Date: March 2009
Re: Addendum 1

This package contains Addendum 1 of API 620, *Design and Construction of Large, Welded, Low-pressure Storage Tanks*, 11th Edition. This package consists of the pages that have changed since the February 2008 printing of the 11th Edition.

To update your copy of API 620, replace, delete or add the following pages as indicated:

<table>
<thead>
<tr>
<th>Part of Book Changed</th>
<th>Old Pages to be Replaced</th>
<th>New Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover</td>
<td>Front Cover (+ blank)</td>
<td>Front Cover (+ blank)</td>
</tr>
<tr>
<td>Front Matter</td>
<td>Title Page and Special Notes v – ix (+ blank)</td>
<td>Title Page and Special Notes v – ix (+ blank)</td>
</tr>
<tr>
<td>Section 1</td>
<td>1-1 – 1-3 (+ blank)</td>
<td>1-1 – 1-3 (+ blank)</td>
</tr>
<tr>
<td>Section 3</td>
<td>3-1 – 3-2</td>
<td>3-1 – 3-2</td>
</tr>
<tr>
<td>Section 4</td>
<td>4-3 – 4-4</td>
<td>4-3 – 4-4</td>
</tr>
<tr>
<td>Section 5</td>
<td>5-5 – 5-8</td>
<td>5-5 – 5-8</td>
</tr>
<tr>
<td></td>
<td>5-31 – 5-32</td>
<td>5-31 – 5-32</td>
</tr>
<tr>
<td></td>
<td>5-49 – 5-50</td>
<td>5-49 – 5-50</td>
</tr>
<tr>
<td></td>
<td>5-59 – 5-60</td>
<td>5-59 – 5-60</td>
</tr>
<tr>
<td>Section 6</td>
<td>6-1 – 6-6</td>
<td>6-1 – 6-6</td>
</tr>
<tr>
<td>Section 7</td>
<td>7-1 – 7-2</td>
<td>7-1 – 7-2</td>
</tr>
<tr>
<td></td>
<td>7-9 – 7-10</td>
<td>7-9 – 7-10</td>
</tr>
<tr>
<td>Section 9</td>
<td>9-1 – 9-2</td>
<td>9-1 – 9-2</td>
</tr>
<tr>
<td>Appendix A</td>
<td>A-1 – A-7 (+ blank)</td>
<td>A-1 (+ blank)</td>
</tr>
<tr>
<td>Appendix L</td>
<td>L-1 – L-11 (+ blank)</td>
<td>L-1 – L-8</td>
</tr>
<tr>
<td>Appendix Q</td>
<td>Q-15 – Q-16</td>
<td>Q-15 – Q-16</td>
</tr>
<tr>
<td></td>
<td>Q-19 – Q-20</td>
<td>Q-19 – Q-20</td>
</tr>
<tr>
<td></td>
<td>Q-25 (+ blank)</td>
<td>Q-25 (+ blank)</td>
</tr>
<tr>
<td>Appendix R</td>
<td>R-1 – R-4</td>
<td>R-1 – R-4</td>
</tr>
<tr>
<td></td>
<td>R-7 – R-16</td>
<td>R-7 – R-16</td>
</tr>
<tr>
<td>Appendix S</td>
<td>S-1 – S-6</td>
<td>S-1 – S-6</td>
</tr>
<tr>
<td>Appendix U</td>
<td>U-1 – U-2</td>
<td>U-1 – U-2</td>
</tr>
</tbody>
</table>

The parts of the text, tables, and figures that contain changes are indicated by a vertical bar and a small “09” in the margin.
Design and Construction of Large, Welded, Low-pressure Storage Tanks

Downstream Segment

API STANDARD 620
ELEVENTH EDITION, FEBRUARY 2008

ADDENDUM 1, MARCH 2009
Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.
9.4 Means of Venting ................................................................. 9-1
9.5 Liquid Relief Valves ............................................................. 9-1
9.6 Marking .............................................................................. 9-1
9.7 Pressure Setting of Safety Devices ........................................ 9-2

Appendix A has been deleted ...................................................... A-1
Appendix B Use of Materials That are Not Identified with Listed Specifications ......................................................... B-1
Appendix C Suggested Practice Regarding Foundations .................... C-1
Appendix D Suggested Practice Regarding Supporting Structures .................. D-1
Appendix E Suggested Practice Regarding Attached Structures (Internal and External) ............................................... E-1
Appendix F Examples Illustrating Application of Rules to Various Design Problems ................................................. F-1
Appendix G Considerations Regarding Corrosion Allowance and Hydrogen-induced Cracking ................................. G-1
Appendix I Suggested Practice for Peening .................................... I-1
Appendix J (Reserved for Future Use) .......................................... J-1
Appendix K Suggested Practice for Determining the Relieving Capacity Required .................................................. K-1
Appendix L Seismic Design of Storage Tanks ................................. L-1
Appendix M Recommended Scope of the Manufacturer’s Report ....................... M-1
Appendix N Installation of Pressure-relieving Devices .......................... N-1
Appendix O Suggested Practice RegardingInstallation of Low-pressure Storage Tanks .............................................. O-1
Appendix P NDE and Testing Requirements Summary .......................... P-1
Appendix Q Low-pressure Storage Tanks for Liquefied Hydrocarbon Gases ........................................................... Q-1
Appendix R Low-pressure Storage Tanks for Refrigerated Products .............................................................. R-1
Appendix S Austenitic Stainless Steel Storage Tanks ......................... S-1
Appendix U Ultrasonic Examination in Lieu of Radiography .................... U-1

Figures
4-1 Isothermal Lines Showing 1-day Mean Ambient Temperature ................................................................. 4-2
4-2 Minimum Permissible Design Metal Temperature for Pipe, Flanges, and Forgings without Impact Testing ............... 4-10
4-3 Governing Thickness for Impact Test Determination of Pipe, Flanges, and Forgings ........................................ 4-11
5-1 Biaxial Stress Chart for Combined Tension and Compression, 30,000 lbf/in.² – 38,000 lbf/in.² Yield Strength Steels ........................................................................ 5-5
5-2 Method for Preparing Lap-welded Bottom Plates under the Tank Sidewall ................................................. 5-15
5-3 Detail of Double Fillet-groove Weld for Bottom Plates with a Nominal Thickness Greater than 1/2 in. ........................................................................ 5-15
5-4 Typical Free-body Diagrams for Certain Shapes of Tanks .................................................................................. 5-18
5-5 Compression-ring Region .......................................................................................................................... 5-30
5-6 Permissible and Non-permissible Details of Construction for a Compression-ring Juncture .......................... 5-31
5-7 Reinforcement of Single Openings .................................................................................................................. 5-38
5-8 Part 1 Acceptable Types of Welded Nozzles and Other Connections. ............................................................ 5-40
5-8 Part 2 Acceptable Types of Welded Nozzles and Other Connections. ............................................................ 5-41
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 −50°F. Appendix S covers stainless steel low-pressure storage tanks in ambient temperature service in all areas, without limit on low temperatures. Appendix R covers low-pressure storage tanks for refrigerated products at temperatures from +40°F to −60°F. Appendix Q covers low-pressure storage tanks for liquefied hydrocarbon gases at temperatures not lower than −270°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 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 Appendix A has been deleted.

1.2.7 Appendix 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 Appendix C provides information on subgrade and foundation loading conditions and foundation construction practices.

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

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

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

1.2.12 Appendix 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 Appendix H covers preheat and post-heat stress-relief practices for improved notch toughness.

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

1.2.15 Appendix J is reserved for future use.

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

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

1.2.18 Appendix 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 Appendix N covers installation practices for pressure- and vacuum-relieving devices.

1.2.20 Appendix 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 Appendix 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 appendix 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 Appendix Q covers specific requirements for the materials, design, and fabrication of tanks to be used for the storage of liquefied ethane, ethylene, and methane.

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

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

1.2.25 Appendix U covers detailed rules for the use of the ultrasonic examination (UT) method for the examination of tank seams.
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 3.7.1.8, 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 walls¹ 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. <text deleted>

¹The term wall refers to the roof, shell and bottom of a tank as defined in 3.3. <text deleted>
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 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 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 Other Terms

3.5.1 Manufacturer: The party having the primary responsibility for constructing the tank.

3.5.2 Purchaser: The owner or the owner’s designated agent, such as an engineering contractor.
### Table 4-1—Minimum Requirements for Plate Specifications to be Used for Design Metal Temperatures

<table>
<thead>
<tr>
<th>Design Metal Temperature (See 4.2.1)</th>
<th>Plate Thickness Including Corrosion Allowance (in.)</th>
<th>Specification</th>
<th>Grade</th>
<th>Special Requirements (in Addition to 4.2.3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>65°F and over</td>
<td>≤ 3/4</td>
<td>Any listed in 4.2.3</td>
<td>—</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>≤ 1</td>
<td>ASTM A36</td>
<td>—</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>&gt; 1</td>
<td>CSA G40.21</td>
<td>38W, 44W, 50W</td>
<td>Note 1</td>
</tr>
<tr>
<td>25°F and over</td>
<td>≤ 3/4</td>
<td>Any listed in 4.2.3</td>
<td>—</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>≤ 1</td>
<td>ASTM A36 Mod 2</td>
<td>—</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>&gt; 1</td>
<td>ASTM A131</td>
<td>B</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSA G40.21</td>
<td>38W, 44W, 50W</td>
<td>None</td>
</tr>
<tr>
<td>-5°F and over</td>
<td>≤ 3/4</td>
<td>ASTMA 131</td>
<td>B</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>&gt; 1</td>
<td>CSA G40.21</td>
<td>38W, 44W, 50W</td>
<td>None</td>
</tr>
<tr>
<td>-35°F and over</td>
<td>≤ 3/4</td>
<td>&lt;text deleted&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 1</td>
<td>&lt;text deleted&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤ 1</td>
<td>ASTM A516</td>
<td>55, 60, 65, 70</td>
<td>Note 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM A573</td>
<td>58, 65, 70</td>
<td>Note 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM A662</td>
<td>B and C</td>
<td>Note 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM A737</td>
<td>B</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM A841</td>
<td>Class 1</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSA G40.21</td>
<td>38W, 44W, 50W</td>
<td>Note 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISO 630</td>
<td>E 275, E355 Quality D</td>
<td>Notes 1 and 2</td>
</tr>
<tr>
<td></td>
<td>≤ 1</td>
<td>&lt;text deleted&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;text deleted&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;text deleted&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;text deleted&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;text deleted&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;text deleted&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;text deleted&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;text deleted&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;text deleted&gt;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
1) All plates over 1 1/2 in. thick shall be normalized.
2) The steel shall be killed and made with fine-grain practice.
3) The plates shall be normalized or quench tempered (see 4.2.4.2).
4) Each plate shall be impact tested in accordance with 4.2.5.
4.2.2  Low-stress Design

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:

a) 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.2.3 and R.2.2).

b) The design metal temperature may be increased by 30°F in selecting material from Table 4-1 for tank components that are exposed to the vapor from the liquid or vapor being stored and are not designed to contain the contents of an inner tank.

c) 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.

