical Partial Penetration Weld
where
\[ R = \text{centerline radius of bend} \]
\[ R_f = \text{mean radius after forming} \]
\[ R_g = \text{original mean radius (equal to infinity for a flat plate)} \]
\[ r_{od} = \text{nominal outside radius of pipe or tube} \]
\[ t_n = \text{nominal thickness of the plate, pipe, or tube before forming} \]

129.3.4.2 When forming strains cannot be calculated as shown in para. 129.3.4.1, the manufacturer shall have the responsibility to determine the maximum forming strain.

129.3.4.3 For flares, swages, or upsets, heat treatment in accordance with Table 129.3.4.1-1 shall apply, regardless of the amount of strain, unless the finishing forming temperature is equal to or greater than the minimum heat treatment temperature for a given grade or UNS number material, provided the requirements of para. 129.3.4.5 are met.

129.3.4.4 Heat treatment, in accordance with Table 129.3.4.1-1, shall not be required if the finishing forming temperature is equal to or greater than the minimum heat treatment temperature for a given grade or UNS number material, provided the requirements of para. 129.3.4.5 are met.

129.3.4.5 The piping components being heat treated shall be held at the temperatures given in Table 129.3.4.1-1 for 20 min/in. (20 min/25 mm) of thickness, or for 10 min, whichever is greater.

129.3.4.6 Postbending or postforming heat treatment of materials not identified in Table 129.3.4.1-1 is neither required nor prohibited. If a postbending or postforming heat treatment is to be performed, the designer shall fully describe the procedure to be used.

129.3.5 For ASME SA/EN 10028-2 15NiCuMoNb5-6-4, (22)
ASTM A335 P36, and ASTM F36, after either cold bending to strains in excess of 5% or any hot bending of this material, the full length of the component shall be heat treated in accordance with the requirements specified in the material specification.

129.3.6 For P-No. 10H materials, if heat treatment is required after bending or forming, it shall be performed in accordance with the heat treatment specified in the applicable material specification.

### Table 129.3.3.1-1

<table>
<thead>
<tr>
<th>Grade UNS Number</th>
<th>Limitations in Lower Temperature Range</th>
<th>Limitations in Higher Temperature Range</th>
<th>Required Heat Treatment When Design Temperature and Forming Strains Are Exceeded</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>For Design Temperature Exceeding</td>
<td>But Less Than or Equal to</td>
<td>And Forming Strains</td>
</tr>
<tr>
<td></td>
<td>°F</td>
<td>°C</td>
<td>°F</td>
</tr>
<tr>
<td>91 K90901</td>
<td>1,000</td>
<td>540</td>
<td>1,115</td>
</tr>
<tr>
<td></td>
<td>1,000</td>
<td>540</td>
<td>1,115</td>
</tr>
</tbody>
</table>

GENERAL NOTE: The limits shown are for pipe and tube formed from plates, spherical or dished heads formed from plate, and tube and pipe bends. The forming strain limits tabulated in this table shall be divided by two if para. 129.3.4.2 is applied.

NOTES:

(1) Normalization and tempering shall be performed in accordance with the requirements in the base material specification, and shall not be performed locally. The material shall either be heat treated in its entirety, or the cold-strained area (including the transition to the unstrained portion) shall be cut away from the balance of the tube or component and heat treated separately or replaced.

(2) Postbend heat treatments shall be performed at 1,350°F to 1,425°F (730°C to 775°C) for 1 hr/in. (1 h/25 mm) or 30 min minimum. Alternatively, a normalization and temper in accordance with the requirements in the base material specification may be performed.

(3) For materials with greater than 5% strain but less than or equal to 25% strain, with design temperatures less than or equal to 1,115°F (600°C), if a portion of the component is heated above the heat treatment temperature allowed above, one of the following actions shall be performed:

(a) The component in its entirety must be renormalized and tempered.

(b) For BEP piping only, the allowable stress shall be that for Grade 9 material (i.e., ASME SA-213 T9, ASME SA-335 P9, or equivalent product specification) at the design temperature, provided that the portion of the component that was heated to a temperature exceeding the maximum holding temperature is subjected to a final heat treatment within the temperature range and for the time required in Note (2) above. The use of this provision shall be noted on the Manufacturer's Data Report.

(4) If a longitudinal weld is made to a portion of the material that is cold strained, that portion shall be normalized and tempered prior to or following welding. This normalizing and tempering shall not be performed locally.
rate of cooling and be maintained in a dry environment. Postweld hydrogen bakeout for P-No. 5B or P-No. 15E materials may be omitted entirely when the following condition applies:

(1) use of low-hydrogen electrodes and filler metals classified by the filler metal specification with an optional supplemental diffusible hydrogen designator of H4 or lower (H5 designation on SAW flux) and suitably controlled by maintenance procedures to avoid contamination by hydrogen-producing sources. The surface of the base metal prepared for welding shall be free of contaminants. The following additional exemptions shall apply:

(a) GTAW welds with a thickness of \( \frac{1}{2} \) in. (13 mm) or less that are wrapped in insulation and allowed to cool slowly to the ambient temperature after completion. Filler metal need not meet the H4 or lower diffusible hydrogen requirements of (1).

(b) multiprocess welds incorporating a GTAW root and one or more hot passes not meeting the H4 or lower diffusible hydrogen requirements of (1), when the remaining processes meet or exceed the electrode and fill metal requirements of (1).

(c) upon weld completion, preheat is reduced below the approximate martensite finish (\( M_f \)) temperature [see (b)], followed by prompt PWHT per para. 132. A written procedure shall be provided to the owner or his/her agent detailing the process used to minimize hydrogen exposure and the time below 200°F (95°C) prior to initiating the PWHT heating cycle.

### Table 131.4.1-1
Preheat Temperatures

<table>
<thead>
<tr>
<th>Base Metal P-Number [Note (1)]</th>
<th>Base Metal Group</th>
<th>Nominal Material Thickness [Note (2)]</th>
<th>Additional Limits</th>
<th>Required Minimum Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>in.</td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>1 Carbon steel ≤1 ≤25 None</td>
<td></td>
<td>50</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>&gt;1 &gt;25 %C ≤ 0.30 [Note (3)]</td>
<td></td>
<td>50</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>&gt;1 &gt;25 %C &gt; 0.30 [Note (3)]</td>
<td></td>
<td>200</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>3 Alloy steel Cr ≤ ( \frac{1}{2} )% ≤1 ≤13 SMTS ≤ 65 ksi (450 MPa)</td>
<td></td>
<td>50</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>&gt;1 &gt;13 SMTS ≤ 65 ksi (450 MPa)</td>
<td></td>
<td>200</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>All All SMTS &gt; 65 ksi (450 MPa)</td>
<td></td>
<td>200</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>4 Alloy steel ( \frac{1}{2} )% &lt; Cr ≤ 2% All All None</td>
<td></td>
<td>250</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>5A Alloy steel All All SMTS ≤ 60 ksi (414 MPa)</td>
<td></td>
<td>300</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>SMTS &gt; 60 ksi (414 MPa)</td>
<td></td>
<td>400</td>
<td>205</td>
<td></td>
</tr>
<tr>
<td>5B Alloy steel All All SMTS ≤ 60 ksi (414 MPa)</td>
<td></td>
<td>300</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>All All SMTS &gt; 60 ksi (414 MPa)</td>
<td></td>
<td>400</td>
<td>205</td>
<td></td>
</tr>
<tr>
<td>&gt;1 &gt;13 %Cr &gt; 6.0 [Note (3)]</td>
<td></td>
<td>400</td>
<td>205</td>
<td></td>
</tr>
<tr>
<td>6 Martensitic stainless steel All All None</td>
<td></td>
<td>400</td>
<td>205</td>
<td></td>
</tr>
<tr>
<td>[Note (4)] [Note (4)]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9A Nickel alloy steel All All None</td>
<td></td>
<td>250</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>9B Nickel alloy steel All All None</td>
<td></td>
<td>300</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>10I 27Cr steel All All None</td>
<td></td>
<td>300</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>[Note (5)] [Note (5)]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15E 9Cr–1Mo–V CSEF steel All All None</td>
<td></td>
<td>400</td>
<td>205</td>
<td></td>
</tr>
<tr>
<td>All other materials ... ... None</td>
<td></td>
<td>50</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

GENERAL NOTE: SMTS = specified minimum tensile strength.

NOTES:
(1) P-Nos. and Group nos. from ASME BPVC, Section IX, QW/QB-422.
(2) The nominal material thickness is defined in para. 132.4.3.
(3) Composition may be based on ladle or product analysis or per specification limits.
(4) Maximum interpass temperature 600°F (315°C).
(5) Maintain interpass temperature between 300°F and 450°F (150°C and 230°C).
(b) P-No. 15E materials are required to be cooled below the approximate martensite finish (Mf) temperature of the filler metals before PWHT is initiated. Approximate Mf temperatures are as follows:

1. P-No. 15E filler metal Ni + Mn ≤ 1.2% = 375°F (190°C)
2. P-No. 15E filler metal Ni + Mn > 1.2% = 200°F (95°C)

132 POSTWELD HEAT TREATMENT

132.1 Minimum PWHT Requirements

132.1.1 Before applying the detailed requirements and exemptions in these paragraphs, satisfactory qualification of the WPS to be used shall be performed in accordance with the essential variables of ASME BPVC, Section IX, including the conditions of postweld heat treatment or lack of postweld heat treatment and including other restrictions listed below. Except as otherwise provided in paras. 127.4.9, 132.2, and 132.3, all welds in materials included in the P-Numbers listed in Table 132.1.1-1 shall be given a postweld heat treatment within the temperature range specified in Table 132.1.1-1. (The range specified in Table 132.1.1-1 may be modified by Table 132.1.1-2 for the lower limit and para. 132.2 for the upper limit.) The materials in Table 132.1.1-1 are listed in accordance with the material P-Numbers and Group numbers of ASME BPVC, Section IX, Table QW/QB-422. (Note that the P-Numbers are also listed in Mandatory Appendix A.) Welds of materials not included in Table 132.1.1-1 shall be heat treated in accordance with the WPS. Austenitizing PWHTs may be performed but are required to be addressed within the qualified WPS.

ASME B31P may be used as an alternative in accordance with para. 127.4.10.

132.1.2 Pressure part welds and attachment welds using ferritic filler metals that have a specified chromium content of more than 3% shall receive a postweld heat treatment. The postweld heat treatment time and temperature range used shall be that shown in Table 132.1.1-1 for a base metal of similar composition.

132.1.3 For ASME SA/EN 10028-2 15NiCuMoNb 5-6-4, ASTM A335 P36, and ASTM F36, postweld heat treatment is mandatory under all conditions. Postweld heat treatment shall be in accordance with Table 132.1.3-1.

132.2 Mandatory PWHT Requirements

Heat treatment may be accomplished by a suitable heating method that will provide the desired heating and cooling rates, the required metal temperature, temperature uniformity, and temperature control.

(a) The upper limit of the PWHT temperature range in Table 132.1.1-1 is a recommended value that may be exceeded provided the actual temperature does not exceed the lower critical temperature of either material (see Table 129.3.1-1).

(b) When parts of two different P-Numbers are joined by welding, the postweld heat treatment shall be that specified for the material requiring the higher PWHT temperature. When a nonpressure part is welded to a pressure part and PWHT is required for either part, the maximum PWHT temperature shall not exceed the maximum temperature acceptable for the pressure-retaining part.

(c) When one of the parts in a joint is exempt from PWHT, the time and temperature shall be that of the part requiring PWHT. For a weld to be exempt, each part must satisfy the exemptions in para. 132.3 and the notes applicable to its respective P-Number and Group number.

(d) When a nonpressure part is welded to a pressure part and PWHT is required for either part, the maximum PWHT temperature shall not exceed the maximum temperature acceptable for the pressure-retaining part.

(e) Caution is necessary to preclude metallurgical damage to some materials or welds not intended or qualified to withstand the PWHT temperatures required. The use of material transition joint designs may be required.

(f) The designer may require PWHT even if not mandatory per Table 132.1.1-1 or Table 132.2-1.

132.3 Exemptions to Mandatory PWHT Requirements

132.3.1 Postweld heat treatment is not required for the following conditions unless required by the qualified WPS or the designer:

(a) welds in nonferrous materials
(b) welds exempted in Table 132.1.1-1 or Table 132.2-1
(c) welds subject to temperatures above the lower critical temperature (see Table 129.3.1-1) during fabrication provided the WPS has been qualified with PWHT (see para. 132.1) at the temperature range to be reached during fabrication

132.3.2 The postweld heat treatment exemptions of Table 132.2-1 may be based on the actual chemical composition as determined by a ladle or product analysis in accordance with the material specification in lieu of the specified or maximum specified chemical composition limits.

132.3.3 Thermocouples may be temporarily attached directly to pressure-containing parts using the capacitor discharge method of welding in accordance with the requirements of para. 127.4.9(b).

132.4 Definition of Thicknesses for PWHT

132.4.1 The term control thicknesses as used in Tables 132.1.1-1 and 132.2-1 and their Notes is the lesser thickness of (a) or (b) as follows:

With the exception of P-No. 15E, Group 1 materials where Table 132.2.2-1 Note (8) applies, the
## Table 132.1-1
### Postweld Heat Treatment

<table>
<thead>
<tr>
<th>P-Number and Group Number (ASME BPVC, Section IX, QW/QB-420)</th>
<th>Holding Temperature Range, °F (°C) [Note (1)]</th>
<th>Minimum Holding Time at Temperature for Control Thickness [Note (2)]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>≤2 in. (50 mm)</td>
</tr>
<tr>
<td>P-No. 1, Groups 1–3</td>
<td>1,100 to 1,200 (595 to 650)</td>
<td>1 hr/in. (25 mm), 15 min minimum</td>
</tr>
<tr>
<td>P-No. 3, Groups 1 and 2</td>
<td>1,100 to 1,200 (595 to 650)</td>
<td></td>
</tr>
<tr>
<td>P-No. 4, Groups 1 and 2</td>
<td>1,200 to 1,300 (650 to 705)</td>
<td></td>
</tr>
<tr>
<td>P-No. 5A, Group 1</td>
<td>1,250 to 1,400 (675 to 760)</td>
<td></td>
</tr>
<tr>
<td>P-No. 5B, Group 1</td>
<td>1,250 to 1,400 (675 to 760)</td>
<td></td>
</tr>
<tr>
<td>P-No. 6, Groups 1–3</td>
<td>1,400 to 1,475 (760 to 800)</td>
<td></td>
</tr>
<tr>
<td>P-No. 7, Groups 1 and 2</td>
<td>1,350 to 1,425 (730 to 775)</td>
<td></td>
</tr>
<tr>
<td>P-No. 10H, Group 1</td>
<td>PWHT not required unless required by WPS</td>
<td></td>
</tr>
<tr>
<td>P-No. 10I, Group 1</td>
<td>1,350 to 1,500 (730 to 815)</td>
<td></td>
</tr>
<tr>
<td>P-No. 15E, Group 1</td>
<td>1,300 to 1,425 (705 to 775)</td>
<td>1 hr/in. (25 mm), 30 min minimum</td>
</tr>
<tr>
<td>All other materials</td>
<td>PWHT as required by WPS</td>
<td>Per WPS</td>
</tr>
</tbody>
</table>

**GENERAL NOTE:** The exemptions for mandatory PWHT are defined in Table 132.2-1.

**NOTES:**

1. The holding temperature range is further defined in paras. 132.1.1 and 1322.
2. The control thickness is defined in para. 132.4.1.
3. Cooling rate shall not be greater than 100°F (55°C) per hour in the range above 1,200°F (650°C), after which the cooling rate shall be sufficiently rapid to prevent embrittlement.
4. If PWHT is required, it shall be performed in accordance with the heat treatment specified in the applicable material specification.
5. See para. 125.1.2(c) for hardness requirements for ASTM A217, Grade C12A and ASTM A1091, Grade C91 castings after PWHT.
6. The minimum PWHT holding temperature may be 1,250°F (675°C) for nominal material thicknesses (see para. 132.4.3) ≤1/2 in. (13 mm).
7. The Ni + Mn content of the filler metal shall not exceed 1.2% unless specified by the designer, in which case the maximum temperature to be reached during PWHT shall be the A<sub>t</sub> (lower transformation or lower critical temperature) of the filler metal, as determined by analysis and calculation or by test, but not exceeding 1,470°F (800°C). If the 1,470°F (800°C) limit was exceeded, the weld and the entire area affected by the PWHT will be removed and, if reused, shall be renormalized and tempered prior to reinstallation.
Table 132.1.1-1

<table>
<thead>
<tr>
<th>P-Number and Group Number (ASME BPVC, Section IX, QW/QB-420)</th>
<th>Holding Temperature Range, °F (°C) [Note(1)]</th>
<th>Minimum Holding Time at Temperature for Control Thickness [Note(2)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-No. 1, Groups 1–3</td>
<td>1,100 to 1,200 (595 to 650)</td>
<td>1 hr/in. (25 mm), 15 min minimum</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)</td>
</tr>
<tr>
<td>P-No. 3, Groups 1 and 2</td>
<td>1,100 to 1,200 (595 to 650)</td>
<td></td>
</tr>
<tr>
<td>P-No. 4, Groups 1 and 2</td>
<td>1,200 to 1,300 (650 to 705)</td>
<td></td>
</tr>
<tr>
<td>P-No. 5A, Group 1</td>
<td>1,250 to 1,400 (675 to 760)</td>
<td></td>
</tr>
<tr>
<td>P-No. 5B, Group 1</td>
<td>1,250 to 1,400 (675 to 760)</td>
<td></td>
</tr>
<tr>
<td>P-No. 6, Groups 1–3</td>
<td>1,400 to 1,475 (760 to 800)</td>
<td></td>
</tr>
<tr>
<td>P-No. 7, Groups 1 and 2</td>
<td>1,350 to 1,425 (730 to 775)</td>
<td></td>
</tr>
<tr>
<td>P-No. 8, Groups 1–4 PWHT not required unless required by WPS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P-No. 9A, Group 1</td>
<td>1,100 to 1,200 (595 to 650)</td>
<td></td>
</tr>
<tr>
<td>P-No. 9B, Group 1</td>
<td>1,100 to 1,175 (595 to 635)</td>
<td></td>
</tr>
<tr>
<td>P-No. 10H, Group 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All other materials PWHT as required by WPS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

GENERAL NOTE: The exemptions for mandatory PWHT are defined in Table 132.2-1.

NOTES:

(1) The holding temperature range is further defined in para. 132.1.1 and 132.2.

(2) The control thickness is defined in para. 132.4.1.

(3) Cooling rate shall not be greater than 100°F (55°C) per hour in the range above 1,200°F (650°C), after which the cooling rate shall be sufficiently rapid to prevent embrittlement.

(4) If PWHT is performed after bending, forming, or welding, it shall be within the following temperature ranges for the specified alloy, followed by rapid cooling:

- Alloys S31803 and S32205 — 1,870°F to 2,010°F (1020°C to 1100°C)
- Alloy S32550 — 1,900°F to 2,050°F (1040°C to 1120°C)
- Alloy S32750 — 1,880°F to 2,060°F (1025°C to 1125°C)
- All others — 1,800°F to 1,900°F (980°C to 1040°C)

(5) See para. 125.1.2(c) for hardness requirements for ASTM A217, Grade C12A and ASTM A1091, Grade C91 castings after PWHT.

(6) The minimum PWHT holding temperature may be 1,250°F (675°C) for nominal material thicknesses (see para. 132.4.3) ≤1/2 in. (13 mm).

(7) The Ni + Mn content of the filler metal shall not exceed 1.2% unless specified by the designer, in which case the maximum temperature to be reached during PWHT shall be 1,470°F (800°C). If the 1,470°F (800°C) limit was exceeded, the weld and the entire area affected by the PWHT will be removed and, if reused, shall be renormalized and tempered prior to reinstallation.

See following page for Note 8
(8) If a portion of a component is heated above the heat treatment temperature allowed above, one of the following actions shall be performed:

(a) The component in its entirety must be renormalized and tempered.

(b) If the maximum holding temperature in the table or [Note (7)] above is exceeded but does not exceed 1,470°F (800°C), the weld metal shall be removed, replaced, and heat treated in accordance with Para. 132.

(c) The portion of the component heated above 1,470°F (800°C) and at least 3 in. (75 mm) on either side of the overheated zone must be removed and be renormalized and tempered or replaced.

(d) An evaluation performed by the designer and when approved by the owner, an evaluation considering the possible degradation of mechanical properties due to excessive heat treatment temperatures is performed and confirms that the component is suitable for the specified design conditions in accordance with the rules of this Code.
as heating a section before assembly or applying local heating in accordance with para. 132.7.

(b) An assembly may be postweld heat treated in more than one heat in a furnace provided there is at least a 1 ft (300 mm) overlap of the heated sections and the portion of the assembly outside the furnace is shielded so that the temperature gradient is not harmful. This method may not be used for austenitizing heat treatments of ferritic materials.

(c) Direct impingement of flame on the assembly is prohibited.

(d) The furnace shall be calibrated such that the PWHT can be controlled within the required temperature range.

132.7 Local Heating

PWHT may be performed locally by heating a circumferential band around the entire component with the weld located in the approximate center of the band. The width of the band heated to the specified temperature range shall be at least three times the wall thickness at the weld of the thickest part being joined. For nozzle and attachment weld, the width of the band heated to the specified temperature range shall extend beyond the nozzle weld or attachment weld on each side at least two times the run pipe thickness and shall extend completely around the run pipe. Guidance for the placement of thermocouples on circumferential butt welds is provided in AWS D10.10, Sections 5, 6, and 8. Special consideration shall be given to the placement of thermocouples when heating welds adjacent to large heat sinks, such as valves or fittings, or when joining parts of different thicknesses. No part of the materials subjected to the heat source shall exceed the lower critical temperature of the material. Particular care must be exercised when the applicable PWHT temperature is close to the material’s lower critical temperature, such as for P-No. 15E materials, or when materials of different P-Nos. are being joined. This method may not be used for austenitizing heat treatments.

133 STAMPING

Stamping, if used, shall be performed by a method that will not result in sharp discontinuities. In no case shall stamping infringe on the minimum wall thickness or result in dimpling or denting of the material being stamped.

CAUTION: Detrimental effects can result from stamping of material that will be in operation under long-term creep or creep fatigue conditions.

135 ASSEMBLY

135.1 General

The assembly of the various piping components, whether done in a shop or as field erection, shall be done so that the completely erected piping conforms with the requirements of the engineering design.

135.2 Alignment

135.2.1 Equipment Connections. When making connections to equipment, such as pumps or turbines or other piping components that are sensitive to externally induced loading, forcing the piping into alignment is prohibited if this action introduces end reactions that exceed those permitted by design.

135.2.2 Cold Springs. Before assembling joints in piping to be cold sprung, an examination shall be made of guides, supports, and anchors for obstructions that might interfere with the desired movement or result in undesired movement. The gap or overlap of piping prior to assembly shall be checked against the design specifications and corrected if necessary.

135.3 Bolted Flanged Connections

135.3.1 Fit Up. All flanged joints shall be fitted up so that the gasket contact surfaces bear uniformly on the gasket and then shall be made up with relatively uniform bolt stress.

135.3.2 Gasket Compression. When bolting gasketed flange joints, the gasket shall be properly compressed in accordance with the design principles applicable to the type of gasket being used.

135.3.3 Cast Iron to Steel Joints. Cast iron to steel flanged joints in accordance with para. 108.3 shall be assembled with care to prevent damage to the cast iron flange.

135.3.4 Bolt Engagement. All bolts shall be engaged so that there is visible evidence of complete threading through the nut or threaded attachment.

135.3.5 Nonmetallic Lined Joints. When assembling nonmetallic lined joints, such as plastic lined steel pipe, consideration should be given to maintaining electrical continuity between flanged pipe sections where required.

135.4 Packed Joints and Caulked Joints

Care shall be used to ensure adequate engagement of joint members. Where packed joints are used to absorb thermal expansion, proper clearance shall be provided at the bottom of the sockets to permit movement.
135.5 Threaded Piping

135.5.1 Thread Compound. Any compound or lubricant used in threaded joints shall be suitable for the service conditions and shall be compatible with the piping material and the service fluid.

135.5.2 Joints for Seal Welding. Threaded joints that are intended to be seal welded in accordance with para. 127.4.5 should be made up without any thread compound.

135.5.3 Joints Using Straight Threads. Some joints using straight threads, with sealing at a surface other than threads, are shown in Figure 135.5.3-1. Care shall be used to avoid distorting the seal when incorporating such joints into piping assemblies by welding or brazing.

135.5.4 Backing Off. Backing off threaded joints to allow for alignment is prohibited.

135.6 Tubing Joints

135.6.1 Flared. The sealing surface shall be free of injurious defects before installation.

135.6.2 Flareless and Compression. Flareless and compression joints shall be assembled in accordance with the manufacturer’s recommendations.

135.7 Ductile Iron Bell End Piping

Assembly of ductile iron pipe, using ANSI/AWWA C111/A21.11 mechanical or push-on joints, shall comply with AWWA C600.

135.3.1 Fit Up.
(a) All flanged joints shall be fitted up so that the gasket contact surfaces bear uniformly on the gasket and then shall be made up with relatively uniform bolt stress.
(b) Any damage to the contact surface that would prevent leak free gasket seating shall be repaired, or the flange shall be replaced. For further guidance, see ASME PCC-1, Pressure Boundary Bolted Flange Joint Assembly.

135.3.2 Gaskets.
(a) When bolting gasketed flange joints, the gasket shall be properly compressed in accordance with the design principles applicable to the type of gasket being used.
(b) Only one gasket shall be used between contact faces in assembling a flanged joint.

135.3.3 Cast Iron to Steel Joints. Cast iron to steel flanged joints in accordance with para. 108.3 shall be assembled with care to prevent damage to the cast iron flange.

135.3.4 Bolting. All bolts shall be engaged so that there is visible evidence of complete threading through the nut or threaded attachment.

135.3.5 Flanged Joint Assembly.
(a) Assembly requirements for bolted flanged joints shall be considered in the engineering design. For guidance, see ASME PCC-1, Pressure Boundary Bolted Flange Joint Assembly.
(b) When the flangeto be joined have different mechanical properties, bolts shall be torqued in accordance with designer’s specifications.

135.3.6 Nonmetallic Lined Joints. When assembling flanges for nonmetallic lined joints, such as those between plastic lined steel pipe, consideration should be given to maintaining electrical continuity between flanged pipe sections where required.
Chapter VI
Inspection, Examination, and Testing

136 INSPECTION AND EXAMINATION

136.1 Inspection

136.1.1 General. Inspection is the responsibility of the owner and may be performed by employees of the owner or a party authorized by the owner, except for Authorized Inspection required by para. 136.2.

136.1.2 Verification of Compliance. Prior to initial operation, a piping installation shall be inspected to ensure that the piping has been constructed in accordance with the design, material, fabrication, assembly, examination, and testing requirements of this Code.

(a) For boiler external piping (BEP), the Authorized Inspector shall verify, in accordance with ASME BPVC, Section I, PG-90, compliance with the requirements of this Code when the ASME Certification Mark and Designator are to be applied. The quality control system requirements of ASME BPVC, Section I, Nonmandatory Appendix A, A-301 and A-302 shall apply.

(b) For nonboiler external piping (NBEP), the owner shall ensure that the design and construction documents and the requirements of this Code have been complied with in accordance with the owner’s requirements.

136.1.3 Rights of Inspectors. Inspectors shall have access to any place where work concerned with the piping is being performed. This includes manufacture, fabrication, heat treatment, assembly, erection, examination, and testing of the piping. They shall have the right to audit any examination, to inspect the piping using any appropriate examination method required by the engineering design or this Code, and to review all certifications and records necessary to satisfy the owner’s responsibility as stated in para. 136.1.1.

136.1.4 Qualifications of the Owner’s Inspector

(a) The owner’s Inspector shall be designated to perform inspections on behalf of the owner and shall be an employee of the owner, an engineering or scientific organization, or a recognized insurance or inspection company acting as the owner’s agent. The owner’s Inspector shall not represent nor be an employee of the piping manufacturer, fabricator, or erector unless the owner is also the manufacturer, fabricator, or erector.

(b) The owner’s Inspector shall meet one of the following requirements:

1. have at least 10 yr of experience in the design, manufacture, erection, fabrication, inspection, or examination of piping systems. Each year of satisfactorily completed work toward an accredited engineering or engineering technology degree shall be considered equivalent to 1 yr of experience, up to 5 yr total.
2. have a professional engineering registration or nationally recognized equivalent with a minimum of 5 yr of experience in the design, manufacture, erection, fabrication, inspection, or examination of piping systems.
3. be a certified Welding Inspector or a Senior Certified Welding Inspector as defined in AWS QC1, or a nationally recognized equivalent, with a minimum of 5 yr of experience in the design, manufacture, erection, fabrication, inspection, or examination of piping systems.
4. be an Authorized Piping Inspector as defined in API 570, Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems, with a minimum of 5 yr of experience in the design, manufacture, erection, fabrication, inspection, or examination of piping systems.

(c) In delegating the performance of inspections, the owner is responsible for determining that a person to whom an inspection function is delegated is qualified to perform that function.

136.2 Inspection and Qualification of Authorized Inspector for Boiler External Piping

136.2.1 Piping for which Authorized Inspection and stamping are required as determined in accordance with para. 100.1.2(a) shall be inspected during construction and after completion and at the option of the Authorized Inspector at such stages of the work as he/she may designate. For specific requirements see the applicable parts of ASME BPVC, Section I, PG-104 through PG-113. Each manufacturer, fabricator, or assembler is required to arrange for the services of Authorized Inspectors.

136.2.1.1 The Authorized Inspection required by this Code Section shall be performed by an Inspector employed by an ASME-accredited Authorized Inspection Agency.

136.2.2 Certification by use of the ASME Certification Mark and Designators, and Data Reports where required, shall be as per ASME CA-1.
Table 136.4.1-1
Mandatory Minimum Nondestructive Examinations for Pressure Welds or Welds to Pressure-Retaining Components

<table>
<thead>
<tr>
<th>Type of Weld</th>
<th>Piping Design Conditions and Nondestructive Examination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temptes Over 750°F (400°C) and at All Pressures</td>
</tr>
<tr>
<td>Butt welds (girth and longitudinal) [Note (1)]</td>
<td>Volumetric examination (RT or UT) for over NPS 2 (DN 50), MT or PT for NPS 2 (DN 50) and less [Note (2)]</td>
</tr>
<tr>
<td>Welded branch connections (size indicated is branch size) [Notes (3) through (5)]</td>
<td>Volumetric examination (RT or UT) for over NPS 4 (DN 100), MT or PT for NPS 4 (DN 100) and less [Note (2)]</td>
</tr>
<tr>
<td>Fillet, socket, attachment, and seal welds</td>
<td>PT or MT for all sizes and thicknesses [Note (6)]</td>
</tr>
</tbody>
</table>

GENERAL NOTES:
(a) All welds shall be given a visual examination in addition to the type of specific nondestructive examination specified.
(b) NPS = nominal pipe size; DN = diameter nominal.
(c) RT = radiographic examination; UT = ultrasonic examination; MT = magnetic particle examination; PT = liquid penetrant examination; VT = visual examination.
(d) For nondestructive examinations of the pressure-retaining component, refer to the standards listed in Table 126.1-1 or manufacturing specifications.
(e) Acceptance standards for nondestructive examinations performed are as follows: MT — see para. 136.4.3; PT — see para. 136.4.4; VT — see para. 136.4.2; RT — see para. 136.4.5; UT — see para. 136.4.6.
(f) All longitudinal welds and spiral welds in pipe intended for sustained operation in the creep range (see paras. 104.1.1 and 123.4, and Table 102.4.7-1) must receive and pass a 100% volumetric examination (RT or UT) per the applicable material specification or in accordance with para. 136.4.5 or 136.4.6.

NOTES:
(1) The thickness of butt welds is defined as the thicker of the two abutting ends after end preparation.
(2) RT may be used as an alternative to PT or MT when it is performed in accordance with para. 136.45.
(3) Volumetric examination (RT or UT) of branch welds shall be performed before any nonintegral reinforcing material is applied.
(4) In lieu of volumetric examination (RT, UT) of welded branch connections when required above, surface examination (PT, MT) is acceptable and, when used, shall be performed at the lesser of one-half of the weld thickness or each 3/8 in. (13 mm) of weld thickness and all accessible final weld surfaces.
(5) Branch thickness is t_{nb} as defined in para. 127.4.8 and Figures 127.4.8-4 and 127.4.9-5.
(6) Except for P-No. 15E materials, fillet welds not exceeding 3/8 in. (6 mm) throat thickness that are used for the permanent attachment of non-pressure-retaining parts are exempt from the PT or MT requirements of this table.
136.4.6 Ultrasonic Examination. When required by this Chapter (see Table 136.4.1-1), ultrasonic examination (UT) shall be performed in accordance with the requirements of ASME BPVC, Section V, Article 4 and the additional requirements below.

(a) The following criteria shall also be met when performing ultrasonic examinations:

(1) The equipment used to perform the examination shall be capable of recording the UT data to facilitate the analysis by a third party and for the repeatability of subsequent examinations, should they be required. Where physical obstructions prevent the use of systems capable of recording the UT data, manual UT may be used with the approval of the owner.

(2) NDE personnel performing and evaluating UT examinations shall be qualified and certified in accordance with their employer’s written practice and the requirements of para. 136.3.2 of this Code. Personnel, procedures, and equipment used to collect and analyze UT data shall have demonstrated their ability to perform an acceptable examination using test blocks approved by the owner.

(b) Acceptance Standards. Welds that are shown by ultrasonic examination to have discontinuities that produce an indication greater than 20% of the reference level shall be investigated to the extent that ultrasonic examination personnel can determine their shape, identity, and location so that they may evaluate each discontinuity for acceptance in accordance with (1) and (2).

(1) Discontinuities evaluated as being cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

(2) Other discontinuities are unacceptable if the indication exceeds the reference level and their length exceeds the following:

\(-a\) the aggregate length of EU and IU, in any combination, in any continuous 12 in. (300 mm) length of weld exceeds 2 in. (50 mm)

\(-b\) the aggregate length of EU and IU, in any combination, exceeds one-sixth of the weld length

\(6\) undercut on the outside (O.D) or inside (I.D) surface of longitudinal butt welds is unacceptable

\(7\) root concavity when the density or brightness of the root image is darker than the density through the adjacent base metal. For digital radiography, brightness comparison may be used.

For the radiography of welds, the area of interest shall include the weld and all adjacent areas within at least \(\frac{1}{4}\) in. (6 mm) from the toe of the weld. Relevant indications outside the area of interest shall be investigated and their disposition determined by the owner.

For image quality indicator (IQI) selection for welds with reinforcement, the thickness used shall be either the nominal wall thickness, \(t_n\) or the minimum required thickness, \(t_m\). In either case, the selected thickness shall also include the allowable combined internal and external reinforcement thicknesses, as specified in Table 137.4.2-1.

Para. 137.4.6, 137.5.6, or 137.8 of this Chapter, in-process visual examination shall be performed and/or witnessed by qualified personnel other than those performing the production work. It shall also be in accordance with para. 136.4.2, which comprises examination of the following, as applicable:

(a) joint preparation and cleanliness

(b) preheating

(c) fit-up, joint clearance, and internal alignment prior to joining

(d) variables specified by the joining procedure, including filler material

(1) for welding: position and electrode

(2) for brazing: position, flux, brazing temperature, proper wetting, and capillary action

(e) for welding: condition of the root pass after cleaning (external and, where accessible, internal) aided by liquid penetrant or magnetic particle examination when specified in the engineering design

(f) for welding: slag removal and weld condition between passes

(g) appearance of the finished joint

NOTE: The method of examination is visual, in accordance with para. 136.4.2, unless additional methods are specified in the engineering design.
137.1 General Requirements

137.1.1 Subassemblies. When conducted in accordance with the requirements of this Code, the pressure testing of piping systems to ensure leak tightness shall be acceptable for the determination of any leaks in piping subassemblies.

137.1.2 Temperature of Test Medium. The temperature of the test medium shall be that of the available source unless otherwise specified by the owner. The test pressure shall not be applied until the system and the pressurizing medium are approximately at the same temperature. When conducting pressure tests at low metal temperatures, the possibility of brittle fracture shall be considered.

137.1.3 Personnel Protection. Suitable precautions in the event of piping system rupture shall be taken to eliminate hazards to personnel in the proximity of lines being tested.

137.1.4 Maximum Stress During Test. At no time during the pressure test shall any part of the piping system be subjected to a stress greater than that permitted by para. 102.3.3(b).

137.1.5 Testing Schedule. Pressure testing shall be performed following the completion of postweld heat treatment required by para. 132, nondestructive examinations required by Table 136.4.1-1, and all other fabrication, assembly, and erection activities required to provide the system or portions thereof subjected to the pressure test with pressure-retaining capability.

137.2 Preparation for Testing

137.2.1 Exposure of Joints. All joints including welds not previously pressure tested shall be left exposed for examination during the test, except as allowed in (b) or (c) below and in para. 137.4.6.

(b) By prior agreement, the complete system or portions thereof subject to test may be insulated prior to the test period, provided an extended holding time pressurization of the system is performed to check for possible leakage through the insulation barrier.

(c) Unless permitted by the owner or the engineering design, pressure-retaining welds shall not be painted or coated either internally or externally prior to the pressure test. Coatings applied to completed welds as corrosion inhibitors that will be removed prior to the pressure test are permitted.

137.2.2 Addition of Temporary Supports. Piping systems designed for vapor or gas shall be provided with additional temporary supports if necessary to support the weight of the test liquid. Such supports shall meet the requirements for testing and system cleanup procedures described in para. 122.10.

137.2.3 Restraint or Isolation of Expansion Joints. Expansion joints shall be provided with temporary restraint if required for the additional pressure load under test, or they shall be isolated during the system test.

137.2.4 Isolation of Flanged Joints Containing Blanks. Flanged joints at which blanks are inserted to blank off other equipment during the test need not be tested after removal of the blank provided the requirements of para. 137.7.1 are subsequently performed.

137.2.5 Treatment of Flanged Joints Containing Blanks. Flanged joints at which blanks are inserted to blank off other equipment during the test need not be tested after removal of the blank provided the requirements of para. 137.7.1 are subsequently performed.

137.2.6 Precautions Against Test Medium Expansion. If a pressure test is to be maintained for a period of time during which the test medium in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure. A pressure relief device set at $1\frac{1}{3}$ times the test pressure is recommended during the pressure test, provided the requirements of paras. 137.1.4, 137.4.5, and 137.5.5 are not exceeded.

137.3 Requirements for Specific Piping Systems

137.3.1 Boiler External Piping. Boiler external piping [see para. 100.1.2(a)] shall be hydrostatically tested in accordance with ASME BPVC, Section I, PG-99. The test shall be conducted in the presence of the Authorized Inspector.

137.3.2 Nonboiler External Piping. All nonboiler external piping shall be hydrostatically tested in accordance with para. 137.4. As an alternative, when specified by the owner, the piping may be leak tested in accordance with para. 137.4.6, para. 137.5, para. 137.6, or para. 137.7. Lines open to the atmosphere, such as vents or drains downstream of the last shutoff valve, need not be tested.

Where the owner and the designer consider both hydrostatic and pneumatic testing impracticable, the alternative specified in para. 137.8 may be used if both (a) and (b) apply.

(a) A hydrostatic test would

(1) damage lining or internal insulation, or

(2) contaminate a process that would be hazardous, corrosive, or inoperative in the presence of moisture, or

(3) present the danger of brittle fracture due to low metal temperature during the test and it is impossible to test at a higher temperature.

(b) A pneumatic test would

(1) present an undue hazard of possible release of energy stored in the system and it is impossible to provide protection for personnel, or

Subjected to Pressure Test. Equipment that is not to be subjected to the pressure test shall be either disconnected from the system or isolated by a blank or similar means. Valves may be used for this purpose provided that valve closure is suitable for the proposed test pressure. The owner shall be aware of the limitations of pressure and temperature for each valve subject to test conditions and as further described in para. 107.1(c). Isolated equipment and piping must be vented.
137.5.4 Preliminary Test. A preliminary pneumatic test not to exceed 25 psig [175 kPa (gage)] may be applied, prior to other methods of leak testing, as a means of locating major leaks. If used, the preliminary pneumatic test shall be performed in accordance with the requirements of paras. 137.5.2 and 137.5.3.

137.5.5 Required Pneumatic Test Pressure. The pneumatic test pressure shall not exceed the maximum allowable test pressure of any nonisolated component, such as vessels, pumps, or valves, in the system. The pressure in the system shall gradually be increased to not more than one-half of the test pressure, after which the pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached. The pressure shall be continuously maintained for a minimum time of 10 min. It shall then be reduced to the lesser of design pressure or 100 psig [700 kPa (gage)] and held for such time as may be necessary to conduct the examination for leakage. Examination for leakage detected by soap bubble or equivalent method shall be made of all joints and connections. The piping system, exclusive of possible localized instances at pump or valve packing, shall show no evidence of leaking.

137.5.6 Special Provisions for Testing

(a) Piping components and subassemblies may be tested either separately or as assembled piping.

