

Design and Construction of Large, Welded, Low-pressure Storage Tanks

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Design and Construction of Large, Welded, Low-pressure Storage Tanks

SECTION 1—SCOPE

1.1 General

The API Downstream Segment has prepared this standard to cover large, field-assembled storage tanks of the type described in 1.2 that contain petroleum intermediates (gases or vapors) and finished products, as well as other liquid products commonly handled and stored by the various branches of the industry.

The rules presented in this standard cannot cover all details of design and construction because of the variety of tank sizes and shapes that may be constructed. Where complete rules for a specific design are not given, the intent is for the manufacturer—subject to the approval of the purchaser's authorized representative—to provide design and construction details that are as safe as those which would otherwise be provided by this standard.

The manufacturer of a low-pressure storage tank that will bear the API 620 nameplate shall ensure that the tank is constructed in accordance with the requirements of this standard.

The rules presented in this standard are further intended to ensure that the application of the nameplate shall be subject to the approval of a qualified inspector who has made the checks and inspections that are prescribed for the design, materials, fabrication, and testing of the completed tank.

1.2 Coverage

1.2.1 This standard covers the design and construction of large, welded, low-pressure carbon steel above ground storage tanks (including flat-bottom tanks) that have a single vertical axis of revolution. This standard does not cover design procedures for tanks that have walls shaped in such a way that the walls cannot be generated in their entirety by the rotation of a suitable contour around a single vertical axis of revolution.

1.2.2 The tanks described in this standard are designed for metal temperatures not greater than 250 °F and with pressures in their gas or vapor spaces not more than 15 lbf/in.² gauge.

1.2.3 The basic rules in this standard provide for installation in areas where the lowest recorded 1-day mean atmospheric temperature is –70 °F or warmer¹ and the designer will additionally have the availability to use the provisions of 4.2.2 low-stress/low-temperature design down to as cold as –155 °F. Annex S covers stainless steel low-pressure storage tanks in ambient temperature service in all areas, without limit on low temperatures. Annex R covers low-pressure storage tanks for refrigerated products at temperatures from +40 °F to –60 °F. Annex Q covers low-pressure storage tanks for liquefied gases at temperatures not lower than –325 °F.

1.2.4 The rules in this standard are applicable to tanks that are intended to (a) hold or store liquids with gases or vapors above their surface or (b) hold or store gases or vapors alone. These rules do not apply to lift-type gas holders.

1.2.5 Although the rules in this standard do not cover horizontal tanks, they are not intended to preclude the application of appropriate portions to the design and construction of horizontal tanks designed in accordance with

¹ The basic rules in this standard were originally written for use within the contiguous 48 United States of America, where the coldest recorded low 1-day mean atmospheric temperature is approximately –50 °F, which would result in a design metal temperature of –35 °F (–50 °F + 15 °F = –35 °F) when using the +15 °F addition per 4.2.1.2 a). Thus, in editions/addenda of API 620 prior to 2021, API 620 Table 4-1 only provided for design metal temperatures as cold as –35 °F, but allowances for colder temperatures have been incorporated since 2021.

good engineering practice. The details for horizontal tanks not covered by these rules shall be equally as safe as the design and construction details provided for the tank shapes that are expressly covered in this standard.

1.2.6 Annex A describes how to submit inquiries and suggestions for changes to this standard.

1.2.7 Annex B covers the use of plate and pipe materials that are not completely identified with any of the specifications listed in this standard.

1.2.8 Annex C provides information on subgrade and foundation loading conditions and foundation construction practices.

1.2.9 Annex D provides information about imposed loads and stresses from external supports attached to a tank wall.

1.2.10 Annex E provides considerations for the design of internal and external structural supports.

1.2.11 Annex F illustrates through examples how the rules in this standard are applied to various design problems.

1.2.12 Annex G provides considerations for service conditions that affect the selection of a corrosion allowance; concerns for hydrogen-induced cracking effects are specifically noted.

1.2.13 Annex H covers preheat and post-heat stress-relief practices for improved notch toughness.

1.2.14 Annex I covers a suggested practice for peening weldments to reduce internal stresses.

1.2.15 Annex J is reserved for future use.

1.2.16 Annex K provides considerations for determining the capacity of tank venting devices.

1.2.17 Annex L covers requirements for the design of storage tanks subject to seismic load.

1.2.18 Annex M covers the extent of information to be provided in the manufacturer's report and presents a suggested format for a tank certification form.

1.2.19 Annex N covers installation practices for pressure- and vacuum-relieving devices.

1.2.20 Annex O provides considerations for the safe operation and maintenance of an installed tank, with attention given to marking, access, site drainage, fireproofing, water draw-off piping, and cathodic protection of tank bottoms.

1.2.21 Annex P summarizes the requirements for inspection by method of examination and the reference paragraphs within the standard. The acceptance standards, inspector qualifications, and procedure requirements are also provided. This annex is not intended to be used alone to determine the inspection requirements within this standard. The specific requirements listed within each applicable section shall be followed in all cases.

1.2.22 Annex Q covers specific requirements for the materials, design, and fabrication of tanks to be used for the storage of liquefied gases such as ethane, ethylene, and methane.

1.2.23 Annex R covers specific requirements for the materials, design, and fabrication of tanks to be used for the storage of refrigerated products.

1.2.24 Annex S covers requirements for stainless steel tanks in non-refrigerated service.

1.2.25 Annex SC provides requirements for mixed material tanks using stainless steel (including austenitic and duplex) and carbon steel in the same tank for walls, bottom plates, roof structure, and other parts of a tank requiring added corrosion resistance.

1.2.26 Annex U covers detailed rules for the use of the ultrasonic examination (UT) method for the examination of tank seams.

1.2.27 Annex X covers materials, design, fabrication, erection, and testing requirements for aboveground, welded, duplex stainless steel storage tanks.

1.2.28 Annex Y covers requirements for materials, design, fabrication, and testing of the metallic membrane of membrane containment tank system.

1.3 Limitations

1.3.1 General

The rules presented in this standard apply to vertical, cylindrical oil storage tanks built according to API 650 as specifically allowed in 5.7.1.8, F.1, and F.7 of that standard. These rules do not apply to tanks built according to rules established for unfired pressure vessels designated for an internal pressure greater than 15 lbf/in.² gauge.

1.3.2 Piping Limitations

The rules of this standard are not applicable beyond the following locations in piping connected internally or externally to the walls² of tanks constructed according to this standard.

- a) The face of the first flange in bolted flanged connections.
- b) The first threaded joint on the pipe outside the tank wall in threaded pipe connections.
- c) The first circumferential joint in welding-end pipe connections that do not have a flange located near the tank.

² The term "wall" refers to the roof, shell, and bottom of a tank as defined in 3.3.

SECTION 2—REFERENCES

The most recent editions or revisions of the following standards, codes, and specifications are cited in this standard.

API Specification 5L, *Specification for Line Pipe*

API Recommended Practice 520, *Sizing, Selection, and Installation of Pressure-relieving Devices in Refineries—Part 2, Installation*

API Recommended Practice 582, *Recommended Practice Welding Guidelines for the Chemical, Oil, and Gas Industries*

API Standard 605, *Large-Diameter Carbon Steel Flanges (Nominal Pipe Sizes 26 Through 60; Classes 75, 150, 300, 400, 600, and 900)* (out-of-print)

API Standard 650, *Welded Tanks for Oil Storage*

API Standard 2000, *Venting Atmospheric and Low-Pressure Storage Tanks*

AAI ³, *Aluminum Design Manual*, “Specification for Aluminum Structures”

ACI 318 ⁴, *Building Code Requirements for Structural Concrete and Commentary* (ANSI/ACI 318)

AISC ⁵, *Steel Construction Manual*

ANSI H35.2 ⁶, *Dimensional Tolerances for Aluminum Mill Products*

ASCE Std 7-16 ⁷, *Minimum Design Loads for Buildings and Other Structures*

ASME B1.20.1 ⁸, *Pipe Threads, General Purpose (Inch)* (ANSI/ASME B1.20.1)

ASME B16.5, *Pipe Flanges and Flanged Fittings* (ANSI/ASME B16.5)

ASME B31.1, *Power Piping*

ASME B31.3, *Process Piping* (ANSI/ASME B31.3)

ASME B36.10M, *Welded and Seamless Wrought Steel Pipe* (ANSI/ASME B36.10)

DELETED

ASME *Boiler and Pressure Vessel Code*, Section V, “Nondestructive Examination;” Section VIII, “Pressure Vessels, Division 1;” and Section IX, “Welding and Brazing Qualifications”

ASNT CP-189 ⁹, *Standard for Qualification and Certification of Nondestructive Testing Personnel*

³ Aluminum Association, 1525 Wilson Blvd, Suite 600, Arlington, Virginia 22209, www.aluminum.org.

⁴ American Concrete Institute, P.O. Box 9094, Farmington Hills, Michigan 48333, www.aci-int.org.

⁵ American Institute of Steel Construction, One East Wacker Drive, Suite 700, Chicago, Illinois 60601, www.aisc.org.

⁶ American National Standards Institute, 25 West 43rd Street, 4th floor, New York, New York 10036, www.ansi.org.

⁷ American Society of Civil Engineers, 1801 Alexander Bell Dr., Reston, Virginia 20191, www.asce.org.

⁸ ASME International, 3 Park Avenue, New York, New York 10016, www.asme.org.

⁹ American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228, www.asnt.org.

ASNT SNT-TC-IA, *Personnel Qualification and Certification in Nondestructive Testing*

ASTM A6¹⁰, *Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling*

ASTM A20, *Standard Specification for General Requirements for Steel Plates for Pressure Vessels*

ASTM A27, *Standard Specification for Steel Castings, Carbon, for General Application*

ASTM A36, *Standard Specification for Carbon Structural Steel*

ASTM A53, *Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless*

ASTM A105, *Standard Specification for Carbon Steel Forgings for Piping Applications*

ASTM A106, *Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service*

ASTM A131, *Standard Specification for Structural Steel for Ships*

ASTM A134, *Standard Specification for Pipe, Steel, Electric-Fusion (Arc)-Welded (Sizes NPS 16 and Over)*

ASTM A139, *Standard Specification for Electric-Fusion (Arc)-Welded Steel Pipe (NPS 4 and Over)*

ASTM A181, *Standard Specification for Carbon Steel Forgings, for General-Purpose Piping*

ASTM A182, *Standard Specification for Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service*

ASTM A193, *Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications*

ASTM A194, *Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High-Pressure or High-Temperature Service, or Both*

ASTM A213, *Standard Specification for Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes*

ASTM A240, *Standard Specification for Chromium and Chromium-nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications*

ASTM A283, *Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates*

ASTM A285, *Standard Specification for Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength*

ASTM A307, *Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60,000 psi Tensile Strength*

ASTM A312, *Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes*

ASTM A320, *Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service*

ASTM A333, *Standard Specification for Seamless and Welded Steel Pipe for Low-Temperature Service*

¹⁰ ASTM International, 100 Bar Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

ASTM A334, *Standard Specification for Seamless and Welded Carbon and Alloy-Steel Tubes for Low-Temperature Service*

ASTM A350, *Standard Specification for Carbon and Low-alloy Steel Forgings, Requiring Notch Toughness Testing for Piping Components*

ASTM A351, *Standard Specification for Castings, Austenitic, Austenitic, for Pressure-Containing Parts*

ASTM A353, *Standard Specification for Pressure Vessel Plates, Alloy Steel, Double-Normalized and Tempered 9% Nickel*

ASTM A358, *Standard Specification for Electric-Fusion-Welded Austenitic Chromium-Nickel Stainless Steel Pipe for High-Temperature Service and General Applications*

ASTM A370, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

ASTM A403, *Standard Specification for Wrought Austenitic Stainless Steel Piping Fittings*

ASTM A479, *Standard Specification for Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels*

ASTM A480, *Standard Specification for General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip*

ASTM A516, *Standard Specification for Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service*

ASTM A522, *Standard Specification for Forged or Rolled 8 and 9% Nickel Alloy Steel Flanges, Fittings, Valves, and Parts for Low-Temperature Service*

ASTM A524, *Standard Specification for Seamless Carbon Steel Pipe for Atmospheric and Lower Temperatures*

ASTM A537, *Standard Specification for Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel*

ASTM A553, *Standard Specification for Pressure Vessel Plates, Alloy Steel, Quenched and Tempered 8 and 9% Nickel*