4.2.3  Plate Specifications

4.2.3.1 General

The specifications listed in 4.2.3.2 through 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:

a) A20.

b) A36, with the following API modification as required (see Table 4-1): Mod 2 requires the manganese content to have a range of 0.80 – 1.20. The material supplied shall not be rimmed or capped steel.

c) A131 (structural quality only).

d) A283 (Grades C and D only, with a maximum nominal thickness of 3/4 in.).

e) A285 (Grade C only, with a maximum nominal thickness of 3/4 in.).

f) A516, with the following API modifications as required: Mod 1 requires the carbon content to be restricted to a maximum of 0.20% by ladle analysis; a maximum manganese content of 1.50% shall be permitted. Mod 2 requires the minimum manganese content to be lowered to 0.70% and the maximum increased to 1.40% by ladle analysis. The carbon content shall be limited to a maximum of 0.20% by ladle analysis. The steel shall be normalized. The silicon content may be increased to a maximum of 0.50% by ladle analysis.

g) 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.

h) A573.

i) A633 (Grades C and D only).

j) A662 (Grades B and C only).

k) A678 (Grades A and B only).

l) A737 (Grade B only).

m) A841 (Class 1 only).
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.

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, $s_{cc}$, 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,

$$S_{cs} = 1,800,000\left[\frac{(t - c)}{R}\right]$$

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

$$S_{cs} = 10,150 + 277,400\left[\frac{(t - c)}{R}\right]$$
For values of \((t - c)/R\) greater than 0.0175,

\[ S_{cs} = 15,000 \]

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

<table>
<thead>
<tr>
<th>Specification (See Note 1)</th>
<th>Grade</th>
<th>Notes</th>
<th>Specified Minimum Tensile Strength (lbf/in.²)</th>
<th>Yield Point (lbf/in.²)</th>
<th>Maximum Allowable Tensile Stress for Tension, (S_{st}) (lbf/in.², See Notes 2 and 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plates</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM A36</td>
<td>—</td>
<td>4</td>
<td>58,000</td>
<td>36,000</td>
<td>16,000</td>
</tr>
<tr>
<td>ASTM A131</td>
<td>A</td>
<td>4, 5 and 6</td>
<td>58,000</td>
<td>34,000</td>
<td>15,200</td>
</tr>
<tr>
<td>ASTM A131</td>
<td>B</td>
<td>4</td>
<td>58,000</td>
<td>34,000</td>
<td>16,000</td>
</tr>
<tr>
<td>ASTM A131</td>
<td>CS</td>
<td>4</td>
<td>58,000</td>
<td>34,000</td>
<td>16,000</td>
</tr>
<tr>
<td>ASTM A283</td>
<td>C</td>
<td>4 and 5</td>
<td>55,000</td>
<td>30,000</td>
<td>15,200</td>
</tr>
<tr>
<td>ASTM A283</td>
<td>D</td>
<td>4, 5 and 6</td>
<td>60,000</td>
<td>33,000</td>
<td>15,200</td>
</tr>
<tr>
<td>ASTM A285</td>
<td>C</td>
<td>5</td>
<td>55,000</td>
<td>30,000</td>
<td>16,500</td>
</tr>
<tr>
<td>ASTM A516</td>
<td>55</td>
<td>—</td>
<td>55,000</td>
<td>30,000</td>
<td>16,500</td>
</tr>
<tr>
<td>ASTM A516</td>
<td>60</td>
<td>—</td>
<td>60,000</td>
<td>32,000</td>
<td>18,000</td>
</tr>
<tr>
<td>ASTM A516</td>
<td>65</td>
<td>—</td>
<td>65,000</td>
<td>35,000</td>
<td>19,500</td>
</tr>
<tr>
<td>ASTM A516</td>
<td>70</td>
<td>—</td>
<td>70,000</td>
<td>38,000</td>
<td>21,000</td>
</tr>
<tr>
<td>ASTM A537</td>
<td>Class 1</td>
<td>7</td>
<td>70,000</td>
<td>50,000</td>
<td>21,000</td>
</tr>
<tr>
<td>ASTM A537</td>
<td>Class 2</td>
<td>7</td>
<td>80,000</td>
<td>60,000</td>
<td>24,000</td>
</tr>
<tr>
<td>ASTM A573</td>
<td>58</td>
<td>4</td>
<td>58,000</td>
<td>32,000</td>
<td>16,000</td>
</tr>
<tr>
<td>ASTM A573</td>
<td>65</td>
<td>4</td>
<td>65,000</td>
<td>35,000</td>
<td>18,000</td>
</tr>
<tr>
<td>ASTM A573</td>
<td>70</td>
<td>4</td>
<td>70,000</td>
<td>42,000</td>
<td>19,300</td>
</tr>
<tr>
<td>ASTM A633</td>
<td>C and D</td>
<td>4 and 7</td>
<td>70,000</td>
<td>50,000</td>
<td>19,300</td>
</tr>
<tr>
<td>ASTM A662</td>
<td>B</td>
<td>—</td>
<td>65,000</td>
<td>40,000</td>
<td>19,500</td>
</tr>
<tr>
<td>ASTM A662</td>
<td>C</td>
<td>7</td>
<td>70,000</td>
<td>43,000</td>
<td>21,000</td>
</tr>
<tr>
<td>ASTM A678</td>
<td>A</td>
<td>4 and 8</td>
<td>70,000</td>
<td>50,000</td>
<td>19,300</td>
</tr>
<tr>
<td>ASTM A678</td>
<td>B</td>
<td>4 and 7</td>
<td>80,000</td>
<td>60,000</td>
<td>22,100</td>
</tr>
<tr>
<td>ASTM A737</td>
<td>B</td>
<td>7</td>
<td>70,000</td>
<td>50,000</td>
<td>21,000</td>
</tr>
<tr>
<td>ASTM A841</td>
<td>Class 1</td>
<td>7</td>
<td>70,000</td>
<td>50,000</td>
<td>21,000</td>
</tr>
<tr>
<td>CSA G40.21</td>
<td>38W and 38WT</td>
<td>4</td>
<td>60,000</td>
<td>38,000</td>
<td>16,500</td>
</tr>
<tr>
<td>CSA G40.21</td>
<td>44W and 44WT</td>
<td>4</td>
<td>65,000</td>
<td>44,000</td>
<td>18,000</td>
</tr>
<tr>
<td>CSA G40.21</td>
<td>50W</td>
<td>4</td>
<td>65,000</td>
<td>50,000</td>
<td>18,000</td>
</tr>
<tr>
<td>CSA G40.21</td>
<td>50WT</td>
<td>4</td>
<td>70,000</td>
<td>50,000</td>
<td>19,300</td>
</tr>
<tr>
<td>ISO 630</td>
<td>E275 Quality C, D</td>
<td>4</td>
<td>59,500</td>
<td>37,000</td>
<td>16,400</td>
</tr>
<tr>
<td>ISO 630</td>
<td>E355 Quality C, D</td>
<td>4</td>
<td>71,000</td>
<td>48,500</td>
<td>19,600</td>
</tr>
<tr>
<td><strong>Pipe</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Seamless</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>API Spec 5L</td>
<td>B</td>
<td>—</td>
<td>60,000</td>
<td>35,000</td>
<td>18,000</td>
</tr>
<tr>
<td>ASTM A33</td>
<td>B</td>
<td>—</td>
<td>60,000</td>
<td>35,000</td>
<td>18,000</td>
</tr>
<tr>
<td>ASTM A106</td>
<td>B</td>
<td>—</td>
<td>60,000</td>
<td>35,000</td>
<td>18,000</td>
</tr>
<tr>
<td>ASTM A106</td>
<td>C</td>
<td>—</td>
<td>70,000</td>
<td>40,000</td>
<td>21,000</td>
</tr>
<tr>
<td>ASTM A333</td>
<td>1</td>
<td>—</td>
<td>55,000</td>
<td>30,000</td>
<td>16,500</td>
</tr>
<tr>
<td>ASTM A333</td>
<td>3</td>
<td>—</td>
<td>65,000</td>
<td>35,000</td>
<td>19,500</td>
</tr>
<tr>
<td>ASTM A333</td>
<td>6</td>
<td>—</td>
<td>60,000</td>
<td>35,000</td>
<td>18,000</td>
</tr>
<tr>
<td>ASTM A524</td>
<td>I</td>
<td>—</td>
<td>60,000</td>
<td>35,000</td>
<td>18,000</td>
</tr>
<tr>
<td>ASTM A524</td>
<td>I1</td>
<td>—</td>
<td>55,000</td>
<td>30,000</td>
<td>16,500</td>
</tr>
<tr>
<td><strong>Electric-fusion Welded</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM A134</td>
<td>A283 Grade C</td>
<td>4, 5 and 9</td>
<td>55,000</td>
<td>30,000</td>
<td>12,100</td>
</tr>
<tr>
<td>ASTM A134</td>
<td>A285 Grade C</td>
<td>5 and 9</td>
<td>55,000</td>
<td>30,000</td>
<td>13,200</td>
</tr>
<tr>
<td>ASTM A139</td>
<td>B</td>
<td>9</td>
<td>60,000</td>
<td>35,000</td>
<td>14,400</td>
</tr>
</tbody>
</table>
Table 5-1—Maximum Allowable Stress Values for Simple Tension (Continued)

