

ASME B31.5-2013
(Revision of ASME B31.5-2010)

Refrigeration Piping and Heat Transfer Components

ASME Code for Pressure Piping, B31

AN AMERICAN NATIONAL STANDARD



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Mechanical Engineers**

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**The American Society of
Mechanical Engineers**

Two Park Avenue • New York, NY • 10016 USA

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FOREWORD

The need for a national code for pressure piping became increasingly evident from 1915 to 1925. To meet this need, the American Engineering Standards Committee (later changed to American Standards Association, then changed to United States of America Standards Institute, and now known as the American National Standards Institute) initiated project B31 in March 1926, at the request of the American Society of Mechanical Engineers and with that Society the sole administrative sponsor. Because of the wide field involved, Sectional Committee B31, later changed to Standards Committee, was composed of representatives of some 40 different engineering societies, industries, government bureaus, institutes, and trade associations. After several years' work, the first edition was published in 1935 as an American Tentative Standard Code for Pressure Piping.

In order to keep the Code abreast of current developments in piping design, welding, stress computations, new dimensional and material standards and specifications, and increases in the severity of service conditions, revisions, supplements, and new editions of the Code were published as follows:

B31.1-1942	American Standard Code for Pressure Piping
B31.1a-1944	Supplement 1
B31.1b-1947	Supplement 2
B31.1-1951	American Standard Code for Pressure Piping
B31.1a-1953	Supplement 1 to B31.1-1951

B31.1-1955 American Standard Code for Pressure Piping

In 1952, a new section of the Code was published to cover Gas Transmission and Distribution Piping Systems. In 1955, after a review by B31 Executive and Sectional Committees, a decision was made to develop and publish other industry sections as separate code documents of the American Standard Code for Pressure Piping.

The first edition of Refrigeration Piping was published as ASA B31.5-1962, superseding Section 5 of B31.1-1955. This Section was revised in 1966. Following approval by the Sectional Committee and the sponsor, this revision was approved by the United States of America Standards Institute on September 8, 1966, and designated USAS B31.5-1966. Revision of this Section was approved on April 18, 1974 by the American National Standards Institute and designated ANSI B31.5-1974.

In December 1978, the American National Standards Committee B31 was reorganized as the ASME Code for Pressure Piping, B31 Committee under procedures developed by the American Society of Mechanical Engineers and accredited by the American National Standards Institute. The Code designation was also changed to ANSI/ASME B31.

Previous editions of this Code include those of 1983, 1987, 1989, 1992, 2001, 2006, and 2010. In this, the 2013 Edition, new additions and revisions have been made to the text, shown in the Summary of Changes page.

This Code was approved as an American National Standard on February 19, 2013.

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Code for Pressure Piping

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INTRODUCTION

The ASME B31 Code for Pressure Piping consists of a number of individually published Sections, each an American National Standard, under the direction of ASME Committee B31, Code for Pressure Piping. Rules for each Section reflect the kinds of piping installations considered during its development. This is the B31.5 Refrigeration Piping and Heat Transfer Components Code Section. Hereafter, in this Introduction and in the text of this Code Section B31.5, when the word “Code” is used without specific identification, it means this Code Section. This Section also includes nonmandatory appendices containing referenced standards (Nonmandatory Appendix A), information instructing users on the preparation of technical inquiries (Nonmandatory Appendix B) and the selection of appropriate piping codes (Nonmandatory Appendix C), and nomenclature (Nonmandatory Appendix D).

It is the owner’s responsibility to select the Code Section that most nearly applies to a proposed piping installation. Factors to be considered by the owner include limitations of the Code Section, jurisdictional requirements, and the applicability of other codes and standards. All applicable requirements of the selected Code Section shall be met. For some installations more than one Code Section may apply to different parts of the installation. The owner is also responsible for imposing requirements supplementary to those of the Code if necessary to assure safe piping for the proposed installation. (See Nonmandatory Appendix C.)

The Code sets forth engineering requirements deemed necessary for safe design and construction of refrigeration, heat transfer components, and secondary coolant piping systems. While safety is the basic consideration of this Code, this factor alone will not necessarily govern the final specifications for any pressure piping system. The designer is cautioned that the Code is not a design handbook. The Code does not eliminate the need for the designer or competent engineering judgment.

The Code contains basic reference data and formulas necessary for design. It is intended to state these requirements in terms of basic design principles to the fullest possible extent, supplemented with specific requirements, where necessary, to obtain uniform interpretation of principle. It contains prohibitions in areas where practices or designs are known to be unsafe. In other areas the Code contains warnings or “flags” where caution is known to be necessary, but where it is considered that a direct prohibition would be unwarranted.

The Code includes the following:

- (a) references to material specifications and component standards that are acceptable for Code usage
- (b) references to acceptable dimensional standards for the elements comprising piping systems
- (c) requirements for the pressure design of component parts and assembled units
- (d) requirements for the evaluation and limitation of stresses, reactions, and movements associated with pressure, temperature, and external forces, and for the design of pipe supports
- (e) requirements for the fabrication, assembly, and erection of piping systems
- (f) requirements for examination, inspection, and testing of piping systems

It is the intent of the Code that this not be retroactive and that, unless agreement is specifically made between contracting parties to use other issues, or the regulatory body having jurisdiction imposes the use of other issues, the latest Code, issued 6 months prior to the original contract date for the first phase of activity covering a piping system(s), be the governing document for all design, materials, fabrication, erection, examination, and testing activities for the piping system(s) until the completion of the work and initial operation.

Manufacturers and users of piping are cautioned against making use of revisions less restrictive than former requirements without having assurance that they have been accepted by the proper authorities in the jurisdiction where the piping is to be installed.

Users of this Code are advised that in some locations legislation may establish jurisdiction over the subject matter of this Code.

Attention of Code users is directed to the fact that the numbering of the Divisions and the text therein may not be consecutive. This is not the result of editorial or printing errors. An attempt has been made to follow a uniform outline of the various Sections. Therefore, the same subject, in general, appears under the same number and subnumber in all Sections.

The Committee is a continuing one and is organized to keep the Code current with new developments in materials, construction, and usage. New Editions are published at 3-yr to 5-yr intervals.

The Committee has established an orderly procedure to consider requests for interpretation and revision of Code requirements. To receive consideration, inquiries must be in writing and must give full particulars. (See Nonmandatory Appendix B covering preparation of technical inquiries.)

The approved reply to an inquiry will be sent directly to the inquirer. In addition, the question and reply will be published as part of an Interpretation supplement issued to the applicable Code Section.

A Case is the prescribed form of reply when study indicates that the Code wording needs clarification, or when the reply modifies existing requirements of the Code or grants permission to use new materials or

alternative constructions. The Case will be published as part of a Case supplement issued to the applicable Code Section.

Requests for interpretations or suggestions for revisions should be addressed to the Secretary, ASME B31 Committee, Two Park Avenue, New York, NY 10016-5990.

ASME B31.5-2013

SUMMARY OF CHANGES

Following approval by the B31 Committee and ASME, and after public review, ASME B31.5-2013 was approved by the American National Standards Institute on February 19, 2013.

ASME B31.5-2013 consists of editorial changes, revisions, and corrections identified by a margin note, **(13)**, placed next to the affected area.

<i>Page</i>	<i>Location</i>	<i>Change</i>
49	523.2.2	First paragraph and subparas. (a) and (e) revised
53	Fig. 523.2.2	Revised in its entirety
56	Table 526.1	Updated
64	528.2.2	Revised
65	528.4.2	Revised
71, 72	536.6.3	Subparagraph (c) revised
	536.6.4	Added
	536.6.5	Added
75–77	Nonmandatory Appendix A	Updated

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REFRIGERATION PIPING AND HEAT TRANSFER COMPONENTS

Chapter I Scope and Definitions

500 GENERAL STATEMENTS

This Refrigeration Piping and Heat Transfer Components Code is a Section of the American Society of Mechanical Engineers Code for Pressure Piping, B31. This Section is published as a separate document for simplicity and for convenience of Code users. The users of this Code are advised that in some areas legislation may establish governmental jurisdiction over the subject matter covered by the Code. The owner of a piping installation shall choose which piping code(s) are applicable to the installation and shall have the overall responsibility for compliance with this Code. (See Nonmandatory Appendix C.) The owner of a complete piping installation shall have the overall responsibility for compliance with this Code.

It is required that the engineering design specify any special requirements pertinent to the particular service involved. For example, the engineering design shall not for any service specify a weld quality lower than that stipulated in para. 527.3.2(d) for the Code-required visual examination quality and for the types of welds involved; but where service requirements necessitate added quality and more extensive nondestructive examination, these are to be specified in the engineering design and any revision thereto, and when so specified, the Code requires that they be accomplished.

500.1 Scope

Rules for this Code Section have been developed considering the needs for applications that include piping and heat transfer components for refrigerants and secondary coolants.

500.1.1 This Code prescribes requirements for the materials, design, fabrication, assembly, erection, test, and inspection of refrigerant, heat transfer components, and secondary coolant piping for temperatures as low as -320°F (-196°C), whether erected on the premises or factory assembled, except as specifically excluded in the following paragraphs.

500.1.3 This Code shall not apply to any of the following:

(a) any self-contained or unit systems subject to the requirements of Underwriters Laboratories or other nationally recognized testing laboratory

(b) water piping, other than where water is used as a secondary coolant or refrigerant

(c) piping designed for external or internal gage pressure not exceeding 15 psi (105 kPa) regardless of size

(d) pressure vessels, compressors, or pumps, but does include all connecting refrigerant and secondary coolant piping starting at the first joint adjacent to such apparatus

500.2 Definitions

For convenience in reference, some of the more common terms relating to piping are defined in this subdivision.

Most welding definitions were taken from the AWS Welding Handbook, Volume 1, 7th Edition. Heat treatment terms were taken from ASM Metals Handbook Properties and Selection of Materials, Volume 1, 8th Edition.

arc welding: a group of welding processes wherein coalescence is produced by heating with an electric arc(s), with or without the application of pressure and with or without the use of filler metal.

automatic welding: welding with equipment that performs the entire welding operation without constant observation and adjustment of the controls by an operator. The equipment may or may not perform the loading and unloading of the work.

backing ring: backing in the form of a ring generally used in the welding of piping.

base metal: the metal to be welded, soldered, brazed, or cut.

brazing: a joining process that produces coalescence of materials by heating them in the presence of a filler metal having a liquidus above 840°F (450°C) but below the solidus of the base metals. Heating may be provided by a variety of processes. The filler metal distributes itself between the closely fitted surfaces of the joint by capillary action. Brazing differs from soldering in that

soldering filler metals have a liquidus below 840°F (450°C).

brine: a secondary coolant that is a solution of a salt and water.

butt joint: an assembly of two members lying approximately in the same plane.

compressor: a specific machine, with or without accessories, for compressing a given refrigerant vapor.

condenser: that part of a refrigerating system designed to liquefy refrigerant vapor by the removal of heat.

condenser coil: a condenser constructed of pipe or tube, not enclosed in a pressure vessel.

design pressure: see section 501.

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 to pipe or piping components.

evaporator: that part of a refrigerating system designed to vaporize liquid refrigerant to produce refrigeration.

evaporator coil: an evaporator constructed of pipe or tube, not enclosed in a pressure vessel.

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

filler metal: metal to be added in making a welded, brazed, or soldered joint.

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 joint.

fusion: see *weld*.

gas metal-arc welding (GMAW): an arc welding process wherein coalescence is produced by heating with an arc between a continuous filler metal (consumable) electrode and the work. Shielding is obtained entirely from an externally supplied gas or gas mixture. (Some methods of this process are called MIG or CO₂ welding.)

gas tungsten-arc welding (GTAW): an arc welding process wherein coalescence is produced by heating with an arc between a single tungsten (nonconsumable) electrode and the work. Shielding is obtained from a gas or gas mixture. Pressure may or may not be used and filler metal may or may not be used. (This process is sometimes called TIG welding.)

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.

header: a pipe or tube (extruded, cast or fabricated) to which a number of other pipes or tubes are connected.

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

heat transfer component: the pressure containing portion of equipment used for heat transfer including pipes, tubes, coils, or other components and their headers not constructed as pressure vessels. (See also *evaporator coil* and *condenser coil*.)

heat treatment

annealing, full: heating a ferrous alloy into the austenitizing transformation temperature range, holding above that range for a proper period of time, followed by cooling slowly through the transformation range.

austenitizing: forming austenite by heating a ferrous alloy into the transformation range (partial austenitizing) or above the transformation range (complete austenitizing).

normalizing: heating a ferrous alloy to a suitable temperature above the transformation range and subsequently cooling in air to a temperature substantially below the transformation range.

stress-relief: uniform heating of a structure or portion thereof to a sufficient temperature below the critical range to relieve the major portion of the residual stresses, and then cooling slowly enough to minimize the development of new residual stresses.

transformation range: the ranges of temperature within which austenite forms during heating and transforms to martensite or other microstructure during cooling. The limiting temperatures of the range are determined by composition of the alloy and on the rate of change of temperature, particularly on cooling wherein the transformation reaction is lower for rapid quench rates.

high side: the parts of a refrigerating system subjected to condenser pressure.

joint design: the joint geometry together with the required dimensions of the welded joint.

joint penetration: the minimum depth a groove or flange weld extends from its face into a joint, exclusive of reinforcement.

limited charge system: a system in which, with the compressor idle, the internal volume and total refrigerant charge are such that the design pressure will not be exceeded by complete evaporation of the refrigerant charge.

low side: the parts of a refrigerating system subjected to evaporator pressure.

manual welding: welding wherein the entire welding operation is performed and controlled by hand.

mechanical joint: a joint obtained by joining of metal parts through a positive holding mechanical construction.

miter joint: two or more straight sections of pipe matched and joined on a plane bisecting the angle or junction so as to produce a change in direction.

nominal: a numerical identification of dimension, capacity, rating, or other characteristic used as a designation, not as an exact measurement.

peening: the mechanical working of metals by means of impact blows.

pipe: a tubular component, usually cylindrical, used for conveying fluid and normally designated "pipe" in the applicable specification. It also includes similar components designated "tube." Types of welded pipe, according to the method of manufacture, are defined as follows:

double submerged-arc welded: pipe having a longitudinal butt joint produced by at least two passes, one of which is on the inside of the pipe. Coalescence is produced by heating with an electric arc or arcs between the 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 for the inside and outside welds is obtained from the electrode or electrodes.

electric-flash welded: 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.

electric-fusion welded: pipe having a longitudinal or spiral butt joint wherein coalescence is produced in the preformed tube by manual or automatic electric-arc welding. The weld may be single or double and may be made with or without the use of filler metal. Spiral welded pipe is also made by the electric-fusion welded process with either a lap joint or a lock-seam joint.

electric-resistance welded: pipe produced in individual lengths, or in continuous lengths from coiled skelp and subsequently cut into individual lengths, having a longitudinal or spiral 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.

furnace butt welded, continuous welded: pipe produced in continuous lengths from coiled skelp heated to approximately 2,500°F (1 371°C). Immediately after forming, the pipe edges are superheated by an oxygen lance to near the melting point. A weld forming roll applies sufficient lateral force to extrude the cast weld

metal to the I.D. and O.D. It is then reduced by a series of horizontal and vertical rolls to its final size.

pipe supporting elements: elements that consist of fixtures and structural attachments. They do not include support structures and equipment, such as stanchions, towers, building frames, pressure vessels, mechanical equipment, and foundations.

fixtures: elements that transfer the load from the pipe or structural attachment to the supporting structure or equipment. They include hanging-type fixtures, such as hanger rods, spring hangers, sway braces, counterweights, turnbuckles, struts, chains, guides, anchors, and bearing type fixtures, such as saddles, bases, rollers, brackets, and sliding supports.

structural attachments: elements that are welded, bolted, or clamped to the pipe, such as clips, lugs, rings, clamps, clevises, straps, and skirts.

pipng: the pipe and tube for interconnecting the various parts in a refrigeration system, which includes pipe, tube, flanges, bolting, gaskets, valves, and fittings; other pressure-containing parts, such as heat transfer components, expansion joints, strainers, and filters; devices that serve such purposes as mixing, separating, snubbing, distributing, metering, or controlling flow; and pipe supporting elements.

postheating: the application of heat to an assembly after a welding, brazing, soldering, or cutting operation.

preheating: the application of heat to the base metal immediately before a welding, brazing, soldering, or cutting operation.

premises: the buildings and that part of the grounds of one property, where an installation would affect the safety of those buildings or adjacent property.

pressure vessel: see Section VIII, Division 1, ASME Boiler and Pressure Vessel Code (hereinafter referred to as the ASME BPV Code).

refrigerant and refrigerant mixtures: the fluid used for heat transfer in a refrigerating system that absorbs heat during evaporation at low temperature and pressure, and releases heat during condensation at a higher temperature and pressure. The safety classification group consists of two characters (e.g., A1 or B2). The capital letter indicates the toxicity and the arabic numeral indicates the flammability, based on the criteria in Tables 500.2-1 and 500.2-2.

refrigerating system: a combination of interconnecting refrigerant-containing parts constituting a closed refrigerant circuit in which a refrigerant is circulated for the purpose of extracting heat.

reinforcement of weld: weld metal in excess of the specified weld size.

root opening: the separation between the members to be joined, at the root of the joint.

Table 500.2-1 Refrigerant Safety Classifications

Refrigerant Number	Chemical Name	Chemical Formula	Safety Group
Methane Series			
11	Trichlorofluoromethane	CCl_3F	A1
12	Dichlorodifluoromethane	CCl_2F_2	A1
12B1	Bromochlorodifluoromethane	CBrClF_2	Note (1)
13	Chlorotrifluoromethane	CClF_3	A1
13B1	Bromotrifluoromethane	CBrF_3	A1
14	Tetrafluoromethane (carbon tetrafluoride)	CF_4	A1
21	Dichlorofluoromethane	CHCl_2F	B1
22	Chlorodifluoromethane	CHClF_2	A1
23	Trifluoromethane	CHF_3	A1
30	Dichloromethane (methylene chloride)	CH_2Cl_2	B2
31	Chlorofluoromethane	CH_2ClF	Note (1)
32	Difluoromethane (methylene fluoride)	CH_2F_2	A2
40	Chloromethane (methyl chloride)	CH_3Cl	B2
41	Fluoromethane (methyl fluoride)	CH_3F	Note (1)
50	Methane	CH_4	A3
Ethane Series			
113	1,1,2-Trichloro-1,2,2-trifluoroethane	$\text{CCl}_2\text{FCClF}_2$	A1
114	1,2-Dichloro-1,1,2,2-tetrafluoroethane	$\text{CClF}_2\text{CClF}_2$	A1
115	Chloropentafluoroethane	CClF_2CF_3	A1
116	Hexafluoroethane	CF_3CF_3	A1
123	2,2-Dichloro-1,1,1-trifluoroethane	CHCl_2CF_3	B1
124	2-Chloro-1, 1,1,2-tetrafluoroethane	$\text{CHClF}_2\text{CF}_3$	A1
125	Pentafluoroethane	CHF_2CF_3	A1
134a	1,1,1,2-Tetrafluoroethane	CH_2FCF_3	A1
141b	1,1-Dichloro-1-fluoroethane	$\text{CH}_3\text{CCl}_2\text{F}$	Note (1)
142b	1-Chloro-1, 1-Difluoroethane	CH_3CClF_2	A2
143a	1,1,1-Trifluoroethane	CH_3CF_3	A2
152a	1,1-Difluoroethane	CH_3CHF_2	A2
170	Ethane	CH_3CH_3	A3
E170	Dimethyl ether	CH_3OCH_3	A3
Propane Series			
218	Octafluoropropane	$\text{CF}_3\text{CF}_2\text{CF}_3$	A1
236fa	1,1,1,3,3,3-Hexafluoropropane	$\text{CF}_3\text{CH}_2\text{CF}_3$	A1
245fa	1,1,1,3,3-Pentafluoropropane	$\text{CHF}_2\text{CH}_2\text{CF}_3$	B1
290	Propane	$\text{CH}_3\text{CH}_2\text{CH}_3$	A3
Cyclic Organic Compounds			
C318	Octafluorocyclobutane	$-(\text{CF}_2)_4-$	A1
Miscellaneous Organic Compounds			
Hydrocarbons			
600	Butane	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$	A3
600a	Isobutane	$\text{CH}(\text{CH}_3)_2\text{CH}_3$	A3
Oxygen Compounds			
610	Ethyl ether	$\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3$	Note (1)
611	Methyl formate	HCOOCH_3	B2
Nitrogen Compounds			
630	Methyl amine	CH_3NH_2	Note (1)
631	Ethyl amine	$\text{CH}_3\text{CH}_2(\text{NH}_2)$	Note (1)

Table 500.2-1 Refrigerant Safety Classifications (Cont'd)

Refrigerant Number	Chemical Name	Chemical Formula	Safety Group
Inorganic Compounds			
702	Hydrogen	H ₂	A3
704	Helium	He	A1
717	Ammonia	NH ₃	B2
718	Water	H ₂ O	A1
720	Neon	Ne	A1
728	Nitrogen	N ₂	A1
732	Oxygen	O ₂	Note (1)
740	Argon	Ar	A1
744	Carbon dioxide	CO ₂	A1
744A	Nitrous oxide	N ₂ O	Note (1)
764	Sulfur dioxide	SO ₂	B1
Unsaturated Organic Compounds			
1150	Ethene (ethylene)	CH ₂ =CH ₂	A3
1270	Propene (propylene)	CH ₃ CH=CH ₂	A3

GENERAL NOTES:

- (a) Refrigerant safety classifications per ANSI/ASHRAE 34-2001, addendum h, are shown here for convenience. More recent addenda may apply.
- (b) *Class A*: refrigerants for which toxicity has not been identified at concentrations less than or equal to 400 ppm (parts per million), based on data used to determine Threshold Limit Values–Time Weighted Average (TLV-TWA) or consistent indices.
- (c) *Class B*: refrigerants for which there is evidence of toxicity at concentrations below 400 ppm, based on data used to determine TLV-TWA or consistent indices.
- (d) *Class 1*: refrigerants that do not show flame propagation when tested in air at 14.7 psia (100 kPa) and 65°F (18°C).
- (e) *Class 2*: refrigerants having a lower flammability limit (LFL) of more than 0.00625 lb/ft³ (0.10 kg/m³) at 70°F (21°C) and 14.7 psia (100 kPa) and a heat of combustion of less than 8,174 Btu/lb (19 000 kJ/kg).
- (f) *Class 3*: refrigerants that are highly flammable as defined by having an LFL of less than or equal to 0.00625 lb/ft³ (0.10 kg/m³) at 70°F (21°C) and 14.7 psia (100 kPa) or a heat of combustion greater than or equal to 8,174 Btu/lb (19 000 kJ/kg).

NOTE:

- (1) No classification assigned as of this date.

Table 500.2-2 Safety Classifications for Refrigerant Blends

Refrigerant Number	Composition (Mass %)	Safety Group
Zeotropes		
400	R-12/114 (must be specified)	A1
401A	R-22/152a/124 (53/13/34)	A1
401B	R-22/152a/124 (61/11/28)	A1
401C	R-22/152a/124 (33/15/52)	A1
402A	R-125/290/22 (60.0/2.0/38.0)	A1
402B	R-125/290/22 (38.0/2.0/60.0)	A1
403A	R-290/22/218 (5/75/20)	A1
403B	R-290/22/218 (5/56/39)	A1
404A	R-125/143a/134a (44/52/4)	A1
405A	R-22/152a/142b/C318 (45/7/5.5/42.5)	Note (1)
406A	R-22/600a/142b (55/4/41)	A2
407A	R-32/125/134a (20/40/40)	A1
407B	R-32/125/134a (10/70/20)	A1
407C	R-32/125/134a (23/25/52)	A1
407D	R-32/125/134a (15/15/70)	A1
407E	R-32/125/134a (25/15/60)	A1
408A	R-125/143a/22 (7/46/47)	A1
409A	R-22/124/142b (60/25/15)	A1
409B	R-22/124/142b (65/25/10)	A1
410A	R-32/125 (50/50)	A1
410B	R-32/125 (45/55)	A1
411A	R-1270/22/152a (1.5/87.5/11.0)	A2
411B	R-1270/22/152a (3/94/3)	A2
412A	R-22/218/142b (70/5/25)	A2
413A	R-218/134a/600a (9/88/3)	A2
414A	R-22/124/600a/142b (51.0/28.5/4.0/16.5)	A1
414B	R-22/124/600a/142b (50.0/39.0/1.5/9.5)	A1
415A	R-22/152a (82.0/18.0)	A2
415B	R-22/152a (25.0/75.0)	A2
416A	R-134a/124/600 (59.0/39.5/1.5)	A1
417A	R-125/134a/600 (46.6/50.0/3.4)	A1
418A	R-290/22/152a (1.5/96.0/2.5)	A2
419A	R-125/134a/E170 (77.0/19.0/4.0)	A2
Azeotropes		
500	R-12/152a (73.8/26.2)	A1
501	R-22/12 (75.0/25.0)	A1
502	R-22/115 (48.8/51.2)	A1
503	R-23/13 (40.1/59.9)	Note (1)
504	R-32/115 (48.2/51.8)	Note (1)
505	R-12/31 (78.0/22.0)	Note (1)
506	R-31/114 (55.1/44.9)	Note (1)
507A	R-125/143a (50/50)	A1
508A	R-23/116 (39/61)	A1
508B	R-23/116 (46/54)	A1
509A	R-22/218 (44/56)	A1

GENERAL NOTES:

- (a) Safety classifications for refrigerant blends per ANSI/ASHRAE 34-2001, addendum h, are shown here for convenience. More recent addenda may apply.
- (b) *Class A*: refrigerants for which toxicity has not been identified at concentrations less than or equal to 400 ppm (parts per million), based on data used to determine Threshold Limit Values–Time Weighted Average (TLV-TWA) or consistent indices.
- (c) *Class B*: refrigerants for which there is evidence of toxicity at concentrations below 400 ppm, based on data used to determine TLV-TWA or consistent indices.
- (d) *Class 1*: refrigerants that do not show flame propagation when tested in air at 14.7 psia (100 kPa) and 65°F (18°C).
- (e) *Class 2*: refrigerants having a lower flammability limit (LFL) of more than 0.00625 lb/ft³ (0.10 kg/m³) at 70°F (21°C) and 14.7 psia (100 kPa) and a heat of combustion of less than 8,174 Btu/lb (19 000 kJ/kg).
- (f) *Class 3*: refrigerants that are highly flammable as defined by having an LFL of less than or equal to 0.00625 lb/ft³ (0.10 kg/m³) at 70°F (21°C) and 14.7 psia (100 kPa) or a heat of combustion greater than or equal to 8,174 Btu/lb (19 000 kJ/kg).

NOTE:

- (1) No classification assigned as of this date.

root penetration: the depth a groove weld extends into the root of a joint measured on the centerline of the root cross section.

seal weld: any weld used primarily to provide a specific degree of tightness against leakage.

secondary coolant: any liquid used for the transmission of heat without a change in its state.

self-contained system: a complete factory-made and factory-tested system in a suitable frame or enclosure that is fabricated and shipped in one or more sections and in which no refrigerant-containing parts are connected in the field other than by companion flanges or block valves.

semiautomatic arc welding: arc welding with equipment that controls only the filler metal feed. The advance of the welding is manually controlled.

shall: where “shall” or “shall not” is used for a provision specified, that provision is intended to be a Code requirement.

shielded metal-arc welding (SMAW): an arc welding process wherein coalescence is produced by heating with an electric arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used, and filler metal is obtained from the electrode.

should: “should” or “it is recommended” is used to indicate provisions that are not mandatory but recommended good practice.

size of weld

equal leg fillet weld: the leg lengths of the largest isosceles right triangle that can be inscribed within the fillet weld cross-section.

groove weld: the joint penetration (depth of chamfering plus the root penetration when specified). The size of the groove weld and its effective throat are one and the same.

unequal leg fillet weld: the leg lengths of the largest right triangle that can be inscribed within the fillet weld cross-section.

slag inclusion: nonmetallic solid material entrapped in weld metal or between weld metal and base metal.

soldering: a joining process that produces coalescence of materials by heating them to a suitable temperature and by using a filler metal having a liquidus not exceeding 840°F (450°C) and below the solidus of the base materials. The filler metal is distributed between the closely fitted surfaces of the joint by capillary action. Soldering

may be performed manually, ultrasonically, or in a furnace.

submerged arc welding (SAW): an arc welding process wherein coalescence is produced by heating an arc(s) between a bare metal electrode or electrodes and the work. The arc 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.

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

throat of a fillet weld

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

effective: the minimum distance from the root of a weld to its face, less any reinforcement.

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.

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

tube: see *pipe*.

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

weld: a localized coalescence of metals or nonmetals produced by heating the materials to suitable temperatures, with or without the application of pressure, and with or without the use of filler metal.

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

welding operator: one who operates machine or automatic welding equipment.

welding procedures: the detailed methods and practices including all joint welding procedures involved in the production of a weldment.

weldment: an assembly whose component parts are joined by welding.

500.3 Nomenclature

Dimensional and mathematical symbols used in this Code are listed in Nonmandatory Appendix D, with definitions and location references to each. Uppercase and lowercase English letters are listed alphabetically, followed by Greek letters.

Chapter II

Design

PART 1 CONDITIONS AND CRITERIA

501 DESIGN CONDITIONS

501.1 General

Section 501 defines the temperatures, pressures, and various forces applicable to the design of piping systems. It also states considerations that shall be given to ambient and mechanical influences and various loadings.

501.2 Pressure

501.2.2 Internal Design Pressure. The piping component shall be designed for an internal pressure representing the most severe condition of coincident pressure and temperature expected in normal operation or standby (including fluid head). The most severe condition of coincident pressure and temperature shall be that condition that results in the greater required piping component thickness and the highest component rating.

Any piping connected to components other than piping shall have a design pressure no less than the lowest design pressure of any component to which it is connected.

501.2.3 External Design Pressure. The piping component shall be designed for an external pressure representing the most severe condition of coincident pressure and temperature expected during shutdown or in normal operation (including fluid head) considering possible loss of internal pressure. Refrigerant piping systems shall be designed to resist collapse when the internal pressure is zero absolute and the external pressure is atmospheric. This is to permit drying the pipe by evacuation. The most severe condition of coincident pressure and temperature shall be that condition that results in the greatest required pipe thickness and the highest component rating.

501.2.4 Minimum Design Pressure. Minimum design gage pressure shall be not less than 15 psi (105 kPa) and, except as noted in para. 501.2.5, shall be not less than the saturation pressure of the refrigerant at the following temperatures:

- (a) low sides of all systems: 80°F (27°C)
- (b) high side of water or evaporatively cooled systems: 104°F (40°C)
- (c) high sides of air cooled systems: 122°F (50°C)

Considerations shall be given to low side systems with hot gas defrost. Such systems impose high side

pressure on the low side during the defrost cycle. This may raise the low side design pressure requirements.

501.2.5 Minimum Design Pressure for Specific Service

(a) Design pressure for either high or low side need not exceed the critical pressure of the refrigerant unless the system is intended to operate at these conditions.

(b) When components of a system are protected by a pressure relief device, the design pressure of the piping need not exceed the setting of the pressure relief device.

(c) In a compound system the piping between stages shall be considered the low side of the next higher stage compressor.

501.3 Temperature

In this Code, metal temperature of piping in service is considered to be the temperature of the fluid conveyed.

501.3.1 Brittle Fracture. Consideration must be given to a reduction in impact strength occurring in some materials when subjected to low temperatures. Notch effects should be avoided. See para. 523.2.

501.4 Ambient Influences

501.4.1 Ambient Temperature. In the design of refrigeration piping systems, consideration must be given to the influence of ambient temperature.

501.4.2 Fluid Expansion Effects (Increased Pressure). Consideration must be given to expansion of liquid refrigerant trapped in or between closed valves and a means provided to prevent overpressure.

501.5 Dynamic Effects

501.5.1 Impact. Impact forces, including hydraulic shock and liquid slugging, caused by either external or internal conditions shall be considered in the design of piping components.

501.5.2 Wind. The effect of wind loading should be taken into account in the design of exposed piping as described in SEI/ASCE 7-05.

501.5.3 Earthquake (Seismic Forces). Piping systems located in regions where earthquakes are a factor shall be designed for horizontal forces. The method of analysis may be as described in SEI/ASCE 7-05. However, this force is not to be considered as acting concurrently with lateral wind force.

501.5.4 Vibration. Piping shall be arranged and supported with consideration to vibration. (See para. 521.3.5.)

501.5.5 Discharge Reactions. Piping systems shall be designed, arranged, and supported so as to withstand reaction forces due to let down or discharge of fluids.

501.6 Weight Effects

The following weight effects combined with loads and forces from other causes shall be taken into account in the design of piping.

501.6.1 Live Loads. The live load consists of the weight of the fluid transported, and snow and ice loads, if the latter will be encountered.

501.6.2 Dead Loads. Dead loads consist of the weight of the piping components and insulation, and other superimposed permanent loads.

501.6.3 Test Loads. The test load consists of the weight of the test fluid.

501.7 Thermal Expansion and Contraction Loads

When a piping system is prevented from free thermal expansion and contraction as a result of anchors and restraints, thrusts and moments are set up that must be taken into account as required by sections 502 and 519. Consideration must be given to stresses developed inside pipe walls by large rapid temperature changes of the contents.

502 DESIGN CRITERIA

502.1 General

Section 502 pertains to ratings, stress values, stress criteria, design allowances, and minimum design values, and formulates the permissible variations to these factors used in the design of piping.

502.2 Pressure–Temperature Design Criteria for Piping Components

502.2.1 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 526.1.

502.2.2 Ratings: Normal Operating Conditions. For normal operation the design pressure and design temperature shall be within the pressure–temperature ratings for all components used.

502.2.3 Ratings: Allowance for Variations From Normal Operation. It is recognized that variations in pressure and temperature inevitably occur, and therefore the piping system shall be considered safe for occasional operation for short periods at higher than the design pressure or temperature.

Either pressure or temperature, or both, may exceed the design values if the stress in the pipe wall calculated by the formulas using the maximum expected pressure during the variation does not exceed the S value allowable for the maximum expected temperature during the variation by more than the following allowances for the periods of duration indicated:

(a) up to 15% increase above the S value during 10% of the operating period

(b) up to 20% increase above the S value during 1% of the operating period

502.2.4 Considerations for Local Conditions and Transitions. When two lines that operate at different pressure–temperature conditions are connected, the valve segregating the two lines shall be rated for the more severe condition. When a line is connected to a piece of equipment that operates at a higher pressure–temperature condition than that of the line, the valve segregating the line from the equipment shall be rated for at least the operating condition of the equipment. If, however, the valve is a sufficient distance from the pipe or piece of equipment operating under the more severe service condition, with the result that the temperature of this valve would be lower than the more severe service condition, this valve may be rated for the most severe coexistent pressure–temperature condition to which it will be actually subjected in normal operation. However, the piping between the more severe conditions and the valve shall be designed to withstand the operating conditions of the equipment or piping to which it is connected.

502.2.5 Standards and Specifications. Where there are manufacturers' standards of long standing, as is the case for flanges, valves, and fittings for certain refrigerants, these shall be permitted for the particular refrigerant service listed by the manufacturer.

502.2.6 Use of Criteria. The design conditions mentioned in section 501 determine the thickness of metal or other material required in the piping system. This thickness can be determined by one of the following three methods:

(a) a combination of allowable stresses for the materials at the various temperature and mathematical formulas that link together the design condition and the thickness of metal or other material required

(b) a pressure–temperature rating for the individual components

(c) an outright requirement that certain standardized components be used or not be used

502.3 Allowable Stresses and Other Stress Limits

502.3.1 Allowable Stress Values

(a) The allowable stress values to be used for design calculations shall conform to Table 502.3.1 unless otherwise modified by requirements of this Code.