ASTM A573, *Standard Specification for Structural Carbon Steel Plates of Improved Toughness*

ASTM A633, *Standard Specification for Normalized High-Strength Low-Alloy Structural Steel Plates*

ASTM A645, *Standard Specification for Pressure Vessel Plates, 5% and 5 1/2% Nickel Alloy Steel, Specially Heat Treated*

ASTM A662, *Standard Specification for Pressure Vessel Plates, Carbon-Manganese-Silicon Steel, for Moderate and Lower Temperature Service*

ASTM A671, *Standard Specification for Electric-Fusion-Welded Steel Pipe for Atmospheric and Lower Temperatures*

ASTM A673, *Standard Specification for Sampling Procedure for Impact Testing of Structural Steel*

ASTM A737, *Standard Specification for Pressure Vessel Plates, High-Strength, Low-Alloy Steel*

ASTM A841, *Standard Specification for Steel Plates for Pressure Vessels, Produced by Thermo-Mechanical Control Process (TMCP)*

ASTM A992, *Standard Specification for Structural Steel Shapes*

ASTM B209, *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate*

ASTM B210, *Standard Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes*

ASTM B211, *Standard Specification for Aluminum and Aluminum-Alloy Rolled or Cold Finished Bar, Rod, and Wire*

ASTM B221, *Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes*

ASTM B241, *Standard Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube*

ASTM B247, *Standard Specification for Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings*

ASTM B308, *Standard Specification for Aluminum-Alloy 6061-T6 Standard Structural Profiles*

ASTM B444, *Standard Specification for Nickel-Chromium-Molybdenum-Columium Alloys (UNS N06625 and UNS N06852) and Nickel-Chromium-Molybdenum-Silicon Alloy (UNS N06219) Pipe and Tube*

ASTM B619, *Standard Specification for Welded Nickel and Nickel-Cobalt Alloy Pipe*

ASTM B622, *Standard Specification for Seamless Nickel and Nickel-Cobalt Alloy Pipe and Tube*

ASTM E23, *Standard Test Methods for Notched Bar Impact Testing of Metallic Materials*

AWS A5.11 ¹¹, *Specification for Nickel and Nickel Alloy Welding Electrodes for Shielded Metal Arc Welding (ANSI/AWS A5.11)*

AWS A5.14, *Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods (ANSI/AWS A5.14)*

CSA G40.21 ¹², *Structural Quality Steel*

EN 10025 ¹³, *Hot Rolled Products of Structural Steels*

EN 10028, *Flat Products Made of Steels for Pressure Purposes*

18 | ISO 630 ¹⁴, *Structural steels*

21 | ISO 9712, *Non-destructive testing—Qualification and certification of NDT personnel*

¹¹ American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126, www.aws.org.

¹² Canadian Standards Association, 5060 Spectrum Way, Suite 100, Mississauga, Ontario L4W 5N6, Canada, www.csa.ca.

¹³ European Committee for Standardization, Avenue Marnix 17, B-1000, Brussels, Belgium, www.cen.eu.

¹⁴ International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland, www.iso.org.

SECTION 3—DEFINITIONS

3.1 Stress and Pressure Terms

3.1.1

design pressure

The maximum positive gauge pressure permissible at the top of a tank when the tank is in operation. It is the basis for the pressure setting of the safety-relieving devices on the tank. The design pressure is synonymous with the nominal pressure rating for the tank as referred to in this standard (see 5.3.1).

3.1.2

maximum allowable stress value

The maximum unit stress permitted to be used in the design formulas given or provided for in this standard for the specific kind of material, character of loading, and purpose for a tank member or element (see 5.5 and 5.6).

3.2 Capacity Terms

3.2.1

nominal liquid capacity

The total volumetric liquid capacity of a tank (excluding deadwood) between the plane of the high liquid design level and elevation of the tank grade immediately adjacent to the wall of the tank or such other low liquid design level as the manufacturer shall stipulate.

3.2.2

total liquid capacity

The total volumetric liquid capacity of a tank (excluding deadwood) below the high liquid design level.

3.3 Tank Wall

The tank wall is any or all parts of the plates located in the surface of revolution that bounds the tank and serves to separate the interior of the tank from the surrounding atmosphere. Flat bottoms of cylindrical tanks are covered by the rules of 5.9.4. As such, the tank walls include the sidewalls (or shell), roof, and bottom of the tank but not any of the following elements located on or projecting from the walls:

- a) nozzles and manways or their reinforcement pads or cover plates;
- b) internal or external diaphragms, webs, trusses, structural columns, or other framing;
- c) those portions of a compression-ring angle, bar, or girder that project from the walls of the tank;
- d) miscellaneous appurtenances.

3.4 Welding Terms

The terms defined in 3.4.1 through 3.4.21 are commonly used welding terms mentioned in this standard. See 5.22 for descriptions of fusion-welded joints.

3.4.1

automatic welding

Welding with equipment which performs the welding operation without adjustment of the controls by a welding operator. The equipment may or may not perform the loading and unloading of the work.

3.4.2

backing

The material—metal, weld metal, carbon, granular flux, and so forth—that backs up the joint during welding to facilitate obtaining a sound weld at the root.

3.4.3**base metal**

The metal or alloy to be welded or cut.

3.4.4**depth of fusion**

The distance that fusion extends into the base metal from the surface melted during welding.

3.4.5**filler metal**

Metal or alloy added in making a weld.

3.4.6**fusion**

The melting together of filler metal and base metal, or the melting of base metal only, which results in coalescence.

3.4.7**heat-affected zone**

The portion of the base metal that has not been melted but whose mechanical properties or microstructures have been altered by the heat of welding or cutting.

3.4.8**joint penetration**

The minimum depth a groove weld extends from its face into a joint, exclusive of reinforcement.

3.4.9**lap joint**

A joint between two overlapping members. An overlap is the protrusion of weld metal beyond the bond at the toe of the weld.

3.4.10**machine welding**

Welding with equipment that performs the welding operation under the constant observation and control of a welding operator. The equipment may or may not perform the loading and unloading of the work.

3.4.11**manual welding**

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

3.4.12**oxygen cutting**

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

3.4.13**porosity**

The existence of gas pockets or voids in metal.

3.4.14**reinforcement of weld**

Weld metal on the face of a groove weld in excess of the metal necessary for the specified weld size.

3.4.15**semiautomatic arc welding**

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

3.4.16**slag inclusion**

Nonmetallic solid material entrapped in weld metal or between weld metal and base metal.

3.4.17**undercut**

A groove melted into the base metal adjacent to the toe of a weld and left unfilled by weld metal.

3.4.18**weld metal**

The portion of a weld that has been melted during welding.

3.4.19**welded joint**

A union of two or more members produced by the application of a welding process.

3.4.20**welder**

One who performs manual or semiautomatic welding.

3.4.21**welding operator**

One who operates machine welding equipment.

3.5 Thickness Terms**3.5.1****nominal thickness**

The ordered thickness of the material. This thickness includes any corrosion allowance and is used for determination of PWHT requirements, weld spacing, minimum and maximum thickness limitations, etc.

NOTE The thickness used in the final structure is the nominal thickness plus or minus any tolerance allowed by this standard.

3.5.2**design thickness**

The thickness necessary to satisfy tension and compression strength requirements by this standard or, in the absence of such expressions, by good and acceptable engineering practice for specified design conditions, without regard to construction limitations or corrosion allowances.

3.5.3**minimum thickness**

The least acceptable nominal thickness that shall be used for the component being considered.

3.6 Other Terms**3.6.1****manufacturer**

The party having the primary responsibility for constructing the tank.

3.6.2**purchaser**

The owner or the owner's designated agent, such as an engineering contractor.

3.6.3**examiner**

21 | A person who performs nondestructive examinations specified by this standard and is qualified and certified as meeting the requirements of ASNT SNT-TC-1A, ISO 9712, and/or other requirements as determined by the manufacturer or purchaser for the method employed.

3.6.4**inspector**

The inspector is the representative of the purchaser who is qualified according to 7.2 and who ensures compliance with this standard as described in 7.1.

SECTION 4—MATERIALS

4.1 General

4.1.1 Material Specifications

Materials used in the construction of API 620 tanks shall comply with the specifications in this section (see Annexes Q, R, and S for specific material requirements). Material produced to specifications other than those listed in this section may be used if the material is certified to meet all the requirements of a material specification listed in this section and that its use is approved by the purchaser.

4.1.2 Materials That Cannot Be Completely Identified

Any plate materials or tubular products on hand that cannot be completely identified with a specification listed in this standard, by records satisfactory to the inspector, may be used to construct tanks according to the rules of this standard if the material passes the test prescribed in Annex B.

4.1.3 Accessory Pressure Parts

All accessory pressure parts, such as pipe fittings, valves, flanges, nozzles, welding necks, welding caps, manhole frames, and covers, shall be made from materials provided for in this standard or in any accepted ANSI standard that covers the particular part. These parts shall be marked with the name or trademark of the manufacturer and any other markings that are required by the applicable standards. Such markings shall be considered the manufacturer's guarantee that the product complies with the material specifications and standards indicated and is suitable for service at the rating indicated. The intent of this paragraph will have been met if, in lieu of the detailed marking on the part itself, the accessory pressure parts have been marked in any permanent or temporary manner that serves to identify the part with the manufacturer's written listing of the particular items and if this listing is available for examination by the inspector.

4.1.4 Small Parts

Cast, forged, or rolled parts of small size (which are ordinarily carried in stock and for which mill test reports or certificates are not customarily furnished) may be used if, in the opinion of the inspector, they are suitable for the purpose intended and that, if such parts are to be welded, they are of welding grade.

4.1.5 Design Metal Temperature

4.1.5.1 The purchaser shall specify the design metal temperature.

4.1.5.2 The design metal temperature for materials in contact with nonrefrigerated fluids shall be assumed to be 15 °F above one of the following:

- a) Lowest one-day mean ambient temperature for the locality involved, as determined from Figure 4-1.
- b) The Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) climatic design conditions minimum dry-bulb temperature for extreme annual design conditions corresponding to a return period of 20 years (2.5 occurrences in 50 years, 5 % probability of exceedance in one year). The latest data needs to be used. A lower return period or different temperature can be specified by the purchaser.

NOTE 1 ASHRAE local temperature data are available at <http://ashrae-meteo.info/> in a chart form. The desired value is located on the ASHRAE chart for the location in the section titled "Extreme Annual Design Conditions." It is in the block identified as the "Min" value for "n = 20 years" on the line for "DB."

NOTE 2 Each station data consists of the name of the observing station; state (province); country; World Meteorological Organization (WMO) station identifier; Weather Bureau Army Navy (WBAN) number; latitude of station, °N/S; longitude of station, °E/W; the period analyzed; and temperatures.

- 21 c) For locations not covered by a) or b), the purchaser may use authentic meteorological data to compute the lowest one-day mean temperature.

4.1.5.3 For locations where data per 4.1.5.2 is not available, the purchaser shall estimate the temperature from the most reliable information at hand.

4.1.5.4 For heated and insulated tanks, wherein the temperature of the tank walls never falls to within 15 °F of the lowest one-day mean ambient temperature, the design metal temperature may be set at a level higher than 4.1.5.2, as established by computations or by actual temperature data on comparable existing tanks.

4.1.5.5 The design metal temperature for components of refrigerated and cryogenic tanks shall be established per the requirements in the "Design Temperature" section of API 625.

4.2 Plates

4.2.1 General

4.2.1.1 All plates that are subject to pressure-imposed membrane stress or are otherwise important to the structural integrity of a tank, including bottom plates welded to the cylindrical sidewall of flat-bottom tanks, shall conform to specifications selected to provide a high order of resistance to brittle fracture at the lowest temperature to which the metal in the walls of the tank is expected to fall on the coldest days of record for the locality where the tank is to be installed.

- 21 **4.2.1.2** The plates used for the tank shall conform to one or more of the specifications listed in Table 4-1 as being acceptable for use at the design metal temperature (refer to 4.2.5 for impact testing requirements).

4.2.1.3 Unless exempted per 4.2.2, notch toughness of specially designed plate flanges and cover plates shall be evaluated using governing thickness in Table 4-1. (See 4.3.6.3 for definition of governing thickness.)

21 4.2.2 Low-stress/Low-temperature Design Provisions

Either of the following a) or b) may be used:

- a) The following design criteria, relative to the use of Table 4-1, apply when the actual stress under design conditions does not exceed one-third of the allowable tensile stress.