<table>
<thead>
<tr>
<th>Specification (See Note 1)</th>
<th>Grade</th>
<th>Notes</th>
<th>Specified Minimum Tensile Strength (lb/in.$^2$)</th>
<th>Yield Point (lb/in.$^2$)</th>
<th>Maximum Allowable Tensile Stress for Tension, $S_u$ (lb/in.$^2$, See Notes 2 and 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forgings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM A105</td>
<td>—</td>
<td>—</td>
<td>60,000</td>
<td>30,000</td>
<td>18,000</td>
</tr>
<tr>
<td>ASTM A181 I</td>
<td>—</td>
<td>—</td>
<td>60,000</td>
<td>30,000</td>
<td>18,000</td>
</tr>
<tr>
<td>ASTM A181 II</td>
<td>—</td>
<td>—</td>
<td>70,000</td>
<td>36,000</td>
<td>21,000</td>
</tr>
<tr>
<td>ASTM A350 LF1</td>
<td>—</td>
<td>—</td>
<td>60,000</td>
<td>30,000</td>
<td>18,000</td>
</tr>
<tr>
<td>ASTM A350 LF2</td>
<td>—</td>
<td>—</td>
<td>70,000</td>
<td>36,000</td>
<td>21,000</td>
</tr>
<tr>
<td>ASTM A350 LF3</td>
<td>—</td>
<td>—</td>
<td>70,000</td>
<td>40,000</td>
<td>21,000</td>
</tr>
<tr>
<td>Castings and Boltin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM A27 60-30</td>
<td>10</td>
<td></td>
<td>60,000</td>
<td>30,000</td>
<td>14,400</td>
</tr>
<tr>
<td>ASTM A36 For anchor bolti</td>
<td>11</td>
<td></td>
<td>58,000</td>
<td>36,000</td>
<td>15,300</td>
</tr>
<tr>
<td>ASTM A193 B7</td>
<td>11</td>
<td></td>
<td>125,000</td>
<td>105,000</td>
<td>24,000</td>
</tr>
<tr>
<td>ASTM A307 B for flanges and pressure parts</td>
<td>11 and 12</td>
<td></td>
<td>55,000</td>
<td>—</td>
<td>8,400</td>
</tr>
<tr>
<td>ASTM A307 B for structura</td>
<td>11</td>
<td></td>
<td>55,000</td>
<td>—</td>
<td>15,000</td>
</tr>
<tr>
<td>and anchor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM A320 bolting L7</td>
<td>11</td>
<td></td>
<td>125,000</td>
<td>105,000</td>
<td>24,000</td>
</tr>
<tr>
<td>Structural Shapes Resisting Internal Pressure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM A36</td>
<td>—</td>
<td>4 and 6</td>
<td>58,000</td>
<td>36,000</td>
<td>15,200</td>
</tr>
<tr>
<td>ASTM A131 A</td>
<td>4 and 6</td>
<td></td>
<td>58,000</td>
<td>34,000</td>
<td>15,200</td>
</tr>
<tr>
<td>ASTM A633 A</td>
<td>4</td>
<td></td>
<td>63,000</td>
<td>42,000</td>
<td>17,400</td>
</tr>
<tr>
<td>ASTM A992</td>
<td>4 and 6</td>
<td></td>
<td>65,000</td>
<td>50,000</td>
<td>15,200</td>
</tr>
<tr>
<td>CSA G40.21 38W and 38WT</td>
<td>4 and 6</td>
<td></td>
<td>60,000</td>
<td>38,000</td>
<td>15,200</td>
</tr>
<tr>
<td>CSA G40.21 44W and 44WT</td>
<td>4 and 6</td>
<td></td>
<td>65,000</td>
<td>44,000</td>
<td>15,200</td>
</tr>
<tr>
<td>CSA G40.21 50W</td>
<td>4 and 6</td>
<td></td>
<td>65,000</td>
<td>50,000</td>
<td>15,200</td>
</tr>
<tr>
<td>CSA G40.21 50WT</td>
<td>4 and 6</td>
<td></td>
<td>70,000</td>
<td>50,000</td>
<td>15,200</td>
</tr>
</tbody>
</table>

Notes:
1. All pertinent modifications and limitations of specifications required by 4.2. through 4.8 shall be complied with.
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.
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 factor 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.
4. Stress values for structural quality steels include a quality factor of 0.92.
5. Plates and pipe shall not be used in thickness greater than $\frac{3}{4}$ in.
6. Stress values are limited to those for steel that has an ultimate tensile strength of only 55,000 lb/in.$^2$.
7. Less than or equal to $2\frac{1}{2}$ in. thickness.
8. Less than or equal to $1\frac{1}{2}$ in. thickness.
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.
10. Stress values for castings include a quality factor of 0.80.
11. See 5.6.
12. Allowable stress based on Section VIII of the ASME Boiler and Pressure Vessel Code multiplied by the ratio of the design stress factors in this standard and Section VI11 of the ASME Code, namely 0.30/0.25.
### Table 5-2—Maximum Allowable Efficiencies for Arc-welded Joints

<table>
<thead>
<tr>
<th>Type of Joint</th>
<th>Limitations</th>
<th>Basic Joint Efficiency (%)</th>
<th>Radiographed (See Note 1)</th>
<th>Maximum Joint Efficiency (%)</th>
<th>Note 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>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 ASME Code; welds using metal backing strips that remain in place are excluded.</td>
<td>None, for all double-welded joints, except for roofs above liquid level.</td>
<td>85</td>
<td>Spot Full (see Note 3)</td>
<td>85</td>
<td>100</td>
</tr>
<tr>
<td>Single-welded butt joint with backing strip or equivalent other than those included above.</td>
<td>Roofs above liquid level.</td>
<td>70</td>
<td>—</td>
<td>70</td>
<td>85</td>
</tr>
<tr>
<td>Single-welded butt joint without backing strip.</td>
<td>Nozzle attachment welding.</td>
<td>70</td>
<td>—</td>
<td>70</td>
<td>85</td>
</tr>
<tr>
<td>Double full-fillet lap joint (see Note 4).</td>
<td>Longitudinal or meridional joints and equivalent (see Note 5) circumferential or latitudinal joints between plates not more and 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.</td>
<td>70</td>
<td>—</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Single full-fillet lap joint (see Note 4).</td>
<td>Other circumferential or latitudinal joints between plates not more than 5/8 in. thick.</td>
<td>65</td>
<td>—</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>Single full-fillet lap joints for head-to-nozzle joints</td>
<td>Longitudinal or meridional joints and circumferential or latitudinal joints between plates not more than 1/8 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.</td>
<td>35</td>
<td>—</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Nozzle-attachment fillet welds</td>
<td>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.</td>
<td>35</td>
<td>—</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Plug welds (see 5.24.5)</td>
<td>Attachment welding for nozzles and their reinforcements.</td>
<td>Attachment welding for nozzle reinforcements (see Note 6).</td>
<td>80</td>
<td>—</td>
<td>80</td>
</tr>
</tbody>
</table>

**Notes:**
1. See 5.26 and 7.15 for examination requirements.
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 $P_2$ 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.
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 7.16.5.2.
4. Thickness limitations do not apply to flat bottoms supported uniformly on a foundation.
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.
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.
Figure 5-6—Permissible and Non-permissible Details of Construction for a Compression-ring Juncture

Notes:
1. When using the alternate roof position (the roof plate under the compression bar as shown in detail f-1), the purchaser should consider the use of caulking on top of the fillet weld to ensure the drainage of rainfall.
2. See Table 5-2 for limitations concerning locations where various types of welded joints may be used and 5.12.2 for limits on material contributing to compression cross-sectional area.
sum of the projection of the width, \( w_h \), and the horizontal width of the added angle or bar is equal to or greater than \( 0.015R_c \).

c) When bracing must be provided as specified in 5.12.5.8, the moment of inertia of the cross section around a horizontal axis shall be not less than that required by Equation 28.

5.12.5.4 When the vertical leg of an angle ring or a vertical flange of a ring girder is located on the sidewall of the tank, it may be built into the sidewall if its thickness is not less than that of the adjoining wall plates. If this construction is not used, the leg, edge, or flange of the compression ring next to the tank shall make good contact with the wall of the tank around the entire circumference and shall be attached thereto along both the top and bottom edges by continuous fillet welds except as provided in 5.12.5.5. These welds shall be sufficiently sized to transmit to the compression-ring angle, bar, or girder that portion of the total circumferential force, \( Q \), which must be carried thereby, assuming in the case of welds separated by the width of a leg or flange of a structural member as shown in Figure 5-6, details a and h, that only the weld nearest the roof or bottom is effective. In no event, however, shall the size of any weld along either edge of a compression ring be less than the thickness of the thinner of the two parts joined or \( 1/4 \) in. (whichever is smaller), nor shall the size of the comer welds between the shell and a girder bar, such as shown in Figure 5-6, details d and e, be less than the applicable weld sizes in Table 5-8. The part thicknesses and weld sizes in Table 5-8 relate to dimensions in the as-welded condition before the deduction of corrosion allowances; with this exception, all other part thicknesses and weld sizes referred to in this paragraph relate to dimensions after the deduction of corrosion allowance.

5.12.5.5 If a continuous weld is not needed for strength or as a seal against corrosive elements, attachment welds along the lower edge of a compression ring on the outside of a tank may be intermittent if (a) the summation of their lengths is not less than one-half the circumference of the tank, (b) the unattached width of tank wall between the ends of welds does not exceed eight times the tank wall thickness exclusive of corrosion allowance, and (c) the welds are sized as needed for strength (if this is a factor), but in no case are they smaller than specified in Table 5-8.