Table 502.3.1 Maximum Allowable Stress Values, ksi
(Multiply by 1,000 to Obtain psi)

Material	Spec. No.	Grade, Type, or Class	Min. Temperature, °F [Notes (1) and (2)]	Min. Tensile Strength, ksi [Note (3)]	Min. Yield Strength, ksi [Note (3)]	Longitudinal or Spiral Joint Factor
Seamless Carbon Steel Pipe and Tube						
Steel pipe	ASTM A53	A	B	48.0	30.0	...
Steel pipe	ASTM A53	B	B	60.0	35.0	...
Steel pipe	ASTM A106	A	B	48.0	30.0	...
Steel pipe	ASTM A106	B	B	60.0	35.0	...
Steel pipe	ASTM A106	C	B	70.0	40.0	...
Steel tube	ASTM A179	...	-20	47.0	26.0	...
Steel tube	ASTM A192	...	-20	47.0	26.0	...
Steel tube	ASTM A210	A-1	-20	60.0	37.0	...
Steel pipe	ASTM A333	1	-50	55.0	30.0	...
Steel pipe	ASTM A333	6	-50	60.0	35.0	...
Steel tube	ASTM A334	1	-50	55.0	30.0	...
Steel tube	ASTM A334	6	-50	60.0	35.0	...
Steel pipe	API 5L	A	B	48.0	30.0	...
Steel pipe	API 5L	B	B	60.0	35.0	...
Carbon Steel Pipe and Tube						
Steel pipe	ASTM A53	F	-20	48.0	30.0	0.60
Steel pipe	API 5L	A25	-20	45.0	25.0	0.60
Carbon Steel Pipe and Tube						
Electric Resistance Welded Pipe and Tube						
Steel pipe	ASTM A53	A	B	48.0	30.0	0.85
Steel pipe	ASTM A53	B	B	60.0	35.0	0.85
Steel pipe	ASTM A135	A	B	48.0	30.0	0.85
Steel pipe	ASTM A135	B	B	60.0	35.0	0.85
Steel tube	ASTM A178	A	-20	47.0	26.0	0.85
Steel tube	ASTM A178	C	-20	60.0	37.0	0.85
Steel tube	ASTM A214	...	-20	47.0	26.0	0.85
Steel tube	ASTM A226	...	-20	47.0	26.0	0.85
Steel pipe	ASTM A333	1	-50	55.0	30.0	0.85
Steel pipe	ASTM A333	6	-50	60.0	35.0	0.85
Steel tube	ASTM A334	1	-50	55.0	30.0	0.85
Steel tube	ASTM A334	6	-50	60.0	35.0	0.85
Steel pipe	ASTM A587	...	-20	48.0	30.0	0.85
Steel pipe	API 5L	A	B	48.0	30.0	0.85
Steel pipe	API 5L	B	B	60.0	35.0	0.85
Carbon Steel Pipe and Tube						
Electric Fusion Welded Pipe						
Steel pipe	ASTM A134	A283 Gr. A	B	45.0	24.0	0.80
Steel pipe	ASTM A134	A283 Gr. B	B	50.0	27.0	0.80
Steel pipe	ASTM A134	A283 Gr. C	A	55.0	30.0	0.80

Table 502.3.1 Maximum Allowable Stress Values, ksi (Cont'd)
(Multiply by 1,000 to Obtain psi)

For Metal Temperatures, °F							
Min. Temp. to 100	150	200	250	300	350	400	Spec. No.
Seamless Carbon Steel Pipe and Tube							
13.7	13.7	13.7	13.7	13.7	13.7	13.7	ASTM A53
17.1	17.1	17.1	17.1	17.1	17.1	17.1	ASTM A53
13.7	13.7	13.7	13.7	13.7	13.7	13.7	ASTM A106
17.1	17.1	17.1	17.1	17.1	17.1	17.1	ASTM A106
20.0	20.0	20.0	20.0	20.0	20.0	20.0	ASTM A106
13.4	13.4	13.4	13.4	13.4	13.4	13.4	ASTM A179
13.4	13.4	13.4	13.4	13.4	13.4	13.4	ASTM A192
17.1	17.1	17.1	17.1	17.1	17.1	17.1	ASTM A210
15.7	15.7	15.7	15.7	15.7	15.7	15.7	ASTM A333
17.1	17.1	17.1	17.1	17.1	17.1	17.1	ASTM A333
15.7	15.7	15.7	15.7	15.7	15.7	15.7	ASTM A334
17.1	17.1	17.1	17.1	17.1	17.1	17.1	ASTM A334
13.7	13.7	13.7	13.7	13.7	13.7	13.7	API 5L
17.1	17.1	17.1	17.1	17.1	17.1	17.1	API 5L
Carbon Steel Pipe and Tube							
8.2	8.2	8.2	8.2	8.2	8.2	8.2	ASTM A53
7.7	7.7	7.7	7.7	7.7	7.7	7.7	API 5L
Carbon Steel Pipe and Tube Electric Resistance Welded Pipe and Tube							
11.7	11.7	11.7	11.7	11.7	11.7	11.7	ASTM A53
14.6	14.6	14.6	14.6	14.6	14.6	14.6	ASTM A53
11.7	11.7	11.7	11.7	11.7	11.7	11.7	ASTM A135
14.6	14.6	14.6	14.6	14.6	14.6	14.6	ASTM A135
11.4	11.4	11.4	11.4	11.4	11.4	11.4	ASTM A178
14.6	14.6	14.6	14.6	14.6	14.6	14.6	ASTM A178
11.4	11.4	11.4	11.4	11.4	11.4	11.4	ASTM A214
11.4	11.4	11.4	11.4	11.4	11.4	11.4	ASTM A226
13.4	13.4	13.4	13.4	13.4	13.4	13.4	ASTM A333
14.6	14.6	14.6	14.6	14.6	14.6	14.6	ASTM A333
13.4	13.4	13.4	13.4	13.4	13.4	13.4	ASTM A334
14.6	14.6	14.6	14.6	14.6	14.6	14.6	ASTM A334
11.7	11.7	11.7	11.7	11.7	11.7	11.7	ASTM A587
11.7	11.7	11.7	11.7	11.7	11.7	11.7	API 5L
14.6	14.6	14.6	14.6	14.6	14.6	14.6	API 5L
Carbon Steel Pipe and Tube Electric Fusion Welded Pipe							
10.3	10.3	10.3	10.3	10.3	...	...	ASTM A134
11.4	11.4	11.4	11.4	11.4	...	...	ASTM A134
12.6	12.6	12.6	12.6	12.6	...	...	ASTM A134

Table 502.3.1 Maximum Allowable Stress Values, ksi (Cont'd)
(Multiply by 1,000 to Obtain psi)

Material	Spec. No.	Grade, Type, or Class	Min. Temperature, °F [Notes (1) and (2)]	Min. Tensile Strength, ksi [Note (3)]	Min. Yield Strength, ksi [Note (3)]	Longitudinal or Spiral Joint Factor
Carbon Steel Pipe and Tube						
Electric Fusion Welded Pipe (Cont'd)						
Steel Pipe	ASTM A134	A283 Gr. D	A	60.0	33.0	0.80
Carbon Steel Pipe and Tube						
Copper Brazed Tubing						
Steel tube	ASTM A254	...	...	42.0	25.0	...
Low and Intermediate Alloy Steel Pipe and Tube						
Seamless Alloy Steel Pipe and Tube						
3½Ni pipe	ASTM A333	3	-150	65.0	35.0	...
Cr-Cu-Ni-Al pipe	ASTM A333	4	-150	60.0	35.0	...
2½Ni pipe	ASTM A333	7	-100	65.0	35.0	...
2Ni pipe	ASTM A333	9	-100	63.0	46.0	...
3½Ni tube	ASTM A334	3	-150	65.0	35.0	...
2½Ni tube	ASTM A334	7	-100	65.0	35.0	...
2Ni tube	ASTM A334	9	-100	63.0	46.0	...
Low and Intermediate Alloy Steel Pipe and Tube						
Electric Resistance Welded Pipe and Tube						
3½Ni pipe	ASTM A333	3	-150	65.0	35.0	0.85
2½Ni pipe	ASTM A333	7	-100	65.0	35.0	0.85
2Ni pipe	ASTM A333	9	-100	63.0	46.0	0.85
3½Ni tube	ASTM A334	3	-150	65.0	35.0	0.85
2½Ni tube	ASTM A334	7	-100	65.0	35.0	0.85
Austenitic Stainless Steel Pipe and Tube						
Seamless Pipe and Tube						
18-8 tube	ASTM A213	TP304	-425	75.0	30.0	...
18-8 tube	ASTM A213	TP304L	-425	70.0	25.0	...
18-8 pipe	ASTM A312	TP304	-425	75.0	30.0	...
18-8 pipe	ASTM A312	TP304L	-425	70.0	25.0	...
18-8 pipe	ASTM A376	TP304	-425	75.0	30.0	...
18-8 pipe	ASTM A376	TP304	-425	70.0	30.0	...
Austenitic Stainless Steel Pipe and Tube						
Welded Pipe and Tube						
18-8 tube	ASTM A249	TP304	-425	75.0	30.0	0.85
18-8 tube	ASTM A249	TP304L	-425	70.0	25.0	0.85
18-8 pipe	ASTM A312	TP304	-425	75.0	30.0	0.85
18-8 pipe	ASTM A312	TP304L	-425	70.0	25.0	0.85

Table 502.3.1 Maximum Allowable Stress Values, ksi (Cont'd)
(Multiply by 1,000 to Obtain psi)

For Metal Temperatures, °F							Spec. No.
Min. Temp. to 100	150	200	250	300	350	400	
Carbon Steel Pipe and Tube Electric Fusion Welded Pipe (Cont'd)							
13.7	13.7	13.7	13.7	13.7	...	...	ASTM A134
Carbon Steel Pipe and Tube Copper Brazed Tubing							
6.0	5.1	4.9	4.8	4.7	4.0	3.0	ASTM A254
Low and Intermediate Alloy Steel Pipe and Tube Seamless Alloy Steel Pipe and Tube							
18.6	18.6	18.6	18.6	18.6	18.6	18.6	ASTM A333
17.1	17.1	17.1	17.1	17.1	17.1	17.1	ASTM A333
18.6	18.6	18.6	18.6	18.6	18.6	18.6	ASTM A333
18.0	...	...	...	...	...	...	ASTM A333
18.6	18.6	18.6	18.6	18.6	18.6	18.6	ASTM A334
18.6	18.6	18.6	18.6	18.6	18.6	18.6	ASTM A334
18.0	...	...	...	...	...	...	ASTM A334
Low and Intermediate Alloy Steel Pipe and Tube Electric Resistance Welded Pipe and Tube							
15.8	15.8	15.8	15.8	15.8	15.8	15.8	ASTM A333
15.8	15.8	15.8	15.8	15.8	15.8	15.8	ASTM A333
15.3	...	...	...	...	...	...	ASTM A333
15.8	15.8	15.8	15.8	15.8	15.8	15.8	ASTM A334
15.8	15.8	15.8	15.8	15.8	15.8	15.8	ASTM A334
Austenitic Stainless Steel Pipe and Tube Seamless Pipe and Tube							
20.0	20.0	20.0	19.5	18.9	18.5	18.3	ASTM A213
16.7	16.7	16.7	16.7	16.7	16.5	15.8	ASTM A213
20.0	20.0	20.0	19.5	18.9	18.5	18.3	ASTM A312
16.7	16.7	16.7	16.7	16.7	16.5	15.8	ASTM A312
20.0	20.0	20.0	19.5	18.9	18.5	18.3	ASTM A376
20.0	20.0	18.9	...	17.7	...	17.1	ASTM A376
Austenitic Stainless Steel Pipe and Tube Welded Pipe and Tube							
17.0	17.0	17.0	16.6	16.1	15.7	15.5	ASTM A249
14.2	14.2	14.2	14.2	14.2	14.0	13.4	ASTM A249
17.0	17.0	17.0	16.6	16.1	15.7	15.5	ASTM A312
14.2	14.2	14.2	14.2	14.2	14.0	13.4	ASTM A312

Table 502.3.1 Maximum Allowable Stress Values, ksi (Cont'd)
(Multiply by 1,000 to Obtain psi)

Material	Spec. No.	Size or Wall, in.	Copper or Copper Alloy No.	Temper	Min. Tensile Strength, ksi [Note (3)]	Min. Yield Strength, ksi [Note (3)]
Seamless Copper and Copper Alloy Pipe and Tube						
Copper pipe	ASTM B42	All	C10200 C12200	Annealed (O61)	30.0	9.0
Copper pipe [Note (4)]	ASTM B42	$\frac{1}{8}$ –2, incl.	C10200 C12200	Hard drawn (H80)	45.0	40.0
Copper pipe [Note (4)]	ASTM B42	2–12, incl.	C10200 C12200	Light drawn (H55)	36.0	30.0
Red brass pipe	ASTM B43	All	C23000	Annealed (O61)	40.0	12.0
Copper tube	ASTM B68	All	C10200 C12200	Light anneal, soft anneal (O50, O60)	30.0	9.0
Copper tube	ASTM B75	All	C10200 C12200	Light anneal, soft anneal (O50, O60)	30.0	9.0
Copper tube [Note (4)]	ASTM B75	All	C10200 C12200 C14200	Light drawn (H55)	36.0	30.0
Copper tube [Note (4)]	ASTM B75	Up to 4	C10200 C12200	Hard drawn (H80)	45.0	40.0
Copper tube [Note (4)]	ASTM B88	All	C10200 C12200	Drawn general purpose (H58)	36.0	30.0
Copper tube	ASTM B88	All	C10200 C12200	Light anneal (O50)	30.0	9.0
Copper tube [Note (4)]	ASTM B111	Up to $3\frac{1}{8}$, incl.	C10200 C12200 C14200	Light drawn (H55)	36.0	30.0
Copper tube [Note (4)]	ASTM B111	Up to $3\frac{1}{8}$, incl.	C10200 C12200 C14200	Hard drawn (H80)	45.0	40.0
Copper alloy	ASTM B111	Up to $3\frac{1}{8}$, incl.	C19200	Annealed (O61)	38.0	12.0
Red brass condenser tube	ASTM B111	Up to $3\frac{1}{8}$, incl.	C23000	Annealed (O61)	40.0	12.0

Table 502.3.1 Maximum Allowable Stress Values, ksi (Cont'd)
(Multiply by 1,000 to Obtain psi)

For Metal Temperatures, °F							Spec. No.
100	150	200	250	300	350	400	
Seamless Copper and Copper Alloy Pipe and Tube							
6.0	5.1	4.9	4.8	4.7	4.0	3.0	ASTM B42
12.9	12.9	12.9	12.9	12.5	11.8	4.3	ASTM B42
10.3	10.3	10.3	10.3	10.0	9.7	9.4	ASTM B42
8.0	8.0	8.0	8.0	8.0	7.0	5.0	ASTM B43
6.0	5.1	4.9	4.8	4.7	4.0	3.0	ASTM B68
6.0	5.1	4.9	4.8	4.7	4.0	3.0	ASTM B75
10.3	10.3	10.3	10.3	10.0	9.7	9.4	ASTM B75
12.9	12.9	12.9	12.9	12.5	11.8	4.3	ASTM B75
10.3	10.3	10.3	10.3	10.0	9.7	9.4	ASTM B88
6.0	5.1	4.9	4.8	4.7	4.0	3.0	ASTM B88
10.3	10.3	10.3	10.3	10.0	9.7	9.4	ASTM B111
12.9	12.9	12.9	12.9	12.5	11.8	4.3	ASTM B111
8.0	7.1	6.7	6.4	6.2	...	...	ASTM B111
8.0	8.0	8.0	8.0	8.0	7.0	5.0	ASTM B111

Table 502.3.1 Maximum Allowable Stress Values, ksi (Cont'd)
(Multiply by 1,000 to Obtain psi)

Material	Spec. No.	Size or Wall, in.	Copper or Copper Alloy No.	Temper	Min. Tensile Strength, ksi [Note (3)]	Min. Yield Strength, ksi [Note (3)]
Seamless Copper and Copper Alloy Pipe and Tube (Cont'd)						
Muntz metal condenser tube	ASTM B111	Up to $3\frac{1}{8}$, incl.	C28000	Annealed (O61)	50.0	20.0
Admiralty metal condenser tube	ASTM B111	Up to $3\frac{1}{8}$, incl.	C44300 C44400 C44500	Annealed (O61)	45.0	15.0
Aluminum bronze condenser tube	ASTM B111	Up to $3\frac{1}{8}$, incl.	C60800	Annealed (O61)	50.0	19.0
Aluminum brass condenser tube	ASTM B111	Up to $3\frac{1}{8}$, incl.	C68700	Annealed (O61)	50.0	18.0
95Cu–5Ni condenser tube	ASTM B111	Up to $3\frac{1}{8}$, incl.	C70400	Annealed (O61)	38.0	12.0
95Cu–5Ni condenser tube	ASTM B111	Up to $3\frac{1}{8}$, incl.	C70400	Light drawn (H55)	40.0	30.0
90Cu–10Ni condenser tube	ASTM B111	Up to $3\frac{1}{8}$, incl.	C70600	Annealed (O61)	40.0	15.0
80Cu–20Ni condenser tube	ASTM B111	Up to $3\frac{1}{8}$, incl.	C71000	Annealed (O61)	45.0	16.0
70Cu–30Ni condenser tube	ASTM B111	Up to $3\frac{1}{8}$, incl.	C71500	Annealed (O61)	52.0	18.0
Copper tube	ASTM B280	Up to $1\frac{5}{8}$	C12200	Soft anneal (O60)	30.0	9.0
Copper tube	ASTM B280	Up to $4\frac{1}{8}$	C12200	Drawn general purpose (H58)	36.0	30.0
Copper silicon A pipe	ASTM B315	Up to 12	C65500	Annealed (O61)	50.0	15.0
90Cu–10Ni pipe	ASTM B466	Up to 6	C70600	Soft anneal (O60)	38.0	13.0
70Cu–30Ni pipe	ASTM B466	Up to 6	C71500	Soft anneal (O60)	52.0	18.0
Welded Copper and Copper Alloy Pipe and Tube						
90Cu–10Ni pipe and tube [Note (5)]	ASTM B467	Up to $4\frac{1}{2}$, incl.	C70600	Welded and annealed (WO61)	40.0	15.0
90Cu–10Ni pipe and tube [Note (5)]	ASTM B467	Over $4\frac{1}{2}$	C70600	Welded and annealed (WO61)	38.0	13.0
70Cu–30Ni pipe and tube [Note (5)]	ASTM B467	Up to $4\frac{1}{2}$, incl.	C71500	Welded and annealed (WO61)	50.0	20.0
70Cu–30Ni pipe and tube [Note (5)]	ASTM B467	Over $4\frac{1}{2}$	C71500	Welded and annealed (WO61)	45.0	15.0
70Cu–30Ni pipe and tube [Note (5)]	ASTM B467	Up to 2, incl.	C71500	Welded, drawn, and tempered	72.0	50.0
Copper tube [Notes (4) and (5)]	ASTM B543	Up to $3\frac{1}{8}$, incl.	C12200	Light cold worked (WC55)	32.0	15.0
Copper alloy tube [Note (5)]	ASTM B543	Up to $3\frac{1}{8}$, incl.	C19400	Annealed (WO61)	45.0	15.0
Copper alloy tube [Notes (4) and (5)]	ASTM B543	Up to $3\frac{1}{8}$, incl.	C19400	Light cold worked (WC55)	45.0	22.0
Red brass tube [Note (5)]	ASTM B543	Up to $3\frac{1}{8}$, incl.	C23000	Annealed (WO61)	40.0	12.0
Red brass tube [Notes (4) and (5)]	ASTM B543	Up to $3\frac{1}{8}$, incl.	C23000	Light cold worked (WC55)	42.0	20.0
Admiralty metal tube [Note (5)]	ASTM B543	Up to $3\frac{1}{8}$, incl.	C44300 C44400 C44500	Annealed (WO61)	45.0	15.0
Aluminum brass tube [Note (5)]	ASTM B543	Up to $3\frac{1}{8}$, incl.	C68700	Annealed (WO61)	50.0	18.0
95Cu–5Ni tube [Note (5)]	ASTM B543	Up to $3\frac{1}{8}$, incl.	C70400	Annealed (WO61)	38.0	12.0
90Cu–10Ni [Note (5)]	ASTM B543	Up to $3\frac{1}{8}$, incl.	C70600	Annealed (WO61)	40.0	15.0
90Cu–10Ni [Notes (4) and (5)]	ASTM B543	Up to $3\frac{1}{8}$, incl.	C70600	Light cold worked (WC55)	45.0	35.0
70Cu–30Ni [Note (5)]	ASTM B543	Up to $3\frac{1}{8}$, incl.	C71500	Annealed (WO61)	52.0	18.0

Table 502.3.1 Maximum Allowable Stress Values, ksi (Cont'd)
(Multiply by 1,000 to Obtain psi)

For Metal Temperatures, °F							
Min. Temp. to 100	150	200	250	300	350	400	Spec. No.
Seamless Copper and Copper Alloy Pipe and Tube (Cont'd)							
13.3	13.3	13.3	13.3	13.3	10.8	5.3	ASTM B111
10.0	10.0	10.0	10.0	10.0	9.8	3.5	ASTM B111
12.7	12.2	12.2	12.2	12.0	10.0	6.0	ASTM B111
12.0	11.9	11.8	11.7	11.7	6.5	3.3	ASTM B111
8.0	7.8	...	...	...	...	...	ASTM B111
11.4	11.4	...	...	...	...	...	ASTM B111
10.0	9.7	9.5	9.3	9.0	8.8	8.7	ASTM B111
10.7	10.6	10.5	10.4	10.2	10.1	9.9	ASTM B111
12.0	11.6	11.3	11.0	10.8	10.5	10.3	ASTM B111
6.0	5.1	4.9	4.8	4.7	4.0	3.0	ASTM B280
9.0	9.0	9.0	9.0	8.7	8.5	8.2	ASTM B280
10.0	10.0	9.9	9.8	9.7	9.5	6.7	ASTM B315
8.7	8.4	8.2	8.0	7.8	7.7	7.5	ASTM B466
12.0	11.6	11.3	11.0	10.8	10.5	10.3	ASTM B466
Welded Copper and Copper Alloy Pipe and Tube							
8.5	8.3	8.1	7.9	7.7	7.5	7.4	ASTM B467
7.4	7.2	7.0	6.8	6.7	6.5	6.4	ASTM B467
11.3	10.9	10.7	10.4	10.2	10.0	9.7	ASTM B467
8.5	8.2	8.0	7.8	7.6	7.5	7.3	ASTM B467
17.5	17.5	17.5	17.5	17.5	17.5	17.5	ASTM B467
7.8	7.8	7.8	7.8	7.6	7.5	2.6	ASTM B543
8.5	8.4	8.3	8.1	7.8	7.6	6.0	ASTM B543
10.9	10.9	10.9	10.6	10.1	7.7	6.0	ASTM B543
6.8	6.8	6.8	6.8	6.8	6.0	4.3	ASTM B543
10.2	10.2	10.1	10.0	9.7	6.0	4.3	ASTM B543
8.5	8.5	8.5	8.5	8.5	8.3	3.0	ASTM B543
10.2	10.1	10.0	10.0	9.9	5.5	2.8	ASTM B543
6.8	6.6	...	...	...	...	...	ASTM B543
8.5	8.3	8.1	7.9	7.7	7.5	7.4	ASTM B543
10.9	10.9	10.8	10.4	10.0	9.6	9.4	ASTM B543
10.2	9.8	9.6	9.4	9.2	9.0	8.8	ASTM B543

Table 502.3.1 Maximum Allowable Stress Values, ksi (Cont'd)
(Multiply by 1,000 to Obtain psi)

Material	Spec. No.	Size or Wall, in.	Copper or Copper Alloy No.	Temper	Min. Tensile Strength, ksi [Note (3)]	Min. Yield Strength, ksi [Note (3)]
Welded Copper and Copper Alloy Pipe and Tube (Cont'd)						
Copper tube	ASTM B743	...	C10200 C10300 C10800 C12000 C12200	Drawn general purpose (H58)	36.0	30.0
Copper tube	ASTM B743	...	C10200 C10300 C10800 C12000 C12200	Light anneal, soft anneal (O50, O60)	30.0	9.0
Seamless Nickel Base Alloy Pipe and Tube						
Nickel and copper pipe	ASTM B165	5 O.D. and under	N04400	Annealed	70.0	28.0
Nickel and copper pipe	ASTM B165	Over 5 O.D.	N04400	Annealed	70.0	25.0
Seamless Aluminum Base Alloy Pipe and Tube						
3003 tube	ASTM B210	0.01 to 0.05	...	O	14.0	5.0
3003 tube [Note (6)]	ASTM B210	0.01 to 0.05	...	H14	20.0	17.0
6063 tube [Note (7)]	ASTM B210	0.025 to 0.50	...	T6	33.0	28.0
6063 tube	ASTM B210	0.025 to 0.50	...	T6 welded	17.0	...
6061 tube [Note (7)]	ASTM B210	0.025 to 0.50	...	T4	30.0	16.0
6061 tube [Note (7)]	ASTM B210	0.025 to 0.50	...	T6	42.0	35.0
6061 tube	ASTM B210	0.025 to 0.50	...	T6 welded	24.0	...
6061 tube [Note (7)]	ASTM B234	0.025 to 0.20	...	T4	30.0	16.0
6061 tube [Note (7)]	ASTM B234	0.025 to 0.20	...	T6	42.0	35.0
6061 tube	ASTM B234	0.025 to 0.20	...	T6 welded	24.0	...
3003 tube or pipe	ASTM B241	...	...	O	14.0	5.0
3003 pipe [Note (6)]	ASTM B241	Under 1	...	H18	27.0	24.0
3003 pipe [Note (6)]	ASTM B241	1 and over	...	H112	14.0	5.0
5083 tube	ASTM B241	...	...	O	39.0	16.0
6063 tube [Note (7)]	ASTM B241	Up to 0.50, incl.	...	T5	22.0	16.0
6063 tube [Note (7)]	ASTM B241	...	...	T6	30.0	25.0
6061 tube [Note (7)]	ASTM B241	...	...	T4	26.0	16.0
6061 pipe [Note (7)]	ASTM B241	1 and over	...	T6	38.0	35.0
6061 pipe	ASTM B241	...	...	T6 welded	24.0	...

Table 502.3.1 Maximum Allowable Stress Values, ksi (Cont'd)
(Multiply by 1,000 to Obtain psi)

For Metal Temperatures, °F							Spec. No.
100	150	200	250	300	350	400	
Welded Copper and Copper Alloy Pipe and Tube (Cont'd)							
10.3	10.3	10.3	10.1	10.0	9.8	9.4	ASTM B743
6.0	5.1	4.9	4.8	4.7	4.0	3.0	ASTM B743
Seamless Nickel Base Alloy Pipe and Tube							
18.7	17.2	16.4	15.7	15.2	14.9	14.7	ASTM B165
16.7	15.3	14.6	14.0	13.6	13.3	13.2	ASTM B165
Seamless Aluminum Base Alloy Pipe and Tube							
3.3	3.2	3.1	3.0	2.4	1.8	1.4	ASTM B210
5.7	5.7	5.7	5.5	4.3	3.0	2.4	ASTM B210
9.4	9.4	9.4	8.3	6.3	3.4	2.0	ASTM B210
4.9	4.9	4.9	4.9	4.9	3.4	2.0	ASTM B210
8.6	8.6	8.6	8.5	8.1	7.1	5.1	ASTM B210
12.0	12.0	12.0	11.7	10.0	7.7	5.2	ASTM B210
6.9	6.9	6.9	6.8	6.5	5.7	4.1	ASTM B210
8.6	8.6	8.6	8.5	8.1	7.1	5.1	ASTM B234
12.0	12.0	12.0	11.7	10.0	7.7	5.2	ASTM B234
6.9	6.9	6.9	6.8	6.5	5.7	4.1	ASTM B234
3.3	3.2	3.1	3.0	2.4	1.8	1.4	ASTM B241
7.7	7.7	7.2	7.2	5.3	3.5	2.5	ASTM B241
3.3	3.2	3.1	3.0	2.4	1.8	1.4	ASTM B241
10.7	10.7	...	...	...	...	...	ASTM B241
6.3	6.3	6.1	5.8	5.2	3.4	2.0	ASTM B241
8.6	8.6	8.6	7.5	5.8	3.4	2.0	ASTM B241
7.4	7.4	7.4	7.4	7.0	6.2	4.4	ASTM B241
10.9	10.9	10.9	10.6	9.1	7.0	5.0	ASTM B241
6.9	6.9	6.9	6.8	6.5	5.7	4.1	ASTM B241

Table 502.3.1 Maximum Allowable Stress Values, ksi (Cont'd)
(Multiply by 1,000 to Obtain psi)

Material	ASTM Spec. No.	Grade	Min. Temp., °F [Note (2)]	Specified Min. Strength, ksi		Basic Allowable Stress S, ksi at Metal Temperature, °F [Notes (2) and (3)]			
				Tensile	Yield	Min. Temp. to 100	200	300	400
Iron Castings									
Gray	A48	20	−20	20	...	2.0	2.0	2.0	2.0
Gray [Notes (8) and (9)]	A278	20	−20	20	...	2.0	2.0	2.0	2.0
Gray [Notes (8) and (9)]	A126	A	−20	21	...	2.1	2.1	2.1	2.1
Gray	A48	25	−20	25	...	2.5	2.5	2.5	2.5
Gray [Notes (8) and (9)]	A278	25	−20	25	...	2.5	2.5	2.5	2.5
Gray	A48	30	−20	30	...	3.0	3.0	3.0	3.0
Gray [Notes (8) and (9)]	A278	30	−20	30	...	3.0	3.0	3.0	3.0
Gray [Notes (8) and (9)]	A126	B	−20	31	...	3.1	3.1	3.1	3.1
Gray	A48	35	−20	35	...	3.5	3.5	3.5	3.5
Gray [Notes (8) and (9)]	A278	35	−20	35	...	3.5	3.5	3.5	3.5
Gray [Notes (8) and (9)]	A48	40	−20	40	...	4.0	4.0	4.0	4.0
Gray [Notes (8) and (9)]	A126	C	−20	41	...	4.1	4.1	4.1	4.1
Gray [Notes (8) and (9)]	A278	40	−20	40	...	4.0	4.0	4.0	4.0
Gray [Notes (8) and (9)]	A48	45	−20	45	...	4.5	4.5	4.5	4.5
Gray [Notes (8) and (9)]	A48	50	−20	50	...	5.0	5.0	5.0	5.0
Gray [Notes (8) and (9)]	A278	50	−20	50	...	5.0	5.0	5.0	5.0
Gray [Notes (8) and (9)]	A48	55	−20	55	...	5.5	5.5	5.5	5.5
Gray [Notes (8) and (9)]	A48	60	−20	60	...	6.0	6.0	6.0	6.0
Gray [Notes (8) and (9)]	A278	60	−20	60	...	6.0	6.0	6.0	6.0
Ferritic ductile [Notes (8) and (9)]	A395	...	−20	60	48	9.6	9.6	9.6	9.6
Ferritic ductile [Notes (8), (9), and (10)]	A536	65-45-12	−20	65	45	10.4	10.4	10.4	10.4
Ferritic ductile [Notes (8), (9), and (10)]	A536	60-40-18	−20	60	40	9.6	9.6	9.6	9.6
Austenitic ductile [Notes (8) and (9)]	A571	D, 2M, Cl. 1	−20	65	30	10.4	...	...	...

Table 502.3.1 Maximum Allowable Stress Values, ksi (Cont'd)
(Multiply by 1,000 to Obtain psi)

Product Form	ASTM Spec. No.	Type/Grade	Min. Temp. [Note (1)]	Min. Tensile Strength, ksi [Note (3)]	Min. Yield Strength, ksi [Note (3)]	Maximum Allowable Stress, ksi (Multiply by 1,000 to Obtain psi), for Metal Temperature, °F [Notes (2) and (3)]					
						Min. Temp. to 100	150	200	250	300	400
Carbon Steel											
Plate	A285	A	B	45	24	12.9	12.9	12.9	12.9	12.9	12.9
Plate	A516 [Note (11)]	55	C	55	30	15.7	15.7	15.7	15.7	15.7	15.7
Plate	A516 [Note (11)]	60	C	60	32	17.1	17.1	17.1	17.1	17.1	17.1
Plate	A516 [Note (11)]	65	B	65	35	18.6	18.6	18.6	18.6	18.6	18.6
Plate	A516 [Note (11)]	70	B	70	38	20.0	20.0	20.0	20.0	20.0	20.0
Sheet	A414	A	B	45	25	12.9	12.9	12.9	12.9	12.9	12.9
Sheet	A414	B	A	50	30	14.3	14.3	14.3	14.3	14.3	14.3
Sheet	A414	C	A	55	33	15.7	15.7	15.7	15.7	15.7	15.7
Sheet	A414	D	A	60	35	17.1	17.1	17.1	17.1	17.1	17.1
Sheet	A414	G	A	75	45	21.4	21.4	21.4	21.4	21.4	21.4

GENERAL NOTE: Except where specific omissions of stress values occur in this Table, the values in Section II, Part D for Section VIII, Division 1, of the ASME BPV Code may be used to supplement this Table for allowable stresses.

NOTES:

- (1) The minimum temperature is that design minimum temperature for which the material is suitable without impact testing other than that required by the specification. See para. 523.2.2 and Table 523.2.2 for temperatures A, B, and C.
- (2) To convert °F to °C, subtract 32 and then multiply by $\frac{5}{9}$.
- (3) To convert ksi to MPa, multiply by 6.895.
- (4) Where brazed construction is employed, stress values for annealed material shall be used.
- (5) 85% joint efficiency has been used in determining the allowable stress value for welded tube.
- (6) For brazed or welded construction or where thermal cutting is employed, stress value for "O" temper material shall be used.
- (7) The stress values given for this material are not applicable when either brazing, welding, or thermal cutting is used.
- (8) For limits on cast iron, see para. 523.2.3.
- (9) For limits on ductile iron, see para. 523.2.4.
- (10) Requires a full ferritizing anneal.
- (11) If not normalized.

For pipe and tube that do not contain longitudinal or spiral joints, the Table shows the basic allowable stress, S . It is the allowable hoop stress.

For pipe and tube that do contain longitudinal or spiral joints, the Table shows the product, SE , of the basic allowable stress, S , and the longitudinal or spiral joint factor, E . SE is the allowable hoop stress.

For materials for which Table 502.3.1 shows longitudinal or spiral joint factors, E , divide the SE value shown in the Table above by the joint factor, E , to get the allowable stress, S , for Code computations in Part 5, Chapter II, where the joint factor, E , need not be considered.

The stress values in this Table are grouped according to temperature, and in every case the temperature is the metal temperature. The stress values in this Table may be interpolated to determine values for intermediate temperatures. Allowable stresses for materials not listed shall not exceed those determined using the basis in para. 502.3.1(b) for ferrous materials and in para. 502.3.1(c) for nonferrous materials.

(b) The basis of establishing basic allowable stress values for ferrous materials in this Code is as follows.

The mechanical properties for materials as developed by the ASME BPV Code were used for establishing stress values.

At 100°F (38°C) and below, an allowable stress value was established at the lower value of stress obtained from using 29% of the specified minimum tensile strength at room temperature, or 67% of the specified minimum yield strength for 0.2% offset at room temperature.

At temperatures above 100°F (38°C) but below 400°F (205°C), allowable stress values were established that did not exceed 67% of the average expected yield strength for 0.2% offset at temperature, or did not exceed 29% of the average expected tensile strength at temperature.

(c) The basis for establishing basic allowable stress values for nonferrous materials in this Code is as follows.

The basic allowable stress values for temperatures over 100°F (38°C) determined as the lowest of the following when the tensile and yield strengths are obtained from standard short-time tests made at the temperature under consideration:

- (1) 29% of the tensile strength as adjusted to minimum
- (2) 67% of the yield strength as adjusted to minimum
- (3) the stress producing a creep rate of 0.01% in 1,000 hr
- (4) the stress producing rupture in 100,000 hr

At 100°F (38°C) and below, an allowable stress value was established at the lowest value of stress obtained by using 29% of the specified minimum tensile strength at room temperature, or 67% of specified minimum yield strength at room temperature.

The tensile strength and yield strength are adjusted to minimum by multiplying the test results by the ratio of the minimum specified or expected tensile or yield strength to the actual room temperature tensile or yield strength for the lot of material under test.

The creep and stress-rupture strengths are determined by plotting the results of the creep and stress-rupture tests in the manner described in "Interpretation of Creep and Stress-Rupture Data" by Francis B. Foley, *Metal Progress*, June 1947, pp. 951–958.

(d) Allowable stress values in shear shall be 0.80 of the values obtained from para. 502.3.1 and Table 502.3.1, and allowable stress values in bearing shall be 1.60 of the values obtained from para. 502.3.1 and Table 502.3.1.

(e) When steel materials of unknown specifications are used at a temperature not to exceed 400°F (204°C) for structural supports and restraints, the allowable stress value shall not exceed 13.7 ksi (94 MPa).

(f) For components not having established pressure-temperature ratings, allowable stress values may be adjusted in accordance with para. 502.2.3 for other than normal operation.

502.3.2 Limits of Calculated Stresses Due to Sustained Loads and Thermal Expansion or Contraction

(a) *Internal Pressure Stresses.* The calculated stress due to internal pressure shall not exceed the allowable stress values given in Table 502.3.1, except as permitted by paras. 502.3.2(b), (c), and (d).