1) Consideration of the design metal temperature is not required in selecting material from Table 4-1 for tank components that are not in contact with the liquid or vapor being stored and are not designed to contain the contents of an inner tank (see Q.2.4 and R.2.3).

2) The design metal temperature may be increased by 30 °F in selecting material from Table 4-1 for tank components conforming to any of the following:

- 14 i) components exposed to the vapor from the liquid or vapor being stored and are not designed to contain the contents of the inner tank;

- 14 ii) components located within, but not welded directly to, a primary liquid container, a secondary liquid container, or a warm product vapor container (see R.2.4).

3) Excluding bottom plates welded to the cylindrical sidewall of flat-bottom tanks, the plates of a non-refrigerated flat-bottom tank, counterbalanced in accordance with 5.11.2, may be constructed of any material selected from Table 4-1.

- 21 b) Except for lap-welded bottoms, lap-welded suspended decks, lap-welded roofs, and lap-welded liner plates for concrete walls, the provisions of ASME *Boiler and Pressure Vessel Code (BPVC)* Section VIII Division 2 issue

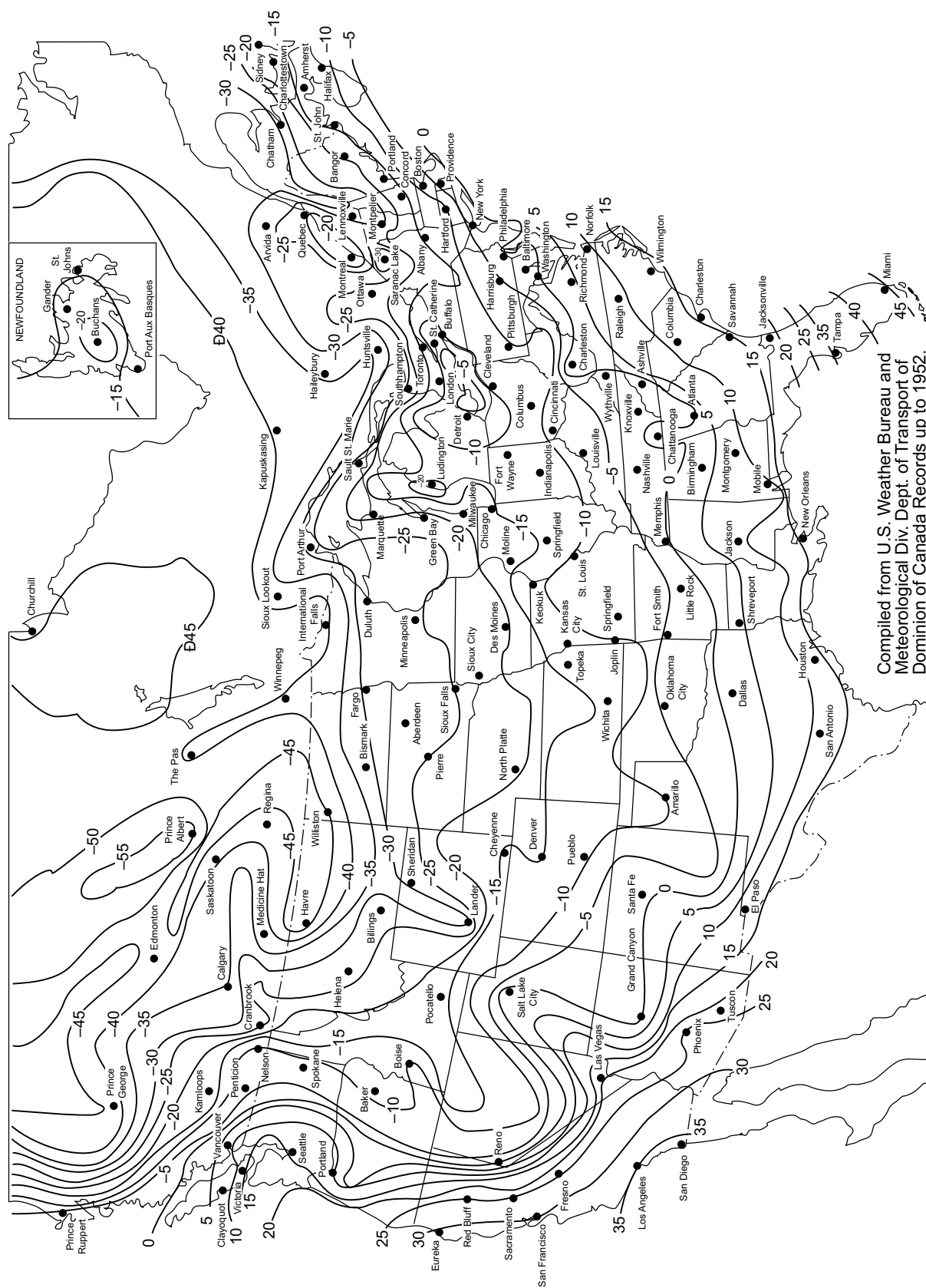


Figure 4-1—Isothermal Lines Showing 1-day Mean Ambient Temperature

Compiled from U.S. Weather Bureau and
Meteorological Div. Dept. of Transport of
Dominion of Canada Records up to 1952.

21 year 2017 (hereinafter referred to as *BPVC VIII-2-2017*) Sections 3.11.2.1 (general); 3.11.2.3 (Exemption From Impact Testing based on the MDMT, Thickness, and Material Specification); 3.11.2.5 (Exemption From Impact Testing Based on Design Stress Values); 3.11.2.6 (Adjusting the MDMT for Impact Tested Materials); 3.11.2.9 (PWHT); and 3.11.2.10 (weld procedure impact testing) together with any referenced paragraphs or sections may be used for material design of components, including but not limited to the allowable stresses, material specifications, locations requiring postweld heat treat, impact test temperatures, impact test exemption temperatures, and impact energy value requirements, with the following clarifications:

- 1) NDE methods and acceptance criteria may follow Section 7 of this standard.
- 2) The use of *BPVC VIII-2-2017* may be by individual components, but for connected components which are materially different, such as annular plate attached to first shell ring, the most stringent criteria of the connected components apply to both parts.
- 3) Allowable stresses from API 620 still applies to component design, even when using *BPVC VIII-2-2017*. When determining stress ratios for the purpose of entering a table or figure in *BPVC VIII-2-2017*, ASME allowable stresses per ASME *BPVC.II.D.C-2017* for Class 1 Vessels (no fatigue analysis) are applicable.

4.2.3 Plate Specifications

4.2.3.1 General

The specifications listed in 4.2.3.2, 4.2.3.3, and 4.2.3.4 are approved for plates, subject to the modifications and limitations of this paragraph, 4.2.4, and Table 4-1.

4.2.3.2 ASTM Specifications

The following ASTM specifications are approved for plates.

- 1) A20.
- 2) A36.
- 18 3) A131 (structural quality only).
- 4) A283 (Grades C and D only, with a maximum nominal thickness of $\frac{3}{4}$ in.).
- 5) A285 (Grade C only, with a maximum nominal thickness of $\frac{3}{4}$ in.).
- 14 6) A516.
- 14 7) A537, with the following modification: The minimum manganese content shall be 0.80 % by ladle analysis. The maximum manganese content may be increased to 1.60 % by ladle analysis if maximum carbon content is 0.20 % by ladle analysis.
- 8) A573.
- 9) A633 (Grades C and D only).
- 18 10) A662 (Grades B and C only).
- 11) A737 (Grade B only).
- 18 12) A841 Classes 1, 2 (Grades A and B only) with the following modification: carbon equivalency (CE) shall be per supplementary requirement S77.

Table 4-1—Minimum Requirements for Plate Specifications to be Used for Design Metal Temperatures

Design Metal Temperature (See 4.2.1)	Plate Thickness Including Corrosion Allowance (in.)	Permissible Specifications		
		Specification	Grade/Class	Special Requirements (in Addition to 4.2.3)
65 °F and warmer	$\leq \frac{3}{4}$	Any listed in 4.2.3	—	None
	≤ 1	ASTM A36	—	None
	> 1	G40.21	38W, 44W, 50W	Note 1
25 °F and warmer	$\leq \frac{1}{2}$	Any listed in 4.2.3	—	None
	≤ 1	ASTM A36	—	Note 5
		ASTM A131	B	None
		CSA G40.21	38W, 44W, 50W	None
–5 °F and warmer	$\leq \frac{1}{2}$	ASTM A131	B	None
		CSA G40.21	38W, 44W, 50W	None
	$> \frac{1}{2}$	ASTM A516	55, 60, 65, 70	Note 1
		ASTM A537	Class 1	None
		ASTM A537	Class 2	Note 6
		ASTM A573	58, 65, 70	Note 1
		ASTM A662	B and C	Note 1
		CSA G40.21	38W, 44W, 50W	Note 2
		ISO 630	S275, S355 Quality D	Notes 1 and 2
		EN 10025	S275, S355 Quality J2	Notes 1 and 2
	$\leq \frac{1}{2}$	ASTM A516	55, 60, 65, 70	None
		ASTM A573	58, 65, 70	None
		ASTM A662	B and C	None
		CSA G40.21	38W, 44W, 50W	Note 2
		ISO 630	S275, S355 Quality D	Note 2
		EN 10025	S275, S355 Quality J2, K2	Note 2
	≤ 1	ASTM A516	55, 60, 65, 70	Note 3
		ASTM A537	Class 1	None
		ASTM A537	Class 2	Note 6
		ASTM A573	58	Note 3
		ASTM A633	C and D	None
		ASTM A662	B and C	Note 3
		ASTM A737	B	None
		ASTM A841	Classes 1, 2 (Grades A and B)	Notes 4 and 6
		CSA G40.21	38W, 44W, 50W	Notes 2 and 3
		ISO 630	S275, S355 Quality D	Notes 2 and 3
		EN 10025	S275, S355 Quality J2, K2	Notes 2 and 3

Table 4-1—Minimum Requirements for Plate Specifications to be Used for Design Metal Temperatures (Continued)

Design Metal Temperature (See 4.2.1)	Plate Thickness Including Corrosion Allowance (in.)	Permissible Specifications		
		Specification	Grade/Class	Special Requirements (in Addition to 4.2.3)
	> 1	ASTM A516	55, 60, 65, 70	Notes 3 and 4
		ASTM A537	Class 1	Note 4
		ASTM A537	Class 2	Notes 4 and 6
		ASTM A573	58	Notes 3 and 4
		ASTM A633	C and D	Note 4
		ASTM A662	B and C	Notes 3 and 4
		ASTM A737	B	Note 4
		ASTM A841	Classes 1, 2 (Grades A and B)	Notes 4 and 6
		CSA G40.21	38W, 44W, 50W	Notes 2, 3, and 4
		ISO 630	S275, S355 Quality D	Notes 2, 3, and 4
		EN 10025	S275, S355 Quality J2, K2	Notes 2, 3, and 4
Colder than –35 °F but warmer than or equal to –55 °F	Thicknesses as designated/allowed above, or as allowed by the references in 4.2.2.	At the DMT, any material specification and grade listed above when both of the following are satisfied: a) the impact requirements in 4.2.5 and Table 4-3 with 5 ft-lbs added to the minimums are satisfied, and b) the weld procedure requirements in 6.7 are satisfied.		Alternatively, the low-stress/low-temperature allowances per 4.2.2 may be used.
NOTE 1 All plates over 1½ in. thick shall be normalized.				
NOTE 2 The steel shall be killed and made with fine-grain practice.				
NOTE 3 The plates shall be normalized or quench tempered (see 4.2.4.2).				
NOTE 4 Each plate shall be impact tested in accordance with 4.2.5.				
NOTE 5 The manganese content shall be within the range of 0.80 % to 1.20 %.				
NOTE 6 See Section 4.2.6.				

4.2.3.3 CSA Specification

The following CSA specification is approved for plates: G40.21 (Grades 38W, 44W, and 50W only; if impact tests are required, these grades are designated 38WT, 44WT, and 50WT). All CSA specification plates shall be ordered with the tensile strength limited to no greater than 140 MPa (20 ksi) above the minimum specified tensile strength.

4.2.3.4 ISO Specification

The following ISO specification is approved for plates: 630 (Grades S275 and S355 in Qualities C and D only). Elements added for grain refining or strengthening shall be restricted in accordance with Table 4-2.