5.12.5.6 The projecting part of a compression ring shall be placed as close as possible to the juncture between the roof or bottom plates and the sidewall plates.

5.12.5.7 If a compression ring on either the inside or outside of a tank is shaped in such a way that liquid may be trapped, it shall be provided with adequate drain holes uniformly distributed along its length. Similarly, if a compression ring on the inside of a tank is shaped in such a way that gas would be trapped on the underside when the tank is being filled with liquid, adequate vent holes shall be provided along its length. Where feasible, such drain or vent holes shall be not less than \( 3/4 \) in. in diameter.

5.12.5.8 The projecting part of a compression ring without an outer vertical flange need not be braced if the width of the projecting part in a radical vertical plane does not exceed 16 times its thickness. With this exception, the horizontal or near-horizontal part of the compression ring shall be braced at intervals around the circumference of the tank with brackets or other suitable members securely attached to both the ring and the tank wall to prevent that part of the ring from buckling laterally (vertically) out of its own plane. When bracing is required, the moment of inertia of the cross section of the angle, bar, or ring girder about a horizontal axis shall be not less than that computed by the following equation:

---

### Table 5-8—Minimum Size of Fillet Weld

<table>
<thead>
<tr>
<th>Thickness of the Thicker of the Two Parts Joined (in.)</th>
<th>Minimum Size of Fillet Weld (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \leq 1/4 )</td>
<td>3/16</td>
</tr>
<tr>
<td>( &gt; 1/4 - 3/4 )</td>
<td>1/4</td>
</tr>
<tr>
<td>( &gt; 3/4 - 11/4 )</td>
<td>5/16</td>
</tr>
<tr>
<td>( &gt; 11/4 )</td>
<td>3/8</td>
</tr>
</tbody>
</table>

---
\( E \) = efficiency, expressed as a decimal, of the least efficient joint cutting across the section considered (see Table 5-2),

\( w_h \) = width, in in., of the roof, bottom, or transition section plate considered to participate in resisting the circumferential force \( Q \),

\( w_n \) = corresponding width, in in., of the participating neck plate,

\( t_h \) = thickness, in in., of the roof, bottom, or transition section plate at and near its juncture with the neck extending from the opening, including corrosion allowance,

\( t_n \) = corresponding thickness, in in., of the cylindrical neck at and near the juncture described for \( t_h \).

### Figure 5-9—Large Head Openings and Conical Shell-reducer Sections

#### 5.18.3 Knuckle Radius

**5.18.3.1** A knuckle radius used for the juncture between the roof, bottom, or transition section and the neck extending from the opening shall be not less than 6\% of the diameter of the opening, and the thicknesses required at this location shall be computed in accordance with 5.10. The use of a knuckle radius as small as 6\% of the sidewall diameter will frequently require an excessively heavy thickness for the knuckle region. The thickness requirements for this region will be found more reasonable if a larger knuckle radius is used.

**5.18.3.2** When a knuckle radius is not used at this location, the stress situation at the juncture is the reverse of that found at the juncture (without a knuckle) between a conical or dished roof and the sidewalls of a cylindrical tank because in this case the horizontal components of the \( T_1 \) meridional unit forces in the roof, bottom, or transition section pull outward on the neck extending from the opening and increase the circumferential tensile stresses acting at the juncture. In this case, the walls of the tank and neck of the opening at and near their juncture must be designed to withstand a total circumferential load, \( Q \), on each side of the opening, as computed using the following formula:

\[
Q = T_2 w_h + T_2 n w_n + T_1 R_n \sin \alpha
\]  

(29)
5.18.4 Cross-sectional Area

The total cross-sectional area of metal required to resist the circumferential force is shown by the following equation:

\[ A_c = \frac{Q}{S_{tu}E} \quad (30) \]

The widths of plate available for providing this area and resisting the force \( Q \) on each side of the opening shall be computed using the following formulas:

\[ w_b = 0.6\sqrt{R_2(t_b - c)} \quad (31) \]

\[ w_a = 0.6\sqrt{R_3(t_a - c)} \quad (32) \]

5.19 Nozzle Necks and Their Attachments to the Tank

5.19.1 General

5.19.1.1 Nozzles to be used for pipe connections, handholes, or manholes may be constructed of pipe, pipe couplings, forged steel, cast steel, fabricated plate, or other suitable material conforming to the provisions of 4.1, 4.2.2, 4.3, or 4.5.

5.19.1.2 Nozzles may be integral with the tank wall or the wall of another nozzle or with a nozzle cover plate; or, subject to the limitations stated in these rules, nozzles may be attached directly to the wall of the tank or another nozzle or nozzle cover plate by threading, fusion welding, bearing against the inside of the wall, studding, or bolting.

5.19.1.3 Openings for all nozzles in the wall of the tank or another nozzle shall be reinforced as required by 5.16 or 5.17. Openings in nozzle cover plates need only be reinforced to the extent required by 5.21.1.2, 5.21.1.3, 5.21.2.7, and 5.21.2.8.

5.19.1.4 Nozzles may be attached to a tank by any of the methods shown in Figure 5-8 or by other methods that conform to sound design principles if the nozzle and its attachment in each case meet the requirements of 5.16.

5.19.2 Minimum Thickness of Nozzle Neck

The thickness of a nozzle neck shall be computed for the applicable loadings in 5.4, using allowable stresses as specified in 5.5, and to this thickness shall be added the corrosion allowance. The minimum thickness of nozzle neck to be used shall be at least equal to the required thickness so obtained; in no case shall the net thickness of the nozzle neck, excluding corrosion allowance, be less than the smaller of the following thicknesses:

a) The net thickness, excluding corrosion allowance, of the tank wall adjacent to the nozzle, disregarding any added thickness that serves as reinforcement for the opening.

b) The thickness of standard-weight pipe (see ASME B36.10M).

5.19.3 Outer Ends of Nozzles

5.19.3.1 The outer ends of nozzles may be flanged, beveled for welding, or threaded except that threaded ends shall not be used unless they are permitted by and meet the requirements of 5.20.4. When bolted flanges are provided on nozzle sizes NPS 2 and greater, the minimum distance from face of flange to the tank wall shall be 8 in.

5.19.3.2 When a bolting flange is welded to the nozzle neck for its entire thickness, the corner formed by the back of the flange and the nozzle wall shall be provided with a fillet weld. The fillet weld size shall be at least 0.25 times the thickness of the nozzle wall, not including corrosion allowance, except that for relatively thick nozzle walls, the fillet weld shall be not less than 0.25 times the thickness of standard-weight or extra-strong pipe, whichever is nearest to
5.24.3 Except as otherwise provided in 5.24.2, the diameter, or width, of the holes shall not exceed twice the thickness of the member through which the hole is cut plus $\frac{1}{4}$ in. In no case, however, does the dimension need to be greater $2\frac{1}{4}$ in.

5.24.4 Plug-weld and slot-weld holes shall be completely filled with weld metal when the thickness of the member through which the hole is cut is $\frac{5}{16}$ in. or less. For thicker members, the holes shall be filled to a depth of at least one-half the thickness of the member or one-third the hole diameter, or width, whichever is greater, but in no case shall they be filled less than $\frac{5}{16}$ in. Fillet-welded holes are not considered to be plug welds or slot welds.

5.24.5 The effective shearing area of plug welds shall be considered to be the area of a circle whose diameter is $\frac{1}{4}$ in. less than the diameter of the hole at the fraying surface. The effective shearing area of the semicircular ends of slot welds shall be computed on a comparable basis, and the effective area between the centers of the semicircular ends shall be taken as the product of the distance between such centers and a width that is $\frac{1}{4}$ in. less than the width of the slot at the fraying surface.

5.25 Stress Relieving

5.25.1 Definition

Stress-relief heat treatment is the uniform heating of a structure or portion of a structure to a sufficient temperature below the critical range to relieve the major portion of the residual stresses, followed by uniform cooling.

5.25.2 Field Stress Relief

A tank built according to the rules of this standard is not usually thermally field stress relieved after erection because its size and weight do not permit adequate support at the temperature required for stress relieving. When a tank is not to be field stress relieved, the field-welding procedure shall be one that (a) has been proven satisfactory by experience or adequate experiments and (b) will minimize locked-up residual stresses, which are thought to be one of the main causes of cracking in or adjacent to welds (see 6.19 and H.4).

5.25.3 Wall Thickness

Tank sections that have a nominal thickness of wall plate greater than $1\frac{1}{4}$ in. at any nozzle or other welded attachment and nozzle necks whose thickness at any welded joint therein exceeds $(D + 50)/120$ shall be thermally stress relieved after welding. Thickness of compression rings as defined in 5.12 (examples shown in Figure 5-6) are not considered in the determination of thermal stress relief requirements. In this formula diameters less than 20 in. shall be assumed to be 20 in. When thermal stress relief cannot be applied to welded assemblies of these parts after erection, all such assemblies, particularly around openings and support attachments, shall be made in the shop and shall be thermally stress relieved before shipment.

5.25.4 Fillet-weld Attachments

The requirement of 5.25.3 does not apply to fillet welds used for small nozzle or lug attachments when the welds have a size that is a) no greater than $\frac{1}{2}$ in. for welds on a flat surface or circumferential welds on a cylindrical or conical surface or b) no greater than $\frac{3}{8}$ in. for longitudinal welds on surfaces of the latter two shapes or for any welds on surfaces that have double curvature.

---

31Any proposed application of stress-relieving requirements and the procedures to be followed in each case should be agreed upon by the Purchaser and the Manufacturer. Peening may be done if it is part of the welding procedure and is approved by the Purchaser (see 6.7 and 6.10).