(b) Flanged joints used to connect piping components and subassemblies that have previously been tested, and flanged joints at which a blank or blind is used to isolate equipment or other piping during a test, need not be leak tested in accordance with para. 137.3.2.

(c) The final welds (closure welds) connecting piping systems or components that have been successfully tested in accordance with para. 137 need not be pneumatically tested provided the owner and designer agree that the weld not be pneumatically tested. However, the weld shall be visually examined in accordance with para. 136.4.7 and examined volumetrically using 100% radiographic examination in accordance with para. 136.4.5 or 100% ultrasonic examination in accordance with para. 136.4.6.

137.6 Mass-Spectrometer and Halide Testing

137.6.1 When specified by the owner, systems with conditions of operation and design that require testing methods having a greater degree of sensitivity than can be obtained by a hydrostatic or pneumatic test shall be tested by a method, such as helium mass-spectrometer test or halide test, which has the required sensitivity.

137.6.2 When a mass-spectrometer or halide test is performed, it shall be conducted in accordance with the instructions of the manufacturer of the test equipment. In all cases, a calibrated reference leak, with a leak rate not greater than the maximum permissible leakage from the system, shall be used. The equipment shall be calibrated against the reference leak in such a way that the system leakage measured by the equipment can be determined to be not greater than the leak rate of the reference leak.

137.7 Initial Service Testing

137.7.1 When specified by the owner, an initial service test and examination is acceptable when other types of tests are not practical or when leak tightness is demonstrable due to the nature of the service. One example is piping where shutoff valves are not available for isolating a line and where temporary closures are impractical. Others may be systems where during the course of checking out of pumps, compressors, or other equipment, ample opportunity is afforded for examination for leakage prior to full-scale operation. An initial service test is not applicable to boiler external piping.

137.7.2 When performing an initial service test, the piping system shall be gradually brought up to normal operating pressure and continuously held for a minimum time of 10 min. Examination for leakage shall be made of all joints and connections. The piping system exclusive of possible localized instances at pump or valve packing shall show no visual evidence of weeping or leaking.

137.8 Alternative to Hydrostatic and Pneumatic Testing

The following procedures may be used only under the conditions stated in para. 137.3.2(a) or para. 137.3.2(b). Welds that must be examined include those used in the manufacture of welded pipe fittings that have not been subjected to hydrostatic or pneumatic leak tests in accordance with paras. 137.4 and 137.5, respectively. They shall be examined as follows:

(a) All welds shall be visually examined in accordance with para. 136.4.7.

(b) Circumferential, longitudinal, and spiral (helical seam) groove welds, in addition to welded branch connections over NPS 4, shall be 100% radiographed in accordance with para. 136.4.5 or 100% ultrasonically examined in accordance with para. 136.4.6.

(c) All welds, including structural attachment welds, not covered in (b), shall be examined using the liquid penetrant method (para. 136.4.4) or, for magnetic materials, the magnetic particle method (para. 136.4.3).
138 GENERAL

Safety is the overriding concern in design, operation, and maintenance of power piping. Managing safe piping service begins with the initial project concept and continues throughout the service life of the piping system. The Operating Company is responsible for the safe operation and maintenance of its power piping.

The Code does not prescribe a detailed set of operating and maintenance procedures that will encompass all cases. Each Operating Company shall develop operation and maintenance procedures for piping systems deemed necessary to ensure safe facility operations based on the provisions of this Code, relevant industry experience, the Operating Company’s experience and knowledge of its facility, and conditions under which the piping systems are operated. The additional requirements described in subsequent paragraphs apply to covered piping systems (CPS). At the owner’s discretion, other piping systems may be included.

139 OPERATION AND MAINTENANCE PROCEDURES

For CPS, this shall be accomplished by the issuance of written operation and maintenance procedures. The operation and maintenance procedures established by the Operating Company for ensuring safe operation of its CPS may vary, but the following aspects shall be covered:

(a) operation of piping system within design limits
(b) documentation of system operating hours and modes of operation
(c) documentation of actual operating temperatures and pressures
(d) documentation of significant system transients or excursions including thermal hydraulic events (e.g., steam hammers, liquid slugging)
(e) documentation of modifications, repairs, and replacements, including welding procedures used and NDE results
(f) documentation of maintenance of pipe supports for piping operating within the creep regime
(g) documentation of maintenance of piping system elements such as vents, drains, relief valves, desuperheaters, and instrumentation necessary for safe operation

(h) assessment of degradation mechanisms, including, but not limited to, creep, fatigue, graphitization, corrosion, erosion, and flow-accelerated corrosion (FAC)
(i) quality of flow medium (e.g., dissolved oxygen, pH)
(j) documentation of the condition assessment (see para. 140)
(k) other required maintenance

140 CONDITION ASSESSMENT OF CPS

A program shall be established to provide for the assessment and documentation of the condition of all CPS. The documentation shall include a statement as to any actions necessary for continued safe operation. A condition assessment shall be performed at periodic intervals as determined by an engineering evaluation.

Condition assessments shall be made of CPS based on established industry practices. The condition assessment may range from a review of previous inspection findings and operating history since the previous inspection, to a thorough nondestructive examination (NDE) and engineering evaluation. The extent of the assessment performed shall be established by the Operating Company or its designee with consideration of the age of the CPS, the previous documented assessment, and anticipated operating conditions.

The CPS condition assessment program shall include implementation of weld examination and hanger inspection methods necessary for evaluating the impact of the applicable material degradation mechanism for the identified piping system.

The condition assessment documentation, in a form established by the Operating Company, should contain (but not be limited to) as many of the following elements as available:

(a) system name.
(b) listing of original material specifications and their editions.
(c) design diameters and wall thicknesses.
(d) design temperature and pressure.
(e) normal operating temperature and pressure.
(f) operating hours, both cumulative (from initial operation) and since last condition assessment.
(g) actual modes of operation since last condition assessment (such as the number of hot, warm, and cold starts).
141.5 Restoration After Failure

The owner is responsible for documenting actions taken to restore failed components, including:

(a) recommendations for actions that are intended to minimize recurrence and documentation of satisfactory implementation

(b) recommendations, if any, for similar action that should be taken in other piping systems containing similar conditions or components

142 PIPING AND PIPE-SUPPORT MAINTENANCE PROGRAM AND PERSONNEL REQUIREMENTS

142.1 Maintenance Program

The maintenance program shall adhere to the requirements of paras. 138 through 141 and 144. For further guidelines regarding the maintenance program, refer to Nonmandatory Appendix V, para. V-5.1.

142.2 Personnel

142.2.1 Only qualified personnel shall be responsible for executing the maintenance program of the Operating Company. For further guidelines regarding typical maintenance program responsibilities, see Nonmandatory Appendix V, para. V-5.2.

142.2.2 Review of records and failure reports, and decisions concerning corrective actions or repairs, shall be carried out by or under the direction of qualified personnel.

142.2.3 Welding and Heat Treatment Personnel

(a) Welders shall be qualified to approved welding procedures. Qualification of weld procedures and the qualification performance of the welder shall be in accordance with the requirements of para. 127.5.

(b) Qualified personnel shall perform preheat and postheat treatment operations as described in the requirements of paras. 131 and 132.

142.2.4 Examination, Inspection, and Testing Personnel. Qualified personnel shall perform nondestructive examinations (NDE), including visual inspections and leak tests (LT), in accordance with the requirements of para. 136.

143 REPAIR OF CPS

Repairs to CPS shall be performed in accordance with the ASME B31.1 Code of record used for the original construction or to a later edition of the ASME B31.1 Code as agreed on by the owner and the jurisdictional authority if applicable.

144 CPS WALKDOWNS

The Operating Company shall develop and implement a program requiring documentation of piping support readings and recorded piping system displacements. Guidelines for this program are provided in Nonmandatory Appendix V, para. V-7. Piping system drawings or sketches, including the identification of all supports, and piping support walkdown forms should be used as part of the hot and cold walkdowns. The condition assessment documentation (on paper or electronic media) shall comply with para. 140(h).

The Operating Company shall evaluate the effects of unexpected piping position changes, significant vibrations, and malfunctioning supports on the piping system’s integrity and safety. Significant displacement variations from the expected design displacements shall be considered to assess the piping system’s integrity. An as-found piping system stress analysis can be used to determine the influence of significant piping displacement anomalies on the piping system’s integrity. Subsequent evaluations and corrective actions may necessitate activities such as detailed examinations of critical weldments and support adjustments, repairs, and replacement of individual supports and restraints.

145 MATERIAL DEGRADATION MECHANISMS

Creep is stress-, time-, temperature-, and material-dependent plastic deformation. Stress allowables for materials having time-dependent properties are noted with italics in Mandatory Appendix A. Material stress rupture or creep properties govern the stress allowables within this temperature regime and may be important in the piping system evaluation.

The Operating Company shall develop and implement a program requiring data collection and evaluation of high-priority areas for CPS materials operating in the creep range. Guidelines provided in Nonmandatory Appendix V, para. V-13 may be used for this program, which may also include non-CPS piping operating in the creep regime.

Although creep is a common mechanism of material degradation for many CPS, other damage mechanisms may also require consideration by the Operating Company. Additional guidance on potential damage mechanisms is provided in Nonmandatory Appendix V, paras. V-12 and V-13, as well as in ASME BPVC, Section II, Part D, Nonmandatory Appendix A; ASME BPVC, Section III, Nonmandatory Appendix W; API 570; and API 571.

146 DYNAMIC LOADING

For those dynamic events identified in para. 140(j), document the following, as appropriate:

Damage Mechanisms Affecting Fixed Equipment in the Refining Industry.
**149 RERATING PIPING SYSTEMS**

**149.1 Uprating Piping Systems**

A piping system is uprated by increasing the design pressure and/or the design temperature. The piping system uprating may be based on the original Code of construction or a later edition/addenda of that Code, as long as reconciliation of the differences in the Codes is completed (in accordance with para. 123.1.7). Once the specific Code is chosen for the uprating, it shall be followed in its entirety, taking into consideration the current condition of the piping system and the condition it is projected to be in at the end of its life. Documents and forms produced in support of uprating shall be preserved for the service life of the piping system. The owner is responsible for verifying that the uprated piping system meets all the requirements of the chosen Code and the jurisdictions. Guidance on some aspects may be found in Nonmandatory Appendix V, para. V-13.

A piping system may be rerated (uprated or derated) based on the original Code of construction, or a later edition of that Code, as long as reconciliation of the differences in the Codes is completed (for example, in accordance with para. 123.1.7). Once the specific Code is chosen for the rerating, it shall be followed in its entirety, taking into consideration the current condition of the piping system and the condition it is expected to be in at the end of its life. Documents and forms produced in support of rerating shall be preserved for the service life of the piping system. The owner is responsible for verifying that the rerated piping system meets all the requirements of the chosen Code and the jurisdictions. Guidance on some aspects of rerating may be found in Nonmandatory Appendix V, para. V-14.

**149.2 Derating Piping Systems**

A piping system is derated by decreasing the design pressure or the design temperature, or both, while not increasing either design value. Although derating is generally expected to result in decreases in stress associated with lower design pressure or temperature, the potential changes in service conditions caused by derating shall be considered. In some instances, such changes in operating conditions can result in unintended service conditions, such as condensation or flashing of steam, flow conditions leading to flow accelerated corrosion (FAC), high localized stresses associated with thermal gradients, cyclic conditions leading to thermal fatigue damage, or inoperability of pressure relief devices.

**149.3 Assessment of Safety Valves, Relief Valves, and Other Pressure-Relieving Devices**

For rerating involving increases in design pressure, design temperature, or both, the safety valves, relief valves, and other pressure-relieving devices must be examined and recertified for the new pressure-temperature design conditions. If the design pressure is decreased, safety valves shall be reset to the lower rating. For any rerating, capacity of relieving equipment shall be investigated, and as necessary, rupture discs shall be replaced.
### Table A-1
Carbon Steel

<table>
<thead>
<tr>
<th>Spec. No.</th>
<th>Grade</th>
<th>Type or Class</th>
<th>Nominal Composition</th>
<th>P-No.</th>
<th>Notes</th>
<th>Specified Minimum Tensile, ksi</th>
<th>Specified Minimum Yield, ksi</th>
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<td>C-Si</td>
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<td>A</td>
<td>E</td>
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<td>C-Mn</td>
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<tr>
<td>6</td>
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<td>C-Mn-Si</td>
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<td>60</td>
<td>35</td>
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<td>API 5L</td>
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<td>I &amp; II</td>
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<td>1 (1) (14)</td>
<td>45</td>
<td>25</td>
<td>0.85</td>
<td></td>
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<tr>
<td>A</td>
<td></td>
<td>C</td>
<td>1 (1) (2) (14)</td>
<td>48</td>
<td>30</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>C-Mn</td>
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</tbody>
</table>
### Table A-1
Carbon Steel (Cont’d)

**GENERAL NOTES:**

(a) The tabulated specifications are ANSI/ASTM or ASTM, except API 5L. For ASME BPVC applications, see related specifications in ASME BPVC, Section II.

(b) The stress values in this table may be interpolated to determine values for intermediate temperatures.

(c) The P-Numbers indicated in this table are identical to those adopted by ASME BPVC. Qualification of welding procedures, welders, and welding operators is required and shall comply with ASME BPVC, Section IX, except as modified by para. 127.5.

(d) Tensile strengths and allowable stresses shown in “ksi” are “thousands of pounds per square inch.”

(e) The materials listed in this table shall not be used at design temperatures above those for which allowable stress values are given except as permitted by para. 122.6.2(g).

(f) The tabulated stress values are $S \times E$ (weld joint efficiency factor) or $S \times F$ (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 1024.3-1.

(g) Pressure–temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this table are for use in designing piping components that are not manufactured in accordance with referenced standards.

(h) All the materials listed are classified as ferritic (see Table 104.1.2-1).

(i) The tabulated stress values that are shown in italics are at temperatures in the range where creep and stress rupture strength govern the selection of stresses.

(j) See para. 124.1.2 for lower temperature limits.

**NOTES:**

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR CONSTRUCTION OF PRESSURE-RETAINING PARTS OF BOILER EXTERNAL PIPING — SEE FIGURES 100.1.2-1 THROUGH 100.1.2-10.

(2) Upon prolonged exposure to temperatures above 800°F (427°C), the carbide phase of carbon steel may be converted to graphite.

(3) The allowable stress values given are for pipe fabricated from plate not exceeding 2½ in. in thickness.

(4) This material shall not be used for flammable fluids. Refer to para. 105.2.1(a).

(5) Tensile value in parentheses is expected minimum.

(6) The 0.80 material quality factor for casting may be increased in accordance with para. 102.4.6.

(7) The stress values for structural quality plate include a material quality factor of 0.92. The allowable stresses for ASTM A283 Grade D and ASTM A36 plate have been limited to 12.7 ksi.

(8) These stress values are permitted only if killed or semikilled steels are used.

(9) ASTM A254 is copper brazed (not welded) steel pipe.

(10) For saturated steam at 250 psi (406°F), the values given for 400°F may be used.

(11) The allowable stress values listed in MSS SP-58 for this material may be used for pipe-supporting elements designed in accordance with MSS SP-58.

(12) These values apply to material less than or equal to 1 in. thick.

(13) These values apply to material greater than 1 in. thick.

(14) This material is not listed in ASME BPVC, Section IX. However, weld procedures shall be qualified in accordance with the P-Number shown. See para. 127.5.1.

(15) This material shall not be used in nominal wall thicknesses exceeding 3/4 in.

(16) These allowable stress values are for pipe made using a butt-welded joint process. Pipe made by other processes shall not be used.
<table>
<thead>
<tr>
<th>Spec. No.</th>
<th>Grade</th>
<th>Type or Class</th>
<th>Nominal Composition</th>
<th>P-No.</th>
<th>Notes</th>
<th>Specified Minimum Tensile, ksi</th>
<th>Specified Minimum Yield, ksi</th>
<th>E or F</th>
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<tr>
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<td>(1)</td>
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<td>Table A-2</td>
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<td>Type or Class</td>
<td>Nominal Composition</td>
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<td>20, 23</td>
<td>1%Cr-$\frac{1}{2}$Mo</td>
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<td></td>
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### Table A-2
Low and Intermediate Alloy Steel (Cont’d)

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<th>Type or Class</th>
<th>Nominal Composition</th>
<th>P-No.</th>
<th>Notes</th>
<th>Specified Minimum Tensile, ksi</th>
<th>Specified Minimum Yield, ksi</th>
<th>E or F</th>
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#### Forgings
- **F22** Class 3 2\(\frac{1}{4}\)Cr–1Mo 5A (5) 75 45 1.00
- **F91** Type 1 9Cr–1Mo-V 15E ... 90 60 1.00
- **F91** Type 2 9Cr–1Mo-V 15E ... 90 60 1.00
- **A350** LF3 ... 3\(\frac{1}{2}\)Ni 9B (1) 70 40 1.00
- **LF4** ... 7\(\frac{1}{4}\)Cr–7\(\frac{1}{2}\)Ni–Cu–Al 4 (1) 60 ... 1.00
- **LF5** Class 1 1\(\frac{1}{2}\)Ni 9A (1) 70 37 1.00
- **LF5** Class 2 1\(\frac{1}{2}\)Ni 9A (1) 70 37 1.00
- **LF9** ... 2Ni–1Cu 9A (1) 63 46 1.00
#### Wrought Fittings (Seamless and Welded)
- **A234** WP1 ... C–\(\frac{1}{2}\)Mo 3 (2) 55 30 1.00
- **WP5** Class 1 5Cr–\(\frac{1}{2}\)Mo 5B ... 60 30 1.00
- **WP5** Class 3 5Cr–\(\frac{1}{2}\)Mo 5B ... 75 45 1.00
- **WP9** Class 1 9Cr–1Mo 5B ... 60 30 1.00
- **WP11** Class 1 1\(\frac{1}{2}\)Cr–\(\frac{1}{2}\)Mo 4 ... 60 30 1.00
- **WP11** Class 3 1\(\frac{1}{2}\)Cr–\(\frac{1}{2}\)Mo 4 ... 75 45 1.00
- **WP12** Class 1 1Cr–\(\frac{3}{4}\)Mo 4 (6) 60 32 1.00
- **WP12** Class 2 1Cr–\(\frac{3}{4}\)Mo 4 ... 70 40 1.00
- **A234** WP22 Class 1 2\(\frac{1}{4}\)Cr–1Mo 5A (5) 60 30 1.00
- **WP22** Class 3 2\(\frac{1}{4}\)Cr–1Mo 5A (5) 75 45 1.00
- **WP91** Type 1 9Cr–1Mo-V 15E = (19) 90 60 1.00
- **WP91** Type 2 9Cr–1Mo-V 15E = (19) 90 60 1.00
#### Castings
- **A217** WC1 ... C–\(\frac{1}{2}\)Mo 3 (2) (3) (4) 65 35 0.80
- **WC4** ... 1Ni–\(\frac{1}{2}\)Cr–\(\frac{1}{2}\)Mo 4 (3) (4) 70 40 0.80
- **WC5** ... \(\frac{1}{2}\)Ni–1Mo–\(\frac{3}{4}\)Cr 4 (3) (4) 70 40 0.80
- **WC6** ... \(\frac{1}{2}\)Cr–\(\frac{3}{4}\)Mo 4 (3) (4) 70 40 0.80
- **A217** WC9 ... 2\(\frac{1}{4}\)Cr–1Mo 5A (3) (4) 70 40 0.80
- **C5** ... 5Cr–\(\frac{1}{4}\)Mo 5B (3) (4) 90 60 0.80
- **C12** ... 9Cr–1Mo 5B (3) (4) 90 60 0.80
- **C12A** ... 9Cr–1Mo-V 15E (4) (14) 85 60 0.80
- **A1091** C91 1 9Cr–1Mo-V 15E (4) (14) 85 60 0.80

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<th>Composition P-No.</th>
<th>Notes</th>
<th>Specified</th>
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<tr>
<td></td>
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<td>Yield, ksi</td>
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<td></td>
<td>or E</td>
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**Forgings (Cont’d)**

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**Wrought Fittings (Seamless and Welded)**

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**Castings**

<table>
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Table A-2

**Low and Intermediate Alloy Steel (Cont’d)**

<table>
<thead>
<tr>
<th>Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding</th>
</tr>
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<tr>
<td>100</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>21.4</td>
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<td>25.7</td>
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<td>25.7</td>
</tr>
<tr>
<td>20.0</td>
</tr>
<tr>
<td>17.1</td>
</tr>
<tr>
<td>17.1</td>
</tr>
<tr>
<td>20.0</td>
</tr>
<tr>
<td>18.0</td>
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</table>

Note the Editor: Values highlighted in yellow are to be italicized.
### Table A-2
Low and Intermediate Alloy Steel (Cont'd)

<table>
<thead>
<tr>
<th>GENERAL NOTES:</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME BPVC applications, see related specifications in ASME BPVC, Section II.</td>
</tr>
<tr>
<td>(b) The stress values in this table may be interpolated to determine values for intermediate temperatures.</td>
</tr>
<tr>
<td>(c) The P-Numbers indicated in this table are identical to those adopted by ASME BPVC, Section IX, except as modified by para. 127.5.</td>
</tr>
<tr>
<td>(d) Tensile strengths and allowable stresses shown in “ksi” are “thousands of pounds per square inch.”</td>
</tr>
<tr>
<td>(e) The materials listed in this table shall not be used at design temperatures above those for which allowable stress values are given.</td>
</tr>
<tr>
<td>(f) The tabulated stress values are $S \times E$ (weld joint efficiency factor) or $S \times F$ (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 102.4.3-1.</td>
</tr>
<tr>
<td>(g) Pressure-temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this table are for use in designing piping components that are not manufactured in accordance with referenced standards.</td>
</tr>
<tr>
<td>(h) All the materials listed are classified as ferritic (see Table 104.1.2-1).</td>
</tr>
<tr>
<td>(i) The tabulated stress values that are shown in italics are at temperatures in the range where creep and stress rupture strength govern the selection of stresses.</td>
</tr>
<tr>
<td>(j) See para. 124.1.2 for lower temperature limits.</td>
</tr>
</tbody>
</table>

### NOTES:

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIGURES 100.1.2-1 THROUGH 100.1.2-10. |
(2) Upon prolonged exposure to temperatures above 800°F (427°C), the carbide phase of carbon-molybdenum steel may be converted to graphite. |
(3) These allowable stress values apply to normalized and tempered material only. |
(4) The material quality factors and allowable stress values for these materials may be increased in accordance with para. 1024.6. |
(5) For use at temperatures above 850°F, the carbon content of the base material and, where applicable, weld filler metal shall be 0.05% or higher. See para. 124.2(d). |
(6) If ASTM A234 Grade WP12 fittings are made from ASTM A387 Grade 12 Class 1 plate, the allowable stress values shall be reduced by the ratio of 55 divided by 60 in the temperature range −20°F through 850°F. At 900°F through 1,100°F, the values shown may be used. |
(7) The mutual quality factor for centrifugally cast pipe (0.85) is based on all surfaces being machined, after heat treatment, to a surface finish of 250 μin. arithmetic average deviation or better. |
(8) These allowable stress values are for pipe fabricated from ASTM A387 Class 1 plate in the annealed condition. |
(9) These allowable stress values are for pipe fabricated from ASTM A387 Class 2 plate. |
(10) DELETED |
(11) DELETED |
(12) Separate weld procedure and performance qualifications shall apply for both classes of this material. The postweld heat treatment shall be in accordance with para. 132.1.3. |
(13) CAUTIONARY NOTE: Corrosion fatigue occurs by the combined actions of cyclic loading and a corrosive environment. In piping systems, corrosion fatigue is more likely to occur in portions of water systems with low strain rates (<1.0%/sec), higher temperatures [above 300°F (150°C)], and higher dissolved oxygen (>0.04 ppm), with a preference toward regions with increased local stresses. While the mechanisms of crack initiation and growth are complex and not fully understood, there is consensus that the two major factors are strain and waterside environment. Strain excursions of sufficient magnitude to fracture the protective oxide layer play a major role. In terms of the waterside environment, high levels of dissolved oxygen and pH excursions are known to be detrimental. Historically, the steels applied in these water-touched components have had the minimum specified yield strengths in the range of 27 ksi to 45 ksi (185 MPa to 310 MPa) and minimum specified tensile strengths in the range of 47 ksi to 80 ksi (325 MPa to 550 MPa). As these materials are supplanted by higher strength steels, some have concern that the higher design stresses and thinner wall thicknesses will render components more vulnerable to failures by corrosion fatigue. Thus, when employing such higher strength steels for water systems, it is desirable to use best practices in design by minimizing localized strain concentrations, in control of water chemistry and during lay-up by limiting dissolved oxygen and pH excursions, and in operation by conservative startup, shutdown, and turndown practices. |
(14) For additional requirements for this material, see para. 125.1. |
(15) These allowable stress values apply to thicknesses less than or equal to 1 1/2 in. (40 mm). |
(16) These allowable stress values apply to thicknesses greater than 1 1/2 in. (40 mm) and less than or equal to 2 1/2 in. (60 mm). |
(17) These allowable stress values apply to thicknesses greater than 2 1/2 in. (60 mm) and less than equal to 4 in. (100 mm). |
(18) These allowable stress values apply to thicknesses greater than 4 in. (100 mm) and less than or equal to 6 in. (150 mm). |
(19) For additional requirements for this material, see para. 125.2.
## Table A-3

### Stainless Steels

<table>
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<th>Spec. No.</th>
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<th>Nominal Composition</th>
<th>P-No.</th>
<th>Notes</th>
<th>Specified Minimum Tensile, ksi</th>
<th>Specified Minimum Yield, ksi</th>
<th>E or F</th>
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**Welded Pipe and Tube — Without Filler Metal: Austenitic**

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TP316H ... S31603 16Cr–12Ni–2Mo 8 (9) 75 30 0.85
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**Stainless Steels (Cont)**

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TP310H ... S31009 23Cr–20Ni 8 (9) 75 30 0.85
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- **316L** ... S31603 16Cr–12Ni–2Mo 8 (4) (9) (29) 70 25 1.00
- **316N** ... S31651 16Cr–12Ni–2Mo 8 (9) (10) 80 35 1.00
- **A240 317** ... S31703 18Cr–13Ni–3Mo 8 (1) (10) (11) 75 30 1.00
- **317L** ... S31703 18Cr–13Ni–3Mo 8 (1) (9) (10) (11) 75 30 1.00
- **321** ... S32100 18Cr–10Ni–Ti 8 (10) (11) 75 30 1.00
- **321** ... S32100 18Cr–10Ni–Ti 8 (1) (9) (10) (11) 75 30 1.00
- **347** ... S34700 18Cr–10Ni–Cb 8 (10) (11) 75 30 1.00
- **348** ... S34800 18Cr–10Ni–Cb 8 (1) (10) (11) 75 30 1.00
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- **348** ... S34800 18Cr–10Ni–Cb 8 (1) (10) (11) 75 30 1.00
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- **XM-33** ... S44626 27Cr–1Mo–Ti 10I (1) (3) 68 45 1.00
- **A240 405** ... S40500 12Cr–1Al 7 (3) 60 25 1.00
- **410** ... S41000 13Cr 6 (1) 65 30 1.00
- **410S** ... S41008 13Cr 7 (1) 60 30 1.00
- **429** ... S42900 15Cr 6 (1) (3) 65 30 1.00
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### Plate, Sheet, and Strip: Ferritic/Martensitic

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**Stainless Steels (Cont’d)**

| Grade | Type or No. | Spec. No. | Grade Class | Alloy | UNS | No. | Notes | Composition | Nominal | P-Minimum | Specified | Tensile, ksi | Minimum | Specified | Yield, ksi | or E F |
|-------|-------------|-----------|-------------|--------|------|-----|-------|------------|---------|-----------|-----------|-------------|---------|-----------|-----------|-------|---|
|       |             |           |             |        |      |     |       |            |         |           |           |             |         |           |           |      | |
| F304L |             |           |             |        |      |     |       |            |         |           |           |             |         |           |           |      | |
| F304H |             |           |             |        |      |     |       |            |         |           |           |             |         |           |           |      | |
| F304  |             |           |             |        |      |     |       |            |         |           |           |             |         |           |           |      | |
| F304N |             |           |             |        |      |     |       |            |         |           |           |             |         |           |           |      | |
| F310  |             |           |             |        |      |     |       |            |         |           |           |             |         |           |           |      | |
| F310H |             |           |             |        |      |     |       |            |         |           |           |             |         |           |           |      | |
| F316  |             |           |             |        |      |     |       |            |         |           |           |             |         |           |           |      | |
| F316H |             |           |             |        |      |     |       |            |         |           |           |             |         |           |           |      | |
| F316L |             |           |             |        |      |     |       |            |         |           |           |             |         |           |           |      | |
| F316N |             |           |             |        |      |     |       |            |         |           |           |             |         |           |           |      | |

**Forgings: Austenitic**

| Grade | Type or No. | Spec. No. | Grade Class | Alloy | UNS | No. | Notes | Composition | Nominal | P-Minimum | Specified | Tensile, ksi | Minimum | Specified | Yield, ksi | or E F |
|-------|-------------|-----------|-------------|--------|------|-----|-------|------------|---------|-----------|-----------|-------------|---------|-----------|-----------|-------|---|
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| A182  |             |           |             |        |      |     |       |            |         |           |           |             |         |           |           |      | |

**Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding**

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Table A-3
Stainless Steels (Cont’d)

Forgings: Austenitic
### Table A-3

Stainless Steels (Cont’d)

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Stainless Steels (Cont'd)

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GENERAL NOTES:
(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME BPVC applications, see related specifications in ASME BPVC, Section II.
(b) The stress values in this table may be interpolated to determine values for intermediate temperatures.
(c) The P-Numbers indicated in this table are identical to those adopted by ASME BPVC. Qualification of welding procedures, welders, and welding operators is required and shall comply with ASME BPVC, Section IX, except as modified by para. 127.5.

d) Tensile strengths and allowable stresses shown in “ksi” are “thousands of pounds per square inch.”
(e) The materials listed in this table shall not be used at design temperatures above those for which allowable stress values are given herein or in Table A-8.

NOTES:
(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIGURES 100.1.2-1 THROUGH 100.1.2-10.
(2) Use of this material at temperatures above 650°F is not approved because of the possibility of temper embrittlement.
(3) This steel may be expected to develop embrittlement at room temperature after service at temperatures above 700°F. Consequently, its use at higher temperatures is not recommended unless due caution is observed.
(4) For fittings made from ASTM forgings over 5 in. in thickness, the allowable stress values tabulated shall be reduced by the ratio of 70 divided by 75.
(5) The material quality factors and allowable stress values for these materials may be increased in accordance with para. 102.4.6.
(6) Tensile strengths in parentheses are expected minimum values.
(7) See MSS SP-43 for requirements for lightweight stainless steel fittings. MSS SP-43 Schedule 5S fittings shall not be used for design temperatures above 400°F. MSS SP-43 Schedule 10S fittings shall not be used for design temperatures above 750°F.
(8) The material quality factor for centrifugally cast pipe (0.85) is based on all surfaces being machined after heat treatment. The surface finish, after machining, shall be 250 μin. arithmetic average deviation or smoother.
(9) Due to the relatively low yield strength of these materials, these higher allowable stress values were established at temperatures where the short time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These stress values exceed 67% but do not exceed 90% of the yield strength at temperature. Use of these stress values may result in dimensional changes due to permanent strain. These values should not be used for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.
(10) The allowable stress values tabulated for temperatures over 1,000°F apply only if the carbon content of the material is 0.04% or higher.
(11) The allowable stress values tabulated for temperatures over 1,000°F apply only if the material is heat treated by heating to a minimum temperature of 1,900°F and quenching in water or rapidly cooling by other means.
(12) These allowable stress values apply to forgings over 5 in. in thickness.
(13) The allowable stress values tabulated for temperatures over 800°F apply only if the carbon content of the material is 0.04% or higher.
(14) These allowable stress values shall be used only when the grain size of the material is ASTM No. 6 or coarser.
(15) These allowable stress values shall be used only when the grain size of the material is finer than ASTM No. 6 or when the grain size has not been determined.
(16) Use of external pressure charts for material in the form of barstock is permitted for stiffening rings only.
(17) At the ferrite levels tabulated below, these materials will have significant reductions in Charpy V-notch toughness values at room temperature and below following service exposure at the indicated temperatures. This reduction indicates the potential for brittle fracture with high rate loading in the presence of sharp notches or cracks.

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<td>35–40</td>
<td>500 and above</td>
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(18) The stress values at 1,050°F and above shall be used only when the grain size is ASTM No. 6 or coarser.
(19) These allowable stress values apply for single or double butt welded pipe with radiography per para. 136.4.5.
(20) These allowable stress values apply for double butt welded pipe, without radiography.
(21) These allowable stress values apply for single butt welded pipe, without radiography.

Table A-3
Stainless Steels (Cont’d)
### Table A-4
### Nickel and High Nickel Alloys (Cont’d)

**GENERAL NOTES:**

(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME BPVC applications, see related specifications in ASME BPVC, Section II.
(b) The stress values in this table may be interpolated to determine values for intermediate temperatures.
(c) The P-Numbers indicated in this table are identical to those adopted by ASME BPVC. Qualification of welding procedures, welders, and welding operators is required and shall comply with ASME BPVC, Section IX, except as modified by para. 127.5.
(d) Tensile strengths and allowable stresses shown in “ksi” are “thousands of pounds per square inch.”
(e) The materials listed in this table shall not be used at design temperatures above those for which allowable stress values are given herein or in Table A-8.
(f) The tabulated stress values are $S \times E$ (weld joint efficiency factor) or $S \times F$ (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 102.4.3-1.
(g) Pressure-temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this table are for use in designing piping components that are not manufactured in accordance with referenced standards.
(h) The $y$ coefficient = 0.4 except where Note (7) applies (see Table 104.1.2-1).
(i) The tabulated stress values that are shown in italics are at temperatures in the range where creep and stress rupture strength govern the selection of stresses.
(j) See para. 124.1.2 for lower temperature limits.

**NOTES:**

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIGURES 100.12-1 THROUGH 100.12-10.
(2) Due to the relatively low yield strengths of these materials, these higher allowable stress values were established at temperatures where the short time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These stress values exceed 67% but do not exceed 90% of the yield strength at temperature. Use of these values may result in dimensional changes due to permanent strain. These values should not be used for flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.
(3) The maximum temperature is limited to 500°F because harder temper adversely affects design stress in the creep rupture temperature range.
(4) These values may be used for plate material only.
(5) These values apply to sizes NPS 5 and smaller.
(6) These values apply to sizes larger than NPS 5.
(7) See Table 104.1.2-1 for $y$ coefficient value.
(8) Heat treatment after forming or welding is neither required nor prohibited. However, if heat treatment is applied, the solution annealing treatment shall consist of heating to a minimum temperature of 2,025°F and then quenching in water or rapid cooling by other means.
(9) These values apply to thickness less than $\frac{3}{16}$ in.
(10) These values apply to thickness from $\frac{3}{16}$ in. up to and including $\frac{3}{8}$ in.
(11) These values apply to thickness more than $\frac{3}{8}$ in.
(12) All filler metal, including consumable insert material, shall comply with the requirements of ASME BPVC, Section IX.
(13) These values ($E = 1.00$) apply only to Class WX or Class WU fittings (all welds radiographed or ultrasonically examined).
(14) This alloy is subject to severe loss of impact strength at room temperature after exposure in the range of 1,000°F to 1,400°F.
(15) The minimum tensile strength of reduced tension specimens in accordance with ASME BPVC, Section IX, QW-462.1 shall not be less than 110,000 psi.
(16) These values apply to material with a thickness of greater than 4 in. prior to machining or fabricating.
(17) These values apply to material with a maximum thickness of 4 in. prior to machining or fabricating.
(18) For service at 1,200°F or higher, the deposited weld metal shall be of the same nominal chemistry as the base metal.
(19) Heat treatment after fabrication and forming is neither required nor prohibited. If heat treatment is performed, the material shall be heated for a sufficient time in the range of 2,010°F to 2,100°F followed by quenching in water or rapid cooling by another means.
(20) Welding electrodes or filler metal used for welding UNS N08926 shall conform to ASME SFA-5.11 ENiCrMo-3 or ENiCrMo-4, or ASME SFA-5.14 ERNiCrMo-3 or ERNiCrMo-4.
(21) These values apply to thicknesses $\frac{3}{16}$ in. or less.
(22) These values apply to thicknesses greater than $\frac{3}{16}$ in.
(23) These values apply to seamless pipe and tubing with outside diameter 5 in. and under.
Table A-5
Cast Iron (Cont’d)

**GENERAL NOTES:**
(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME BPVC applications, see related specifications in ASME BPVC, Section II.
(b) The stress values in this table may be interpolated to determine values for intermediate temperatures.
(c) Cast iron components shall not be welded during fabrication or assembly as part of the piping system.
(d) Tensile strengths and allowable stresses shown in “ksi” are “thousands of pounds per square inch.”
(e) The materials listed in this table shall not be used at design temperatures above those for which allowable stress values are given.
(f) The tabulated stress values for ductile cast iron materials are \( S \times F \) (material quality factor). Material quality factors are not applicable to other types of cast iron.
(g) Pressure–temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this table are for use in designing piping components that are not manufactured in accordance with referenced standards.
(h) See para. 124.1.2 for lower temperature limits.

**NOTES:**
1. THIS MATERIAL IS NOT ACCEPTABLE FOR BOILER EXTERNAL PIPING — SEE FIGURES 100.1.2-1 THROUGH 100.1.2-10.
2. Material quality factors are not applicable to these materials.
3. For saturated steam at 250 psi (406°F), the stress values given at 400°F may be used.
4. For limitations on the use of this material, see para. 124.4.
5. This material shall not be used where the design pressure exceeds 250 psig [1725 kPa (gage)] or where the design temperature exceeds 450°F (230°C).
6. This material shall not be used for boiler external piping where the design pressure exceeds 350 psig [2415 kPa (gage)] or where the design temperature exceeds 450°F (230°C).
7. Piping components conforming to either ASME B16.1 or ASME B16.4 may be used for boiler external piping, subject to all the requirements of the particular standard.
8. For limitations on the use of this material, see para. 124.6.
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<th>UNS Alloy No.</th>
<th>Temper or Condition</th>
<th>Size or Thickness, in.</th>
<th>P-No.</th>
<th>Notes</th>
<th>Specified Minimum Tensile, ksi</th>
<th>Specified Minimum Yield, ksi</th>
<th>E or F</th>
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### Table A-6

**Copper and Copper Alloys**

- **Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding**
- **UNS Alloy No.**
- **Spec. No.**
- **Temper or Condition**
- **Size or No.**
- **Notes**

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<th>UNS Alloy No.</th>
<th>Spec. No.</th>
<th>Temper or Condition</th>
<th>Size or No.</th>
<th>Notes</th>
<th>Minimum Yield, ksi</th>
<th>Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding</th>
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<td>100 150 200 250 300 350 400 450 500 550 600 650 700 750 800</td>
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### Welded Pipe and Tube

- **8.5 8.3 8.1 7.9 7.7 7.5 7.4 7.2 6.3 5.7 4.3 | C70600 | B467**
- **7.4 7.2 7.0 6.8 6.7 6.5 6.4 6.3 6.2 5.7 4.3 | C70600 | B467**
- **11.3 10.9 10.7 10.4 10.2 10.0 9.7 9.6 9.4 9.2 9.1 | C71500 |**
- **8.5 8.2 8.0 7.8 7.6 7.5 7.3 7.2 7.0 6.9 6.8 | C71500 |**
GENERAL NOTES:

(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME BPVC applications, see related specifications in ASME BPVC, Section II.

(b) The stress values in this table may be interpolated to determine values for intermediate temperatures.

(c) The P-Numbers listed in this table are identical to those adopted by ASME BPVC. Qualification of welding procedures, welders, and welding operators is required and shall comply with ASME BPVC, Section IX, except as modified by para. 127.5.

(d) Tensile strengths and allowable stresses shown in "ksi" are "thousands of pounds per square inch."

(e) The materials listed in this table shall not be used at design temperatures above those for which allowable stress values are given. However, for saturated steam at 250 psi (406°F), the allowable stress values given for 400°F may be used.

(f) The tabulated stress values are \( S \times E \) (weld joint efficiency factor) or \( S \times F \) (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 1024.3-1.

(g) Pressure-temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this table are for use in designing piping components that are not manufactured in accordance with referenced standards.

(h) For limitations on the use of copper and copper alloys for flammable liquids and gases, refer to paras. 122.7, 122.8, and 124.7.

(i) The \( y \) coefficient = 0.4 (see Table 104.1.2-1).

(j) The tabulated stress values that are shown in italics are at temperatures in the range where creep and stress rupture strength govern the selection of stresses.

(k) See para. 124.1.2 for lower temperature limits.

NOTES:

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR BOILER EXTERNAL PIPING — SEE FIGURES 100.1.2-1 THROUGH 100.1.2-10.