(b) *External Pressure Stresses.* Stress due to external pressures shall be considered safe when the wall thickness of the piping component and means of stiffening meet the requirements of sections 503 and 504.

(c) *Allowable Stress Range for Expansion Stresses in Systems Stressed Primarily in Bending and Torsion.* The expansion stress range, S_E (see para. 519.4.5), shall not exceed the allowable stress range, S_A , given by eq. (1):

$$S_A = f(1.25S_c + 0.25S_h) \quad (1)$$

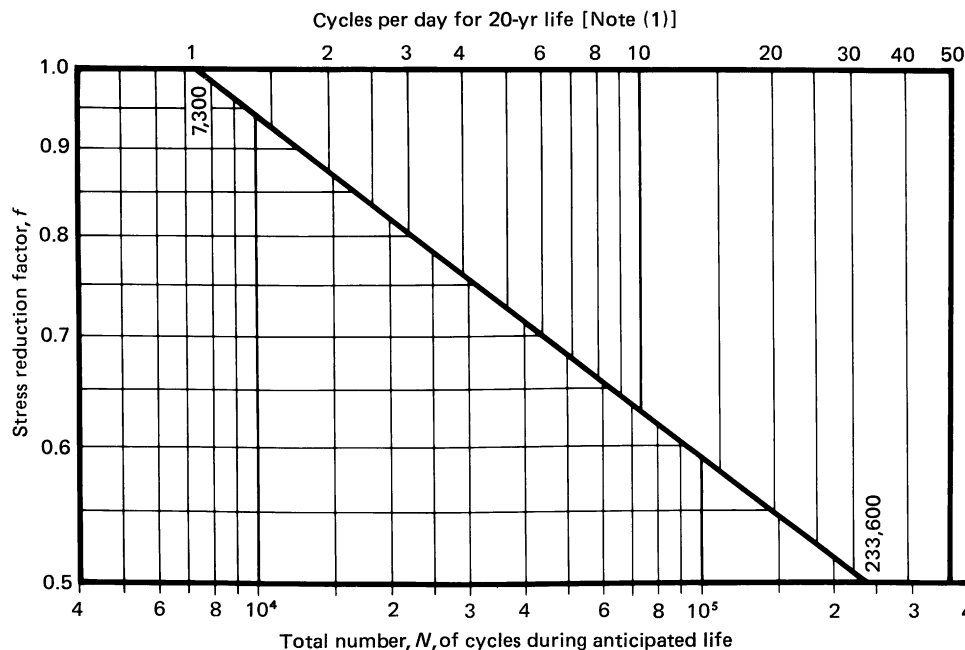
where

f = stress-range reduction factor for cyclic conditions [see Note (1)] for total number N of full temperature cycles over total number of years during which system is expected to be in active operation (read or interpolate from Fig. 502.3.2). By full temperature cycles is meant the number of cycles of temperature change from minimum to maximum temperature expected to be encountered. [See Note (2).]

NOTES:

- (1) Applies to essentially noncorrosive services. Corrosion can sharply decrease cyclic life. Corrosion resistant materials should be used where a large number of major stress cycles is anticipated.
- (2) If the range of temperature changes varies, equivalent full temperature cycles may be computed from the equation:

$$N = N_E + r_1^5 N_1 + r_2^5 N_2 + \dots + r_n^5 N_n$$

Fig. 502.3.2 Stress Range Reduction Factors

NOTE:

(1) Assuming 365-day-per-year operation.

where

N_E = number of cycles of full temperature change, ΔT_E , for which expansion stress, S_E , has been calculated

N_1, N_2, \dots, N_n = number of cycles of less temperature change $\Delta T_1, \Delta T_2, \dots, \Delta T_n$

r_1, r_2, \dots, r_n = $\Delta T_1 / \Delta T_E, \Delta T_2 / \Delta T_E, \dots, \Delta T_n / \Delta T_E$
= ratio of any lesser temperature cycle to that for which S_E has been calculated

S_A = maximum allowable stress range due to thermal expansion and contraction, ksi (MPa)

S_c = basic material allowable stress at minimum (cold) normal temperature, ksi (MPa) (use S , not SE from para. 502.3.1 and Table 502.3.1)

S_h = basic material allowable stress at maximum (hot) normal temperature, ksi (MPa) (use S , not SE from para. 502.3.1 and Table 502.3.1)

NOTE: Does not include abnormal conditions, such as exposure to fires.

(d) The sum of the longitudinal stresses (in the corroded condition) due to pressure, weight, and other sustained external loading shall not exceed S_h . Where the sum of these stresses is less than S_h , the difference between S_h and this sum may be added to the term in parentheses in eq. (1).

In calculating the longitudinal pressure stress, consider the internal pressure as acting only on the area established by the internal diameter.

502.3.3 Limits of Calculated Stresses Due to Occasional Loads

(a) *Operation.* The sum of the longitudinal stresses produced by pressure, live and dead loads, and those produced by occasional loads, such as wind or earthquake, may not exceed 1.33 times the allowable stress values given in Table 502.3.1. It is not necessary to consider wind and earthquake as occurring concurrently.

(b) *Test.* Stresses due to test conditions are not subject to the limitations of para. 502.3 of this Code. It is not necessary to consider other occasional loads, such as wind and earthquake, as occurring concurrently with the live, dead, and test loads existing at the time of test.

502.4 Allowances

502.4.1 Corrosion and Erosion. When corrosion or erosion is expected, an increase in wall thickness of the components over that dictated by other design requirements shall be provided, consistent with the expected life of the particular piping involved.

502.4.2 Threading and Grooving. See definition for c in para. 504.1.1(b).

502.4.4 Mechanical Strength. When necessary to prevent damage, collapse, or buckling due to superimposed loads from supports, backfill, or other causes, the pipe wall thickness shall be increased, or, if this is impractical or would cause excessive local stresses, the factors that would contribute to damage of the piping shall be compensated for by other design methods.

Section 502 pertains to ratings, stress values, stress criteria, design allowances, and minimum design values, and formulates the permissible variations to these factors used in the design of piping.

PART 2 DESIGN OF PIPING COMPONENTS

503 CRITERIA FOR DESIGN OF PIPING COMPONENTS

The design of piping components, considering the effects of pressure, and providing for mechanical, corrosion, and erosion allowances, shall be in accordance with section 504. In addition, the designs must be checked for adequacy of mechanical strength under other applicable loadings as given in section 501.

504 PRESSURE DESIGN OF PIPING COMPONENTS

504.1 Straight Pipe

504.1.1 General

(a) The required wall thickness of straight sections of pipe shall be determined in accordance with eq. (2). (Also, see section 503.)

$$t_m = t + c \quad (2)$$

(b) The notations described below are used in the equations for the pressure design of straight pipe.

c = for internal pressure, the sum, in. (mm), of the mechanical allowances (thread depth, groove depth, and manufacturer's minus tolerance) plus corrosion and erosion allowances. (See para. 502.4.1.) For threaded components, the nominal 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. (0.5 mm) in addition to the specified depth of the cut.

$=$ for external pressure, the sum, in. (mm), of corrosion and erosion allowances plus manufacturer's minus tolerance (see para. 502.4.1)

D_o = outside diameter of pipe, in. (mm)

d = inside diameter of pipe, in. (mm), excluding metal required for corrosion or erosion allowance, manufacturer's minus tolerance, and any allowance required for the depth of internal threads or grooves

P = internal design pressure (see para. 501.2.2), psi (kPa), or external design pressure (see para. 501.2.3), psi (kPa)

S = applicable allowable hoop stress in accordance with para. 502.3.1 and Table 502.3.1, psi (kPa)

t = pressure design wall thickness, in. (mm), as calculated from eqs. (3a) and (3b) for internal pressure, or in accordance with the procedures given in para. 504.1.3 for external pressure

t_m = minimum required wall thickness, in. (mm), satisfying requirements for design pressure and mechanical, corrosion, and erosion allowances

y = coefficient for materials indicated: for ductile nonferrous materials, use $y = 0.4$ (see Note); for ferritic steels, use $y = 0.4$ (see Note); for austenitic steels, use $y = 0.4$ (see Note). For cast iron, use $y = 0.0$.

NOTE: If D_o/t is in the range of 4–6, use $y = d/(d + D_o)$ for ductile materials.

504.1.2 Straight Pipe Under Internal Pressure. For metallic pipe with diameter–thickness ratios $D_o/t > 4$, the internal pressure design wall thickness, t , shall be calculated using eq. (3a) or (3b).

$$t = \frac{PD_o}{2(S + Py)} \quad (3a)$$

or

$$t = \frac{Pd}{2(S + Py - P)} \quad (3b)$$

where

$$P = \frac{2St}{D_o - 2yt}$$

NOTE: The following simpler alternative equations, which give somewhat greater wall thickness, may be employed:

$$t = \frac{PD_o}{2S}$$

or

$$t = \frac{Pd}{2(S - P)}$$

where

$$P = \frac{2St}{D_o}$$

504.1.3 Straight Pipe Under External Pressure. To determine wall thickness and stiffening requirements for straight pipe under external pressure, the procedure outlined in the BPV Code, Section VIII, Division 1, UG-28 through UG-30 shall be followed, using as the design length, L , the running centerline length between any two sections stiffened in accordance with UG-29. As an exception, for pipe with $D_o/t < 10$, the value of S to be

used in determining P_{a2} shall be the lesser of the following values for pipe material at design temperature:

(a) 1.5 times the stress value from Table 502.3.1 of this Code.

(b) 0.9 times the yield strength tabulated in Section II, Part D, Table Y-1 for materials listed therein. (The symbol D_o in Section VIII of the ASME BPV Code is equivalent to D_o in this Code.)

504.2 Curved Segments of Pipe

504.2.1 Pipe Bends. Pipe after bending shall conform to the following:

(a) The minimum thickness after bending shall not be less than as required for straight pipe in accordance with para. 504.1.

(b) The difference between maximum and minimum diameters for pipe bends subjected to internal pressure should not exceed 8% of the nominal outside diameter of the pipe.

(c) The difference between maximum and minimum diameters for pipe bends subjected to external pressure should not be greater than 8% of the nominal outside diameter of the pipe.

(d) Bends made with greater flattening than indicated above shall meet the requirements of para. 504.7.

(e) Bends for use on heat transfer components such as U-bends (return bends) shall be designed in accordance with the requirements of para. 504.7.

504.2.2 Elbows. Elbows manufactured in accordance with the standards listed in Table 526.1 shall be considered suitable for use at the pressure-temperature ratings specified by such standards, and in the case of standards under which elbows are made to a nominal pipe thickness, the elbows shall be considered suitable for use with pipe of the same nominal thickness unless otherwise stated by the fittings standard. Commercially manufactured elbows not made in accordance with the standards listed in Table 526.1 shall meet the requirements of para. 504.7.

504.3 Intersections

504.3.1 Branch Connections

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

Branch connections in which the smaller angle between the axes of the branch and the run is less than 45 deg impose special design and fabrication problems; the rules given for angles greater than 45 deg may be used as a guide, but sufficient additional strength must be provided to assure safe and satisfactory service, and these branch connections shall be designed to meet the requirement of para. 504.7.

(b) Branch connections in piping may be made by the use of one of the following:

(1) fittings (tees, laterals, crosses, and multiple opening headers, qualified as fully reinforced in accordance with para. 504.7)

(2) welding outlet fittings, such as forged nozzles, couplings [maximum NPS 3 (DN 75)], or adaptors or similar items having butt welding, socket welding, threaded, or flanged ends for attachment of the branch pipe, such welding outlet fittings being attached to the main pipe by welding

(3) by attaching the branch pipe directly to the run pipe by welding (acceptable methods of making welded pipe-to-pipe branch connections are contained in para. 527.3.5) or by threading

(c) Right angle branch connections may be made by attaching the branch pipe directly to the run pipe by socket welding provided

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

(2) the depth of the socket in the run is at least $\frac{3}{8}$ in. (10 mm) deep with a minimum shoulder of $\frac{1}{16}$ in. (1.5 mm) between the bottom of the socket and the inside diameter of the run pipe. [Weld metal may be deposited on the run pipe to provide the required socket depth and to provide any reinforcement required by paras. 504.3.1(f) and (g).]

(3) the size of the fillet weld is not less than 1.25 times the nominal branch wall thickness.

(d) Right angle branch connections may be made by threading 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 the nominal size of the run, whichever is lesser.

(2) minimum thread engagement is six full threads for NPS $\frac{1}{2}$ (DN 15) and NPS $\frac{3}{4}$ (DN 20) branches, seven for NPS 1 (DN 25) and NPS $1\frac{1}{2}$ (DN 40) branches, and eight for NPS 2 (DN 50) branches. [Weld metal may be deposited on the run to provide sufficient thickness for the required thread engagement and to provide any reinforcement required by paras. 504.3.1(f) and (g). In interpreting paras. 504.3.1(f) and (g) for connections threaded directly into the run pipe, no part of the branch pipe may be counted in calculating the reinforcement area, and the value of d_1 shall be taken as the nominal outside diameter of the branch pipe.]

(e) A pipe having a branch connection is weakened by the opening that must be made in it, and unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide reinforcement. The amount of reinforcement required shall be determined in accordance with paras. 504.3.1(f) and (g). There are, however, certain branch connections for which no supporting calculations are required. It may be assumed without calculation that a branch connection has adequate strength to

sustain the internal and external pressure that will be applied to it if

(1) the branch connection is made by the use of a fitting (tee, lateral, or cross) manufactured in accordance with a standard listed in Table 526.1 and used within the limits of pressure-temperature ratings given in the standard. (A butt welding fitting made in accordance with ASME B16.9 shall be of a nominal thickness not less than the nominal thickness required for the adjoining pipe.)

(2) the branch connection is made by welding a threaded or socket welding coupling or half coupling directly to the main pipe using an appropriate type of minimum size weld (see Chapter V) and the nominal diameter of the branch does not exceed NPS 2 (DN 50) pipe size and does not exceed one-fourth the nominal diameter of the run. The minimum wall thickness of the coupling anywhere in the reinforcement zone shall be not less than that of the branch pipe, and in no case shall the coupling have a rating less than Class 3000 per ASME B16.11.

(3) the branch connection is made by welding a threaded, socket, or butt weld outlet integrally reinforced branch connection fitting to the main pipe, provided the fitting is made from materials in accordance with Table 523.1 and provided the fitting has demonstrated by full-scale internal pressure destructive tests that the branch fitting is as strong as the main or branch pipe. See para. 504.7.

(f) *Reinforcement of Welded Branch Connections.* Additional reinforcement is required when it is not provided inherently in the components of the branch connection. This subparagraph gives rules governing 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.

(1) *Notation.* The notations described below are used in the pressure design of branch connections. The notations are illustrated in Fig. 504.3.1-1. Note the use of subscripts *b* for branch and *h* for header. Note also that Fig. 504.3.1-1 does not indicate details of construction or welding.

b = subscript referring to branch

C = corrosion allowance, in. (mm)

D_o = outside diameter of pipe, in. (mm)

d₁ = actual corroded length removed from run pipe, in. (mm)

$$= [D_b - 2(T_t - C)] / \sin \beta$$

d₂ = half-width of reinforcement zone, in. (mm)

$$= d_1 \text{ or } [(T_b - C) + (T_h - C) + d_1/2], \text{ whichever is greater, but in any case not more than } D_{oh}$$

h = subscript referring to run or header

L₄ = height of reinforcement zone outside of run pipe, in. (mm)

$$= 2.5(T_h - C) \text{ or } 2.5(T_b - C) + t_r, \text{ whichever is less}$$

T = minimum wall thickness of pipe or minimum thickness permissible under purchase specification, in. (mm)

\bar{T} = nominal wall thickness of pipe, in. (mm)

t = pressure design wall thickness of pipe, in. (mm), according to the appropriate wall thickness equation or procedure in para. 504.1. When the branch does not intersect the longitudinal weld of the run, use *S* from para. 502.3.1 and Table 502.3.1, not *SE*, in determining *t* for the purpose of reinforcement calculation only. The allowable stress, *SE*, of the branch shall be used in calculating *t_b*.

t_r = nominal thickness of reinforcing ring or saddle in. (mm)

= 0, if there is no reinforcement pad or saddle

β = angle between axes of branch and run, deg

(2) Required Area, *A₁*

(a) *For Internal Pressure.* The quantity *t_hd₁(2 - sin β)* is known as the required area; in the case of right angle nozzles, the required area becomes *t_hd₁* in.² (mm²). The branch connection must be designed so that reinforcement area defined in para. 504.3.1(f)(3) is not less than the required area.

(b) *For External Pressure.* The reinforcement area required for the branch connections subject to external pressure need be only *0.5t_hd₁(2 - sin β)*.

(3) *Reinforcement Area.* The reinforcement area shall be the sum of areas *A₂ + A₃ + A₄* and shall not be less than the required area.

(a) *Areas A₂ and A₃.* The area lying within the reinforcement zone [defined in para. 504.3.1(f)(4)] resulting from any excess thickness available in the main run pipe wall (*A₂*) and branch pipe wall (*A₃*) over that required by the proper wall thickness equations (i.e., the thickness *T_h - t_h - C* and *T_b - t_b - C* multiplied by appropriate lengths) as in the following example:

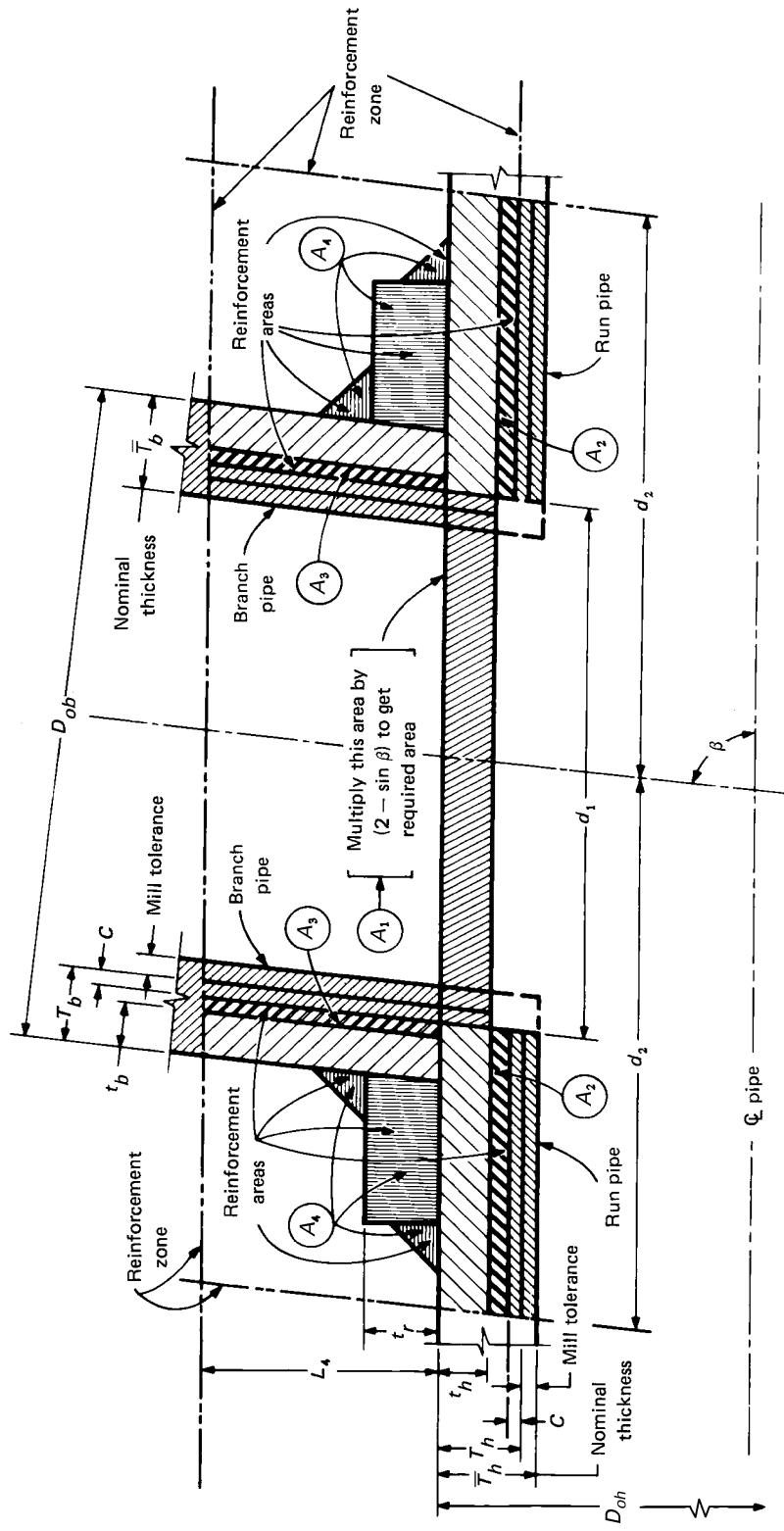
$$A_2 = (2d_2 - d_1)(T_h - t_h - C) \quad (4)$$

$$A_3 = [2L_4(T_b - t_b - C)] / \sin \beta \quad (5)$$

(b) *Area A₄.* The area of all other metal within the reinforcement zone [defined in para. 504.3.1(f)(4)] provided by weld metal and other reinforcement metal properly attached to the run or branch. In computing area of weld metal deposits, the minimum dimensions required by Chapter V shall be used unless a definite procedure is employed to instruct the welder to provide specific larger dimensions, in which case the latter dimensions may be used in calculations. Deduct mill tolerance from *t_r* when computing area of reinforcement pad.

Portions of the reinforcement area may be composed of materials other than those of the main run pipe, but if the allowable stress of these materials (see para. 502.3.1 and Table 502.3.1) is less than that for the main run pipe,

Fig. 504.3.1-1 Reinforcement of Branch Connections



GENERAL NOTE: This figure is merely to illustrate the notation of para. 504.3.1(f) and does not indicate complete welding details, or a preferred method of construction. For typical weld details, see Fig. 527.3.5-4.

the calculated area for such portions must be reduced in the ratio of the allowable stress values before being credited to the reinforcement area. No additional credit shall be taken for materials having higher allowable stress values than for the main run pipe.

(4) *Reinforcement Zone.* The reinforcement zone is a parallelogram whose length shall extend a distance, d_2 , on each side of the centerline of the branch pipe and whose width shall start at the actual corroded inside surface of the main run pipe and extend to a distance, L_4 , from the outside surface of the main pipe measured perpendicular to this outside surface.

(5) *Reinforcement of Multiple Openings.* When any two or more adjacent openings are so closely spaced that their reinforcement zones overlap, the two or more openings shall be reinforced in accordance with para. 504.3.1(f)(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 to be provided with a combined reinforcement, the minimum distance between centers of any two of these openings should preferably be at least 1.5 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.

(6) *Rings and Saddles.* Additional reinforcement provided in the form of rings or saddles shall not be appreciably narrower in the transverse direction than in the longitudinal direction.

(g) *Extruded Outlet Headers*

(1) The above principles of reinforcement are essentially applicable to extruded outlet headers. An extruded outlet header is defined as a header in which the outlet is extruded using a die (or dies) that controls the radii of the extrusion. The extruded lip at the outlet has a height 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., $h_x \geq r_x$). [See para. 504.3.1(g)(3) for notation and Fig. 504.3.1-2.]

(2) When the design meets the limitations of geometry outlined below, the rules herein established are valid. These rules cover minimum requirements and are designed to assure satisfactory performance of extruded outlet headers subjected to pressure. 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.

(3) *Notations.* The notations used herein are illustrated in Fig. 504.3.1-2. Note the use of subscript x for extruded outlet. Refer to para. 504.3.1(f) for notations not listed here.

d_2 = half-width of reinforcement zone, in. (mm) (equal to d_x)

d_x = the corroded design inside diameter of the extruded outlet, in. (mm), at the level of the outside surface of the run

h_x = height of the extruded outlet, in. (mm). This must be equal to or greater than r_x .

L_5 = height of reinforcement zone, in. (mm)
 $= 0.7\sqrt{D_{ob} T_x}$

r_x = radius of curvature of external contoured portion of outlet measured in the plane containing the axis of the run and branch, in. (mm). 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 NPS 8 (DN 200) and larger, this dimension shall not exceed $0.10D_{ob} + 0.50$ in. (12.7 mm). For outlet pipe sizes less than NPS 8 (DN 200) this dimension shall not be greater than 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 for maximum and minimum radii.

(d) Machining shall not be employed in order to meet the above requirements.

T_x = corroded finished thickness of extruded outlet at a height equal to r_x above the outside surface of the run, in. (mm)

(4) *Required Area.* The required area is defined as

$A_1 = Kt_h d_x$ where K shall be taken as follows:

(a) For D_{ob}/D_{oh} greater than 0.60, $K = 1.00$.

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

$$K = 0.6 + \frac{2}{3} D_{ob}/D_{oh} \quad (6)$$

(c) For D_{ob}/D_{oh} equal to or less than 0.15, $K = 0.70$.

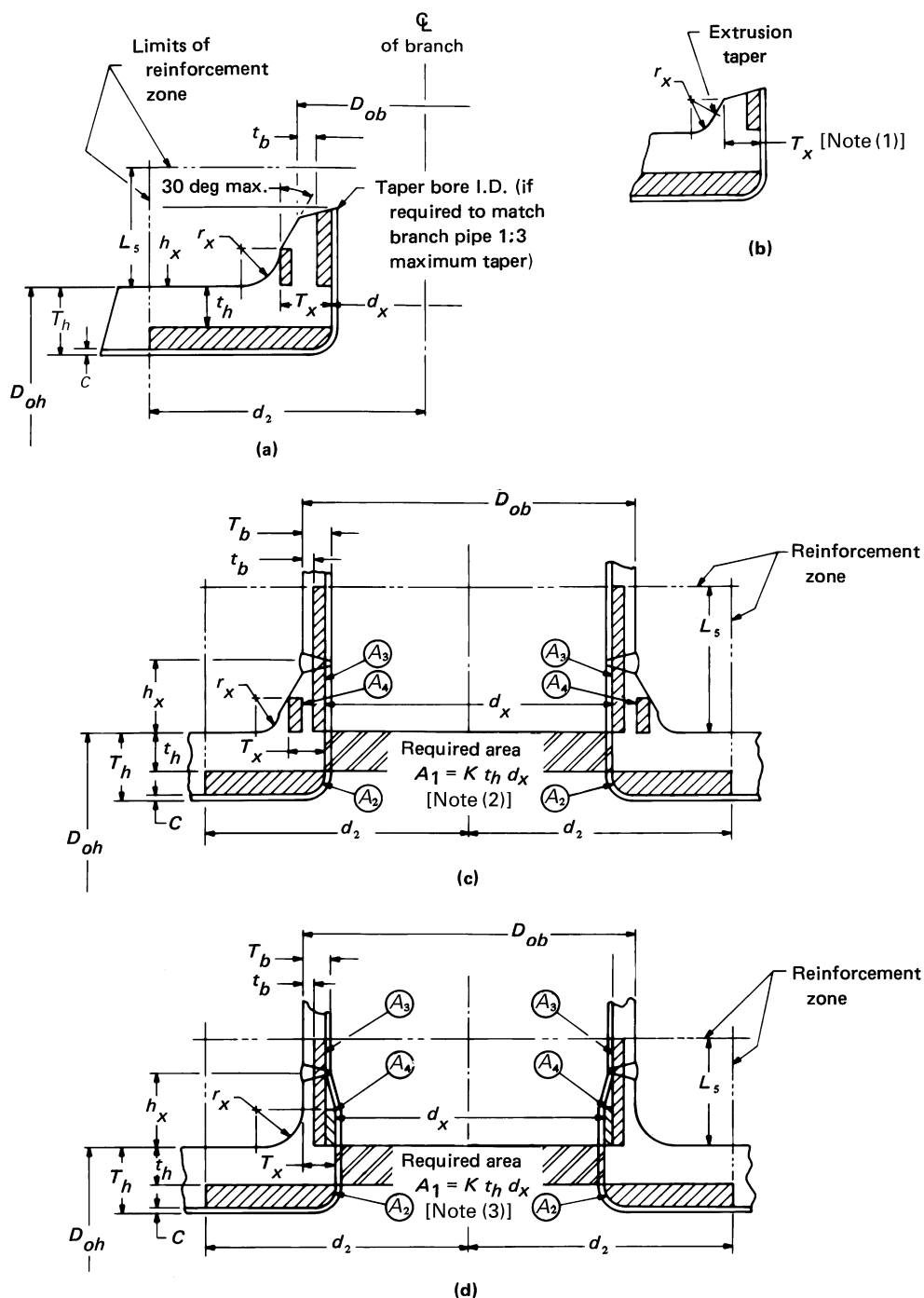
The design must meet the criteria that the reinforcement area defined in para. 504.3.1(g)(5) is not less than the required area A_1 .

(5) *Reinforcement Area.* The reinforcement area shall be the sum of areas $A_2 + A_3 + A_4$ as defined below.

(a) *Area A_2 .* The area lying within the reinforcement zone resulting from any excess thickness available in the run wall.

$$A_2 = d_x(T_h - t_h) \quad (7)$$

(b) *Area A_3 .* The area lying within the reinforcement zone resulting from any excess thickness available in the branch pipe wall.

Fig. 504.3.1-2 Extruded Outlet Header Notation

GENERAL NOTE: This figure is merely to illustrate the notations of para. 504.3.1(g) and does not indicate complete welding details, or a preferred method of construction.

NOTES:

- (1) Illustration to show method of establishing T_x when the taper encroaches on the crotch radius.
- (2) Illustration is drawn for condition where $K = 1.00$.
- (3) Illustration is drawn for condition where $K = 1.00$ and $d_x < (D_{ob} - 2T_b)$.

$$A_3 = 2L_5(T_b - t_b) \quad (8)$$

(c) *Area A_4 .* The area lying within the reinforcement zone resulting from any excess thickness available in the extruded outlet lip.

$$A_4 = 2r_x(T_x - t_b) \quad (9)$$

(6) *Reinforcement of Multiple Openings.* The rules of para. 504.3.1(f)(5) shall be followed except that the required area and reinforcement area shall be as given in para. 504.3.1(g).

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

(h) *Mechanically Formed Tee Connections in Copper Materials (Types K, L, M)*

(1) These mechanically formed connections shall be perpendicular to the axis of the run tube (header). They shall be formed by drilling a pilot hole and drawing out the tube surface to form a collar having a height of not less than 3 times the thickness of the branch wall. The collaring device shall be such as to assure proper fit up of the joint.

(2) The inner branch tube end shall conform to the shape of the inner curve of the run tube. Insertion of the branch tube shall be controlled to assure alignment with specified depth into the collar without extending into the flow stream so as to provide internal reinforcement to the collar as illustrated in Fig. 504.3.1-3.

(3) Branches can be formed up to the run tube size. Manufacturing procedures shall be in accordance with tool manufacturer's recommendations.

(4) These types of connections may not be used in other than Group A1 refrigerant service.

(5) All joints shall be brazed in accordance with paras. 528.1 and 528.2.

(i) *Other Designs.* Components to which design rules given in paras. 504.3.1 (c) and (d) are not applicable shall meet the requirements of para. 504.7.

(j) The requirements of the preceding subparagraphs are designed to assure satisfactory performance of a branch connection subjected only to pressure. However, in addition, external forces and moments are usually applied to a branch connection by such agencies as thermal expansion and contraction, by dead weight of piping, valves, and fittings; covering and contents; and by earth settlement. Special consideration shall be given to the design of a branch connection to withstand these forces and moments.

Where the ratio of branch diameter to run diameter is large or where repetitive stresses may be imposed on the connection due to vibration, pulsating pressure, temperature cycling, etc., it is recommended that the design be rather conservative and that consideration be

given to the use of tee fittings or complete encirclement types of reinforcement.

Use of ribs, gussets, and clamps is permissible to stiffen the branch connection, but their areas cannot be counted as contributing to the reinforcement area defined in para. 504.3.1(d)(3). Consideration should be given to stress arising from a temperature gradient between the piping and gussets during a sudden change in temperature of the fluid in the piping.

It is not practicable to give definite rules for design to accommodate the effects mentioned in this subparagraph. The purpose is to call them to the attention of the engineer so that from experience and judgment he may adequately provide for them.

Attention is especially directed to the design of small branches out of large and relatively heavy runs. Adequate flexibility must be provided in the smaller line to accommodate thermal expansion and other movements of the larger line.

504.3.2 Openings in Closures

(a) The rules of this paragraph are intended to apply to openings in closures in which the size of the opening is not greater than 50% of the inside diameter of the closure (as defined in para. 504.4). Larger openings should be designed as reducers, or in the case of flat closures, the closure shall be designed as a flange in accordance with para. 504.5.

(b) A closure is weakened by an opening and unless the thickness of the closure is sufficiently in excess of that required to sustain pressure, it is necessary to provide reinforcement. The need for reinforcement and amount of reinforcement required shall be determined in accordance with the subparagraphs below except that it shall be considered that the opening has adequate reinforcement if subparas. (1) through (3) apply.

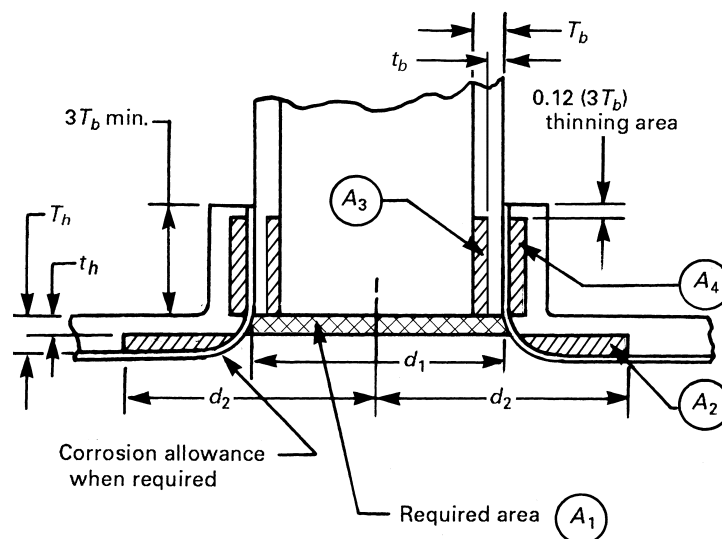
(1) The outlet connection is made by welding a threaded or socket welding coupling or half-coupling directly to the closure (using an appropriate weld as given in Fig. 527.3.5-4 for branch connections).

(2) The nominal diameter of the outlet pipe does not exceed NPS 2 (DN 50) and does not exceed 25% of the nominal diameter of the closure.

(3) The minimum wall thickness of the coupling anywhere in the reinforcement zone shall not be less than that of the branch pipe and in no case shall a coupling have a rating less than Class 3000 per ASME B16.11.

(c) Reinforcement shall be provided for openings in closures in amount and distribution such that the area requirements for distribution are satisfied for all planes passing through the center of the opening and normal to the surface of the closure.

(d) The total cross section area required for reinforcement in any given plane passing through the center of the opening shall be not less than the quantity $d_5 t$. (See Note below.)

Fig. 504.3.1-3 Mechanically Formed Tee Connections in Copper Materials

$$A_2 + A_3 + A_4 \geq A_1$$

where

- A_1 = required area, in.² (mm²) = $t_h d_1$
- A_2 = area lying within the reinforcement zone resulting from any excess thickness available in the header wall
- A_3 = area lying within the reinforcement zone resulting from any excess thickness in the branch tube wall
- A_4 = area lying within the reinforcement zone resulting from any excess thickness available in the extruded lip
- d_1 = opening size in header tube
- d_2 = d_1 = reinforcement zone
- T_b = minimum wall thickness of tube branch
- t_b = pressure design wall thickness of tube branch
- T_h = minimum wall thickness of tube run or header
- t_h = pressure design wall thickness of tube run or header

where

- d_5 = the diameter, in the plane under consideration, of the finished opening in the corroded condition, in. (mm)
- t = the pressure design thickness for the closure according to the equations and procedures specified in para. 504.4, in. (mm), except that a lesser thickness may be used where applicable in accordance with the provisions contained in Section VIII, Division 1, of the ASME BPV Code relative to openings in pressure vessel heads

NOTE: Flat heads that have an opening with a diameter that does not exceed one-half the head diameter as defined in UG-34 of Section VIII, Division 1 of the ASME BPV Code may have a total cross section of required reinforcement not less than that given by the formula $A = 0.5d_5t$.

(e) The reinforcement area and reinforcement zone shall be calculated in accordance with para. 504.3.1 considering the subscript h and other references to main run pipe to apply to the closure rather than to the run or header. Likewise, where the closure is curved, the boundaries of the reinforcement zone shall follow the contour of the closure, and dimensions of the reinforcement zone shall be measured parallel to and perpendicular to the closure surface.