32For P-1 materials, the $1\frac{1}{4}$ in. thickness may be increased to $1\frac{1}{2}$ in., provided that a minimum preheat temperature of 200°F is maintained during welding.
5.26 Radiographic/Ultrasonic Examination

5.26.1 General

Examination for the quality of butt welds where required by 5.26 shall be made using either the radiographic method specified in 7.15.1 or alternatively, by agreement between the Purchaser and the Manufacturer, using ultrasonic examination in lieu of radiography as specified in 7.15.3.1. When the term "examination" is used in 5.26, it shall be understood to refer to radiographic or ultrasonic examination.

Note: Ultrasonic testing (UT) and radiography (RT) are complementary methods. UT can detect some types of flaws better than RT and vice versa. Therefore, the acceptance criteria provided in API 620 for the two methods differ. In the case of RT, all weld flaws require characterization as their type (e.g., crack, incomplete fusion, rounded indication, etc.) and acceptance criteria vary according to the characterization. RT acceptance criteria in API 620 are based on definitions of good workmanship. In the case of UT, flaw characterization by type or shape is not required (except for results of supplemental MT/PT). Rather the sizing of both the length and height of flaws is emphasized. The UT acceptance criteria provided in Appendix U are based on fracture mechanics and assume that any flaw may have crack-like characteristics.

5.26.2 Definitions

Radiography is the process of passing electromagnetic radiation, such as X-rays or Gamma rays through an object and obtaining a record of its soundness upon a sensitized film.

Ultrasonic examination is a method of detecting imperfections in material by passing ultrasonic waves through the material and interpreting the reflected and/or diffracted waves.

5.26.3 Examination Required by Wall Thickness

Complete examination is required for all butt joints having complete penetration and complete fusion wherever the thinner of the plates or the tank-wall thicknesses at the joint exceed 1\(\frac{1}{4}\) in. and the joint is subjected to tension stress greater than 0.1 times the specified minimum tensile strength of the material.

5.26.4 Examination Required for Joint Efficiency

5.26.4.1 The increased joint efficiency allowed in Table 5-2 for completely radiographed joints in a tank or tank sections may be used in the design calculations if the conditions described in 5.26.4.2 and 5.26.4.3 are met.

5.26.4.2 Main joints (all longitudinal and circumferential joints in the tank wall or meridional and latitudinal joints in walls of double curvature) are of the butt-welded type except for nozzle, manhole, and support attachment welds to the tank wall, which need not be of the butt-welded type.

5.26.4.3 All butt-welded joints described in 5.26.4.2 are examined throughout their length, as prescribed in 7.15, except under the following conditions:

a) When parts of tanks do not require complete examination (see 5.26.3). In this case, circumferential joints in cylindrical or conical surfaces need to be prepared and examined for a distance of only 3 in. on each side of any intersection with a longitudinal joint. All joints in a spherical, torispherical, or ellipsoidal shape or in any other surface of double curvature shall be considered longitudinal joints. For similar reasons, the juncture without a knuckle between a conical or dished roof or bottom, and cylindrical sidewalls and the circumferential joints without a knuckle at either or both ends of a transition section shown in Figure 5-9 shall be examined if the adjacent longitudinal joints are to receive credit for being radiographed.

b) When welded butt joints in nozzle necks do not require complete examination (see 5.26.3). This provision applies to their fabrication and is not necessarily the form of attachment to the tank.
Section 6—Fabrication

6.1 General
This section covers details in fabrication practices that are considered essential in constructing large, welded tanks designed according to the rules in this standard.

6.2 Workmanship

6.2.1 All work of fabricating API 620 tanks shall be done in accordance with this standard and with the permissible alternatives specified in the Purchaser’s inquiry or order. The workmanship and finish shall be first class in every respect and subject to the closest inspection by the Manufacturer’s inspector, whether or not the Purchaser waives any part of the inspection.

6.2.2 When material requires straightening, the work shall be done by pressing or another non injurious method prior to any layout or shaping. Heating or hammering is not permissible unless the material is heated to a forging temperature during straightening.

6.3 Cutting Plates

6.3.1 Plates, edges of heads, and other parts may be cut to shape and size by mechanical means such as machining, shearing, and grinding or by gas or arc cutting. After gas or arc cutting, all slag and detrimental discoloration of material that has been molten shall be removed by mechanical means before further fabrication or use.

6.3.2 All holes made in the tank wall, the edges of which are not to be fused by welds, should preferably be tool-cut. If openings are manually flame-cut, the edges to remain unwelded shall be tool-cut or ground smooth (see Figure 5-8 for finish of unwelded exposed edges).

6.4 Forming Sidewall Sections and Roof and Bottom Plates

6.4.1 Cylindrical Side Wall Sections
Figure 6-1 for steel tanks and Figure 6-2 for aluminum tanks provide criteria for shaping of cylindrical sidewalls to the curvature of the tank prior to installation in the tank. Shaping of plates concurrently with installation in the tank shell is permitted if the diameter exceeds the limits in Figure 6-1 (for steel tanks) and Figure 6-2 (for aluminum tanks) or if the Manufacturer’s alternate procedure for any diameter has been accepted by the Purchaser.

6.4.2 Roof and Bottom Plates
If curved, roof and bottom plates shall be formed to the required shape by any process that will not unduly impair the mechanical properties of the material.

6.5 Dimensional Tolerances

6.5.1 General
Tank walls subject to membrane stresses that are more than \( \frac{1}{3} \) of the allowable design stress under service conditions shall conform to the tolerances described in 6.5.2 through 6.5.6. The number and frequency of measurements are left to the judgement of the Manufacturer in order to produce an acceptable tank. Outer walls of double-wall tanks (see Appendices Q and R) that contain insulation and are not in contact with the design liquid are excluded. These tolerances may be waived or modified by agreement between the Purchaser and the Manufacturer.

6.5.2 Plumbness

6.5.2.1 For cylindrical sidewalls, the maximum out-of-plumbness of the top of the shell relative to the bottom of the shell shall not exceed \( \frac{1}{200} \) of the total tank height.
Note: Any combination of diameter and thickness falling on or above the solid line requires shaping prior to installation.

Figure 6-1—Shaping of Plates for Steel Tanks (See 6.4)

Note: Any combination of diameter and thickness falling on or above the solid line requires shaping prior to installation.

Figure 6-2—Shaping of Plates for Aluminum Tanks (See 6.4)
6.5.2.2 The out-of-plumbness in one shell plate shall not exceed the permissible variations for flatness and waviness specified in ASTM A6 or ASTM A20, whichever is applicable for carbon and alloy steels. For stainless steels, ASTM A480 is applicable. For aluminum plates, Table 5.13 of ANSI H35.2 provides the dimensional flatness tolerance.

6.5.3 Roundness

6.5.3.1 For cylindrical sidewalls, the horizontal circular cross section of a large, low pressure storage tank shall be sufficiently true to round so that the difference between the maximum and minimum diameters (measured inside or outside) at any section in a cylindrical wall shall not exceed 1% of the average diameter or 12 in., whichever is less, except as modified for flat-bottom tanks for which the radii measured at 1 ft 0 in. above the bottom corner weld shall not exceed the tolerances listed in Table 6-1.

6.5.3.2 The skirts or cylindrical ends of formed tops or bottoms shall be sufficiently true to round so that the difference between the maximum and minimum diameters shall not exceed 1% of the nominal diameter.

6.5.4 Local Deviations

Local deviations from the theoretical shape, such as weld discontinuities and flat spots, shall be limited as follows:

a. Using a horizontal sweep board 36-in. long, peaking at vertical joints shall not exceed 1/2 in. This may be increased to 1 in. for aluminum shells (see Appendix Q).

b. Using a vertical sweep board 36-in. long, banding at horizontal joints shall not exceed 1/2 in. This may be increased to 1 in. for aluminum shells (see Appendix Q).

c. Flat spots in the vertical plane shall not exceed the appropriate plate flatness and waviness requirements of 6.5.2.2.

6.5.5 Fitting Attachments

All lugs, brackets, nozzles, manhole frames, reinforcement around openings, and other appurtenances shall fit and conform to the curvature of the surface to which they are attached.

6.5.6 Foundation

6.5.6.1 To achieve the tolerances outlined in 6.5, a level foundation must be provided for the tank erection. The foundation should have adequate bearing power to maintain the levelness of the foundation.

6.5.6.2 The top of the foundation with a concrete ringwall shall be level within ± 1/8 in. in any 30 ft of circumference and within ± 1/4 in. in the total circumference. Without a concrete ringwall, the foundation shall be within ± 1/2 in. of the design shape.

6.5.6.3 For concrete slab foundations, from the outside of the tank radially toward the center, the first foot of the foundation (or width of the annular ring) shall comply with the concrete ringwall requirement. The remainder of the foundation shall be within ± 1/2 in. of the design shape.

6.5.7 Measurements

When measurements are required by agreement between the Purchaser and the Manufacturer, they shall be taken before the hydrostatic test. Measurements of local deviations shall be taken during construction. They shall be taken
with a steel tape—making corrections for temperature, sag, and wind—when the length being measured makes such corrections necessary. Deviation measurements shall be taken on the surface of the plate and not on welds.

6.5.8 Double-curvature Roofs, Bottoms, and Sidewalls

For double-curvature roofs, bottoms and sidewalls, the tolerances shall be as follows: The surface shall not deviate outside the design shape by more than 1.25% of D and inside the specified shape by more than 5/8% of D where D is the nominal inside diameter of the roof (or bottom) under consideration. Such deviations shall be measured perpendicular to the design shape and shall not be abrupt but shall merge smoothly into the adjoining surfaces in all directions. For a knuckle, D shall be considered to be twice the radius of the knuckle.

6.6 Details of Welding

6.6.1 General

6.6.1.1 Tanks and tank parts fabricated under these rules shall be welded by the processes defined in 6.6.2. Welding may be performed by manual, semi-automatic arc, or machine welding according to procedures described in ASME Section IX, and by welders and welder operators qualified under 6.7 and 6.8.