(2) This material may be used for boiler external piping provided that the nominal size does not exceed 3 in. and the design temperature does not exceed 400°F. This material shall not be used for blowoff or blowdown piping except as permitted in para. 122.1.4. Where threaded brass or copper pipe is used for feedwater piping, it shall have a wall thickness not less than that required for Schedule 80 steel pipe of the same nominal size.

(3) Welding or brazing of this material is not permitted.

(4) When this material is used for welded or brazed construction, the allowable stress values used shall not exceed those given for the same material in the annealed condition.

(5) Castings that are welded or repair welded shall be heat treated at 1,150°F to 1,200°F, followed by moving-air cooling. The required time at temperature is based on the cross-section thicknesses as follows:
   \( (a) \ 1 \frac{1}{2} \text{ hr for the first inch or fraction thereof} \)
   \( (b) \ \frac{1}{2} \text{ hr for each additional inch or fraction thereof} \)

(6) Welds must be made by an electric fusion welding process involving the addition of filler metal.

(7) Material conforming to ASTM B16 alloy C36000 shall not be used in primary pressure relief valve applications.

(8) Materials shall be tested to determine the presence of residual stresses that might result in failure of individual parts due to stress corrosion cracking. Tests shall be conducted in accordance with ASTM B154 or ASTM B858. The test frequency shall be as specified in ASTM B249.

(9) This material shall be used in a precipitation-hardened condition; temper TF00 in ASTM B706.
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<td>All</td>
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<td>Up thru 0.500</td>
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<td>T5</td>
<td>0.501–1.000</td>
<td>23</td>
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<td>Up thru 1.000</td>
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**Castings**

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<tr>
<th>Spec. No.</th>
<th>UNS Alloy No.</th>
<th>Temper</th>
<th>Size or Thickness, in.</th>
<th>P-No.</th>
<th>Notes</th>
<th>Specified Minimum Tensile, ksi</th>
<th>Specified Minimum Yield, ksi</th>
<th>E or F</th>
</tr>
</thead>
<tbody>
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</tr>
</tbody>
</table>
GENERAL NOTES:
(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME BPVC applications, see related specifications in ASME BPVC, Section II.
(b) The stress values in this table may be interpolated to determine values for intermediate temperatures.
(c) The P-Numbers listed in this table are identical to those adopted by ASME BPVC. Qualification of welding procedures, welders, and welding operators is required and shall comply with ASME BPVC, Section IX, except as modified by para. 127.5.
(d) Tensile strengths and allowable stresses shown in "ksi" are "thousands of pounds per square inch."
(e) Materials listed in this table shall not be used at design temperatures above those for which allowable stress values are given.
(f) The tabulated stress values are \( S \times E \) (weld joint efficiency factor) or \( S \times F \) (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 102.4.3-1.
(g) Pressure-temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this table are for use in designing piping components that are not manufactured in accordance with referenced standards.
(h) Aluminum and aluminum alloys shall not be used for flammable fluids within the boiler plant structure (see para. 122.7).
(i) The \( \gamma \) coefficient = 0.4 (see Table 104.1.2-1).
(j) The tabulated stress values that are shown in italics are at temperatures in the range where creep and stress rupture strength govern the selection of stresses.
(k) See para. 124.1.2 for lower temperature limits.

NOTES:
(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIGURES 100.1.2-1 THROUGH 100.1.2-10.
(2) These allowable stress values are not applicable when either welding or thermal cutting is employed.
(3) These allowable stress values are not applicable when either welding or thermal cutting is employed. In such cases, the corresponding stress values for the 0 temper shall be used.
(4) These allowable stress values are 90% of those for the corresponding core material.
(5) These allowable stress values apply only to seamless pipe smaller than NPS 1 that is extruded and then drawn.
(6) These allowable stress values are not applicable when either welding or thermal cutting is employed. In such cases, the corresponding stress values for the welded condition shall be used.
(7) The strength of a reduced-section tensile specimen is required to qualify welding procedures. Refer to ASME BPVC, Section IX, QW-150.
(8) ASTM B210 does not include this alloy/grade of material.
(9) For stress relieved tempers (T351, T3510, T3511, T451, T4510, T4511, T651, T6510, and T6511), stress values for the material in the basic temper shall be used.
(10) These allowable stress values apply to all thicknesses and sizes of seamless tubing. They also apply to NPS 1 and larger seamless pipe.
(11) These allowable stress values are for die forgings.
(12) These allowable stress values are for hand forgings.
(13) For temperatures up to 300°F, these allowable stress values are 83% of those for the corresponding core material. At temperatures of 350°F and 400°F, these allowable stress values are 90% of those for the corresponding core material.
(14) These allowable stress values are for the heat treated tempers listed that are tempered after welding.
(15) The tension test specimen from plate that is not less than 0.500 in. thick is machined from the core and does not include the cladding alloy. Therefore, the allowable stress values for thicknesses less than 0.500 in. shall be used.
(16) These allowable stress values are for seamless extruded tube in all sizes and for seamless pipe in sizes NPS 1 and larger.
(17) Stress values in restricted shear, such as in dowel bolts or similar construction in which the bearing member is so restricted that the section under consideration would fail without reduction of area, shall be 0.80 times the values in this table.
(18) Stress values in bearing shall be 1.60 times the values in this table.
(19) These allowable stress values are for the tempers listed in the welded condition.

For info - Notes 17 and 23 are not used so we are renumbering 18 to 14, 19 to 15, 20 to 16, 21 to 17, 22 to 18 and deleting note 23.
<table>
<thead>
<tr>
<th>Temperature (°F)</th>
<th>General Notes</th>
</tr>
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<tbody>
<tr>
<td>1,200 and Above</td>
<td>(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME BPVC applications, see related specifications in ASME BPVC, Section II.</td>
</tr>
<tr>
<td></td>
<td>(b) The stress values in this table may be interpolated to determine values for intermediate temperatures.</td>
</tr>
<tr>
<td></td>
<td>(c) The P-Numbers listed in this table are identical to those adopted by ASME BPVC. Qualification of welding procedures, welders, and welding operators is required and shall comply with ASME BPVC, Section IX, except as modified by para. 1275.</td>
</tr>
<tr>
<td></td>
<td>(d) The materials listed in this table shall not be used at design temperatures above those for which allowable stress values are given.</td>
</tr>
<tr>
<td></td>
<td>(e) The tabulated stress values are $S \times E$ (weld joint efficiency factor) or $S \times F$ (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 102.4.3-1.</td>
</tr>
<tr>
<td></td>
<td>(f) The materials listed in this table shall not be used at design temperatures above those for which allowable stress values are given.</td>
</tr>
<tr>
<td></td>
<td>(g) Pressure–temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this table are for use in designing piping components that are not manufactured in accordance with referenced standards.</td>
</tr>
<tr>
<td></td>
<td>(h) All the materials listed are classified as austenitic (see Table 104.1.2-1).</td>
</tr>
<tr>
<td></td>
<td>(i) The tabulated stress values that are shown in italics are at temperatures in the range where creep and stress rupture strength govern the selection of stresses.</td>
</tr>
</tbody>
</table>

**NOTES:**

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIGURES 100.1.2-1 THROUGH 100.1.2-10.
(2) These allowable stress values shall be used only if the carbon content of the material is 0.04% or higher.
(3) These allowable stress values shall be used only if the material is heat treated by heating to a minimum temperature of 1,900°F and quenching in water or rapid cooling by other means.
(4) These allowable stress values shall be used only when the grain size of the material is ASTM No. 6 or coarser.
(5) These allowable stress values shall be used only when Supplementary Requirement S1 per ASTM A479 has been specified.
(6) Seamless.
(7) Welded — all filler metal, including consumable insert material, shall comply with the requirements of ASME BPVC, Section IX.
(8) These allowable stress values apply to seamless pipe $\leq 3/8$ in. wall thickness.
(9) These allowable stress values apply to seamless pipe $> 3/8$ in. wall thickness.
(10) Creep-fatigue, thermal ratcheting, and environmental effects are increasingly significant failure modes at temperatures in excess of 1,500°F and shall be considered in the design.
### Table A-9
Titanium and Titanium Alloys (Cont’d)

<table>
<thead>
<tr>
<th>GENERAL NOTES:</th>
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<tbody>
<tr>
<td>(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME BPVC applications, see related specifications in ASME BPVC, Section II.</td>
</tr>
<tr>
<td>(b) The stress values in this table may be interpolated to determine values for intermediate temperatures.</td>
</tr>
<tr>
<td>(c) The P-Numbers listed in this table are identical to those adopted by ASME BPVC. Qualification of welding procedures, welders, and welding operators is required and shall comply with ASME BPVC, Section IX, except as modified by para. 127.5.</td>
</tr>
<tr>
<td>(d) Tensile strengths and allowable stresses shown in “ksi” are “thousands of pounds per square inch.”</td>
</tr>
<tr>
<td>(e) The materials listed in this table shall not be used at design temperatures above those for which allowable stress values are given.</td>
</tr>
<tr>
<td>(f) The tabulated stress values are $S \times E$ (weld joint efficiency factor) or $S \times F$ (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 102.4.3-1.</td>
</tr>
<tr>
<td>(g) Pressure–temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this table are for use in designing piping components that are not manufactured in accordance with referenced standards.</td>
</tr>
<tr>
<td>(h) The $y$ coefficient = 0.4 (see Table 104.1.2-1).</td>
</tr>
<tr>
<td>(i) See para. 124.1.2 for lower temperature limits.</td>
</tr>
</tbody>
</table>

<table>
<thead>
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<th>NOTES:</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIGURES 100.1.2-1 THROUGH 100.1.2-10.</td>
</tr>
<tr>
<td>(2) Filler metal shall not be used in the manufacture of welded pipe or tubing.</td>
</tr>
<tr>
<td>(3) Welding of this material is not permitted.</td>
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### Table A-10
Bolts, Nuts, and Studs

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<th>Spec. No.</th>
<th>Grade</th>
<th>Type or Class</th>
<th>Material Category/UNS No.</th>
<th>Notes</th>
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<th>Specified Minimum Yield, ksi</th>
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<td><strong>Carbon Steel</strong></td>
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<td>1, 2, 2H</td>
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<td>(1)</td>
<td>...</td>
<td>...</td>
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<td>Carbon steel</td>
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<td>100</td>
</tr>
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<tr>
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<td>18Cr–8Ni</td>
<td>S30400</td>
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<tr>
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<td>18Cr–8Ni</td>
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<tr>
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<td>18Cr–10Ni–Cb</td>
<td>S34700</td>
<td>(5) (18) (22)</td>
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<td><strong>SAE J429</strong></td>
<td>8</td>
<td>...</td>
<td>Cr-Ni-Mo</td>
<td>Alloy steel</td>
<td>(33) (34)</td>
<td>150</td>
</tr>
<tr>
<td><strong>F3125 A325</strong></td>
<td>3</td>
<td>C-Ni-Cr-Cu</td>
<td>Alloy steel</td>
<td>(2)</td>
<td>120</td>
<td>92</td>
</tr>
<tr>
<td><strong>A490</strong></td>
<td>3</td>
<td>C-Ni-Cr-Cu</td>
<td>Alloy steel</td>
<td>(2)</td>
<td>150</td>
<td>130</td>
</tr>
<tr>
<td>Spec. No.</td>
<td>Grade</td>
<td>Type or Class Nominal Composition</td>
<td>Material</td>
<td>Category/UNS No.</td>
<td>Notes</td>
<td>Specified Minimum Tensile, ksi</td>
</tr>
<tr>
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</tbody>
</table>

**Carbon Steel**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Spec. No.</th>
<th>Notes</th>
<th>Specified Minimum Tensile, ksi</th>
<th>Specified Minimum Yield, ksi</th>
<th>Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td></td>
<td>7.0</td>
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</tbody>
</table>

**Low and Intermediate Alloy Steel**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Spec. No.</th>
<th>Notes</th>
<th>Specified Minimum Tensile, ksi</th>
<th>Specified Minimum Yield, ksi</th>
<th>Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

**Stainless Steels: Austenitic**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Spec. No.</th>
<th>Notes</th>
<th>Specified Minimum Tensile, ksi</th>
<th>Specified Minimum Yield, ksi</th>
<th>Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>
GENERAL NOTES:
(a) The tabulated specifications are ANSI/ASME or ASTM. For ASME BPVC applications, see related specifications in ASME BPVC, Section II.
(b) The stress values in this table may be interpolated to determine values for intermediate temperatures.
(c) Tensile strengths and allowable stresses shown in "ksi" are "thousands of pounds per square inch."
(d) The materials listed in this table shall not be used at design temperatures above those for which allowable stress values are given.
(e) The tabulated stress values that are shown in italics are at temperatures where creep and stress rupture strength govern the selection of stresses.
(f) See para. 124.1.2 for lower temperature limits.
(g) The materials listed are classified as carbon steel; low and intermediate alloy steel; austenitic, martensitic, and precipitation hardened stainless steels; and copper alloys.
(h) ASTM specifications listed for bar or rod can be used for bolts and the corresponding nuts.

NOTES:
1. This table is for use in the design of bolting materials. This specification for use under ASME B31.1 are as follows:
   (a) Grades 1 and 2, −20°F to 600°F
   (b) Grade 2H, −20°F to 800°F
   (c) Grades 3 and 7, −20°F to 1,100°F
   (d) Grades 6 and 8F, −20°F to 800°F
   (e) Grades 8, 8C, 8M, and 8T, −20°F to 1,200°F

2. THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIGURES 100.1.2-1 THROUGH 100.1.2-10.

3. This material shall not be used above 400°F. The allowable stress value is 7,000 psi.

4. The allowable stress values listed in MSS SP-58 for this material may be used for pipe-supporting elements designed in accordance with MSS SP-58.

5. These allowable 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 relative flexibility of the flange, bolt, and corresponding relaxation properties.

6. These allowable stress values apply to bolting materials ≤ 1 in. in diameter.

7. These allowable stress values apply to bolting materials > 1 in. in diameter and ≤ 1 1/2 in. in diameter.

8. These allowable stress values apply to bolting materials > 1 1/2 in. in diameter and ≤ 3 in. in diameter.

9. Between temperatures of −20°F and 400°F, allowable stress values to the lower of the following may be used: 20% of the specified tensile strength or 25% of the specified yield strength.

10. These allowable stress values apply to bolting materials ≤ 4 in. in diameter.

11. These allowable stress values apply to bolting materials ≤ 2 1/2 in. in diameter.

12. These allowable stress values apply to bolting materials larger than 2 1/2 in. in diameter but not larger than 4 in. in diameter.

13. These allowable stress values apply to bolting materials larger than 4 in. in diameter but not larger than 7 in. in diameter.

14. DELETED

15. Minimum tempering temperature shall be 800°F.

16. The allowable stress values tabulated for temperatures over 1,000°F apply only if the carbon content of the material is 0.04% or higher.

17. The allowable stress values tabulated for temperatures over 1,000°F apply only if the material is heat treated by heating to a minimum temperature of 1,900°F and quenching in water or rapid cooling by other means.

18. The hardness of this material, under the thread roots, shall not exceed Rockwell C35. The hardness shall be measured on a flat area, at least 1/8 in. across, prepared by removing thread. No more material than necessary shall be removed to prepare the flat area. Hardness measurements shall be made at the same frequency as the tensile test.

19. These allowable stress values apply to bolting materials ≤ 7 in. in diameter.

20. These allowable stress values apply to bolting materials larger than 7 in. but not larger than 10 in. in diameter.

21. These allowable stress values apply to bolting materials larger than 10 in. but not larger than 1 1/2 in. in diameter.

22. These allowable stress values apply to bolting materials larger than 1 1/2 in. but not larger than 2 1/2 in. in diameter.

23. These allowable stress values apply to bolting material that has been carbide solution treated.

24. Due to relatively low yield strength of these materials, these higher allowable stress values were established at temperatures where the short time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These stress values exceed 67% but do not exceed 90% of the yield strength at temperature. Use of these stress values may result in dimensional change due to permanent strain. These values should not be used for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

25. These allowable stress values apply to bolting materials 10 in. in diameter.

26. Welding or brazing of this material is not permitted.

27. These allowable stress values apply to bolting materials ≤ 2 in. in diameter and smaller.

28. Tempered to HR50.

29. These allowable stress values apply to bolting materials larger than 1/4 in. but not larger than 1 in. in diameter.

30. These allowable stress values apply to bolting materials larger than 1 in. but not larger than 2 in. in diameter.

31. These allowable stress values apply to bolting materials larger than 2 in. but not larger than 3 in. in diameter.

Excerpts from the table:

Table A-10
Bolts, Nuts, and Studs (Cont’d)

1. The allowable stress for bolting is established in accordance with ASME BPVC, Section II, Part D, Mandatory Appendix 2 para. 2-120.
(32) Carbon steel with additives (e.g., B, Cr, or Mn) or medium carbon steel.
(33) Alloy steel shall contain at least one of the following elements in the minimum quantity given: chromium 0.30 %, nickel 0.30 %, molybdenum 0.20 %, vanadium 0.10 %, manganese 1.65%. Where elements are specified in combinations of two, three, four, or five and have alloy contents less than those given above, the limit value to be applied for steel class determination is 70 % of the sum of the individual limit values shown above for the two, three, four or five elements concerned.
(34) These allowable stress values apply to bolting materials 1/4 in. through 1-1/2 in., inclusive. Due to the variety of materials permitted by the specification, the lowest allowable stress is assigned, and the material is limited to 400°F.
MANDATORY APPENDIX D
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

See Table D-1 and Figures D-1 through D-3.

Insert "DELETED (see ASME B31J)".

Comment: ASME B31.3 did this when Appendix D was removed from it.
Table D-1
Flexibility and Stress Intensification Factors

<table>
<thead>
<tr>
<th>Description</th>
<th>Flexibility Characteristic, $h$</th>
<th>Flexibility Factor, $k$</th>
<th>Stress Intensification Factor, $i$</th>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welding elbow or pipe bend</td>
<td>$t_n R \over r^2$</td>
<td>1.65</td>
<td>0.9 $k^{2/3}$</td>
<td></td>
</tr>
<tr>
<td>Closely spaced miter bend</td>
<td>$s_n \cot \theta \over 2r^2$</td>
<td>1.52</td>
<td>0.9 $k^{2/3}$</td>
<td></td>
</tr>
<tr>
<td>Widely spaced miter bend</td>
<td>$t_n (1 + \cot \theta) \over 2r$</td>
<td>1.52</td>
<td>0.9 $k^{2/3}$</td>
<td></td>
</tr>
<tr>
<td>Welding tee per ASME B16.9</td>
<td>$3.1 t_n \over r$</td>
<td>1</td>
<td>0.9 $k^{2/3}$</td>
<td></td>
</tr>
<tr>
<td>Reinforced fabricated tee</td>
<td>$\left( t_n + \frac{t}{2} \right)^{5/2} \over r(t_n)^{3/2}$</td>
<td>1</td>
<td>0.9 $k^{2/3}$</td>
<td></td>
</tr>
<tr>
<td>Unreinforced fabricated tee</td>
<td>$t_n \over r$</td>
<td>1</td>
<td>0.9 $k^{2/3}$</td>
<td></td>
</tr>
<tr>
<td>Description</td>
<td>Flexibility Factor, $k$</td>
<td>Stress Intensification Factor, $i$</td>
<td>Illustration</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>-------------------------</td>
<td>-----------------------------------</td>
<td>--------------</td>
<td></td>
</tr>
<tr>
<td>Branch welded-on fitting (integrally reinforced) per MSS SP-97 [Notes (1), (2)]</td>
<td>$3.3 \frac{t_n}{r}$</td>
<td>$0.9 \frac{1}{r^{3/3}}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extruded outlet meeting the requirements of para. 104.3.1(g) [Notes (1), (2)]</td>
<td>$\frac{t_n}{r}$</td>
<td>$0.9 \frac{1}{r^{3/3}}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Welded-in contour insert [Notes (1), (2), (7)]</td>
<td>$3.1 \frac{t_n}{r}$</td>
<td>$0.9 \frac{1}{r^{3/3}}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Branch connection [Notes (1), (10)]</td>
<td>$1$</td>
<td>$1.0$</td>
<td>See Figure D-1</td>
<td></td>
</tr>
<tr>
<td>Butt weld [Note (1)]</td>
<td>$t \geq 0.237$ in., $\delta_{\text{max}} \leq \frac{1}{16}$ in., and $\delta_{\text{avg}}/t \leq 0.13$</td>
<td>$1$</td>
<td>$1.0$ [Note (11)]</td>
<td></td>
</tr>
<tr>
<td>Butt weld [Note (1)]</td>
<td>$t \geq 0.237$ in., $\delta_{\text{max}} \leq \frac{1}{8}$ in., and $\delta_{\text{avg}}/t$ = any value</td>
<td>$1$</td>
<td>$1.9 \max \text{ or } [0.9 + 2.7(\delta_{\text{avg}}/t)]$, but not less than $1.0$ [Note (11)]</td>
<td></td>
</tr>
<tr>
<td>Butt weld [Note (1)]</td>
<td>$t &lt; 0.237$ in., $\delta_{\text{max}} \leq \frac{1}{16}$ in., and $\delta_{\text{avg}}/t \leq 0.33$</td>
<td>$1$</td>
<td>$1.3$ [Note (12)]</td>
<td></td>
</tr>
<tr>
<td>Fillet welds</td>
<td>$1$</td>
<td>$1.3$</td>
<td>See Figures 127.4.4-1–127.4.4-3</td>
<td></td>
</tr>
<tr>
<td>Tapered transition per para. 127.4.2(b) and ASME B16.25 [Note (1)]</td>
<td>$1$</td>
<td>$1.9 \max \text{ or } 1.3 + 0.0036 \frac{D_o}{t_n} + 3.6 \frac{\delta}{t_n}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table D-1
Flexibility and Stress Intensification Factors (Cont’d)

<table>
<thead>
<tr>
<th>Description</th>
<th>Flexibility Factor, $k$</th>
<th>Stress Intensification Factor, $i$</th>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentric reducer per ASME B16.9 [Notes (1), (13)]</td>
<td>1</td>
<td>2.0 max. or $0.5 + 0.01\left(\frac{D_2}{t_2}\right)^{1/2}$</td>
<td><img src="image" alt="Illustration" /></td>
</tr>
</tbody>
</table>
| Threaded pipe joint or threaded flange | 1 | 2.3 | ...
| Corrugated straight pipe, or corrugated or creased bend [Note (14)] | 5 | 2.5 | ...

GENERAL NOTES:
(a) The validity of the stress intensification and flexibility factor data in Table D-1 has been demonstrated for $D_o/t_n \leq 100$.
(b) The designer may use the stress intensification and flexibility factors from ASME B31J instead of the stress intensification and flexibility factors herein. When using the stress intensification factors from ASME B31J, the maximum of the in-plane ($i_i$), out-of-plane ($i_o$), and torsional ($i_t$) stress intensification factors shall be used in calculating stresses in accordance with para. 104.8. Alternatively, stress intensification factors may be developed using ASME B31J, Nonmandatory Appendix A.

NOTES:
(1) The following nomenclature applies to Table D-1:
- $B =$ length of miter segment at crotch, in. (mm)
- $D_1 =$ outside diameter of reducer on large end, in. (mm)
- $D_2 =$ outside diameter of reducer on small end, in. (mm)
- $D_o =$ outside diameter, in. (mm)
- $D_{ob} =$ outside diameter of branch, in. (mm)
- $R =$ bend radius of elbow or pipe bend, in. (mm)
- $r =$ mean radius of pipe, in. (mm) (matching pipe for tees)
- $r_s =$ external crotch radius of welded-in contour inserts and welding tees, in. (mm)
- $s =$ miter spacing at centerline, in. (mm)
- $T_c =$ crotch thickness of welded-in contour inserts and welding tees, in. (mm)
- $t_n =$ nominal wall thickness of pipe, in. (mm) (matching pipe for tees)
- $t_r =$ reinforcement pad or saddle thickness, in. (mm)
- $\alpha =$ reducer cone angle, deg
- $\delta =$ mismatch, in. (mm)
- $\theta =$ one-half angle between adjacent miter axes, deg

(2) The flexibility factors, $k$, and stress intensification factors, $i$, in Table D-1 apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and mitered elbows, and to the intersection point for tees. The values of $k$ and $i$ can be read directly from Figure D-2 by entering with the characteristic, $h$, computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of $k$ and $i$ in Table D-1 shall be multiplied by the factor, $c$, given below, which can be read directly from Figure D-3, entering with the computed $h$: one end flanged, $c = h^{1/6}$; both ends flanged, $c = h^{1/3}$.

(4) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than those of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(5) In large diameter thin-wall elbows and bends, pressure can significantly affect magnitudes of $k$ and $i$. Values from the Table may be corrected by dividing $k$ by

$$1 + 6 \left(\frac{P}{E} \frac{r}{t_n} \right)^{7/3} \left(\frac{R}{r}\right)^{1/3}$$

and dividing $i$ by

$$1 + 3.25 \left(\frac{P}{E} \frac{r}{t_n} \right)^{5/2} \left(\frac{R}{r}\right)^{2/3}$$

(6) Also includes single miter joints.
NOTES: (Cont'd)

(7) If \( r_x \geq D_{o}/8 \) and \( T_c \geq 1.5t_w \), a flexibility characteristic, \( h \), of \( 4.4t_n/r \) may be used.

(8) When \( t_c > 1.5t_w \), \( h = 4.05t_o/r \).

(9) The stress intensification factors in the Table were obtained from tests on full-size outlet connections. For less than full-size outlets, the full-size values should be used until more applicable values are developed.

(10) The equation applies only if the following conditions are met:

(a) The reinforcement area requirements of para. 104.3 are met.

(b) The axis of the branch pipe is normal to the surface of run pipe wall.

(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times the sum of their radii along the circumference of the run pipe.

(d) The inside corner radius \( r_1 \) (see Figure D-1) is between 10% and 50% of \( t_{o} \).

(e) The outer radius \( r_2 \) (see Figure D-1), is not less than the largest of \( (T_c^2 + y^2)/2 \) (shown in Figure D-1, illustration (c)), or \( t_{o}/2 \).

(f) The outer radius, \( r_3 \) (see Figure D-1), is not less than the larger of

\[
(1) 0.0026d_d
\]

\[
(2) 2(\sin \theta)^3 \text{ times the offset for the configurations shown in Figure D-1, illustrations (a) and (b)}
\]

(g) \( R_m/t_{o} \leq 50 \) and \( r_m/R_m \leq 0.5 \).

(11) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between 0.875t and 1.10t for an axial distance of \( D_c \), \( D_o \) and \( t \) are nominal outside diameter and nominal wall thickness, respectively. \( \delta_{avg} \) is the average mismatch or offset.

(12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a full weld is made between the pipe and fitting as shown in Figure 127.4.4-3. For welds to socket welding flanges, the stress intensification factor is based on the weld geometry shown in Figure 127.4.4-2 and has been shown to envelop the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld, with no undercut, smoothly into the pipe wall, as shown in the concave fillet welds in Figure 127.4.4-1, illustrations (b) and (d), has been shown to improve the fatigue performance of the weld.

(13) The equation applies only if the following conditions are met:

(a) Cone angle, \( \alpha \), does not exceed 60 deg, and the reducer is concentric.

(b) The larger of \( D_1/t_1 \) and \( D_2/t_2 \) does not exceed 100.

(c) The wall thickness is not less than \( t_2 \) throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than \( t_o \).

(14) Factors shown apply to bending; flexibility factor for torsion = 0.9.
Figure D-1
Branch Connection Dimensions

Legend:

- $D_b$ = outside diameter of branch pipe, in. (mm)
- $L_1$ = height of nozzle, in. (mm)
- $r_1, r_2, r_3$ = transition radii of branch reinforcement, in. (mm)
- $R_m$ = mean radius of branch pipe, in. (mm)
- $r_i$ = inside radius of branch, in. (mm)
- $T_b = t_{nb} + 0.667y$
- $T_b = t_{nb}$
- $T_b = t_{nb} = T_b$
- $r_p$ = outside radius of branch reinforcement, in. (mm)
- $T_b$ = effective thickness of branch reinforcement, in. (mm)
- $t_{nb}$ = nominal thickness of branch pipes, in. (mm)
- $t_{nh}$ = nominal thickness of run pipe, in. (mm)
- $\theta_n$ = transition angle of branch reinforcement, deg
Figure D-2: Flexibility Factor, $k$, and Stress Intensification Factor, $i$.

- Flexibility factor for elbows: $k = 1.65/h$
- Flexibility factor for miters: $k = 1.52/h$
- Stress intensification factor: $i = 0.9/h^{2/3}$

Characteristic, $h$: 0.01, 0.03, 0.04, 0.05, 0.06, 0.08, 0.10, 0.14, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8, 1.0, 1.4, 2.0.
Figure D-3

Correction Factor, $c$

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<tr>
<td>0.25 0.30 0.50 0.60 0.80 1.0</td>
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</tbody>
</table>

Both ends flanged

$c = h^{1/3}$

One end flanged

$c = h^{1/6}$
MANDATORY APPENDIX F
REFERRED STANDARDS

Specific editions of standards incorporated in this Code by reference are shown in this Appendix. It is not practical to refer to a specific edition of each standard throughout the Code text, but instead, the specific edition reference dates are shown here. This Appendix is revised as needed. The names and addresses of the sponsoring organizations are also shown in this Appendix.

American National Standard
Z223.1-2012

API Specifications
570, 3rd Edition, 2009
571, 3rd Edition, 2020

ASCE/SEI Standard
7-16 [Note (1)]

ASME Codes and Standards
Boiler and Pressure Vessel Code, latest edition
A13.1-2015
B1.1-1989
B1.13M-2001
B120.1-1983 (R2001) (ANSI/ASME B1.20.1)
B120.3-1976 (R1998) (ANSI B1.20.3)

B16.1, latest edition
B16.3, latest edition
B16.4, latest edition
B16.5, latest edition
B16.9, latest edition
B16.10, latest edition
B16.11, latest edition
B16.14, latest edition
B16.15, latest edition
B16.18, latest edition
B16.20, latest edition
B16.21, latest edition
B16.22, latest edition
B16.24, latest edition
B16.25, latest edition
B16.26, latest edition
B16.34, latest edition

ASME Codes and Standards (Cont’d)
B16.36, latest edition
B16.42, latest edition
B16.47, latest edition
B16.48, latest edition
B16.50, latest edition

B18.2.1-1996 (1999a)
B18.2.2-1987 (R1999) (ASME/ANSI B18.2.2)
B18.2.3M-1979 (R2001)
B18.2.6M-1979 (R2001)
B18.2.4M-1979 (R1998)
B18.211-1999
B18.22M-1981
B18.22.1-1965 (R1998)
B18.31M-2008 (R2016)
B18.31.2-2014

B31.3-2020
B31.4-2019
B31.8-2020
B31Ea-2010
B31J-2017
B3IP-2017
B3IT-2018
B36.10M-2018
B36.19M-2018

CA-1, latest edition
PCC-3-2017
QAI-1, latest edition
TDP-1-2013

ASNT Standards
CP-189-20
SNT-TC-1A-20

ASTM Specifications [Note (2)] (Cont’d)
A47/A47M-99 (2018) ε1
A48/A48M-16
A53/A53M-20
A105/A105M-21
A106/A106M-19
A125-96 (2018)
A126-14
A134-19
A135/A135M-21
A139/A139M-16
A178/A178M-19
A179/A179M-19
A181/A181M-14 (2020)
A182/A182M-21
A192/A192M-17
A193/A193M-20
A194/A194M-20a
A197/A197M-00 (2019)
A210/A210M-19
A213/A213M-21a
A214/A214M-19
A216/A216M-18
A217/A217M-20
A229/A229M-18
A234/A234M-19
A240/A240M-20a
A242/A242M-13 (2008)
A249/A249M-18a
A254/A254M-12 (2019)
A268/A268M-20
A276/A276M-17
A278/A278M-01 (2020)
A283/A283M-18
A285/A285M-17
A299/A299M-17
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**ASTM Standard Test Methods**

- B223-06

**Notes:**

1. ε1 indicates a specification with additional notes or conditions.

**References:**

- F3226-19
- F3125/F3125M-23
- B706-18
GENERAL NOTE: The issue dates shown immediately following the hyphen after the number of the standard (e.g., B1.1-1989, A36/A36M-05, SP-6-12) is the effective date of issue (edition) of the standard. B18.2.2-1987 (R1999) designates reaffirmation without change in 1999.

NOTES:
(1) The Code incorporates by reference the listed edition of ASCE 7. A different edition of the standard may be required by the authority having jurisdiction.
(2) For boiler external piping material application, see para. 123.2.2.

SAE Standard
SAE J429  May 2014
Specifications and standards of the following organizations appear in this Appendix:

<table>
<thead>
<tr>
<th>Organization</th>
<th>Address</th>
<th>Phone</th>
<th>Website</th>
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</thead>
<tbody>
<tr>
<td>AISC</td>
<td>130 East Randolph Street, Suite 2000</td>
<td>(312) 670-2400</td>
<td><a href="http://www.aisc.org">www.aisc.org</a></td>
</tr>
<tr>
<td>ANSI</td>
<td>25 West 43rd Street</td>
<td>(212) 642-4900</td>
<td><a href="http://www.ansi.org">www.ansi.org</a></td>
</tr>
<tr>
<td>API</td>
<td>200 Massachusetts Avenue NW Suite 1100</td>
<td>(202) 682-8000</td>
<td><a href="http://www.api.org">www.api.org</a></td>
</tr>
<tr>
<td>ASCE</td>
<td>1801 Alexander Bell Drive</td>
<td>(800) 548-2723 (703) 295-6300</td>
<td><a href="http://www.asce.org">www.asce.org</a></td>
</tr>
<tr>
<td>ASME</td>
<td>Two Park Avenue</td>
<td>(973) 802-1717</td>
<td><a href="http://www.asme.org">www.asme.org</a></td>
</tr>
<tr>
<td>ASNT</td>
<td>1711 Arlingate Lane</td>
<td>(800) 344-3555</td>
<td><a href="http://www.asnt.org">www.asnt.org</a></td>
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<tr>
<td>ASTM</td>
<td>100 Barr Harbor Drive</td>
<td></td>
<td><a href="http://www.astm.org">www.astm.org</a></td>
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<td>MSS</td>
<td>127 Park Street, NE</td>
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<td><a href="http://www.msshq.org">www.msshq.org</a></td>
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<tr>
<td>AWS</td>
<td>8669 NW 36 Street, No. 130</td>
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<td>AWWA</td>
<td>6666 West Quincy Avenue</td>
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<td><a href="http://www.awwa.org">www.awwa.org</a></td>
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<tr>
<td>NFPA</td>
<td>1 Batterymanch Park</td>
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<td><a href="http://www.nfpa.org">www.nfpa.org</a></td>
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<tr>
<td>PFI</td>
<td>USA Office: 511 Avenue of the Americas, #601</td>
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<td><a href="http://www.pfi-institute.org">www.pfi-institute.org</a></td>
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<td><a href="http://www.plasticpipe.org">www.plasticpipe.org</a></td>
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<td>SEI</td>
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<td>ISO</td>
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Note: The above information includes addresses, phone numbers, and websites for the organizations mentioned.
This Appendix is a compilation of the nomenclature used within this Code. Included are the term definitions and units that can be uniformly applied. These terms are also defined at a convenient location within the Code. When used elsewhere within the Code, definitions given here shall be understood to apply.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
<th>SI</th>
<th>USC</th>
<th>References</th>
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<td>A</td>
<td>Corrosion, erosion, and mechanical allowances (including threading, grooving)</td>
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<td>in.</td>
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<td>104.2.3(a) [eqs. (3), (4)]; 104.1.2(a) [eqs. (7), (8), (9), (10)] 104.3.1(g) 104.4.1(b) 104.5.2(b) [eq. (13)] 104.5.3(a) Figure 104.3.1-2</td>
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<tr>
<td>A₁</td>
<td>Area available for reinforcement in run pipe</td>
<td>mm²</td>
<td>in.²</td>
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<td>104.3.1(d)(2)(-c) Figure 104.3.1-1</td>
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<tr>
<td>A₂</td>
<td>Area available for reinforcement in branch pipe</td>
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<td>in.²</td>
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<td>104.3.1(d)(2)(-c) Figure 104.3.1-1</td>
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<tr>
<td>A₃</td>
<td>Area available for reinforcement by deposited metal beyond outside diameter of run and branch and for fillet weld attachments of rings, pads, and saddles</td>
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<td>in.²</td>
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<td>104.3.1(d)(2)(-c) Figure 104.3.1-1</td>
</tr>
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<td>Area available for reinforcement by reinforcing ring, pad, or integral reinforcement</td>
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<td>in.²</td>
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<td>104.3.1(d)(2)(-c) Figure 104.3.1-1</td>
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<td>Area available for reinforcement in saddle on right angle connection</td>
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<td>in.²</td>
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<td>A₇</td>
<td>Required reinforcement area</td>
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<td>Cross-sectional material area of the pipe</td>
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<td>Length of miter segment at crotch</td>
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<td>$D_{ob}$</td>
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<td>104.3.1(e)</td>
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<td>Inside centerline longitudinal direction of the finished branch opening in the run of the pipe</td>
<td>mm in.</td>
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<td>$d_2$</td>
<td>Half width of reinforcement zone</td>
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<td>$d_3$</td>
<td>Diameter of finished opening</td>
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<td>$d_b$</td>
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<td>$R$</td>
<td>Centerline radius of elbow or bend, and effective &quot;radius&quot; of miter bends</td>
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<td>$R_f$</td>
<td>Mean radius after forming</td>
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<td>$R_o$</td>
<td>Original mean radius</td>
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<td>$R_m$</td>
<td>Mean radius of run pipe</td>
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<td>$R_f$</td>
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<td>Transition radii of branch-reinforcement</td>
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<td>$r_o$</td>
<td>Inside radius of branch</td>
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<td>$r_{m_i}$</td>
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Modification Based on Dave Creates’ comment to 23-772RC1
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<td>104.2.3(c)(3)</td>
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<td>104.5.2(b) [eq. (13)]</td>
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<td>104.5.3(a) [eq. (14)]</td>
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<td>104.8.4(c)</td>
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<td>127.4.8(b)</td>
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<td>132.4.2(e)</td>
</tr>
<tr>
<td>$t_r$</td>
<td>Nominal-wall-thickness of reducer</td>
<td>mm</td>
<td>102.4.5-1</td>
</tr>
<tr>
<td>$t_c$</td>
<td>Throat thickness of cover fillet weld, branch connection</td>
<td>mm</td>
<td>127.4.8(b)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>in.</td>
<td>132.4.2(e)</td>
</tr>
<tr>
<td>$t_e$</td>
<td>Effective branch wall thickness</td>
<td>mm</td>
<td>104.8.4(c)</td>
</tr>
<tr>
<td>$t_m$</td>
<td>Minimum required thickness of component, including allowances ($A$) for mechanical joining, corrosion, etc. (used with subscripts), namely $t_{mb} = minimum thickness of branch$ $t_{mh} = minimum thickness of header$</td>
<td>mm</td>
<td>104.1.2(a) [eqs. (7), (8), (9), (10)]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>in.</td>
<td>104.3.1(d)(2)</td>
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<td>104.3.1(g)</td>
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<td>104.4.1(b)</td>
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<td>104.5.3(a)</td>
</tr>
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<td>Symbol</td>
<td>Definition</td>
<td>Units</td>
<td>SI</td>
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<td>--------</td>
<td>------------</td>
<td>-------</td>
<td>----</td>
</tr>
<tr>
<td>$t_n$</td>
<td>Nominal wall thickness of component (used with subscripts), namely $t_{nb} = \text{nominal wall thickness of branch}$ $t_{nh} = \text{nominal wall thickness of header}$ $t_{nr} = \text{nominal thickness of reinforcement}$</td>
<td>mm in.</td>
<td>102.3.2(a)(3)</td>
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<td>104.8.4(c)</td>
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<td>127.4.8(b)</td>
</tr>
<tr>
<td>$t_r$</td>
<td>Thickness of reinforcing pad or saddle</td>
<td>mm in.</td>
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<td></td>
<td>104.3.1(e)</td>
</tr>
<tr>
<td>$t_s$</td>
<td>Wall thickness of segment or miter</td>
<td>mm in.</td>
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<tr>
<td>$t_w$</td>
<td>Weld thickness</td>
<td>mm in.</td>
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<tr>
<td>$U$</td>
<td>Anchordistance (length of straight line joining anchors)</td>
<td>m ft</td>
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<tr>
<td>$W$</td>
<td>Weld strength reduction factor</td>
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</tr>
<tr>
<td>$x_{\text{min}}$</td>
<td>Size of fillet weld for slip-on and socket welding flanges or socket wall for socket welds</td>
<td>mm in.</td>
<td>...</td>
</tr>
<tr>
<td>$Y$</td>
<td>Resultant of movement to be absorbed by pipelines</td>
<td>... ...</td>
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<tr>
<td>$y$</td>
<td>A coefficient having values given in Table 104.1.2-1</td>
<td>... ...</td>
<td>104.1.2(a) [eqs. (7), (8), (9), (10)]</td>
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<td>$y'$</td>
<td>Branch-offset-dimension</td>
<td>mm in.</td>
<td>...</td>
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<tr>
<td>$Z$</td>
<td>Section modulus of pipe</td>
<td>mm$^3$ in.$^3$</td>
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<td>104.8.3</td>
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<tr>
<td>$\alpha$</td>
<td>Angle between axes of branch and run</td>
<td>deg deg</td>
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<td>104.3.1(e)</td>
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<tr>
<td>$\alpha'$</td>
<td>Reducer-cone-angle</td>
<td>deg deg</td>
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<td>$\delta$</td>
<td>Mismatch-or-offset</td>
<td>mm in.</td>
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<tr>
<td>$\theta$</td>
<td>Angle of miter cut</td>
<td>deg deg</td>
<td>104.2.3</td>
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<tr>
<td>$\theta_{\text{nr}}$</td>
<td>Transition angle of branch reinforcement</td>
<td>deg deg</td>
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</tr>
<tr>
<td>$\geq$</td>
<td>Equal to or greater than</td>
<td>... ...</td>
<td>...</td>
</tr>
<tr>
<td>$\leq$</td>
<td>Equal to or less than</td>
<td>... ...</td>
<td>...</td>
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</table>

Modification Based on Dave Creates' comment to 23-772RC1
MANDATORY APPENDIX H
PREPARATION OF TECHNICAL INQUIRIES

H-1 INTRODUCTION

The ASME B31 Committee, Code for Pressure Piping, will consider written requests for interpretations and revisions of the Code rules and develop new rules if dictated by technical development. The Committee's activities in this regard are limited strictly to interpretations of the rules or to the consideration of revisions to the present rules on the basis of new data or technology. The Introduction to this Code states: "It is the owner's responsibility to determine which Code Section is applicable to a piping installation." The Committee will not respond to inquiries requesting assignment of a Code Section to a piping installation. As a matter of published policy, ASME does not approve, certify, rate, or endorse any item, construction, proprietary device, or activity, and, accordingly, inquiries requiring such consideration will be returned. Moreover, ASME does not act as a consultant on specific engineering problems or on the general application or understanding of the Code rules. If, based on the inquiry information submitted, it is the opinion of the Committee that the inquirer should seek professional assistance, the inquiry will be returned with the recommendation that such assistance be obtained.