4.2.3.5 EN Specification

The following EN specification is approved for plates: EN 10025 (Grades S275 and S355 in Qualities J0, J2, and K2 only). Elements added for grain refining or strengthening shall be restricted in accordance with Table 4-2.

Table 4-2—Maximum Permissible Alloy Content

Alloy	%	Notes
Columbium	0.05	1, 2, and 3
Vanadium	0.10	1, 2, and 4
Columbium (0.05 % maximum) Plus Vanadium	0.10	1, 2, and 3
Nitrogen	0.015	1, 2, and 4
Copper	0.35	1 and 2
Nickel	0.50	1 and 2
Chromium	0.25	1 and 2
Molybdenum	0.08	1 and 2
NOTE 1 When not included in the material specification, the use of these alloys, or combinations thereof, shall be at the option of the plate producer, subject to the approval of the purchaser. These elements shall be reported when requested by the purchaser.		
NOTE 2 The material shall conform to these requirements on product analysis subject to the product analyses tolerances of the specification.		
NOTE 3 Columbium, when added either singly or in combination with vanadium, shall be restricted to plates of 0.50-in. maximum thickness unless it is combined with a minimum of 0.15 % silicon.		
NOTE 4 When added as a supplement to vanadium, nitrogen (a maximum of 0.015 %) shall be reported and the minimum ratio of vanadium to nitrogen shall be 4:1.		

4.2.4 Plate Manufacture

4.2.4.1 All material for plates shall be made using the open-hearth, electric-furnace, or basic-oxygen process. Universal mill plates shall not be used. All plates for pressure parts, with the exception of those whose thicknesses are established by the requirements of Table 5-6, shall be ordered on the basis of edge thickness to ensure that the plates furnished from the mill will not underrun the specified thickness by more than 0.01 inch. This stipulation shall not be construed to prohibit the use of plates purchased based on weight if it is established by actual measurements (taken at a multiplicity of points along the edges of the plates) that the minimum thicknesses of the plates do not underrun the required design thickness by more than 0.01 in.

4.2.4.2 Subject to the purchaser's approval, thermo-mechanical-control-process (TMCP) plates (plates produced by a mechanical-thermal rolling process designed to enhance notch toughness) may alternatively be used where heat treated plates are normally required by Table 4-1 (note 1) because of thickness over 1½ in. In this case, each TMCP plate-as-rolled shall receive Charpy V-notch impact energy testing in accordance with 4.2.5.

4.2.5 Impact Test Requirements for Plates

4.2.5.1 Table 4-1 provides exemption and impact testing requirements of plates for various grades for given thickness range and design metal temperature. Any material listed in Table 4-1 may be used for any thickness and temperature provided the material meets impact test requirements as specified in 4.2.5 and Table 4-3 and welding procedure requirements specified in 6.7. When the plate is not exempted from impact testing per Table 4-1 or 4.2.2, each plate shall be impact tested; plate refers to the unit plate rolled from a slab or directly from an ingot. The ASTM A370, Type A, Charpy V-notch test shall be used. The long dimension of the specimen shall be parallel to the direction of the expected maximum stress. When the coincident stresses are approximately equal, the specimens shall be taken transverse to the final direction of the plate rolling. The minimum energy absorption values of Table 4-3 shall be satisfied.

Table 4-3—Minimum Charpy V-notch Requirements for Plate Specimens

	Group	Specification Number	Grade/Class	Range in Thickness (in.)	Impact Value ^a (foot-pounds)	
					Average	Individual
18	I (semikilled)	A 36		$\frac{3}{16}$ to 1	13	9
14		A 36 ^d		$\frac{3}{16}$ to 1	13	9
		A 131	A and B	$\frac{3}{16}$ to 1	13	9
		A283	C and D	$\frac{3}{16}$ to $\frac{3}{4}$	13	9
		A285	C	$\frac{3}{16}$ to $\frac{3}{4}$	13	9
18		ISO 630	S275 Quality C	$\frac{3}{16}$ to $1\frac{1}{2}$	13	9
		EN 10025	S275 J0	$\frac{3}{16}$ to $1\frac{1}{2}$	13	9
14	II (fully killed)	A 573	58 ^b	$\frac{3}{16}$ to $1\frac{1}{2}$	15	10
		A 131	CS	$\frac{3}{16}$ to $1\frac{1}{2}$	15	10
		A 516	55 and 60	$\frac{3}{16}$ to 2	15	10
14		A 516	55 and 60 ^c	$\frac{3}{16}$ to $\frac{1}{2}$	15	10
18		ISO 630	S275 Quality D	$\frac{3}{16}$ to $1\frac{1}{2}$	15	10
		EN 10025	S275 J2	$\frac{3}{16}$ to $1\frac{1}{2}$	15	10
		CSA G40.21	38WT	$\frac{3}{16}$ to 2	15	10
14	III (fully killed and high strength)	A 573	65 and 70	$\frac{3}{16}$ to 2	15	10
		A 516	65 and 70	$\frac{3}{16}$ to 2	15	10
18		A 537	Class 1	$\frac{3}{16}$ to 2	15	10
18		A 537 ^e	Class 2	$\frac{3}{16}$ to 2	20	15
		A 633	C and D	$\frac{3}{16}$ to 2	15	10
18		A 662	B and C	$\frac{3}{16}$ to 2	15	10
21		ISO 630	S355 Quality C and D	$\frac{3}{16}$ to 2	15	10
		EN 10025	S355 J2 and K2	$\frac{3}{16}$ to 2	15	10
		CSA G40.21	44WT	$\frac{3}{16}$ to 2	15	10
		CSA G40.21	50WT	$\frac{3}{16}$ to 2	15	10
		A 737	B	$\frac{3}{16}$ to 2	15	10
18		A 841 ^e	Class 1	$\frac{3}{16}$ to 2	15	10
18		A 841 ^e	Class 2	$\frac{3}{16}$ to 2	20	15
14	^a The stated values apply to full-sized specimens. For sub-size specimen acceptance criteria, see ASTM A20. An impact test temperature lower than the design metal temperature may be used by the manufacturer, but the impact value at the test temperature must comply with Table 4-3. When plate is selected, consideration must be given to the possible degradation of the impact properties of the plate in the weld heat-affected zone.					
	^b The steel shall be made with fine-grain practice, without normalizing, for thicknesses of $\frac{3}{16}$ in. to $1\frac{1}{2}$ in.					
	^c The manganese content shall be in the range from 0.85 % to 1.20 % by ladle analysis.					
14	^d The manganese content shall be in the range of 0.80 % to 1.20 %.					
18	^e See Section 4.2.6					

4.2.5.2 All other impact requirements of ASTM A20, supplementary requirement S5, shall apply for all materials listed in Table 4-3, including specifications that do not refer to ASTM A20.

4.2.5.3 For thickness exceeding the range in Table 4-3, impact test requirements shall be mutually agreed by the manufacturer and the purchaser. ASME Section VIII, Division 1, Part UG-84 may be used as a guide.

4.2.6 Simulated Test Coupons

When used in stress-relieved assemblies, the material of quenched and tempered steels A537, Cl 2, and TMCP steel A841 shall be represented by test specimens that have been subjected to the same heat treatment as that used for the stress relieved assembly.

18

4.3 Pipe, Flanges, Forging, and Castings

4.3.1 General

All pipe, flanges, forgings, and castings used in the parts of the tanks that are subject to internal pressure shall conform to applicable requirements of 4.3.2 to 4.3.6 inclusive.

4.3.2 Pipe

18

4.3.2.1 Carbon steel pipe shall conform to one of the following specifications:

- a) ASTM A53;
- b) ASTM A106;
- c) ASTM A134, excluding helical (spiral) welded pipe;
- d) ASTM A139, excluding helical (spiral) welded pipe;
- e) ASTM A333;
- f) ASTM A524;
- g) ASTM A671 (Grades CA, CC, and CD);
- h) API 5L (Grades A and B only).

18

4.3.2.2 When ASTM A134, A139, or A671 pipe is used, it shall comply with the following.

- a) The pipe shall be certified to have been pressure tested.
- b) The plate specification for the pipe shall satisfy the requirements of 4.2.3, 4.2.4, and 4.2.5 that are applicable to that plate specification.
- c) Impact tests for qualifying the welding procedure for the pipe longitudinal welds shall be performed in accordance with 6.7.1.

18

4.3.2.3 For design metal temperatures below -20°F , the materials shall conform to Tables R-1 and/or R-3.

18

4.3.3 Built-up Fittings

Built-up fittings, such as ells, tees, and return bends, may be fabricated by fusion welding when they are designed according to the applicable paragraphs in this standard.

4.3.4 Flanges

4.3.4.1 Hub, slip-on welding neck and long welding neck flanges shall conform to the material requirements of ASME B16.5 for forged carbon steel flanges. Plate material used for nozzle flanges shall have physical properties better than or equal to those required by ASME B16.5. Plate flange material shall conform to 4.2.3.

4.3.4.2 For nominal pipe sizes greater than 24 in., flanges that conform to ASME B16.47, Series B, may be used, subject to the purchaser's approval. Particular attention should be given to ensuring that mating flanges of appurtenances are compatible.

4.3.5 Castings and Forgings

18 Large castings and forgings not covered in 4.1.3 shall be of welding grade if welding is to be done on them. If castings or forging materials have design metal temperatures below -20°F , the materials shall conform to Tables R-1 and/or R-3. They shall conform to one of the following ASTM specifications:

- a) A27 (Grade 60-30, for structural parts only),
- b) A105,
- c) A181,
- d) A350.

4.3.6 Toughness Requirements

Except as covered in 4.3.2.2, the toughness requirements of pipe, flanges, and forgings shall be established as described in 4.3.6.1 through 4.3.6.4.

4.3.6.1 No impact testing is required for ASME B16.5 ferritic steel flanges used at minimum design metal temperature, no colder than -20°F . Piping materials made according to ASTM A333 and ASTM A350 may be used at a minimum design metal temperatures, no lower than the impact test temperature required by the ASTM specification for the applicable material grade, unless additional impact tests (see 4.3.6.4) are conducted.

4.3.6.2 Other pipe and forging materials shall be classified under the material groups shown in Figure 4-2 as follows:

- a) Group I—API 5L, Grades A, B, ASTM A 106, Grades A and B; ASTM A53, Grades A and B; ASTM A181; and ASTM A105;
- b) Group II—ASTM A524, Grades I and II.

4.3.6.3 The materials in the groups listed in 4.3.6.2 may be used at nominal thicknesses, including corrosion allowance, at minimum design metal temperatures no lower than those shown in Figure 4-2 without impact testing (see 4.3.6.4). The governing thickness (see Figure 4-3) to be used in Figure 4-2 shall be as follows.

- a) For butt-welded joints, it is the nominal thickness of the thickest welded joint.
- b) For corner weld (groove or fillet) or lap welds, it is the thinner of the two parts joined.
- c) For nonwelded parts (such as bolted flanges), it is $1/4$ of flat cover nominal thickness.