6.6.1.2 Welding shall be fusion welding without the application of mechanical pressure or blows.

6.6.1.3 Peening is permitted in accordance with 6.19.

6.6.1.4 Pipe materials that have longitudinal joints of the types permitted by the specifications listed in 4.3 are allowed.

6.6.2 Welding Processes

Tanks and their structural attachments shall be welded by the shielded metal-arc, gas metal-arc, gas tungsten-arc, oxyfuel, flux-cored-arc, submerged-arc, electroslag, or electrogas process using suitable equipment. Use of the oxyfuel, electroslag, or electrogas process shall be by agreement between the Manufacturer and the Purchaser. Use of the oxyfuel process is not permitted when impact testing of the material is required. Welding may be performed by manual, semi-automatic arc, machine, or automatic welding according to procedures described in ASME Section IX. Welding shall be performed in such a manner as to ensure complete fusion with the base metal. The Purchaser may designate applicable sections of API 582 for supplementary welding guidelines and practices.

6.7 Qualification of Welding Procedure

6.7.1 Each Welding Procedure Specification (WPS) shall be qualified in accordance with the latest practice as given in Section IX of the ASME Code. When impact tests are required by 4.2.5 or when required by appropriate appendices, the weld metal and heat affected zone shall be tested and the Supplementary Essential Variables in Section IX of the ASME Code shall be applied. In addition, the heat treated condition and the application or omission of fine grain practice for the base metal shall be an additional Supplementary Essential Variable. Welding procedures for ladder and platform assemblies, handrails, stairways, and other miscellaneous assemblies but not their attachments to the tank, shall comply with either AWS D1.1, AWS D1.6, or Section IX of the ASME Code, including the use of SWPSs.

6.7.2 Carbon steel materials not listed in Table QW-422 of Section IX of the ASME Code shall be considered as P-Number 1 material with group numbers assigned as follows, according to the minimum tensile strength specified:

   a. < 70 kips/in.² (Group 1).
   b. ≥ 70 kips/in.² but < 80 kips/in.² (Group 2).
   c. ≥ 80 kips/in.² (Group 3).

6.7.3 The required tests to qualify the Welding Procedure Specification (WPS) shall be conducted by the fabricator.

6.7.4 The stress-relieving requirements in the procedures to be followed in each case should be agreed upon between the Manufacturer and the Purchaser. Peening may be done if it is part of the welding procedure and is approved by the Purchaser.
6.8 Qualification of Welders

6.8.1 All welders assigned to manual or semi-automatic arc welding, and welding operators assigned to machine welding, shall have successfully passed the tests conducted by the fabricator, or Manufacturer, as prescribed for welder qualification in Section IX of the ASME Code. Tests conducted by one Manufacturer shall not qualify a welder or welding operator to do work for any other Manufacturer.

6.8.2 The Manufacturer shall assign each welder or welding operator an identifying number, letter, or symbol. Except for all lap-welded roof seams and flange-to-neck joints, this identifying mark shall be stamped, either by hand or machine, on all tanks adjacent to and at intervals of not more than 3 ft along the welds made by a welder or welding operator; alternatively, the Manufacturer may keep a record of welders employed on each joint and shell-opening joint and omit the stamping. If such a record is kept, it shall be maintained until tests are completed and shall be available to the inspector.

6.8.3 The Manufacturer shall maintain a record of the welders employed, showing the date and result of tests and the identification mark assigned to each. These records shall be certified by the Manufacturer and shall be accessible to the inspector.

6.9 Matching Plates

6.9.1 The plates that are being welded shall be accurately matched and retained in position during the welding operation. Tack welds may be used to hold the plate edges in line if the requirements of 6.9.1.1 through 6.9.1.4 are followed.

6.9.1.1 The tack welds in butt joints to be welded manually are removed before welding.

6.9.1.2 The tack welds in butt joints to be machine welded by a process that will re-melt the tack welds shall be thoroughly cleaned of all welding slag and examined for soundness.

6.9.1.3 Tack welds in lap and fillet welded joints need not be removed if they are sound and the subsequently applied weld beads are thoroughly fused into the tack welds.

6.9.1.4 Tack welds, whether removed or left in place, shall be made using a fillet-weld or butt-weld procedure qualified in accordance with Section IX of the ASME Code. Tack welds to be left in place shall be made by welders qualified in accordance with Section IX of the ASME Code and shall be examined visually for defects; if welds are found to be defective, they shall be removed.

6.9.2 During assembly of the plates and subject to agreement between the Manufacturer and the Purchaser, the welded joints in adjoining segments, which abut at a common transverse joint from opposite sides, need not be staggered unless specified by the Purchaser. When specified, the stagger should be at least five times the plate thickness of the thicker course.

6.10 Cleaning Surfaces to be Welded

6.10.1 Immediately before any welding operation, the surface to be welded or to which weld metal is to be applied shall be cleaned thoroughly of all scale, slag, grease, and any oxide that would lower the quality of the deposited weld metal. A light oxide film resulting from flame cutting is not considered detrimental.

6.10.2 On all multilayer welding, each layer of weld metal shall be cleaned of slag and other deposits before the next layer is applied.

6.10.3 The reverse side of double welded butt joints shall be prepared by chipping, grinding, or melting out to ensure sound metal at the base of the weld metal first deposited before weld metal is applied from the reverse side. This operation shall be done to ensure complete penetration and proper fusion in the final weld. When melting out is done, particular care shall be exercised to prevent contamination of the melted area by foreign materials, especially carbon.

Note: The proceeding requirements of this section are not intended to apply to any welding procedure by which proper fusion and complete penetration are otherwise obtained and by which unacceptable defects at the base of the weld are avoided.
6.10.4 Cast steel surfaces to be welded must first be machined or chipped to remove foundry scale and to expose sound metal.

6.11 Weather Conditions for Welding

No welding of any kind shall be done (a) when the surfaces to be welded are wet from rain, snow, or ice, (b) when rain or snow is falling on such surfaces, or (c) during periods of high winds, unless the welder and work are properly shielded. Preheat shall be applied when the metal temperature is below the temperature required by Table 6-2. In that case the base metal shall be heated to at least the temperature indicated in Table 6-2 within 3 in. of the place where welding is to be started and maintained 3 in. ahead of the arc. Material P-Numbers and Groups shall be as designated in ASME IX, Table QW-422 or in API 620, 6.7.2 for materials not listed in Table QW-422.

<table>
<thead>
<tr>
<th>Material P-No. and Group</th>
<th>Thickness (t) of Thicker Plate (inches)</th>
<th>Minimum Preheat Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-No. 1 Group 1</td>
<td>$t \leq 1.25$</td>
<td>32°F</td>
</tr>
<tr>
<td></td>
<td>$1.25 &lt; t \leq 1.50$</td>
<td>50°F</td>
</tr>
<tr>
<td></td>
<td>$t &gt; 1.50$</td>
<td>200°F</td>
</tr>
<tr>
<td>P-No. 1 Groups 2 &amp; 3</td>
<td>$t \leq 1.25$</td>
<td>50°F</td>
</tr>
<tr>
<td></td>
<td>$1.25 &lt; t \leq 1.50$</td>
<td>100°F</td>
</tr>
<tr>
<td></td>
<td>$t &gt; 1.50$</td>
<td>200°F</td>
</tr>
</tbody>
</table>

6.12 Reinforcement on Welds

6.12.1 Butt joints shall have complete joint penetration and complete fusion for the full length of the weld and shall be free from undercuts, overlaps, or abrupt ridges or valleys. To ensure that the weld grooves are completely filled so that the surface of the weld metal at any point does not fall below the surface of the adjoining plate, weld metal may be built up as reinforcement on each side of the plate. The thickness of the reinforcement on each side of the plate shall not exceed the thickness listed in Table 6-3, but the reinforcement need not be removed except when it exceeds the permissible thickness or when required in 7.15.1.

6.12.2 When a single-welded butt joint is made by using a backing strip that is left in place (see Table 5-2), the requirement for reinforcement applies to only the side opposite the backing strip.

6.13 Merging Weld With Plate Surface

The edges of the weld shall merge smoothly with the surface of the plate without a sharp angle. Maximum permissible weld undercut is $\frac{1}{64}$ in. for longitudinal or meridional butt joints, similarly oriented permanent attachments, attachment welds for nozzles, manholes, flush-type openings, and the inside shell-to-flat bottom welds. For circumferential and latitudinal butt joints, similarly oriented permanent attachments, and annular ring butt joints, the maximum permissible undercutting is $\frac{1}{32}$ in.

6.14 Aligning of Main Joints

Particular care shall be taken in matching up the edges of all plates within the tolerances of offset as follows:

a. For plates $\frac{1}{4}$ in. in thickness and less, $\frac{1}{16}$ in.

b. For plates over $\frac{1}{4}$ in. in thickness, 25% of the plate thickness or $\frac{1}{8}$ in., whichever is smaller.

6.15 Repairing Defects in Welds

Defects in welds shall be chipped, melted out, or machined out until sound metal is reached on all sides. Subject to the approval of the inspector, the resulting cavity shall be filled with the weld metal and retested.
Section 7—Inspection, Examination and Testing

7.1 Responsibility of Examiner

7.1.1 The inspector shall ensure that all materials used in tanks constructed according to the rules in this standard comply in all respects with the requirements of these rules. This shall be done either by witnessing mill tests or examining certified mill test reports supplied by the Manufacturer.

7.1.2 Tanks constructed according to the rules in this standard shall be inspected and tested in accordance with the sections that follow. The inspector shall carefully follow the fabrication and testing of each tank and shall make sure that they comply in all details with the design, fabrication, and tests specified in these rules.

7.2 Qualifications of Examiners

7.2.1 Examiners for tanks constructed according to the rules in this standard shall have had not less than 5 years experience in design, construction, maintenance and/or repair, or in the responsible supervision of the construction, maintenance and/or repair of various types of unfired pressure vessels and/or tanks, including at least 1 year of experience in the construction or supervision of the construction of vessels or tanks by fusion welding. Satisfactory completion of a suitable course of training approved by the Purchaser or the Purchaser’s agent may be substituted for 3 of the 5 years experience. However, training cannot replace more than 6 months of the required experience on fusion-welding construction.