Inquiries that do not provide the information needed for the Committee's full understanding will be returned.

H-2 REQUIREMENTS

Inquiries shall be limited strictly to interpretations of the rules or to the consideration of revisions to the present rules on the basis of new data or technology. Inquiries shall meet the following requirements:

(a) Scope. Involve a single rule or closely related rules in the scope of the Code. An inquiry letter concerning unrelated subjects will be returned.

(b) Background. State the purpose of the inquiry, which may be either to obtain an interpretation of Code rules or to propose consideration of a revision to the present rules. Provide concisely the information needed for the Committee's understanding of the inquiry, being sure to include reference to the applicable Code Section, edition, paragraphs, figures, and tables. If illustrations are provided, they shall be limited to the scope of the inquiry.

(c) Inquiry Structure

(1) Proposed Question(s). The inquiry shall be stated in a condensed and precise question format, omitting superfluous background information, and, where appropriate, composed in such a way that "yes" or "no" (perhaps with provisos) would be an acceptable reply. The inquiry statement should be technically and editorially correct.

(2) Proposed Reply(ies). Provide a proposed reply stating what it is believed that the Code requires. If in the inquirer's opinion, a revision to the Code is needed, recommended wording shall be provided in addition to information justifying the change.

H-3 SUBMITTAL

Inquiries shall be submitted in typewritten form; however, legible handwritten inquiries will be considered. They shall include the name and mailing address of the inquirer, and be mailed to the following address:

Secretary
ASME B31 Committee
Two Park Avenue
New York, NY 10016-5990
Chapter N-II
Design

PART 1
CONDITIONS AND CRITERIA

N-101 DESIGN CONDITIONS

N-101.1 General

N-101.1.1 The design conditions of para. 101 shall apply for the design of nonmetallic piping systems, except as noted below.

N-101.1.2 The design of nonmetallic piping systems must ensure the adequacy and suitability of material and its manufacture, considering at least the following:
   (a) tensile, compressive, flexural, shear strength, and modulus of elasticity at design temperature (long-term and short-term)
   (b) creep characteristics for the service conditions
   (c) design stress and its basis
   (d) coefficient of thermal expansion
   (e) ductility and plasticity
   (f) impact and thermal shock properties
   (g) temperature limits for the service
   (h) transition temperatures: melting and vaporization
   (i) toxicity of the material or of the gases produced by its combustion or exposure to elevated temperatures
   (j) porosity and permeability
   (k) test methods
   (l) methods of making joints and their efficiency
   (m) deterioration in the service environment
   (n) the effects on unprotected piping from external heat sources, including solar radiation

N-101.2 Pressure

N-101.2.1 Basis for Design Pressure. For metallic piping, design pressure is based on the maximum sustained operating pressure, in accordance with para. 101.2.2, with an allowance for occasional operation above design pressure, in accordance with para. 102.2.4. For nonmetallic piping, allowances for variations of pressure, temperature, or both above design conditions are not permitted. It is the designer's responsibility to identify probable occasional temperature variations and to allow for them in determining design temperature. See para. N-102.2.4(a).

N-101.3 Temperature

N-101.3.1 Basis for Design Temperature. For metallic piping, design temperature is based on the maximum sustained operating temperature, in accordance with para. 101.3.2, with an allowance for occasional operation above design temperature, in accordance with para. 102.2.4. For nonmetallic piping, allowances for variations of pressure, temperature, or both above design conditions are not permitted. It is the designer's responsibility to identify probable occasional temperature variations and to allow for them in determining design temperature. See para. N-102.2.4(a).

N-101.3.2 Temperature Gradient Through Wall. Because some nonmetallic piping materials have low thermal conductivity, there can be a significant temperature gradient through the component walls. Table N-102.2.1-1, Note (2) describes how this is considered in determining allowable stresses for nonmetallic materials.

N-102 DESIGN CRITERIA

N-102.1 General

These criteria cover pressure–temperature ratings for standard and specially designed components, allowable stresses, stress limits, and various allowances to be used in the design of piping and piping components.

N-102.2 Pressure–Temperature Ratings for Components

N-102.2.1 Components Having Specific Ratings

(a) Standard components have specific pressure–temperature ratings established in accordance with the standards listed in Table N-126.1-1. Other components may be used in accordance with para. N-102.3. The ratings of Tables N-102.2.1-1 through N-102.2.1-3 are the limiting values for allowable stresses at temperature in this Appendix.

(b) The application of pressures exceeding the pressure–temperature ratings of valves and other standard components is not permitted. Valves shall be selected for operation within the limits defined in para. N-102.2.4.
**Table N-102.2.1-1**

Hydrostatic Design Stresses (HDS) and Recommended Temperature Limits for Thermoplastic Piping Components

### U.S. Customary Units

<table>
<thead>
<tr>
<th>ASTM Spec. No.</th>
<th>Material</th>
<th>Recommended Temperature Limits</th>
<th>Hydrostatic Design Stress, $S_a$, ksi [Note (6)], at</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum, °F [Note (4)]</td>
<td>Maximum, °F [Note (5)]</td>
<td>Hydrostatic Design Basis, ksi, at 73°F [Note (7)]</td>
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<tr>
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<td>CPVC 4120</td>
<td>0</td>
<td>200</td>
<td>4.0</td>
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<tr>
<td>D2513, F2145</td>
<td>PA32312</td>
<td>-20</td>
<td>180</td>
<td>2.5</td>
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<tr>
<td>D2104, D2239, D2447, D2513, D2737, D3035</td>
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<td>-30</td>
<td>140</td>
<td>1.60</td>
</tr>
<tr>
<td>D2513, F2145</td>
<td>PE3608</td>
<td>-30</td>
<td>140</td>
<td>1.60</td>
</tr>
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<td>D2513, F2145</td>
<td>PE3708</td>
<td>-30</td>
<td>140</td>
<td>1.60</td>
</tr>
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<td>PE3710</td>
<td>-30</td>
<td>140</td>
<td>1.60</td>
</tr>
<tr>
<td>D2513, F2145</td>
<td>PE4710</td>
<td>-30</td>
<td>140</td>
<td>1.60</td>
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<tr>
<td>...</td>
<td>POP2125 [Note (8)]</td>
<td>30</td>
<td>210</td>
<td>...</td>
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<td>...</td>
<td>PP [Note (8)]</td>
<td>30</td>
<td>210</td>
<td>...</td>
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<td>4.0</td>
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<td>100</td>
<td>4.0</td>
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<td>PVDF [Note (8)]</td>
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### SI Units

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<tr>
<th>ASTM Spec. No.</th>
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<th>Recommended Temperature Limits</th>
<th>Hydrostatic Design Stress, $S_a$, MPa [Note (6)], at</th>
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<td>Minimum, °C [Note (4)]</td>
<td>Maximum, °C [Note (5)]</td>
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Table N-102.2.1-1
Hydrostatic Design Stresses (HDS) and Recommended Temperature Limits for Thermoplastic Piping Components (Cont’d)

<table>
<thead>
<tr>
<th>ASTM Spec. No.</th>
<th>Material</th>
<th>Recommended Temperature Limits [Notes (1), (2), (3)]</th>
<th>Hydrostatic Design Basis, MPa, at 23°C</th>
<th>Hydrostatic Stress, $S_{tu}$ MPa [Note (6)], at 23°C</th>
<th>Minimum, °C [Note (4)]</th>
<th>Maximum, °C [Note (5)]</th>
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<th>38°C</th>
<th>60°C</th>
<th>82°C</th>
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<td>...</td>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F491</td>
<td>PVDF [Note (8)]</td>
<td>-18 135</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTES:
(1) These recommended limits are for low-pressure applications with water and other fluids that do not significantly affect the properties of the thermoplastic material. In conservative practice, the upper temperature limits may be reduced at higher pressures depending on the required service and expected life. Lower temperature limits are affected more by the environment, safeguarding, and installation conditions than by strength.
(2) Because of low thermal conductivity, temperature gradients through the piping component wall may be substantial. Tabulated limits apply where more than half the wall thickness is at or below the stated temperature.
(3) These recommended limits apply only to listed materials. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.
(4) Minimum for installation.
(5) Maximum for operation.
(6) The HDS listed is for water service only, reflecting a design factor of 0.5 applied to the HDB. For other services, refer to PPI TR-9 or the manufacturer for recommended design factors.
(7) Use these HDS values at all lower temperatures.
(8) Nonpressure-boundary materials used primarily as liners. No established HDS.
Metallic Piping Lined With Nonmetals. Allowances for pressure and temperature variations provided in para. 102.2.4 are permitted only if the suitability of the lining material for the increased conditions is established through prior successful extensive experience or tests under comparable conditions.

N-102.2.5 Ratings at Transitions. Where two services that operate at different pressure–temperature conditions are connected, the valve segregating the two services shall be rated for the most severe service conditions. Other requirements of para. 102.2.5 must be considered where applicable.

N-102.3 Allowable Stresses and Other Limits

N-102.3.1 Allowable Stress Values

(a) General. Tables N-102.2.1-1 through N-102.2.1-3 list recommended maximum allowable stresses in the form of hydrostatic design stresses (HDS), allowable design stresses (DS), and the hydrostatic design basis (HDB) that may be used in design calculations except where modified by other provisions of this Appendix. The use of HDS for calculations other than pressure design has not been established. The basis for determining allowable stresses and pressures is outlined in (b). The allowable stresses are grouped by materials and listed for stated temperatures. Where sufficient data have been provided, straight-line interpolation between temperatures is permissible. The materials listed are available from one or more manufacturers, and some manufacturers may publish somewhat different HDS values for the materials from the values listed in Tables N-102.2.1-1 through N-102.2.1-3. The manufacturer’s published values for these materials are acceptable for use where they have been established in accordance with (b) and verified in accordance with para. N-104.7.

(b) Basis for Allowable Stresses for Internal Pressure

(1) Thermoplastics. A method of determining HDB and pressure rating (PR) is described in ASTM D2837, which also describes application of a design factor to the HDB to determine HDS and PR. Hydrostatic design stresses are provided in Table N-102.2.1-1, based on HDB values listed in PPI TR-4 and design factors for water from PPI TR-9. Design factors for other services are also given in PPI TR-9.

(2) Reinforced Thermosetting Resin (Laminated). For laminated piping components, the design stresses are listed in Table N-102.2.1-2. These typically are based on one-tenth of the minimum tensile strengths specified in Table 1 of ASTM C582.

(3) Reinforced Thermosetting Resin (Filament Wound and Centrifugally Cast). For filament-wound and centrifugally cast piping components, HDB values are listed in Table N-102.2.1-3. These values may be obtained by procedures in ASTM D2992. HDS may be obtained by multiplying the HDB by a service (design) factor selected for the application, in accordance with procedures described in ASTM D2992, within the following limits:

(a) When using the cyclic HDB from Table N-102.2.1-3, the service (design) factor shall not exceed 1.0.

(b) When using the static HDB from Table N-102.2.1-3, the service (design) factor shall not exceed 0.5.

(c) The evaluation of stresses in filament-wound reinforced thermosetting resin pipe and fitting components must consider the different strengths in the hoop and axial directions of the material. For a 55-deg filament-winding angle (which is typical for filament-wound pipe), the axial strength is approximately one-

Table N-102.2.1-3
Hydrostatic Design Basis (HDB) for Machine-Made Reinforced Thermosetting Resin Pipe (Cont’d)

<table>
<thead>
<tr>
<th>ASTM Spec. No. and Type</th>
<th>Grade</th>
<th>Material Designation</th>
<th>HDB Stress, $S_c$ [Note (1)], at 23°C [Note (2)]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cyclic, MPa [Note (3)]</td>
</tr>
<tr>
<td>Epoxy resin liner, nonreinforced</td>
<td></td>
<td>RTRP-21CT</td>
<td>68.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RTRP-21CU</td>
<td>86.2</td>
</tr>
</tbody>
</table>

NOTES:

(1) A service (design) factor must be applied to the HDB values to obtain the HDS.

(2) These HDB values apply only at 73°F (23°C). The standards covered in this table only require testing at 73°F (23°C), using ASTM D2992 test procedures. ASTM D2992 makes provision for testing at higher temperatures, and manufacturers also usually test to higher temperatures. It is the designer’s responsibility to verify that the manufacturer has test data covering the design temperature for the application, and that pressure–temperature ratings provided by the manufacturer reflect the service factor selected by the designer for the application.

(3) When using the cyclic design basis, the service factor shall not exceed 1.0.

(4) When using the static design basis, the service factor shall not exceed 0.5.

1 The service (design) factor, $F_s$, should be selected by the designer after evaluating fully the service conditions and the engineering properties of the specific material under consideration. Aside from the limits in paras. N-102.3.1(b)(3)(a) and N-102.3.1(b)(3)(b), it is not the intent of this Code to specify service (design) factors.
half of the hoop strength of the material. For greater winding angles, the axial strength will be even lower. Figure N-102.3.1 shows a typical axial strength versus hoop strength diagram for a filament-wound material. The data points for the axial strength at zero hoop stress and the axial strength at the maximum hoop stress will need to be provided by the vendor for his/her specific product, since no generic allowable stress diagrams currently exist. Note that for most filament-wound fiberglass products, the portion of the allowable axial stress available for weight, thermal expansion, and occasional loads will approach zero as the hoop stress approaches the maximum allowable limit for the material.

(d) The stress analysis of the filament-wound pipe and fitting components must consider the simultaneous axial and hoop stresses at each point in the piping system, and take into account any hoop stress, stress intensification factors (SIFs), and axial stress SIFs that may be applicable to a given component.

(e) Note that for aboveground pipe, due to the different axial and hoop strengths of filament-wound reinforced thermosetting resin pipe and fitting components, the minimum wall thickness required for the pipe and fitting components may be governed by the axial strength requirements, rather than just by hoop strength considerations.

N-102.3.2 Limits of Calculated Stresses Due to Sustained Loads

(a) Internal Pressure Stresses. The limits for stress due to internal pressure are provided in para. N-104.1.2.

(b) External Pressure Stresses. Thermoplastic piping, reinforced thermosetting resin piping, and metallic piping lined with nonmetals, subject to external pressure, shall be considered safe when the wall thickness and/or means of stiffening meet the requirements of para. N-104.7.2.

(c) External Loading Stresses. Design of piping under external loading shall be based on the following:

1. For thermoplastic piping, see ASTM D2774 and AWWA M23.
2. For reinforced thermosetting resin (RTR) piping, see ASTM D3839 and AWWA M45.
3. The allowable deflection for RTR and thermoplastic pipe shall be not more than 5% of the pipe inside diameter.
4. Where other nonmetallic piping is intended for use under conditions of external loading due to underground installation, it shall be subject to a crushing or three-edge bearing test, in accordance with ASTM C14 or ASTM C301, and the allowable load shall be 25% of the minimum value obtained. The limits of calculated stresses due to external loading in aboveground installations shall be qualified in accordance with para. N-104.7.2.
N-102.3.3 Limits of Calculated Stresses Due to Occasional Loads

(a) Operation. The sum of the stresses in any component in a piping system due to sustained loads, such as pressure and weight, and of the stresses produced by occasional loads, such as wind or earthquake, shall not exceed the limits in the applicable part of para. N-102.3.2. Wind and earthquake forces need not be considered as acting concurrently. (For nonmetallic piping, anticipated transient pressure and temperature variations are not considered occasional loads.)

(b) Test. Stresses due to test conditions are not subject to the limitations in (a). It is not necessary to consider other occasional loads, e.g., wind and earthquake, as occurring concurrently with test loads.

N-102.4 Allowances

(a) Erosion, Corrosion, Threading, and Grooving. In determining the minimum required thickness of a piping component, allowances shall be included for erosion and for thread depth or groove depth.

(b) Mechanical Strength. When necessary, pipe wall thicknesses shall be increased to prevent overstress, damage, collapse, or buckling due to superimposed loads from supports, ice formation, backfill, or other causes. Where increasing thickness will cause excessive local stress or is otherwise impractical, the required strength may be obtained through the use of additional supports, braces, or other means without an increased wall thickness. Particular consideration should be given to the mechanical strength of a small branch connected to large piping or to equipment.

PART 2
PRESSURE DESIGN OF PIPING COMPONENTS

N-103 CRITERIA FOR PRESSURE DESIGN

The design of piping components shall consider the effects of pressure, temperature, and other factors in accordance with paras. N-102.2 and N-104.1 through N-104.7, and provide for allowances in accordance with para. N-102.4. In addition, the design shall be checked for adequacy of mechanical strength under other applicable loadings as required in paras. N-102.3.2 and N-102.3.3.

N-104 PRESSURE DESIGN OF COMPONENTS

N-104.1 Straight Pipe

N-104.1.1 The required minimum wall thickness of straight sections of pipe, \( t_m \), shall be determined as

\[
t_m = t + c
\]

where

\( c \) = the sum of the mechanical allowances (thread or groove depth), plus erosion and/or corrosion allowance, and the manufacturer’s minus tolerance for product wall thickness, in. For non-threaded components, the nominal thread depth shall apply. For mechanical surfaces or grooves where a tolerance is not specified, the tolerance shall be assumed to be 0.02 in. (0.5 mm) in addition to the specified depth of the thread or groove.

\( t \) = pressure design thickness, in. (mm)

\( t_m \) = minimum required thickness, in. (mm)

N-104.1.2 Straight Pipe Under Internal Pressure

(a) The internal pressure design thickness, \( t \), shall be not less than that calculated with the following equations:

(1) For thermoplastic pipe

\[
t = \frac{D}{2S_a/P + 1}
\]

(2) For reinforced thermosetting resin (laminated)

\[
t = \frac{D}{2S_b/P + 1}
\]

(3) For reinforced thermosetting resin (filament wound and centrifugally cast)

\[
t = \frac{D}{2S_c/P + 1}
\]

where

\( D \) = outside diameter of pipe, in. (mm)

\( F \) = service design factor in accordance with para. N-102.3.1(b)(3)

\( P \) = internal design gage pressure, psig [kPa (gage)]

\( S_a \) = hydrostatic design stress from Table N-102.2.1-1

\( S_b \) = design stress from Table N-102.2.1-2

\( S_c \) = hydrostatic design basis from Table N-102.2.1-3

(4) Metallic Pipe Lined With Nonmetals. Pressure limitations shall be those established by the manufacturer, considering both pressure and temperature limitations of the metal housings and sealing ability of the liner at flanged joints. In addition, the metallic pipe shall meet the requirements of the mandatory sections of ASME B31.1, including the pressure design requirements of Chapter II.

(b) The internal pressure design thickness, \( t \), in (a)(1) and (a)(2) shall not include any thickness of pipe wall reinforced with less than 30% (by weight) of reinforcing fibers, or added liner thickness.

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N-104.1.3 Straight Pipe Under External Pressure

(a) Thermoplastic Pipe. The external pressure design thickness shall be qualified as required by para. N-104.7.

(b) Reinforced Thermosetting Resin Pipe. For determining design pressure thickness for straight pipe under external pressure, the procedures outlined in ASTM D2924 shall be followed. A safety factor of at least 4 shall be used.

(c) Metallic Pipe Lined With Nonmetals
   (1) The external pressure design thickness for the base (outer) material shall be determined in accordance with para. 104.1.3.
   (2) The external pressure design thickness, \( t \), for the lining material shall be qualified as required by para. N-104.7.

N-104.2 Curved and Mitered Segments of Pipe

(a) Pipe Bends. The minimum required thickness, \( t_{\text{min}} \), of a pipe bend after bending shall be determined as for straight pipe in accordance with para. N-104.1.

(b) Elbows. Manufactured elbows not in accordance with para. N-102.2.1 shall meet the requirements of para. N-104.7.

(c) Mitered Bends. Mitered bend sections shall meet the requirements of para. N-104.7.

N-104.3 Intersections

N-104.3.1 Branch Connections

(a) General. A pipe having a branch connection is weakened by the opening that must be made in it. Unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide added reinforcement. The amount of reinforcement required shall be in accordance with the requirements of para. N-104.7 except as provided in (b) and (c).

(b) Branch Connections Using Fittings. A branch connection shall be considered to have adequate strength to sustain the internal and external pressure that will be applied to it if a fitting (at tee, lateral, or cross) is used in accordance with para. N-102.2.1.

(c) Additional Considerations. The requirements of (a) and (b) are designed to ensure satisfactory performance of a branch connection subject only to internal or external pressure. The designer shall also consider the following:
   (1) External forces and moments may be applied to a branch connection by a thermal expansion and contraction, by dead and live loads, by vibration or pulsating pressure, or by movement of piping terminals, supports, and anchors.
   (2) Adequate flexibility shall be provided in branch piping to accommodate movements of the run piping.

(3) Ribs, gussets, or clamps may be used for pressure-strengthening a branch connection in lieu of the reinforcement required by (a) if the adequacy of the design is established in accordance with para. N-104.7.

N-104.4 Closures

Closures in piping systems, e.g., those provided for temporary or future lateral or end-point branches, shall be made using fittings, flanges, or parts listed in Table N-126.1-1 or designed in accordance with paras. N-104.3, N-104.5, and N-104.7.

N-104.5 Pressure Design of Flanges

(a) General
   (1) Nonmetallic flanges that are rated in accordance with published ASTM standards listed in Table N-126.1-1 shall be considered suitable for use within the limitations specified in this Appendix. Alternatively, flanges shall be in accordance with para. 103 or may be designed in conformance with the requirements of this paragraph or para. N-104.7.
   (2) Flanges for use with ring-type gaskets may be designed in accordance with ASME BPVC, Section VIII, Division 1, Mandatory Appendix 2, except that the allowable stresses for nonmetallic components shall govern. All nomenclature shall be as defined in ASME BPVC, except the following:
   \[
   \begin{align*}
   P & = \text{design gage pressure} \\
   S_a & = \text{maximum allowable bolt stress at ambient temperature, psi (kPa) (see Mandatory Appendix A, Table A-10)} \\
   S_b & = \text{maximum allowable bolt stress at design temperature, psi (kPa) (see Mandatory Appendix A, Table A-10)} \\
   S_f & = \text{allowable stress for flange material from Tables N-102.2.1-1 through N-102.2.1-3}
   \end{align*}
   \]

   (3) The flange design rules in (2) are not applicable for designs employing full face gaskets that extend beyond the bolts. The forces and reactions in such a joint differ from those joints employing ring-type gaskets, and the flanges should be designed in accordance with ASME BPVC, Section VIII, Division 1, Nonmandatory Appendix Y. (Note that the plastic flange sealing surface may be more irregular than the sealing surface of a steel flange. For this reason, thicker and softer gaskets may be required for plastic flanges.)

   (b) Blind Flanges. Blind flanges shall be in accordance with para. 103 or, alternatively, may be designed in accordance with para. 104.5.2, except that the allowable stresses for nonmetallic components shall be taken from the data in Tables N-102.2.1-1 through N-102.2.1-3. Otherwise, the design of blind flanges shall meet the requirements of para. N-104.7.
N-104.6 Reducers
Reducers not in compliance with para. N-102.2.1 shall meet the requirements of para. N-104.7.

N-104.7 Design of Other Components

N-104.7.1 Listed Components. Pressure-retaining components manufactured in accordance with standards listed in Table N-126.1-1 may be used in accordance with para. N-102.2.1.

N-104.7.2 Unlisted Components and Products. For nonmetallic pressure-retaining components and piping products not complying with the standards and specifications listed in Table N-126.1-1, and for proprietary components and joints for which the rules in paras. N-103 through N-104.6 do not apply, pressure design shall be based on calculations consistent with the design criteria of this Appendix and the Code. This must be substantiated by one or more of the following, with consideration given to applicable dynamic effects, e.g., vibration and cyclic operation, the effects of thermal expansion or contraction, and the load effects of impact and thermal shock:
(a) extensive successful service experience under comparable design conditions with similarly proportioned components or piping elements made of the same or like material
(b) performance tests under design conditions, including applicable dynamic and creep effects, continued for a time period sufficient to determine the acceptability of the component or piping element for its design life
For either (a) or (b), reasonable interpolations between sizes and pressure classes, and reasonable analogies among related materials, are permitted.

PART 3
SELECTION OF PIPING COMPONENTS

N-105 PIPE
Pipe and tube conforming to the standards and specifications listed in Table N-126.1-1 shall be used within the limitations of para. N-124 and within any limitations imposed by the applicable standards themselves.

N-106 FITTINGS

N-106.1 Listed Fittings
Fittings made in accordance with the standards and specifications listed in Table N-126.1-1 shall be used within the limitations of para. N-124, within limitations imposed by this Appendix or the body of this Code for specific service or application, and within any limitations imposed by the applicable standards themselves.

N-106.2 Unlisted Fittings
Fittings not covered by the standards listed in Table N-126.1-1 may be used if they conform to para. N-104.7.

N-107 VALVES

N-107.1 Listed Valves
Valves conforming to the standards and specifications listed in Table N-126.1-1 shall be used within the specified pressure–temperature ratings. Metallic valves conforming to the standards and specifications listed in Table N-126.1-1, and used in nonmetallic piping, shall be used within the specified pressure–temperature ratings.

N-107.2 Unlisted Valves
Valves not complying with para. N-107.1 shall be of a design, or equal to the design, that the manufacturer recommends for the service and that conforms with para. N-104.7.2.

PART 4
SELECTION AND LIMITATIONS OF PIPING JOINTS

N-110 GENERAL
Joints shall be suitable for the pressure–temperature design conditions and shall be selected giving consideration to joint tightness and mechanical strength under those conditions (including external loadings), the materials of construction, the nature of the fluid service, and the limitations of paras. N-111 through N-118.

N-111 BONDED JOINTS

N-111.1 General Limitations
Unless limited elsewhere in para. N-111, joints made by bonding in accordance with para. N-127 and examined in accordance with para. N-136.4 may be used within other limitations on materials and piping components in this Appendix.

N-111.2 Specific Limitations

N-111.2.1 Hot-Gas Welded Joints. Hot-gas welded joints shall not be used for ASME B31.1 nonmetallic pressure piping.

N-111.2.2 Butt-and-Wrapped Joints. Butt-and-wrapped joints in RTR piping shall be made with sufficient strength to withstand the design pressure and external loadings.
N-112 FLANGED JOINTS: GENERAL LIMITATIONS

Unless limited elsewhere in para. N-112, flanged joints may be used, considering the requirements for materials in Chapter N-III and for piping components in Part 3 of Chapter N-II, within the following limitations:

(a) Joints With Flanges of Different Ratings. Where flanges of different ratings are bolted together, the rating of the joint shall be that of the lower-rated flange. Bolting torque shall be limited so that excessive loads will not be imposed on the lower-rated flange in obtaining a tight joint.

(b) Metallic-to-Nonmetallic Flanged Joints. Where metallic and nonmetallic flanges are to be joined, both should be flat face. Full face gaskets are preferred. If full face gaskets are not used, bolting torque shall be limited so that the nonmetallic flange is not overloaded.

N-113 EXPANDED OR ROLLED JOINTS

Expanded or rolled joints are not permitted in nonmetallic piping systems.

N-114 THREADED JOINTS

N-114.1 General Limitations

N-114.1.1 Threaded joints may be used within the requirements for materials in Chapter N-III and on piping components in Part 3 of Chapter N-II within the limitations below.

N-114.1.2 Threaded joints shall be avoided in any service where severe erosion or cyclic loading may occur, unless the joint has been specifically designed for these conditions.

N-114.1.3 Where threaded joints are designed to be seal welded, thread-sealing compound shall not be used.

N-114.1.4 Layout of piping should minimize reaction loads on threaded joints, giving special consideration to stresses due to thermal expansion or contraction and the operation of valves.

N-114.1.5 Metallic-to-nonmetallic and dissimilar nonmetallic threaded joints are not permitted in piping NPS 2½ (DN 65) and larger.

N-114.2 Specific Limitations

N-114.2.1 Thermoplastic Piping. Threaded joints in thermoplastic piping shall conform to the following requirements:

(a) The pipe wall shall be at least Schedule 80 thickness.
(b) Pipe threads shall conform to ASME B1.20.1 NPT. Threaded fittings shall be compatible with that standard.
(c) A suitable thread lubricant and sealant shall be specified.

(d) Threaded piping joints are not permitted in polyolefin materials, because of creep characteristics that must be considered.

(e) For PVC piping, the allowable pressure for threaded piping shall be no more than 50% of that for unthreaded piping of the same wall thickness and material grade.

N-114.2.2 Thermosetting Resin Piping. Threaded joints in thermosetting resin piping shall conform to the following requirements:

(a) Threads shall be factory cut or molded on pipe ends and in matching fittings, with allowance for thread depth in accordance with para. N-104.1.1.

(b) Threading of plain ends of piping is not permitted, except where such male threads are limited to the function of forming a mechanical lock with matching female threads during bonding.

(c) Factory-cut or molded threaded nipples, couplings, or adapters bonded to plain end components may be used where necessary to provide connections to threaded metallic piping.

N-115 FLARED LINING JOINTS FOR METALLIC PIPING LINED WITH NONMETALS

The following apply:

(a) Welding. Welding is not permitted on lined components in the field. Welding performed by the manufacturer to produce pipe, fittings, and flanges to be used for joints in elastomeric-lined piping systems shall be performed so as to maintain the continuity of the lining and its serviceability.

(b) Flared Linings

(1) General. Flared ends of linings made in accordance with the rules in this paragraph may be used, subject to material limitations.

(2) Specific Requirements. Flaring shall be limited to applications that do not affect the serviceability of the lining.

N-116 BELL END JOINTS

Paragraph 116 applies.

N-118 PROPRIETARY JOINTS

Metal coupling, mechanical, gland, and other proprietary joints may be used within the limitations on materials in Part 3 of this Chapter.

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2 The polyolefin group of materials includes polyethylene, polypropylene, and polybutylene.
PART 5
EXPANSION, FLEXIBILITY, AND PIPE-SUPPORTING ELEMENTS

N-119 EXPANSION AND FLEXIBILITY

N-119.1 General Concepts

N-119.1.1 Elastic Behavior. The concept of piping strain imposed by the restraint of thermal expansion or contraction, and by external movements, applies in principle to nonmetals. Nevertheless, the assumption that stresses can be predicted from these strains in a nonmetallic piping system, based on the linear elastic characteristics of the material, is generally not valid. The variation in elastic characteristics between otherwise similar material types, between source manufacturers, and between batch lots of the same source material can at times be significant. If a method of flexibility analysis that assumes elastic behavior is used, the designer must be able to demonstrate its validity for the system and must establish conservative limits for the computed stresses.

N-119.1.2 Overstrained Behavior. Stresses cannot be considered proportional to displacement strains in nonmetallic piping systems where an excessive level of strain may be produced in a localized area of the system and in which elastic behavior of the piping material is uncertain (see unbalanced systems in para. 119.3). Overstrain must be minimized by effective system routing to avoid the necessity of a requirement for special joints or expansion devices for accommodating excessive displacements.

N-119.1.3 Progressive Failure. In thermoplastics and some thermosetting resins, displacement strains are not likely to produce immediate failure of piping, but may produce unacceptable distortion. Thermoplastics, particularly, are prone to progressive deformation that may occur upon repeated thermal cycling or under prolonged exposure to elevated temperature.

N-119.1.4 Brittle Failure. In brittle thermosetting resins, the materials are essentially rigid in behavior and may readily develop high displacement stresses, to the point of sudden breakage or fracture, under moderate levels of strain.

N-119.5 Flexibility

N-119.5.1 Piping systems shall have sufficient flexibility to prevent the effects of thermal expansion or contraction, the movement of pipe supports or terminal points, or pressure elongation from causing
(a) failure of piping or supports from overstrain or fatigue
(b) leakage at joints
(c) unacceptable stresses or distortion in the piping or in connected equipment

N-119.5.2 Where nonmetallic piping and components are used, piping systems shall be designed and routed so that flexural stresses resulting from displacements due to expansion, contraction, and other causes are minimized. This concept requires special attention for supports and restraints, for the terminal connections, and for the techniques outlined in para. 119.5.1. Further information on the design of thermoplastic piping can be found in PPI TR-21.

N-119.5.3 For metallic piping lined with nonmetals, the designer must consider the integrity of the lining in designing for piping flexibility. This is a special consideration for linings that are less flexible than the metallic piping, e.g., glass or ceramics.

N-119.6 Properties for Flexibility Analysis

N-119.6.1 Thermal Expansion Data. Table N-119.6.1-1 lists coefficients of thermal expansion for several nonmetallic materials. More-precise values in some instances may be obtained from the manufacturers of these materials. If the values are to be used in stress analysis, the thermal displacements shall be determined as indicated in para. 119.

N-119.6.2 Modulus of Elasticity. Table N-119.6.2-1 lists representative data on the tensile modulus of elasticity, $E$, for several nonmetals. More-precise values in some instances may be obtained from the manufacturers of these materials. (Note that the modulus may vary with the geometrical orientation of a test sample for filler-reinforced, filament-wound, or impregnated nonmetallic materials.) For materials and temperatures not listed, refer to an authoritative source, e.g., publications of the National Institute of Standards and Technology.

N-119.6.3 Poisson's Ratio. For nonmetals, Poisson's ratio will vary widely, depending on materials and temperature. For that reason, formulas used in linear elastic stress analysis can be used only if the manufacturer has test data to substantiate the use of a specific Poisson's ratio for that application.

N-119.6.4 Dimensions. The nominal thickness and outside diameters of pipe and fittings shall be used in flexibility calculations.

N-119.6.5 Metallic Pipe Lined With Nonmetals. Flexibility and stress analysis for metallic pipe lined with nonmetals shall be in accordance with para. 119, except that any limitations on allowable stresses or moments recommended by the manufacturers of the lined pipe shall be observed.
N-121.1 Support or restraint loads shall be transmitted to piping attachment or bearing points in a manner that will preclude pipe-wall deformation or damage. Padding or other isolation material should be installed in support or restraint clearance spaces for added protection.

N-121.2 Valves and in-line components should be independently supported to prevent the imposition of high load effects on the piping or adjacent supports.

N-121.3 Nonmetallic piping should be guarded where such systems are exposed to casual damage from traffic or other work activities.

N-121.4 A manufacturer’s recommendations for support shall be considered.

N-121.11 Thermoplastic and RTR Piping

Supports shall be spaced to avoid excessive displacement at design temperature and within the design life of the piping system. Decreases in the modulus of elasticity with increasing temperature, and creep of the material with time shall be considered where applicable. The coefficient of thermal expansion of most plastic materials is high and must be considered in the design and location of supports and restraints.

N-121.12 Burial of Thermoplastic and RTR Pipe

N-121.12.1 Design. Buried pipe design requires consideration of burial depth, soil type, and compaction to determine the external loads on the pipe. For AWWA C900 PVC pipe, AWWA Manual M23 outlines applicable design procedures for water utility service. For AWWA C950 RTR pipe, AWWA Manual M45 outlines similar procedures. It is the designer’s responsibility to verify that the procedures are applicable for other services and piping materials. Minimum pipe stiffness for RTR pipe shall meet the requirements of AWWA C950 for 5% deflection. The minimum stiffness shall be determined at 5% deflection using the apparatus and procedures of ASTM D2412.

N-121.12.2 Installation. The pipe manufacturer’s recommendations shall be equal to or more stringent than those described in ASTM D3839 for RTR pipe or ASTM D2774 for thermoplastic pipe. The manufacturer’s recommendations shall be followed.

PART 6
SYSTEMS

N-122 DESIGN REQUIREMENTS PERTAINING TO SPECIFIC PIPING SYSTEMS

The use of nonmetallic piping materials and components, under the scope of this Appendix, shall be limited to those services and conditions stated in para. 100.1.2 or specifically permitted in this section. In addition

(a) nonmetallic materials shall not be used under severe cyclic conditions unless it can be demonstrated that the materials are suitable for the intended service in accordance with para. N-104.7.

(b) these materials shall be appropriately protected against transient or operating temperatures and pressures beyond design limits, and shall be adequately protected against mechanical damage.
limitations on the use or application of materials in this Appendix apply to pressure-containing parts. They do not apply to the use of materials for supports, linings, gaskets, or packing.

**N-122.7 Piping for Flammable or Combustible Liquids**

**N-122.7.1** Polyethylene and reinforced thermosetting resin pipe may be used for flammable or combustible liquids in buried installations only. The fluid temperatures shall not exceed 140°F (60°C) and pressures shall be limited to 150 psig [1.035 MPa (gage)]. Particular care must be exercised to prevent damage to RTR piping at the connection to the main or other facility. Precautions shall be taken to prevent crushing or shearing of RTR piping due to external loading or settling of backfill and to prevent damage or pullout from the terminal connection resulting from thermal expansion or contraction.

RTR piping may terminate above ground and outside a building, provided that

(a) the aboveground portion of the RTR pipe is completely enclosed in a conduit or casing of sufficient strength to provide protection from external damage and deterioration. Where a flexible conduit is used, the top of the riser must be attached to a solid support. The conduit or casing shall extend a minimum of 6 in. (150 mm) below grade.

(b) the RTR pipe is not subjected to excessive stresses due to external loading.

**N-122.8 Piping for Flammable Gases, Toxic Gases or Liquids, or Nonflammable Nontoxic Gases**

**N-122.8.1** Polyethylene pipe may be used for natural gas service in buried installations only. The fluid temperatures shall not exceed 140°F (60°C) nor be below −20°F (−29°C), and pressures shall be limited to 100 psig [0.690 MPa (gage)]. Pipe joints shall be heat fused in accordance with a Bonding Procedure Specification meeting the requirements of para. N-127.

**N-122.9 Piping for Corrosive Liquids and Gases**

**N-122.9.1** For nonmetallic piping used to convey corrosive or hazardous liquids or gases in accordance with para. 122.9, the design shall meet the requirements of para. N-104.7.2, in addition to the materials limitation requirements of para. N-124.9.

**N-122.9.2** Aboveground nonmetallic piping conveying corrosive or hazardous fluids shall be installed in a guarded manner that will prevent damage during construction, operation, or service.

**N-122.9.3** For metallic piping lined with nonmetals used to convey corrosive or hazardous liquids or gases in accordance with para. 122.9, the design shall meet the requirements of para. N-104.7.2.
Chapter N-V
Fabrication, Assembly, and Erection

N-127 BONDING PLASTIC JOINTS

N-127.1 General

N-127.1.1 Bonded joints that conform to this Chapter may be used in accordance with para. N-111.

N-127.1.2 Production joints shall be made only in accordance with a written Bonding Procedure Specification (BPS) that has been qualified in accordance with para. N-127.5.

N-127.1.3 Production joints shall be made only by qualified bonders or bonding operators who have satisfactorily passed a performance qualification test that has been performed in accordance with a written BPS, in accordance with para. N-127.5.

N-127.1.4 Qualification in one BPS does not qualify a bonder or bonding operator for any other bonding procedure.

N-127.1.5 Bonding materials that have been deteriorated by exposure to air or prolonged storage, or that will not spread smoothly, shall not be used.

N-127.1.6 Longitudinal joints are not within the scope of this paragraph.

N-127.1.7 Joint Identification. Each qualified bonder and bonding operator shall be assigned an identification symbol. Unless otherwise specified in the engineering design, each pressure-containing bond or adjacent area shall be stenciled or otherwise suitably marked with the identification symbol of the bonder or bonding operator. Identification stamping shall not be used and any marking paint or ink shall not be detrimental to the piping material. In lieu of marking the bond, appropriate records shall be filed.