4.3.6.4 When impact tests are required by 4.3.6.2 or 4.3.6.3, they shall be performed in accordance with the requirements, including minimum energy requirements of ASTM A333, Grade 1 for pipe, or ASTM A350 Grade LF1

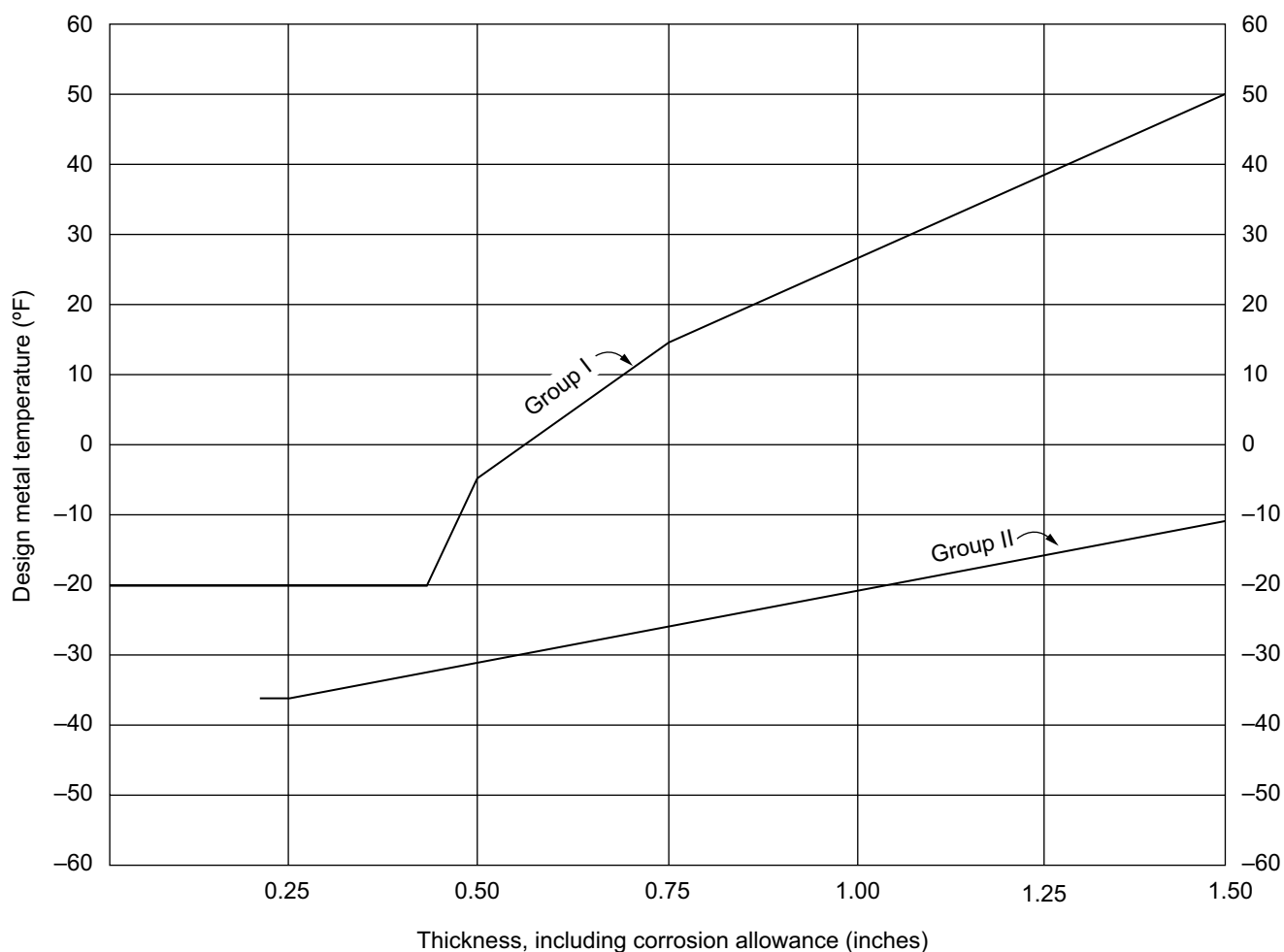


Figure 4-2—Minimum Permissible Design Metal Temperature for Pipe, Flanges, and Forgings without Impact Testing

for forgings at a test temperature no higher than the minimum design metal temperature. Except for the plate specified in 4.2.3, the material specified in 4.3 shall have a minimum Charpy V-notch impact strength of 13 ft-lb (full size specimen) at a temperature no higher than the minimum design metal temperature.

4.4 Bolting Material

4.4.1 Carbon steel bolts may be used if they conform to the following, or to better¹⁵, specifications:

- a) ASTM A193,
- b) ASTM A307,
- c) ASTM A320.

4.4.2 For design metal temperatures below -20°F , bolting materials shall conform to Tables R-1 and/or R-3.

¹⁵ If higher-strength grades of bolts are used, higher bolt stress values are not recommended with full-faced gaskets.

4.5 Structural Shapes

- 18 All structural shapes that are subject to pressure-imposed loads or are otherwise important to the structural integrity of a tank shall be made only by the open-hearth, electric-furnace, or basic-oxygen process. If structural shapes have design metal temperatures below -20°F , the materials shall conform to Tables R-1 and/or R-3. Structural shapes shall conform to one of the following specifications:
- a) ASTM A36;
 - b) ASTM A131;
 - c) ASTM A633 (Grade A only);
 - d) ASTM A992;
 - e) CSA G40.21 (Grades 38W, 44W, and 50W only; if impact tests are required, these grades are designated 38WT, 44WT, and 50WT);
 - 18 f) ISO 630, Grade S275, Qualities B, C, and D;
 - 18 g) EN 10025, Grade S275, Qualities JR, J0, J2, and K2.

4.6 Anchor Bolting Material

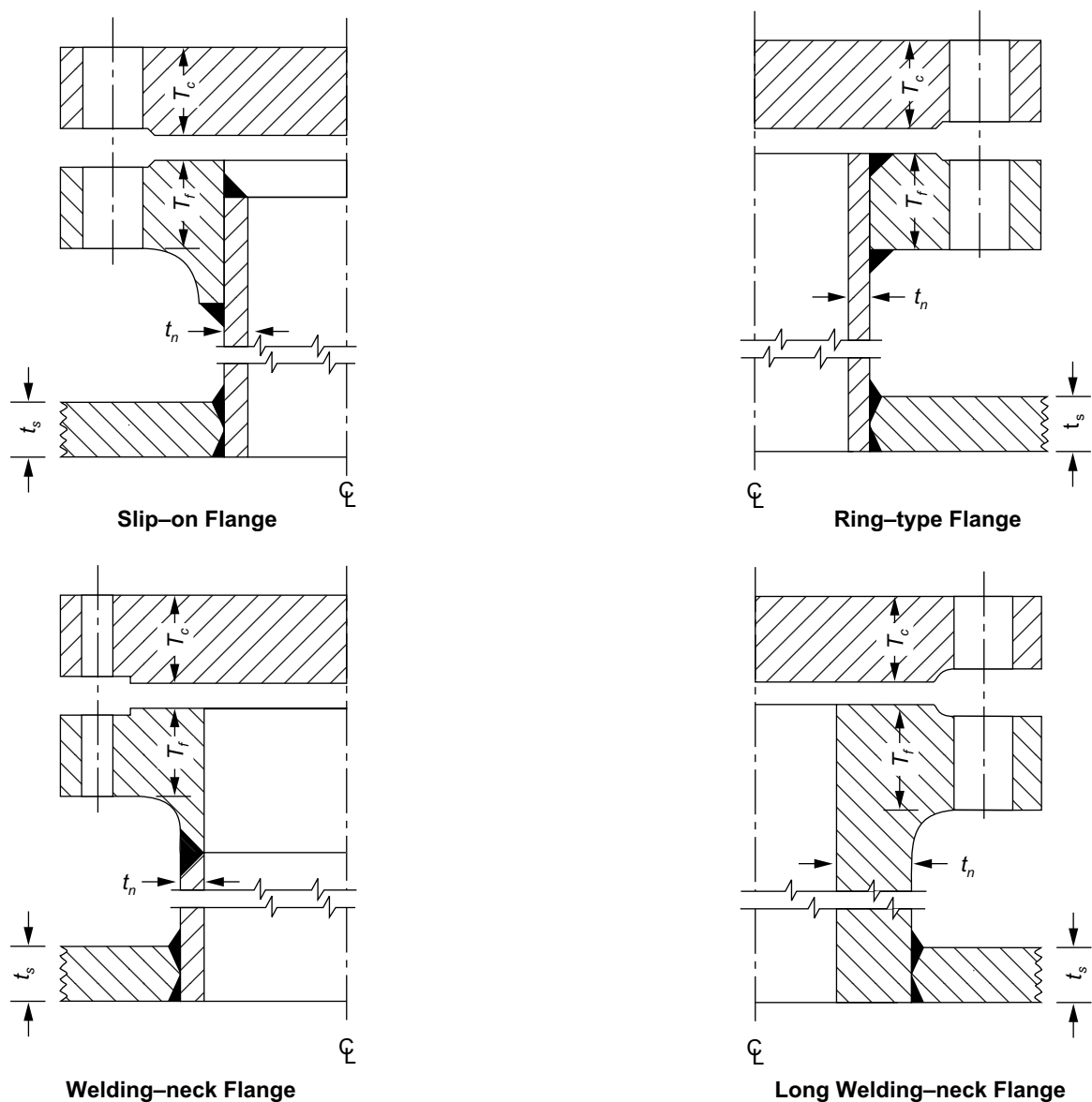
4.6.1 Unless otherwise specified by the purchaser, anchor bolts shall be one of the following:

- a) round bar to ASTM A36, threaded and galvanized;
- 18 b) bolts to ASTM F1554, Grade 36 or 55, galvanized;
- c) round bar to ASTM A479-TP304 stainless steel, annealed;
- d) bolts to ASTM A193-B8-CLASS 1;
- e) bolts to ASTM F468, Alloy 6061-T6.

4.6.2 Anchor bolts with minimum specified yield strength greater than 55 ksi are prohibited.

- 18 **4.6.3** Nuts for carbon steel anchors shall be galvanized heavy hex. Welding is not permitted on anchors that are galvanized. Nuts for stainless steel anchors shall be Type 316 stainless steel heavy hex.

4.6.4 Aluminum anchorage option is provided for certain tanks designed to the provisions of Annex Q.



NOTE 1 Shell reinforcing plate is not included in the illustration above.

NOTE 2 t_s = shell thickness; t_n = nozzle neck thickness; T_f = flange thickness; T_c = bolted cover thickness.

NOTE 3 The governing thickness for each component shall be as follows:

Components	Governing Thickness (whichever is less)
Nozzle neck	t_n or t_s
Slip-on flange	t_n or T_f
Ring-type flange	t_n or T_f
Welding-neck flange	t_n or T_f
Long welding-neck flange	t_n or t_s
Bolted cover	$1/4 T_c$

Figure 4-3—Governing Thickness for Impact Test Determination of Pipe, Flanges, and Forgings

SECTION 5—DESIGN

5.1 General

5.1.1 Scope of Rules

The rules presented in this standard are intended to establish approved engineering practices for low-pressure storage tanks constructed of any shape within the scope of 1.2 and to provide the fundamental rules for design and testing, which can serve as a sufficient basis for an inspector to judge the safety of any vessel and improve the application of the API 620 nameplate. Where these rules do not cover all details of design and construction, the manufacturer, subject to the approval of the inspector, shall provide details of design and construction that will be as safe as those provided by this standard.

5.1.2 Pressure Chambers

For tanks that consist of two or more independent pressure chambers and have a roof, bottom, or other elements in common, each pressure part shall be designed for the most severe combination of pressure or vacuum that can be experienced under the specified operating conditions.

5.1.3 Avoidance of Pockets

Tank walls shall be shaped to avoid any pockets on the inside where gases may become trapped when the liquid level is being raised or on the outside where rainwater may collect.

5.1.4 Volume of Vapor Space

The volume of the vapor space above the high liquid design level upon which the nominal capacity is based shall be not less than 2 % of the total liquid capacity (see 3.2.2).

5.1.5 Tests of New Design

When a tank is of a new design and has (a) an unusual shape or (b) large branches or openings that may make the stress system around these locations in the tank wall unsymmetrical to a degree that, in the judgment of the designer, does not permit computation with a satisfactory assurance of safety, the tank shall be subjected to a proof test, and strain-gauge surveys shall be made as provided in 7.24.

5.2 Operating Temperature

The temperature of the liquids, vapor, or gases stored in, or entering, these tanks shall not exceed 250 °F (see 1.2.2).

5.3 Pressures Used in Design

5.3.1 Above Maximum Liquid Level

5.3.1.1 Tank components, including those above the maximum liquid level, subjected principally to gas pressure shall be designed for the following.

- a) A pressure not less than the relief valves' set pressure. The maximum positive gauge pressure shall be understood to be the nominal pressure rating for the tank (sometimes called the design pressure) and shall not exceed 15 lbf/in.² gauge.
- b) The maximum partial vacuum (also called the design vacuum) when the inflow of air (or another gas or vapor) through the vacuum relief valves is at the tank design maximum in-breathing flow rate.

- 18 | **5.3.1.2** If the maximum liquid level is below the top of the roof, but the tank will be filled to the top of the roof during the hydrostatic test as provided in 7.18.4, the tank shall be designed for both maximum liquid-level conditions.

5.3.1.3 A suitable margin shall be provided between the operating pressure in the gas or vapor space and the relief valve's set pressure. This margin allows for pressure increases caused by variations in temperature, atmospheric pressure, or other factors that affect the pressure in the gas or vapor space.

5.3.1.4 The set pressure of the vacuum relief valve shall limit the vacuum pressure accumulation in the tank to the design vacuum pressure.