(f) When two or more openings are to be located in a closure, the rules given in para. 504.3.1 for the reinforcement of multiple openings shall apply.

(g) Attention is directed to the general considerations for the design of branch connections discussed in para. 504.3.1(f) as they are equally applicable to openings in closures.

504.3.3 Miters. When the maximum stress due to internal pressure [eqs. (3a) and (3b)] does not exceed 50% of the allowable hoop stress, miters may be used subject to the following limitations:

(a) The number of full pressure or thermal cycles shall not exceed 7,000 during the expected life of the piping system.

(b) The direction change for any single assembled miter weld should not exceed 45 deg.

(c) The centerline distance between adjacent miters should not be less than one nominal pipe diameter.

(d) Complete penetration welds shall be used in joining miter segments.

(e) Miter joints with greater directional changes and closer centerline distances shall conform to para. 504.7. Deflections caused by misalignments up to 3 deg are not considered miters.

504.3.4 Attachments. External and internal attachments to piping shall be designed so they will not 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 either to pressure or thermal effect, is relatively large for the expected life of the equipment.

504.4 Closures

504.4.1 General

(a) The required thickness of closures, considering pressure and mechanical, corrosion, and erosion allowances, shall be determined in accordance with eq. (10).

$$t_m = t + c \quad (10)$$

The minimum thickness for the closure selected, considering the manufacturer's minus tolerances, shall not be less than t_m .

Closure fittings manufactured in accordance with the standards listed in Table 526.1 shall be considered suitable for use at the pressure-temperature ratings specified by such standards, and in the case of standards under which closure fittings are made to a nominal pipe thickness, the closure fittings shall be considered suitable for use with pipe of the same nominal thickness. Commercially manufactured closures not made in accordance with the standards listed in Table 526.1 and for which design rules are not given in this paragraph (para. 504.4) shall meet the requirements of para. 504.7.

(b) The notations described below are used for determining the pressure design of closures.

c = the sum of the mechanical allowances (thread depth, groove depth, manufacturer's minus tolerances) plus corrosion and erosion allowances, in. (mm) (see para. 502.4)

P = internal design pressure (see para. 501.2.2), psi, or external design pressure (see para. 501.2.3), psi (kPa)

S = applicable allowable stress (the value of S or product SE) in accordance with para. 502.3.1 and Table 502.3.1, ksi (MPa)

t = pressure design thickness as calculated for the given closure shape and direction of pressure loading from the appropriate equations and procedures in Section VIII, Division 1, of the ASME BPV Code, in. (mm). (Symbols P and S , used in these equations, shall have the meanings described in this paragraph instead of those given in the ASME BPV Code. All other symbols shall be as defined in the ASME BPV Code.)

t_m = minimum required closure thickness satisfying requirements for pressure and mechanical, corrosion and erosion allowances, in. (mm)

504.4.2 Flat Plate Closures. The minimum required thickness, t_m , for a flat plate closure (shown in Fig. 527.3.6-1) shall be determined in accordance with eq. (11).

$$t_m = d \sqrt{CP/S} + c \quad (11)$$

where

C = $0.33 [t_r / (t_n - c)]$ but not less than 0.20

c = as defined in para. 504.4.1(b)

d = inside diameter of pipe, in. (mm)

P = as defined in para. 504.4.1(b)

S = as defined in para. 504.4.1(b)

\bar{T} = nominal pipe wall thickness, in. (mm)

\bar{T}_p = nominal thickness of plate

t_r = required wall thickness of pipe [equal to t_m of eq. (2)], in. (mm)

504.5 Pressure Design of Flanges and Blanks

504.5.1 General

(a) Flanges manufactured in accordance with the standards listed in Table 526.1 shall be considered suitable for use at the pressure-temperature ratings specified by such standards. Flanges not made in accordance with the standards listed in Table 526.1 shall be designed in accordance with Section VIII, Division 1, of the ASME BPV Code except that the requirements for fabrication, assembly, inspection, and testing, and the pressure and temperature limits for materials of this Code shall govern. Also, certain notations used in the ASME BPV Code, namely, P , S_a , S_b , and S_f , shall have the meanings described in this paragraph instead of those given in the ASME BPV Code. All other notations shall be as defined in the ASME BPV Code.

P = internal design gage pressure (see para. 501.2.2), psi (kPa). (Flanges subject to external pressure should be designed for an internal pressure equal to the external design pressure.)

S_a = bolt design stress, ksi (MPa), at 100°F (38°C) (from Section VIII, Division 1, of the ASME BPV Code)

S_b = bolt design stress, ksi (MPa), at design temperature (from Section VIII, Division 1, of the ASME BPV Code)

S_f = allowable stress, ksi (MPa), for flange material or pipe (from para. 502.3.1 and Table 502.3.1)

(b) The flange design rules presented in para. 504.5.1(a) are not applicable to designs employing flat faced flanges used with full-face gaskets that extend beyond the bolts, usually to the outside diameter of the flange. The forces and reactions in such a joint are very different from those found on ring-gasketed joints, and the flange should be designed to meet the requirements of para. 504.7.

504.5.2 Blind Flanges. Blind flanges manufactured in accordance with the standards listed in Table 526.1

shall be considered suitable for use at the pressure-temperature ratings specified by such standards.

(a) The required thickness of blind flanges not manufactured in accordance with standards in Table 526.1 shall be calculated in accordance with eq. (12), considering pressure and mechanical, corrosion, and erosion allowances. The minimum thickness for the blind flange selected, considering manufacturer's minus tolerance, shall be not less than t_m .

$$t_m = t + c \quad (12)$$

(b) The notations described below are used for the determining of pressure design of blind flanges:

c = sum of the mechanical, corrosion, and erosion allowances, in. (mm)

P = internal design pressure (see para. 501.2.2), psi (kPa), or external design pressure (see para. 501.2.3), psi (kPa)

S = applicable allowable stress in accordance with para. 502.3.1 and Table 502.3.1, ksi (MPa)

t = pressure design thickness, in. (mm), as calculated for the given closure shape and direction of pressure loading from the appropriate equations and procedures in Section VIII, Division 1, of the ASME BPV Code. (Symbols P and S , used in these equations, shall be considered to have the meanings described in this paragraph instead of those given in the ASME BPV Code. All other symbols shall be as defined in the ASME BPV Code.)

t_m = minimum required blind flange thickness, satisfying requirements for pressure and mechanical, corrosion, and erosion allowances, in. (mm)

504.5.3 Blanks

(a) The pressure design thickness of permanent blanks (see Fig. 504.5.3) shall be calculated in accordance with eqs. (12) and (13).

$$t = d_g \sqrt{\frac{3P}{16S}} \quad (13)$$

where

d_g = inside diameter of gasket for raised or flat (plain) face flanges, or the gasket pitch diameter for retained gasketed flanges, in. (mm)

P = internal design pressure (see para. 501.2.2), psi (kPa), or external design pressure (see para. 501.2.3), psi (kPa)

S = applicable allowable stress in accordance with para. 502.3.1 and Table 502.3.1, ksi (MPa)

(b) Blanks to be used for test purposes only shall be designed in accordance with eq. (13), except that P shall be at least equal to the test pressure and S may be as great as 95% of the specified minimum yield strength of the blank material. (This applies only if the test fluid is incompressible.)

504.6 Headers

Headers used on heat transfer components shall be designed in accordance with para. 504.3 and/or shall meet the requirements of para. 504.7.

504.7 Design of Other Pressure-Containing Components

Other pressure-containing components manufactured in accordance with the standards listed in Table 526.1 shall be considered suitable for use at the pressure-temperature ratings specified by such standards. Pressure-containing components not covered by the standards listed in Table 526.1 and for which design formulas or procedures are not given in this paragraph (section 504) may be used where they have been proven satisfactory by successful performance under comparable service conditions. (Where such satisfactory service experience exists, interpolation may be made to other sized components with a geometrically similar shape.) In the absence of such service experience, the pressure design shall be based on an analysis consistent with the general design philosophy embodied in this Code section and substantiated by at least one of the following:

(a) proof tests (as described in UG-101 of Section VIII, Division 1, of the ASME BPV Code)

(b) experimental stress analysis

(c) for heat transfer components, proof test a sample at three times the design pressure of the component

PART 3

DESIGN APPLICATION OF PIPING COMPONENTS SELECTION AND LIMITATIONS

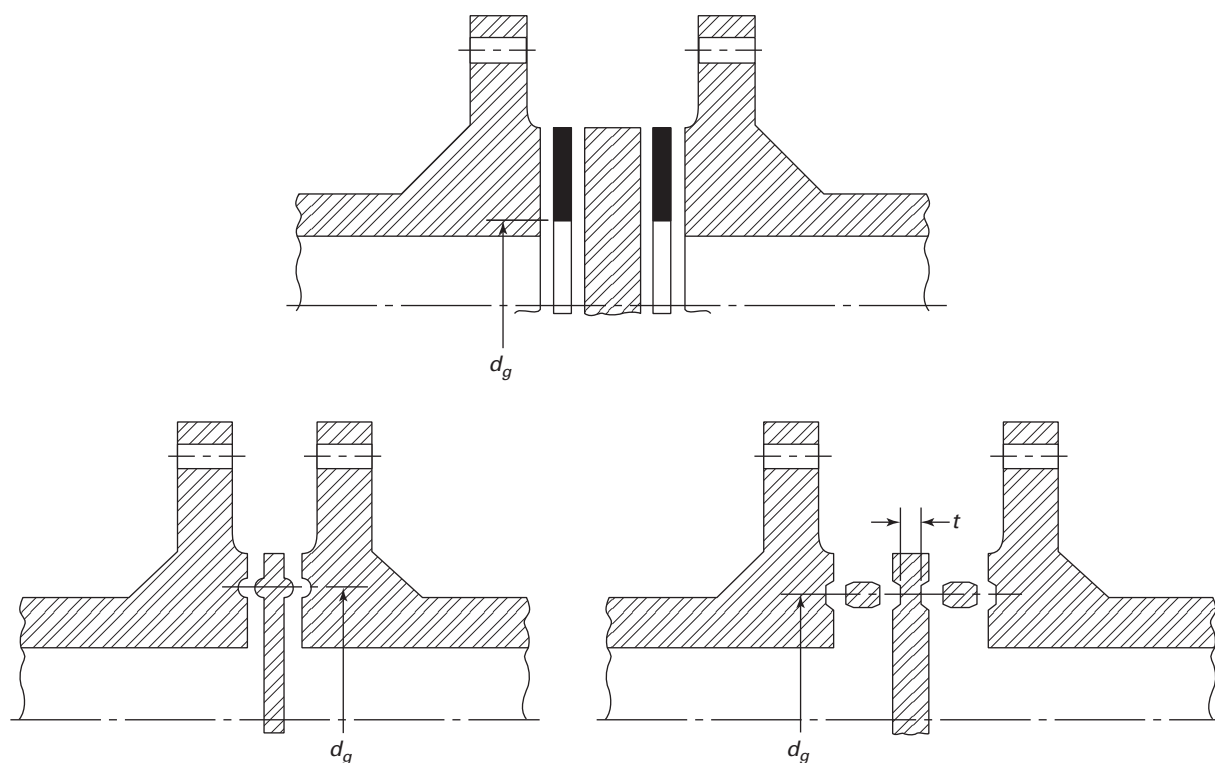
505 PIPE

505.1 General

Pipe, tubes, and other materials conforming to the standards and specifications listed in Tables 502.3.1 and 526.1 shall be used within the limitations of temperature and stress given in para. 502.3.1 and Table 502.3.1 and within the additional limitations contained in this Code.

505.1.1 Additional Limitations for Carbon Steel Pipe. The wall thickness for refrigerant pipe sizes NPS 6 (DN 150) and smaller shall be no less than Schedule 40 (ASME B36.10M), and for liquid refrigerants in Groups A2, A3, B2, and B3, pipe sizes smaller than NPS 2 (DN 50) shall be no less than Schedule 80.

ASTM A53 Type F and API 5L A25 PSL 1 furnace butt welded pipe is permitted in service at temperatures between -20°F (-29°C) and 366°F (186°C) and design pressure not exceeding 150 psig for use in heat transfer components and piping with water-based secondary coolants. The coolants must be nonflammable and nontoxic.

Fig. 504.5.3 Blanks**505.1.2 Additional Limitations for Cast Iron Pipe.**

Cast iron pipe shall not be used for refrigerant service.

505.1.3 Pressure Design of Other Piping Components. Pressure design of other piping components shall meet the requirements of para. 504.7.

505.2 Nonferrous Pipe or Tube

505.2.1 Copper, copper alloy, aluminum, or aluminum alloy pipe and tube of any size may be used for any refrigerant service where compatible with the refrigerant used and when selected in accordance with the design rule in para. 504.1 and allowable stress values in Table 502.3.1.

505.2.2 Soft annealed copper tubing larger than $1\frac{3}{8}$ in. (35 mm) O.D. shall not be used for field assembled refrigerant piping, unless it is protected from mechanical damage.

506 FITTINGS, BENDS, AND INTERSECTIONS**506.1 Fittings**

506.1.1 General. If fittings complying with applicable standards and specifications listed in Tables 523.1 and 526.1 are used, they shall be used within the limitations specified in this Code.

Other fittings, including those exceeding the range of sizes in the standards listed in Table 526.1, may be used

provided the designs meet the requirements in section 504.

506.1.2 Bell and Spigot Fittings. Bell and spigot fittings shall not be used for refrigerant service.

506.2 Bends and Intersections

Bends, miters, and extruded branch connections may be used when they are designed in accordance with the principles in Chapter II, Part 2.

506.3 Limitation on Materials for Fittings

Malleable iron and cast iron shall not be used in couplings or fittings for piping containing flammable or toxic fluids.

507 VALVES

(a) Valves complying with the standards listed in Table 526.1 may be used in accordance with the limitations listed in the specific standards and in this Code.

(b) Refrigerant gate valves, ball valves, and plug cocks shall not be used in liquid refrigerant lines unless consideration is given to the expansion of liquid trapped in the valve cavities when the valve or cock is closed.

508 FLANGES, BLANKS, FLANGE FACINGS, GASKETS, AND BOLTING

508.1 Flanges

508.1.1 General. If flanges complying with applicable standards and specifications listed in Tables 523.1 and 526.1 are used, they shall be used within the limitations specified in this Code.

Other flanges, including those exceeding the range of sizes in the standards listed in Table 526.1, may be used provided the designs meet the requirements of section 504.

508.1.2 Screwed Flanges. Screwed flanges are subject to restrictions on threaded joints established in section 514.

508.2 Blanks

Blanks shall conform to design requirements in para. 504.5.3.

508.3 Flange Facings

Flange facings complying with standards listed in Table 526.1 are suitable for use under this Code. Other special facings may be used provided they meet the requirements of para. 504.7.

Class 150 steel flanges may be bolted to cast iron valves, fittings, or other cast iron piping components having either Class 125 cast integral or screwed flanges. If such construction is used, it is preferred that the $\frac{1}{16}$ in. (1.5 mm) raised face on steel flanges be removed. If the raised face is removed and a ring gasket extending to the inner edge of the bolt holes is used, or if the raised face is not removed, the bolting shall be carbon steel not stronger than ASTM A307, Grade B. If a full-face gasket is used, the bolting may be alloy steel (ASTM A193).

Class 300 steel flanges may be bolted to cast iron valves, fittings, or other cast iron piping components having either Class 250 cast iron integral or screwed flanges, without any change in the raised face on either flange. If such construction is used, the bolting shall be carbon steel not stronger than ASTM A307, Grade B.

508.4 Gaskets

Selection of suitable material for a given service is the responsibility of the user, and subject to any applicable code or jurisdictional regulation. The material selected shall be compatible with the fluid and suitable for the pressure-temperature conditions and shall meet the requirements of ASME B16.20 or ASME B16.21.

508.5 Bolting

508.5.1 General. If bolts, nuts, and washers complying with applicable standards and specifications listed in Tables 523.1 and 526.1 are used, they shall be used within the limitations specified in this Code and

shall also be subject to the requirements of Chapter III and paras. 508.3 and 508.5.2(a) and (b).

508.5.2 Bolting for Cast Iron Flanges

(a) Classes 25 and 125 cast iron integral or screwed companion flanges may be used with a full-face gasket or with a flat ring gasket extending to the inner edge of the bolts. When using a full-face gasket, the bolting may be alloy steel (ASTM A193). When using a flat ring gasket, the bolting shall be of carbon steel equal to or less than ASTM A307, Grade B. Materials other than carbon steels may be used provided the physical properties are equal to or less than the requirements of ASTM A307, Grade B.

(b) When bolting together two Class 250 cast iron, integral, or screwed companion flanges having $\frac{1}{16}$ in. (1.5 mm) raised faces, the bolting shall be of carbon steel equal to or less than ASTM A307, Grade B. Materials other than carbon steels may be used provided the physical properties are equal to or less than the requirements of ASTM A307, Grade B.

PART 4

SELECTION AND LIMITATIONS OF PIPING JOINTS

510 PIPING JOINTS

510.1 General

The type of piping joint used shall be suitable for the pressure-temperature conditions, and shall be selected giving consideration to joint tightness and mechanical strength under the service conditions (including thermal expansion and vibration) and to the nature of the fluid handled with respect to corrosion, erosion, flammability, and toxicity.

The following limitations are in addition to applicable requirements in other portions of this Code Section.

511 WELDED JOINTS

511.1 General

Welded joints may be used with any materials for which it is possible to qualify welding procedures, welders, and welding operators in conformance with Chapter V.

511.2 Butt Welds

Butt welds shall be made in accordance with the applicable requirements of Chapter V and section 500. When backing rings are used in services where their use will result in severe corrosion or erosion, the backing ring should be removed and the internal joint ground smooth. In such services where it is impractical to remove the backing ring, consideration shall be given to welding the joint without backing rings, or consumable inserts may be used.

511.3 Socket Welds

511.3.1 Socket welds shall be made in accordance with the applicable requirements of Chapter V and section 500. Dimensions of socket welding piping joints shall conform to ASME B16.5 for flanges and ASME B16.11 for fittings, and the weld dimensions shall be not less than the minimum dimensions shown in Figs. 527.3.3-2 and 527.3.3-3.

511.3.2 Socket welded connections inserted directly into the wall of the run pipe shall be in accordance with requirements of para. 504.3.1(c).

511.3.3 Drains and bypasses may be attached to a fitting or valve by socket welding, provided the socket depth, bore diameter, and shoulder thickness conform to the requirements of ASME B16.5.

511.4 Fillet Welds

Fillet welds shall be made in accordance with the applicable requirements of Chapter V and section 500. Fillet welds shall not have dimensions less than the minimum dimensions shown in Figs. 527.3.3-2, 527.3.3-3, and 527.3.5-4.

511.5 Seal Welds

Seal welds may be used to avoid joint leakage; however, they shall not be considered as contributing any strength to the joint. (See also para. 527.3.4.)

512 FLANGED JOINTS

Flanged joints shall meet the requirements of section 508.

513 EXPANDED JOINTS

Expanded joints may be used where experience or tests have demonstrated that the joint is suitable for the conditions and where adequate provisions are made in the design to prevent separations of the joints.

514 THREADED JOINTS

(a) Threaded joints may be used within the limits stated in paras. 514(b) through (f).

(b) When used, all pipe threads shall be taper pipe threads where the tightness of joint depends upon the seating of the thread. Straight threads on pipe joints that depend upon a seating surface other than the thread are allowed within the limitations of section 518 if the thread root is no deeper than a standard pipe thread.

(c) Threaded joints larger than NPS 4 (DN 100) should not be used in refrigerant service.

(d) Threaded joints larger than NPS 2 (DN 50) shall not be used for Groups A2 and B2, and Class 3 refrigerants.

Table 514 Minimum Thickness of Male Threaded Components

Notch Sensitive Material	Size Range		Minimum Wall Thickness [Note (1)]
	DN	NPS	
Yes [Note (2)]	≤ 40	≤ 1½	Sch. 80
	50	2	Sch. 40
	65–150	2½–6	Sch. 40
No [Note (3)]	≤ 50	≤ 2	Sch. 40S
	65–150	2½–6	Sch. 40S

GENERAL NOTE: Use the greater of para. 504.1.1, paras. 514(b) through (e), or this Table.

NOTES:

- (1) Nominal wall thickness is listed for carbon steel in ASME B36.10M and for Sch. 40S in ASME B36.19M.
- (2) For example, carbon steel.
- (3) For example, austenitic stainless steel.

(e) Threaded joints larger than NPS 6 (DN 150) should not be used for salt brines.

(f) Male threaded components may be used in accordance with Table 514 and its Notes.

515 FLARED, FLARELESS, AND COMPRESSION JOINTS

515.1 Selection and Application

In selecting and applying flared, flareless, and compression type tube fittings, the designer shall consider the adverse effects on the joints of such factors as assembly and disassembly, cyclic loading, vibration, shock, thermal expansion and contraction, and the problem of frost growth between the tube and fitting.

515.2 Piping Joints With Applicable Standards

Piping joints using flared, flareless, or compression fittings may be used within the limitations of applicable standards or specifications listed in Table 526.1 and the following requirements:

(a) Fittings and their joints shall be suitable for the tubing with which they are to be used with consideration to minimum tubing wall thickness and method of assembly recommended by the manufacturer.

(b) Fittings shall not be used in services that exceed the manufacturer's maximum pressure-temperature recommendations.

515.3 Piping Joints Without Applicable Standards

For piping joints using flared, flareless, or compression fittings for which there are no applicable standards or specifications listed in Table 526.1, the engineer shall determine that the type of fitting selected is adequate and safe for the design conditions and that it meets the

requirements of paras. 515.2(a) and (b) and the following requirements:

(a) The pressure design shall meet the requirements of para. 504.7.

(b) A suitable quantity of the type and size of fitting to be used shall meet successful performance tests to determine the safety of the joint under simulated service conditions. When vibration, fatigue, cyclic conditions, low temperature, thermal expansion, hydraulic shock, or frost growth are anticipated, the applicable conditions shall be incorporated in the test.

517 BRAZED AND SOLDERED JOINTS

Brazed and soldered socket type joints may be used with the following limitations for the attachment of valves, fittings, and flanges to nonferrous pipe and tubing:

(a) Soldered joints shall not be used for piping containing other than Group A1 refrigerants or any other toxic or flammable fluid.

(b) Bores and depths of sockets of brazed and soldered fittings shall conform to the dimensions in ASME B16.18 or ASME B16.22. Depths of sockets for brazed fittings only may conform to MIL-F-1183J.

(c) Brazed socket type joints may be used provided it is determined that the fittings are adequate and safe for the design conditions in accordance with the requirements listed in section 515 for flared and flareless fittings.

(d) The piping systems should be kept free of flux and other foreign materials.

(e) Solder joints shall not be used for temperatures in excess of those given in ASME B16.22.

518 SLEEVE COUPLED AND OTHER NOVEL OR PATENTED JOINTS

Coupling type, mechanical gland type, and other patented or novel type joints may be used provided adequate provisions are made to prevent separation of the joints and provided a prototype joint has been subjected to performance tests to determine the safety of the joint under simulated service conditions. When vibration, fatigue, cyclic conditions, low temperature, thermal expansion, or hydraulic shock are anticipated, the applicable conditions shall be incorporated in the tests.

PART 5 EXPANSION, FLEXIBILITY, STRUCTURAL ATTACHMENTS, SUPPORTS, AND RESTRAINTS

519 EXPANSION AND FLEXIBILITY

519.1 General

The following clauses define the objectives of piping flexibility analysis and alternative ways in which these can be realized.

519.1.1 Objectives. Piping systems shall be designed to have sufficient flexibility to prevent thermal expansion from causing either of the following:

(a) failure of piping or anchors from overstress or overstrain

(b) leakage at joints

(c) detrimental distortion of connected equipment (pumps, turbines, or valves) resulting from excessive thrusts and moments

519.1.2 Expansion Strains. Expansion strains may be taken up in two ways, either primarily by bending or torsion, in which case only the extreme fibers at the critical location are stressed to the limit, or by axial compression and tension, in which case the entire cross-sectional area over the entire length is substantially equally stressed.

(a) Bending or torsional flexibility may be provided by the use of bends, loops, or offsets; or by swivel joints, ball joints, corrugated pipe, or expansion joints of the bellows type permitting angular movement. Suitable anchors, ties, or other devices shall be provided as necessary to resist end forces from fluid pressure, frictional, or other resistance to joint movement and other causes.

(b) Axial flexibility may be provided by expansion joints of the slip-joint or bellows types. Pipe running from anchors to the joints must be guided where necessary to keep the pipe from bowing because of end forces originating in the joint from fluid pressure, friction, and deformation of the bellows. Anchors must be adequate for these forces plus the force arising from friction in the guides. For design and selection of expansion joints of the bellows type, reference to the standards of the Expansion Joint Manufacturers Association is recommended.

519.2 Concepts

Concepts peculiar to piping flexibility analysis and requiring special consideration are explained in the following paragraphs.

519.2.1 Stress Range. As contrasted with stresses from sustained loads (such as internal pressure or weight), stresses caused by thermal expansion in systems stressed primarily in bending and torsion are permitted to attain sufficient initial magnitude to cause local yielding or creep. The attendant relaxation or reduction of stress in the hot condition leads to the creation of a stress reversal when the component returns to the cold condition. This phenomenon is designated as self-springing of the line and is similar in effect to cold springing. The amount of self-springing depends on the initial magnitude of the expansion stress, the material, the temperature, and the elapsed time. While the expansion stress in the hot condition tends to diminish with time, the arithmetic sum of the expansion stresses in the hot and cold conditions during any one cycle remains substantially constant. This sum, referred to as the stress range, is the determining factor in the thermal design of piping.

519.2.2 Expansion Range. In computing the stress range, the full thermal expansion range from the minimum to maximum metal temperature normally expected during installation and operation shall be used, whether the piping is cold sprung or not. Linear or angular movements of the equipment to which the piping is attached shall be included. For values of the unit thermal expansion range, refer to para. 519.3.1.

Where substantial anchor or terminal movements are anticipated as a result of tidal changes (unloading dock piping) or wind sway (piping attached to slender towers), these effects shall be considered analogous to terminal movements caused by thermal expansion.

519.2.3 Cold Spring. Cold spring is recognized as beneficial in that it serves to balance hot and cold stresses without drawing on the ductility of the material, for which reason it is recommended in particular for materials of relatively low ductility. In addition, it helps assure minimum departure from as-erected hanger settings. Inasmuch as the life of a system under cyclic conditions depends primarily on the stress range rather than the stress level at any one time, no credit for cold spring is given for stress range calculations. In calculating end thrusts and moments where actual reactions at any one time rather than their range are considered significant, cold spring is credited. (See para. 519.4.6.)

519.2.4 Local Overstrain. All the commonly used methods of piping flexibility analysis assume elastic behavior of the entire piping system. This assumption is sufficiently accurate for systems where plastic straining occurs at many points or over relatively wide regions, but fails to reflect the actual strain distribution in unbalanced systems where only a small portion of the piping undergoes plastic strain, or where, in piping operating in the creep range, the strain distribution is very uneven. In these cases, the weaker or higher stressed portions will be subjected to strain concentrations due to elastic followup of the stiffer or lower stressed portions. Unbalance can be produced

(a) by use of small pipe runs in series with larger or stiffer pipe with the small lines relatively highly stressed

(b) by local reduction in size or cross section, or local use of a weaker material

(c) in a system of uniform size, by use of a line configuration for which the neutral axis (actually, the wrench axis) is situated close to the major portion of the line with only a very small portion projecting away from it absorbing most of the expansion strain

Conditions of this type should preferably be avoided, particularly where materials of relatively low ductility are used; if unavoidable, they should be mitigated by the judicious application of cold spring.

519.3 Properties

The following paragraphs deal with materials and geometric properties of pipe and piping components

and the manner in which they are to be used in piping flexibility analysis.

519.3.1 Unit Thermal Expansion Range. The thermal expansion range, e , in./100 ft (mm/m), shall be determined from Table 519.3.1 as the algebraic difference between the unit expansion shown for the maximum normal operating metal temperature and that for the minimum normal operating metal temperature. For materials not included in this Table, reference shall be made to authoritative source data, such as publications of the National Institute of Standards and Technology.

519.3.2 Moduli of Elasticity. The cold and hot moduli of elasticity, E_c and E_h , respectively, shall be taken from Table 519.3.2 for the minimum and maximum normal operating metal temperatures in Table 519.3.2. For materials not included in these Tables, reference shall be made to authoritative source data, such as publications of the National Institute of Standards and Technology.

519.3.3 Poisson's Ratio. Poisson's ratio is the ratio of the unit deformation at right angles to the direction of the load to the unit deformation in the direction of the load, and may be taken as 0.3 at all temperatures for all metals. However, more-accurate data may be used if available.

519.3.4 Allowable Expansion Stress Range. The allowable basic expansion stress range, S_A , and permissible additive stresses shall be as specified in paras. 502.3.2(c) and (d) for systems primarily stressed in bending or torsion.

519.3.5 Dimensions. Nominal dimensions of pipe and fittings, and cross-sectional areas, moments of inertia, and section moduli based thereon shall be used in flexibility calculations, including the permissible additive stresses.

519.3.6 Flexibility and Stress Intensification Factors. Calculations shall take into account stress intensification factors found to exist in components other than plain straight pipe. Credit may be taken for the extra flexibility of such components. In the absence of more directly applicable data, the flexibility and stress intensification factors shown in Table 519.3.6 may be used. For piping components or attachments (such as valves, strainers, anchor rings, or bands) not covered in the Table, suitable stress intensification factors may be assumed by comparison of their significant geometry with that of the components shown.

519.4 Analysis for Bending Flexibility

The following paragraphs establish under what circumstances and in what manner piping flexibility analyses are to be made where the system primarily derives its flexibility from bending or torsional strains.

Table 519.3.1 Thermal Expansion Data, ϵ (IP and SI)

Linear Thermal Expansion (IP), in./100 ft							
Material	Temperature Range 70°F to						
	−325	−150	−50	70	200	300	400
Carbon steel, carbon moly	−2.37	−1.45	−0.84	0.00	0.99	1.82	2.70
Nickel steel (3½Ni)	−2.25	−1.48	−0.84	0.00	1.01	1.84	2.69
Nickel steel (9Ni)	−2.27	−1.43	−0.81	0.00	0.98	1.77	2.57
Austenitic stainless steels	−3.85	−2.27	−1.24	0.00	1.46	2.61	3.80
Ductile iron	...	−1.29	−0.77	0.00	0.94	1.72	2.56
Monel (67Ni–30Cu)	−2.62	−1.79	−0.98	0.00	1.22	2.21	3.25
Copper (99.90Cu) C12000, C12200	−3.70	−2.28	−1.28	0.00	1.51	2.67	3.88
Red brass (85Cu) C23000	−3.88	−2.24	−1.29	0.00	1.52	2.76	4.05
Copper nickel (90Cu–10Ni) C70600	−4.10	−2.26	−1.29	0.00	1.49	2.62	3.77
Copper nickel (70Cu–30Ni) C71500	−3.15	−1.95	−1.13	0.00	1.33	2.40	3.52
Aluminum	−4.68	−2.88	−1.67	0.00	2.00	3.66	5.39
Copper silicon (3Si) C65500	−4.21	−2.31	−1.32	0.00	1.51	2.67	3.88

Linear Thermal Expansion (SI), mm/m							
Material	Temperature Range 21°C to						
	−198	−101	−46	21	93	149	204
Carbon steel, carbon moly	−1.97	−1.21	−0.70	0.00	0.82	1.52	2.25
Nickel steel (3½Ni)	−1.87	−1.23	−0.70	0.00	0.84	1.53	2.24
Nickel steel (9Ni)	−1.89	−1.19	−0.68	0.00	0.82	1.48	2.14
Austenitic stainless steels	−3.21	−1.89	−1.03	0.00	1.22	2.18	3.17
Ductile iron	...	−1.07	−0.64	0.00	0.78	1.43	2.13
Monel (67Ni–30Cu)	−2.18	−1.49	−0.82	0.00	1.02	1.84	2.71
Copper (99.90Cu) C12000, C12200	−3.08	−1.90	−1.07	0.00	1.26	2.22	3.23
Red brass (85Cu) C23000	−3.23	−1.87	−1.07	0.00	1.27	2.30	3.37
Copper nickel (90Cu–10Ni) C70600	−3.42	−1.88	−1.07	0.00	1.24	2.18	3.14
Copper nickel (70Cu–30Ni) C71500	−2.62	−1.62	−0.94	0.00	1.11	2.00	2.83
Aluminum	−3.90	−2.40	−1.39	0.00	1.67	3.05	4.49
Copper silicon (3Si) C65500	−3.51	−1.92	−1.10	0.00	1.26	2.22	3.23

Table 519.3.2 Moduli of Elasticity, E (IP and SI)

Moduli of Elasticity (IP), psi [Note (1)]							
Material	Temperature, °F						
	−325	−150	−50	70	200	300	400
Carbon steel, carbon 0.30 or less	31.4	30.5	30.0	29.5	28.8	28.3	27.7
Cast iron	...	...	...	13.4	13.2	12.9	12.6
Monel (67Ni–30Cu)	27.8	27.1	26.6	26.0	25.4	25.0	24.7
Copper (99.90Cu) C12000, C12200	18.0	17.6	17.3	17.0	16.6	16.3	16.0
Red brass (85Cu) C23000	18.2	17.7	17.5	17.0	16.6	16.4	15.8
Copper nickel (90Cu–10Ni) C70600	19.0	18.6	18.3	18.0	17.6	17.3	16.9
Copper nickel (70Cu–30Ni) C71500	22.3	22.8	22.4	22.0	21.5	21.1	20.7
Aluminum	11.1	10.6	10.3	10.0	9.6	9.2	8.7
Copper silicon (3Si) C65500	15.9	15.5	15.3	15.0	14.6	14.4	14.1

Moduli of Elasticity (SI), kPa [Note (2)]							
Material	Temperature, °C						
	−198	−101	−46	21	93	149	204
Carbon steel, carbon 0.30 or less	216	210	207	203	198	195	191
Cast iron	...	...	...	92.4	91.0	88.9	86.9
Monel (67Ni–30Cu)	192	187	183	179	175	173	170
Copper (99.90Cu) C12000, C12200	124	121	119	117	114	112	110
Red brass (85Cu) C23000	125	122	121	117	114	113	109
Copper nickel (90Cu–10Ni) C70600	131	128	126	124	121	119	117
Copper nickel (70Cu–30Ni) C71500	154	157	155	152	148	145	143
Aluminum	77	73	71	69	66	63	60
Copper silicon (3Si) C65500	110	107	105	103	101	99	97

NOTES:

(1) E in psi = tabulated values multiplied by 10^6 .(2) E in kPa = tabulated values multiplied by 10^6 .