N-127.5 Qualification

N-127.5.1 General. Qualification of the BPS to be used, and of the performance of bonders and bonding operators, is required. The BPS shall specify, for both the bonding operation and qualification testing requirements, all required materials, including material storage requirements; the fixtures and tools required, including the care and handling of tools; the environmental (e.g., temperature and humidity) requirements for all operations, including the methods required for measurement; joint preparation requirements; dimensional requirements and tolerances; cure time; protection of work requirements; tests and examinations other than those required by para. N-127.5.3(c)(2); and acceptance criteria for the completed test assembly.

N-127.5.2 Bonding Responsibility. An employer of bonding personnel is responsible for the bonding done by members of his/her organization and, except as provided in para. N-127.5.3, shall conduct the required performance qualification tests to qualify BPSs and the bonders or bonding operators.

N-127.5.3 Qualification by Others

(a) BPS. Each employer (e.g., piping fabricator or erector) shall be responsible for qualifying any BPS that personnel of his/her organization will use. Subject to the specific approval of the owner, a BPS qualified by others may be used if the following conditions apply:

1. The owner, or his/her agent, accepts that the proposed qualified BPS has been prepared and executed by a responsible recognized organization with expertise in the field of bonding.

2. The employer accepts both the BPS and Procedure Qualification Record (PQR) by signature as his/her own.

3. The employer has at least one bonder, currently employed, who has satisfactorily passed a performance qualification test using the proposed qualified BPS.

(b) Bonding Performance Qualification. An employer shall not accept a performance qualification test made by a bonder or bonding operator for another employer without the owner’s specific approval. If approval is given, acceptance is limited to performance qualification tests on piping using the same or an equivalent BPS. The employer accepting such performance qualification tests shall obtain a copy of the PQR from the previous employer, showing the name of the piping employer by whom bonders or bonding operators were qualified, the dates of such qualification, and the date the bonder or bonding operator last assembled pressure piping under the previous performance qualification.

(c) Qualification tests for the bonding procedure and operator performance shall comply with the requirements of the BPS and the following:
(1) A test assembly shall be fabricated in accordance with the BPS. The test assembly shall consist of at least one pipe-to-pipe joint and one pipe-to-fitting joint. The size of the pipe used for the test assembly shall be as follows:

(a) When the largest size to be joined (within the BPS) is NPS 4 (DN 100) or smaller, the test assembly shall be the same NPS as the largest size to be joined.

(b) When the largest size to be joined within the BPS is greater than NPS 4 (DN 100), the test assembly shall be made of piping components either NPS 4 (DN 100) or a minimum of 25% of the NPS of the largest piping component to be joined, whichever is larger.

(2) The test assembly shall be subjected to one of the following qualification test operations:

(a) When the test assembly has been cured, it shall be subjected to a hydrostatic pressure test of the maximum of either 150 psig [1.035 MPa (gage)] or 1.5 times an equivalent allowable pressure, which shall be calculated using the least nominal wall thickness and outside diameter of the pipe in the test assembly. This pressure shall be determined using the equation in para. N-104.1.2(a) for the test material. The test shall be conducted so that the joint is loaded in both the circumferential and longitudinal directions. Joints shall not leak or separate when tested.

(b) When a test assembly is joined by heat fusion, the fusion joints may be tested by cutting a minimum of three coupons containing the joint and bending the strips using a procedure that shall be defined in the BPS. As a minimum requirement, the test strips shall not break when bent a minimum of 90 deg, at ambient temperature, over an inside bend radius of 1.5 times the nominal diameter of the tested pipe.

(d) Performance Requalification

(1) Renewal of a bonding performance qualification is required when

(a) a bonder or bonding operator has not used the specific bonding process for a period of time greater than 6 months, or a specific maximum period of time otherwise permitted in the BPS for the work

(b) there is a specific reason to question a bonder’s or bonding operator’s ability to make bonds that meet the BPS

(2) Renewal of a bonding performance qualification for a specific bonding process may be made in only a single test assembly.

N-127.6 Qualification Records

An erector using bonders or bonding operators shall maintain a record of the procedures used and of operators employed by him/her who are qualified in these procedures.

N-127.7 Thermoplastic Pipe Joints

N-127.7.1 Solvent-Cemented Joints

(a) Preparation. PVC and CPVC surfaces to be cemented shall be cleaned by wiping with a clean cloth moistened with acetone or methyl ethyl ketone. Cleaning for ABS shall conform to ASTM D2235. Cuts shall be free of burrs and circumferential cuts shall be as square as those obtained by the use of a saw with a mitre box or a square-end sawing vise. A slight interference fit between the pipe and a fitting socket is preferred, and the diametral clearance between a pipe and the entrance of a mating socket shall not exceed 0.04 in. (1.0 mm). This fit shall be checked before solvent cementing.

(b) Procedure. Joints shall be made in accordance with a qualified BPS. ASTM D2855 provides a suitable basis for such a procedure. Solvent cements for PVC, CPVC, and ABS shall conform to ASTM D2564, ASTM D2846, and ASTM D2235, respectively. Cement shall be sufficient to produce a small continuous fillet of cement at the outer limits of the joints. See Figure N-127.7.1-1.

(c) Branch Connections. For branch connections not using a tee, a manufactured full reinforcement saddle with an integral branch socket shall be solvent cemented to the run pipe over its entire contact surface.

(d) Limitations on Imperfections. Imperfections exceeding the following limitations are considered defects and shall be repaired and reexamined in accordance with para. N-127.7.3:

(1) protrusion of dried cement exceeding 50% of pipe wall thickness into the bore of the pipe

(2) unfilled or unbonded areas in a joint, as indicated by the lack of interruption of the continuous fillet noted in (b)
N-135 ASSEMBLY AND ERECTION

N-135.1 General

The assembly and erection of nonmetallic piping systems shall comply with the requirements of para. 135 and this Chapter. In addition

(a) when assembling nonmetallic flanges, flat washers shall be used under all bolt heads and nuts. The specified maximum bolt torque shall not be exceeded.

(b) full circumference wrenches shall be used to tighten threaded pipe joints. Tools and other devices used to hold or apply forces to the pipe shall be such that pipe surfaces are not scored or deeply scratched. For thermosetting resin piping, threads shall be coated with sufficient adhesive to cover the threads and completely fill the clearance between the pipe and fittings.

N-135.3 Bolted Flanged Connections

N-135.3.5 Flaring of Nonmetallic Linings. The provisions of this paragraph apply to metallic pipe lined with plastic or other flexible material. To prevent the fluid from contacting the metallic piping where the lining must be interrupted at a field-installed flanged joint, the metal piping shall be trimmed so that the end of the lining projects beyond the face of the flange. The projecting lining shall then be flared back so that it covers a portion of the flange face, in a manner similar to a lap joint. When the flange is made up, the corresponding flared ends shall be pressed together, forming a seal.

(a) This paragraph applies only to the flaring of linings in pipe that has previously been lined with nonmetals.

(b) Flaring that conforms to this paragraph may be used in accordance with para. N-115(b).

(c) Flaring shall be performed only in accordance with a written flaring procedure specification, and only by qualified operators who have appropriate training or experience in the use of the applicable flaring procedures.
(4) Perform a random visual examination during erection of piping, including checking of alignment and supports.

(5) Examine erected piping for evidence of damage that would require repair or replacement and for other deviations from the design.

(b) Minimum acceptance criteria shall be as indicated in Table N-136.4.1-1.

(c) The inspector shall be assured, by examination of certifications, records, or other evidence, that the materials and components are of the specified grades and that they have received the required examination and testing.

(d) When examination reveals a defect requiring repair

(1) two additional examinations of the same type shall be made of the same kind of item (if of a bond, others by the same bonder or bonding operator), and

(2) if the additional items examined as required by (1) are acceptable, the item requiring repair shall be replaced or repaired and reexamined to meet the requirements of the Code, and all items represented by this additional examination shall be accepted, or

(3) if either of the items examined as required by (1) reveals a defect, two additional items shall be examined, and

(4) if the additional items examined as required by (3) are acceptable, the items requiring repair shall be replaced or repaired and reexamined to meet the requirements of the Code, and all items represented by this additional examination shall be accepted, or

(5) if either of the additional items examined as required by (3) reveals a defect, all comparable items shall be replaced or they shall be fully examined, and all items requiring repair shall be repaired and reexamined to meet the requirements of the Code.

N-136.4.2 Visual Examination

(a) Visual examination consists of observation of the portion of components, joints, and other piping elements that are, or can be, exposed to view before, during, or after manufacture, fabrication, assembly, erection, inspection, or testing.

(b) Visual examination shall be performed in accordance with ASME BPVC, Section V, Article 9.

N-137 PRESSURE TESTS

Leak tests, when specified, shall be performed in accordance with para. 137.

<table>
<thead>
<tr>
<th>Kind of Imperfection</th>
<th>Thermoplastic</th>
<th>RTR and RPM [Note (1)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crazes</td>
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<td>Not-applicable</td>
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<tr>
<td>Unfilled areas in joint</td>
<td>None permitted</td>
<td>None permitted</td>
</tr>
<tr>
<td>Unbonded areas in joint</td>
<td>None permitted</td>
<td>None permitted</td>
</tr>
<tr>
<td>Inclusions of charred material</td>
<td>Not-applicable</td>
<td>Not-applicable</td>
</tr>
<tr>
<td>Unfused filler material inclusions</td>
<td>Not-applicable</td>
<td>Not-applicable</td>
</tr>
<tr>
<td>Protrusion of material into pipe bore, % of pipe wall thickness</td>
<td>Cement, 50%</td>
<td>Fused material, 25%</td>
</tr>
</tbody>
</table>

NOTE: (1) RTR = reinforced thermosetting resin; RPM = reinforced plastic mortar.
MANDATORY APPENDIX Q
QUALITY MANAGEMENT PROGRAM REQUIREMENTS FOR METALLIC NONBOILER EXTERNAL PIPING-COVERED PIPING SYSTEMS (NBEP-CPS)

FOREWORD
This Appendix contains the requirements of a documented quality management program for metallic NBEP-CPS. This program shall be used to document the design, materials, fabrication, examination, assembly, erection, testing, and inspection of these piping systems. The program includes vent, instrumentation, drain, and other piping connected to the NBEP-CPS up to the first circumferential welded joint, threaded joint, flange face, or other sealing surface from the NBEP-CPS. (See para. 100.2 and Chapter VII for a definition of and additional requirements for CPS.)

Q-1 RESPONSIBILITIES
The following shall be considered “relevant parties” as used in this Appendix: owner (or its designee), designer, component manufacturer, fabricator, installer, and inspector(s). The relevant parties have responsibilities for meeting the requirements of this Code. These requirements include, as applicable, design, materials, fabrication, examination, erection, testing, and inspection of piping. The responsibilities set forth in this Appendix relate only to compliance with this Code.

It shall be the responsibility of the relevant parties completing the Certificate of Compliance Forms established in Mandatory Appendix R (CCR-3-1 or CCR-3-2) to have and maintain a documented quality management program which will establish that all Code requirements, applicable to their responsibility, have been met. With the exception of the owner, the relevant parties completing Forms CCR-3-1 and CCR-3-2 shall maintain a copy of their supporting records incorporated into the Piping System Final Report (PSFR) described in Mandatory Appendix R for a minimum of 5 years after the PSFR has been certified.

Q-1.1 Owner. The owner is responsible for providing a design basis document that contains the complete basis for design and construction of a facility’s piping system in accordance with this Code. The owner shall ensure that the facility where the piping system is located, maintains a complete and up-to-date copy of the PSFR, supporting records, and associated Forms CCR-3-1 and CCR-3-2 for the life of the piping system.

Q-1.2 Designer. The designer is responsible for the overall design of the piping system, which includes but is not limited to:
(a) defining the design conditions and selecting material
(b) performing calculations to show the pressure-retaining integrity of the pipe and piping components
(c) specifying special requirements. Special requirements may include those for the purchasing of material; fabrication of assemblies; and installation, examination, and testing of the completed piping system.
(d) providing calculations, drawings, and specifications for the purchasing, fabrication, examination, and installation of piping materials, such that the final piping system will meet the requirements of this Code and any supplemental requirements defined by the owner.

Q-1.3 Component Manufacturer. The component manufacturer is responsible for:
(a) producing pipe and piping components in accordance with specifications allowed in this Code, and any additional requirements specified by the designer, the owner, or both.
(b) providing Material Test Reports or material Certificates of Conformance and all other documentation to ensure the pipe and piping components can be directly traceable as defined in the Code and in this Appendix.
When the design of specially designed components is deferred by the designer or owner, the component manufacturer shall be responsible to provide design calculations and documentation necessary to show the components’ compliance with para. 104.7.2.

Q-1.4 Fabricator. The fabricator is responsible for:
(a) joining two or more manufactured components or piping sub-assemblies into piping sub-assemblies to be used by the installer for the erection of the final piping system.
(b) ensuring conformance of the materials received from the component manufacturer; appropriately installing them into piping sub-assemblies;
(c) performing fabrication processes such as bending and forming, welding and heat treatments;
(d) performing cleaning operations in accordance with specifications supplied by the designer and owner;
(e) performing examination and testing in accordance with the Code and specifications supplied by the designer, the owner, or both;
(f) preparing the subassemblies for shipment to the installation location.

The fabricator may also be responsible for certain design activities deferred by the designer such as the development of subassembly detail drawings (i.e., spool drawings), final selection of specific piping components, selection of final purchased material to meet the design requirements after performing fabrication processes, or calculations for branch reinforcement.

Q-1.5 Installer. The installer (may also be referred to as the erector, assembler, or contractor) is responsible for:
(a) installation of pipe, piping components, and piping sub-assemblies into an entire piping system at its final installed location, including installation of pipe supports and other accessories as designated by the designer.
(b) confirming compliance of the materials received from the fabricator
(c) installing the piping sub-assemblies and pipe supports and other accessories;
(d) performing processes such as welding and heat treatments;
(e) performing cleaning operations in accordance with specifications supplied by the designer and the owner;
(f) performing examination and testing in accordance with the Code, and any additional requirements provided by the specifications supplied by the designer, the owner, or both.

If during the installation of the piping system, it is discovered that it is not in accordance with the design drawings, the relevant parties shall resolve these variations as nonconformities in accordance with their quality management program. Any actual changes, resultant from these resolved variations, shall be incorporated into the installation drawings and submitted to the designer (for record purposes only) and the owner for approval prior to being incorporated into the PSFR.

Q-1.6 Inspector. The inspector(s) for each relevant party, as applicable, are responsible for:
(a) inspecting that portion of the work their organization performs to ensure it complies with the design, material, assembly, installation, examination, and testing requirements of this Code.
(b) confirming compliance with additional specified requirements.

The inspector for the Installer shall ensure that the PSFR includes all required documentation and applicable CCR-3-2 Forms for the report prior to signing the appropriate sections of Form CCR-3-1 for the complete piping system.

Q-1.6.1 Owner’s Inspector. The owner’s inspector (see para. 136.1.4) shall ensure that the design and construction documents and the requirements of this Code have been complied with in accordance
with the owner's requirements. Upon request, the owner's inspector shall have access to any relevant party's quality management program and calculations or documentation attesting to compliance with this Code. The owner's inspector shall:
(a) verify that the piping system conforms to the design layout (including that supports are located correctly and are of the type specified in the design documents).
(b) review the documentation to verify that the subassemblies, assemblies, or complete piping system have been properly described on the appropriate Forms CCR-3-1 or CCR-3-2 and sign the final acceptance of Form CCR-3-1.

Q-2 QUALITY MANAGEMENT PROGRAM

Q-2.1 General. Each relevant party shall have and maintain a current, documented quality management program covering the processes for which the party is responsible. These programs shall establish that all Code requirements will be met for the material, design, fabrication, assembly, examination, and inspection of the piping systems as appropriate to the relevant parties. The Quality Management System may be supported by additional procedures documenting methods of nondestructive examination, heat treatment, welding, etc.

The quality management program shall be suitable to the relevant party’s specific circumstances. The necessary scope and detail of the quality management program shall depend on the complexity of the work performed and, on the size, and complexity of the organization performing the work. Each relevant party shall prepare a written description of its quality management program which shall be available for review at the owner’s request.

The written description may contain proprietary information related to the relevant party’s processes. Therefore, the Code does not require any distribution of this information, except as requested by the owner or the owner’s inspector. The owner or owner’s inspector shall treat as confidential any proprietary information revealed during evaluation of a quality management program.

For a program to be considered current, the relevant party shall establish a triennial review of the quality management program and make any updates or changes as necessary to ensure the program is effectively being utilized and maintained. This review shall be certified by the relevant party’s authorized representative.

Q-2.2 Features to Be Included in the Written Description of the Quality Management Program. The written description of the quality management program shall cover the applicable features described in paras. Q-2.2.1 through Q-2.2.11.

Q-2.2.1 Authority and Responsibility. The authority and responsibility of the individuals in charge of the quality management program shall be clearly established. Persons performing quality management functions shall have the responsibility, authority, and organizational freedom to identify quality management problems and to initiate, recommend, and provide solutions.

Q-2.2.2 Organization. An organization chart shall illustrate the relationship between management and engineering, purchasing, manufacturing, field assembling, inspection, and quality management. The purpose of this chart is to identify the various organizational groups and associate them with the function for which they are responsible. This Code does not limit the relevant parties’ right to establish and alter whatever form of organization they consider appropriate for their Code work.

Q-2.2.3 Control of Drawings, Design Documentation, Calculations, and Specifications. The quality management program shall provide revision-control procedures that ensure the relevant party uses the latest applicable requirements in the design, manufacture, assembly, examination, inspection, and testing of the piping system. These procedures shall include numbering or otherwise tracking revisions to design basis requirements, design calculations, specifications, and other design control documentation for the piping systems.

Q-2.2.4 Material Control. The material control system shall ensure that only material which conforms to the design specifications and is traceable to specific Material Test Reports or Certificates of
Conformance (only if allowed by the material specification) is used in the construction of metallic NBEP-CPS.

**Q-2.2.5 Examination and Inspection Program.** The quality management system shall specify how the plan for the required examinations, inspections, and testing will be documented. Documentation may be in the format of a shop traveler, inspection and test plan, or similar document. These documents shall be formatted to provide the owner with adequate information to determine that all requirements as defined by the owner or designer are incorporated.

**Q-2.2.5.1 Nondestructive Examination.** The quality management program shall identify the nondestructive examination procedures used to conform with the requirements of this Code.

**Q-2.2.5.2 Calibration of Measurement and Test Equipment.** The relevant parties shall demonstrate the calibration of examination, measuring, and test equipment used in fulfillment of requirements of this Code are maintained.

**Q-2.2.6 Correction of Nonconformances.** A nonconformance is any condition that does not comply with the applicable rules of this Code and the design specification. Nonconformances shall be corrected to the owner’s satisfaction before the completed component, assembly, or installation can be considered compliant with this Code.

**Q-2.2.7 Welding.** The quality management program shall demonstrate that welding used to manufacture, assemble, and install metallic NBEP-CPS meet the requirements of this Code and ASME BPVC, Section IX.

**Q-2.2.8 Heat Treatment.** The quality management program shall specify controls to ensure that heat treatments required by the rules of this Code or supplemental specifications are applied. The heat treatment records shall be made available to the owner or designer upon request, to verify that the Code or supplemental heat treatment specifications have been met.

**Q-2.2.9 Records Retention.** Each relevant party shall have a records retention policy that meets or exceeds the requirements of Section Q-2 for the documentation developed during its work on the metallic NBEP-CPS. This documentation, as applicable, shall include the following:

- (a) design-basis requirements
- (b) design calculations
- (c) drawings
- (d) specifications (design, procurement, and erection as applicable)
- (e) material certifications and test reports
- (f) welding records
- (g) heat treatment records
- (h) examination and testing reports

**Q-2.2.10 Sample Forms.** The written description of the quality management program shall include examples of any forms required by the program.

**Q-2.2.11 Inspection of Pipe, Piping Components, Assemblies, and Installation.** The quality management system shall address the right of access of the owner’s inspector to inspect on behalf of the owner as required by para. 136.1.4. The relevant party shall allow the owner’s inspector to review, either at a facility or construction site, the following:

- (a) a copy of the written description of the current quality management program
- (b) drawings and calculations
- (c) specifications, procedures, and process sheets
- (d) test results
- (e) any other documents necessary for the inspector to perform these duties in accordance with this Code.
MANDATORY APPENDIX R
DOCUMENTATION, RECORDS AND REPORT REQUIREMENTS FOR METALLIC NONBOILER EXTERNAL PIPING-COVERED PIPING SYSTEMS (NBEP-CPS)

R-1 PIPING SYSTEM FINAL REPORT (PSFR)

R-1.1 General. Each metallic NBEP-CPS shall have an associated PSFR. The PSFR shall reference the design basis requirements, design calculations, drawings, specifications, material certifications and test reports, welding requirements, heat treatment records, examination and testing reports, and other pertinent documentation. Unless specifically required by the owner, the PSFR does not require the complete documents to be compiled as part of the report, but the document numbers, revisions, and other identifying information shall be clearly identified in the report. In accordance with the requirements of Chapter VII, all documentation cited in the PSFR shall be provided to the owner (or its designee whenever reference to “the owner” is used in this Appendix) prior to the operation of the piping system.

More than one PSFR may be developed for a specific system when there is a basis for such a separation as determined by the owner or designer.

R-1.2 Content of the PSFR. Paras. R-1.2.1 through R-1.2.11 describe the minimum content that shall be included, as applicable, in a PSFR. The contents of the report may be initially assembled by the designer based on information from the owner and design documentation developed by designer, and then transferred to the installer for the inclusion of other documents from the component manufacturer(s), assembler(s), and installer prior to final submission to the owner or designer.

R-1.2.1 Certificates of Compliance. The PSFR shall include Forms CCR-3-1 and CCR-3-2. Form CCR-3-1 shall be used to document that the completed piping system or subsystem complies with this Code. Form CCR-3-2 shall be used to document the Code compliance of non-standard piping components (see para. 126.2), subassemblies, and assemblies of the piping system produced by other than the signers of Form CCR-3-1.

R-1.2.2 Design Basis Requirements.
   (a) design code
   (b) supplemental requirements

R-1.2.3 Design Calculations or Qualification Methods.
   (a) design temperature, pressure, and sizing of components required by the Code
   (b) pipe stress analysis
   (c) specially designed components according to para. 104.7.2

R-1.2.4 Drawings.
   (a) piping design drawings, erection drawings
   (b) pipe support design drawings
   (c) spool and other pressure part shop drawings
   (d) pipe support shop drawings
R-1.2.5 Purchase Specifications.
   (a) piping material purchase or fabrication specifications
   (b) pipe support purchase or fabrication specifications
   (c) piping system erection specification, including insulation and refractory.

R-1.2.6 Material Test Reports or Certificates of Conformance.
   (a) pressure part base materials traceable to the component
   (b) electrodes, filler metals, and consumables

R-1.2.7 Bending and Forming Operations.
   (a) bending/forming procedures
   (b) bending/forming heat treatment records
   (c) bending/forming dimensional records

R-1.2.8 Welding / Postweld Heat Treatment Operations.
   (a) welding procedure specifications (WPS) traceable to the joint
   (b) welding examination log or welding map - that shows which welder or welding operator performed the welds throughout the piping system
   (c) preheat and postweld heat treatment records traceable to the joint

R-1.2.9 Inspection, Examination and Testing Reports

R-1.2.10 Other Documentation Prior to Initial Startup
   (a) records of position settings for all spring supports and snubbers
   (b) reports for flushing, cleaning, or other significant startup activities

R-1.2.11 Nonconformances

R-2 MARKING.
   Each part, subassembly or assembly listed on a Form CCR-3-2 shall be marked with low stress stamps or other permanent marking system. The name or trademark of the assembler and all identifying numbers shall be directly traceable to Form CCR-3-2.
   Each completed piping system shall have an identifier that shall be directly traceable to Form CCR-3-1. This permanent identification may be marked in accordance with ASME A13.1 and shall be visible on the finished piping system.

R-3 CERTIFICATE OF COMPLIANCE FORMS.
   See Forms CCR-3-1 and CCR-3-2 and related Tables CCR-3-1 and CCR-3-2 on the following pages.
PSFR FORM CCR-3-1 CERTIFICATE OF COMPLIANCE FOR THE COMPLETE PIPING SYSTEM
(As Required by the Applicable Rules of ASME B31.1)

### DESCRIPTION OF INSTALLATION

| Item | 
|------|---|
| 1 | Form CCR-3-1 Identification Number |
| 2 | **Owner**  
(Name and Address) |
| 3 | **Location of Installation**  
(Plant Name, Address, Building) |
| 4 | **Description of Piping System**  
(Type of Service) |
| 5 | **Design Code**  
(Code Section, Year) |
| 6 | **Supplemental Requirements**  
(Code Cases, Special Requirements) |
| 7 | **Materials of Construction**  
(ASTM Specifications, Piping Specs) |
| 8 | **Design Pressure and Temperature** |
| 9 | **Pipe Size and Schedules/Wall** |
| 10 | **Quality Management Program(s)**  
(Organization, Document, Revision) |
| 11 | **Piping System Final Report**  
(Document Number, Revision) |
| 12 | **List of Applicable CCR-3-2 Forms** |
| 13 | **List of Material Test Reports / Material Certificates of Conformance Not Listed on Separate CCR-3-2 Form** |
| 14 | **List of Pipe Supports, Anchors, and Guides**  
(Support ID, Document Number, Revision, etc.) |
| 15 | **Final Testing.**  
(Method, Pressure, Date) |
| 16 | **Remarks.** |

17. CERTIFICATION OF PIPING SYSTEM REQUIREMENTS

I, _____________________, certify to the best of my knowledge and belief, the information in items 1 through 6 applies to the owner’s installation and conforms with the requirements of ASME B31.1, Mandatory Appendix Q, para. Q-1.1.  I further certify that the owner accepts the piping system requirements listed in items 5 and 6.

(Owner Company Name)  
Date _____________________ Signed ____________________________________________  
(Authorized Representative of Owner)

18. CERTIFICATION OF DESIGN
I, _____________________, certify to the best of my knowledge and belief, the piping system has been designed and documented in accordance with the requirements of ASME B31.1, Mandatory Appendix Q, para. Q-1.2 and the supplemental requirements in item 6. I further certify that items 7 through 9 define the specified materials of construction and design conditions of the piping system, and the Quality Management Programs for all relative parties defined in Mandatory Appendix Q, para. Q-2 and item 10 address all processes necessary for the successful design and construction of the piping system.

____________________________________________________________________________

(Design Company Name and Address)  
Date _____________________ Signed ____________________________________________ 
(Authorized Representative of Design Company)

19. CERTIFICATION OF PIPING INSTALLATION
I, _____________________, certify to the best of my knowledge and belief, the piping system has been installed and tested in accordance with the requirements of ASME B31.1, Mandatory Appendix Q, para. Q-1.5 and the drawings and design documentation on which the above design certification is based. I further certify that the materials, fabricated components, assemblies, subassemblies, supports, anchors, and guides received from the component manufacturer(s) or assembler(s) and installed in the system are only those listed in items 11 through 14, the system has been successfully tested as indicated in item 15, and all relative documentation has been compiled in the final Piping System Final Report as required by para. R-1 and item 11.

____________________________________________________________________________

(Installer Company Name and Address)  
Date _________________ Signed _______________________________________________
(Authorized Representative of Piping Installer)

20. CERTIFICATION OF THE COMPLETE PIPING SYSTEM
We, ________________________________________, representing the organization listed in item 2 of this report, certify to the best of my knowledge and belief, the statements in this ASME CERTIFICATE OF COMPLIANCE to be correct and that all details of design, materials, construction, installation, inspection, testing and workmanship on the described piping conform to the ASME B31.1 Power Piping Code and supplemental requirements listed herein. We further certify that the complete and final Piping System Final Report has been provided in accordance with para. R-1 and item 11.

Date _________________ Signed ________________________________________________
(Owner’s Inspector)  
Date _________________ Signed ________________________________________________
(Authorized Representative of Owner)
Table CCR-3-1 Guide for Completing PSFR Form CCR-3-1 Certificate of Compliance for the Complete Piping System

<table>
<thead>
<tr>
<th>Item Number from Form CCR-3-1</th>
<th>Instructions</th>
<th>To Be Completed by</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Enter a unique number to identify the complete piping system.</td>
<td>Designer</td>
</tr>
<tr>
<td>2</td>
<td>Enter the name and address of the owner responsible for Code compliance of the complete piping system described on Form CCR-3-1.</td>
<td>Owner</td>
</tr>
<tr>
<td>3</td>
<td>Enter the location of installation. Provide address of the facility and the location within the facility where the complete piping system is installed.</td>
<td>Owner</td>
</tr>
<tr>
<td>4</td>
<td>Describe the piping system. State the function and its identification within the facility.</td>
<td>Designer</td>
</tr>
<tr>
<td>5</td>
<td>List the design Code applicable to the installation of the piping system. Include the edition and any applicable addenda.</td>
<td>Owner</td>
</tr>
<tr>
<td>6</td>
<td>Describe or list any requirements imposed by the owner to supplement the design Code(s). Include all applicable Code Case numbers and revision.</td>
<td>Owner</td>
</tr>
<tr>
<td>7</td>
<td>List the materials of construction ASTM, or other material specifications and grade/type. This does not need to provide a complete listing of all product forms used.</td>
<td>Designer</td>
</tr>
<tr>
<td>8</td>
<td>Specify design pressure and temperature of the piping system. If sections of the piping system have unique design pressures and temperatures, you may list the sections and their design pressures and temperatures here.</td>
<td>Designer</td>
</tr>
<tr>
<td>9</td>
<td>List the various pipe sizes and schedules or wall thicknesses used in the piping system.</td>
<td>Designer</td>
</tr>
<tr>
<td>10</td>
<td>List the various quality management programs indicated in Mandatory Appendix Q, para. Q-2.</td>
<td>Designer and Installer</td>
</tr>
<tr>
<td>11</td>
<td>List the title and revision of the completed Piping System Final Report as defined in para. R-1.</td>
<td>Designer and Installer</td>
</tr>
<tr>
<td>12</td>
<td>List the Form CCR-3-2 Certificates of Compliance for the fabricated parts, subassemblies, and assemblies installed in the complete piping system.</td>
<td>Installer</td>
</tr>
<tr>
<td>13</td>
<td>List the Material Test Reports or Certificates of Conformance for any materials not Listed in Item 12 of a Form CCR-3-2.</td>
<td>Installer</td>
</tr>
<tr>
<td>14</td>
<td>List pipe support identification numbers, support types, drawings, or other means to identify supports, anchors, and guides for materials that are not included in Item 11 or 12 on a Form CCR-3-2.</td>
<td>Installer</td>
</tr>
<tr>
<td>15</td>
<td>List the final hydrostatic, pneumatic, or initial service leak test pressure, or alternative NDE in lieu of such a test and the date which the test was performed.</td>
<td>Installer</td>
</tr>
<tr>
<td>16</td>
<td>Record any additional information relevant to the system.</td>
<td>Owner, Designer, or Installer</td>
</tr>
<tr>
<td>17</td>
<td>Enter the name of the authorized representative to sign on behalf of the owner along with the owner company name, and the date when signed.</td>
<td>Owner</td>
</tr>
<tr>
<td>18</td>
<td>Enter the name of the authorized representative to sign on behalf of the designer along with the designer company name and address, and the date when signed.</td>
<td>Designer</td>
</tr>
<tr>
<td>19</td>
<td>Enter the name of the authorized representative of the installer, the installer company name and address, and the date when signed.</td>
<td>Installer</td>
</tr>
<tr>
<td>20</td>
<td>The owner’s authorized representative shall sign the complete, certified form. If the owner’s inspector is a person other than the authorized representative, the owner’s inspector shall also sign the completed, certified form. The authorized representative and the owner’s inspector may be the same individual provided the requirements in Mandatory Appendix Q, para. Q-1.6.1 have been met.</td>
<td>Owner</td>
</tr>
</tbody>
</table>

Note: Where Lists are specified, alternative methods of reporting are acceptable (i.e., Piping Line Lists, ISO’s, BOM’s, etc.) These reports shall have a unique identification number and revision levels.
PSFR FORM CCR-3-2 CERTIFICATE OF COMPLIANCE FOR FABRICATED COMPONENTS, SUBASSEMBLIES, AND ASSEMBLIES
(As Required by the Applicable Rules of ASME B31.1)

<table>
<thead>
<tr>
<th>Item</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Form CCR-3-2 Identification Number</td>
</tr>
<tr>
<td>2.</td>
<td>Shop/Job/Contract Number</td>
</tr>
<tr>
<td>3.</td>
<td>Component Manufacturer or Assembler (Name and Address)</td>
</tr>
<tr>
<td>4.</td>
<td>Purchaser (Name of Purchaser)</td>
</tr>
<tr>
<td>5.</td>
<td>Description of Part, Subassembly, Assembly (Description of Part, Assembly, or Subassembly, Spool No.)</td>
</tr>
<tr>
<td>6.</td>
<td>Design Code(s) (Code Section, Year)</td>
</tr>
<tr>
<td>7.</td>
<td>Supplemental Requirements (Code Cases, Special Requirements)</td>
</tr>
<tr>
<td>8.</td>
<td>Materials of Construction (ASTM Specifications, Piping Specs)</td>
</tr>
<tr>
<td>9.</td>
<td>Design Pressure and Temperature</td>
</tr>
<tr>
<td>10.</td>
<td>Pipe Size and Schedules/Wall</td>
</tr>
<tr>
<td>11.</td>
<td>Quality Management Program(s) (Document, Revision)</td>
</tr>
<tr>
<td>12.</td>
<td>Reference Documentation (Drawings, WPS/PQR, Calculations, Qualification Test Reports, NDE, PWHT)</td>
</tr>
<tr>
<td>13.</td>
<td>List of Material Test Reports or Material Certificates of Conformance</td>
</tr>
<tr>
<td>14.</td>
<td>Shop Testing if Performed. (Method, Pressure, Date)</td>
</tr>
<tr>
<td>15.</td>
<td>Remarks</td>
</tr>
</tbody>
</table>

16. CERTIFICATION OF COMPLIANCE
I, _____________________________, representing the organization listed on item 3, certify to the best of my knowledge and belief, the statements in this report to be correct and that all details of material, construction, inspection, testing, and workmanship on the described fabricated components, subassemblies, or assemblies conform to the ASME B31.1 Power Piping Code and supplemental requirements listed herein.

Date _________________ Signed _______________________________________________
(Authorized Representative of the Component Manufacturer or Assembler)
## Table CCR-3-2 Guide for Completing PSFR Form CCR-3-2, Certificate of Compliance for Fabricated Components, Subassemblies, and Assemblies

<table>
<thead>
<tr>
<th>Item Number from Form CCR-3-2</th>
<th>Instructions</th>
<th>To Be Completed by</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Enter a unique number to identify the CCR-3-2 Form.</td>
<td>Fabricator</td>
</tr>
<tr>
<td>2</td>
<td>Enter the identification number assigned to the fabricated components, subassemblies or assemblies by the component manufacturer or assembler.</td>
<td>Fabricator</td>
</tr>
<tr>
<td>3</td>
<td>Enter the name and address of the organization manufacturing the part, subassembly, or assembly described on the form.</td>
<td>Fabricator</td>
</tr>
<tr>
<td>4</td>
<td>Enter the name of the organization purchasing the part, subassembly, or assembly.</td>
<td>Fabricator</td>
</tr>
<tr>
<td>5</td>
<td>Describe the components, subassemblies, or assemblies. For example, provide identifying spool or component number.</td>
<td>Fabricator</td>
</tr>
<tr>
<td>6</td>
<td>List the Standard or Code applicable to the components, subassemblies, or assemblies. Include the edition and any applicable addenda.</td>
<td>Fabricator</td>
</tr>
<tr>
<td>7</td>
<td>Describe any requirements imposed by the owner or designer to supplement the Standard or Code(s). Include all applicable Code Case numbers and revisions.</td>
<td>Fabricator</td>
</tr>
<tr>
<td>8</td>
<td>List the materials of construction ASTM, or other material specifications and grade/type.</td>
<td>Fabricator</td>
</tr>
<tr>
<td>9</td>
<td>Specify design pressure and temperature of the components, subassemblies, or assemblies.</td>
<td>Fabricator</td>
</tr>
<tr>
<td>10</td>
<td>List the pipe sizes and schedules or wall thicknesses used in the components, subassemblies, or assemblies.</td>
<td>Fabricator</td>
</tr>
<tr>
<td>11</td>
<td>List the quality management programs indicated in Mandatory Appendix Q, para. Q-2 used by the relevant parties involved with the design, manufacturing, or assembly of the components, subassemblies, or assemblies.</td>
<td>Fabricator</td>
</tr>
<tr>
<td>12</td>
<td>List any reference documentation associated with the components, subassemblies, or assemblies. This shall include drawings, WPS/PQRs, Calculations, Qualification Test Reports, bending/forming procedures, NDE, heat treatment procedures and records, as applicable to the component, subassembly, and assemblies.</td>
<td>Fabricator</td>
</tr>
<tr>
<td>13</td>
<td>List the Material Test Reports or Certificates of Conformance for any materials used for the components, subassemblies, or assemblies.</td>
<td>Fabricator</td>
</tr>
<tr>
<td>14</td>
<td>List the shop hydrostatic or pneumatic test pressure and the date which the test was performed. If such a test was not performed, state Not Pressure Tested.</td>
<td>Fabricator</td>
</tr>
<tr>
<td>15</td>
<td>Record any additional information relevant to the components, subassemblies, or assemblies.</td>
<td>Fabricator</td>
</tr>
<tr>
<td>16</td>
<td>The authorized representative of the organization listed in Item 3 shall sign and date the form.</td>
<td>Fabricator</td>
</tr>
</tbody>
</table>

Note: Where Lists are specified, alternative methods of reporting are acceptable (i.e., Piping Line Lists, ISO’s, BOM’s, etc.) These reports shall have a unique identification number and revision levels.
FOREWORD

ASME B31.1 contains rules governing the design, fabrication, materials, erection, and examination of power piping systems. Experience over the years has demonstrated that these rules may be reasonably applied to safety valve installations. Nevertheless, instances have occurred wherein the design of safety valve installations may not have properly and fully applied the ASME B31.1 rules. Accordingly, this Appendix to ASME B31.1 has been prepared to illustrate and clarify the application of ASME B31.1 rules to safety valve installations. To this end, this Appendix presents the designer with design guidelines and alternative design methods.

II-1 SCOPE AND DEFINITION

II-1.1 Scope

The scope of this Appendix is confined to the design of the safety valve installations as defined in para. II-1.2. The loads acting at the safety valve station will affect the bending moments and stresses in the complete piping system, out to its anchors and/or extremities, and it is the designer’s responsibility to consider these loads. This Appendix, however, deals primarily with the safety valve installation, and not the complete piping system.

The design of the safety valve installation requires that careful attention be paid to
(a) all loads acting on the system
(b) the forces and bending moments in the piping and piping components resulting from the loads
(c) the loading and stress criteria
(d) general design practices

All components in the safety valve installation must be given consideration, including the complete piping system, the connection to the main header, the safety valve, valve and pipe flanges, the downstream discharge or vent piping, and the system supports. The scope of this Appendix is intended to cover all loads on all components. It is assumed that the safety valve complies with the requirements of American National Standards prescribed by ASME B31.1 for structural integrity.

This Appendix has application to safety, relief, or safety relief valve installations. For convenience, however, the overpressure protection device is generally referred to as a safety valve. The loads associated with relief or safety relief valve operation may differ significantly from those of safety valve operation, but otherwise the rules contained herein are equally applicable to each type of valve installation. See para. II-1.2 for definition.

This Appendix provides analytic and nomenclature definition figures to assist the designer, and is not intended to provide actual design layout (drains, drip pans, suspension, air gaps, flanges, weld ends, and other design details are not shown). Sample problems have been provided at the end of the text to assist the designer in application of the rules in this Appendix.