5.3.2 Below Maximum Liquid Level

All pressure-containing elements of the tank below the maximum liquid level shall be designed for the most severe combination of gas pressure (or partial vacuum) and static liquid head affecting the element.

5.3.3 Weight for Liquid Storage

The weight for liquid storage shall be assumed to be the weight per ft^3 of the specified liquid contents at 60 °F. When the minimum weight is less than 48 lb/ft^3 , the provisions of 5.5.7 shall be followed. This minimum weight does not apply to tanks used for gas storage only, or used for refrigerated liquid storage as discussed in Annexes Q and R.

5.4 Loads

5.4.1 Individual Loads

- a) **dead load (D_L)**: the weight of the tank or tank component, including any insulation, lining, or corrosion allowance unless otherwise noted.
- b) **hydrostatic and pneumatic tests (H_T)**: the load due to conducting the tests specified in 7.18.
- c) **loads from connected piping (L_P)**.
- d) **loads from platforms and stairways (L_S)** (see Annex E).
- e) **minimum roof live load (L_r)**: 20 lb/ft^2 on the horizontal projected area of the roof.
- f) **pressure (P_g)**: the maximum positive gauge pressure given in 5.3.1.
- g) **pressure (P_v)**: the maximum partial vacuum given in 5.3.1. The maximum partial vacuum shall be at least 1 in. w_c .
- h) **seismic (E)**: seismic loads given in Annex L.
- 18 | i) **snow (S)**: The ground snow load (lb/ft^2) shall be determined from ASCE 7 Figure 7.2-1 or Tables 7.2-2 through 7.2-8 unless the ground snow load is specified by the purchaser. The design uniform roof snow load shall be 0.84 times the ground snow load. Alternately, the design uniform roof snow load shall be determined from the ground snow load in accordance with ASCE 7 or a national standard.
- j) **stored liquid (P_l)**: gauge pressure (lb/in^2) resulting from the liquid head of the liquid with the density given in 5.3.3. All liquid levels from empty to the maximum liquid level shall be considered.
- k) **wind (W)**: The design wind speed (V) shall be either; 1) the 3-sec gust design wind speed (mph) determined from ASCE 7, Figure 6-1, multiplied by $\sqrt{I}$; or 2) the 3-sec gust design wind speed determined from ASCE 7-16 for risk category specified by the purchaser (typically risk category 2 applies—Figure 26.5-1b) multiplied by 0.78; or 3) the 3-sec gust design wind speed specified by the purchaser. When wind is specified as

measured by fastest mile, the speed shall be multiplied by 1.2. For tank components exposed to wind up to 80 ft above ground, the design wind pressures normal to the tank's outside surface shall be the pressures below, multiplied by $(V/120)^2$. For tank components located more than 80 ft above ground, use ASCE 7 to determine wind pressures.

Surface	Direction	Average Pressure (lbf/ft ²)	Maximum Pressure (lbf/ft ²)
cylinder	inward	16	31
sphere	inward or outward	16	31
dome or cone roof or bottom	outward	30	50

Alternatively, pressures may be determined in accordance with ASCE 7 or a national standard for the specific conditions for the tank being designed.

Average wind pressure on the roof shall be used to design the roof to shell compression region and for overturning. Maximum wind pressure shall be used to design the roof and shell.

NOTE ASCE 7-16 wind velocities now have LRFD load factors and risk category (importance factors) built in, whereas API 620 uses the working stress. The 0.78 factor applied to the ASCE 7-16 wind speed provides a conversion to working stress levels.

5.4.2 Load Combinations

The tank shall be designed for the following load combinations. If the absence of any load other than dead load results in a more severe condition, that load shall not be included in the combination.

- a) $D_L + P_g + P_l$
- b) $D_L + W_L + 0.7P_g$
- c) $D_L + W_L + 0.4P_v$
- d) $D_L + P_v + 0.4(L_r \text{ or } S)$
- e) $D_L + 0.4P_v + (L_r \text{ or } S)$
- f) $D_L + 0.7P_g + P_l + E + 0.1S$
- g) $D_L + H_t$
- h) $D_L + L_s$
- i) $D_L + L_p + P_g + P_l$

5.5 Maximum Allowable Stress for Walls¹⁶

5.5.1 General

Higher localized shear and secondary bending stresses may exist in the walls of tanks designed and fabricated according to this standard, and the prescribed test loadings may result in some localized reshaping. This is permissible, since localized reshaping is expected as part of a legitimate fabrication operation, if the reshaping is not

¹⁶ See *Biaxial Stress Criteria for Large Low-Pressure Tanks*, written by J. J. Dvorak and R. V. McGrath and published as *Bulletin No. 69* (June 1961) by the Welding Research Council, 3 Park Avenue, 27th Floor, New York, New York 10016.

so severe that upon release of the test pressure, plastic straining occurs in the opposite direction. This would tend to develop continuing plastic straining in subsequent normal operation.

5.5.2 Nomenclature

5.5.2.1 Variables relating to stresses common to the requirements of 5.5.3 through 5.5.5 and Figure 5-1 are defined as follows:

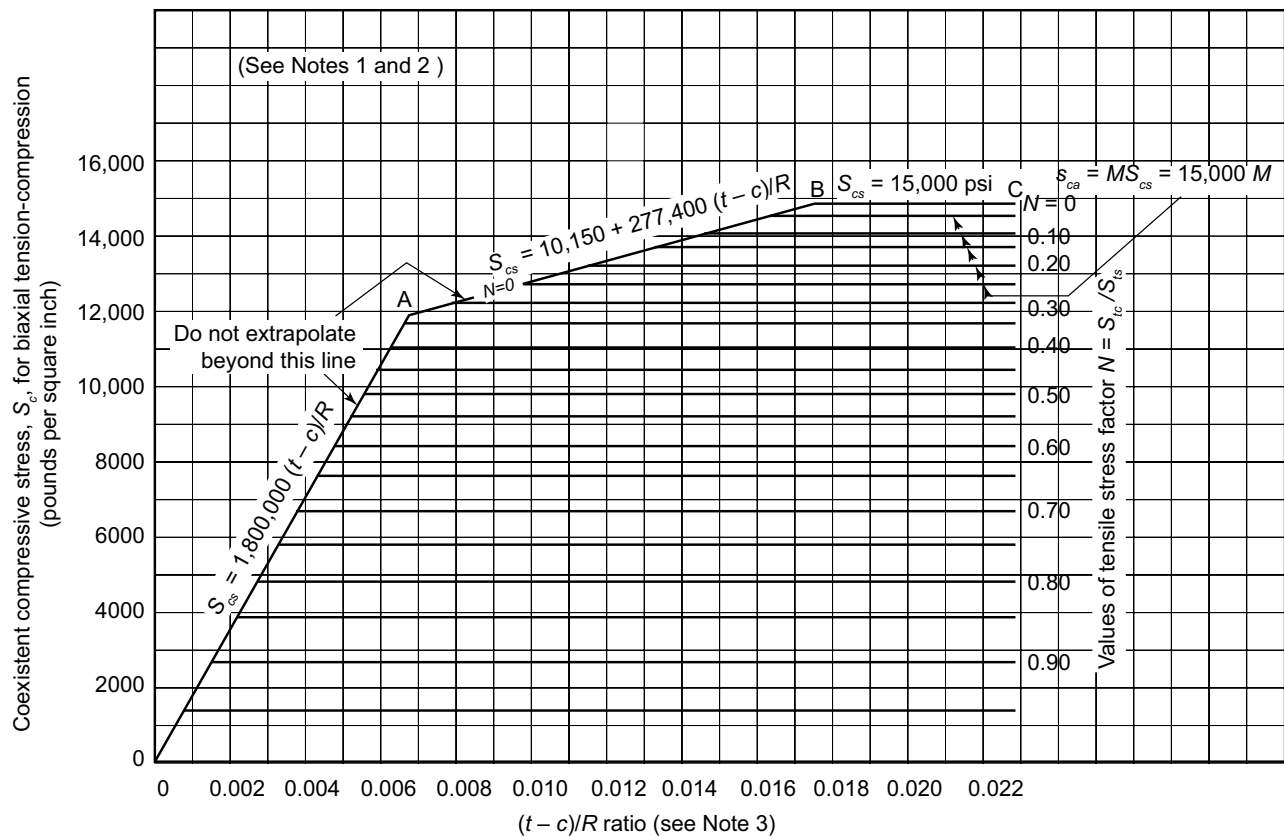
- t is the thickness of the wall, in inches;
- R is the radius of the wall, in inches;
- c is the corrosion allowance, in inches;
- S_{ts} is the maximum allowable stress for simple tension, in lbf/in.², as given in Table 5-1;
- S_{cs} is the maximum allowable longitudinal compressive stress, in lbf/in.², for a cylindrical wall acted upon by an axial load with neither a tensile nor a compressive force acting concurrently in a circumferential direction (determined in accordance with 5.5.4.2 for the thickness-to-radius ratio involved);
- s_{ta} is the allowable tensile stress, in lbf/in.²; s_{ta} lower than S_{ts} because of the presence of a coexistent compressive stress perpendicular to it;
- s_{ca} is the allowable compressive stress, in lbf/in.²; s_{ca} is lower than S_{cs} because of the presence of a coexistent tensile or compressive stress perpendicular to it;
- s_{tc} is the computed tensile stress, in lbf/in.², at the point under consideration;
- s_{cc} is the computed compressive stress, in lbf/in.², at the point under consideration;
- s_t is the general variable for indicating a tensile stress, in lbf/in.², which may be either an allowable or computed value depending on the context in which the variable is used;
- s_c is the general variable for indicating a compressive stress, in lbf/in.², which may be either an allowable or computed value depending on the context in which the variable is used;
- N is the ratio of the tensile stress, s_t , to the maximum allowable stress for simple tension, S_{ts} ;
- M is the ratio of the compressive stress s_c , to the maximum allowable compressive stress, S_{cs} (see Figure F-1).

5.5.2.2 The term tank wall is defined in 3.3. Unless otherwise stipulated in this standard, the stresses in nozzle and manway necks, reinforcing pads, flanges, and cover plates shall not exceed the values that apply for the walls of the tank.

5.5.3 Maximum Tensile Stresses

5.5.3.1 The maximum tensile stresses in the outside walls of a tank, as determined for any of the loadings listed in 5.4 or any concurrent combination of such loadings that is expected to be encountered in the specified operation, shall not exceed the applicable stress values determined in accordance with provisions described in 5.5.3.2 and 5.5.3.3.

5.5.3.2 If both the meridional and latitudinal unit forces, T_1 and T_2 , are tensile or if one force is tensile and the other is zero, the computed tensile stress, s_{tc} , shall not exceed the applicable value given in Table 5-1.



NOTE 1 At no time can a compressive stress for a particular value of $(t - c)/R$ exceed S_{cs} represented by curve 0ABC, no values of compressive stress or N are permitted to fall to the left or above this curve.

NOTE 2 See Figure F-1 for relationship between factors M and N .

NOTE 3 If compressive stress is latitudinal, use $R = R_1$; if compressive stress is meridional, use $R = R_2$.

Figure 5-1—Biaxial Stress Chart for Combined Tension and Compression, 30,000 lbf/in.² to 38,000 lbf/in.² Yield Strength Steels

5.5.3.3 If the meridional force, T_1 , is tensile and the coexistent latitudinal unit force, T_2 , is compressive or if T_2 is tensile and T_1 is compressive, the computed tensile stress, s_{cs} , shall not exceed a value of the allowable tensile stress, s_{ta} , obtained by multiplying the applicable stress value given in Table 5-1 by the appropriate value of N obtained from Figure 5-1 for the value of compressive stress ($s_c = s_{cc}$) and the co-related ratio of $(t - c)/R$ involved. However, in cases where the unit force acting in compression does not exceed 5 % of the coexistent tensile unit force acting perpendicular to it, the designer has the option of permitting a tensile stress of the magnitude specified in 5.5.3.2 instead of complying strictly with the provisions of this paragraph, (see F.1 for examples illustrating the determination of allowable tensile stress values, s_{ta} , in accordance with this paragraph). In no event shall the value of s_{ta} exceed the product of the applicable joint efficiency for tension as given in Table 5-2 and the allowable stress for simple tension shown in Table 5-1.