Table 519.3.6 Illustration

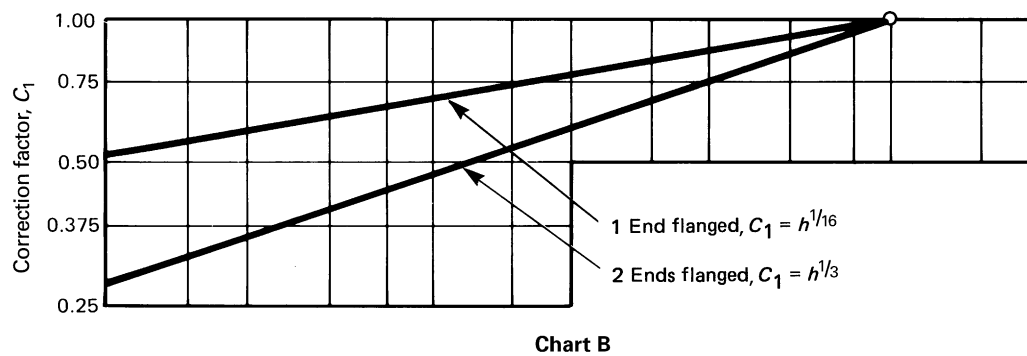
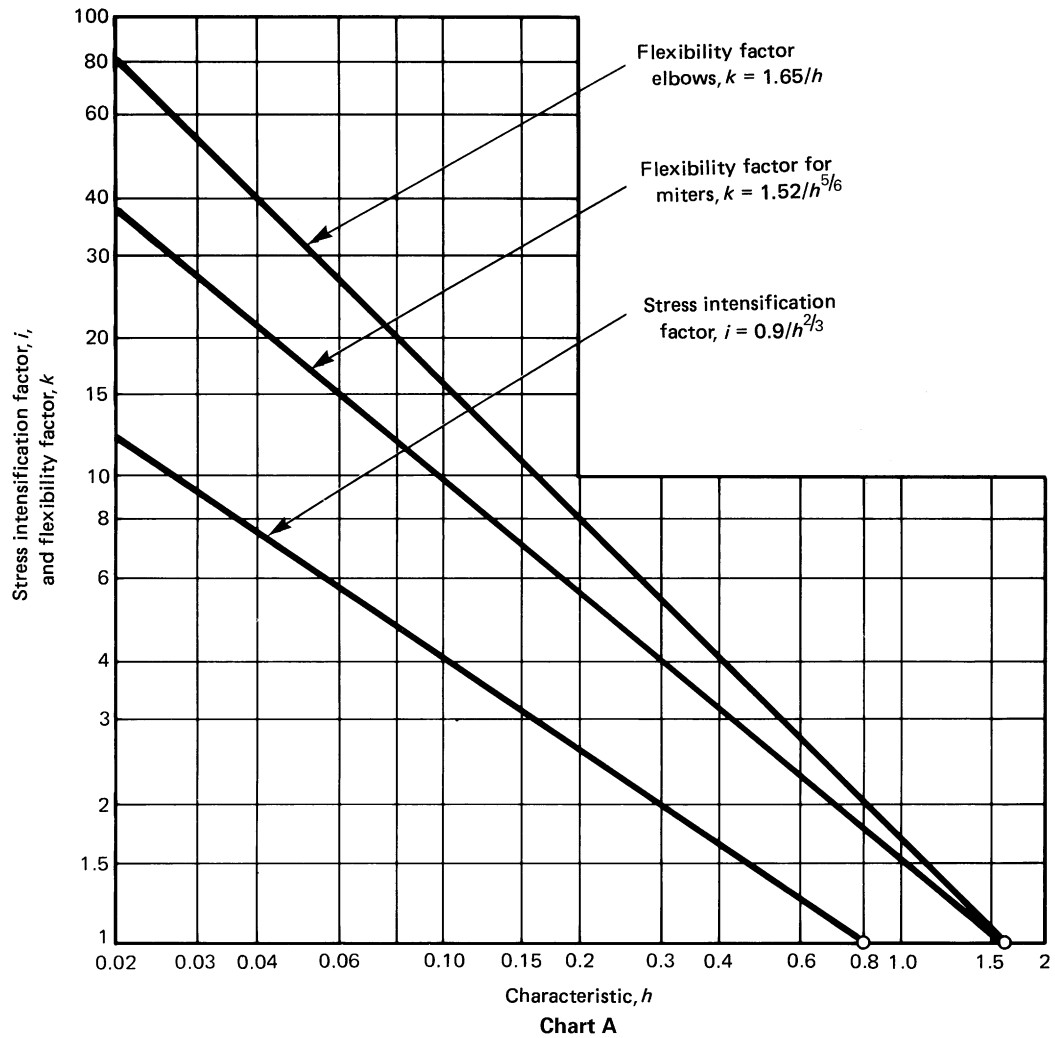


Table 519.3.6 Flexibility Factor, k , and Stress Intensification Factor, i

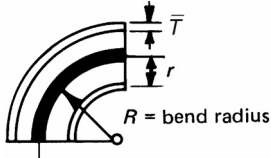
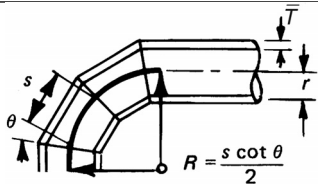
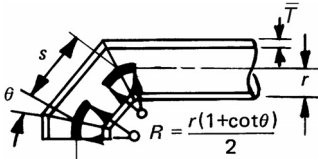
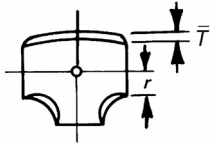
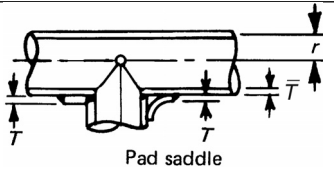
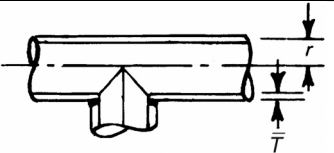
Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor		Illustration
			i_i [Note (1)]	i_o [Note (2)]	
Welding elbow or pipe bend [Notes (3)–(7)]	$\frac{\bar{T}R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	
Closely spaced miter bend [Notes (3), (4), (5), and (7)], $s < r(1 + \tan \theta)$	$\frac{\bar{T}s}{r^2} \left(\frac{\cot \theta}{2} \right)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	
Widely spaced miter bend [Notes (3), (4), (7), and (8)], $s \geq r(1 + \tan \theta)$	$\frac{\bar{T}}{r} \left(\frac{1 + \cot \theta}{2} \right)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	
Welding tee ASME B16.9 [Notes (3) and (4)]	$4.4 \frac{\bar{T}}{r}$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee with pad or saddle [Notes (3), (4), and (9)]	$\frac{(\bar{T} + \frac{1}{2}T)^{5/2}}{t^{3/2}r}$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee [Notes (3) and (4)]	$\frac{\bar{T}}{r}$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	
Butt welded joint, reducer, or welding neck flange	...	1	1.0	1.0	...
Double-welded slip-on flange	...	1	1.2	1.2	...

Table 519.3.6 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor		Illustration
			i_i [Note (1)]	i_o [Note (2)]	
Fillet welded joint (single-welded), socket welded flange, or single-welded slip-on flange	...	1	1.3	1.3	...
Lap flange (with ASME B16.9 lap-joint stub)	...	1	1.6	1.6	...
Threaded pipe joint or threaded flange	...	1	2.3	2.3	...
Corrugated straight pipe, or corrugated or creased bend [Note (10)]	...	5	2.5	2.5	...

GENERAL NOTE: For reference, see Table 519.3.6 Illustration on page 41.

NOTES:

- (1) In-plane.
- (2) Out-plane.
- (3) For fittings and miter bends the flexibility factors, k , and stress intensification factors, i , in the Table apply to bending in any plane and shall not be less than unity; factors for torsion equal unity.
- (4) Both factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter elbows and to the intersection point for tees. The values of k and i can be read directly from Chart A by entering with the characteristic, h , computed from the equations given where
 - R = bend radius of welding elbow or pipe bend, in. (mm)
 - r = mean radius of matching pipe, in. (mm)
 - s = miter spacing at centerline, in. (mm)
 - T = pad or saddle thickness, in. (mm)
 - \bar{T} = nominal wall thickness, in. (mm), of: part itself for elbows and curved or miter bends; matching pipe for welding tees; run or header for fabricated tees (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter).
 - θ = one-half angle between adjacent miter axes, deg
- (5) Where flanges are attached to one or both ends, the values of k and T in the Table shall be corrected by the factors C_1 given below, which can be read directly from Chart B; entering with the computed h : one end flanged, $h^{1/6} \geq 1$; both ends flanged, $h^{1/2} \geq 1$.
- (6) The engineer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.
- (7) In large-diameter thin-wall elbows and bends, pressure can significantly affect the magnitude of flexibility and stress intensification factors. To correct values obtained from the Table for the pressure effect, divide
 - (a) flexibility factor, k , by

$$1 + 6 \frac{P}{E_c} \left(\frac{r}{T} \right)^{1/3} \left(\frac{R}{r} \right)^{1/3}$$

- (b) stress intensification factor, i , by

$$1 + 3.25 \frac{P}{E_c} \left(\frac{r}{T} \right)^{5/2} \left(\frac{R}{r} \right)^{2/3}$$

where

E_c = cold modulus of elasticity, ksi (MPa)

P = internal design pressure, psi (kPa)

- (8) Also includes single-miter joint.
- (9) When $T > 1.5\bar{T}$, use $h = 4.05 \bar{T}/r$.
- (10) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

519.4.1 Calculations/Tests. Formal calculations or model tests shall be required only where reasonable doubt exists as to the adequate flexibility of a system.

519.4.2 Flexibility. Adequate flexibility may generally be assumed to be available in systems that

(a) are duplicates of successfully operating installations or replacements of systems with a satisfactory service record

(b) can be readily adjudged adequate by comparison with previously analyzed systems

(c) are of uniform size, have no more than two points of fixation and no intermediate restraints, are designed for essentially noncyclic service (less than 7,000 total cycles), and satisfy the following approximate criterion:

$$\frac{D_o Y}{(L - U)^2} \leq \frac{30S_A}{E_c} \quad (14)$$

where

D_o = outside diameter of pipe, in. (mm)

E_c = modulus of elasticity of the piping material in the cold condition, ksi (MPa)

L = developed length of piping between anchors, ft (m)

S_A = allowable stress range from eq. (1), ksi (MPa), include stress range reduction factor, f , where more than 7,000 cycles of movement are anticipated during the life of the installation (see Fig. 502.3.2)

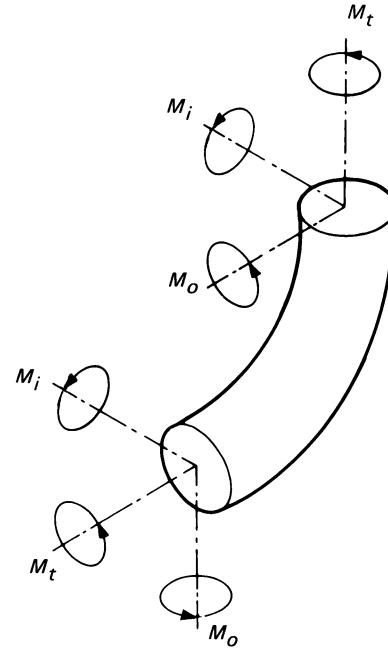
U = anchor distance (length of straight line joining anchors), ft (m)

Y = resultant of movements to be absorbed by pipe-line, in. (mm)

519.4.3 Methods of Analysis. Systems that do not meet the requirements of para. 519.4.2 shall be analyzed by a method appropriate to the hazard entailed by failure of the line, the importance of maintaining continuous service, the complexity of the layout, and strain sensitivity of the pipe material. Simplified or approximate methods may be applied without correction only if they are used for the range of configurations for which their adequate accuracy has been demonstrated. Accompanying any flexibility calculation, there shall be an adequate statement of the method and any simplifying assumptions used.

519.4.4 Standard Assumptions. Standard assumptions specified in para. 519.3 shall be followed in all cases. In calculating the flexibility of a piping system between anchor points, the system shall be treated as a whole. The significance of all parts of the line and of all restraints, such as solid hangers or guides, including intermediate restraints introduced for the purpose of reducing moments and forces on equipment or small branch lines, and also the restraint introduced by support friction, shall be recognized. Not only the expansion of the line itself, but also linear and angular movements

Fig. 519.4.5-1 Bends



of the equipment to which it is attached shall be considered.

519.4.5 Flexibility Stresses

(a) Bending and torsional stress shall be computed using the as-installed modulus of elasticity, E_j ($E_j = E_c$ at installation temperature) and then combined in accordance with eq. (15) to determine the computed stress range, S_E , which shall not exceed the allowable stress range, S_A , in para. 502.3.2.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \quad (15)$$

where

M_t = torsional moment, in.-lb (N·m)

S_b = resultant bending stress, ksi (MPa)

S_t = torsional stress, ksi (MPa)

$= M_t / 2Z$

Z = section modulus of pipe, in.³ (mm³)

(b) The resultant bending stresses, S_b , ksi (MPa), to be used in eq. (15) for elbows and miter bends shall be calculated in accordance with eq. (16), with moments as shown in Fig. 519.4.5-1.

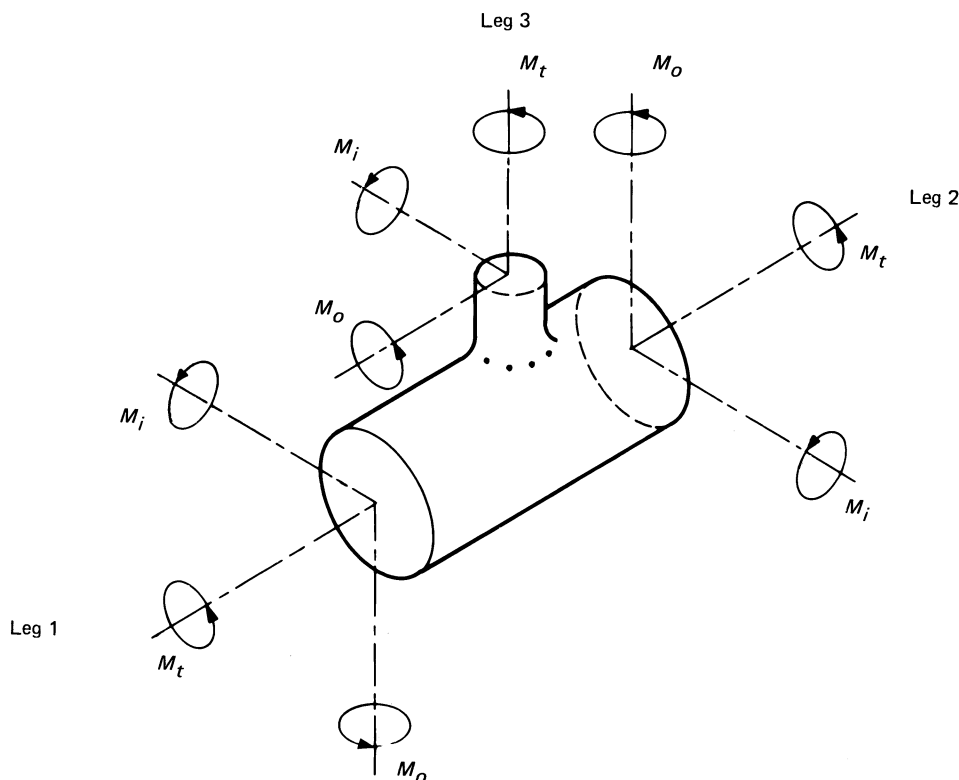
$$S_b = \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z} \quad (16)$$

where

i_i = in-plane stress intensification factor from Table 519.3.6

i_o = out-plane stress intensification factor from Table 519.3.6

Fig. 519.4.5-2 Branch Connections



M_i = in-plane bending moment, in.-lb (N·m)
 M_o = out-plane bending moment, in.-lb (N·m)
 Z = sectional modulus of pipe, in.³ (mm³)

(c) The resultant bending stresses, S_b , to be used in eq. (15) for branch connections shall be calculated in accordance with eqs. (17) and (18) with moments as shown in Fig. 519.4.5-2.

(1) For header (Legs 1 and 2),

$$S_b = \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z} \quad (17)$$

(2) For branch (Leg 3),

$$S_b = \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z_e} \quad (18)$$

where

i_i = in-plane stress intensification factor
 i_o = out-plane stress intensification factor
 r_m = mean branch cross-sectional radius, in. (mm)
 S_b = resultant bending stress, ksi (MPa)
 \bar{T}_b = nominal wall thickness of pipe matching branch, in. (mm)
 \bar{T}_h = nominal wall thickness of pipe matching run of tee or header exclusive of reinforcing elements, in. (mm)

\bar{T}_s = effective branch wall thickness, in. (mm)
 (lesser of \bar{T}_h and $i_o \bar{T}_b$)

Z_e = effective section modulus for branch of tee, in.³ (mm³)
 $= \pi r_m^2 \bar{T}_s$

(d) Allowable stress range, S_A , and permissible additive stresses shall be computed in accordance with paras. 519.2.1 and 519.2.2.

519.4.6 Reactions. The reactions (forces and moments), R_h and R_c , in the hot and cold conditions, respectively, shall be obtained from the reaction range, R , derived from the flexibility calculations, using eqs. (19) and (20).

In the design of anchors and restraints and in the evaluation of some mechanical effects of expansion on terminal equipment (such as pumps and heat exchangers) either reaction range, R (see definition below), or instantaneous values of reaction forces and moments in the hot or cold condition may be of significance. Determination of the latter may be complicated by the difficulty of performing the desired cold spring and by other factors. Thus their determination may require an elaborate engineering calculation, the basis of which should be clearly set forth. In the absence of a better procedure, in the case of one-material, uniform-temperature, two-anchor systems without intermediate

constraints, the hot and cold reactions may be estimated by the following formulas:

$$R_L = (1 - \frac{2}{3}C) \frac{E_h}{E_c} R \quad (19)$$

$$R_c = CR \text{ or } C_1R, \text{ whichever is greater} \quad (20)$$

where

C = cold spring factor varying from 0 for no cold spring to 1 for 100% cold spring

NOTE: Factor $\frac{2}{3}$ appearing in eq. (19) accounts for observation that specified cold spring cannot be fully assured, even with elaborate precautions.

C_1 = estimated self-spring or relaxation factor; use zero if value becomes negative

$$= 1 - S_h E_c / S_E E_h$$

E_c = modulus of elasticity in the cold condition, ksi (kPa)

E_h = modulus of elasticity in the hot condition, ksi (kPa)

R = range of reaction forces or moments corresponding to the full expansion range based on E_c , lb (N) or in.-lb (N·m)

R_c, R_h = maximum reaction forces or moments estimated to occur in the cold and hot conditions, respectively, lb (N) or in.-lb (N·m)

S_E = maximum computed expansion stress range at any point in the line, ksi (MPa) (see paras. 519.2.1 and 519.2.2)

S_h = basic material allowable stress at maximum (hot) normal temperature, ksi (MPa) (use S , not SE , from para. 502.3.1 and Table 502.3.1)

519.4.7 Reaction Limits. The computed reactions shall not exceed limits that connected equipment, specifically strain sensitive components, such as pumps, compressors, valves, strainers, tanks, and pressure vessels, can safely sustain.

519.4.8 Movements. Calculation of displacements and rotations at specific locations may be required where clearance problems are involved. In cases where small-size branch lines attached to stiff main lines are to be calculated separately, the linear and angular movements of the junction point must be calculated or estimated for proper analysis of the branch.

520 DESIGN OF PIPE SUPPORTING ELEMENTS

520.1 General

Loads on equipment supporting, bracing, guiding, or anchoring piping include, in addition to weight effects, loads due to service pressure and temperatures, vibration, wind, earthquake, shock, erection contingencies (including testing), thermal expansion and contraction, and differential settlement of foundations, all as defined in section 501. The design of all elements supporting

or restraining pipe shall have regard to the degree of probability of concurrence of loads and whether they are sustained or tend to relax themselves as defined in para. 519.2.1.

520.1.1 Objectives. Supporting elements shall be designed to prevent the loadings and deflections due to the influences delineated in para. 520.1 from causing one of the following:

(a) piping stresses in excess of those permitted in this Section of the Code

(b) leakage at joints

(c) detrimental distortion of connected equipment (such as pumps, turbines, valves, etc.) resulting from excessive forces and moments

(d) excessive stresses in the pipe supporting (or restraining) elements themselves

(e) resonance with imposed vibrations

(f) excessive interference with the thermal expansion and contraction of a piping system that is otherwise adequately flexible

(g) unintentional disengagement of the piping from its supports

(h) excessive piping sag in systems requiring drainage slope

520.1.2 Allowable Stresses in Piping. The design of piping-support elements shall be such that the sustained piping stresses shall not exceed the allowable value as defined in paras. 502.3.2(d) and 523.2.2(f)(4).

520.1.3 Allowable Stresses in Piping Support and Restraint Components

(a) The allowable stress for the base material of all parts of supporting and restraint assemblies shall not exceed the appropriate S value taken from para. 502.3.1 and Table 502.3.1 including Notes except as permitted in 520.1.3(b). It is not necessary to include joint factors. The allowable stress shall be reduced 25% for threaded members and for welds in support assemblies or for attachments to piping. For threaded members stresses shall be based on the root area of the threads.

(b) An increase in allowable stress of 20% shall be allowed for short-time overloading conditions.

(c) For requirements pertaining to springs, see para. 521.3.2.

(d) For requirements pertaining to anchors and guides, see paras. 521.1.3 and 521.1.4.

(e) The principles in para. 502.3.1(d) are not applicable to design of springs.

(f) Pipe support and hanger components conforming to the requirements of para. 502.3.1 may have an increase in their working stress to 80% of minimum yield strength at room temperature for the period of hydrostatic testing. This applies only to supports that have been engineered by the designer and not to standard catalog items unless they have been carefully analyzed by the designer.

520.1.4 Materials — Steel. All equipment for permanent supports and restraints shall be fabricated from durable materials suitable for the service conditions. Unless otherwise permitted in para. 520.1.5, steel shall be used for pipe supporting elements. All materials shall be capable of meeting the respective standard specifications given in Table 523.1 with regard to the tests and physical properties.

Parts of supporting elements that are subjected principally to bending or tension loads and that are subjected to working temperatures for which carbon steel is not recommended shall be made of suitable alloy steel, or shall be protected so that the temperature of the supporting members will be maintained within their temperature limits.

520.1.5 Materials Other Than Those in Para. 520.1.4. Cast iron may be used for roller bases, rollers, anchor bases, brackets, and parts of pipe supporting elements upon which the loading will be mainly that of compression. Malleable or nodular iron castings may be used for pipe clamps, beam clamps, hanger flanges, clips, bases, swivel rings, and parts of pipe supporting elements. Treated wood may be used for pipe supporting elements that are primarily in compression when the metal temperatures are at or below ambient temperature.

Materials other than those listed in Table 523.1 may be employed to take advantage of their superior properties, in specialty items such as constant support hangers. In such cases, allowable stresses shall be determined in accordance with the principles given in para. 502.3.1.

520.1.6 Protective Coatings

(a) Under conditions causing mild corrosion, such as atmospheric rusting, which are not of an intensity to warrant the use of corrosion resistant materials, a durable protective coating, such as hot-dipped galvanizing, weather resistant paint, or other suitable protection, should be applied to all parts after fabrication or after installation.

(b) Under any conditions, exposed screw threads on parts of the equipment where corrosion resistant materials are not used shall be greased immediately after fabrication. Paints, slushes, or other suitable protective coatings may be used instead of grease.

520.1.7 Threaded Components. Threads shall be in accordance with ASME B1.1, except that other thread forms may be used to facilitate adjustment under heavy loads. All threaded adjustments shall be provided with lock nuts or be locked by other positive means. Turnbuckles and adjusting nuts shall have the full length of thread in service. Means shall be provided for determining that full length of thread is in service.

521 DESIGN LOADS FOR PIPE SUPPORTING ELEMENTS

521.1 General

521.1.1 Forces and moments at pipe supporting elements caused by thermal expansion or contraction shall be determined as necessary.

521.1.2 Weight calculations for gas, vapor, or safety valve discharge piping should not include the weight of liquid if the possibility of these lines containing liquid is remote and provided the lines are not subjected to hydrostatic tests.

521.1.3 Restraints, such as anchors and guides, shall be provided where necessary to control movement or to direct expansion and/or other effects into those portions of the system that are adequate to absorb them for the purpose of protecting terminal equipment and/or other (weaker) portions of the system. The effect of friction in other supports of the system shall be considered in the design of such anchors and guides.

521.1.4 Anchors or guides for expansion joints of the corrugated or slip-type (or variants of these types) shall be designed to resist end forces from fluid pressure and frictional or other applicable resistance to joint movement, in addition to other loadings.

521.2 Resilient Variable-Support and Constant-Support Types

Reactions or load calculations for resilient or constant effort type supports, such as springs or weight loaded supports and braces, shall be based on the maximum working conditions of the piping. However, the support shall be capable of carrying the total load under test conditions, unless additional support is provided for the test period. The amount of variation that can be tolerated shall be determined by incorporating the change in supporting effect in the flexibility analysis or shall be based on such considerations as bending effect, control of piping elevation, allowable terminal reactions, etc.

521.3 Design Details

521.3.1 General

(a) *Hanger Rods.* Safe axial loads for threaded hanger rods shall be based on the root area of the threads and subject to 25% reduction in allowable stress as in para. 520.1.3(a). Pipe, straps, or bars of strength and effect area equal to the equivalent hanger rod may be used instead of hanger rods. See Table 521.3.1.

(b) *Chains.* Chain may be used for pipe hangers and shall be designed in accordance with para. 521.3.1(a).

Table 521.3.1 Minimum Sizes of Straps, Rods, and Chains for Hangers

Nominal Pipe Size NPS (DN)	Component (Steel)	Minimum Stock Size, in. (mm)	
		Exposed to Weather	Protected From Weather
1 and smaller [1 in. (25 mm)]	Strap	$\frac{1}{8}$ in. (3 mm) thick	$\frac{1}{16}$ in. (1.5 mm) thick \times $\frac{3}{4}$ in. (19 mm) wide
Above 1 [1 in. (25 mm)]	Strap	$\frac{1}{4}$ in. (6 mm) thick	$\frac{1}{8}$ in. (3 mm) thick \times 1 in. (25 mm) wide
2 and smaller [2 in. (50 mm)]	Rod	$\frac{3}{8}$ in. (10 mm) diameter	$\frac{3}{8}$ in. (10 mm) diameter
Above 2 [2 in. (50 mm)]	Rod	$\frac{1}{2}$ in. (13 mm) diameter	$\frac{1}{2}$ in. (13 mm) diameter
2 and smaller [2 in. (50 mm)]	Chain	$\frac{3}{16}$ in. (5 mm) diameter or equivalent area	$\frac{3}{16}$ in. (5 mm) diameter or equivalent area
Above 2 [2 in. (50 mm)]	Chain	$\frac{3}{8}$ in. (10 mm) diameter or equivalent area	$\frac{3}{8}$ in. (10 mm) diameter or equivalent area
All sizes	Bolted clamps	$\frac{3}{16}$ in. (5 mm) thick; bolts $\frac{3}{8}$ in. (10 mm) diameter	$\frac{3}{16}$ in. (5 mm) thick; bolts $\frac{3}{8}$ in. (10 mm) diameter

GENERAL NOTE: For nonferrous materials, the minimum stock area shall be increased by the ratio of allowable stress of steel to the allowable stress of the nonferrous material.

(c) *Sliding Supports.* Sliding supports (or shoes) and brackets shall be designed to resist the forces due to friction in addition to the loads imposed by bearing. The dimensions of the support shall provide for the expected movement of the supported piping.

(d) At point of support subject to horizontal movement, the movement shall be provided for by the swing of long hanger rods or chains or by the use of trolleys, rollers, sliding, or swinging supports.

(e) Covering on insulated piping shall be protected from damage at all hanger locations. Saddles, bases, or suitable shields properly constructed and secured to the covered pipe shall be used at points of roller, base, and trapeze support.

(f) Lugs, plates, angle clips, etc., used as part of an assembly for the support or guiding of pipe may be welded directly to the pipe provided the material is of good weldable quality and the design is adequate for the load. Preheating, welding, and postheating shall be in accordance with the rules of Chapter V.

(g) See MSS SP-58 for typical design details.

521.3.2 Spring Supports. Spring type supports shall be provided with means to prevent misalignment, buckling, or eccentric loading of the spring, and to prevent unintentional disengagement of the load. Materials

shall be in accordance with the provisions of paras. 520.1.4 and 520.1.5. Constant support spring hangers shall be designed to provide a substantially uniform supporting force throughout the range of travel. All spring elements shall be provided with means of adjustment for the pipe position in the operating and nonoperating condition. Means shall be provided to prevent overstressing the spring due to excessive deflections. It is desirable that all spring hangers be provided with position indicators.

521.3.3 Counterweights. Counterweights when used instead of spring hangers shall be provided with stops to prevent overtravel. Weights shall be positively secured. Chains, cables, hanger and rocker arm details, or other devices used to attach the counterweight load to the piping, shall be subject to requirements of para. 521.3.1.

521.3.4 Hydraulic-Type Supports. An arrangement utilizing a constant hydraulic head may be installed to give a constant supporting effort. Safety devices and stops shall be provided to support the load in case of hydraulic failure.

521.3.5 Sway Braces or Vibration Dampeners. Sway braces and vibration dampeners may be used to limit the movement of piping due to vibration.

Chapter III

Materials

523 MATERIALS — GENERAL REQUIREMENTS

523.1 Materials and Specifications

The materials used shall conform to the specifications listed in Table 523.1 or shall meet the requirements of this Code for materials not so established.

523.1.1 Listed Materials

(a) Any material used in pressure containing piping components shall conform to a listed specification except as provided in para. 523.1.2.

(b) Materials manufactured to specification editions other than those listed in Nonmandatory Appendix A meet the requirements of this Code, provided

(1) the material meets the listed edition's requirements for chemical composition and heat treatment condition

(2) the material grain size requirements are the same as the listed edition

(3) the material toughness requirements are the same as the listed edition

(4) the material tensile and yield strength requirements are the same as the listed edition

(5) the material has been tested and examined in accordance with the requirements of the listed edition

523.1.2 Unlisted Materials. Unlisted materials may be used provided they conform to a published specification covering chemistry, physical, and mechanical properties, method and process of manufacture, heat treatment, and quality control and otherwise meet the requirements of this Code. Allowable stresses shall be determined in accordance with the applicable allowable stress basis of this Code or a more conservative basis.

523.1.3 Unknown Materials. Materials of unknown specification shall not be used for pressure-containing piping components.

523.1.4 Reclaimed Materials. Reclaimed pipe and other piping components may be used, provided they are properly identified as conforming to a listed or published specification (para. 523.1.1 or 523.1.2) and otherwise meet the requirements of this Code. Sufficient cleaning and inspection shall be made to determine minimum wall thickness and freedom from imperfections that would be unacceptable in the intended service.

523.2 Limitations on Materials

523.2.1 General. The materials listed in Table 502.3.1 shall not be used at design metal temperatures above those for which stress values are given in the Table. The materials shall not be used below the

minimum temperature listed unless they meet the requirements of para. 523.2.2.

523.2.2 Impact Tests. Materials subject to design metal temperatures below the minimum temperature listed in Table 502.3.1 and in para. 523.2.2(f)(5), except for those exempted in paras. 523.2.2(f)(4) and (f)(5), shall be impact tested as required by UG-84 of Section VIII, Division 1, of the ASME BPV Code. The following requirements shall also be met:

(a) A welded test section shall be prepared for each P-Number and Group Number as defined by ASME Section IX and in accordance with UG-84(e).

(b) If the material to be used is not certified, test sections shall be prepared from each piece of pipe, plate, or tubing used.

(c) One set of impact-test specimens shall be taken across the weld (the metal tested is the weld metal) with the notch in the weld, and one set shall be taken similarly with the notch at the fusion line (the metal tested is the base metal).

(d) Impact test specimens shall be cooled to a temperature not higher than the lowest temperature to which the pipe, plate, or tubing may be subjected in its operating cycle.

(e) One set of impact-test specimens with the notch in the weld metal and one set with the notch in the heat-affected zone shall be made for each range of pipe thicknesses as required by ASME Section IX.

(f) The following materials are exempted from the requirements for impact testing:

(1) Impact tests are not required for aluminum: Types 304 or CF8, 304L or CF3, 316 or CF8M, and 321 austenitic stainless steel; copper; red brass; copper-nickel alloys; and nickel-copper alloys.

(2) Impact tests are not required for bolting material conforming with A193, Grade B7, for use at temperatures not lower than -55°F (-48°C).

(3) Impact tests are not required for bolting materials conforming with A320, Grades L7, L10, and L43, at temperatures above -150°F (-101°C) or above -225°F (-143°C) for A320, Grade L9.

(4) Impact tests are not required for ferrous materials used in fabricating a piping system for metal temperatures colder than -20°F (-29°C) down to -150°F (-101°C), provided the maximum circumferential or longitudinal tensile stress resulting from coincident pressure, thermal contraction, or bending between supports does not exceed 35% of the allowable stress

Table 523.1 Acceptable Materials — Specifications

Component	Specification	Material
Bolting	ASTM A193	Alloy steel and stainless steel bolting materials for high-temperature service
	ASTM A194	Carbon and alloy steel nuts for bolts for high pressure and high-temperature service
	ASTM A307	Carbon steel bolts and studs, 60 ksi (414 MPa) tensile
	ASTM A320	Alloy steel bolting materials for low-temperature service
	ASTM A325	Structured bolts, steel, heat treated, 120/105 ksi, minimum tensile strength
	ASTM A354	Quenched and tempered alloy steel bolts, studs, and other externally threaded fasteners
	ASTM B21	Naval brass rod, bar, and shapes
	ASTM B98	Copper-silicon alloy rod, bar, and shapes
Fittings, valves, flanges	ASTM B211	Aluminum and aluminum alloy bar, rod, and wire
	ASTM A47	Ferritic malleable iron castings
	ASTM A48	Gray iron castings
	ASTM A105	Forgings, carbon steel, for piping components
	ASTM A126	Gray iron castings for valves, flanges, and pipe fittings
	ASTM A181	Forgings, carbon steel for general purpose piping
	ASTM A182	Forged or rolled alloy steel pipe flanges, forged fittings, and valves and part for high-temperature service
	ASTM A197	Cupola malleable iron
	ASTM A216	Steel castings, carbon, suitable for fusion welding for high-temperature service
	ASTM A217	Steel castings, martensitic stainless and alloy, for pressure-containing parts suitable for high-temperature service
	ASTM A234	Piping fittings of wrought carbon steel and alloy steel for moderate and elevated temperatures
	ASTM A278	Gray iron castings for pressure-containing parts for temperatures up to 650°F (345°C)
	ASTM A350	Forgings, carbon and low alloy steel, requiring notch toughness testing for piping components
	ASTM A351	Castings, austenitic, austenitic–ferritic (duplex) for pressure-containing parts
	ASTM A352	Steel castings, ferritic and martensitic, for pressure-containing parts, suitable for low-temperature service
	ASTM A395	Ferritic ductile iron for pressure retaining castings for use at elevated temperatures
	ASTM A403	Wrought austenitic stainless steel piping fittings
	ASTM A420	Piping fittings of wrought carbon steel and alloy steel for low-temperature service
	ASTM A522	Forged or rolled 8% and 9% nickel alloy steel flanges, fittings, valves, and parts for low-temperature service
	ASTM A536	Ductile iron castings
	ASTM A571	Austenitic ductile iron castings for pressure-containing parts suitable for low temperature service
	ASTM A743	Castings, iron–chromium, iron–chromium–nickel, and nickel base, corrosion resistant, for general application
	ASTM A744	Castings, iron–chromium–nickel and nickel base, corrosion resistant, for severe service
	ASTM B16	Free-cutting brass rod, bar, and shapes for use in screw machines
	ASTM B21	Naval brass rod, bar, and shapes
	ASTM B26	Aluminum alloy sand castings
	ASTM B61	Steam or valve bronze castings
	ASTM B62	Composition bronze or ounce metal castings
	ASTM B85	Aluminum alloy die castings
	ASTM B124	Copper and copper alloy forging rod, bar, and shapes
	ASTM B179	Aluminum alloys in ingot form for sand castings, permanent mold castings, and die castings
	ASTM B247	Aluminum and aluminum alloy die forgings, hand forgings, and rolled ring forgings
	ASTM B283	Copper and copper alloy die forgings (hot pressed)

Table 523.1 Acceptable Materials — Specifications (Cont'd)

Component	Specification	Material
Fittings, valves, flanges (cont'd)	ASTM B361 ASTM B584 AWWA C110	Factory-made wrought aluminum and aluminum alloy welding fittings Copper alloy sand castings for general applications Gray iron and ductile iron fittings NPS 2 (DN 50) through NPS 48 (DN 1200) for water and other liquids
Steel pipe	ASTM A53 [Note (1)] ASTM A106 ASTM A134 ASTM A135 ASTM A139 ASTM A312 ASTM A333 ASTM A358 ASTM A376 ASTM A409 ASTM A587 API 5L [Note (1)]	Pipe, steel, black and hot dipped, zinc coated, welded and seamless Seamless carbon steel pipe for high-temperature service Pipe, steel electric-fusion (arc) welded [sizes NPS 16 (DN 400) and over] Electric-resistance welded steel pipe Electric-fusion (arc) welded steel pipe [sizes NPS 4 (DN 100) and over] Seamless and welded austenitic stainless steel pipe Seamless and welded steel pipe for low-temperature service Electric-fusion welded austenitic chromium–nickel alloy steel pipe for high temperature service Seamless austenitic steel pipe for high-temperature central-station service Welded large outside diameter austenitic steel pipe for corrosive or high temperature service Electric resistance-welded low carbon steel pipe for the chemical industry Line pipe
Nonferrous pipe	ASTM B42 ASTM B43 ASTM B165 ASTM B241 ASTM B302 ASTM B315 ASTM B345 ASTM B466 ASTM B467	Seamless copper pipe, standard sizes Seamless red brass pipe, standard sizes Nickel–copper alloy (UNS N04400) seamless pipe and tube Aluminum and aluminum alloy seamless pipe and seamless extruded tube Threadless copper pipe Seamless copper alloy pipe and tube Aluminum and aluminum alloy seamless pipe and seamless extruded tube for gas and oil transmission and distribution piping systems Seamless copper–nickel alloy pipe and tube Welded copper–nickel pipe
Steel tube	ASTM A178 ASTM A179 ASTM A192 ASTM A210 ASTM A213 ASTM A214 ASTM A226 ASTM A249 ASTM A254 ASTM A269 ASTM A271 ASTM A334	Electric-resistance welded carbon steel boiler tubes Seamless cold-drawn low carbon steel heat exchanger and condenser tubes Seamless carbon steel boiler tubes for high pressure service Seamless medium-carbon steel boiler and superheater tubes Seamless ferritic and austenitic alloy steel boiler, superheater, and heat exchanger tubes Electric-resistance welded carbon steel heat exchanger and condenser tubes Electric-resistance welded carbon steel boiler and superheater tubes for high pressure service Welded austenitic steel boiler, superheater, heat exchanger and condenser tubes Copper brazed steel tubing Seamless and welded austenitic stainless steel tubing for general service Seamless austenitic chromium–nickel steel still tubes for refinery service Seamless and welded carbon and alloy steel tubes, for low-temperature service
Nonferrous tube	ASTM B68 ASTM B75 ASTM B88 ASTM B111 ASTM B165 ASTM B210 ASTM B234 ASTM B280 ASTM B315	Seamless copper tube, bright annealed Seamless copper tube Seamless copper water tube Copper and copper alloy seamless condenser tubes and ferule stock Nickel–copper alloy (UNS N04400) seamless pipe and tube Aluminum alloy drawn seamless tubes Aluminum and aluminum alloy drawn seamless tubes for condensers and heat exchangers Seamless copper tube for air conditioning and refrigeration field service Seamless copper alloy pipe and tube