II-1.2 Definitions (Valve Descriptions Follow the Definitions Given in ASME BPVC, Section I)

closed discharge installation: an installation where the effluent is carried to a distant spot by a discharge pipe that is connected directly to the safety valve. Figure II-1.2-1 shows a typical closed discharge system.
open discharge installation: an installation where the fluid is discharged directly to the atmosphere or to a vent pipe that is uncoupled from the safety valve. Figure II-1.2-2 shows a typical open discharge installation with an elbow installed at the valve discharge to direct the flow into a vent pipe. The values for \( L_o \) and \( m \) in Figure II-1.2-2 are upper limits for which the rules for open discharge systems may be used. \( L_o \) shall be limited to a value less than or equal to 4\( D_o \); \( m \) shall be limited to a value less than or equal to 6\( D_o \), where \( D_o \) is the outside diameter of the discharge pipe. Open discharge systems that do not conform to these limits shall be evaluated by the designer for the applicability of these rules.

power-actuated pressure-relieving valve: a relieving device whose movements to open or close are fully controlled by a source of power (electricity, air, steam, or hydraulic). The valve may discharge to atmosphere or to a container at lower pressure. The discharge capacity may be affected...
by the downstream conditions, and such effects shall be taken into account. If the power-actuated pressure-relieving valves are also positioned in response to other control signals, the control impulse to prevent over-pressure shall be responsive only to pressure and shall override any other control function.

relief valve: an automatic pressure-relieving device actuated by the static pressure upstream of the valve that opens further with the increase in pressure over the opening pressure. It is used primarily for liquid service.
safety relief valve: an automatic pressure-actuated relieving device suitable for use either as a safety valve or as a relief valve, depending on application.
safety valve: an automatic pressure-relieving device actuated by the static pressure upstream of the valve and characterized by full opening pop action. It is used for gas or vapor service.
safety valve installation: the safety valve installation is defined as that portion of the system shown in Figures II-1.2-1 and II-1.2-2. It includes the run pipe, branch connection, inlet pipe, valve, discharge piping, and vent pipe. Also included are the components used to support the system for all static and dynamic loads.

II-2 LOADS

II-2.1 Thermal Expansion

Loads acting on the components in the safety valve installation and the displacements at various points due to thermal expansion of the piping shall be determined by analyzing the complete piping system out to its anchors, in accordance with procedures in para. 119.

II-2.1.1 Installations With Open Discharge. For safety valve installations with open discharge, there will be no thermal expansion loads acting on the discharge elbow, the valve, or the valve inlet other than that from restraint to thermal expansion as described below. Restraint to thermal expansion can sometimes occur due to drain lines, or when structural supports are provided to carry the reaction forces associated with safety valve lift. Examples of such structural supports are shown in Figure II-6-1, illustration (b). When such restraints exist, the thermal expansion loads and stresses shall be calculated and effects evaluated.

II-2.1.2 Installations With Closed Discharge. Loads due to thermal expansion and back pressure of a safety valve installation with a closed discharge can be high enough to cause malfunction of the valve, excessive leakage of the valve or flange, or overstress of other components. The loads due to thermal expansion shall be evaluated for all significant temperature combinations, including the cases where the discharge piping is hot following safety valve operation.

II-2.2 Pressure

Pressure loads acting on the safety valve installation are important from two main considerations. The first consideration is that the pressure acting on the walls of the safety valve installation can cause membrane stresses that could result in rupture of the pressure-retaining parts. The second consideration is that the pressure effects associated with discharge can cause high loads acting on the system, which create bending moments throughout the piping system. These pressure effects are covered in para. II-2.3.

All parts of the safety valve installation must be designed to withstand the design pressures without exceeding the Code-allowable stresses. The branch connection, the inlet pipe, and the inlet flanges shall be designed for the same design pressure as that of the run pipe. The design pressure of the discharge system will depend on the safety valve rating and on the configuration of the discharge piping. The open discharge installation and the closed discharge installation present somewhat different problems in the determination of design pressures, and these problems are discussed in paras. II-2.2.1 and II-2.2.2.

II-2.2.1 Design Pressure and Velocity for Open Discharge Installation Discharge Elbows and Vent Pipes. There are several methods available to the designer for determining the design pressure and velocity in the discharge elbow and vent pipe. It is the responsibility of the designer to ensure himself/herself that the method used yields conservative results. A method for determining the design pressures and velocities in the discharge elbow and vent pipe for open discharge installations is shown below and illustrated in the sample problem.

(a) First, calculate the design pressure and velocity for the discharge elbow.

(1) Determine the pressure, $P_1$, that exists at the discharge elbow outlet (Figure II-2.2.1-1).

$$P_1 = \frac{m}{A_1} \left( b - 1 \right) \sqrt{\frac{2(h_o - a)}{g_c(2b - 1)}}$$

(2) Determine the velocity, $V_1$, that exists at the discharge elbow outlet (Figure II-2.2.1-1).

$$V_1 = \sqrt{\frac{2g_c(h_o - a)}{2b - 1}}$$

where

$A_1 = $ discharge elbow area, in.$^2$
$g_c = $ gravitational constant
$= 32.2$ lbf-ft/lbf-sec$^2$
$h_o = $ stagnation enthalpy at the safety valve inlet, Btu/lbm
$f = 778.16$ ft-lbf/Btu
$m = $ actual mass flow rate, lbf/sec

22
(3) Repeat steps (a)(3)(-a) to (a)(3)(-g) in the calculation of the discharge elbow maximum operating pressure to determine the maximum operating pressure of the vent pipe.

(4) Determine the velocity, $V_2$, and pressure, $P_2$, that exist at the inlet to the vent pipe (Figure II-2.2.1-3).

(-a) Enter Figure II-2.2.1-2 with the value of $f_{\Sigma(L/D)}$ from step (a)(3)(-d) and determine values of $V/V^*$ and $P/P^*$. 

(-b) Calculate $V_2$.

\[
V_2 = V_3(V/V^*)
\]

(-c) $P_2 = P_3(P/P^*)$. This is the highest pressure the vent stack will see and should be used in calculating vent pipe blowback (see para. II-2.3.1.2).

II-2.2.2 Pressure for Closed Discharge Installations. The pressures in a closed discharge pipe during steady-state flow may be determined by the methods described in para. II-2.2.1. However, when a safety valve discharge is connected to a relatively long run of pipe and is suddenly opened, there is a period of transient flow until the steady-state discharge condition is reached. During this transient period, the pressure and flow will not be uniform. When the safety valve is initially opened, the discharge pipe may be filled with air. If the safety valve is on a steam system, the steam discharge from the valve must purge the air.

---

Footnote: Figure II-2.2.1-2 may be extended to other values of $f_{\Sigma(L/D)}$ by use of the Keenan and Kaye gas tables for Fanno lines. The Darcy-Weisbach friction factor is used in Figure II-2.2.1-2, whereas the gas tables use the Fanning factor, which is one-fourth the value of the Darcy-Weisbach factor.
from the pipe before steady-state steam flow is established and, as the pressure builds up at the valve outlet flange and waves start to travel down the discharge pipe, the pressure wave initially emanating from the valve will steepen as it propagates, and it may steepen into a shock wave before it reaches the exit. Because of this, it is recommended that the design pressure of the closed discharge pipe be greater than the steady-state operating pressure by a factor of at least 2.

II-2.3 Reaction Forces From Valve Discharge

It is the responsibility of the piping system designer to determine the reaction forces associated with valve discharge. These forces can create bending moments at various points in the piping system so high as to cause catastrophic failure of the pressure boundary parts. Since the magnitude of the forces may differ substantially depending on the type of discharge system, each system type is discussed in paras. II-2.3.1 and II-2.3.2.

II-2.3.1 Reaction Forces With Open Discharge Systems

II-2.3.1.1 Discharge Elbow. The reaction force, \( F \), due to steady-state flow following the opening of the safety valve includes both momentum and pressure effects. The reaction force applied is shown in Figure II-2.2.1-1, and may be computed by the following equation:

\[
F_1 = \frac{\dot{m}}{g_c} V_1 + (P_1 - P_a) A_1
\]

where

- \( A_1 \) = exit flow area at Point 1, in.\(^2\)
- \( F_1 \) = reaction force at Point 1, lbf
- \( g_c \) = gravitational constant
  \[ = 32.2 \text{ lbm-ft/lbf-sec}^2 \]
- \( \dot{m} \) = mass flow rate (relieving capacity stamped on the valve × 1.11), lbm/sec
- \( P_1 \) = static pressure at Point 1, psia
- \( P_a \) = atmospheric pressure, psia
- \( V_1 \) = exit velocity at Point 1, ft/sec

To ensure consideration of the effects of the suddenly applied load \( F \), a dynamic load factor, DLF, should be applied (see para. II-3.5.1.3).

The methods for calculating the velocities and pressures at the exit point of the discharge elbow are the same as those discussed in para. II-2.2 of this Appendix.

II-2.3.1.2 Vent Pipe. Figure II-2.2.1-3 shows the external forces resulting from a safety valve discharge that act on the vent pipe. The methods for calculating \( F_2 \) and \( F_3 \) are the same as those previously described. The vent pipe anchor and restraint system must be capable of taking the moments caused by these two forces, and also be capable of sustaining the unbalanced forces in the vertical and horizontal directions.

While beveled ends are not recommended, should they be used, the additional lateral forces generated at the vent pipe exit must be considered in the design.

The terms in the equations shown in Figure II-2.2.1-3 are the same as those defined in para. II-2.3.1.

The vent pipe must be sized so that no steam is blown back at the vent line entrance. The criteria that may be used as a guide to prevent this condition are listed below.

\[
\frac{\dot{m}(V_1 - V_2)}{g_c} > (P_2 - P_a) A_2 - (P_1 - P_a) A_1
\]

where

- \( A \) = area, in.\(^2\)
- \( g_c \) = gravitational constant
  \[ = 32.2 \text{ lbm-ft/lbf-sec}^2 \]
- \( \dot{m} \) = mass flow rate, lbm/sec
- \( P_1, P_2 \) = local absolute pressure, psia
- \( P_a \) = standard atmospheric pressure, psia
- \( V \) = velocity, ft/sec

The inequality states that the momentum at Point 1 has to be greater than the momentum at Point 2 in order that air is ejected into the vent pipe. If the momentum at Point 1 equaled the momentum at Point 2, no air would be ejected into the vent pipe. If the momentum at Point 1 was less than the momentum at Point 2, steam would “blow back” from the vent pipe.

The ejection effect of the vent pipe is especially important for indoor installation of safety valves. The steam being vented from the upper body during safety valve operation will be removed from the area through the vent pipe. For that reason, the fluid momentum at Point 1 should exceed the fluid momentum at Point 2, not just be equal.

If this inequality is satisfied, blowback will not occur. The pressures and velocities are those calculated in para. II-2.2.1.

II-2.3.2 Reaction Forces With Closed Discharge Systems. When safety valves discharge a closed piping system, the forces acting on the piping system under steady-state flow will be self-equilibrated, and do not create significant bending moments on the piping system. The large steady-state force will act only at the point of discharge, and the magnitude of this force may be determined as described for open discharge systems.

Relief valves discharging into an enclosed piping system create momentary unbalanced forces that act on the piping system during the first few milliseconds following relief valve lift. The pressure waves traveling through the piping system following the rapid opening of the safety valve will cause bending moments in the safety valve discharge piping and throughout the remainder of the
piping system. In such a case, the designer must compute the magnitude of the loads, and perform appropriate evaluation of their effects.

II-2.4 Other Mechanical Loads

Other design mechanical loads that must be considered by the piping designer include the following:
(a) interaction loads on the pipe run when more than one valve opens
(b) loads due to earthquake and/or piping system vibration (see para. II-3.4)

II-3 BENDING MOMENT COMPUTATIONS

II-3.1 General

One of the most important considerations related to the mechanical design and analysis of safety valve installation is the identification and calculation of the moments at critical points in the installation. If the bending moments are not properly calculated, it will not be possible to meet the loading and stress criteria contained in ASME B31.1. As a minimum, the following loads, previously discussed in para. II-2 of this Appendix, should be considered in determining these moments:
(a) thermal expansion
(b) deadweight
(c) earthquake
(d) reaction force from valve discharge
(e) other mechanical loads

The analysis of the safety valve installation should include all critical sections, such as intersection points, elbows, and transition sections, and any related piping, vessels, and their supports that may interact with the safety valve installation. It is often most appropriate to model the safety valve installation and its related piping as a lumped mass system joined by straight or curved elements.

II-3.2 Thermal Expansion Analysis

There are many standard and acceptable methods for determination of moments due to thermal expansion of the piping installation. The thermal expansion analysis shall comply with the requirements in para. 119. The safety valve installation often presents a special problem in that there may be a variety of operational modes to consider where each mode represents a different combination of temperatures in various sections of the piping system. The design condition shall be selected so that none of the operational modes represents a condition that gives thermal expansion bending moments greater than the design condition.

The design of the safety valve installation should consider the differential thermal growth and expansion loads, as well as the local effects of reinforcing and supports. The design should also consider the differential thermal growth and expansion loads existing after any combination of safety valves (one valve to all valves) operates, raising the temperature of the discharge piping.

II-3.3 Deadweight Analysis

The methods used for determination of bending moments due to deadweight in a safety valve installation are not different from the methods used in any other piping installation. If the support system meets the requirements in para. 121, the bending moments due to deadweight may be assumed to be 1,500Z (in.-lb), where Z is the section modulus (in. 3) of the pipe or fitting being considered. However, bending moments due to deadweight are easily determined and should always be calculated in systems where stresses exceed 90% of the allowable stress limits in meeting the requirements of Figure 104.8-1, eqs. (15) and (16).

II-3.4 Earthquake Analysis

Seismic loads must be known to calculate bending moments at critical points in the safety valve installation. If a design specification exists, it should stipulate if the piping system must be designed for earthquake. If so, it should specify the magnitude of the earthquake, the plant conditions under which the earthquake is assumed to occur, and the type of earthquake analysis to be used (equivalent static or dynamic). If a design specification does not exist, it is the responsibility of the designer to determine what consideration must be given to earthquake analysis. It is beyond the scope of this Appendix to provide rules for calculating moments due to earthquake. The literature contains satisfactory references for determining moments by use of static seismic coefficients and how to perform more sophisticated dynamic analyses of the piping system using inputs in such form as time histories of displacement, velocity, and acceleration or response spectra where displacement, velocity, or acceleration is presented as a function of frequency.

II-3.5 Analysis for Reaction Forces Due to Valve Discharge

II-3.5.1 Open Discharge Systems

II-3.5.1.1 The moments due to valve reaction forces may be calculated by simply multiplying the force, calculated as described in para. II-2.3.1.1, times the distance from the point in the piping system being analyzed (moment arm), times a suitable dynamic load factor. In no case shall the reaction moment used in para. II-4.2 at the branch connection below the valve be taken at less than the product of

\[(DLF)(F_L)(L_o)\]

where
the Code provides rules to ensure that sufficient wall thickness is provided to prevent failures due to pressure. It is not necessary to repeat these rules in this Appendix; however, some of the more important are listed below for reference.

(a) All pipe (plus other components) must satisfy the minimum required wall thickness of eq. (7) in para. 104.1.2. In addition, wall thickness must be adequate to satisfy Figure 104.8-1, eqs. (15) and (16). These two equations may govern determination of wall thickness in low-pressure systems.

(b) No minimum wall thickness calculations are needed for components purchased to approved standards in Table 126.1-1.

(c) Pipe bends must meet the requirements of eq. (1) in para. II-4.1 after bending.

(d) Branch connections that do not meet the requirements of eq. (2) in para. II-4.1 must meet the area replacement requirements of para. 104.3.

II-4.2.2 Pressure Plus Bending Stresses. To guard against membrane failures (catastrophic), to prevent fatigue (leak) failures, and to ensure shakedown, the equations in para. 104.8 must be satisfied. These equations apply to all components in the safety valve installation and will not be repeated here. However, some additional explanation of these equations in regard to the very critical points upstream of the safety valve are in paras. II-4.2.2.1 and II-4.2.2.2.

II-4.2.2.1 Additive Stresses at Branch Connection. For the purposes of Figure 104.8-1, eqs. (15) through (17), the section modulus and moments for application to branch connections, such as safety valve inlet pipes, are as follows:

(a) For branch connections, Z shall be the effective section modulus for the branch as defined in para. 104.8. Thus,

\[ Z = \frac{I}{t} \]  

where

(b) Moment convention for branch connections is given in ASME B31J, Figure 1-1.

GENERAL NOTE: This figure is based on curves from Introduction to Structural Dynamics, J. M. Biggs, McGraw-Hill Book Co., 1964.
these two pressures, is then added to the internal pressure. The sum of convert the moments into an equivalent pressure that valve inlet and outlet. One method of doing this is to be noted that the values intensification factor used will be different. It should from a point on the inlet pipe such that

\[ M_{\text{flange}} = \sqrt{M_{x1}^2 + M_{y1}^2 + M_{z1}^2} \]

where \( M_{x1}, M_{y1}, M_{z1} \) are defined in para. 104.8.

(c) Where the \( D_o/t_n \) of the branch connection differs from the \( D_o/t_n \) header or run, the larger of the two \( D_o/t_n \) values should be used in the first term of Figure 104.8-1, eqs. (15) and (16), where \( D_o \) and \( t_n \) are defined in paras. 104.1 and 104.8, respectively.

II-4.2.2 Additive Stresses in Inlet Pipe. Figure 104.8-1, eqs. (15), (16), and (17) may be applied to the inlet pipe in the same manner as described above for the branch connection, except that the values for \( D_o/t_n \) and \( Z \) should be for the inlet pipe and the stress intensification factor used will be different. It should be noted that the values \( D_o/t_n \) and \( Z \) should be taken from a point on the inlet pipe such that \( D_o/t_n \) will have a maximum and \( Z \) a minimum value for the inlet pipe.

II-4.2.3 Analysis of Flange. It is important that the moments from the various loading conditions described in para. II-4.2.2 do not overload the flanges on the safety valve inlet and outlet. One method of doing this is to convert the moments into an equivalent pressure that is then added to the internal pressure. The sum of these two pressures, \( P_{FD} \), would be acceptable if either of the following criteria is met:

(a) \( P_{FD} \) does not exceed the ASME B16.5 flange rating.
(b) \( S_P, S_{br}, \) and \( S_T \) should be less than the yield stress at design temperature, where \( S_P, S_{br}, \) and \( S_T \) are as defined in ASME BPVC, Section VIII, Division 1, 2-7 with the following exceptions:

1) \( P_{FD} \) should be used in the ASME BPVC, Section VIII, Division 1 equations instead of the design pressure.
2) \( S_P \) should include the longitudinal pressure stress at the flange hub.

II-4.2.4 Analysis of Valve. The allowable forces and moments that the piping system may place on the safety valves shall be determined by the valve manufacturer. In some cases, the valve flanges are limiting rather than the valve body.

II-5 DESIGN CONSIDERATIONS

II-5.1 General

The design of safety valve installations shall be in accordance with para. 104 except that consideration be given to the rules provided in the following subparagraphs. These rules are particularly concerned with that portion of the piping system attached to and between the safety valve and the run pipe, header, or vessel that the valve services and includes the branch connection to the run pipe, header, or vessel.

II-5.2 Geometry

II-5.2.1 Locations of Safety Valve Installations. Safety valve installations shall be located at least eight pipe diameters (based on I.D.) downstream from any bend in a high-velocity steam line to help prevent sonic vibrations. This distance should be increased if the direction of the change of the steam flow is from vertical upwards to horizontal in such a manner as to increase density of the flow in the area directly beneath the station nozzles. Similarly, safety valve installation shall not be located closer than eight pipe diameters (based on I.D.) either upstream or downstream from fittings.

II-5.2.2 Spacing of Safety Valve Installation. Spacing of safety valve installations must meet the requirements in Mandatory Appendix D, Table D-1, Note (10)(c).

II-5.3 Types of Valves and Installations

II-5.3.1 Installations With Single Outlet Valves. Locate unsupported valves as close to the run pipe or header as is physically possible to minimize reaction moment effects.

Orientation of the valve outlet should preferably be parallel to the longitudinal axis of the run pipe or header. Angular discharge elbows oriented to minimize the reaction force moment shall have a straight pipe of at least one pipe diameter provided on the end of the elbow to ensure that the reaction force is developed at the desired angle. Cut the discharge pipe square with the centerline. Fabrication tolerances, realistic field erection tolerances, and reaction force angle tolerances shall meet the requirements in the following subparagraphs. The length of unsupported discharge piping between the valve outlet and the first outlet elbow (Figure II-1.2-2), distance \( l \) should be as short as practical to minimize reaction moment effects.

II-5.3.2 Installations With Double Outlet Valves. Double outlet valves with symmetrical tailpipes and vent stacks will eliminate the bending moment in the nozzle and the run pipe or header, provided there is equal and steady flow from each outlet. If equal flow
cannot be guaranteed, the bending moment due to the unbalanced flow must be considered. Thrust loads must also be considered.

II-5.3.3 Multiple Installations. The effects of the discharge of multiple safety valves on the same header shall be such as to tend to balance one another for all modes of operation.

II-5.4 Installation Branch Connections

Standard branch connections shall as a minimum meet the requirements of para. 104.3. It should be noted that branch connections on headers frequently do not have sufficient reinforcement when used as a connection for a safety valve. It may be necessary to provide additional reinforcing (weld deposit buildup) or special headers that will satisfactorily withstand the reaction moments applied.

Material used for the branch connection and its reinforcement shall be the same or of higher strength than that of the run pipe or header.

It is strongly recommended that branch connections intersect the run pipe or header normal to the surface of the run pipe or header at $\alpha = 90$ deg, where $\alpha$ is defined as the angle between the longitudinal axis of the branch connection and the normal surface of the run pipe or header. Branch connections that intersect the run pipe or headers at angles,

\[ 90\, \text{deg} > \alpha \geq 45\, \text{deg} \]

should be avoided. Branch connections should not in any case intersect the run pipe or header at angles,

\[ \alpha < 45\, \text{deg} \]

II-5.5 Water in Installation Piping

II-5.5.1 Drainage of Discharge Piping. Drains shall be provided so that condensed leakage, rain, or other water sources will not collect on the discharge side of the valve and adversely affect the reaction force. Safety valves are generally provided with drain plugs that can be used for a drain connection. Discharge piping shall be sloped and provided with adequate drains if flow points are unavoidable in the layout.

II-5.5.2 Water Seals. Where water seals are used ahead of the safety valve, the total water volume in the seals shall be minimized. To minimize forces due to slug flow or water seal excursion, the number of changes of direction and the lengths of straight runs of installation piping shall be limited. The use of short radius elbows is also discouraged; the pressure differential across the cross section is a function of the elbow radius.

II-5.6 Discharge Stacks

If telescopic or uncoupled discharge stacks or equivalent arrangements are used, then care should be taken to ensure that forces on the stack are not transmitted to the valve discharge elbow. Stack clearances shall be checked for interference from thermal expansion, earthquake displacements, etc. Discharge stacks shall be supported adequately for the forces resulting from valve discharge so that the stack is not deflected, allowing steam to escape in the vicinity of the valve. In addition, the deflection of the safety valve discharge nozzle (elbow) and the associated piping system when subjected to the reaction force of the blowing valve shall be calculated. This deflection shall be considered in the design of the discharge stack’s slip-joint to ensure that the discharge nozzle remains in the stack, preventing steam from escaping in the vicinity of the valve.

To prevent blowback of discharging steam from the inlet end of the vent stack, consider the use of an antiblowback device that still permits thermal movements of the header.

II-5.7 Support Design

Supports provided for safety valves and the associated piping require analysis to determine their role in restraint as well as support. These analyses shall consider at least the following effects:

(a) differential thermal expansion of the associated piping, headers, and vessels.
(b) dynamic response characteristics of the support in relation to the equipment being supported and the structure to which it is attached, during seismic events and valve operation. Maximum relative motions of various portions of the building and structures to which supports are attached resulting from seismic excitation must be considered in selecting, locating, and analyzing support systems.
(c) capability of the support to provide or not provide torsional rigidity, per the support design requirements.

II-5.7.1 Pipe Supports. Where necessary, it is recommended that the support near the valve discharge be connected to the run pipe, header, or vessel rather than to adjacent structures to minimize differential thermal expansion and seismic interactions.

Each straight leg of discharge piping should have a support to take the force along that leg. If the support is not on the leg itself, it should be as near as possible on an adjacent leg.

When a large portion of the system lies in a plane, the piping, if possible, should be supported normal to that plane even though static calculations do not identify a direct force requiring restraint in that direction. Dynamic analyses of these systems have shown that out-of-plane motions can occur.
II-5.7.2 Snubbers. Snubbers are often used to provide a support or a stop against a rapidly applied load, such as the reaction force of a blowing valve or the pressure-momentum transient in a closed piping system. Since snubbers generally displace a small distance before becoming rigid, the displacement must be considered in the analysis. In addition, if the load is applied to the snubber for a relatively long time, the snubber performance characteristics shall be reviewed to ensure that the snubber will not permit motion during the time period of interest, or the additional displacement shall be considered in the analysis. The snubber performance shall also be reviewed for response to repetitive load applications caused by the safety valve cycling open and closed several times during a pressure transient.

II-5.8 Silencer Installation

Silencers are occasionally installed on safety valve discharges to dissipate the noise generated by the sonic velocity attained by the fluid flowing through the valve.

Silencers must be properly sized to avoid excessive backpressure on the safety valve causing improper valve action or reducing relieving capacity.

Safety valve discharge piping, silencers, and vent stacks shall be properly supported to avoid excessive loading on the valve discharge flange.

II-6 SAMPLE DESIGNS

Examples of various safety valve installations that a designer may encounter in practice are presented in Figures II-1-2 and II-6-1.

II-7 SAMPLE PROBLEM (SEE FIGURES II-7-1 AND II-7-2)

II-7.1 Procedure

(a) Determine the pressure and velocity at the discharge elbow exit.
NONMANDATORY APPENDIX V
RECOMMENDED PRACTICE FOR OPERATION, MAINTENANCE, AND MODIFICATION OF POWER PIPING SYSTEMS

FOREWORD

The ASME B31.1 Power Piping Code prescribes minimum requirements for the construction of power and auxiliary service piping within the scope of para. 100.1. The Code, however, does not provide rules or other requirements for a determination of optimum system function, effective plant operations, or other measures necessary to ensure the useful life of piping systems. These concerns are the responsibility of the designer and, after construction turnover, the Operating Company personnel responsible for plant activities.

Past experience has shown that a need exists for the definition of acceptable plant practices for achieving both reliable service and a predictable life in the operation of power piping systems. This Appendix is intended to serve that purpose. For this objective, this Appendix is structured in three parts that recognize and address the following basic concepts:

(a) Operation. The design of a piping system is based on specified service requirements and operating limitations. Subsequent operation within these defined limits is assumed and, for some systems, will be important for an acceptable service life.

(b) Maintenance. The design of a piping system assumes that reasonable maintenance and plant service will be provided. The lack of this support will, in some cases, introduce an increasing degree of piping system life uncertainty.

(c) Modifications. Future modifications of a piping system or its operational functions are not assumed in original design unless specified. Modifications must not invalidate the integrity of a piping system design.

The practices in this Appendix are recommended for all plants and systems within the scope of the Power Piping Code, both for new construction and for existing plants in operation. An acceptable implementation of these or equivalent practices will be beneficial for new systems. The application of these practices is recommended for power piping systems in operating plants.

The recommended practices in this Appendix define minimum requirements for establishing a program to accommodate the basic considerations for piping system operation, maintenance, service, modification, and component replacement.

Chapter VII of this Code requires that each Operating Company develop operation and maintenance procedures for covered piping systems (CPS) to ensure safe facility operations after construction. This Appendix is intended to provide direction to the Operating Company in the development of these procedures. Additionally, this Appendix provides requirements that may be useful for maintenance of noncovered piping systems.

A record-keeping program is prescribed that can serve as a point of reference for analyzing piping system distortions or potential failures. Such a program is intended to identify distortions or failures and assure compatibility between the materials and components of existing piping systems with those portions undergoing repair, replacement, or modification.

V-1 DEFINITIONS


component: equipment, such as vessel, piping, pump, or valve, that is combined with other components to form a system.

critical piping systems: those piping systems that are part of the feedwater-steam circuit of a steam generating power plant, and all systems that operate under two-phase flow conditions. Critical piping systems include runs of piping and their supports, restraints, and root valves. Hazardous gases and liquids, at all pressure and temperature conditions, are also included herein. The Operating Company may, in its judgment, consider other piping systems as being critical, in which case it may consider them as part of this definition.

examination: an element of inspection consisting of investigation of materials, components, supplies, or services to determine conformance to those specified requirements that can be determined by such investigation. Examination is usually nondestructive and includes simple physical manipulation, gaging, and measurement.

failure: a physical condition that renders a system, component, or support inoperable.

1The definitions pertain specifically to this Appendix.
or restrained on both sides of the component to be removed so as to maintain its as-found cold position until the component or components are installed. If the desired piping position cannot be maintained, an analysis shall be made to determine the reason for the problem. A new stress analysis may be necessary. Care shall be exercised when working on a system that has been subjected to self-springing, relaxation, or cold pull.

V-6.1.3 Weld preparations and fit-up of the weld joints shall meet the requirements of Chapter V.

V-6.1.4 Welding procedures and preheat/postheat treatments of the weld joints shall meet the minimum requirements of Chapter V.

V-6.2 Inspection Program for Materials With Adverse History

V-6.2.1 Materials that have been reported to the industry to exhibit an adverse performance under certain conditions shall be given special attention by the Operating Company through a program of planned examination and testing. This program shall include the development of procedures for repair or replacement of the material when the Operating Company determines that such action is necessary.

V-6.2.2 Methods of surveillance and analysis shall be determined by the Operating Company. ASME PCC-3, Inspection Planning Using Risk-Based Methods, offers guidance for the development and implementation of a risk-based inspection program.

V-6.2.3 The frequency of the material inspection shall also consider the expected service life of the component.

V-6.3 Nondestructive Examination

Nondestructive examinations used to investigate any suspect materials or problem areas shall be in accordance with Chapter VI.

Other techniques or acceptance criteria may be used when appropriate for the investigation being performed and when approved by the owner.

V-7 CPS POSITION HISTORY

V-7.1 General

V-7.1.1 The Operating Company shall develop and implement a program and procedures requiring recording and documentation of piping support observations and piping displacements. This program should include, at a minimum, CPS operating in the creep range. Records should be kept and maintained of position indicator readings, load adjustments, travel adjustments, repairs, and replacements.

V-7.1.2 Although the Code recognizes that CPS pipe supports seldom return to their exact original positions after each heat cycle, piping system displacements should be maintained within the bounds of engineering-evaluated limitations.

V-7.1.3 Documentation of the piping support observations and piping displacements should be performed on a periodic basis. Each set of hot and cold walkdowns should not exceed 5-yr intervals (typically associated with a scheduled major outage). Specific unit walkdown intervals are determined by the Operating Company. The intervals may be dependent on previous walkdown and NDE results, unit operating conditions, environment, and industry experience with specific piping or pipe supports. If a set of hot and cold walkdowns is not performed within 5 yr, the justification should be documented.

V-7.2 Visual Survey

The CPS should be observed visually, as frequently as deemed necessary. Any unusual conditions should be brought to the attention of plant management personnel as prescribed in the procedures of para. V-3.1. Observations should include determination of interferences with or from other piping or equipment, vibrations, and general condition of the piping system and supports, including but not limited to hangers, guides, restraints, anchors, supplementary steel, and attachments.

V-7.3 Piping Position Markers

V-7.3.1 Piping position and displacements may be monitored periodically at selected locations to document field conditions and to identify any migration beyond the bounds of engineering-evaluated limitations. For the purpose of easily making periodic position determinations at the selected locations, permanent markings or pointers may be attached to piping components. The positions of these markings or pointers should be noted and recorded with respect to stationary datum reference points.

V-7.3.2 Placement of pointers should be such that personnel safety hazards are not created.

V-7.4 Pipe Supports on CPS

V-7.4.1 Pipe support readings should be observed and recorded periodically. Piping system anomalies, such as interferences and lagging/insulation damage, should also be noted and recorded. Readings should be obtained while the piping is within the range of normal operating temperatures. The online pipe temperature range during the time of reading supports should be recorded. Walkdowns during unit shutdown should also be performed when the pipe is sufficiently cool [approximately 100°F (38°C) or below]. In addition to online and off-line walkdowns, a postadjustment walkdown of

API 574 "Inspection Practices for Piping System Components" contains guidance on the types of service damage that can affect pipe other than CPS and the types of examinations to evaluate such deterioration.
the adjusted and adjacent supports should be performed. Walkdowns should be scheduled to evaluate the most critical operation scenarios; readings associated with each critical operation mode should be documented.

V-7.4.2 Variable and constant spring supports, dynamic restraints and snubbers, sliding supports, and rigid rod supports should be maintained so that they function as designed and within the limits specified by the manufacturers and designers. Maintenance of these items may include, but not necessarily be limited to, cleaning, lubrication, and corrosion protection. Snubbers should be examined and tested periodically in accordance with the manufacturer's recommendations to assure that they travel freely without binding and lock up within design parameters.

V-7.5 CPS Records

CPS support design details may be documented as provided in Form V-7.5-1. Records of position settings of all constant and variable spring supports and of all snubbers should be made before initial startup of the plant. Pipe position indicator readings, as observed on the travel scales of variable and constant spring supports, should be recorded in a manner that can be easily interpreted. The condition of rigid rod and sliding supports should also be recorded on walkdown logs. As examples, a suggested support hot walkdown record form is provided in Form V-7.5-2, and a suggested support cold walkdown record form is provided in Form V-7.5-3. The walkdown log sheet information may be organized and postprocessed on electronic media as part of the engineering evaluation process.

The log sheets should be accompanied by a pipe-support location plan or piping-system isometric drawing with hanger mark number designations clearly noted. Records should include positions of sliding supports and snubbers in the hot and cold (operating and shutdown) conditions. Records should be maintained showing axial and lateral displacements in expansion joints, including records of hot and cold (operating and shutdown) positions, particularly those not equipped with control rods or gimbals. If necessary, robust reference markings should be created for measuring differential displacements. Physical measurement records should include a description of location and measurement setup. Any adjustments to pipe-support travel and load ratings should be documented.

V-7.6 Recommendations

After complete examination of the records of observations made in accordance with para. V-7.5, recommendations for necessary corrective actions should be made by a qualified individual. Evaluations, repairs, and/or modifications should be carried out by qualified personnel for all of the following discrepancies:

(a) excessively corroded support components
(b) broken springs or any damaged hardware that is part of the complete support assembly
(c) excessive piping vibration; valve operator shaking or movements
(d) piping interferences
(e) excessive piping deflection that may require the installation of spring supports having a greater travel range or higher spring constant, or sliding support redesign
(f) significantly reduced or increased movement compared to the expected design movement (such as the maximum of more than 20% variation or \(\frac{1}{2}\) in. from the expected travel)
(g) pipe sagging that may require support adjustment or the reanalysis and redesign of the support system
(h) spring support unit riding at either the top or the bottom of the available travel
(i) need for adjustment of spring support load-carrying capacity
(j) need for adjustments of support rods or turnbuckle
(k) loose or broken anchors
(l) inadequate clearances at guides or limit stops
(m) inadequate clearances between safety valve vent pipes, discharge elbows, and drip pans
(n) any failed or deformed support or support component (such as hanger, guide, U-bolt, anchor, snubber or shock absorber, dampener, and slide support) or supporting steel
(o) unacceptable movement in expansion joints
(p) low fluid levels in hydraulic pipe restraints
(q) severely damaged or missing lagging and insulation
(r) loose or missing fastener

V-8 PIPING CORROSION

V-8.1 General

V-8.1.1 This section pertains to the requirements for inspection of critical piping systems that may be subject to internal or external erosion or corrosion, such as buried pipe, piping in a corrosive atmosphere, or piping having corrosive or erosive contents. Requirements for inspection of piping systems to detect wall thinning of piping and piping components due to flow-accelerated corrosion (FAC) are also included. FAC of carbon steel piping may occur at locations where high fluid velocity exists adjacent to the metal surface, due to either high velocity or the presence of some flow discontinuity (elbow, reducer, expander, tee, control valve, etc.) causing high levels of local turbulence. The FAC process may be associated with wet steam or high-purity, low-oxygen-content water systems. Damage may occur under both single- and two-phase flow conditions. Piping systems that may be damaged by FAC include, but are not limited to, feedwater, condensate, heater drains, and wet steam extraction lines. Maintenance of corrosion
line slopes, adding drain pots, adding warm-up lines around valves, and checking for leaking desuperheaters, faulty electrical controls on automatic drains, etc.

**V-11.3** Water hammer due to column separation in feedwater or booster pump suction piping results when the deaerator pegging pressure is not maintained. This type of water hammer can be particularly severe and requires prompt attention to control and reduce it.

**V-11.4** As a priority, corrective action should address the cause of water hammer first. If such corrective action is ineffective in reducing the effects of water hammer to acceptable levels, installation of restraints may be necessary to limit piping displacements and/or damage from fatigue.

**V-12 DAMAGE MECHANISMS**

As discussed in para. 145, creep is a material degradation mechanism that must be considered when designing many CPS; detailed information regarding creep damage is provided in para. V-13. However, other damage mechanisms may also require consideration by the Operating Company so that appropriate monitoring, maintenance, or repairs can be performed, as necessary. Factors that can influence the potential for these mechanisms to occur include operating conditions, operating history, system geometry, materials of construction, and stress levels.

(a) If a specific damage mechanism other than creep is considered to be active or potentially active, programs or procedures related to monitoring or evaluating such a damage mechanism shall be carried out by, or under the direction of, persons qualified by training and experience in the assessment of material damage in power plant piping.

(b) Brief descriptions of some of the potential damage mechanisms that can affect CPS (including creep) are provided in (1) through (16) below. Additional information on material degradation mechanisms is provided in ASME BPVC, Section II, Part D, Nonmandatory Appendix A; ASME BPVC, Section III, Nonmandatory Appendix W; API 570; and API 571.

1. creep: as described in para. V-13, a stress-, temperature-, time-, and material-dependent plastic deformation process that can eventually lead to crack initiation and failure.

   (2) fatigue: a mechanism of microstructural damage, crack initiation, and crack propagation caused by cyclic loading.

   (3) creep/fatigue interaction: a mechanism by which creep damage and fatigue damage occur concomitantly, thereby increasing the propensity for crack formation and failure.

   (4) corrosion fatigue: a mechanism that is normally initiated at the internal surface of water-wetted tubing and piping and results from cyclic loads (thermal or mechanical) repetitively cracking internal oxide layers and exposing new metal to fluid within the system.

   (5) differential thermal expansion/contraction: a mechanism in which high localized stresses can result from joined materials or components with different thermal expansion coefficients. A common location for resulting damage is along the fusion lines of dissimilar metal welds (DMWs).

   (6) thermal fatigue: a form of fatigue failure wherein the driving force for crack initiation and propagation is cyclic thermal stresses, which are normally greatest near attachment points or geometric features that act as stress risers.

   (7) thermal degradation: a general mechanism by which exposure to excessive temperatures causes microstructural changes and an undesirable change in material properties, including ductility and strength. This mechanism can occur rapidly or over a very long period of time; the rate at which this mechanism occurs is dependent on the temperature exposure (both magnitude and duration).

   (8) thermal shock: a mechanism in which rapidly changing thermal conditions induce deformation or cracking associated with high stresses caused by localized differential thermal expansion.

   (9) thermal ratcheting: a mechanism in which cyclic thermal loading causes an accumulation of plastic strain and associated geometry changes or material damage.

   (10) erosion: a mechanical degradation mechanism, which includes the specific case of cavitation damage, in which wall loss occurs, either on a general basis or in a localized region, due to wear by flowing fluid.

   (11) flow-accelerated corrosion (FAC): a specific mechanism of damage in which wall loss occurs due to a breakdown of the protective internal oxide and subsequent corrosion or oxidation of the metal; also called flow-assisted corrosion.

   (12) graphitization: a long-term damage mechanism that affects some carbon and low alloy steels through the transformation of carbides into graphite particles or flakes, either in the base metal or along weld heat-affected zones.

   (13) corrosion: a broad category of degradation involving any of a wide range of specific mechanisms that reduce wall thickness uniformly (general corrosion) or in a localized manner (localized corrosion, including pitting
For example, a component constantly operates at a specific temperature, $X$, that is within the material creep regime. If the component continuously operates at 9°F (5°C) below $X$, the time to failure due to creep is increased by about 45%. If the component continuously operates at 9°F (5°C) above $X$, the time to failure is decreased by about 30%.

V-13.1.3 The remaining useful life of a component may be estimated by determining the extent of current and predicted creep and fatigue damage. The evaluation should consider the past and future (estimated) temperatures, pressures, and redistributed multiaxial (bending and through-wall) stresses for the applicable service-degraded material within the component. Independent evaluations may be appropriate for parent metal, weld metal, or heat-affected zones at welds.

V-13.2 Procedures

V-13.2.1 The Operating Company shall develop a program and procedures to determine the extent of creep damage. The procedures shall be carried out by, or under the direction of, persons qualified by training and experience in the evaluation of creep effects in power plant piping. The NDE and evaluation procedures may include the following considerations:

(a) a review of prior NDE results to determine the extent of prior creep damage.

(b) liquid penetrant, magnetic particle, radiographic, or ultrasonic examination, and other NDE methods approved by the Operating Company to detect surface and internal cracks.

(c) diametral measurements to detect creep swelling.

(d) an examination of the microstructure to determine the degree of material degradation. This can be performed by surface replication techniques, metallography using specimens obtained by boat-sampling or trepanning, and other methods approved by the Operating Company.

V-13.2.2 A procedure should be developed to select piping system areas more likely to have greater creep damage. The procedure should include an evaluation process, which may include a review of

(a) material specifications

(b) operating stress levels

(c) previous walkdown results (considering noted anomalies)

(d) NDE results

(e) operating history (including temperature, pressure, and severe transient events)

(f) cycles (for creep–fatigue interaction)

(g) maintenance history

(h) industry experience

The procedure should establish a prioritized examination schedule based on the evaluation process. Following an examination, the evaluation process should be periodically repeated to select subsequent sets of high-priority creep damage areas. The frequency of examination shall be in accordance with para. V-13.5.