7.2.2 Inspectors shall be employed by the Purchaser or by an organization regularly engaged in making inspections. An examiner is the accredited representative of the Purchaser.

7.2.3 The Manufacturer shall also provide inspection to help ensure that all requirements of these rules have been met before signing the certificate and Manufacturer’s report (see 8.3).

7.3 Access for Inspector

The inspector shall be permitted free access to all parts of the plant concerned with the manufacture of the tank during fabrication and to all parts of the plants of material suppliers who are concerned with the manufacture of materials to be used in the tank.

7.4 Facilities for Inspector

The Manufacturer shall afford the inspector all reasonable facilities for testing and inspection and shall provide mutually agreeable advance notification to permit the examiner to witness all tests of the equipment and materials during fabrication, including all laboratory tests of the material to be used and all hydrostatic and pneumatic tests at the site of erection.

7.5 Approval of Repairs

Approval by the inspector shall be required before and after any defects are repaired. Defective material that cannot be satisfactorily repaired shall be rejected (see 6.16 for repair of defects in welds).

7.6 Inspection of Materials

The plates and other material for parts that will be subjected to pressure-imposed loads shall be inspected before being incorporated in the tank. Particular attention shall be given to all cut edges to ensure that the material is free from serious laminations and other defects.

---

34 The term inspector, as used here and elsewhere in this standard, refers to an individual who has the qualifications set forth in 7.2
7.7 Stamping of Plates

Before plates required to be stamped by the steel mill are used, the inspector shall see that they bear the stamp. In laying out and cutting the plates, at least one set of the original material identification markings should, if possible, be left where it will be plainly visible when the tank is completed. Should the identifying marks be obliterated, one set shall be accurately transferred by the tank Manufacturer to a location that will be visible on the completed tank, or a coded marking shall be used to ensure identification of each piece of material during fabrication and subsequent identification of the markings on the completed tank. These latter markings shall be readily distinguishable from the mill markings. The inspector need not witness the transfer of the markings but shall be satisfied that the transfer of the markings has been made correctly. Care should be taken not to damage the plate by stamping the figures too deeply. To guard against incipient cracks in plates less than \( \frac{1}{4} \) in. thick, the mill markings shall be transferred in some manner other than by die stamping.

7.8 Measuring Thickness of Material

All material shall be gauged or measured to determine whether the thickness meets the requirements.

7.9 Inspection of Surfaces Exposed during Fabrication

7.9.1 The edges of plates, openings and fittings exposed during fabrication shall be inspected carefully to make sure that any defects have been uncovered, as well as to determine that the work has been performed properly.

7.9.2 Minor defects found may be repaired only after the inspector approves the method and extent of repairs. Materials that have more than minor defects that cannot be satisfactorily repaired shall be rejected.

7.10 Surface Inspection of Component Parts

Before assembly, unless already so certified by shop inspectors, all sidewall plates or sections and roof and bottom plates shall be inspected for thickness, freedom from injurious defects, and soundness of any welded joints.

7.11 Check of Dimensions of Component Parts

All formed plates and curved sections shall be checked for conformance with the planned dimensions and cross section. For unusual repairs the inspector should keep a record of measurements taken at sufficient intervals to constitute a satisfactory record.

7.12 Check of Chemical and Physical Property Data

The inspector shall check the material being assembled by the lists of the plates from the mill, their heat numbers, chemical analyses, and mechanical properties as given on mill reports and shall see that copies are available to be attached to the Manufacturer’s report (see 8.3).

7.13 Data Required from Manufacturer on Completed Tanks

If specified in the purchase order, the Manufacturer shall supply marked copies of plans (or a separate sketch) showing the location of all plates, with a means of identifying each plate with the heat numbers. These markings shall be checked by the inspector. A copy shall be attached to the Manufacturer’s report.

7.14 Check of Stress-relieving Operation

The inspector shall check any thermal stress-relieving operation and shall be satisfied that the temperature readings are accurate and that the procedure conforms to the applicable requirements of these rules.
7.18.2.5 Tanks with anchors shall be grouted (if required by design) and anchor retainers shall be attached.

7.18.2.6 After all the welding has been examined and tested and all defective welding disclosed by such examination and testing has been repaired and retested, the tank shall be filled with air to a pressure of 2 lbf/in.² gauge or one-half the pressure $P_g$ for which the vapor space at the top of the tank is designed, whichever pressure is smaller. A solution film shall be applied to all joints in the tank wall above the high liquid (capacity) design level. If any leaks appear, the defects shall be removed and rewelded, and the applicable preliminary tightness tests specified shall be repeated. When anchors are not provided near the boundary of contact to hold down a dished tank bottom resting directly on the tank grade, the bottom at this boundary may be rise slightly off the foundation during the tightness test when air pressure is in the tank. In this case, sand shall be tamped firmly under the bottom to fill the gap formed while the tank is under pressure (see 7.18.8).

7.18.3 Combination Hydrostatic-pneumatic Tests

7.18.3.1 Tanks that have not been designed to be filled with liquid to a test level higher than their specified capacity level (see 5.3.1.2) shall be subjected to combination hydrostatic-pneumatic pressure tests in accordance with the procedure described in 7.18.3.2 through 7.18.3.5.

7.18.3.2 After the preliminary tightness tests specified in 7.18.4 have been completed, the pressure-vacuum relief valve or valves shall be blinded off. With the top vented to the atmosphere to prevent accumulation of pressure, the tank shall be filled with water to its high liquid (capacity) design level (see 7.18.7). Tank anchor retainers shall be adjusted to a uniform tightness after the tank is filled with water. If the pressure-vacuum valve or valves are not available at the time of the test, the tank connections may be blinded off and the test procedure continued by agreement between the Purchaser and the Manufacturer. With the vents at the top of the tank closed, air shall be injected slowly into the top of the tank until the pressure in the vapor space is about one-half the pressure $P_g$, for which this space is designed. The air pressure shall be increased slowly until the pressure in the vapor space is 1.25 times the pressure, $P_g$, for which the space is designed.

7.18.3.3 An air test introduces some hazard. In view of the large amount of air that will be present in the tank during this test, no one should be permitted to go near the tank while pressure is being applied for the first time during this test. While the pressure in the tank exceeds the pressure for which the vapor space is designed, the inspections should be made at a reasonable distance from the tank using field glasses as required for close-up observation of particular areas.

7.18.3.4 As the pressure is being increased, the tank shall be inspected for signs of distress. The maximum test pressure of 1.25 times the vapor space design pressure shall be held for at least one hour, after which the pressure shall be released slowly and the blinds shall be removed from the pressure-vacuum relief valves. The operation of the relief valves shall then be checked by injecting air into the top of the tank until the pressure in the vapor space equals the pressure, $P_g$, for which this space is designed, at which time the relief valves shall start to release air.

7.18.3.5 This latter pressure shall be held for a sufficient period of time to permit a close visual examination of all joints in the walls of the tank and of all welding around manways, nozzles, and other connections. As part of this examination, a solution film shall be applied to all of the welding involved above the high liquid (capacity) design level for which the tank is designed.

7.18.4 Complete Hydrostatic Tests

7.18.4.1 Tanks that have been designed and constructed to be filled with liquid to the top of the roof (see 5.3.1.2) shall be subjected to full hydrostatic tests in accordance with the procedure prescribed in 7.18.4.2 and 7.18.4.4, in lieu of the procedure specified in 7.18.3.

7.18.4.2 Following the test preliminaries called for in 7.18.2, the pressure-vacuum relief valve or valves shall be blinded off; with the top of the tank vented to the atmosphere, the tank shall be filled with water to the top of the roof (see 7.18.7) while allowing all air to escape to prevent the accumulation of pressure. If the pressure-vacuum relief
valve or valves are not available at the time of the test, the tank connections may be blinded off and the test procedure continued by agreement between the Purchaser and the Manufacturer. The vents used during water filling of the tank shall then be closed, and the pressure in the tank shall be increased slowly until the hydrostatic pressure under the topmost point in the roof is 1.25 times the pressure, $P_g$, which the vapor space is designed to withstand when in operation with the tank filled to its specified high liquid (capacity) level.

7.18.4.3 This test procedure shall be held for at least one hour. The hydrostatic pressure under the topmost point in the roof shall then be reduced to the pressure, $P_g$, for which the vapor space is designed and shall be held at this level for a sufficient time to permit close visual inspection of all joints in the walls of the tank and all welding around manways, nozzles and other connections.

7.18.4.4 The tank shall then be vented to atmosphere, the water level shall be lowered below the inlets to the pressure-relief valves, and the blinds shall be removed from the relief valves. The operation of the relief valves shall then be checked by injecting air into the top of the tank until the pressure in the vapor space equals the pressure, $P_g$, for which this space is designed, at which time the relief valves shall start to release air.

7.18.5 Partial-vacuum Tests

7.18.5.1 Following the tests specified in 7.18.3 (or in 7.18.4) where this latter procedure has been used), the pressure in the vapor space of the tank shall be released and a manometer shall be connected to this space. The ability of the upper part of the tank to withstand the partial vacuum for which it is designed and the operation of the vacuum-relief valve or valves on the tank shall then be checked by withdrawing water from the tank, with all vents closed, until the design partial vacuum is developed at the top of the tank and by observing the differential pressure at which the valve or valves start to open. The vacuum-relief valve or valves must be of a size and be set to open at a partial vacuum closer to the external atmospheric pressure than the partial vacuum for which the tank is designed. The partial vacuum in the tank should never exceed the design value (see Appendix K).