Table 523.1 Acceptable Materials — Specifications (Cont'd)

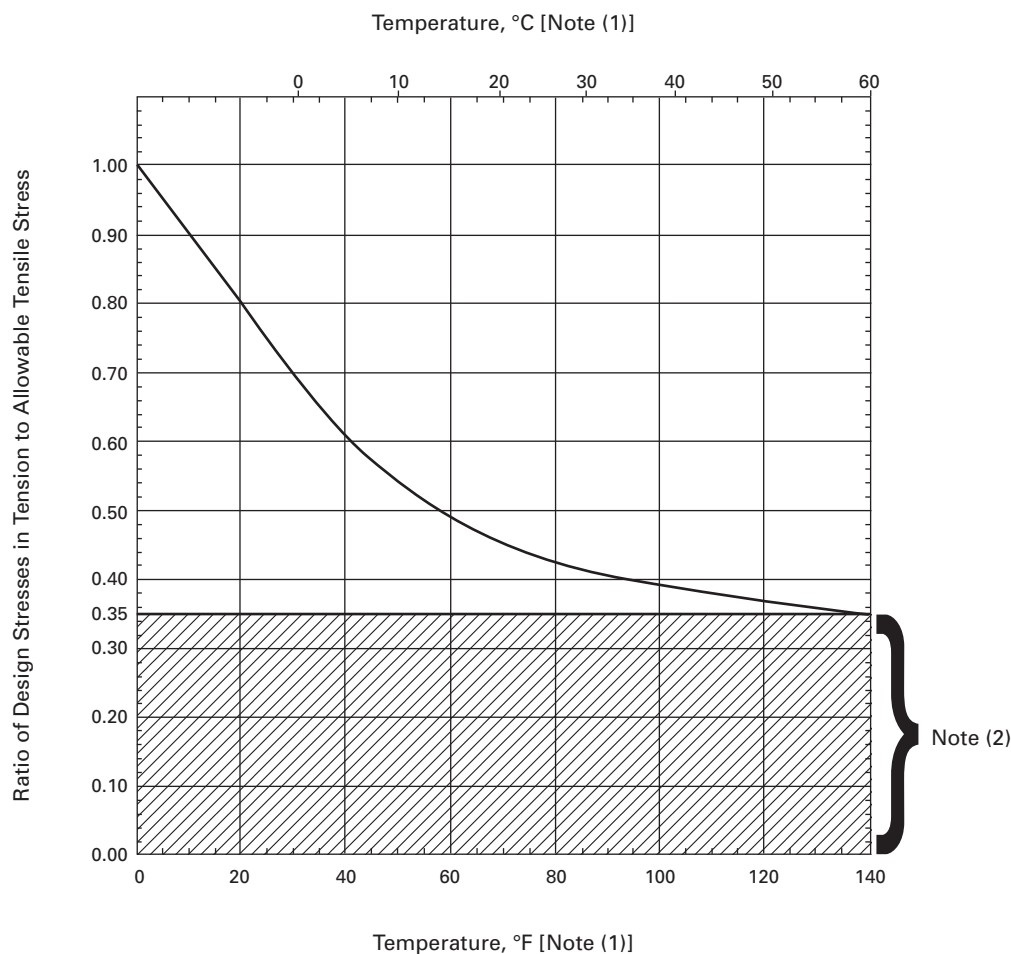
Component	Specification	Material
Nonferrous tube (cont'd)	ASTM B466 ASTM B743	Seamless copper–nickel pipe and tube Seamless copper tube in coil
Steel plate	ASTM A36 ASTM A240 ASTM A283 ASTM A285 ASTM A353 ASTM A414 ASTM A515 ASTM A516 ASTM A553 ASTM A1008 ASTM A1011	Structural steel Heat-resisting chromium and chromium–nickel stainless steel plate, sheet, and strip for pressure vessels Low and intermediate tensile strength carbon steel plates Pressure vessel plates, carbon steel, low and intermediate tensile strength Pressure vessel plates, alloy steel, 9% nickel, double-normalized and tempered Steel, sheet, carbon, for pressure vessels Pressure vessel plates, carbon steel, for intermediate- and higher-temperature service Pressure vessel plates, carbon steel, for moderate- and lower-temperature service Pressure vessel plates, alloy steel, quenched and tempered 8% and 9% nickel Steel sheet, carbon cold-rolled, structural quality Steel sheet and strip, carbon hot-rolled, structural quality
Nonferrous plate	ASTM B96 ASTM B152 ASTM B171 ASTM B209 ASTM B248	Copper-silicon alloy plate, sheet, strip, and rolled bar for general purposes and pressure vessels Copper, sheet, strip, plate, and rolled bar Copper alloy plate and sheet for pressure vessels, condensers, and heat exchangers Aluminum and aluminum alloy sheet and plate General requirements for wrought copper and copper alloy plate, sheet, strip, and rolled bar
Welding electrodes and rods for steel and iron	ASME SFA-5.1 or AWS A5.1 ASME SFA-5.2 or AWS A5.2 ASME SFA-5.4 or AWS A5.4 ASME SFA-5.9 or AWS A5.9	Carbon steel electrodes for shielded metal arc welding Carbon and low alloy steel rods for oxyfuel gas welding Stainless steel electrodes for shielded metal arc welding Bars, strip, steel electrodes, and rods
Welding electrodes for nonferrous metals	AWS A5.3 ASME SFA-5.6 or AWS A5.6 ASME SFA-5.7 or AWS A5.7 ASME SFA-5.10 or AWS A5.10 AWS A5.12	Aluminum and aluminum alloy covered arc welding electrodes Copper and copper alloy covered electrodes Copper and copper alloy bare welding rods and electrodes Bare aluminum and aluminum alloy welding electrodes and rods Tungsten for arc welding electrodes
Solder and brazing metal	ASTM B32 ASME SFA-5.8 or AWS A5.8	Solder metal Filler metals for brazing and braze welding
Springs	ASTM A125	Steel springs, helical, heat treated
Chains	ASTM A413 ASTM A466 ASTM A467	Carbon steel chain Weldless carbon steel chain Machine and boiler chain
Bars	ASTM A663 ASTM A675 ASTM B221	Steel bars, carbon, merchant quality, mechanical properties Steel bars, carbon, hot wrought, special quality, mechanical properties Aluminum alloy extended bar, rod, wire, shapes, and tube

GENERAL NOTES:

- (a) For specific edition of specifications referred to in this Code, see Nonmandatory Appendix A and subsequent addenda.
 (b) All ASME SFA specifications appear in Section II, Part C, of the ASME BPV Code.

NOTE:

- (1) For furnace butt weld pipe, see para. 505.1.1.

Fig. 523.2.2 Reduction in Minimum Design Metal Temperature Without Impact Testing**(13)****NOTES:**

- (1) See para. 523.2.2(f).
 (2) See para. 523.2.2(f)(4) when ratios are 0.35 and smaller.

for the materials as given in Table 502.3.1. See para. 502.3.2 and sections 519 and 520.

(5) Or, alternatively, in the temperature range colder than -20°F (-29°C) down to -55°F (-48°C), impact tests are not required for ferrous materials used in fabrication provided the minimum design metal temperature is above the allowable temperature determined from applying the temperature reduction due to the ratio from Fig. 523.2.2 to the listed minimum temperature in Table 502.3.1. For minimum temperature listings of "A" or "B," use the minimum temperature corresponding to the governing thickness shown in Table 523.2.2.

The following governing thickness applies when using Table 523.2.2:

(a) for a welded part is as follows:

(1) for butt joints except those for flat heads, the nominal thickness of the thickest welded joint

(2) for corner or fillet welds, the thinner of the two parts joined

(3) for flat heads, the larger of para. 523.2.2(f)(5)(a)(2) or the flat component thickness divided by 4

(4) for welded assemblies composed of more than two components (e.g., branch-to-run pipe with reinforcing pad), the governing thickness and permissible minimum design metal temperature of each of the individual welded joints of the assembly shall be determined, and the warmest of the minimum design metal temperatures shall be used as the permissible minimum design metal temperature of the welded assembly

(b) for nonwelded flat components is the flat component thickness divided by 4

(6) *Flanges*

Table 523.2.2 Impact Exemption Temperatures

Thickness, in.	Curve A, °F [Note (1)]	Curve B, °F [Note (2)]	Curve C, °F
0.375	18	-20	-55
0.4375	25	-13	-40
0.5	32	-7	-34
0.5625	37	-1	-26
0.625	43	5	-22
0.6875	48	10	-18
0.75	53	15	-15
0.8125	57	19	-12
0.875	61	23	-9
0.9375	65	27	-6
1	68	31	-3

GENERAL NOTE: For other nominal thickness, see Curves A, B, and C in Fig. UCS-66 in Section VIII, Division 1, ASME BPV Code.

NOTES:

- (1) *Curve A.* All carbon and low alloy pipe, tube, plates, valves, fittings, and flanges listed for minimum temperature as "A" in Table 502.3.1. Use the minimum temperature in Curve A corresponding to the nominal material thickness in Table 523.2.2.
- (2) *Curve B.* Specifications are ASTM unless otherwise noted. Use the minimum temperature in Curve B corresponding to the nominal material thickness in Table 523.2.2 for
 - (a) A285 Grades A and B
 - (b) A414 Grade A
 - (c) A515 Grade 60
 - (d) A516 Grades 65, and 70 (if not normalized)
 - (e) API 5L Grades A25, A, and B
 - (f) A135 Grades A and B
 - (g) A53 Grades A and B
 - (h) A106 Grades A, B, and C
 - (i) A134 Grade B
 - (j) all materials of Curve A, if produced to fine grain practice and normalized

(a) Impact tests are not required for the following flanges when used at minimum design metal temperatures no colder than -20°F (-29°C):

- (1) ASME B16.5 flanges of ferritic steel
- (2) ASME B16.47 flanges of ferritic steel
- (3) split loose flanges of SA-216 Grade WCB

when the outside diameter and bolting dimensions are either ASME B16.5 Class 150 or Class 300, and the flange thicknesses are not greater than that of either ASME B16.5 Class 150 or Class 300, respectively

(b) Impact tests are not required for the flanges listed in para. 523.2.2(6)(a) for metal temperatures colder than -20°F (-29°C) and no colder than -55°F (-48°C) provided the minimum design metal temperature (MDMT) is above the allowable temperature determined from applying the temperature reduction (Fig. 523.2.2). The ratio used for determining the temperature reduction is defined as the design pressure at the MDMT to the maximum allowable pressure as permitted by ASME B16.5.

(7) No impact testing is required for carbon steel 0.10 in. (2.5 mm) and thinner, but such materials shall not be used at design metal temperatures colder than -55°F (-48°C). See the exception in para. 523.2.2(8).

(8) Carbon steel pipe and tube in sizes of NPS 4 (DN 100) or smaller, with specified minimum yield strength of 35 ksi or less and thickness of 0.237 in. (6 mm) or less are exempted from impact testing for metal temperatures of -155°F (-105°C) and warmer.

(9) Carbon steel pipe and tube in sizes of NPS 4 (DN 100) or smaller, with specified minimum yield strength of 45 ksi or less and thickness of 0.125 in. (3 mm) or less are exempted from impact testing for metal temperatures of -155°F (-105°C) and warmer.

523.2.3 Cast Iron and Malleable Iron. Cast iron and malleable iron shall not be used for piping components in hydrocarbon or other flammable fluid service at temperatures above 300°F (149°C), nor at gage pressures above 300 psi (2 070 kPa). Cast iron or malleable iron shall not be used at temperatures below -150°F (-101°C).

523.2.4 Ductile (Nodular) Iron. Ductile iron shall not be used for piping components at gage pressures above 1,000 psi (6 895 kPa) or at temperatures below -150°F (-101°C).

523.2.5 Clad and Lined Materials. Clad and lined materials may be used in accordance with the applicable requirements in Part UCL of Section VIII, Division 1, of the ASME BPV Code.

523.2.6 Nonmetallic Pressure-Containing Components. Nonmetallic pressure-containing components, such as plastics, glass, carbon, rubber, or ceramics, may be used even if not specifically listed in this Code. Materials and methods in Chapter VIII of B31.3 are acceptable. If stress data are not available for establishment of allowable stresses, the components may be qualified per para. 504.7. Consideration shall be given to the suitability of the material for the service temperature, its resistance to deterioration from the service fluid or environment, its flammability, its resistance to shock, its creep, and its proper support and protection from mechanical damage.

523.3 Deterioration of Materials in Service

The selection of materials to resist deterioration in service is outside the scope of this Code. It is the responsibility of the engineer to select materials suitable for the conditions of operation.

524 MATERIALS APPLIED TO MISCELLANEOUS PARTS

524.1 Gaskets

Limitations on gasket materials are covered in para. 508.4.

524.2 Bolting

Limitations on bolting materials are covered in paras. 508.3, 508.5, and 523.2.2.

Chapter IV

Dimensional Requirements

526 DIMENSIONAL REQUIREMENTS FOR STANDARD AND NONSTANDARD PIPING COMPONENTS

526.1 Standard Piping Components

Dimensional standards for piping components are listed in Table 526.1. Also, certain material specifications listed in Table 523.1 contain dimensional requirements that are requirements of section 526. Dimensions of piping components shall comply with these standards and specifications unless the provisions of para. 526.2 are met.

526.2 Nonstandard Piping Components

The dimensions for nonstandard piping components shall, where possible, provide strength and performance equivalent to standard components, except as permitted under section 504. For convenience, dimensions shall conform to those of comparable standard components.

526.3 Threads

The dimensions of all piping connection threads not otherwise covered by a governing component standard or specification shall conform to the requirements of applicable standards listed in Table 526.1.

(13)

Table 526.1 Dimensional Standards

Standard	Designation
Bolting	
Square, Hex, Heavy Hex, and Askew Head Bolts and Hex, Heavy Hex, Hex Flange, Lobed Head, and Lag Screws (Inch Series)	ASME B18.2.1
Nuts for General Applications: machine Screw Nuts, Hex, Square, Hex Flange, and Coupling Nuts (Inch Series)	ASME B18.2.2
Fittings, Valves, Flanges, and Gaskets	
Gray Iron Pipe Flanges and Flanged Fittings: Classes 25, 125, and 250	ASME B16.1
Malleable Iron Threaded Fittings: Classes 150 and 300.	ASME B16.3
Gray Iron Threaded Fittings: Classes 125 and 250	ASME B16.4
Pipe Flanges and Flanged Fittings	ASME B16.5
Factory-Made Wrought Butt welding Fittings	ASME B16.9
Face-to-Face and End-to-End Dimensions of Valves	ASME B16.10
Forged Fittings, Socket-Welding and Threaded	ASME B16.11
Ferrous Pipe Plugs, Bushings, and Locknuts With Pipe Threads	ASME B16.14
Cast Copper Alloy Threaded Fittings: Classes 125 and 250	ASME B16.15
Cast Copper Alloy Solder Joint Pressure Fittings	ASME B16.18
Metallic Gaskets for Pipe Flanges: Ring-Joint, Spiral-Wound, and Jacketed.	ASME B16.20
Wrought Copper and Copper Alloy Solder Joint Pressure Fittings	ASME B16.22
Cast Copper Alloy Pipe Flanges and Flanged Fittings: Classes 150, 300, 600, 900, 1500, and 2500	ASME B16.24
Butt welding Ends.	ASME B16.25
Valves — Flanged, Threaded, and Welding End	ASME B16.34
Wrought Copper and Copper Alloy Braze-Joint Pressure Fittings.	ASME B16.50
Ductile-Iron and Gray Iron Fittings, for Water.	AWWA C110
Metal-Seated Gate Valves for Water Supply Service	AWWA C500
Refrigeration Tube Fittings General Specifications.	ANSI/SAE J513
Steel Gate Valves — Flanged and Butt-welding Ends, Bolted Bonnets.	API 600
Fittings, Pipe, Cast Bronze, Silver Brazing	MIL-F-1183E
Standard Finishes for Contact Faces of Pipe Flanges and Connecting-End Flanges of Valves and Fittings.	MSS SP-6
Spot Facing for Bronze, Iron, and Steel Flanges	MSS SP-9
Standard Marking System for Valves, Fittings, Flanges, and Unions	MSS SP-25
Class 150 Corrosion-Resistant Gate, Globe, Angle, and Check Valves With Flanged and Buttweld Ends.	MSS SP-42
Wrought Stainless Steel Butt-Welding Fittings	MSS SP-43
Bypass and Drain Connections	MSS SP-45
Class 150LW Corrosion Resistant Cast Flanges and Flanged Fittings.	MSS SP-51
Pipe Hangers and Supports — Materials, Design and Manufacture.	MSS SP-58
Cast Iron Gate Valves, Flanged and Threaded Ends.	MSS SP-70
Cast Iron Swing Check Valves, Flanged and Threaded Ends	MSS SP-71
Bronze Gate, Globe, Angle, and Check Valves	MSS SP-80
Integrally Reinforced Forged Branch Outlet Fittings — Socket Welding and Buttwelding Ends.	MSS SP-97
Pipe and Tube	
Welded and Seamless Wrought Steel Pipe	ASME B36.10M
Stainless Steel Pipe	ASME B36.19M
Miscellaneous	
Unified Inch Screw Threads (UN and UNR Thread Form).	ASME B1.1
Pipe Threads, General Purpose (Inch)	ASME B1.20.1
Dryseal Pipe Threads (Inch)	ASME B1.20.3
Safety Standard for Refrigeration Systems	ANSI/ASHRAE 15
Designation and Safety Classification of Refrigerants	ANSI/ASHRAE 34

GENERAL NOTE: For specific edition of specifications referred to in this Code, see Nonmandatory Appendix A.

Chapter V

Fabrication and Assembly

527 WELDING

527.1 Material

527.1.1 Electrodes and Filler Metal. Welding electrodes and filler metal, including consumable inserts, shall conform to the requirements of the ASME BPV Code, Section II, Part C. An electrode or filler metal not conforming to the above may be used provided the welding procedure specification (WPS) and the welders and welding operators who follow the WPS have been qualified as required by ASME Section IX.

Unless otherwise specified by the designer, welding electrodes and filler metals used shall comply with the following:

(a) The minimum tensile strength of the filler metal shall equal or exceed the respective minimum tensile strength of the base metals joined.

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

(c) The nominal chemical composition of the filler metal shall be like the nominal chemical composition of the major alloying elements of the base metal.

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

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

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

(g) Where impact testing of the WPS is required by section 527, the filler metal used shall be of a classification in the applicable ASME Section II, Part C filler metal specification that exhibits absorbed energy (ft-lb) equal to or greater than that required for the base metals to be welded at a temperature equal to or lower than the lowest service temperature for the base metal.

527.1.2 Backing Rings. The use of backing rings is not mandatory; however, when used, they shall conform to the following requirements: (Also, see para. 511.2.)

(a) *Ferrous Rings.* Backing rings shall be made from material of good weldable quality, and the sulfur content

shall not exceed 0.05%. The backing ring material should preferably be of the same chemical composition as the parts to be joined.

Backing rings may be of the continuous machined, or split band type. Some acceptable split types are shown in Fig. 527.1.2.

(b) *Nonferrous and Nonmetallic Rings.* Backing rings of nonferrous or nonmetallic materials may be used provided they have no effect on the weld or the contained fluid. The satisfactory use of such materials shall be determined by the qualification of the welding procedure.

527.2 Preparation

527.2.1 Butt Welds

(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.

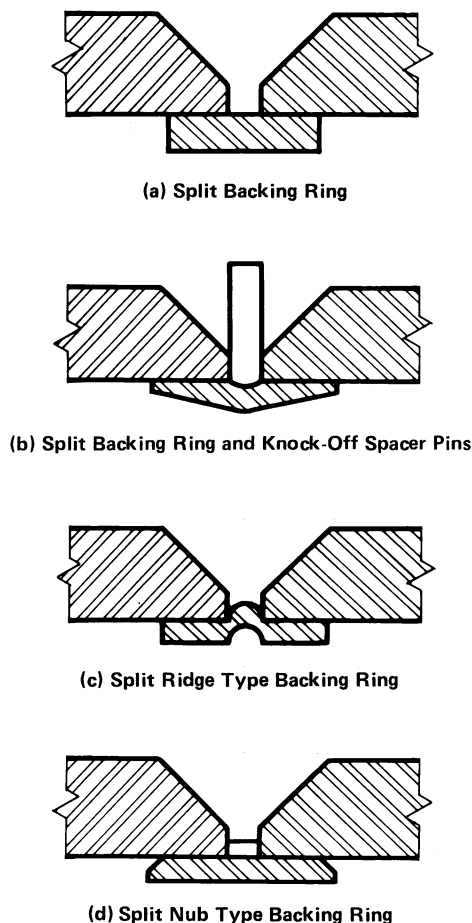
(2) Butt welding end preparation dimensions contained in ASME B16.25 or any other angles that meet the requirements of the welding procedure are acceptable. (For convenience, the basic bevel angles taken from ASME B16.25 are shown in Fig. 527.2.1-1.)

(3) If piping component ends are bored for fitting backing rings, such boring shall not result in a finished wall thickness after welding less than the minimum design thickness plus corrosion and erosion allowances. Where necessary, weld metal may be deposited on the inside of the piping component to provide sufficient material for machining to insure satisfactory seating of the rings.

(4) If the piping 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 plus corrosion and erosion allowance.

(b) *Cleaning.* Surfaces for welding shall be clean and shall be free from rust, scale, or other material that is detrimental to welding. Galvanizing must be removed from the weld zone of galvanized carbon steel.

(c) *Alignment.* Misalignment of the inside surfaces of piping components to be joined by butt welding may result from out-of-roundness, outside diameter tolerance, wall thickness tolerance, or from the inclusion in

Fig. 527.1.2 Typical Joints With Backing Ring**GENERAL NOTES:**

- (a) Usual width of rings vary from $\frac{3}{8}$ in. (9.5 mm) and tubes to 1 in. (25.4 mm) for large pipes and tubes.
- (b) Usual spacing at bottom of welds varies from $\frac{3}{32}$ in. (2.4 mm) to $\frac{7}{32}$ in. (5.6 mm) diameter and thickness.

the piping of components having wall thicknesses different from the wall thicknesses of most of the components.

The inside surfaces of piping components to be joined by butt welding shall be aligned so that the misalignment at any point on the inside circumference does not exceed $\frac{1}{16}$ in. (1.6 mm) or one-fourth the nominal thickness of the component with the thinnest wall, whichever is smaller. [See Fig. 527.2.1-2, illustration (a).]

Where it is impossible to adhere to this limit by moving one component relative to the other, alignment shall be obtained by internally trimming the component, extending internally by building up with welding, by expanding, or by swaging. It is preferred that these methods of adjustment be applied to such an extent that the adjoining internal surfaces are approximately flush. [See Fig. 527.2.1-2, illustration (b).]

However, internal trimming shall not be applied to such an extent that it results in a piping component wall

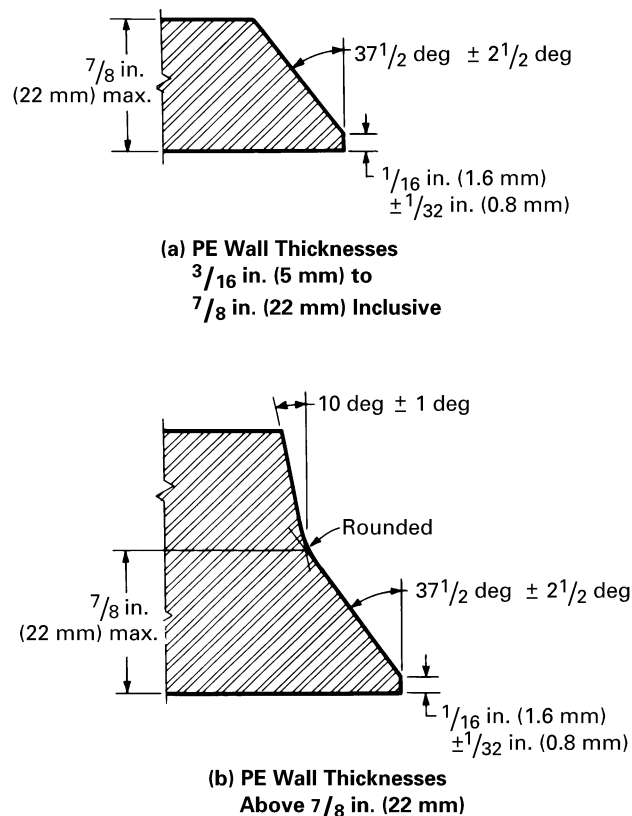
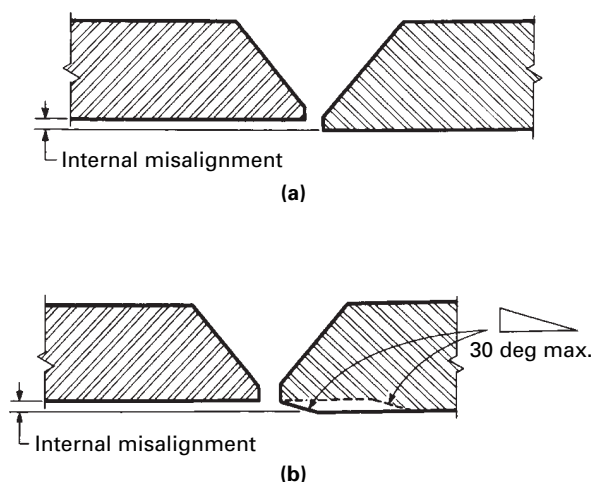
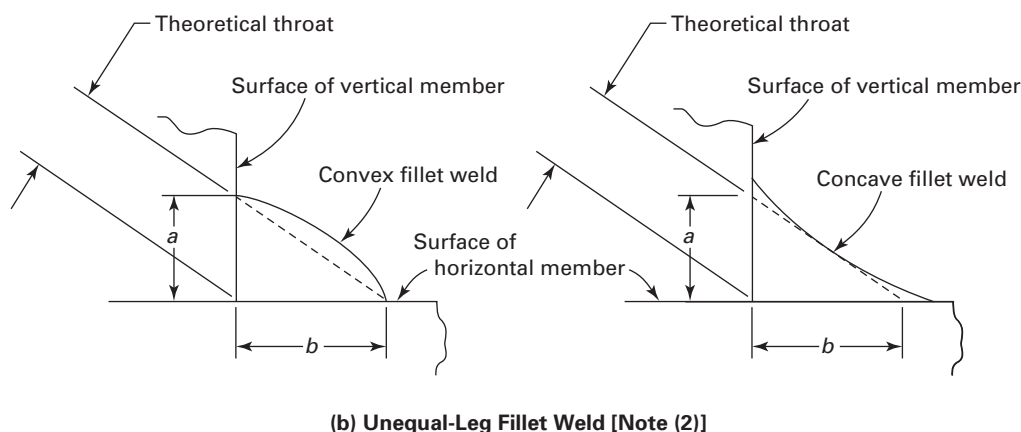
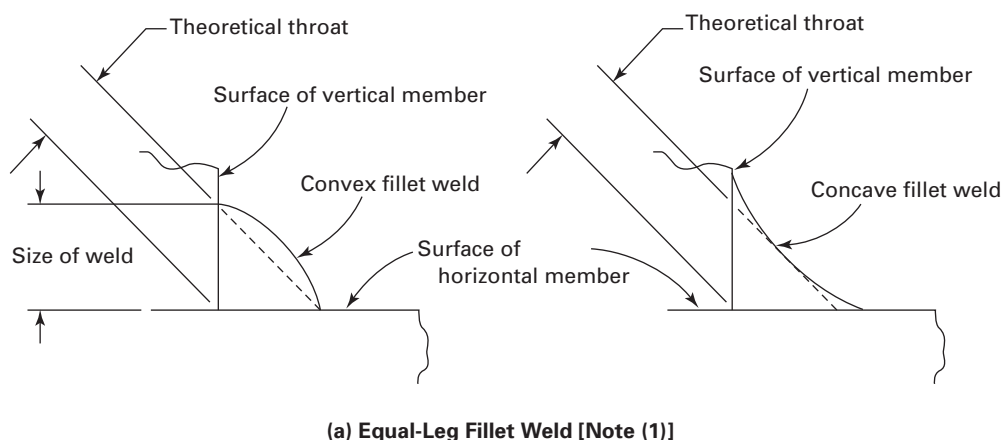
Fig. 527.2.1-1 Butt Welding End Preparation**Fig. 527.2.1-2 Internal Trimming for Butt Welding of Piping Components With Internal Misalignment**

Fig. 527.3.3-1 Fillet Weld Size**NOTES:**

- (1) The size of an equal-leg fillet weld is the leg length of the largest inscribed right isosceles triangle. Theoretical throat = $0.707 \times$ size of weld.
- (2) The size of an unequal-leg fillet weld is "a by b" for the largest right triangle that can be inscribed within the fillet cross-section.
Theoretical throat = $(a \times b) / (a^2 + b^2)^{0.5}$.

thickness less than the minimum design thickness plus corrosion and erosion allowance. Alignment shall be preserved during welding.

(d) *Spacing.* The root opening of the joint shall be as given in the welding procedure specification.

527.2.2 Fillet Welds. Piping components that are joined by means of fillet welds shall be prepared in accordance with applicable provisions and requirements of para. 527.2.1. Details of typical fillet welds are shown in Figs. 527.3.3-1, 527.3.3-2, and 527.3.3-3.

527.3 Procedure

527.3.1 General. No welding shall be done if the weld area is wet or exposed to high wind or at a metal temperature below 32°F (0°C).

527.3.2 Butt Welds

(a) Butt joints not made in accordance with the standards and specifications listed in Table 502.3.1 may be made with a single-V, double-V, or other suitable type of groove, with or without backing rings.

(b) Tack welds shall be made by a qualified welder or shall be removed. Tack welds that are not removed shall be made with a filler metal that is the same or equivalent to the electrode to be used for the first pass. Tack welds that have cracked shall be removed. Before assemblies are transferred from a location of fit-up to a location of welding, all joints shall have been adequately tack welded or partially welded, so as to prevent the cracking of these welds or the distortion of the assembly during such transfer. Piping that is to be welded in place

Fig. 527.3.3-2 Welding Details for Slip-On and Socket Welding Flanges, and Some Acceptable Types of Flange Attachment Welds

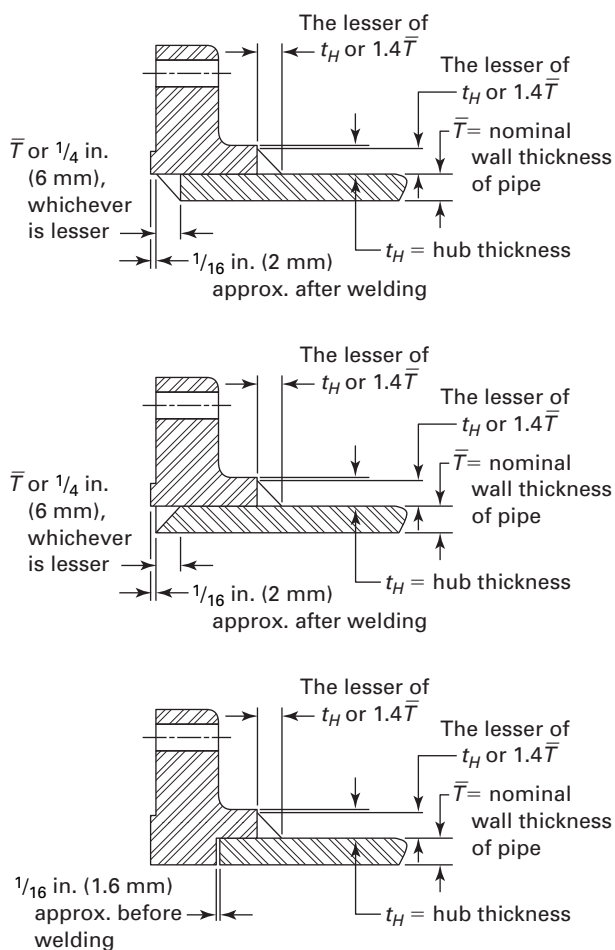
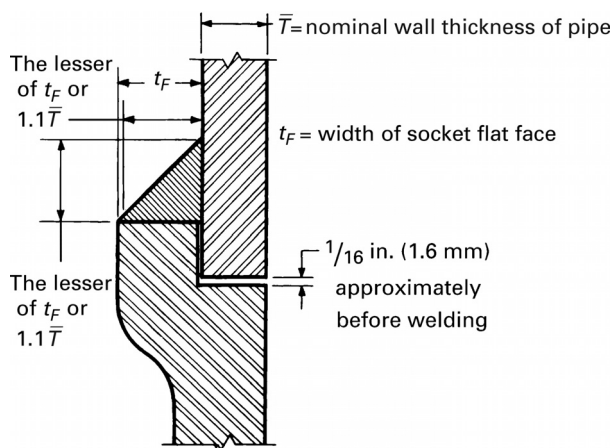


Fig. 527.3.3-3 Minimum Welding Dimensions Required for Socket Welding Components Other Than Flanges



shall be properly aligned and adequately supported during tack welding and subsequent welding in order to avoid the cracking of welds.

(c) If the external surfaces of the two components are not aligned, the weld shall be tapered between the surfaces.

(d) The welding shall be such as to assure that the following requirements are met:

(1) The external surface of butt welds shall be free from undercuts greater than $\frac{1}{32}$ in. (0.8 mm) deep, or one-half the weld reinforcement, whichever is smaller.

(2) The thickness of weld reinforcement shall not exceed the following considering the thinner component being joined:

Pipe Wall Thickness, in. (mm)	Reinforcement Thickness, in. (mm)
$\frac{1}{4}$ (6) and under	$\frac{1}{16}$ (1.6)
Over $\frac{1}{4}$ (6) through $\frac{1}{2}$ (13)	$\frac{3}{32}$ (2.4)
Over $\frac{1}{2}$ (13) through 1 (25)	$\frac{1}{8}$ (3)
Over 1 (25)	$\frac{3}{16}$ (5)

(3) *Cracks.* None permitted.

(4) *Incomplete Penetration.* The total joint penetration shall not be less than the thinner of the two components being joined, except to the extent that incomplete root penetration is permitted for girth welds only. The depth of incomplete root penetration at the weld root of girth welds shall not exceed $\frac{1}{32}$ in. (0.8 mm) or one-half the thickness of the weld reinforcement, whichever is smaller. The total length of such incomplete root penetration or at the root shall not exceed $1\frac{1}{2}$ in. (38 mm) in any 6 in. (152 mm) of weld length.

(5) *Lack of Fusion.* None permitted.

527.3.3 Socket and Fillet Welds. Fillet welds may vary from convex to concave. The size of a fillet weld is determined by the leg length of the largest inscribed right angle triangle as shown in Fig. 527.3.3-1. Typical fillet weld details for slip-on flanges and socket welding components are shown in Figs. 527.3.3-2 and 527.3.3-3. The limitations as to imperfections of these socket and fillet welds shall be as set forth in para. 527.3.2(d) for butt welds.

527.3.4 Seal Welds. Where seal welding of threaded joints is performed, external threads shall be entirely covered by the seal weld. Seal welding shall be done by qualified welders.