To evaluate the potential for accelerated creep damage in longitudinal seam welds, para. 102.4.7 may be used to provide seam weld strength reduction factors.

V-13.3 Records

Records of creep damage survey findings and evaluations shall be maintained in accordance with paras. 140 and 141.

V-13.4 Examination of Records

V-13.4.1 Records of creep damage surveys and test reports shall be examined by personnel qualified, by training and experience, to evaluate and interpret NDE and metallographic studies.

V-13.4.2 Where surveys and examinations of piping systems operating in the creep range indicate that creep damage has progressed to an unacceptable level (determined by the Operating Company), those portions of the piping system shall be considered for more extensive evaluations or replacement.

V-13.5 Frequency of Examination

The frequency of examination, determined by the Operating Company, should be based on previous evaluation results and industry experience. Particular consideration should be given to the selected high-priority weldments.

V-14 RERATING PIPING SYSTEMS

V-14.1 Conditions

An existing piping system may be rerated for use at a higher pressure and/or temperature if all of the following conditions are met:

(a) A design analysis shall be performed to demonstrate that the piping system meets the requirements of the Code at the new design conditions.

(b) The condition of the piping system and support/restraint scheme shall be determined by field inspections and the examination of maintenance records, manufacturer’s certifications, and/or other available information to ensure conformance with the Code requirements for the new design conditions.

(c) Necessary repairs, replacements, or alterations to the piping system are made to conform with the requirements prescribed in (a) and (b).

(d) The system has been leak tested to a pressure equal to or greater than that required by the Code for a new piping system at the new design conditions.

(e) The rate of pressure and temperature increase to the higher maximum allowable operating conditions shall be gradual so as to allow sufficient time for periodic

For rerating involving increases in design pressure, the
observations of the piping system movements and leak tightness.

(f) Records of investigations, work performed, and pressure tests conducted in rerating the piping systems shall be preserved for the service life of the piping systems.

(g) All safety valves, relief valves, and other pressure-relieving devices must be examined, and recertified for the new pressure–temperature design conditions. Capacity of relieving equipment shall be investigated if the design pressure and/or temperature is changed in rerating a piping system.

(g) Changes in design pressure or temperature shall be evaluated with respect to resulting changes in service conditions, which may include unintended conditions as listed in para. 149.2.

V-15 REPAIR OF PIPING SYSTEMS

V-15.1 Guidance for Repairs

The referenced standards/codes listed below may be used by the Operating Company to assist in the preparation of repair procedures. This list is not intended to be all-inclusive, nor should it be considered an endorsement of the listed referenced standards. Jurisdictional requirements may also apply and should be reviewed prior to making any repairs.

(a) ASME PCC-2, Repair of Pressure Equipment and Piping

(b) ANSI/NB-23, National Board Inspection Code — Part 3: Repairs and Alterations

(c) API 570, Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems

(d) API 579-1/ASME FFS-1, Fitness-For-Service. This standard provides guidance for evaluating flaws, damage, and adverse operating conditions in order to make run-repair-replace decisions. For piping systems operating in the creep range, additional methods may be required (to evaluate welds and multi-axial stress effects). For piping systems with metal loss in cyclic service, simpler methods may be more appropriate.
NONMANDATORY APPENDIX VII
PROCEDURES FOR THE DESIGN OF RESTRAINED UNDERGROUND PIPING

FOREWORD

The Code contains rules governing the design, fabrication, materials, erection, and examination of power piping systems. Experience over the years has demonstrated that these rules may be conservatively applied to the design and analysis of buried piping systems. However, the ASME B31.1 rules were written for piping suspended in open space, with the supports located at local points on the pipe. Buried piping, on the other hand, is supported, confined, and restrained continuously by the passive effects of the backfill and the trench bedding. The effects of continuous restraint cannot be easily evaluated by the usual methods applied to exposed piping, since these methods cannot easily accommodate the effects of bearing and friction at the pipe/soil interface. Accordingly, this Appendix has been prepared to illustrate and clarify the application of Code rules to restrained buried piping.

All components in the buried piping system must be given consideration, including the building penetrations, branches, bends, elbows, flanges, valves, grade penetrations, and tank attachments. It is assumed that welds are made in accordance with this Code and that appropriate corrosion protection procedures are followed for buried piping.

This Appendix provides analytic and nomenclature definition figures to assist the designer, and is not intended to provide actual design layout. Sample calculations for various configurations of semirigid buried piping have been provided at the end of the text to assist the designer in the application of these procedures.

VII-1 SCOPE AND DEFINITIONS

VII-1.1 Scope

The scope of this Appendix is confined to the design of buried piping as defined in para. VII-1.2. Thermal expansion in buried piping affects the forces, the resulting bending moments and stresses throughout the buried portions of the system, particularly at the anchors, building penetrations, buried elbows and bends, and branch connections, and it is the designer’s responsibility to consider these forces. This Appendix, however, deals only with the buried portions of the system, and not the complete system.

The design and analysis of buried piping requires that careful attention be paid to
(a) all loads acting on the system
(b) the forces and the bending moments in the piping and piping components resulting from the loads
(c) the loading and stress criteria
(d) general design practices

VII-1.2 Definitions

confining pressure: the pressure imposed by the compacted backfill and overburden on a buried pipe. Confining pressure is assumed to act normal to the pipe circumference.
flexible coupling: a piping component that permits a small amount of axial or angular movement while maintaining the pressure boundary.
friction: the passive resistance of soil to axial movement. Friction at the pipe/soil interface is a function of confining pressure and the coefficient of friction between the pipe and the backfill material. Friction forces exist only where there is actual or impending slippage between the pipe and soil.
influence length: the portion of a transverse pipe run that is deflected or “influenced” by pipe thermal expansion along the axis of the longitudinal run.
modulus of subgrade reaction: the rate of change of soil bearing stress with respect to compressive deformation of the soil. It is used to calculate the passive spring rate of the soil.
penetration: the point at which a buried pipe enters the soil either at grade or from a wall or discharge structure.
settlement: the changes in volume of soil under constant load that result in the downward movement, over a period of time, of a structure or vessel resting on the soil.
virtual anchor: a point or region along the axis of a buried pipe where there is no relative motion at the pipe/soil interface.
VII-1.3 Nomenclature

\[ A = \text{cross-sectional metal area of pipe, in.}^2 \]
\[ A_c = \text{surface area of a 1-in. long pipe segment, in.}^2 \]
\[ a, b, c = \text{quadratic equation functions} \]
\[ B_d = \text{trench width at grade, in.} \]
\[ C_b = \text{horizontal stiffness factor for backfill (ref. [8]), dimensionless} \]
\[ D = \text{pipe outside diameter, in.} \]
\[ d_L = \text{length of pipe element, in.} \]
\[ E = \text{Young’s modulus for pipe, psi} \]
\[ f = \text{unit friction force along pipe, lb/in.} \]
\[ F_{f_{\text{max}}} = \text{maximum axial force in pipe, lb} \]
\[ f_{\text{min}}, f_{\text{max}} = \text{minimum, maximum unit friction force on pipe, lb/in.} \]
\[ H = \text{pipe depth below grade, in.} \]
\[ I = \text{pipe section moment of inertia, in.}^4 \]
\[ k = \text{soil modulus of subgrade reaction, psi} \]
\[ k_{h} = \text{soil horizontal modulus of subgrade reaction, psi} \]
\[ k_{i,j} = \text{orthogonal soil springs on pipe, lb/in.} \]
\[ k_v = \text{soil vertical modulus of subgrade reaction, psi} \]
\[ L_1 = \text{length of transverse pipe run, in.} \]
\[ L_2 = \text{length of longitudinal pipe run, in.} \]
\[ L' = \text{effective slippage length for short pipes, in.} \]
\[ L'' = \text{effective slippage length for long pipes, in.} \]
\[ L_m = \text{minimum slippage length of pipe, in.} \]
\[ n = \text{number of modeling elements for pipe springs, dimensionless} \]
\[ N_h = \text{horizontal force factor (ref. [8]), dimensionless} \]
\[ P = \text{maximum operating pressure in pipe, psi} \]
\[ P_c = \text{confining pressure of backfill on pipe, psi} \]
\[ S_a = \text{allowable expansion stress range, psi} \]
\[ S_b = \text{basic material allowable stress at T degrees Fahrenheit, psi} \]
\[ S E = \text{expansion stress, psi} \]
\[ T = \text{maximum operating temperature, °F} \]
\[ t = \text{pipe wall thickness, in.} \]
\[ T_o = \text{ambient temperature of pipe, °F} \]
\[ w = \text{soil density, lb/ft}^3, \text{lb/in.}^3 \]
\[ W_p = \text{unit weight of pipe and contents, lb/in.} \]
\[ \alpha = \text{coefficient of thermal expansion of pipe, in./in./°F} \]
\[ \beta = \text{pipe/soil system characteristic (ref. [2]), in.}^{-1} \]
\[ \varepsilon = \text{pipe unit thermal expansion, in./in.} \]
\[ \mu = \text{coefficient of friction, dimensionless} \]
\[ \Omega = \text{effective length parameter, in.} \]

VII-2 LOADS

VII-2.1 Thermal Expansion

Thermal displacements at the elbows, branch connections, and flanges in a buried piping system and the forces and moments resulting from the displacements may be determined by analyzing each buried run of pipe using the method described in this Appendix.

VII-2.1.1 Installations With Continuous Runs. For buried piping installations that contain continuous runs without flexible couplings, the passive restraining effects of soil bearing on the transverse legs at the ends of long runs subject to thermal expansion may be significant and result in high axial forces and elbow or branch connection bending moments.

VII-2.1.2 Installations With Flexible Couplings. For buried piping installations that incorporate flexible couplings into the pipe runs subject to thermal expansion, the bending moments and stresses may be substantially reduced. However, the flexible couplings must be chosen carefully to accommodate the thermal expansion in the pipe, and the friction forces or stiffness in the coupling must be considered.

VII-2.1.3 Installations With Penetration Anchors. For buried piping systems in which the building penetration provides complete restraint to the pipe, it is necessary to calculate the penetration reactions to thermal expansion in the initial buried run. If this run incorporates flexible couplings, piping reactions at the penetration resulting from unbalanced forces due to internal pressure must be considered.

VII-2.1.4 Installations With Flexible Penetrations. For buried piping systems in which the building penetrations permit some axial or angular movements, the interaction between the buried run outside the penetration and the point-supported portion of the system inside the building must be considered.

VII-2.2 Pressure

Pressure loads in buried piping are important for two primary reasons.

VII-2.2.1 In pipe runs that incorporate flexible couplings, there is no structural tie between the coupled ends, with the result that internal pressure loads must be reacted externally. External restraint may be provided by thrust blocks, external anchors, soil resistance to elbows or fittings at each end of the pipe run, or control rods across the coupling. Where one or both of the ends terminate at a penetration or an anchor, or at connected equipment such as a pump or vessel, the pressure forces can be quite high and must be considered in the anchor or equipment design.
VII-1.3 Nomenclature

\( A = \) cross-sectional metal area of pipe, in.\(^2\) (mm\(^2\))
\( A_c = \) surface area of a 1-in. long pipe segment, in.\(^2\) (mm\(^2\))

\( a, b, c = \) quadratic equation functions
\( B_d = \) trench width at grade, in. (mm)
\( C_p = \) soil bearing parameter from Table VII-3.2.3-1, dimensionless
\( C_h = \) horizontal stiffness factor for backfill (ref. [8]), dimensionless
\( C_p = \) pipe outside diameter, in. (mm)
\( dL = \) length of pipe element, in. (mm)
\( E = \) Young’s modulus for pipe, psi (MPa)
\( f = \) unit friction force along pipe, lb/in., lbf/in. (N/mm)
\( F_i = \) friction force along effective length, lbf (N)
\( F_{max} = \) maximum axial force in pipe, lbf (N)
\( f_{min} - F_{max} = \) minimum, maximum unit friction force on pipe, lbf/in., lbf/in. (N/mm)
\( F_{max} = \) maximum friction force on pipe, lbf (N)
\( H = \) pipe depth below grade, in. (mm)
\( I = \) pipe section moment of inertia, in.\(^4\) (mm\(^4\))
\( k = \) soil modulus of subgrade reaction, psi (MPa)
\( k_h = \) soil horizontal modulus of subgrade reaction, psi (MPa)
\( k_d = \) orthogonal soil springs on pipe, lb/in., lbf/in. (N/mm)
\( k_v = \) soil vertical modulus of subgrade reaction, psi (MPa)
\( L_1 = \) length of transverse pipe run, in. (mm)
\( L_2 = \) length of longitudinal pipe run, in. (mm)
\( L' = \) effective slippage length for short pipes, in. (mm)
\( L'' = \) effective slippage length for long pipes, in. (mm)
\( L_{min} = \) minimum slippage length of pipe, in. (mm)
\( n = \) number of modeling elements for pipe springs, dimensionless
\( N_h = \) horizontal force factor (ref. [8]), dimensionless
\( P = \) maximum operating pressure in pipe, psi (MPa)
\( P_c = \) confining pressure of backfill on pipe, psi (MPa)
\( S_a = \) allowable expansion stress range, psi (MPa)
\( S_m = \) basic material allowable stress at degrees Fahrenheit, psi
\( T = \) maximum operating temperature, °F (°C)
\( t = \) pipe wall thickness, in. (mm)
\( T_a = \) ambient temperature of pipe, °F (°C)
\( w = \) soil density, lb/ft\(^3\), lbm/ft\(^3\), lbm/in.\(^3\) (kg/m\(^3\), kg/mm\(^3\))
\( W_p = \) unit weight of pipe and contents, lb/in., lbf/in. (kg/mm)
\( \alpha = \) coefficient of thermal expansion of pipe, in./in./°F (mm/mm/°C)
\( \beta = \) pipe/soil system characteristic (ref. [2]), in.-\(^1\) (mm\(^-1\))
\( \varepsilon = \) pipe unit thermal expansion, in./in. (mm/mm)
\( \mu = \) coefficient of friction, dimensionless
\( \Omega = \) effective length parameter, in. (mm)
VII-2.2.2 For discharge structures, the reaction forces due to upstream pressure and mass flow momentum in the discharge leg may be high and must be considered in the design of the last elbow or bend before the discharge.

VII-2.3 Earthquake

An earthquake subjects buried piping to axial loads and bending moments from soil strain due to seismic waves, or from ground faulting across the axis of the pipe. The seismic soil strain can be estimated for a design earthquake in a specific geographical region, from which design values for forces and moments in buried piping can be calculated. However, consideration of the magnitude and effects of seismic ground faulting on buried piping is beyond the scope of this Appendix.

VII-3 CALCULATIONS

The calculations for stresses in restrained underground piping are carried out in four steps, as follows.

VII-3.1 Assembling the Data

The pipe material and dimensions, soil characteristics, and operating conditions must be established.

VII-3.1.1 Pipe Data

(a) pipe outside diameter, \( D \), in.
(b) wall thickness, \( t \), in.
(c) length of pipe runs, \( L_1 \) (transverse) and \( L_2 \) (longitudinal), in.
(d) Young’s modulus, \( E \), psi (from Mandatory Appendix C)
(e) pipe depth below grade, \( H \), in.

VII-3.1.2 Soil Characteristics

(a) soil density, \( w \), lb/ft\(^3\) (from site tests)
(b) type of backfill
(c) pipe trench width at grade, \( B_{dp} \), in.
(d) range of coefficient of friction, \( \mu \), between pipe and backfill

VII-3.1.3 Operating Conditions

(a) maximum operating pressure, \( P \), psi
(b) maximum pipe temperature, \( T \), °F
(c) ambient pipe temperature, \( T_{oc} \), °F
(d) pipe coefficient of thermal expansion, \( \alpha \), in./in./°F

\[ \varepsilon = \alpha (T - T_o) \] (1)

where

\( T - T_o \) = difference between operating and installation temperatures
\( \alpha \) = coefficient of thermal expansion

VII-3.2 Calculations of Intermediate Parameters

The parameters specified in paras. VII-3.2.1 through VII-3.2.6 must be calculated.

VII-3.2.1 Maximum Relative Strain, \( \varepsilon \), at the Pipe/Soil Interface, in./in.

For thermal expansion, this is the unit thermal elongation of the unrestrained pipe

\[ f = \mu (P A_c + W_p) \text{ lb/in.} \] (3)

where

\( A_c \) = surface area of a pipe segment, in.\(^2\)
\( P_c \) = confining pressure of soil on pipe, psi
\( W_p \) = unit weight of pipe and contents, lb/in.
\( \mu \) = coefficient of friction between pipe and soil

For piping that is buried within 3 pipe diameters of the surface, confining pressure, \( P_o \), may be estimated by
VII-3 CALCULATIONS

The calculations for stresses in restrained underground piping are carried out in four steps, as follows.

VII-3.1 Assembling the Data

The pipe material and dimensions, soil characteristics, and operating conditions shall be established.

VII-3.1.1 Pipe Data

(a) pipe outside diameter, D, in. (mm)
(b) wall thickness, t, in. (mm)
(c) length of pipe runs, L₁ (transverse) and L₂ (longitudinal), in. (mm)
(d) Young's modulus, \( E \), psi (MPa)
(e) pipe depth below grade, \( H \), in. (mm)

VII-3.1.2 Soil Characteristics

(a) soil density, \( w \), lb/ft³ (kg/m³)
(b) type of backfill
(c) pipe trench width at grade, \( B_0 \), in. (mm)
(d) range of coefficient of friction, \( \mu \), between pipe and backfill

VII-3.1.3 Operating Conditions

(a) maximum operating pressure, \( P \), psi (MPa)
(b) maximum pipe temperature, \( T \), °F (°C)
(c) ambient pipe temperature, \( T_{\text{amb}} \), °F (°C)
(d) pipe coefficient of thermal expansion, \( \alpha \), in./in./°F (mm/mm/°C)
where

\[ P = wH \text{lb/in.}^2 \]

For piping that is buried more than 3 pipe diameters below grade, confining pressure, \( P \), is found by using the modified Marston equation (ref. [9]).

\[ P = wCDB_D \text{lb/in.}^2 \]

where

\( B_D \) = the trench width, with a maximum value of 24 in. plus the pipe diameter

\( C_D \) = a dimensionless parameter obtained from Table VII-3.2.3-1

### VII-3.2.4 Pipe/Soil System Characteristic (ref. [2])

\[ \beta = \left( \frac{k}{4EI} \right)^{1/4}, \text{in.}^{-1} \]  

where

\( E \) = Young’s modulus for pipe, psi

\( I \) = area moment of inertia for pipe, in.⁴

\( k \) = soil modulus of subgrade reaction \( k_h \) or \( k_v \), psi

### VII-3.2.5 Minimum Slippage Length, \( L_m \) (ref. [1])

\[ L_m = \varepsilon AE/f, \text{in.} \]

where

\( A \) = pipe cross section area

### VII-3.3 Classification of the Pipe Runs

#### VII-3.3.1 Purpose.
The classification and subclassification of the buried pipe elements are used in choosing the proper equation for effective slippage length, \( L’ \) or \( L” \), which is then used in calculating piping forces and stresses. The pipe segment identified by the dimension \( L’ \) or \( L” \) always begins at an elbow, bend, tee, or branch connection and terminates at the point (described below as the “virtual anchor”) at which there is no slippage or relative movement at the pipe/soil interface.

#### VII-3.3.2 Classification of the Pipe Elements.
It is in the bends, elbows, and branch connections that the highest stresses are found in buried piping subject to thermal expansion of the pipe. These stresses are due to the soil forces that bear against the transverse run (the run running perpendicular or at some angle to the direction of the pipe expansion). The stresses are proportional to the amount of soil deformation at the elbow or branch connection.

Piping elements are divided into three major categories depending on what type of transverse element is being analyzed, as follows:

- **Category A**: elbow or bend (see Figure VII-3.3.2-1)
- **Category B**: branch pipe joining the longitudinal run (see Figure VII-3.3.2-2)
- **Category C**: longitudinal run ending in a tee (see Figure VII-3.3.2-3)
- **Category D**: straight pipe, no branch or transverse run (see Figure VII-3.3.2-4)

---

### Table VII-3.2.3-1

**Approximate Safe Working Values of \( C_D \) for Use in Modified Marston Formula**

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<th>Ratio ( H/BD )</th>
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<th>Saturated Top Soil</th>
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<th>Saturated Yellow Clay</th>
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<tr>
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<td>3.63</td>
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</tr>
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<td>3.34</td>
<td>3.72</td>
<td>4.34</td>
</tr>
<tr>
<td>( \infty )</td>
<td>3.03</td>
<td>3.38</td>
<td>3.79</td>
<td>4.50</td>
</tr>
</tbody>
</table>
VII-3.2 Calculations of Intermediate Parameters

The parameters specified in paras. VII-3.2.1 through VII-3.2.6 shall be calculated.

VII-3.2.1 Maximum Relative Strain, $\varepsilon$, at the Pipe/Soil Interface, in./in. For thermal expansion, this is the unit thermal elongation of the unrestrained pipe

$$\varepsilon = a(T - T_o)$$

where

- $T - T_o = \text{difference between operating and installation temperatures} \, ^\circ F \left( ^\circ C \right)$
- $a = \text{coefficient of thermal expansion}\, \text{in./in./}^\circ F \left( \text{mm/mm}/^\circ C \right)$

VII-3.2.2 Modulus of Subgrade Reaction, $k_h$, psi. This is a factor that defines the resistance of the soil or backfill to pipe movement due to the bearing pressure at the pipe/soil interface. Several methods for calculating $k_h$ have been developed by Audibert and Nyman (ref. [7]), Trautmann and O’Rourke (ref. [8]), and others ([refs. [4], [5], [6]]). For example (ref. [8]), for pipe movement horizontally, the modulus of subgrade, $k_h$, may be found by

$$k_h = C_h N_h w D, \text{ psi} (\text{MPa})$$

where

- $C_h = \text{a dimensionless factor for estimating horizontal stiffness of compacted backfill}. C_h$ may be estimated at 20 for loose soil, 30 for medium soil, and 80 for dense or compacted soil.
- $D = \text{pipe outside diameter, in. (mm)}$
- $N_h = \text{a dimensionless horizontal force factor from Figure 8 of ref. [8]. For a typical value where the soil internal friction angle is 30 deg., the curve from ref. [8] may be approximated by a straight line defined by}$

$$N_h = 0.285H/D + 4.3$$

where

- $H = \text{the depth of pipe below grade at the pipe centerline, in. (mm)}$
- $w = \text{soil density, lbm/in}^3 \left( \text{kg/mm}^3 \right)$

For pipe movement upward or downward, the procedures recommended in ref. [4] may be applied. Conservatively, the resistance to upward movement may be considered the same as for horizontal movement with additional consideration for the weight of the soil. Resistance to downward movement may conservatively be considered as rigid for most expansion stress analysis.
VII-3.2.3 Unit Friction Force at the Pipe/Soil Interface, \( f \)

\[
f = \mu (P_c + W_p), \text{lbf/in.} \text{ lbm/in.} \text{ (N/mm)} \quad (3)
\]

where

- \( A_c \) = surface area of a pipe segment, \( \text{in.}^2 \text{ (mm}^2) \)
- \( P_c \) = confining pressure of soil on pipe, psi (MPa)
- \( W_p \) = unit weight of pipe and contents, lbm/in. \text{ lbm/in.} \text{ (kg/mm)}
- \( \mu \) = coefficient of friction between pipe and soil

For piping that is buried within 3 pipe diameters of the surface, confining pressure, \( P_c \), may be estimated by

\[
P_i = wH, \text{ lbm/in.}^2 \text{ psi (MPa)}
\]

where

- \( H \) = the depth below grade, \text{in.} \text{ (mm)}
- \( w \) = the soil density, \text{ lbm/in.}^3 \text{ (kg/mm}^3) \)

For piping that is buried more than 3 pipe diameters below grade, confining pressure, \( P_c \), is found by using the modified Marston equation (ref. [9]),

\[
P_i = wCDB_D, \text{ lbm/in.}^2 \text{ psi (MPa)}
\]

where

- \( B_D \) = the trench width, with a maximum value of 24 in. \text{ (610 mm)}
- plus the pipe diameter, \text{ in. (mm)}
- \( C_D \) = a dimensionless parameter obtained from Table VII-3.2.3-1

**Table VII-3.2.3-1 Approximate Safe Working Values of \( C_D \) for Use in Modified Marston Formula**

<table>
<thead>
<tr>
<th>( \frac{H}{B_D} )</th>
<th>Damp Top Soil and Dry Sand</th>
<th>Saturated Top Soil</th>
<th>Damp Yellow Clay</th>
<th>Saturated Yellow Clay</th>
</tr>
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<tr>
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<td>2.02</td>
<td>2.98</td>
<td>3.79</td>
<td>4.50</td>
</tr>
</tbody>
</table>
VII-3.2.4 Pipe/Soil System Characteristic (ref. [2])

\[ \beta = \left( \frac{k}{4El} \right)^{1/4}, \text{in}^{-1} (\text{mm}^{-1}) \]  \hspace{1cm} (4)

where

\( E \) = Young’s modulus for pipe, psi (MPa)
\( l \) = area moment of inertia for pipe, in.\(^4\) (mm\(^4\))
\( k \) = soil modulus of subgrade reaction \( k_n \) or \( k_m \), psi (MPa)

VII-3.2.5 Minimum Slippage Length, \( L_m \) (ref. [1])

\[ L_m = \frac{eAE}{f}, \text{in} \ (\text{mm}) \]  \hspace{1cm} (5)

where

\( A \) = pipe cross section area \ in.\(^2\) (mm\(^2\))

VII-3.2.6 Maximum Axial Force, \( F_{max} \) in the Longitudinal Pipe Run. The maximum axial force in a pipe long enough for friction force to develop to the point where a region of the pipe is totally restrained longitudinally by the soil is found by

\[ F_{max} = fL_m = eAE\gamma lbf (N) \]  \hspace{1cm} (6)
Categories A, B, and C are further divided into three subcategories depending on the configuration of the pipe run at the end opposite that being analyzed. The piping elements are classified as follows:

- **A1, B1, C1**: other end free or terminating in a flexible coupling or joint
- **A2, B2, C2**: other end contains an elbow or tee
- **A3, B3, C3**: other end is anchored

Category D elements include straight runs between an anchor (either actual or virtual) and a free end or a pipe section that is connected to an expansion joint.

The elements are further broken down into subtypes depending on whether the longitudinal run (the pipe or P leg) and the transverse run (called the T leg) are long or short with respect to certain criteria. The transverse or T leg is the run against which the soil bears, producing an in-plane bending moment in elbow, branch, or tee. (Category D elements have no transverse leg.)

The strict criterion for a long or short transverse leg is whether the length of the transverse run, \( L_1 \), is longer or shorter than \( 3\pi/4\beta \), the length at which the hyperbolic functions in Hetenyi's equations (ref. [2]) approach unity. The critical value for \( L_1 \) is often called the "influence" length, or that portion of the transverse or T run that is deflected or "influenced" by seismic soil strain or pipe thermal expansion along the axis of the longitudinal or P run. In practice, a critical influence length, \( L_1 \), of \( 1/\beta \) to \( 1.2/\beta \) may often be used, since there is very little deformation or load in that portion of the transverse run that exceeds this length. This implies that the vast majority of the bearing load on the transverse or T leg occurs in the first several feet of the pipe at the bend or branch. In summary, a transverse pipe is "long" if

\[
L_1 \geq 3\pi/4\beta \text{ (conservative)}
\]

or

\[
L_1 \geq 1/\beta \text{ to } 1.2/\beta \text{ (usually acceptable)}
\]

The criterion for a short or long P leg is whether its length, \( L_2 \), is sufficiently long to experience the maximum force that can develop at the friction interface. For full maximum friction force \( F_{\text{max}} = \varepsilon AE \) to occur in a straight pipe axially free at each end, its length, \( L_2 \), would have to equal or exceed \( 2L_m \) with \( L_m \) calculated by eq. (5). If one end terminates in an elbow or a tee, with the other end remaining axially unrestrained, the total length, \( L_2 \), necessary for full friction to develop is \( L'' + L_m \); the friction force over \( L_m \) is equal to the soil bearing force, \( S \), plus the friction force acting on the length, \( L' \) or \( L'' \), which is called the effective slippage length. The effective slippage length is the maximum length along which slippage occurs at the pipe/soil interface of a pipe with a transverse leg or branch. The effective slippage length, \( L'' \), for long pipes with long transverse legs is calculated by

\[
L'' = \Omega\left(1 + 2F_{\text{max}}/f\Omega\right)^{1/2} - 1 \text{, in.} \tag{7}
\]

where

\[
\Omega = AE\beta/k
\]

and \( F_{\text{max}} \) is calculated by eq. (6).
Equation (7) applies to bends, tees, and branches. Although eq. (7) was developed for the case where \( L_2 = L'' + L_m \), it applies also for any case where \( L_2 > L'' + L_m \) since the length of the region where there is zero slippage at the friction interface is immaterial (ref. [1]). Using \( L'' \) as calculated by eq. (7), it can now be established that a P leg is classified as long if it meets the following criteria:

(a) for Types A1, B1, and C1, \( L_2 \geq L_m + L'' \)
(b) for Types A2, B2, and C2, \( L_2 \geq 2L'' \)
(c) for Types A3, B3, C3, and D, \( L_2 \geq L'' \)

The point located a distance \( L' \) or \( L'' \) from the bend, branch, or tee is called the virtual anchor, since it acts as if it were a three-axis restraint on the pipe.

### VII-3.3.3 Locating the Virtual Anchor
Calculation of the forces and moments in buried piping at changes in direction requires that the location of the virtual anchor (the effective slippage length, \( L' \), away from the bend or branch element) in the P run and deformation, \( \delta \), of the soil at the buried element be established. For elements of all types with long P legs, \( L'' \) may be calculated by eq. (7).

For Types A1, B1, and C1 elements (with one end of the P leg free or unrestrained axially) with "short" P legs, \( L' \) must be found by a less direct method as follows (ref. [1]):

\[
L' = \left[-b + \left(b^2 - 4ac\right)^{1/2}\right]/2a, \text{ in.}
\]  

(9)

where

\[
a = 3f/(2AE)
\]

\[
b = -fL_2/(AE) + 2f\beta/k
\]

\[
c = -f\beta L_2/k
\]

However, the most highly stressed runs in a buried piping system typically are restrained at both ends, by either a combination of transverse runs or a transverse and an anchor (either real or virtual).

For Types A2, B2, and C2 elements with short P legs, \( L' \) is expressed by

\[
L' = L_2/2, \text{ in.}
\]  

(10)

For Types A3, B3, C3, and D elements with short P legs, \( L' \) is expressed by

\[
L' = L_2, \text{ in.}
\]  

(11)

### VII-4 COMPUTER MODELING OF BURIED PIPING

#### VII-4.1 Determination of Stresses

With \( f, k, \) and \( L' \) or \( L'' \) established, the stresses in a buried pipe due to thermal expansion can be determined with a general-purpose pipe stress computer program. A buried piping system can be modeled with a typical mainframe or microcomputer pipe stress program by breaking the buried portions into elements of convenient length and then imposing a transverse spring at the center of each element to simulate the passive resistance of the soil. The entire pipe can be divided into spring-restrained elements in this manner; however, the only regions of the pipe that really need to be modeled in this manner are the lengths entering and leaving elbows or tees. The analyst should refer to the program users’ manual for guidance in modeling soil springs.

All pipe stress computer programs with buried piping analysis options require that the following factors be calculated or estimated:

(a) location of the virtual anchor (dimension \( L' \) or \( L'' \))
(b) soil spring rate, \( k_{i,j} \) which is a function of the modulus of subgrade reaction, \( k \)
(c) influence length, also a function of \( k \)

Some programs ignore the friction at the pipe/soil interface; this is conservative for calculating bending stresses on the buried elbows and branch connections but may be unconservative for calculating anchor reactions.

#### VII-4.2 Determination of Element Lengths

The element lengths and transverse soil spring rates for each element are calculated by the following procedure.

**VII-4.2.1** Establish the element length, \( dL \), and the number \( n \) of elements, as follows:

(a) Set the element length to be equal to between 2 and 3 pipe diameters. For example, \( dL \) for an NPS 6 may be set at either 1 ft or 2 ft, whichever is more convenient for the analyst.

(b) Establish the number of elements, \( n \), by

\[
n = (3\pi/4\beta)/dL
\]  

(11)

This gives the number of elements, each being \( dL \) inches in length, to which springs are to be applied in the computer model. The number of elements, \( n \), is always rounded up to an integer.

**VII-4.2.2** Calculate the lateral spring rate, \( k_{i,j} \) to be applied at the center of each element.

\[
k_{i,j} = kdL, \text{ lbf/in.}
\]  

(12)

where

\[
k = \text{the modulus of subgrade reaction calculated from eq. (2)}.
\]

**VII-4.2.3** Calculate the equivalent axial load necessary to simulate friction resistance to expansion. The friction resistance at the pipe/soil interface can be simulated in the computer model by imposing a single force \( F_j \) in a direction opposite that of the thermal growth.

\[
F_j = fL'/2 \text{ or } fL''/2, \text{ lb}
\]  

(13)

**VII-4.2.4** Incorporate the springs and the friction force in the model. The mutually orthogonal springs \( k_{i,j} \) are applied to the center of each element, perpendicular to the pipe axis. Shorter elements, with proportionally
smaller values for the springs on these elements, may be necessary to model the soil restraint at elbows and bends. The friction force, \( F_f \), for each expanding leg is imposed at or near the elbow tangent node, opposite to the direction of expansion.

**VII-4.3 Determination of Soil Parameters**

Soil parameters are difficult to establish accurately due to variations in backfill materials and degree of compaction. Consequently, values for elemental spring constants on buried pipe runs can only be considered as rational approximations. Stiffer springs can result in higher elbow stresses and lower bending stresses at nearby anchors, while softer springs can have the opposite effects. Backfill is not elastic; testing has shown that soil is stiffest for very small pipe movements, but becomes less stiff as the pipe movements increase. References [4], [7], and [8] discuss soil stiffness and recommend procedures for estimating values for \( k \) that are consistent with the type of soil and the amount of pipe movement expected. The analyst should consult the project geotechnical engineer for assistance in resolving any uncertainties in establishing soils parameters, such as the modulus of subgrade reaction, \( k \); confining pressure, \( p_c \); and coefficient of friction, \( \mu \).

**VII-4.4 Pipe With Expansion Joints**

An expansion joint must be considered as a relatively free end in calculating stresses on buried elbows and loads on anchors. Since incorporation of expansion joints or flexible couplings introduces a structural discontinuity in the pipe, the effects of the unbalanced pressure load and the axial joint friction or stiffness must be superimposed on the thermal expansion effects to determine the maximum pipe stresses and anchor loads.

**VII-4.5 Pipe Stresses at Building Penetrations**

Stresses at building penetrations can be calculated easily after the reactions due to thermal expansion in the buried piping have been determined. If the penetration is an anchor, then the stress due to the axial force, \( F_{\text{max}} \), and the lateral bending moment, \( M \), can be found by

\[
S_E = \frac{F_{\text{max}}}{A + M/Z}, \text{ psi (MPa)} \quad (14)
\]

If the penetration is not an anchor, but is instead a simple support with a flexible water seal, it is necessary to determine the stiffness effects of the water seal material to calculate the stress in the pipe at the penetration. Differential movement due to building or trench settlement can generate high theoretical stresses at piping penetrations to buildings. Calculation of such stresses is beyond the scope of this Appendix.

**VII-5 ALLOWABLE STRESS IN BURIED PIPE**

Buried piping under axial stress can theoretically fail in one of two ways — either by column buckling (pipe pops out of the ground at mid-span) or local failure by crippling or tensile failure (much more serious than column buckling). Since buried piping stresses are secondary in nature, and since the piping is continuously supported and restrained (see Figure VII-5-1), higher total stresses may be permitted as follows:

\[
S_C \leq S_A + S_h \quad (15)
\]

where \( S_A \) and \( S_h \) are as defined in para. 102.3.2.

**VII-6 EXAMPLE CALCULATIONS**

**VII-6.1 Assemble the Data**

**VII-6.1.1 Pipe Data**

(a) diameter, \( D = 12.75 \) in.
(b) wall thickness = 0.375 in.
(c) length of runs
   
   (1) Run 1: \( L_1 = 100 \) ft, \( L_2 = 400 \) ft
   (2) Run 2: \( L_1 = 20 \) ft, \( L_2 = 100 \) ft
   (3) Run 3: \( L_1 = 100 \) ft, \( L_2 = 20 \) ft
(d) Young’s modulus, \( E = 27.9 \times 10^6 \) psi
(e) moment of inertia, \( I = 279.3 \) in.\(^4\)
(f) cross section metal area, \( A = 14.57 \) in.\(^2\)

**VII-6.1.2 Soil Characteristics**

(a) soil density, \( w = 130 \) lb/ft\(^3\)
(b) pipe depth below grade, \( H = 12 \) ft (144 in.)
(c) type of backfill: dense sand
(d) trench width, \( B_d = 3 \) ft (36 in.)
(e) coefficient of friction, \( \mu = 0.3 \) minimum to 0.5 maximum (estimated)
(f) horizontal soil stiffness factor, \( C_k = 80 \)

**VII-6.1.3 Operating Conditions**

(a) pressure, \( P = 100 \) psig
(b) temperature = 140°F
(c) ambient temperature = 70°F

**Figure VII-5-1**

Plan of Example Buried Pipe

Pipe: NPS 12
Material: ASME SA-106 Grade B C.S.
Depth below grade: 12 ft
Trench width: 3 ft
L.R. elbow (typical)
VII-6.2 Calculate the Intermediate Parameters

VII-6.2.1 Relative Strain at the Pipe/Soil Interface.
Thermal expansion for ASME SA-106 Grade B carbon steel pipe from 70°F to 140°F is 0.0053 in./ft. Therefore,
\[
\varepsilon = \frac{(0.0053 \text{ in./ft})}{(12 \text{ in./ft})} = 0.000424 \text{ in./in.}
\]

VII-6.2.2 Modulus of Subgrade Reaction, \(k\) (ref. [8]).
Since the expansion is in the horizontal plane, use \(k_h\) from eq. (2).
\[
k_h = C_k N_h \omega D
\]
\[
C_k = 80
\]
\[
N_h = 0.285 \frac{H}{D} + 4.3
\]
\[
= 0.285(12 \text{ ft})(12 \text{ in./ft})/12.75 \text{ in.} + 4.3
\]
\[
= 7.519
\]
\[
\omega = \left(130 \text{ lb/ft}^3\right)/\left(1,728 \text{ in.}^3/\text{ft}^3\right)
\]
\[
= 0.0752 \text{ lb/in.}^3
\]
\[
D = 12.75 \text{ in.}
\]
\[
k_h = (80)(7.519)(0.0752)(12.75) = 577 \text{ lb/in.}^2
\]

VII-6.2.3 Friction Forces per Unit Length Acting at the Pipe/Soil Interface
\[
f = \mu \left(P_c A_c + W_p\right)
\]
Since the pipe lies more than 3 diameters below grade, the modified Marston equation from ref. [1] is used to determine the confining pressure \(P_c\) of soil on the pipe.
\[
P_c = wC_D R_d
\]
\[
C_D = 2.22 \text{ for } H/B_d = 12 \text{ ft}/3 \text{ ft}
\]
\[
= 4 \text{ (see Table VII-3.2.3-1 for sand)}
\]
\[
P_c = \left(130 \text{ lb/ft}^3\right)(2.22)(3 \text{ ft})/\left(144 \text{ in.}^2/\text{ft}^2\right)
\]
\[
= 6.01 \text{ psi}
\[
A_c = D(1 \text{ in.}) = (12.75 \text{ in.})(1 \text{ in.})
\]
\[
= 40.05 \text{ in.}^2/\text{in. of length}
\]
\[
W_p = 8.21 \text{ lb/in. for water-filled carbon steel pipe}
\]
Maximum value of friction force per unit length, \(f_{max}\)
\[
f_{max} = 0.5 \left(6.01 \text{ psi}\right)\left(40.05 \text{ in.}^2/\text{in.}\right) + 8.21 \text{ lb/in.}
\]
\[
= 124.5 \text{ lb/in.}
\]
Minimum value of friction force per unit length, \(f_{min}\)
\[
f_{min} = 0.3(6.01)(40.05) + 8.21
\]
\[
= 74.7 \text{ lb/in.}
\]

VII-6.2.4 Pipe/Soil System Characteristic, \(\beta\) (ref. [2])
\[
\beta = \left[k_h/(4EI)^{1/4}\right]
\]
\[
= \left[577 \text{ psi}/4\left(27.9 \times 10^6 \text{ psi}\right)\left(279.3 \text{ in.}^4\right)\right]^{1/4}
\]
\[
= 0.01166 \text{ in.}^{-1}
\]

VII-6.2.5 Minimum Slippage Length, \(L_m\)
\[
L_m = \varepsilon A E / f_{min}
\]
\[
= \left(0.000424 \text{ in./in.}\right)\left(14.57 \text{ in.}^2\right)\left(27.9 \times 10^6 \text{ psi}\right)
\]
\[
/74.7 \text{ lb/in.}
\]
\[
= 2,307 \text{ in. or } 192 \text{ ft 4 in.}
\]

VII-6.2.6 Maximum Axial Force, \(F_{max}\), Corresponding to \(L_m\)
\[
F_{max} = \varepsilon A E = \left(0.000424\right)(14.57)(27.9 \times 10^6)
\]
\[
= 172,357 \text{ lb}
\]

VII-6.3 Classification of Runs
Classify the pipe runs in accordance with the models given in Table VII-6.3-1 and calculate the effective slippage length, \(L'\) or \(L''\), for each run.