5.5.4 Maximum Compressive Stresses

5.5.4.1 Except as provided in 5.12.4.3 for the compression-ring region, the maximum compressive stresses in the outside walls of a tank, as determined for any of the loadings listed in 5.4 or any concurrent combination of loadings expected to be encountered in the specified operation, shall not exceed the applicable stress values determined in accordance with the provisions described in 5.5.4.2 through 5.5.4.8. These rules do not purport to apply when the circumferential stress on a cylindrical wall is compressive (as in a cylinder acted upon by external pressure). However, values of S_{cs} computed as in 5.5.4.2, with R equal R_1 when the compressive unit force is latitudinal or to R_2 when the compressive unit force is meridional, in some degree form the basis for the rules given in 5.5.4.3, 5.5.4.4, and 5.5.4.5, which apply to walls of double curvature.

Table 5-1—Maximum Allowable Stress Values for Simple Tension

18	Specification (See Note 1)	Grade/Class	Notes	Specified Minimum		Maximum Allowable Tensile Stress for Tension, S_{ts} (lbf/in. ² , See Notes 2 and 3)
				Tensile Strength (lbf/in. ²)	Yield Point (lbf/in. ²)	
	Plates					
	ASTM A36	—	4	58,000	36,000	16,000
	ASTM A131	A	4, 5, and 6	58,000	34,000	15,200
	ASTM A131	B	4	58,000	34,000	16,000
	ASTM A131	CS	4	58,000	34,000	16,000
	ASTM A283	C	4 and 5	55,000	30,000	15,200
	ASTM A283	D	4, 5, and 6	60,000	33,000	15,200
	ASTM A285	C	5	55,000	30,000	16,500
	ASTM A516	55	—	55,000	30,000	16,500
	ASTM A516	60	—	60,000	32,000	18,000
	ASTM A516	65	—	65,000	35,000	19,500
	ASTM A516	70	—	70,000	38,000	21,000
	ASTM A537	Class 1	7	70,000	50,000	21,000
	ASTM A537	Class 2	7	80,000	60,000	24,000
	ASTM A573	58	4	58,000	32,000	16,000
	ASTM A573	65	4	65,000	35,000	18,000
	ASTM A573	70	4	70,000	42,000	19,300
	ASTM A633	C and D	4 and 7	70,000	50,000	19,300
	ASTM A662	B	—	65,000	40,000	19,500
18	ASTM A662	C	7	70,000	43,000	21,000
	ASTM A737	B	7	70,000	50,000	21,000
18	ASTM A841	Class 1 (Grades A and B).	7	70,000	50,000	21,000
21	ASTM A841	Class 2 (Grades A and B).	7	80,000	60,000	24,000
	CSA G40.21	38W and 38WT	4	60,000	38,000	16,500
	CSA G40.21	44W and 44WT	4	64,000	44,000	17,700
	CSA G40.21	50W and 50WT	4	65,000	50,000	18,000
	ISO 630	S275 Quality C, D	4	59,500	37,000	16,400
	ISO 630	S355 Quality C, D	4	68,100	48,500	18,800
	EN 10025	S275 Quality J0, J2	4	59,500	37,000	16,400
	EN 10025	S355 Quality J0, J2, K2	4	68,100	48,500	18,800
	Pipe					
	Seamless					
	API Spec 5L	B	—	60,000	35,000	18,000
21	ASTM A53	B	—	60,000	35,000	18,000

Table 5-1—Maximum Allowable Stress Values for Simple Tension (Continued)

Specification (See Note 1)	Grade/Class	Notes	Specified Minimum		Maximum Allowable Tensile Stress for Tension, S_{ts} (lbf/in. ² , See Notes 2 and 3)
			Tensile Strength (lbf/in. ²)	Yield Point (lbf/in. ²)	
ASTM A106	B	—	60,000	35,000	18,000
ASTM A106	C	—	70,000	40,000	21,000
ASTM A333	1	—	55,000	30,000	16,500
ASTM A333	3	—	65,000	35,000	19,500
ASTM A333	6	—	60,000	35,000	18,000
ASTM A524	I	—	60,000	35,000	18,000
ASTM A524	I1	—	55,000	30,000	16,500
Electric-fusion Welded					
ASTM A134	A283 Grade C	4, 5, and 9	55,000	30,000	12,100
ASTM A134	A285 Grade C	5 and 9	55,000	30,000	13,200
ASTM A139	B	9	60,000	35,000	14,400
ASTM A671	CA55	9	55,000	30,000	13,200
ASTM A671	CC60	9	60,000	32,000	14,400
ASTM A671	CC65	9	65,000	35,000	15,600
ASTM A671	CC70	9	70,000	38,000	16,800
ASTM A671	CD70	7 and 9	70,000	50,000	16,800
ASTM A671	CD80	7 and 9	80,000	60,000	19,200
ASTM A671	CE55	9	55,000	30,000	13,200
ASTM A671	CE60	9	60,000	32,000	14,400
Forgings					
ASTM A105	—	—	60,000	30,000	18,000
ASTM A181	I	—	60,000	30,000	18,000
ASTM A181	II	—	70,000	36,000	21,000
ASTM A350	LF1	—	60,000	30,000	18,000
ASTM A350	LF2	—	70,000	36,000	21,000
ASTM A350	LF3	—	70,000	40,000	21,000
Castings and Bolting					
ASTM A27	60-30	10	60,000	30,000	14,400
ASTM A193	B7	11	125,000	105,000	24,000
ASTM A307	B for flanges and pressure parts	11 and 12	55,000	—	8,400
ASTM A307	B for structural parts.	11	55,000	—	15,000
ASTM A320	bolting L7	11	125,000	105,000	24,000

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Documents

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Table 5-1—Maximum Allowable Stress Values for Simple Tension (Continued)

Specification (See Note 1)	Grade/Class	Notes	Specified Minimum		Maximum Allowable Tensile Stress for Tension, S_{ts} (lbf/in. ² , See Notes 2 and 3)
			Tensile Strength (lbf/in. ²)	Yield Point (lbf/in. ²)	
Structural Shapes Resisting Internal Pressure					
ASTM A36	—	4 and 6	58,000	36,000	15,200
ASTM A131	A	4 and 6	58,000	34,000	15,200
ASTM A633	A	4	63,000	42,000	17,400
ASTM A992	—	4 and 6	65,000	50,000	15,200
CSA G40.21	38W and 38WT	4 and 6	60,000	38,000	15,200
CSA G40.21	44W and 44WT	4 and 6	64,000	44,000	15,200
CSA G40.21	50W and 50WT	4 and 6	65,000	50,000	15,200
ISO 630	S275 Quality B, C, D	4 and 6	59,500	37,000	15,200
ISO 630	S355 Quality B, C, D	4 and 6	68,100	48,500	15,200
EN 10025	S275 Quality JR, J0, J2	4 and 6	59,500	37,000	15,200
EN 10025	S355 Quality JR, J0, J2, K2	4 and 6	68,100	48,500	15,200
NOTE 1 All pertinent modifications and limitations of specifications required by 4.2 through 4.6 shall be complied with.					
NOTE 2 Except for those cases where additional factors or limitations are applied as indicated by references to Notes 4, 6, 10, and 12, the allowable tensile stress values given in this table for materials other than bolting steel are the lesser of (a) 30% of the specified minimum ultimate tensile strength for the material or (b) 60 % of the specified minimum yield point.					
NOTE 3 Except when a joint efficiency factor is already reflected in the specified allowable stress value, as indicated by the references to Note 10, or where the value of N determined in accordance with 5.5.3.3. is less than the applicable joint efficiency given in Table 5-2 (and, therefore, effects a greater reduction in allowable stress than would the pertinent joint efficiency factor, if applied), the specified stress values for welds in tension shall be multiplied by the applicable joint efficiency factor, E , given in Table 5-2.					
NOTE 4 Stress values for structural quality steels include a quality factor of 0.92.					
NOTE 5 Plates and pipe shall not be used in thickness greater than $\frac{3}{4}$ in.					
NOTE 6 Stress values are limited to those for steel that has an ultimate tensile strength of only 55,000 lbf/in. ² .					
NOTE 7 Less than or equal to 2 $\frac{1}{2}$ in. thickness.					
NOTE 8 Less than or equal to 1 $\frac{1}{2}$ in. thickness.					
NOTE 9 Stress values for fusion-welded pipe include a welded-joint efficiency factor of 0.80 (see 5.23.3). Only straight-seam pipe shall be used; the use of spiral-seam pipe is prohibited.					
NOTE 10 Stress values for castings include a quality factor of 0.80.					
NOTE 11 See 5.6.					
NOTE 12 Allowable stress based on Section VIII of the ASME <i>Boiler and Pressure Vessel Code</i> multiplied by the ratio of the design stress factors in this standard and Section VIII of the ASME <i>Code</i> , namely 0.30/0.25.					

5.5.4.2 If a cylindrical wall, or a portion thereof, is acted upon by a longitudinal compressive force with neither a tensile nor a compressive force acting concurrently in a circumferential direction, the computed compressive stress, s_{cs} , shall not exceed a value, S_{cs} , established for the applicable thickness-to-radius ratio as follows:

for values of $(t - c)/R$ less than 0.00667,

$$S_{cs} = 1,800,000 [(t - c)/R]$$

for values of $(t - c)/R$ between 0.00667 and 0.0175,

$$S_{cs} = 10,150 + 277,400 [(t - c)/R]$$

for values of $(t - c)/R$ greater than 0.0175,

$$S_{cs} = 15,000$$

5.5.4.3 If both the meridional and latitudinal unit forces, T_1 and T_2 , are compressive and of equal magnitude, the computed compressive stress, s_{cc} , shall not exceed a value, s_{ca} , established for the applicable thickness-to-radius ratio as follows:

for values of $(t - c)/R$ less than 0.00667,

$$s_{ca} = 1,000,000 [(t - c)/R]$$

for values of $(t - c)/R$ between 0.00667 and 0.0175,

$$s_{ca} = 5650 + 154,200 [(t - c)/R]$$

for values of $(t - c)/R$ greater than 0.0175,

$$s_{ca} = 8340$$

5.5.4.4 If both the meridional and latitudinal unit forces, T_1 and T_2 , are compressive but of unequal magnitude, both the larger and smaller computed compressive stresses shall be limited to values that satisfy the following requirements:

$$(S_l + 0.8S_s)/S_{cs} \leq 1.0$$

$$1.8S_s/S_{cs} \leq 1.0$$

where

S_l is the larger stress, in lbf/in.²;

S_s is the small stress, in lbf/in.²;

S_{cs} is the maximum allowable longitudinal compressive stress, in lbf/in.², determined as in 5.5.4.2 using R for the larger unit force in the first equation and for the smaller unit force in the second equation.

NOTE In the previous expressions, if the unit force involved is latitudinal, R shall be equal to R_1 ; if the force is meridional, R shall be equal to R_2 .

5.5.4.5 If the meridional unit force, T_1 , is compressive and the coexistent unit force T_2 , is tensile, except as otherwise provided in 5.5.4.6, or if T_2 is compressive and T_1 is tensile the computed compressive stress, s_{cc} , shall not exceed a value of the allowable compressive stress, s_{ca} , determined from Figure 5-1 by entering the computed value of N and the value of t/R associated with the compressive unit stress and reading the value of s_c that corresponds to that point. The value of s_c will be the limiting value of s_{ca} for the given conditions. (See F-1 for examples illustrating the determination of allowable compressive stress values in accordance with this paragraph.)