527.3.5 Welded Branch Connections

(a) Figures 527.3.5-1, 527.3.5-2, and 527.3.5-3 show typical details of branch connections, with and without added reinforcement. However, no attempt has been made to show all acceptable types of construction, and the fact that a certain type of construction is illustrated does not indicate that it is recommended over other

Fig. 527.3.5-1 Typical Welded Branch Connection Without Additional Reinforcement

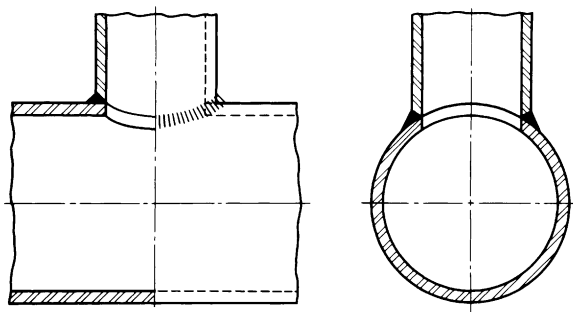


Fig. 527.3.5-2 Typical Welded Branch Connection With Additional Reinforcement

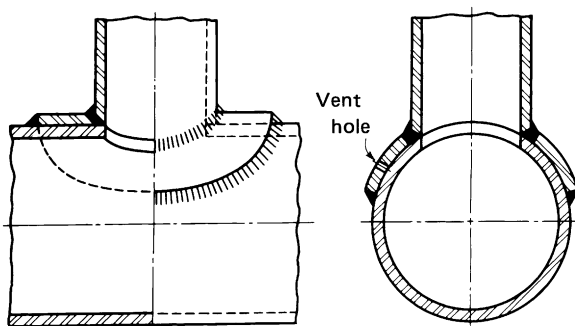
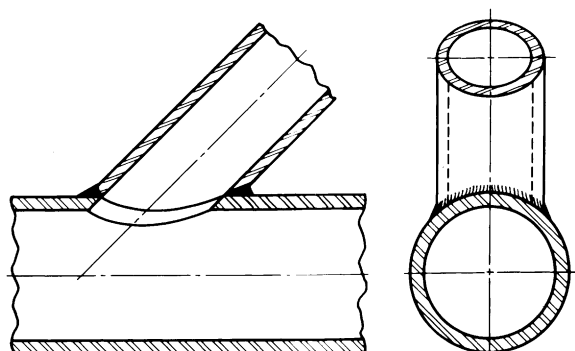


Fig. 527.3.5-3 Typical Welded Angular Branch Connection Without Additional Reinforcement



types not illustrated. Whenever possible, branch connections shall be made in such a manner that the longitudinal seam of welded pipe is not pierced.

(b) Figure 527.3.5-4 shows basic types of weld attachments used in the fabrication of branch connections. The location and minimum size of these attachment welds shall conform to the requirements of this paragraph. Welds shall be calculated in accordance with para. 504.3.1 but shall be not less than the sizes shown in Fig. 527.3.5-4.

The notations and symbols used in this paragraph and in Fig. 527.3.5-4 are as follows:

\bar{T}_b = nominal wall thickness of branch pipe, in. (mm)

t_c = $0.7\bar{T}_b$ and not less than $\frac{1}{4}$ in. (6 mm) except on thin material $1.4\bar{T}_b$ is acceptable

t_e = nominal thickness of reinforcing element (ring or saddle), in. (mm) ($t_e = 0$ if there is no added reinforcement)

t_{\min} = t_e or \bar{T}_b , whichever is smaller

(c) Branch connections (including specially made integrally reinforced branch connection fittings) that abut the outside surface of the run (header) wall, or that are inserted through an opening cut in the run (header) wall, shall have opening and branch contour where necessary to provide a good fit and shall be attached by means of completely penetrated groove welds. The completely penetrated groove welds shall be finished with cover fillet welds having a minimum throat dimension not less than t_c . [See Fig. 527.3.5-4, illustrations (a) and (b).] The limitations as to imperfection of these groove welds shall be as set forth in para. 527.3.2(d) for butt welds.

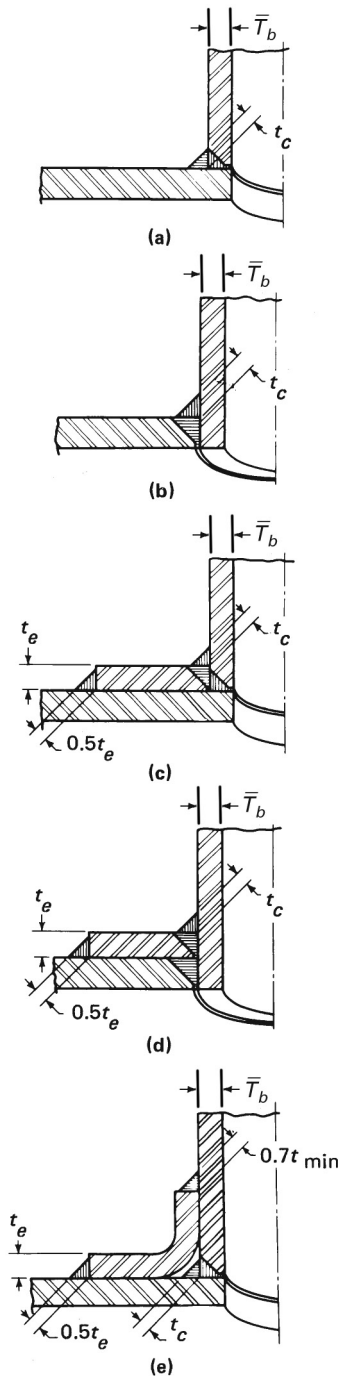
(d) In branch connections having reinforcement pads or saddles, the reinforcement shall be attached by welds at the outer edge and at the branch periphery as follows:

(1) If the weld joining the added reinforcement to the branch is a completely penetrated groove weld, it shall be finished with a cover fillet weld having a minimum throat dimension not less than t_c ; the weld at the outer edge, joining the added reinforcement to the run (header), shall be a fillet weld with a minimum throat dimension of $0.5t_e$. [See Fig. 527.3.5-4, illustrations (c) and (d).]

(2) If the weld joining the added reinforcement to the branch is a fillet weld, the throat dimension shall not be less than $0.7t_{\min}$. [See Fig. 527.3.5-4, illustration (e).] The weld at the outer edge joining the outer reinforcement to the run (header) shall also be a fillet weld with a minimum throat dimension of $0.5t_c$.

(e) When rings or saddles are used, a vent hole shall be provided (at the side and not at the crotch) in the ring or saddle to reveal leakage in the weld between branch and main run and to provide venting during welding and heat treating operations. Rings or saddles may be made in more than the one piece if the joints

Fig. 527.3.5-4 Some Acceptable Types of Welded Branch Attachment Details Showing Minimum Acceptable Welds



GENERAL NOTE: Weld dimensions may be larger than the minimum values shown here.

between the pieces have adequate strength and if each piece is provided with a vent hole. A good fit shall be provided between reinforcing rings or saddles and the parts to which they are attached.

527.3.6 Welded Flat Plate Closures.

Figures 527.3.6-1 and 527.3.6-2 show acceptable and unacceptable welds for flat plate closures in pipe. See para. 504.4.2 for nomenclature.

527.3.7 Heat Treatment for Welds. Heat treatment of welds shall be in accordance with section 531.

527.4 Responsibility

Each employer is responsible for

(a) the welding and brazing performed by personnel of his organization

(b) conducting the qualification tests required to qualify the Welding Procedure Specifications (WPSs) and Brazing Procedure Specifications (BPSs) used by personnel in his organization, except as provided in para. 527.4.3

(c) conducting the qualification tests required to qualify the welders and welding operators, except as provided in para. 527.4.4

527.4.1 Qualification Requirements. WPSs and BPSs to be followed in production welding shall be prepared and qualified. Welders, brazers, and operators shall be qualified as required by Section IX of the ASME Boiler and Pressure Vessel Code, except as modified in paras. 527.4.2, 527.4.3, and 527.4.4.

527.4.2 Standard Welding Procedures. Standard Welding Procedure Specifications (SWPSs) published by the American Welding Society and listed in Appendix E of ASME Section IX are permitted within the limitations established by Article V of ASME Section IX. Before being used, the employer shall either qualify one welder following each SWPS or make demonstration welds as provided by Section IX, Article V.

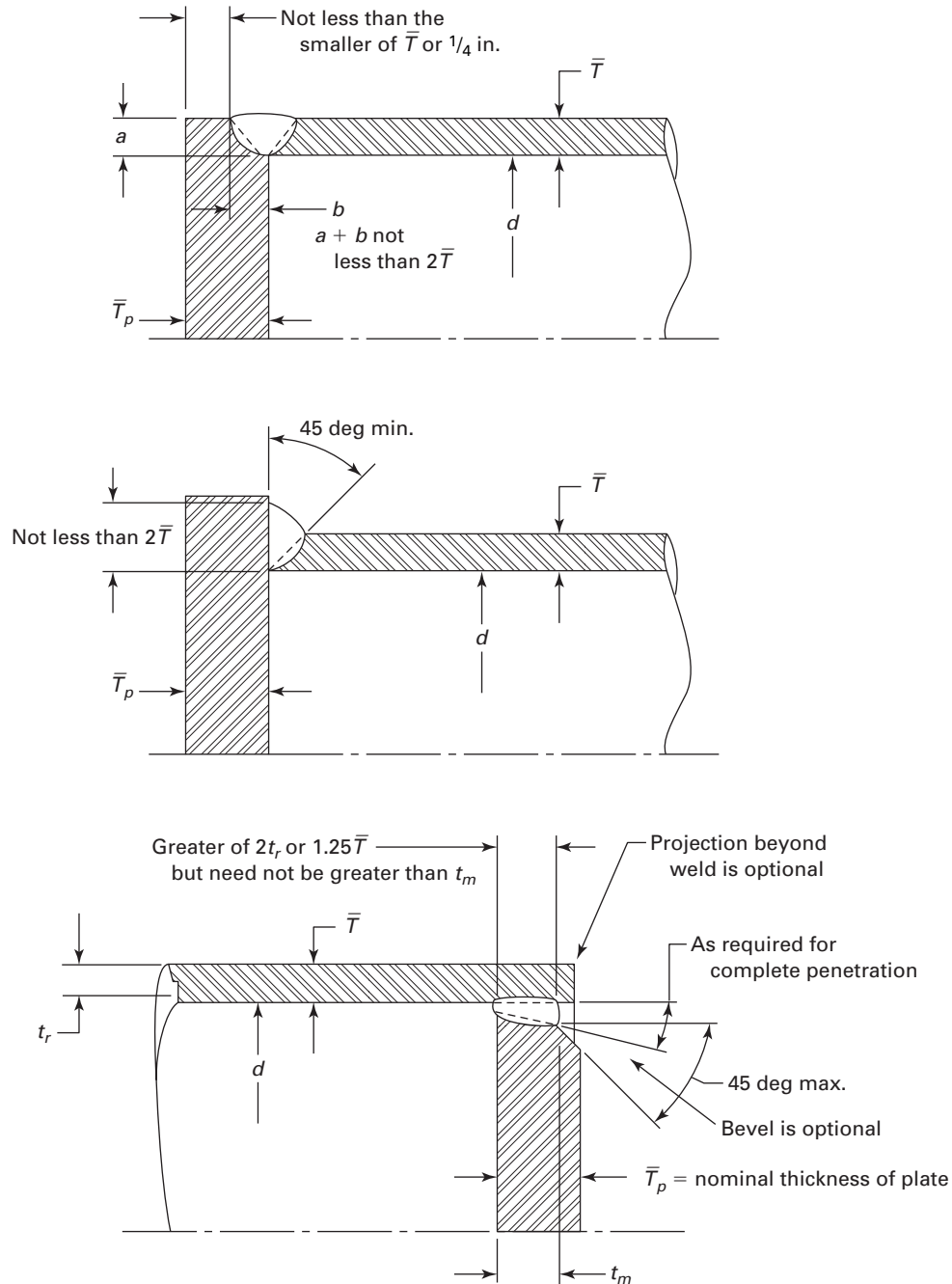
527.4.3 Procedure Qualification by Others. In order to avoid duplication of effort and subject to the approval of the owner, WPSs and BPSs qualified by a technically competent group or agency may be used provided the following are met:

(a) The WPS or BPS meet the requirements of ASME Section IX and any additional qualification requirements of this Code.

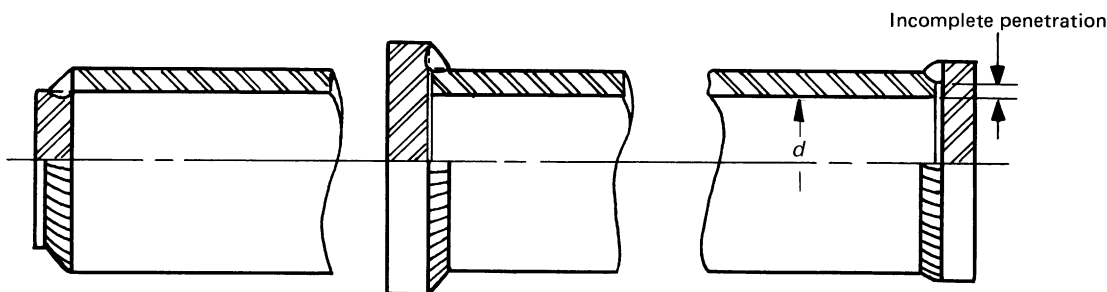
(b) The employer has qualified at least one welder or welding operator following each WPS or BPS.

(c) The employer's business name shall be shown on each WPS or BPS and on each qualification record. In addition, qualification records shall be signed and dated by the employer, thereby accepting responsibility for the qualifications performed by others.

527.4.4 Performance Qualification by Others. In order to avoid duplication of effort and subject to the

Fig. 527.3.6-1 Acceptable Welds for Flat Plate Closures

GENERAL NOTE: For other acceptable welds, see ASME BPV Code, Section VIII, Division 1. For nomenclature, see para. 504.4.2.

Fig. 527.3.6-2 Unacceptable Welds for Flat Plate Closures

approval of the owner, an employer may accept the performance qualification of a welder, brazer, or operator made by a previous employer. This acceptance is limited to performance qualifications that were made on pipe or tube test coupons. The new employer shall have the WPS or BPS that was followed during qualification or an equivalent WPS or BPS that is within the limits of the essential variables set forth in ASME Section IX. An employer accepting such qualification tests shall obtain a copy of the performance qualification test record from the previous employer. The record shall show the name of the employer by whom the welder, brazer, or operator was qualified and the date of that qualification. A record shall be available showing use of each process at no less than 6-mo intervals from the date of qualification with that process to the date that the qualification record is transferred to the new employer. The new employer's business name shall be shown on the qualification record, and it shall be signed and dated by the employer, thereby accepting responsibility for the qualifications performed by others.

527.5 Qualification Records

The employer shall maintain copies of the procedure and performance qualification records specified by ASME Section IX, which shall be available to the owner or the owner's agent and the Inspector at the location where welding is being done.

After completing a welded joint, the welder or welding operator shall identify it as his or her work by applying his or her assigned letter, number, or symbol as a permanent record in a manner specified by his or her employer.

527.6 Defect Repairs

All defects in welds requiring repair shall be removed by flame or arc gouging, grinding, chipping, or machining. All repair welds shall be preheated and postheated as originally required, and the basic principles of the same welding procedure initially used shall be employed as far as applicable. This recognizes that the cavity of the weld may not be of the same contour or dimensions as the original joint.

Preheating may be required on certain alloy materials of the air hardening type in order to prevent surface checking or cracking adjacent to the flame or arc gouged surface.

528 BRAZING AND SOLDERING

528.1 Brazing Materials

528.1.1 Filler Metal. The filler metal used in brazing shall be a nonferrous metal or alloy having a melting point above 840°F (449°C) and below that of the metal being joined. The filler metal shall melt and flow freely with the desired temperature range and, in conjunction with a suitable flux or controlled atmosphere, shall wet and adhere to the surfaces to be joined. Brazing material containing other than residual phosphorus as an impurity is prohibited on joints made of ferrous materials.

528.1.2 Flux. Fluxes that are fluid and chemically active at the brazing temperature shall be used when necessary to prevent oxidation of the filler metal and the surfaces to be joined and to promote free flowing of the filler metal.

528.2 Brazing Preparation and Procedures

528.2.1 Surface and Joint Preparation. The surfaces to be brazed shall be clean and free of grease, oxides, paint, scale, and dirt of any kind, except as noted in para. 528.2.5. Any suitable chemical or mechanical cleaning method may be used to provide a clean wettable surface for brazing. The procedure for joints covered in section 517 shall be as outlined in the Copper Tube Handbook, published by the Copper Development Association.

528.2.2 Joint Clearance. The tube shall meet the dimensional requirements of ASTM B280, and fittings shall meet the dimensional requirements of ASME B16.50. (13)

528.2.3 Heating. The joint shall be brought uniformly to brazing temperature in as short a time as possible to minimize oxidation.

528.2.4 Brazing Qualification. The qualification of brazing procedures and brazing operators shall be in

accordance with the requirements of Part QB, Section IX, ASME BPV Code.

528.2.5 Oil. Oil used for lubrication during mechanical expansion of tubing in coils need not be removed provided that sample(s) used for procedure qualification were in a similar condition and that the requirements of para. 528.2.4 are met.

528.3 Soldering Materials

528.3.1 Solder. The solder metal used in soldering shall be a nonferrous metal or alloy having a solidus between 400°F (204°C) and 840°F (449°C) and below that of the metal being joined. The solder shall melt and flow freely within the desired temperature range and, in conjunction with a suitable flux, ASTM B813, shall wet and adhere to the surface to be joined.

528.3.2 Flux. Fluxes that are fluid and chemically active at the soldering temperature shall be used to prevent oxidation of the solder or filler metal and the surfaces to be joined and to promote the free flowing of the solder.

528.4 Soldering Preparation and Procedure

528.4.1 Surface Preparation. The surfaces to be soldered shall be clean and free from grease, oxides, paint, scale, and dirt of any kind. Any suitable chemical or mechanical cleaning method may be used to provide a clean wettable surface for soldering.

- (13) **528.4.2 Joint Clearance.** The tube shall meet the dimensional requirements of ASTM B280, and fittings shall meet the dimensional requirements of ASME B16.18 or ASME B16.22, as applicable.

528.4.3 Heating. The joint shall be brought to soldering temperature in as short a time as possible to minimize oxidation without localized underheating or overheating.

528.4.4 Procedure. Solderers shall follow the procedure as outlined in ASTM B828.

529 BENDING — HOT AND COLD

529.1 Radii of Bends

Pipe and tube may be bent to any radius that will result in a bend surface free of cracks and substantially free of buckles. Out-of-roundness and minimum finished thickness of bend shall be such that design requirements of section 504 are met. This shall not prohibit the use of bends designed as creased or corrugated.

529.2 Procedure

Pipe and tube may be bent by any hot or cold method permissible by radii and material characteristics of the sizes being bent. Bending shall be done within a temperature range consistent with material characteristics and

end use. Postheat treatment may be used to achieve this result.

529.3 Heat Treatment

Heat treatment shall be in accordance with paras. 531.1, 531.3.2, 531.3.3, and 531.3.5.

530 FORMING

530.1 Procedure

Piping components may be formed by any suitable method, including hot or cold pressing, rolling, forging, hammering, spinning, or drawing. Forming shall be done within a temperature range consistent with material characteristics and end use. Postheat treatment may be used to achieve this result.

530.2 Heat Treatment

Heat treatment shall be in accordance with paras. 531.1, 531.3.2, 531.3.3, and 531.3.5.

531 HEAT TREATMENT

531.1 Heating and Cooling Method

Heat treatment may be accomplished by a suitable heating method that will provide the required metal temperature, metal temperature uniformity, and temperature control, such as an enclosed furnace, local fuel firing, electric resistance, or electric induction. Cooling may be accomplished in a furnace, in air, with the aid of local thermal control, with the application of heat or insulation, or in any other manner required to achieve the desired cooling rate.

531.2 Preheating

531.2.1 Unless otherwise specified in the qualified procedure specification, preheating for welds in materials shall be as stipulated in Table 531.2.1. (See Section IX, ASME BPV Code, for P-Numbers of materials.)

531.2.2 When welding dissimilar metals having different preheat requirements, the preheat temperature shall be that established in the welding procedure specification.

531.2.3 The preheat temperature shall be checked by use of temperature indicating crayons, thermocouple pyrometers, or other suitable methods to ensure that the required preheat temperature is obtained prior to and maintained during the welding operation.

531.3 Postheat Treatment

531.3.1 Unless other postheat treatment is stipulated in the welding procedure to meet the requirements of para. 531.3.2, post-heat treatment for the welds (except seal welds of threaded joints for P-Nos. 1 and 3 materials) shall be as stipulated in Table 531.2.1. Seal welds of

Table 531.2.1 Heat Treatment of Welds

ASME BPV Code, Section IX, P-Nos.	Material	Preheat Required		Postheat Treatment Requirement [Notes (4) and (5)]		
		Minimum Wall [Notes (1) and (2)]	Minimum Temperature, °F (°C) [Note (3)]	Minimum Wall and Other [Notes (1) and (2)]	Temperature, °F (°C) [Notes (6)–(8)]	
					Min.	Max.
1	Mild steel	None	None required	Over $\frac{3}{4}$ in. (19 mm)	1,100 (595)	1,200 (650)
1	Mild steel	All walls	175 (80)	Over $\frac{3}{4}$ in. (19 mm)	1,100 (595)	1,200 (650)
3 [Note (9)]	Carbon moly $\frac{1}{2}$ Cr– $\frac{1}{2}$ Mo	All walls	175 (80)	Over $\frac{1}{2}$ in. (13 mm)	1,100 (650)	1,300 (705)
4 [Note (9)]	Cr– $\frac{1}{2}$ Mo $1\frac{1}{4}$ Cr– $\frac{1}{2}$ Mo	Up to $\frac{3}{4}$ in. (19 mm) Over $\frac{3}{4}$ in. (19 mm)	300 (150) 400 (205)	Over $\frac{1}{2}$ in. (13 mm) or over 4 in. (DN 100) nominal size; over 0.150 maximum	1,300 (705)	1,400 (760)
5 [Note (9)]	$2\frac{1}{2}$ Cr–Mo	Up to $\frac{3}{4}$ in. (19 mm) Over $\frac{3}{4}$ in. (19 mm)	300 (150) 400 (205)	Over $1\frac{1}{2}$ in. (13 mm) or over 4 in. (DN 100) nominal size, over 0.150 maximum	1,300 (705)	1,425 (775)
5 [Note (10)]	5Cr– $\frac{1}{2}$ Mo 7Cr– $\frac{1}{2}$ Mo 9Cr–Mo	Up to $\frac{3}{4}$ in. (19 mm) Over $\frac{3}{4}$ in. (19 mm)	300 (150) 400 (205)	All walls	1,300 (705)	1,425 (775)
6	High alloy mar- tensitic TP-410 (12Cr)	All walls	300 (150) [Note (11)]	All walls	1,400 (760)	1,500 (825)
8	High alloy aus- tenitic	All walls	None required	All walls	None required	...
9	A333 $2\frac{1}{2}$ Ni and $3\frac{1}{2}$ Ni	All walls	300 (150)	Over $\frac{5}{8}$ in. (16 mm)	1,100 (595)	1,200 (650)

NOTES:

- (1) Wall thickness is defined as the thicker of the two abutting ends after end preparation including inside diameter machining.
- (2) The thickness of socket, fillet, and seal welds is defined as the throat thickness for pressure and nonpressure retaining welds.
- (3) Preheat temperatures shall be checked by use of temperature indicating crayons, thermocouple pyrometers, or other suitable methods.
- (4) Not applicable to dissimilar metal welds.
- (5) For materials not listed, preheat and postheat treatment shall be in accordance with the qualified Welding Procedure Specification.
- (6) Postheat treatment temperatures shall be checked by use of thermocouple pyrometers or other suitable means.
- (7) (a) The heating rate for furnace, gas, electric resistance, and other surface heating method shall be
 - (1) 600°F (316°C)/hr maximum for thickness 2 in. (51 mm) and under
 - (2) 600°F (316°C)/hr divided by one half the thickness for thickness over 2 in. (51 mm)
 (b) The heating rate for induction heating shall be
 - (1) 600°F (316°C)/hr maximum for thickness less than $1\frac{1}{2}$ in. (38 mm) at 60 Hz and 400 Hz
 - (2) 500°F (260°C)/hr maximum at 60 Hz and 400°F (205°C)/hr maximum at 400 Hz for thickness $1\frac{1}{2}$ in. (38 mm) and over

Table 531.2.1 Heat Treatment of Welds (Cont'd)

ASME BPV Code, Section IX, P-Nos.	Postheat Treatment Requirement [Notes (4) and (5)]		Other Limiting, Maximum, or Contingent Conditions, or Other	Approximate Lower Critical Temperature, °F (°C)
	Time Cycle			
	hr/in. (25 mm) of Wall [Notes (1) and (2)]	Minimum Time, hr, Within Range		
1	1	1	No preheat for 0.30C maximum or 0.65 maximum C equivalent per applicable material specification [Note (12)]	1,375 (745)
1	1	1	Preheat required above 0.30C maximum and above 0.65 maximum C equivalent as per applicable material speci- fication [Note (12)]	...
3 [Note (9)]	1	1	Brinell hardness 215 maximum [Note (10)]	1,400 (760) (¹ / ₂ Cr– ¹ / ₂ Mo)
4 [Note (9)]	1	1	Lower preheat temperatures may apply for inert gas tung- sten arc root pass welding; Brinell hardness 215 maxi- mum [Note (10)]	1,430 (775) (Cr– ¹ / ₂ Mo) 1,430 (775) (¹ / ₄ Cr– ¹ / ₂ Mo)
5 [Note (9)]	1	1	Lower preheat temperatures may apply for inert gas tung- sten arc root pass welding; Brinell hardness 241 maxi- mum [Note (10)]	1,400 (805) (² / ₂ Cr–Mo)
5 [Note (10)]	1	2	Lower preheat temperatures may apply for inert gas tung- sten arc root pass welding; Brinell hardness 241 maxi- mum [Note (10)]	1,515 (825) (5Cr– ¹ / ₂ Mo) 1,515 (825) (7Cr– ¹ / ₂ Mo) 1,515 (825) (9Cr–Mo)
6	1	2	Note (10)	12Cr
8	...	...	...	...
9	¹ / ₂	1	...	...

- (8) Local postheat treatment of butt welded joints shall be performed on a circumferential band of the pipe. The minimum width of this band, centered on the weld, shall be the width of the weld plus 2 in. (51 mm). Local postheat treatment of welded branch connections shall be performed by heating a circumferential band of the pipe to which the branch is welded. The width of the heated band shall extend at least 1 in. (25 mm) beyond the weld joining the branch.
- (9) Welding on P-Nos. 3, 4, and 5 with 3Cr maximum may only be interrupted provided
- a minimum of at least $\frac{3}{8}$ in. (10 mm) thickness of weld deposit or 25% of welding groove is filled, whichever is greater
 - the weld is allowed to cool slowly to room temperature
 - the required preheat must be resumed before welding is continued
- (10) The maximum Brinell hardness of welds in and of materials P-Nos. 3 through 6 shall be as listed. A minimum of 10% of welds that are furnace heat treated, and 100% of welds that are locally heat treated, shall be Brinell hardness tested at a point in the base metal as near as practical to the edge of weld metal and in the weld metal.
- (11) 600°F (316°C) maximum interpass temperature, Brinell hardness 241 maximum.
- (12) 0.65 maximum C equivalent is defined as %C $1\frac{1}{4}$ % Mn.

threaded joints for P-Nos. 1 and 3 materials do not require postheat treatment.

531.3.2 Postheat treatment shall be performed as necessary to restore physical property requirements (such as strength, ductility, and corrosion resistance, or a combination thereof) with respect to material design, and end use requirements. Physical property requirements shall determine the treatment to be performed, such as stress relief, anneal, or normalize.

531.3.3 The heating method selected for restoration of physical properties desired for parts of any assembly shall be such as will accomplish this result without adversely affecting other components. Heating a fabricated assembly as a complete unit is usually desirable. However, the size or shape of the unit or the adverse effect of a desired heat treatment on one or more components where dissimilar materials are involved may dictate alternative procedures such as heating a section of the assembly before the attachment of others, or local circumferential band heating of welded joints in accordance with this section. The hardness limitations of Table 531.2.1 are mandatory regardless of the heat treatment used.

531.3.4 Postheat treatment of welded joints between dissimilar metals having different postheat requirements shall be established in the welding procedure specification.

531.3.5 Postheat treatment temperatures shall be checked by the use of thermocouple pyrometers or other suitable equipment to assure that the desired treatment cycle has been accomplished.

531.3.6 If welding is interrupted before completed and allowed to cool prior to postheat treatment, adequate heat treatment or controlled rate of cooling shall be effected to assure that no detrimental effect to the work shall result.

531.3.7 Postheat treatment of welds shall be compatible with the analysis of the base materials being joined and the weld deposit. Postheat treatment of welded joints shall be established in the welding procedure specification.

531.3.8 Where Table 531.2.1 indicates thickness as a factor in determining the requirement for post-heat treatment, nominal pipe wall thickness of the thicker pipe of the governing material that governs the weld size is intended. However, for lugs, supports, or other external nonpressure-containing attachments, the throat thickness of the attachment welds shall govern for those welds.

531.3.9 Local Postheat Treatment

(a) Local postheat treatment of welded joints shall require the entire band to be brought up to uniform temperature over the circumference of the heated pipe

section with a gradual diminishing of temperature outward from the band.

(b) When local heat treating a circumferential weld, the minimum width of the band centered on the weld shall be the larger of the following:

(1) twice the width of the weld reinforcement

(2) width of weld reinforcement plus 2 in. (51 mm)

(c) When local heat treating welded branch connections or other attachments, a circumferential band of the pipe to which the branch or attachment is welded shall be heated to the desired temperature. The width of this band shall extend at least 1 in. (25 mm) beyond the weld joining the branch or attachment to the pipe.

535 ASSEMBLY

535.1 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 all requirements of this Code and with the specified requirements of the engineering design.

535.2 Bolting Procedure

535.2.1 All flanged joints shall be fitted up so that the gasket contact faces bear uniformly on the gasket. The joints shall then be progressively tightened in a diametrically staggered pattern.

535.2.2 In bolting gasketed flanged joints, the gasket shall be properly compressed in accordance with the design principle applicable to the type of gasket used.

535.2.3 Steel-to-cast-iron flanged joints shall be assembled with care to prevent damage to the cast-iron flange. See paras. 508.3 and 508.5.

535.2.4 Bolt threads shall extend completely through the mating nut.

535.2.5 In refacing flanges, dimensions must not be reduced below those shown in ASME B16.5.

535.3 Threaded Piping

535.3.1 Threaded joints that are to be seal welded shall be made up without any thread compound.

535.3.2 Any compound used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with the service fluid.

535.3.3 Threaded joints in ferrous metal pipe shall conform to ASME B1.20.1. Exposed threads should be coated to inhibit corrosion. See section 514.

535.3.4 Threaded joints in copper or brass pipe of standard size shall conform to ASME B16.15.

535.3.5 All threaded joints shall be made up tight. Backing off for alignment is not permitted.

535.4 Welded Joints

All welded joints shall be assembled in accordance with section 527.

535.5 Brazed Sleeve Joints

All brazed sleeve joints shall be assembled in accordance with paras. 528.1 through 528.2.

535.6 Soldered Sleeve Joints

All soldered sleeve joints shall be assembled in accordance with paras. 528.3 and 528.4.

535.7 Flare Type Fitting Joints

Ends of tubing shall be cut square and all burrs removed. No scratches, breaks, or other mars at sealing surface of flare shall be permitted. Assembly shall be performed in accordance with the fitting manufacturer's recommendation.

535.8 Flareless and Compression-Type Fitting Joints

Ends of tubing shall be cut square and all burrs removed. No scratches, breaks, or mars at the outside of the tube at fitting shall be permitted. Flareless and

compression-type fittings shall be of a design in which the gripping member or sleeve shall grip or bite into the outer surface of the tube with sufficient strength to hold the tube against pressure, but without appreciably distorting the inside tube diameter. The gripping member shall also form a pressure seal against the fitting body. Assembly shall be performed in accordance with the fitting manufacturer's recommendations.

535.9 Assembly of Hangers

Threaded hanger connections shall be prevented from being loosened by vibration or by deforming threads by use of double nuts, by use of self-locking nuts, or by other means. Where hanger rods carry loads close to the maximum allowed by para. 520.1.3(a) and pass through and transfer their load to structural steel by means of a nut threaded on the rod, assembly shall be such that the load is not carried on one corner of the nut.

535.10 Piping Identification

The owner should give consideration to the need to mark the piping with regard to contents. ASME A13.1, Scheme for Identification of Piping Systems, may be used for guidance.

Chapter VI

Examination, Inspection, and Testing

536 EXAMINATION

536.1 Definition

Examination applies to visual examination and to nondestructive examination when specified in this Code or in the engineering design. These quality control functions are performed by an examiner employed by the manufacturer, fabricator, or erector.

536.2 Responsibility

The manufacturer, fabricator, or erector is responsible for

- (a) providing materials, components, and workmanship in accordance with the requirements of the Code
- (b) performing the required examinations
- (c) performing the supplemental examinations when specified in the engineering design
- (d) preparing suitable records of materials, examination, and tests for the inspector's use when required in the Code

536.3 Examination Personnel Qualification and Certification

Examiners shall have training and experience commensurate with the needs of the specified examinations. For this purpose, SNT-TC-1A, Recommended Practice for Nondestructive Testing Personnel Qualification and Certification, may be used as a guide. The owner shall determine whether examination by other than personnel performing the work is required.

536.4 Required Examination

536.4.1 Visual Examination. Prior to operation, visual examination is required in accordance with this paragraph for all refrigerant and secondary coolant piping.

(a) *Definition.* Visual examination is the observation of whatever portions of components, joints, and other piping elements that are exposed to such observation either 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, mechanical joints, supports, assembly, and erection.

(b) *Requirements.* Visual examination shall be performed, as necessary, during the fabrication and erection of piping components to provide verification that the design and procedure specifications are met.

(c) *Acceptance Criteria.* The acceptance criteria shall be as stated in Chapter V of this Code; section 527 for welded joints, section 528 for brazed and soldered joints, and section 535 for other mechanical joints and assembly of hangers.

536.4.2 Additional Examination for Groups A3 and B3 Piping. In addition to visual examination per para. 536.4.1, the following examinations are required for Groups A3 and B3 refrigerant piping:

(a) Not less than 5% of circumferential butt and miter groove welds shall be fully examined by random radiography. Welds to be examined shall be selected to ensure that the work product of each welder or welding operator doing production welding is included. Welds to be examined shall be selected to maximize coverage of intersections with longitudinal joints. At least 1½ in. (38 mm) of the longitudinal welds shall be examined. In-process examination in accordance with para. 536.6.2 may be substituted for all or part of radiographic examination on a weld-for-weld basis if specified in the engineering design and specifically approved by the Inspector.

(b) Not less than 5% of all brazed joints shall be examined by in-process examination in accordance with para. 536.6.2. The joints to be examined shall be selected to ensure that the work of each brazer making production joints is included.

536.4.3 Defects

(a) If a defect (i.e., an imperfection of a type or magnitude exceeding the acceptance criteria of this Code) is revealed in an examination per para. 536.4.2, two additional items of the same kind (if welded or brazed joints, by the same welder, welding operator or brazer) shall be given the same type of examination; and

(b) if the items examined as required in para. 536.4.3(a) are acceptable, the defective item shall be repaired or replaced and reexamined as specified in para. 536.6.1(a) and all items represented by this additional examination shall be accepted; but

(c) if any of the items examined as required in para. 536.4.3(a) reveals a defect, two further samples of the same kind shall be examined for each defective item found by the examination; and

(d) if the items examined as required by para. 536.4.3(c) are acceptable, the defective item(s) shall be repaired or replaced and reexamined as specified in para. 536.6.1(a) and all items represented by this additional examination shall be accepted; but

(e) if any of the items examined as required by para. 536.4.3(c) reveals a defect, all items represented by the progressive examination shall be either

(1) repaired or replaced and reexamined as specified in para. 536.6.1(a); or

(2) fully examined and repaired or replaced and reexamined as specified in para. 536.6.1(a).

536.5 Supplementary Examination

Any of the types of examination described in section 536 may be specified in the engineering design to supplement the examination required by para. 536.4. The extent of supplementary examination and the acceptance criteria shall be specified in the engineering design.

536.6 Types of Examinations

536.6.1 General

(a) Items examined with one or more defects shall be repaired or replaced. The repaired or replaced work shall be examined by the same methods and to the same extent, and shall meet the same acceptance criteria as required for the original work.