VII-6.3.1 Run 1 is a Category A1 (elbow on one end, the other end free). Check to see if the transverse leg, \(L_1\), is long or short.
\[
L_1 = 1,200 \text{ in.}
\]
\[
3\pi/\left(4\right)\left(0.01166 \text{ in.}^{-1}\right) = 202 \text{ in.}
\]
Since 1,200 in. > 202 in., \(L_1\) is long. Check to see if the longitudinal leg, \(L_2\), is long or short, that is, longer or shorter than \(L_m + L''\). Using eq. (7) to calculate \(L''\),
\[
L'' = \Omega (1 + 2F_{max}/f_{min} \Omega)^{1/2} - 1
\]
### Table VII-6.3-1

**Equations for Calculating Effective Length \( L' \) or \( L'' \)**

<table>
<thead>
<tr>
<th>Element Category</th>
<th>( L' ) for Short P Leg</th>
<th>( L'' ) for Long P Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1, B1, C1</td>
<td>If ( L_2 &lt; L_m + L'' ), ( L' = \frac{-b + (b^2 - 4ac)^{1/2}}{2a} ) [(8)]</td>
<td>If ( L_2 \geq L_m + L'' ), ( L'' = \left[ \frac{1 + 2F_{max}/f_{min}}{\Omega} - 1 \right] {1/2} ) [(7)]</td>
</tr>
<tr>
<td></td>
<td>where ( a = \frac{3f}{2AE} ) ( b = \varepsilon - \beta_2/(AE) + 2\beta/k )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( c = -f\beta_2/k )</td>
<td></td>
</tr>
<tr>
<td>A2, B2, C2</td>
<td>If ( L_2 &lt; 2L'' ), ( L' = L_2/2 ) [(9)]</td>
<td>If ( L_2 \geq 2L'' ), ( L'' = \left[ \frac{1 + 2F_{max}/f_{min}}{\Omega} - 1 \right] {1/2} ) [(7)]</td>
</tr>
<tr>
<td>A3, B3, C3</td>
<td>If ( L_2 &lt; L'' ), ( L' = L_2 ) [(10)]</td>
<td>If ( L_2 \geq L'' ), ( L'' = \left[ \frac{1 + 2F_{max}/f_{min}}{\Omega} - 1 \right] {1/2} ) [(7)]</td>
</tr>
<tr>
<td>D</td>
<td>If ( L_2 &lt; L_m ), ( L' = L_2 ) [(10)]</td>
<td>If ( L_2 \geq L_m ), ( L'' = L_m = \varepsilon AE/f ) [(5)]</td>
</tr>
</tbody>
</table>

\[ \Omega = \frac{AE\beta}{k} = \left( 14.57 \text{ in.}^2 \right) \left( 27.9 \times 10^6 \text{ psi} \right) \times \left( 0.01166 \text{ in.}^{-1} \right) /577 \text{ psi} = 8,214 \text{ in.} \]

\[ L'' = 8,214 \left\{ \left[ 1 + 2 \times 172,357/(74.7 \times 8,214) \right]^{1/2} - 1 \right\} = 2,051 \text{ in.} \]

\[ L_m + L'' = 2,307 + 2,051 = 4,358 \text{ in.} \]

\( L_2 = 400 \text{ ft or 4,800 in.} \) and since \( 4,800 > 4,358 \), the pipe run length \( L_2 \) is long, and Run 1 can be fully classified as Category A1 (long transverse, long pipe).

**NOTE:** If \( L_m + L'' \) would have exceeded \( L_2 \), then \( L' \) would be recalculated using eq. \((8)\), the correct equation for a short pipe.

#### VII-6.3.2 Run 2 is a Category A2 (elbow on each end).

Check to see if the legs \( L_1 \) and \( L_2 \) are long or short.

Since \( L_1 > 3\pi/4\beta \) (240 in. > 202 in.) and \( L_2 < 2L'' \) (1,200 in. < 2(2,051 in.)], then Run 2 can be fully classified as a Category A2 (long transverse, short pipe). Then \( L' = L_2/2 = (1,200 \text{ in.})/2 = 600 \text{ in.} \)

#### VII-6.3.3 Run 3 is a Category A3 (anchor on one end, elbow on the other).

Check to see if the legs \( L_1 \) and \( L_2 \) are long or short.

Since \( L_1 > 3\pi/4\beta \) (1,200 in. > 202 in.) and \( L_2 < L'' \) (240 in. < 2,051 in.), then Run 3 can be fully classified as a Category A3 (long transverse, short pipe). Then

\[ L' = L_2 = 240 \text{ in.} \]

**NOTE:** If fully qualify a buried piping system, it may also be necessary to include stresses due to weight of overburden (backfill) and vehicular loads (refs. [5], [6]).

#### VII-6.4 Computer Modeling

Calculate the soil springs and friction force for use in a computer model of the buried pipe.

**VII-6.4.1 Element Length.** Set the element length to be \( \approx 3 \text{ pipe diameters} \).

\[ dL = 36 \text{ in.} \]

**VII-6.4.2 Number of Elements.** Only the soil within a length \( \frac{3\pi}{4\beta} \) from the elbow will be subject to bearing force from the pipe. For the example system, \( \frac{3\pi}{4\beta} = 202 \text{ in.} \) Therefore, the number of elements needed is found by

\[ n = \frac{(3\pi/4\beta)}{dL} = \frac{202}{36} = 5.61 \]

Therefore, use six elements, each 36 in. long.

**VII-6.4.3 Spring Rate, \( k_{i,j} \).** The spring rate to be applied to each element is found by

\[ k_{i,j} = kdL \]

where \( k \) is from eq. \((2)\)

\[ k_{i,j} = (577 \text{ psi})(36 \text{ in.}) = 20,772 \text{ lb/in.} \]
This is the theoretical spring rate to be imposed at the center of each element and normal to the surface of the pipe, with \( k_i \) in the plane of the expansion, and \( k_j \) perpendicular to the plane of expansion.

**VII-6.4.4 Friction Force, \( F_f \).** The friction forces to be applied at the elbow tangent points in Runs 1 and 2 are calculated as follows:

Parallel to Run 1,

\[
F_f = \frac{fL''}{2}
\]

where

\[
\begin{align*}
  f &= f_{\text{min}} = 74.7 \text{ lb/in.} \\
  L'' &= 2,051 \text{ in.}
\end{align*}
\]

\[
F_f = \frac{(74.7 \text{ lb/in.})(2,051 \text{ in.})}{2} = 76,605 \text{ lb}
\]

Parallel to Run 2,

\[
F_f = \frac{(74.7 \text{ lb/in.})(600 \text{ in.})}{2} = 22,410 \text{ lb}
\]

The friction force to be applied at the elbow tangent point in Run 3 is calculated as follows:

Parallel to Run 3,

\[
F_f = \frac{(74.7 \text{ lb/in.})(240 \text{ in.})}{2} = 8,964 \text{ lb}
\]

The computer model then appears as is shown in Figure VII-6.4.4-1.

**VII-6.5 Results of Analysis**

Computer analysis of the model shown in Figure VII-6.4.4-1 gives combined stress, \( SC \), at various locations in the buried pipe as follows:

<table>
<thead>
<tr>
<th>Location</th>
<th>( SC ), psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual anchor</td>
<td>7,036</td>
</tr>
<tr>
<td>Elbow A</td>
<td>26,865</td>
</tr>
<tr>
<td>Elbow B</td>
<td>9,818</td>
</tr>
<tr>
<td>Penetration anchor</td>
<td>2,200</td>
</tr>
</tbody>
</table>

NOTE: \( SC \) for this example includes longitudinal pressure stress, intensified bending stresses, and direct stresses due to axial loads from friction and soil bearing loads. It does not include weight of backfill or live loads.

The allowable stress as given by eq. (15) is \( S_A + S_b \) which for ASME SA-106 Grade B steel pipe is 22,500 psi + 15,000 psi = 37,500 psi. Therefore, since the maximum \( SC \) of 26,865 psi < 37,500 psi, the Code conditions are met.

**VII-6.6 Anchor Load Example**

If Element 1 is simply a straight pipe anchored at one end with the other end terminating in an expansion joint (see Figure VII-6.6-1), the load on the anchor is found as follows:

(a) Calculate the maximum friction force acting along the friction interface.

\[
F_f = F_{\text{max}} = cAE
\]

\[
F_{\text{max}} = cAE = (0.000424)(14.57)(27.9 \times 10^6) = 172,357 \text{ lb}
\]

(b) Calculate the load, \( S \), at the expansion joint.

\[
S = F_f + S_p
\]

where

\[
\begin{align*}
  F_f &= \text{expansion joint friction force} \\
  S_p &= \text{pressure force} \\
        &= PA_s
\end{align*}
\]

where

\[
\begin{align*}
  P &= \text{design pressure} \\
  &= 100 \text{ psig} \\
  A_s &= \text{effective cross-sectional area} \\
  &= \pi D^2/4 \\
  &= \pi (12.75^2)/4 \\
  &= 127.6 \text{ in.}^2 \\
  &= (100)(127.6) = 12,760 \text{ lb}
\end{align*}
\]

\[
S = 9,000 + 12,760 = 21,760 \text{ lb}
\]

(c) The total axial load, \( F_a \), at the anchor then becomes

\[
F_a = 172,357 + 21,760 = 194,117 \text{ lb}
\]

If anchor loads must be limited, then the expansion joint should be located closer to the anchor to reduce the force due to friction at the pipe/soil interface.

**VII-7 REFERENCES**


Figure VII-3.3.2-3 Element Category C, Tee on End of P Leg

Figure VII-3.3.2-4 Element Category D, Straight Pipe

NOTE: (1) Expansion joint pressure load plus sliding or convolution loads.

Category D elements include straight runs between an anchor (either actual or virtual) and a free end or a pipe section that is connected to an expansion joint.

The elements are further broken down into subtypes depending on whether the longitudinal run (the pipe or P leg) and the transverse run (called the T leg) are long or short with respect to certain criteria. The transverse or T leg is the run against which the soil bears, producing an in-plane bending moment in elbow, branch, or tee. (Category D elements have no transverse leg.)

The strict criterion for a long or short transverse leg is whether the length of the transverse run, \( L_1 \), is longer or shorter than \( 3\pi/4\beta \), the length at which the hyperbolic functions in Hetenyi's equations (ref. [2]) approach unity. The critical value for \( L_1 \) is often called the "influence" length, or that portion of the transverse or T run that is deflected or "influenced" by seismic soil strain or pipe thermal expansion along the axis of the longitudinal or P run. In practice, a critical influence length, \( L_1 \), of \( 1/\beta \) to \( 1.2/\beta \) may often be used, since there is very little deformation or load in that portion of the transverse run that exceeds this length. This implies that the vast majority of the bearing load on the transverse or T leg occurs in the first several feet of the pipe at the bend or branch. In summary, a transverse pipe is "long" if

\[
L_1 \geq 3\pi/4\beta \quad \text{(conservative)} \quad \text{in. (mm)}
\]

or

\[
L_1 \geq 1/\beta \quad \text{to} \quad 1.2/\beta \quad \text{(usually acceptable)} \quad \text{in. (mm)}
\]

The criterion for a short or long P leg is whether its length, \( L_2 \), is sufficiently long to experience the
maximum force that can develop at the friction interface. For full maximum friction force \( F_{\text{max}} = \varepsilon AE \) to occur in a straight pipe axially free at each end, its length, \( L_2 \), would have to equal or exceed \( 2L_m \) with \( L_m \) calculated by eq. (5). If one end terminates in an elbow or a tee, with the other end remaining axially unrestrained, the total length, \( L_2 \), necessary for full friction to develop is \( L'' + L_m \); the friction force over \( L_m \) is equal to the soil bearing force, \( S \), plus the friction force acting on the length, \( L' \) or \( L'' \), which is called the effective slippage length. The effective slippage length is the maximum length along which slippage occurs at the pipe-soil interface of a pipe with a transverse leg or branch. The effective slippage length, \( L'' \), for long pipes with long transverse legs is calculated by

\[
L'' = \Omega \left[ 1 + 2F_{\text{max}}/\Omega \right]^{1/2} - 1 \text{ in. (mm)}
\]

where

\[
\Omega = \frac{AE\beta}{k} \text{ in. (mm)}
\]

and \( F_{\text{max}} \) is calculated by eq. (6).

Equation (7) applies to bends, tees, and branches. Although eq. (7) was developed for the case where \( L_2 = L'' + L_m \), it applies also for any case where \( L_2 > L'' + L_m \), since the length of the region where there is no slippage at the friction interface is immaterial (ref. [1]). Using \( L'' \) as calculated by eq. (7), it can now be established that a P leg is classified as long if it meets the following criteria:

(a) for Types A1, B1, and C1, \( L_2 \geq L_m + L'' \)

(b) for Types A2, B2, and C2, \( L_2 \geq 2L'' \)

(c) for Types A3, B3, C3, and D, \( L_2 \geq 2L'' \)

The point located a distance \( L' \) or \( L'' \) from the bend, branch, or tee is called the virtual anchor, since it acts as if it were a three-axis restraint on the pipe.

**VII-3.3.3 Locating the Virtual Anchor.** Calculation of the forces and moments in buried piping at changes in direction requires that the location of the virtual anchor (the effective slippage length, \( L' \), away from the bend or branch element) in the P run and deformation, \( \delta \), of the soil at the buried element be established. For elements of all types with long P legs, \( L'' \) may be calculated by eq. (7).

For Types A1, B1, and C1 elements (with one end of the P leg free or unrestrained axially) with "short" P legs, \( L' \) must be found by a less direct method as follows (ref. [1]):

\[
L' = \left[ -b + \left( b^2 - 4ac \right)^{1/2} \right] / 2a \text{ in. (mm)}
\]

where

\[
a = 3f/(2AE) \text{ in.}^{-1} \text{ (mm)}^{-1}
\]

\[
b = fL_2/(AE) + 2f\beta/k \text{ dimensionless}
\]

\[
c = -f\beta L_2/k \text{ in. (mm)}
\]

However, the most highly stressed runs in a buried piping system typically are restrained at both ends, by either a combination of transverse runs or a transverse and an anchor (either real or virtual).

For Types A2, B2, and C2 elements with short P legs, \( L' \) is expressed by

\[
L' = L_2/2 \text{ in. (mm)}
\]

For Types A3, B3, C3, and D elements with short P legs, \( L' \) is expressed by

\[
L' = L_2 \text{ in. (mm)}
\]
VII-4 COMPUTER MODELING OF BURIED PIPING

VII-4.1 Determination of Stresses

With \( f, k, \) and \( L' \) or \( L'' \) established, the stresses in a buried pipe due to thermal expansion can be determined with a general-purpose pipe stress computer program. A buried piping system can be modeled with a typical mainframe or microcomputer pipe stress program by breaking the buried portions into elements of convenient length and then imposing a transverse spring at the center of each element to simulate the passive resistance of the soil. The entire pipe can be divided into spring-restrained elements in this manner; however, the only regions of the pipe that really need to be modeled in this manner are the lengths entering and leaving elbows or tees. The analyst should refer to the program users' manual for guidance in modeling soil springs.

All pipe stress computer programs with buried piping analysis options require that the following factors be calculated or estimated:

(a) location of the virtual anchor (dimension \( L' \) or \( L'' \))

(b) soil spring rate, \( k_{ij} \), which is a function of the modulus of subgrade reaction, \( k \)

(c) influence length, also a function of \( k \)

Some programs ignore the friction at the pipe-soil interface; this is conservative for calculating bending stresses on the buried elbows and branch connections but may be unconservative for calculating anchor reactions.

VII-4.2 Determination of Element Lengths

The element lengths and transverse soil spring rates for each element are calculated by the following procedure.

VII-4.2.1 Establish the element length, \( dL \), and the number \( n \) of elements, as follows:

(a) Set the element length to be equal to between 2 and 3 pipe diameters. For example, \( dL \) for a NPS 6 may be set at either 1 ft or 2 ft, whichever is more convenient for the analyst.

(b) Establish the number of elements, \( n \), by

\[
 n = \left( \frac{3\pi}{4\theta} \right) / dL \quad (11)
\]

This gives the number of elements, each being \( dL \) inches in length, to which springs are to be applied in the computer model. The number of elements, \( n \), is always rounded up to an integer.

VII-4.2.2 Calculate the lateral spring rate, \( k_{ij} \), to be applied at the center of each element.

\[
 k_{ij} = k dL, \text{ lb/in. lbf/in. (N/mm)} \quad (12)
\]

where

\[
k = \text{the modulus of subgrade reaction calculated from eq. (2)}.
\]

VII-4.2.3 Calculate the equivalent axial load necessary to simulate friction resistance to expansion. The friction resistance at the pipe-soil interface can be simulated in the computer model by imposing a single force \( F_f \) in a direction opposite that of the thermal growth.

\[
 F_f = \frac{fL' \text{ or } fL''}{2} \text{ lb lbf (N)} \quad (13)
\]
VII-4.2.4 Incorporate the springs and the friction force in the model. The mutually orthogonal springs $k_f$ are applied to the center of each element, perpendicular to the pipe axis. Shorter elements, with proportionally smaller values for the springs on these elements, may be necessary to model the soil restraint at elbows and bends. The friction force, $F_f$, for each expanding leg is imposed at or near the elbow tangent node, opposite to the direction of expansion.

VII-4.3 Determination of Soil Parameters

Soil parameters are difficult to establish accurately due to variations in backfill materials and degree of compaction. Consequently, values for elemental spring constants on buried pipe runs can only be considered as rational approximations. Stiffer springs can result in higher elbow stresses and lower bending stresses at nearby anchors, while softer springs can have the opposite effects. Backfill is not elastic; testing has shown that soil is stiffest for very small pipe movements, but becomes less stiff as the pipe movements increase. References [4], [7], and [8] discuss soil stiffness and recommend procedures for estimating values for $k$ that are consistent with the type of soil and the amount of pipe movement expected. The analyst should consult the project geotechnical engineer for assistance in resolving any uncertainties in establishing soils parameters, such as the modulus of subgrade reaction, $k$; confining pressure, $p_c$; and coefficient of friction, $\mu$.

VII-4.4 Pipe With Expansion Joints

An expansion joint must be considered as a relatively free and in calculating stresses on buried elbows and loads on anchors. Since incorporation of expansion joints or flexible couplings introduces a structural discontinuity in the pipe, the effects of the unbalanced pressure load and the axial joint friction or stiffness must be superimposed on the thermal expansion effects to determine the maximum pipe stresses and anchor loads.

VII-4.5 Pipe Stresses at Building Penetrations

Stresses at building penetrations can be calculated easily after the reactions due to thermal expansion in the buried piping have been determined. If the penetration is an anchor, then the stress due to the axial force, $F_{max}$, and the lateral bending moment, $M$, can be found by

$$S_D = F_{max}/A + M/Z, \text{ psi (MPa)}$$  \hspace{1cm} (14)

If the penetration is not an anchor, but is instead a simple support with a flexible water seal, it is necessary to determine the stiffness effects of the water seal material to calculate the stress in the pipe at the penetration. Differential movement due to building or trench settlement can generate high theoretical stresses at piping penetrations to buildings. Calculation of such stresses is beyond the scope of this Appendix.
VII-5 ALLOWABLE STRESS IN BURIED PIPE

Buried piping under axial stress can theoretically fail in one of two ways — either by column buckling (pipe pops out of the ground at mid-span) or local failure by crippling or tensile failure (much more serious than column buckling). Since buried piping stresses are secondary in nature, and since the piping is continuously supported and restrained (see Figure VII-5-1), higher total stresses may be permitted as follows:

\[ S_C \leq S_A + S_h \]  \hspace{1cm} (15)

where \( S_A \) and \( S_h \) are as defined in para. 102.3.2.

Figure VII-5-1 Plan of Example Buried Pipe

Pipe: NPS 12 (DN 300)
Material: ASME SA-106 Grade B C.S.
Depth below grade: 12 ft (3.7 m)
Trench width: 3 ft (0.9 m)

L.R. elbow (typical)

A

B

20 ft (6 m)

100 ft (30 m)

400 ft (152 m)

500 ft (152 m)
VII-6 EXAMPLE CALCULATIONS

VII-6.1 Assemble the Data

VII-6.1.1 Pipe Data

(a) diameter, \( D = 12.75 \text{ in.} (323.9 \text{ mm}) \)

(b) wall thickness = 0.375 in. (9.53 mm)

(c) length of runs

(1) Run 1: \( L_1 = 100 \text{ ft}, L_2 = 400 \text{ ft} \) (30 m), \( L_3 = 500 \text{ ft} \) (152 m)

(2) Run 2: \( L_1 = 20 \text{ ft}, L_2 = 100 \text{ ft} \) (6 m), \( L_3 = 100 \text{ ft} \) (30 m)

(3) Run 3: \( L_1 = 100 \text{ ft}, L_2 = 20 \text{ ft} \) (6 m), \( L_3 = 20 \text{ ft} \) (6 m)

(d) Young’s modulus, \( E = 29 \times 10^6 \text{ psi} \) (200 x 10^6 MPa)

(e) moment of inertia, \( I = 279.3 \text{ in}^4 \) (116 x 10^6 mm^4)

(f) cross section metal area, \( A = 14.57 \text{ in}^2 \) (9400 mm^2)

VII-6.1.2 Soil Characteristics

(a) soil density, \( w = 130 \text{ lb/ft}^3 \) (130 lbm/ft^3) (2100 kg/m^3)

(b) pipe depth below grade, \( H = 12 \text{ ft} \) (3.7 m)

(c) type of backfill: dense sand

(d) trench width, \( B_d = 3 \text{ ft} \) (0.9 m)

(e) coefficient of friction, \( \mu = 0.3 \) minimum to 0.5 maximum (estimated)

(f) horizontal soil stiffness factor, \( C_h = 80 \)

VII-6.1.3 Operating Conditions

(a) pressure, \( P = 100 \text{ psig} \) (0.7 MPa(g))

(b) temperature = 140°C (60°C)

(c) ambient temperature = 70°F (20°C)
7.2 Calculate the Intermediate Parameters

7.2.1 Relative Strain at the Pipe/Soil Interface.

Thermal expansion for ASME SA-106 Grade B carbon steel pipe from 70° F (20°C) to 140° F (60°C) is 6.6 x 10^6 in./in./°F (11.8 x 10^-6 mm/mm/°C). Therefore, from eq. (1),

\[ \varepsilon = \alpha(T - T_0) \]

Customary Units

\[ \varepsilon = 6.6 \times 10^6 \text{ in./in./°F} \]

SI Units

\[ \varepsilon = 11.8 \times 10^{-6} \text{ mm/mm/°C} \]

7.2.2 Modulus of Subgrade Reaction, \( k \) (ref. [8]).

Since the expansion is in the horizontal plane, use \( k_h \) from eq. (2).

\[ k_h = C_k N_h (D - h) \]

\[ C_k = 80 \]

Customary Units

\[ N_h = 0.285 \frac{H}{D} + 4.3 \]

\[ = 0.285(12 \text{ ft})(12 \text{ in./ft})/12.75 \text{ in.} + 4.3 \]

\[ = 7.519 \]

\[ w = \left( \frac{130 \text{ lb/ft}^3}{1,728 \text{ in.}^3} \right) \]

\[ = 0.0752 \text{ lbm/in.}^3 \]

\[ D = 12.75 \text{ in.} \]

\[ k_h = (80)(7.519)(0.0752)(12.75) = 577 \text{ lbm/in.}^2 = 577 \text{ psi} \]

SI Units

\[ N_h = 0.285 \frac{H}{D} + 4.3 \]

\[ = 0.285(3.7 \text{ m})(1000 \text{ mm/m}) / 323.9 \text{ mm} + 4.3 \]

\[ = 7.556 \]

\[ w = (2100 \text{ kg/m}^3)/(1x10^9 \text{ mm}^3 / \text{ m}^3) \]

\[ = 0.0000021 \text{ kg/mm}^3 \]

\[ D = 323.9 \text{ mm} \]

\[ k_h = (80)(7.556)(0.0000021 \text{ kg/mm}^3)(323.9 \text{ mm}) = 0.4116 \text{ kg/mm}^2 \]

\[ k_h = (0.4116 \text{ kg/mm}^2)(9.81 \text{ N/kg}) = 4.03 \text{ N/mm}^2 = 4.03 \text{ MPa} \]
VII-6.2.3 Friction Forces per Unit Length Acting at the Pipe/Soil Interface

\[ f = \mu \left( P_e A_e + W_p \right) \]

Since the pipe lies more than 3 diameters below grade, the modified Marston equation from ref. [1] is used to determine the confining pressure \( P_e \) of soil on the pipe.

\[ P_e = wCDd \]

\[ C_D = 2.22 \text{ for } H/B_d = 12 \text{ ft}/3 \text{ ft} \ (3.7 \text{ m} / 0.9 \text{ m}) \]
\[ = 4 \text{ (see Table VII-3.2.3-1 for sand)} \]

**Customary Units**

\[ P_e = \left( 130 \text{ lb/in}^3 \right) (2.22) \left( 3 \text{ ft} \right) / \left( 144 \text{ in}^2/\text{ft}^2 \right) \]
\[ = 6.01 \text{ psi} \]

\[ A_e = \frac{\pi D(1 \text{ in}.)}{(12.75 \text{ in})(1 \text{ in})} \]
\[ = 40.05 \text{ in}^2/\text{in. of length} \]

\[ W_p = 8.21 \text{ lb/in. for water-filled carbon steel pipe} \]

Maximum value of friction force per unit length, \( f_{\text{max}} \)

\[ f_{\text{max}} = 0.5 \left( 6.01 \text{ psi} \right) (40.05 \text{ in}^2/\text{in.}) + 8.21 \text{ lb/in.} \]
\[ = 124.5 \text{ lb/in.} \]

Minimum value of friction force per unit length, \( f_{\text{min}} \)

\[ f_{\text{min}} = 0.3 \left( 6.01 \text{ psi} \right)(40.05) + 8.21 \]
\[ = 74.7 \text{ lb/in.} \]

**SI Units**

\[ P_e = \frac{(2100 \text{ kg/m}^3)(2.22)(0.9 \text{ m})}{(1 \times 10^6 \text{ mm}^2/\text{m}^2)} \]
\[ = 0.0041958 \text{ kg/mm}^2 (9.81 \text{ N/kg}) \]
\[ = 0.0411 \text{ N/mm}^2 = 0.0411 \text{ MPa} \]

\[ A_e = \pi D (25.4 \text{ mm}) = \pi (323.9 \text{ mm})(25.4 \text{ mm}) \]
\[ = 25846 \text{ mm}^2/25.4 \text{ mm of length} \]
\[ = 1018 \text{ mm}^2/\text{mm of length} \]

\[ W_p = 0.147 \text{ kg/mm for water-filled carbon steel pipe} \]

Maximum value of friction force per unit length, \( f_{\text{max}} \)

\[ f_{\text{max}} = 0.5(0.0411 \text{ N/mm}^2)(1018 \text{ mm}^2/\text{mm}) + (0.147 \text{ kg/mm})(9.81 \text{ N/kg}) \]
\[ = 21.6 \text{ N/mm} \]

Minimum value of friction force per unit length, \( f_{\text{min}} \)

\[ f_{\text{min}} = 0.3(0.0411 \text{ N/mm}^2)(1018 \text{ mm}^2/\text{mm}) + (0.147 \text{ kg/mm})(9.81 \text{ N/kg}) \]
\[ = 13.0 \text{ N/mm} \]
VII-6.2.4 Pipe/Soil System Characteristic, $\beta$ (ref. [2])

**Customary Units**

$$\beta = \left[\frac{k_h}{(4EI)}\right]^{1/4}$$

$$= \left[\frac{577 \text{ psi}/4 (25.9 \times 10^6 \text{ psi})(279.3 \text{ in.}^3)}{403 \text{ in.}^2}ight]^{1/4}$$

$$= 0.0116 \text{ in.}^{-1}$$

**SI Units**

$$\beta = \left[\frac{k_h}{(4EI)}\right]^{1/4}$$

$$= \left[\frac{4.03 \text{ MPa}/4 (200 \times 10^3 \text{ MPa})(116 \times 10^6 \text{ mm}^4)}{13.0 \text{ N/mm}}\right]^{1/4}$$

$$= 0.0004565 \text{ mm}^{-1}$$

---

VII-6.2.5 Minimum Stipage Length, $L_m$

**Customary Units**

$$L_m = \frac{\epsilon AE}{f_{\text{min}}}$$

$$= \left(\frac{0.000424 \text{ in.}^2}{74.7 \text{ lb/in.}}\right)(14.57 \times 10^6 \text{ psi})$$

$$= 2.009 \text{ in. or } 192 \text{ ft.} \quad = 2.613 \text{ in.}$$

**SI Units**

$$L_m = \frac{\epsilon AE}{f_{\text{min}}}$$

$$= \left(\frac{0.000472 \text{ mm/mm}}{13.0 \text{ N/mm}}\right)(9400 \text{ mm}^2)$$

$$= 68,258 \text{ mm}$$

---

VII-6.2.6 Maximum Axial Force, $F_{\text{max}}$, Corresponding to $L_m$

**Customary Units**

$$F_{\text{max}} = \epsilon AE = \left(\frac{0.000424 \text{ in.}^2}{14.57 \times 10^6 \text{ psi}}\right)$$

$$= 172,357 \text{ lb} \quad = 195,209 \text{ lbf}$$

**SI Units**

$$F_{\text{max}} = \epsilon AE = (0.000472)(9400)(200 \times 10^3)$$

$$= 887,360 \text{ N}$$
VII-6.3 Classification of Runs

Classify the pipe runs in accordance with the models given in Table VII-6.3-1 and calculate the effective slippage length, \( L' \) or \( L'' \), for each run.

### Table VII-6.3-1 Equations for Calculating Effective Length \( L' \) or \( L'' \)

<table>
<thead>
<tr>
<th>Element Category</th>
<th>Equations for ( L' ) or ( L'' )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short P Leg ( L' )</td>
<td>Long P Leg ( L'' )</td>
</tr>
<tr>
<td>A, B, C</td>
<td>( \text{if } L_2 \leq L_m + L' ), ( L' = (3 - (5 - 6\pi)^{1/3})/20 )</td>
</tr>
<tr>
<td>A, B, C, D</td>
<td>( \text{if } L_2 \leq L'' ), ( L'' = L_2/2 )</td>
</tr>
<tr>
<td>A, B, C, D</td>
<td>( \text{if } L_2 \leq L'' ), ( L'' = L_2 )</td>
</tr>
<tr>
<td>D</td>
<td>( \text{if } L_2 \leq L_m ), ( L'' = L_2 )</td>
</tr>
</tbody>
</table>

#### VII-6.3.1 Run 1

Run 1 is a Category A1 (elbow on one end, the other end free). Check to see if the transverse leg, \( L_1 \), is long or short.

\[
L_1 = 1,200 \text{ in.} \ (30,500 \text{ mm})
\]

**Customary Units**

\[
3\pi / (4)(0.01155 \text{ in.}^{-1}) = 204 \text{ in.}
\]

**SI Units**

\[
3\pi / (4)(0.0004565 \text{ mm}^{-1}) = 5161 \text{ mm}
\]

\((30,500 \text{ mm}) 204 (5161 \text{ mm})\)

Since 1,200 in. > 204 in., \( L_1 \) is long. Check to see if the longitudinal leg, \( L_2 \), is long or short, that is, longer or shorter than \( L_m + L' \). Using eq. (7) to calculate \( L'' \),

\[
L'' = \Omega \left[ 1 + 2L_{\text{max}}/f_{\text{min}} \Omega^{1/2} - 1 \right]
\]

**Customary Units**

\[
\Omega = AE\beta/k = \left( 14.57 \text{ in.}^2 \right) \left( 27,900 \times 10^6 \text{ psi} \right) \left( 0.01155 \text{ in.}^{-1} \right) / 577 \text{ psi} = 8,214 \text{ in.}
\]

\[
L'' = 8,214 \left[ 1 + 2 \times 172,337 / (74.7 \times 8,214) \right]^{1/2} - 1 \]

\[
= 2,051 \text{ in.} \ (2,300 \text{ in.})
\]

**SI Units**

\[
\Omega = AE\beta/k = (9,400 \text{ mm}^2)(200 \times 10^6 \text{ MPa}) \left( 0.0004565 \text{ mm}^{-1} / 4.03 \text{ MPa} = 212,958 \text{ mm} \right)
\]

\[
L'' = 212,958 [1 + 2 \times 887,360 / (13.0 \times 212,958)]^{1/2} - 1 \]

\[
= 59,849 \text{ mm}
\]

\[
L_m + L'' = 68,258 + 59,849 = 128,107 \text{ mm}
\]

\( L_2 = 500 \text{ ft} \) (152 m) or 6,000 in. (152,400 mm) and since 6,000 (152,400) > 4,913 (128,107), the pipe run length \( L_2 \) is long, and Run 1 can be fully classified as Category A1 (long transverse, long pipe).

**NOTE:** If \( L_m + L'' \) would have exceeded \( L_2 \), then \( L' \) would be recalculated using eq. (9), the correct equation for a short pipe.
VII-6.3.2 Run 2 is a Category A2 (elbow on each end). Check to see if the legs \( L_1 \) and \( L_2 \) are long or short.

Since \( L_1 < \frac{3\pi}{4}\beta \) (240 in. > 202 in.) and \( L_2 < 2L'' \) (1,200 in. < 2(204 in.)), then Run 2 can be fully classified as a Category A2 (long transverse, short pipe). Then

\[
L' = \frac{L_2}{2} = \frac{204 \text{ in.}}{2} = 600 \text{ in.} (15,250 \text{ mm})
\]

NOTE: To fully qualify a buried piping system, it may also be necessary to include stresses due to weight of overburden (backfill) and vehicular loads (refs. [5], [6]).

VII-6.3.3 Run 3 is a Category A3 (anchor on one end, elbow on the other). Check to see if the legs \( L_1 \) and \( L_2 \) are long or short.

Since \( L_1 > \frac{3\pi}{4}\beta \) (1,200 in. > 202 in.) and \( L_2 < L'' \) (240 in. < 204 in.), then Run 3 can be fully classified as a Category A3 (long transverse, short pipe). Then

\[
L' = \frac{L_2}{2} = 240 \text{ in.} (6,100 \text{ mm})
\]

VII-6.4 Computer Modeling

Calculate the soil springs and friction force for use in a computer model of the buried pipe.

VII-6.4.1 Element Length. Set the element length to be \( \approx 3 \) pipe diameters. \( dL = 36 \) in. (910 mm)

VII-6.4.2 Number of Elements. Only the soil within a length \( 3\pi/4\beta \) from the elbow will be subjected to bearing force from the pipe. For the example system, \( 3\pi/4\beta = 202 \) in. Therefore, the number of elements needed is found by

\[
n = \frac{(3\pi/4\beta)}{dL} = \frac{202}{36} = 5.67
\]

Therefore, use six elements, each 36 in. long.

VII-6.4.3 Spring Rate, \( k_{ij} \). The spring rate to be applied to each element is found by

\[
k_{ij} = kdL
\]

where \( k \) is from eq. (2)

Customary Units

\[
k_{ij} = (577 \text{ psi})(36 \text{ in.}) = 20,772 \text{ lb/in. lbf/in.}
\]

SI Units

\[
k_{ij} = (4.03 \text{ MPa})(914 \text{ mm}) = 3,683 \text{ N/mm}
\]

This is the theoretical spring rate to be imposed at the center of each element and normal to the surface of the pipe, with \( k_i \) in the plane of the expansion, and \( k_j \) perpendicular to the plane of expansion.
VII-6.4.4 Friction Force, \( F_f \). The friction forces to be applied at the elbow tangent points in Runs 1 and 2 are calculated as follows:

Parallel to Run 1,

\[
F_f = \frac{fL''}{2}
\]

where

\[
f = f_{\text{min}} = 74.7 \text{ lb/in. (13.0 N/mm)}
\]

\[
L'' = 2,300 \text{ in. (59,849 mm)}
\]

Customary Units

\[
F_f = \frac{(74.7 \text{ lb/in.})(2,300 \text{ in.})}{2} = 66,605 \text{ lb} \quad 85,905 \text{ lbf}
\]

SI Units

\[
F_f = \frac{(13.0 \text{ N/mm})(59,849 \text{ mm})}{2} = 389,019 \text{ N}
\]

Parallel to Run 2,

Customary Units

\[
F_f = \frac{(74.7 \text{ lb/in.})(600 \text{ in.})}{2} = 22,410 \text{ lbf}
\]

SI Units

\[
F_f = \frac{(13.0 \text{ N/mm})(15,250 \text{ mm})}{2} = 99,130 \text{ N}
\]

The friction force to be applied at the elbow tangent point in Run 3 is calculated as follows:

Parallel to Run 3,

Customary Units

\[
F_f = \frac{(74.7 \text{ lb/in.})(240 \text{ in.})}{2} = 8,964 \text{ lbf}
\]

SI Units

\[
F_f = \frac{(13.0 \text{ N/mm})(6,096 \text{ mm})}{2} = 39,624 \text{ N}
\]

The computer model then appears as is shown in Figure VII-6.4.4-1.
VII-6.5 Results of Analysis

Computer analysis of the model shown in Figure VII-6.4-1 gives combined stress, $S_C$, at various locations in the buried pipe as follows:

<table>
<thead>
<tr>
<th>Location</th>
<th>$S_C$, psi (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual anchor</td>
<td>7,036 (48.5)</td>
</tr>
<tr>
<td>Elbow A</td>
<td>26,865 (185.2)</td>
</tr>
<tr>
<td>Elbow B</td>
<td>9,818 (67.7)</td>
</tr>
<tr>
<td>Penetration anchor</td>
<td>2,200 (15.2)</td>
</tr>
</tbody>
</table>

NOTE: $S_C$ for this example includes longitudinal pressure stress, intensified bending stresses, and direct stresses due to axial loads from friction and soil bearing loads. It does not include weight of backfill or live loads.

The allowable stress as given by eq. (15) is $S_A + S_P$, which for ASME SA-106 Grade B steel pipe is 22,500 psi (155 MPa) + 15,000 psi (103 MPa) = 37,500 psi (258 MPa). Therefore, since the maximum $S_C$ of 26,865 psi (185.2 MPa) < 37,500 psi (258 MPa), the Code conditions are met.

VII-6.6 Anchor Load Example

If Element 1 is simply a straight pipe anchored at one end with the other end terminating in an expansion joint (see Figure VII-6.6-1), the load on the anchor is found as follows:

(a) Calculate the maximum friction force acting along the friction interface.

$$F_f = F_{max} = \varepsilon AE$$

**Customary Units**

$$F_{max} = \varepsilon AE = (0.000462)(14.57)(29 \times 10^6) = 195,209 \text{ lbf}$$

**SI Units**

$$F_{max} = \varepsilon AE = (0.000472)(9400)(200 \times 10^3) = 887,360 \text{ N}$$

(b) Calculate the load, $S$, at the expansion joint.

$$S = F_f + S_p$$

where

- $F_f =$ expansion joint friction force
  
  $$= 9,000 \text{ lbf (40,000 N)} \text{ (from vendor data)}$$

- $S_p =$ pressure force
  
  $$= P A_g$$

  where
  
  - $P =$ design pressure
    
    $$= 100 \text{ psig (0.7 MPa(g))}$$

**Customary Units**

$$A_g = \text{effective cross-sectional area}$$

$$= \pi D^2 / 4$$

$$= \pi (12.75^2) / 4$$

$$= 127.6 \text{ in}^2$$

$$= (100)(127.6) = 12,760 \text{ lb f}$$

$$S = 9,000 + 12,760 = 21,760 \text{ lb f}$$

**SI Units**

$$A_g = \text{effective cross-sectional area}$$

$$= \pi D^2 / 4$$

$$= \pi (323.9^2) / 4$$

$$= 82,400 \text{ mm}^2$$

$$= (0.7)(82,400) = 57,680 \text{ N}$$

$$S = 40,000 + 57,680 = 97,680 \text{ N}$$
(c) The total axial load, \( F_a \), at the anchor then becomes

**Customary Units**

\[ F_a = 195,209 + 21,760 = 216,969 \text{ lbf} \]

**SI Units**

\[ F_a = 887,360 + 97,680 = 985,040 \text{ N} \]

If anchor loads must be limited, then the expansion joint should be located closer to the anchor to reduce the force due to friction at the pipe/soil interface.

![Figure VII-6.6-1 Example Plan of Element 1 as a Category D Element](image)

**VII-7 REFERENCES**