5.5.4.6 When a local axial compressive buckling stress in a cylindrical shell is primarily due to a moment in the cylinder, then the allowable longitudinal compressive stress S_{cs} or s_{ca} , as specified in 5.5.4.2 or 5.5.4.3, may be

Table 5-2—Maximum Allowable Efficiencies for Arc-welded Joints

Type of Joint	Limitations	Basic Joint Efficiency (%)	Radiographed (See Note 1)	Maximum Joint Efficiency (%; see Note 2)
Butt joints, attained by double-welding or other means approved by the purchaser, that will obtain the quality of deposited weld metal on the inside and outside weld surfaces that agrees with the requirements of Paragraph UW-35 in Section VIII of the <i>ASME Code</i> ; welds using metal backing strips that remain in place are excluded.	None, for all double-welded joints, except for roofs above liquid level.	85	Spot Full (see Note 3)	85 100
	Roofs above liquid level.	70	Spot Full (see Note 3)	70 85 100
Single-welded butt joint with backing strip or equivalent other than those included above.	Longitudinal or meridional circumference or latitudinal joints between plates not more than 1 ¹ / ₄ in. thick; nozzle attachment welding without thickness limitation.	75	Spot Full (see Note 3)	75 85
	Roofs above liquid level.	70	Spot Full (see Note 3)	70 75 85
Single-welded butt joint without backing strip.	Nozzle attachment welding.	70	—	70
Double full-fillet lap joint (see Note 4).	Longitudinal or meridional joints and equivalent (see Note 5) circumferential or latitudinal joints between plates not more than 3/8 in. thick; joints of this type shall not be used for longitudinal or meridional joints that the provisions of 5.12.2 require to be butt-welded.	70	—	70
	Other circumferential or latitudinal joints between plates not more than 5/8 in. thick.	65	—	65
Single full-fillet lap joint (see Note 4).	Longitudinal or meridional joints and circumferential or latitudinal joints between plates not more than 3/8 in. thick; joints of this type shall not be used for longitudinal or meridional joints that the provisions of 5.12.2 require when the thinner plate joined exceeds 1/4 in.	35	—	35
Single full-fillet lap joints for head-to-nozzle joints	For attachment of heads convex to pressure not more than 5/8 in. required thickness, only with use of the fillet weld on the inside of the nozzle.	35	—	35
Nozzle-attachment fillet welds	Attachment welding for nozzles and their reinforcements.		(Included in the strength factors in 5.16.8.3)	
Plug welds (see 5.24.5)	Attachment welding for nozzle reinforcements (see Note 6).	80	—	80

NOTE 1 See 5.26 and 7.15 for examination requirements.

NOTE 2 Regardless of any values given in this column, the efficiency for lap-welded joints between plates with surfaces of double curvature that have a compressive stress across the joint from a negative value of P_c or other external loading may be taken as unity; such compressive stress shall not exceed 700 lbf/in.². For all other lap-welded joints, the joint efficiency factor must be applied to the allowable compressive stress, S_{ca} . The efficiency for full-penetration butt-welded joints, which are in compression across the entire thickness of the connected plates, may be taken as unity.

NOTE 3 All main butt-welded joints (see 5.26.4.2) shall be completely radiographed or ultrasonically examined as specified in 5.26 and nozzle and reinforcement attachment welding shall be examined by the magnetic-particle method as specified in 7.15.2.

NOTE 4 Thickness limitations do not apply to flat bottoms supported uniformly on a foundation.

NOTE 5 For the purposes of this table, a circumferential or latitudinal joints shall be considered subject to the same requirements and limitations as are longitudinal or meridional joints when such a circumferential or latitudinal joint is located (a) in a spherical, tori spherical or ellipsoidal shape or in any other surface of double curvature, (b) at the junction between a conical or dished roof (or bottom) and cylindrical sidewalls, as considered in 5.12.3 or (c) at a similar juncture at either end of a transition section or reducer as shown in Figure 5-9.

NOTE 6 The efficiency factors shown for fillet welds and plug welds are not to be applied to the allowable shearing stress values shown in Table 5-3 for structural welds.

increased by 20 %. If the shell bending is due to wind (tank full or empty) or due to earthquake (tank empty), then in addition to the above allowed 20 % increase, the allowable buckling stress due to a moment can be increased an additional $\frac{1}{3}$. For tanks full or partially full of liquid and for an earthquake induced longitudinal compressive stress, the allowable compression stress need not be limited for biaxial stress as otherwise may be required by Figure 5-1.

For seismic design, the tank full is usually the worst case. For wind loading, the tank empty and with internal pressure is usually the worst case for local, bending induced compressive stress.

5.5.4.7 The allowable compressive stresses previously specified in 5.5.4 are predicated on butt-welded construction. If one or more of the main joints across which the compressive force acts are of the lap-welded type, the allowable compressive stress will be determined according to 5.5.4, but subject to the limitations of 5.12.2 and Table 5-2 (including Note 2).

5.5.4.8 Cylindrical shells can be checked for wind buckling to determine if there is the need for intermediate wind girders using the rules of 5.10.6. If the transition between the roof or bottom is a curved knuckle section (5.12.3) then $\frac{1}{3}$ of the knuckle height shall be included as part of the unstiffened shell height.

5.5.5 Maximum Shearing Stresses

The maximum shearing stresses in welds used for attaching manways and nozzles and their reinforcements or other attachments to the walls of a tank and in sections of manway or nozzle necks that serve as reinforcement attachment shall not exceed 80 % of the value of the applicable maximum allowable tensile stress, S_{ts} , given in Table 5-1 for the kind of material involved. Such maximum shearing stresses are permissible only where the loading is applied in a direction perpendicular to the length of the weld and must be reduced where the loading is applied differently (see 5.16.8.3).

5.5.6 Maximum Allowable Stresses for Wind or Earthquake Loadings

The maximum allowable stresses for design loadings combined with wind or earthquake loadings shall not exceed 133 % of the stress permitted for the design loading condition; except as allowed in Annex L, this stress shall not exceed 80 % of the specified minimum yield strength for carbon steel. For stainless steel and aluminum, see Q.3.3.6.

5.5.7 Allowable Stress for Tests

Stresses for hydrostatic and hydrostatic-pneumatic tests shall not exceed 130 % of the allowable design tensile stress or 125 % of the allowable design compressive stress except as modified in 5.12.4.3. Calculations are required for product density less than 48 lb/ft³ to verify test stresses will not exceed these limits.

5.6 Maximum Allowable Stress Values for Structural Members and Bolts

5.6.1 Subject to the provisions of 5.6.5, the maximum stresses in internal or external diaphragms, webs, trusses, columns, and other framing, as determined for any of the loadings listed in 5.4 or any concurrent combination of such loadings expected to be encountered in the specified operation, shall not exceed the applicable allowable stresses given in Table 5-3.

Table 5-3—Maximum Allowable Stress Values for Structural Members

Structural Member	Value for Members Not Subject to Pressure-imposed Loads (lb/in. ²)	Value for Members Subject to Pressure-imposed Loads (lb/in. ²)
Tension		
Rolled steel, on net section	18,000	Per Table 5-1
Butt welds on smaller cross-sectional area, in or at edge of weld (see 5.16.8.3, Item a)	18,000	Per Table 5-1
Bolts and other threaded parts on net area at roof of thread	18,000	Per Table 5-1
Compression (see Note 1)		
Axially loaded structural columns, structural bracing, and structural secondary members, on gross section	$18,000 / [1 + (l^2/18,000r^2)]$ but not to exceed 15,000	$18,000 / [1 + (l^2/18,000r^2)]$ but not to exceed 15,000
Axially loaded tubular columns, tubular bracing and tubular secondary members, on gross section (minimum permissible thickness of 1/4 in.)	$18,000Y / [1 + (l^2/18,000r^2)]$ but not to exceed 15,000Y	$18,000Y / [1 + (l^2/18,000r^2)]$ but not to exceed 15,000Y
Butt welds on smaller cross-sectional area, in or at edge of weld (crushing)	18,000	15,000
Plate-girder stiffeners, on gross section	18,000	15,000
Bending (see Note 2)		
Tension on extreme fibres of rolled sections, plate girders, and built-up members	18,000	Per Table 5-1
Compression on extreme fibers of rolled sections, plate girders, and built-up members With ld/bt not in excess of 600 With ld/bt in excess of 600	18,000 $10,800,000/(ld/bt)$	Same as tens. val. from Table 5-1 [(600) (tension value from Table 5-1)/(ld/bt)]
Stress on extreme fibers of pins Members subjected to both axial and bending loads shall be proportioned so that maximum combined axial and bending stress will not exceed the permissible value for axial loading alone	27,000	20,000
Stresses on extreme fibers of butt welds resulting from bending shall not exceed the values prescribed for tension and compression, respectively; such values for welds in tension must be multiplied by the applicable joint efficiency		
Stresses on extreme fibers of butt welds resulting from bending shall not exceed the values prescribed for tension and compression, respectively; such values for welds in tension must be multiplied by the applicable joint efficiency		

Table 5-3—Maximum Allowable Stress Values for Structural Members (Continued)

Structural Member	Value for Members Not Subject to Pressure-imposed Loads (lb/in. ²)	Value for Members Subject to Pressure-imposed Loads (lb/in. ²)
Shearing (see Note 2)		
Pins and turned bolts in reamed or drilled holes	13,500	12,000
Unfinished bolts	10,000	8,000
Webs of beams and plate girders where h/t is not more than 60, or where web is adequately stiffened, on gross section of web	12,000	$\frac{2}{3}$ tension value from Table 5-1
Webs of beams and plate finders where web is not adequately stiffened and h/t is more than 60, on gross section of web	$18,000/[1 + (h^2/7200t^2)]$	(Tension value from Table 5-1) $/[1 + (h^2/7200t^2)]$
Fillet welds where load is perpendicular to the length of weld, on the section through the throat (see 5.16.8.3, Item b)	12,600	70% tension value from Table 5-1
Fillet welds where load is parallel to the length of weld, on the section through the throat (see 5.16.8.3, Item b)	9,000	50% tension value from Table 5-1
Plug welds or slot welds, on effective faying-surface area of weld (see 5.24.5 and Table 5-2)	11,700	65% tension value from Table 5-1
Butt welds on least cross-sectional area, in or at edge of weld (see 5.16.8.3, Item a)	14,400	80% tension value from Table 5-1
Bearing		
Pins and turned bolts in reamed or drilled holes		
Load applied to bolt at only one side of the member connected	24,400	$1.33 \times$ tension value from Table 5-1
Load distributed uniformly, approximately, across thickness of the member connected	30,000	$1.67 \times$ tension value from Table 5-1
Unfinished bolts		
Load applied to bolt at only one side of the member connected	16,000	$0.09 \times$ tension value from Table 5-1
Load distributed uniformly, approximately, across thickness of the member connected	20,000	$1.1 \times$ tension value from Table 5-1

Table 5-3—Maximum Allowable Stress Values for Structural Members (Continued)

Structural Member	Value for Members Not Subject to Pressure-imposed Loads (lb/in. ²)	Value for Members Subject to Pressure-imposed Loads (lb/in. ²)
NOTE 1 The variables in the compressive stress equations are defined as follows: l = unbraced length of the column, in inches.; r = corresponding least radius of gyration of the column, in inches; t = thickness of the tubular column, in inches; Y = unity (1.0) for values of t/R equal to or greater than 0.015; $Y = (2/3)[100(t/r)] \{2 - (2/3)[100(t/r)]\}$ for values of t/R less than 0.15. NOTE 2 The variables in the bending stress equations are defined as follows: l = unsupported length of the member; for a cantilever beam not fully stayed at its outer end against translation or rotation, l shall be taken as twice the length of the compression flange, in inches; d = depth of the member, in inches; b = width of its compression flange, in inches; t = thickness of its compression flange, in inches. NOTE 3 The variables in the shearing stress equations are defined as follows: h = clear distance between web flanges, in inches; t = thickness of the web, in inches.		

5.6.2 The slenderness ratio (that is, the ratio of the unbraced length, l , to the least radius of gyration, r , for structural members in compression and for tension members other than rods shall not exceed the following values, except as provided in 5.6.3.

- a) For main compression members—120.
- b) For bracing and other secondary members in compression—200.
- c) For main tension members—240.
- d) For bracing and other secondary members in tension—300.

5.6.3 The slenderness ratio of main compression members inside a tank may exceed 120 but not 200, provided that the member is not ordinarily subject to shock or vibration loads and that the unit stress under full design loadings does not exceed the following fraction of the stress value stipulated in Table 5-3 for the member's actual l/r ratio: $f = 1.6 - (l/200r)$.

5.6.4 The gross and net sections of structural members shall be determined as described in 5.6.4.1 through 5.6.4.5.

5.6.4.1 The gross section of a member at any point shall be determined by summing the products of the thickness and the gross width of each element as measured normal to the axis of the member. The net section shall be determined by substituting for the gross width the net width which, in the case of a member that has a chain of holes extending across it in any diagonal or zigzag line, shall be computed by deducting from the gross width the sum of the diameters of all holes in the chain and adding the following quantity for each gauge space in the chain:

$$\frac{s^2}{4g}$$

where

- s is the longitudinal spacing (pitch), in inches, of any two successive holes;
- g is the transverse spacing (gauge), in inches, of the same two holes.

5.6.4.2 In the case of angles, the gauge for holes in opposite legs shall be the sum of the gauges from the back of the angle minus the thickness.