(b) Welds and joints not included in the examinations required by para. 536.4 shall be deemed acceptable when they meet the testing requirements of section 538.

536.6.2 In-Process Examination. In-process examination comprises visual 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) external condition of the root pass after cleaning, and internal where accessible, 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

(13) 536.6.3 Radiographic Examination

(a) *Definitions.* The following definitions apply to radiography required by this Code:

(1) *Radiography* applies only to circumferential butt welds and miter groove welds unless otherwise specified.

(2) *100% Radiography* requires complete radiography of all of a specified kind of item in a designated lot of piping.

(3) *Random Radiography* requires complete radiography of a percent of specified kind of item in a designated lot of piping.

(4) *Spot Radiography* requires a single exposure radiograph at a specified point within the weld of a percent of a specified kind of item in a designated lot of piping. For circumferential butt welds and miter groove welds the minimum requirement is one of the following:

(a) a single elliptical exposure encompassing the entire weld circumference for pipe up to NPS 2½ (DN 65)

(b) the lesser of 25% of the inside circumference or 6 in. (150 mm) for pipe greater than NPS 2½ (DN 65)

(c) a minimum of 6 in. (150 mm) of weld length for longitudinal welds

(b) *Method.* Radiographic examination shall be performed in accordance with Article 2 of Section V of the ASME BPV Code.

(c) *Acceptance Criteria.* The acceptance criteria shall be

(1) for Group A3 and B3 refrigerants, as specified for Normal Fluid Service in Table 341.3.2 of ASME B31.3

(2) for other than Group A3 and B3 refrigerants, as specified in para. 527.3.2(d)

536.6.4 Ultrasonic Examination

(13)

(a) *Method.* Ultrasonic examination of welds shall be performed in accordance with BPV Code, Section V, Article 4, except that the alternative specified in (a) and (b) below is permitted for basic calibration blocks specified in T-434.2.1 and T-434.3.

(1) When the basic calibration blocks have not received heat treatment in accordance with T-434.1.5, transfer methods shall be used to correlate the responses from the basic calibration block and the component. Transfer is accomplished by noting the difference between responses received from the same reference reflector in the basic calibration block and in the component and correcting for the difference.

(2) The reference reflector may be a V-notch (which must subsequently be removed), an angle beam search unit acting as a reflector, or any other reflector that will aid in accomplishing the transfer.

(3) When the transfer method is chosen as an alternative, it shall be used

(a) for sizes ≤ NPS 2 (DN 50), once in each 10 welded joints examined

(b) for sizes > NPS 2 (DN 500) and ≤ NPS 18 (DN 450), once in each 5 ft (1.5 m) of welding examined

(c) for sizes > NPS 18 (DN 450), once for each welded joint examined

(4) Each type of material and each size and wall thickness shall be considered separately in applying the

transfer method. In addition, the transfer method shall be used at least twice on each type of weld joint.

(5) The reference level for monitoring discontinuities shall be modified to reflect the transfer correction when the transfer method is used.

(b) *Acceptance Criteria.* The acceptance criteria shall be the same as para 536.6.3(c) for radiographic examination.

- (13) **536.6.5 Special Methods.** If a method not specified herein is to be used, it and its acceptance criteria shall be specified in the engineering design in enough detail to permit qualification for the necessary procedures and examiners.

537 INSPECTION

537.1 Definition

Inspection applies to functions performed by the owner's Inspector or the Inspector's Delegate.

537.2 Responsibility

Prior to operation, it is the owner's responsibility to inspect a piping system to the extent necessary to assure compliance with the engineering design, and with the material, fabrication, assembly, examination, and testing requirements of this Code. Systems shall be inspected visually after complete installation and before operation, except that parts of the system that would not be accessible after complete installation shall be inspected after completion of those parts.

537.3 Rights of Inspectors

The Inspector or Delegate shall have access to any place where work concerned with the piping is being performed. When the work is not performed on the owner's premises, the Inspector's access is subject to negotiation with the manufacturer or fabricator. This includes, but is not limited to, manufacture, fabrication, assembly, erection, examination, and testing of the piping. Inspectors shall have the right to review all records pertaining to the examination requirements of section 536.

537.4 Qualifications of the Owner's Inspector

The Inspector shall be designated by the owner. The Inspector (or Delegate) shall be an employee of the owner or of a company acting as the owner's agent. The Inspector (or Delegate) shall neither represent nor be an employee of the manufacturer, fabricator, or erector unless the owner is the manufacturer, fabricator, or erector. The Inspector (or Delegate) shall have at least 5 years' experience in the design, fabrication, examination, testing, or inspection of industrial piping.

538 TESTING

538.1 Testing Before Erection or Assembly

When system components (including compressors, pumps, heat exchangers, valves, gauges, regulators, pipe, tube, and fittings) have been pressure tested by the component manufacturer or assembler according to standards or applicable specifications, no further pressure testing of these components, other than leak testing, is required.

538.2 Preparation for Testing

All joints to be tested shall be exposed, unpainted, and free of rust, dirt, oil, and other foreign materials. Joints previously tested in accordance with this Code may be painted and insulated or covered.

538.3 Factory Testing of Refrigerant Piping

(a) All factory-assembled refrigerant piping of every system shall be tested and proved tight by the manufacturer to at least 110% of the design pressure for which it is rated.

(b) A pneumatic pressure test applied to the piping of each factory-assembled refrigerating system shall not exceed 130% of the design pressure of any component.

538.4 Field Testing of Refrigerant Piping

538.4.1 General Requirements. Refrigerant piping erected on the premises, except piping components that are factory tested, shall be pressure tested and leak tested after installation and before operation.

538.4.2 Pressure Test

(a) Piping shall be examined before pressure is applied to ensure that it is tightly connected. All items not subject to the pressure test shall be disconnected or isolated by valves, blanks, plugs, or other suitable means.

(b) A preliminary test at a gauge pressure of up to 25 psig (170 kPa) may be applied, prior to other testing, as a means of locating major leaks.

(c) The temperature of the piping system during testing shall be above the ductile-brittle transition temperature.

CAUTION: Take measures to protect personnel from the potential of rupture of piping components during pneumatic testing of systems.

(d) The means used to furnish the test pressure shall have either a pressure limiting device or a pressure reducing device and a pressure relief device and gage on the outlet side. The pressure relief device shall be set above the test pressure, but low enough to prevent permanent deformation of any of the system components.

(e) The pneumatic test pressure used shall be at least 110% of the design pressure. The test pressure shall not

exceed 130% of the design pressure of any component in the system.

(f) For large systems that are not completely visible to the testing operator, the pressure in the system shall be gradually increased to 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 test pressure shall be continuously maintained for at least 10 min. It may then be reduced to the leak test pressure per para. 538.4.3(c).

(g) Mechanical joints at which blanks or plugs are inserted to blank off or facilitate removal of equipment during the pressure test need not be pressure tested after removal of the blank or plug provided the joint passes a subsequent leak test.

538.4.3 Leak Test. After the pressure test in para. 538.4.2 is completed, a leak test shall be performed.

(a) Examination for leaks shall be by the gas and bubble formation testing as detailed in Article 10, Section V of the ASME Boiler and Pressure Vessel Code, or by other methods of equal sensitivity.

EXCEPTION: Refrigerant vapor detection methods shall be used when refrigerant is used in the test medium. Comply with environmental regulations when venting refrigerants.

(b) Examination shall be made of all joints and connections. The piping system shall show no evidence of leaking.

(c) The pressure used for leak tests shall be either the design pressure or a pressure specified in the engineering design.

538.5 Testing Medium for Refrigerant Piping

(a) A suitable dry gas such as nitrogen or air shall be used for pressure testing per para. 538.4.2. Toxic gases shall not be used unless personnel are adequately protected from harmful exposure should leaks occur during testing.

(b) Oxygen or any medium with a lower flammable limit below 13% shall not be used for pressure testing.

(c) The system refrigerant may be used for leak testing per para. 538.4.3.

CAUTION: Comply with environmental regulations when testing with refrigerants.

(d) Water or water solutions should not be used in testing refrigerant piping.

538.6 Pressure Tests for Secondary Coolant Piping

(a) Piping for secondary coolants tested hydrostatically shall be proven tight at a pressure of 150% of the

design pressure. The pressure at the bottom of vertical runs shall not produce a stress that exceeds either 90% of the minimum yield strength or 1.7 times the allowable stress for brittle materials.

(b) Piping systems for secondary coolants tested pneumatically shall be tested as refrigerant piping.

(c) Piping for a refrigerant used as a secondary coolant shall be tested as refrigerant piping.

538.7 Pressure Gages

Pressure gages shall be checked for accuracy prior to use in testing, either by comparison with master gages or by setting the pointer as determined by a dead-weight pressure gage tester.

538.8 Repair of Joints

(a) All leaking joints shall be repaired.

(b) Solder joints that leak shall be disassembled, cleaned, refluxed, reassembled, and resoldered. Solder joints shall not be repaired by brazing.

(c) Brazed joints that leak may be repaired by cleaning the exposed area, refluxing, and rebrazing.

(d) Welded joints that leak shall have the defective areas of the weld removed and rewelded.

(e) After joints have been repaired, the joints shall be retested in accordance with paras. 538.3 and 538.4.

539 RECORDS

539.1 Definition

Records are the reduction to writing or film image of performances, evaluations, or data required by the Code.

539.2 Responsibility

It is the responsibility of the piping designer, manufacturer, fabricator, and erector as applicable to prepare the records required by this Code.

539.3 Extent and Retention of Records

The following records shall be maintained for 3 yr:

(a) procedure specification, procedure qualification, and performance qualification records

(b) results of weld examinations other than visual

(c) records of the testing of each piping system, which shall include the following information:

(1) date

(2) identification of piping system tested

(3) testing medium

(4) test pressure

(5) signature of examiner and inspector

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NONMANDATORY APPENDIX A

REFERENCED STANDARDS

(13)

Standards incorporated in this Code by reference and the names and addresses of the sponsoring organizations are shown in this Nonmandatory Appendix. It is not practical to refer to a specific edition of each standard throughout the Code text; instead, the specific edition reference dates are shown here. Specific edition reference dates are not provided for ASME codes and standards. For ASME codes and standards, the latest published edition in effect at the time this Code is specified is the specific edition referenced by this Code unless otherwise specified in the engineering design. The Nonmandatory Appendix will be revised as needed.

API Specifications	ASME Codes and Standards (Cont'd)	ASTM Specifications (Cont'd)
5L, 43rd Edition, 1995 600–2001	B16.22 B16.24 B16.25 B16.28 B16.47 B16.50 B18.2.1 B18.2.2	A217/A217M-04 A234/A234M-05a A240/A240M-05a A249/A249M-04a A254-97 (2002) A269-04 A278/A278M-01 A283/A283M-03 A285/A285M-03
ASCE Standards		
SEI/ASCE 7-05		
ASHRAE Standards		
15-2004 34-2004	B36.10M B36.19M	A307-04 A312/A312M-05a A320/A320M-05a A325-04b/A325M-05
ASME Codes and Standards	ASTM Specifications	
The latest edition of the following: Boiler and Pressure Vessel Code, Section II, Part C Section VIII, Division 1 Section IX	A36/A36M-05 A47/A47M-99 (2004) A48/A48M-03 A53/A53M-05 A105/A105M-05 A106/A106M-04b A126-04 A134-96 (2005) A135-01 A139-05 A178/A178M-02 A179/A179M-90a (2005) A181/A181M-01 A182/A182M-05a A192/A192M-02 A193/A193M-06 A194/A194M-05b A197/A197M-00 (2006) A210/A210M-02 A213/A213M-05c A214/A214M-96 (2005) A216/A216M-04	A333/A333M-05 A334/A334M-04a A350/A350M-04a A351/A351M-05 A352/A352M-03 A353/A353M-04 A354-04 A358/A358M-05 A376/A376M-04 A395/A395M-99 (2004) A403/A403M-04 A409/A409M-01 (2005) A413/A413M-01 A420/A420M-05 A450/A450M-04a A466/A466M-01 A467/A467-01 A515/A515M-03 A516/A516M-05 ^{e1} A522/A522M-01 A533/A533M-93 (2004) ^{e1}
B1.1 B1.20.1 B1.20.3 B16.1 B16.3		
B16.4 B16.5 B16.9 B16.10 B16.11 B16.14 B16.15 B16.18 B16.20 B16.21		

REFERENCED STANDARDS (CONT'D)

ASTM Specifications (Cont'd)

A536-84 (2004)
 A571/A571M-01
 A587-96 (2005)
 A663/A663M-89 (2000)
 A675/A675M-05a

A743/A743M-03
 A744/A744M-00 (2004)
 A1008/A1008M-05b
 A1011/A1011M-05a

B16/B16M-05
 B21/B21M-06
 B26/B26M-05
 B32-04

B42-02^{e1}
 B43-98 (2004)
 B61-02
 B62-02
 B68-02/B68M-99 (2005)

B75-02/B75M-99 (2005)
 B85-03
 B88-03/B88M-05
 B96/B96M-01
 B98/B98M-03

B111/B111M-04
 B124/B124M-06
 B152/B152M-00
 B165-05
 B171/B171M-04^{e1}

B179-03
 B209-04/B209M-04
 B210-04/B210M-05
 B211-03/B211M-05a
 B221-05a/B221M-05a
 B234-04/B234M-04

ASTM Specifications (Cont'd)

B241/B241M-02
 B247-02a/B247M-02a
 B248-01^{e1}/B248M-01^{e1}
 B280-03
 B283-06

B302-02
 B315-06
 B345/B345M-02
 B361-02
 B466/B466M-03

B467-88 (2003)
 B543-96 (2003)
 B584-06
 B828-02
 D93-02a

AWS Specifications

A5.01-93
 A5.1/A5.1M-04
 A5.2-92
 A5.3/A5.3M-99
 A5.4-92

A5.6-84R
 A5.7-84
 A5.8/A5.8M-04
 A5.9-93
 A5.10/A5.10M-99

A5.12/A5.12M-98
 A5.18/A5.18M-01
 A5.20/A5.20M-05
 A5.22-95R
 A5.29/A5.29M-05
 A5.30-97

AWWA Standards

C110/A21.10-03
 C111/A21.11-00
 C500-02

CDA Publications

Copper Tube Handbook, 2006

MIL Standards

MIL-F-1183J-5/87

MSS Standard Practices

SP-6-2001
 SP-9-2001 (R2005)
 SP-25-1998
 SP-42-2004
 SP-43-1991 (R2001)
 SP-45-2003
 SP-51-2003
 SP-58-2002
 SP-97-2001

SAE Specifications

J 513-1999

GENERAL NOTE: The issue date shown immediately following the hyphen after the number of the standard (e.g., A126-04 and SP-6-2001) is the effective date of issue (edition) of the standard.

REFERENCED STANDARDS (CONT'D)

Specifications and standards of the following organizations appear in this Nonmandatory Appendix:

API	American Petroleum Institute 1220 L Street, NW Washington, DC 20005 Phone: 202 682-8000 www.api.org	AWS	American Welding Society 8669 Doral Boulevard Doral, FL 33166 Phone: 800 443-9353 www.aws.org
ASCE	American Society of Civil Engineers 1801 Alexander Bell Drive Reston, VA 20191 Phone: 800 548-2723 www.asce.org	AWWA	American Water Works Association 6666 West Quincy Avenue Denver, CO 80235 Phone: 303 794-7711 www.awwa.org
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 1791 Tullie Circle, NE Atlanta, GA 30329 Phone: 800 527-4723 www.ashrae.org	CDA	Copper Development Association 260 Madison Avenue New York, NY 10016 Phone: 212 251-7200 www.copper.org
ASME	The American Society of Mechanical Engineers Two Park Avenue New York, NY 10016-5990 Phone: 212 591-8500 www.asme.org Customer Care Orders/Inquiries: P.O. Box 2900 Fairfield, NJ 07007-2900 Phone: 800 843-2763	MIL	Department of Defense (DOD) Single Stock Point Document Automation and Product Service Building 4/D 700 Robbins Avenue Philadelphia, PA 19111-5094 Phone: 215 697-2664 http://dodssp.daps.dla.mil/
ASTM	American Society for Testing and Materials 100 Barr Harbor Drive P.O. Box C700 West Conshohocken, PA 19428-2959 Phone: 610 832-9585 www.astm.org	MSS	Manufacturers Standardization Society of the Valve and Fittings Industry, Inc. 127 Park Street, NE Vienna, VA 22180 Phone: 703 281-6613 www.mss-hq.org
		SAE	Society of Automotive Engineers 400 Commonwealth Drive Warrendale, PA 15096 Phone: 724 776-4841 or 877 606-7323 www.sae.org

NONMANDATORY APPENDIX B

PREPARATION OF TECHNICAL INQUIRIES

B-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 technological 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. 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.

B-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 would 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, addenda, paragraphs, figures, and tables. If sketches 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.

B-3 SUBMITTAL

Inquiries should 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.

NONMANDATORY APPENDIX C

SELECTING APPLICABLE PIPING CODES

C-1 GENERAL

It is the owner's responsibility to select the Code section(s) that most nearly apply to a proposed piping installation. Factors to be considered by the owner include Scopes of the Code sections; jurisdictional requirements; and the applicability of other codes and standards. Each Code Section may apply to different parts of the installation. The owner is also responsible for imposing requirements supplementary to those of the Code to assure safe piping for the proposed installation. This Appendix provides guidance in the form of descriptions of the ASME B31 Code Section to assist the owner in making the best selection.

C-2 ASME B31 CODES

The ASME B31 Code for Pressure Piping consists of a number of individually published Sections, each an American National Standard, under the direction of ASME Committee B31, Code for Pressure Piping.

Rules for each Section reflect the kinds of piping installations considered by the members of the cognizant Section Committee during its development. An abbreviated description of the piping considered and the requirements for each Section follows.

C-2.1 ASME B31.1 Power Piping

This Section covers piping typically found in electric power generating stations, industrial and institutional plants, geothermal heating systems, and district heating systems, that requires the range of sizes, pressures, and temperatures beyond that covered in ASME B31.9. ASME B31.1 has requirements for

- (a) piping for steam, water, oil, gas, air, and other services
- (b) boiler external piping
- (c) metallic and nonmetallic piping
- (d) pressures above 15 psi (105 kPa)
- (e) ambient and higher temperatures

C-2.2 ASME B31.3 Process Piping

This Section covers piping typically found in petroleum refineries, chemical, pharmaceutical, textile, paper, semiconductor, cryogenic plants, and related processing plants and terminals. ASME B31.3 has requirements for

- (a) piping for all fluid services
- (b) metallic and nonmetallic piping

- (c) all pressures
- (d) all temperatures

C-2.3 ASME B31.4 Pipeline Transportation Systems for Liquids and Slurries

This Section covers piping transporting products that are predominantly liquid between plants and terminals and within terminals, pumping, regulating, and metering stations. ASME B31.4 has requirements for

- (a) piping transporting liquids such as crude oil, condensate, natural gasoline, natural gas liquids, liquefied petroleum gas, carbon dioxide, liquid alcohol, liquid anhydrous ammonia, and liquid petroleum products
- (b) piping at pipeline terminals (marine, rail, and truck), tank farms, pump stations, pressure reducing stations, and metering stations, including scraper traps, strainers, and prover loops

- (c) all pressures
- (d) temperatures from ambient to 250°F (121°C)

ASME B31.4 does not have requirements for auxiliary piping, such as water, air, steam, lubricating oil, gas, and fuel.

C-2.4 ASME B31.5 Refrigeration Piping and Heat Transfer Components

This Section covers piping and heat transfer components for refrigerants and secondary coolants. ASME B31.5 has requirements for

- (a) refrigerant and secondary coolant piping
- (b) heat transfer components such as condensers and evaporators
- (c) all pressures
- (d) temperatures at and above -320°F (-196°C)

C-2.5 ASME B31.8 Gas Transportation and Distribution Piping Systems

This Section covers piping transporting products that are predominantly natural gas between sources and terminals. ASME B31.8 has requirements for

- (a) pipeline facilities for the transport of gas
- (b) auxiliary piping, such as water, air, steam, lubricating oil, and fuel
- (c) gathering pipelines
- (d) piping at compressor, regulating, and metering stations
- (e) natural gas distribution systems
- (f) onshore and offshore natural gas piping

- (g) all pressures
- (h) temperatures from -20°F to 450°F (-29°C to 232°C)

C-2.6 ASME B31.9 Building Services Piping

This Section covers piping typically found in industrial, institutional, commercial, and public buildings and in multi-unit residences, that does not require the range of sizes, pressures, and temperatures covered in ASME B31.1.

C-2.6.1 ASME B31.9 has requirements for

- (a) piping with water or antifreeze solutions used for heating and cooling, steam and steam condensate, air, combustible liquids, and other nontoxic, nonflammable fluids
- (b) compressed air, steam, and steam condensate to 150 psi (1 035 kPa)
- (c) liquids to 350 psi (2 415 kPa)
- (d) steam and steam condensate from ambient to 366°F (186°C)
- (e) other gases from 0°F to 200°F (-18°C to 93°C)
- (f) liquids from 0°F to 250°F (-18°C to 121°C)
- (g) boiler external piping to 15 psi (103 kPa)

C-2.6.2 ASME B31.9 also has the following NPS and wall thickness limits:

- (a) carbon steel pipe: NPS 30 and $\frac{1}{2}$ in. (13 mm) wall thickness
- (b) stainless steel pipe: NPS 12 and $\frac{1}{2}$ in. (13 mm) wall thickness
- (c) aluminum alloy piping: NPS 12
- (d) copper and copper alloy piping: standard water tube size 12

- (e) nonmetallic piping: NPS 24
- (f) ductile iron piping: NPS 18

C-2.7 ASME B31.11 Slurry Transportation Piping Systems¹

This Section covers piping transporting aqueous slurries between plants and terminals and within terminals. ASME B31.11 has requirements for

- (a) piping transporting aqueous slurries of nonhazardous materials
 - (b) piping in pumping and regulating stations
 - (c) all pressures
 - (d) temperatures from -20°F to 250°F (-29°C to 121°C)
- ASME B31.11 does not have requirements for auxiliary piping such as water, air, steam, lubricating oil, gas, and fuel.

C-3 OTHER PIPING CODES

Frequently, piping within a facility is subject to codes other than those listed in section C-2. Fluid services that are frequently subject to other codes include

- (a) fuel gas from the point of delivery to the connection of each fuel utilization device
- (b) sprinkler, deluge, carbon dioxide, and other fire protection systems
- (c) medical and laboratory gas systems
- (d) plumbing and potable hot and cold water and sewer and drain systems
- (e) nuclear power piping

¹ Incorporated into B31.4-2012.

NONMANDATORY APPENDIX D NOMENCLATURE

Table D-1 lists dimensional and mathematical symbols used in this Code.

Table D-1 Nomenclature

Symbol	Definition	Units [Note (1)]		References		
		U.S.	SI	Paragraph	Table/Fig./Appendix	Equation
A	Cross-sectional area required of flat head with opening (in note re BPV Code, Section VIII-1, UG-34)	in. ²	mm ²	504.3.2	...	...
a	Weld depth in flat plate closure	in.	mm	...	527.3.6-1	...
a	Height of unequal-leg fillet weld	in.	mm	...	527.3.3-1	...
A_1	Area required for branch reinforcement	in. ²	mm ²	504.3.1	504.3.1-1	...
				504.3.2	504.3.1-2	...
				...	504.3.1-3	...
A_2	Area available for branch reinforcement in run pipe	in. ²	mm ²	504.3.1	504.3.1-1	(4), (7)
				504.3.2	504.3.1-2	...
				...	504.3.1-3	...
A_3	Area available for branch reinforcement in branch pipe	in. ²	mm ²	504.3.1	504.3.1-1	(5), (8)
				504.3.2	504.3.1-2	...
				...	504.3.1-3	...
A_4	Area available for branch reinforcement in pad or connection	in. ²	mm ²	504.3.1	504.3.1-1	(9)
				504.3.2	504.3.1-2	...
				...	504.3.1-3	...
b	Bevel and weld width in flat plate closure	in.	mm	...	527.3.6-1	...
b	Width of unequal-leg fillet weld	in.	mm	...	527.3.3-1	...
b	Subscript referring to branch	...	...	504.3.1	...	...
C	Corrosion allowance	in.	mm	504.3.1	504.3.1-1	(4), (5)
C	Factor based on ratio of required to nominal pipe wall thickness	...	...	504.4.2	...	(11)
C	Cold spring factor	...	...	519.4.6	...	(19), (20)
c	Sum of the mechanical allowances (thread depth, groove depth, and manufacturer's minus tolerances) plus corrosion and erosion allowances, as required	in.	mm	504.1.1	...	(2)
				504.4.1	...	(10)
				504.4.2	...	(11)
c	Sum of mechanical, corrosion, and erosion allowances	in.	mm	504.5.2	...	(12)
C_1	Estimated self-spring or relaxation factor	...	...	519.4.6	...	(20)
C_1	Correction factor, a function of the flexibility characteristic	...	...	...	519.3.6	...
d	Inside diameter of pipe excluding metal required for corrosion or erosion allowance, manufacturer's minus tolerance, and any allowance required for the depth of internal threads or grooves	in.	mm	504.1.1	...	(3b)
				504.1.2	...	...
d	Inside diameter of pipe	in.	mm	504.4.2	527.3.6-1	(11)
d_g	Inside diameter of gasket for raised or flat (plain) face flanges, or the gasket pitch diameter for retained gasketed flanges	in.	mm	504.5.3	...	(13)
D_o	Outside diameter of pipe	in.	mm	504.1.1	...	(3a)
				504.1.2	...	...
				504.3.1	...	...
				519.4.2	...	(14)
D_{ob}	Outside diameter of branch pipe	in.	mm	504.3.1	504.3.1-1	(6)
				...	504.3.1-2	...
D_{oh}	Outside diameter of run pipe or header	in.	mm	504.3.1	504.3.1-2	(6)
d_x	Corroded design inside diameter of the extruded outlet	in.	mm	504.3.1	504.3.1-2	(7)
d_1	Actual corroded length removed from run pipe	in.	mm	504.3.1	504.3.1-1	(4)
d_1	Opening size in header tube	in.	mm	...	304.3.1-3	...
d_2	Half-width of reinforcement zone	in.	mm	504.3.1	504.3.1-1	(4)
				...	504.3.1-2	...
d_2	Reinforcement zone, equal to opening size in header tube	in.	mm	...	504.3.1-3	...
d_5	Diameter, in the plane under consideration, of the opening in a closure	in.	mm	504.3.2	...	...

Table D-1 Nomenclature (Cont'd)

Symbol	Definition	Units [Note (1)]		References		
		U.S.	SI	Paragraph	Table/Fig./Appendix	Equation
E	Longitudinal or spiral joint factor	ksi	MPa	502.3.1	...	...
E	Modulus of elasticity	ksi	MPa	...	519.3.2	...
e	Thermal expansion range	in./100 ft	mm/m	519.3.1	519.3.1	...
E_c	Modulus of elasticity, cold	ksi	MPa	519.3.2	519.3.6	(14), (19)
				519.4.2	...	...
				519.4.6	...	...
E_h	Modulus of elasticity, hot	ksi	MPa	519.3.2	...	(19)
				519.4.6	...	...
E_I	Modulus of elasticity, as installed (cold)	ksi	MPa	519.4.5	...	...
f	Stress-range reduction factor for cyclic conditions	...	...	502.3.2	...	(1)
				519.4.2	...	...
h	Subscript referring to run or header	...	...	504.3.1	...	...
h	Flexibility characteristic	...	...	...	519.3.6	...
h_x	Height of the extruded outlet	...	...	504.3.1	504.3.1-2	...
i	Stress intensification factor for fittings and miters	...	...	...	519.3.6	...
i_i	Stress intensification factor, in-plane	...	...	519.4.5	519.3.6	(16), (17), (18)
i_o	Stress intensification factor, out-plane	...	...	519.4.5	519.3.6	(16), (17), (18)
K	Constant used to calculate the required branch reinforcement area, A_1	...	...	504.3.1	...	(6)
k	Flexibility factor for fittings and miters	...	...	...	519.3.6	...
L	Developed length of piping between anchors	ft	m	519.4.2	...	(14)
L_4	Height of reinforcement zone outside of run pipe	in.	mm	504.3.1	...	(5)
L_5	Height of the reinforcement zone	in.	mm	504.3.1	504.3.1-2	(8)
M_i	In-plane bending moment	in.-lb	N-m	519.4.5	...	(16), (17), (18)
M_o	Out-plane bending moment	in.-lb	N-m	519.4.5	...	(16), (17), (18)
M_t	Torsional moment	in.-lb	N-m	519.4.5	...	...
N	Total number of temperature cycles	...	...	502.3.2	...	...
N_E	Number of cycles of full temperature change	...	...	502.3.2	...	...
N_n	Number of cycles of less temperature change ($n = 1, 2, \dots$)	...	...	502.3.2	...	...
P	Internal design pressure	psi	kPa	...	519.3.6	...
P	Internal or external design pressure	psi	kPa	504.1.1	...	...
				504.1.2	...	(3a), (3b)
				504.4.1	...	...
				504.4.2	...	(11)
				504.5.1	...	...
				504.5.2	...	...
				504.5.3	...	(13)
R	Bend radius of welding elbow or pipe bend	in.	mm	...	519.3.6	...
R	Range of reaction forces or moments corresponding to the full expansion range based on E_c	lbf	N	519.4.6	...	(19), (20)
		in.-lbf	N-m	...	...	...
r	Mean radius of matching pipe	in.	mm	...	519.3.6	...
R_c	Maximum reaction forces or moments estimated to occur in the cold conditions	lbf	N	519.4.6	...	(19), (20)
		in.-lbf	N-m	...	...	...
R_h	Maximum reaction forces or moments estimated to occur in the hot conditions	lbf	N	519.4.6	...	(19), (20)
		in.-lbf	N-m	...	...	...
R_L	Reaction limit	lbf	N	519.4.6	...	(19)
		in.-lbf	N-m	...	...	...
r_m	Mean branch cross-sectional radius	in.	mm	519.4.5	...	...
r_n	Ratio of any lesser temperature cycle to that for which S_E has been calculated ($n = 1, 2, \dots$)	in.	mm	502.3.2	...	...
r_x	Radius of curvature of external contoured portion of the extruded outlet	in.	mm	504.3.1	504.3.1-2	(9)
S	Basic material allowable stress for pipe and tube in accordance with para. 502.3.1 and Table 502.3.1	ksi	MPa	502.3.1	502.3.1	(3a), (3b)
				504.1.1	...	(11), (13)
				504.1.2	...	...

Table D-1 Nomenclature (Cont'd)

Symbol	Definition	Units [Note (1)]		References		
		U.S.	SI	Paragraph	Table/Fig./Appendix	Equation
S	Applicable stress in accordance with para. 502.3.1 and Table 502.3.1 for closures	ksi	MPa	504.4.1 504.4.2 504.5.2 504.5.3	...	...
s	Miter spacing at centerline	in.	mm	...	519.3.6	...
S_A	Maximum allowable stress range for thermal expansion and contraction	ksi	MPa	502.3.2 519.3.4 519.4.2 519.4.5	...	(1), (14)
S_a	Bolt design stress at 100°F (from BPV Code)	ksi	MPa	504.5.1	...	...
S_b	Bolt design stress at design temperature (from BPV Code)	ksi	MPa	504.5.1	...	...
S_b	Resultant bending stress	ksi	MPa	519.4.5	...	(15)–(18)
S_c	Basic material allowable stress at minimum (cold) normal temperature (use S not SE) in accordance with para. 502.3.1 and Table 502.3.1	ksi	MPa	502.3.2	...	(1)
S_E	Maximum computed expansion stress range	ksi	MPa	502.3.2	...	(15)
S_f	Allowable stress for flange material or pipe (from BPV Code)	ksi	MPa	504.5.1	...	...
S_h	Basic material allowable stress at maximum (hot) normal temperature (use S not SE) in accordance with para. 502.3.1 and Table 502.3.1	ksi	MPa	502.3.2 519.4.6	...	(1)
S_t	Torsional stress	ksi	MPa	519.4.5	...	(15)
T	Pad or saddle thickness	in.	mm	...	519.3.6	...
T	Actual measured wall thickness of pipe or minimum thickness permissible under purchase specification	in.	mm	504.3.1	...	...
\bar{T}	Nominal wall thickness of pipe	in.	mm	504.3.1 504.4.2 ...	519.3.6 527.3.3-2 527.3.3-3 527.3.6-1	...
t	Pressure design wall thickness of pipe	in.	mm	504.1.1 504.1.2 504.3.1	...	(2), (3a), (3b)
t	Pressure design thickness for the closure	in.	mm	504.3.2 504.4.1	...	(10)
t	Pressure design thickness (of blind flanges)	in.	mm	504.5.2	...	(12)
t	Pressure design thickness (of blanks)	in.	mm	504.5.3	...	(13)
T_b	Actual measured wall thickness of pipe branch or minimum thickness permissible under purchase specification	in.	mm	504.3.1 ...	504.3.1-1 504.3.1-2 504.3.1-3	(5), (8)
t_b	Pressure design wall thickness of pipe branch	in.	mm	504.3.1 ...	504.3.1-1 504.3.1-2 504.3.1-3	(5), (8), (9)
\bar{T}_b	Nominal wall thickness of branch pipe	in.	mm	527.3.5	504.3.1-1	...
\bar{T}_b	Nominal wall thickness of pipe matching branch	in.	mm	519.4.5	527.3.5-4	...
t_c	Throat depth of weld	in.	mm	527.3.5	527.3.5-4	...
t_e	Nominal thickness of reinforcing element	in.	mm	527.3.5	527.3.5-4	...
T_h	Actual measured wall thickness of pipe run or header or minimum thickness permissible under purchase specification	in.	mm	504.3.1 ...	504.3.1-1 504.3.1-2 504.3.1-3	(4), (7)
t_H	Hub thickness	in.	mm	...	527.3.3-2	...
t_h	Pressure design wall thickness of pipe run or header	in.	mm	504.3.1 ...	504.3.1-1 504.3.1-2 504.3.1-3	(4), (7)
\bar{T}_h	Nominal wall thickness of run or header pipe	in.	mm	...	504.3.1-1	...
\bar{T}_h	Thickness of pipe matching run of tee or header exclusive of reinforcing elements	in.	mm	519.4.5	...	...

Table D-1 Nomenclature (Cont'd)

Symbol	Definition	Units [Note (1)]		References		
		U.S.	SI	Paragraph	Table/Fig./Appendix	Equation
t_m	Minimum required wall thickness of pipe	in.	mm	504.1.1	...	(2)
t_m	Minimum required thickness (for closures)	in.	mm	504.4.1	...	(10), (11)
				504.4.2	...	(12)
				504.5.2	527.3.6-1	...
t_{min}	Smaller of t_c or \bar{T}_b	in.	mm	527.3.5	527.3.5-4(e)	...
\bar{T}_p	Nominal thickness of plate	in.	mm	504.4.2	527.3.6-1	...
t_r	Nominal thickness of reinforcing ring or saddle	in.	mm	504.3.1	504.3.1-1	...
t_r	Required wall thickness of pipe [value equal to t_m of eq. (2)]	in.	mm	504.4.2	527.3.6-1	...
\bar{T}_s	Effective branch wall thickness (lesser of \bar{T}_h or $i_o \bar{T}_b$)	in.	mm	519.4.5	...	...
T_x	The corroded finished thickness of the extruded outlet	in.	mm	504.3.1	504.3.1-2	(9)
ΔT_E	Full temperature change	°F	°C	502.3.2	...	...
ΔT_n	Cycles of lesser temperature cycles ($n = 1, 2, \dots$)	°F	°C	502.3.2	...	...
U	Anchor distance (length of straight line joining anchors)	ft	m	519.4.2	...	(14)
Y	Resultant of movements to be absorbed by pipeline	in.	mm	519.4.2	...	(14)
y	Coefficient for (piping) materials			504.1.1	...	(3a), (3b)
				504.1.2	...	...
Z	Section modulus of pipe	in. ³	mm ³	519.4.5	...	(16), (17)
Z_e	Effective section modulus for branch of tee	in. ³	mm ³	519.4.5	...	(18)
β	Angle between axes of branch and run	deg	deg	504.3.1	...	(5)
θ	One-half angle between adjacent miter axes	deg	deg	519.3.6	...	...

GENERAL NOTE: For Code reference to this Nonmandatory Appendix, see para. 500.3.

NOTE:

- (1) The use of these units is not required by the Code. They represent sets of consistent units (except where otherwise stated) that may be used in computations, if stress values in ksi and MPa are multiplied by 1,000 for use in equations that also involve pressure in psi and kPa values.

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NOTE:

(1) B31.11 has been incorporated into B31.4.

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