7.18.5.2 After completing 7.18.5.1, the withdrawal of water from the tank shall be continued, with the vents closed and without exceeding the specified maximum partial vacuum in the top of the tank, until the level in the tank reaches one-half the high liquid (capacity) level for which the tank is designed. Alternatively, to speed up the withdrawal of water to the degree thought expedient, the vents may either be kept closed and air pressure not exceeding $P_g$ at the top of the tank applied, or the vents may be opened during most of this interval if in either procedure they are closed long enough before the level in the tank reaches half height for the specified partial vacuum to be developed by the time the level of the water reaches half height. Air shall then be again injected into the tank until the pressure above the water level equals the pressure, $P_g$, for which the vapor space at the top of the tank is designed.

7.18.5.3 Careful observation shall be made under all of the specified conditions of loading, as well as with atmospheric pressure above the surface of the water when the level is at half height, to determine whether any appreciable changes occur in the shape of the tank (see 7.18.8). In the case of a vertical tank with cylindrical sidewalls, no tests are required with the water level at half height; in this case, the tests specified in 7.18.5.4 shall be applied immediately after the first vacuum test specified in 7.18.5.

7.18.5.4 The water remaining in the tank shall then be withdrawn and when the tank is substantially empty, a vacuum test comparable to that specified in 7.18.5.1, except with regard to the level of water in tank, shall be applied to the tank. After this, air shall again be injected into the tank until the pressure in the tank equals the pressure, $P_g$, for which the vapor space at the top of the tank is designed. Observations shall be made, both with the specified partial vacuum and with the vapor space design pressure above the surface of the water, to determine whether any appreciable changes in the shape of the tank occur under either condition of loading. In the case of a tank whose dished bottom rests directly on

---

36 These provisions presuppose that an ejector or vacuum pump is not available for drawing a partial vacuum on the tank. However, if such equipment is available, it may be used; vents may be opened during the entire period while the water level is being lowered; and the sequence of the vacuum and pressure test may be reversed if either the tank Manufacturer or the Purchaser so selects.
Section 9—Pressure- and Vacuum-relieving Devices

9.1 Scope

The Manufacturer or Purchaser shall equip tanks constructed within the pressure limits of these rules with pressure-relieving and emergency vacuum-relieving valves, or other equivalent permissible devices, as a means of safeguarding the storage and adjacent equipment involved (see 9.6.1.2 and Appendix N).

9.2 Pressure-relieving Devices

9.2.1 Tanks shall be protected by automatic pressure-relieving devices that will prevent the pressure at the top of the tank from rising more than 10% above the maximum positive gauge pressure except as provided in 9.2.2 (see Appendix K).

9.2.2 Where an additional hazard can be created by the exposure of the tank to accidental fire or another unexpected source of heat external to the tank, supplemental pressure-relieving devices shall be installed. These devices shall be capable of preventing the pressure from rising more than 20% above the maximum positive gauge pressure. A single pressure-relieving valve may be used if it satisfies the requirements of this paragraph and 9.2.1.

9.2.3 Vacuum-relieving devices shall be installed to permit the entry of air (or other gas or vapor is so designed) to avoid collapse of the tank wall if this could occur under natural operating conditions. These devices shall be located on the tank so that they will never be sealed off by the contents of the tank. Their size and pressure (or vacuum) setting shall be such that the partial vacuum developed in the tank at the maximum specified rate of air (or gas) inflow will not exceed the partial vacuum for which the tank is required to be designed (see 5.10.5).

9.3 Construction of Devices

Pressure- and vacuum-relieving valves shall be constructed of materials that are not subject to excessive corrosion for the intended service or subject to sticking at the seat or moving parts under any climatic conditions for which they are supplied.

9.4 Means of Venting

The applicable rules of 5.4 in API 2000 shall govern.

9.5 Liquid Relief Valves

A tank, which is likely to operate completely filled with liquid, shall be equipped with one or more liquid relief valves at the top of the roof, unless otherwise protected against overpressure. When such valves are, in effect, supplementary relief devices, they may be set at a pressure not greater than 1.25 times the design pressure. Because the relief valve at the pump, which provides the inflow of liquid to the tank, is set at a pressure greater than 1.25 times the design pressure of any tank that may be built under these rules, provision should be made for preventing overfilling of the tank by a self-closing float valve, by some practicable pilot-valve control, or by any other proven device.

9.6 Marking

9.6.1 Safety and Relief Valves

9.6.1.1 Each safety and relief valve 1/2-in. pipe size and larger shall be plainly marked by the manufacturer with the required data in such a way that the marking will not be obliterated in service. Smaller valves are exempted from marking requirements. The marking may be placed on the valve or on a plate or plates securely fastened to the valve. Valves may be marked with the required data stamped, etched, impressed, or cast on the valve or nameplate. The marking shall include the following:
a) Name or identifying trademark of the manufacturer.

b) Manufacturer’s design or type number.

c) Size of valve (pipe size of the valve inlet).

d) Set pressure, in lbf/in.\(^2\) gauge.

e) Full open pressure, in lbf/in.\(^2\) gauge.

f) Capacity of valve, in \(\text{ft}^3\) or \(\text{air}^{38}\) per minute (60°F and 14.7 lbf/in.\(^2\) absolute). See 9.6.1.2.

9.6.1.2 In many installations of tanks constructed according to these rules, the safety- or relief-valve inlet pressure is so low in relation to the outlet pressure that valve capacities predicted on acoustic velocity of flow through the discharge area of the valve (the usual basis for establishing safety-valve ratings) are not attainable. For valves that handle light hydrocarbons or vapors, the condition described will exist if the ratio of the absolute pressure at the valve outlet to the absolute pressure at the valve inlet (set pressure in lbf/in.\(^2\) gauge times 1.10, plus atmospheric pressure) exceeds a value of approximately 0.6: in such cases, formulas of the type given in Section VIII, Appendix 11, of the ASME Code are not appropriate for computing safety- or relief-valve capacity conversions. Where this condition exists, the valve manufacturer should be consulted concerning the size of the valve or valves required for the desired capacity in terms of the specific gas or vapor to be handled, the set pressure to be employed, and the pressure to be imposed on the outlet of the valve. If atmospheric pressure in the locality where the valve is to be used differs materially from 14.7 lbf/in.\(^2\) absolute, its normal value should be given in the inquiry to the manufacturer.

9.6.2 Liquid Relief Valves

Each liquid relief valve shall be marked with the following data:

a) Name or identifying trademark of the manufacturer.

b) Manufacturer’s design or type number.

c) Size of valve, in in. (pipe size of inlet).

d) Set pressure, in lbf/in.\(^2\) gauge.

e) Full open pressure, in lbf/in.\(^2\) gauge.

f) Relieving capacity, in \(\text{ft}^3\) of water (see Footnote 16) per minute at 70°F.

9.7 Pressure Setting of Safety Devices

9.7.1 Except as provided in 9.5 for certain liquid relief valves, the pressure setting of a pressure-relieving device shall in no case exceed the maximum pressure that can exist at the level where the device is located when the pressure at the top of the tank equals the nominal pressure rating for the tank (see 5.3.1) and the liquid contained in the tank is at the maximum design level.

9.7.2 Vacuum-relieving devices shall be set to open at such a pressure or partial vacuum that the partial vacuum in the tank cannot exceed that for which the tank is designed when the inflow of air (or other gas or vapor) through the device is at its maximum specified rate.

\[38\] In addition, the manufacturer may indicate the corresponding capacity in other fluids.
Appendix A has been deleted
Appendix L
Seismic Design of API 620 Storage Tanks

L.1 Scope

This appendix provides minimum requirements for the design of welded storage tanks that may be subject to seismic ground motion and are designed and constructed to the API 620 standard. These requirements represent accepted practice for application to welded steel flat-bottom tanks supported at grade. This appendix is based on the requirements of API 650, Appendix E and uses the same notations except as supplemented herein. The design procedures contained in this appendix are based on allowable stress design (ASD) methods.

All tanks designed and constructed to the requirements defined in 1.2 shall meet the requirements of API 650, Appendix E unless specifically modified or augmented herein. All of the requirements contained in API 650, Appendix E are not duplicated here, but are wholly incorporated by reference. Special provisions for tanks designed and constructed in accordance with Appendices Q and R are included in this appendix.

Application to tanks supported on a framework elevated above grade is beyond the scope of this appendix.

Design procedures are included for the consideration of the increased damping and increase in natural period of vibration due to soil-structure interaction for mechanically anchored tanks.

Tanks located in regions where $S_1$ is less than or equal to 0.04 and $S_2$ less than or equal to 0.15, or the peak ground acceleration for the ground motion defined by the regulatory requirements is less than or equal to 0.05 g, need not be designed for seismic forces; however, in these regions, tanks in SUG III shall comply with the freeboard requirements of this appendix.

Dynamic analysis methods incorporating fluid-structure and soil-structure interaction are permitted to be used in lieu of the procedures contained in this appendix with Purchaser approval and provided the design and construction details are as safe as otherwise provided in this appendix.

The provisions for outer tanks of double walled tank systems are limited to metallic outer tanks designed and constructed in accordance with API 650 or API 620. Outer tanks designed and constructed of other materials such as reinforced or prestressed concrete are outside the scope of this standard.

L.2 Notations

L.2.1 Notations

- $h_s$ is additional shell height required above the sloshing wave height, mm (ft);
- $W_{ns}$ is the effective weight of insulation acting on the tank shell for lateral seismic load, N (lbf);
- $W_{nr}$ is the effective weight of insulation acting on the tank roof for lateral seismic load, N (lbf);
- $X_{ns}$ is the height from the bottom of the shell to the center of action for the insulation load on the tank shell, m (ft);
- $X_{nsr}$ is the height from the bottom of the shell to the center of action for the insulation load on the tank roof, m (ft);

L.3 Special Provisions for Tanks Designed and Constructed to API 620, Appendix Q and Appendix R

For storage tanks required to meet Appendix Q and Appendix R, the provisions of API 650, Appendix E shall be modified as shown in API 620, Appendix L. If the requirements of API 650, Appendix E or API 620, Appendix L conflict with those of API 620, Appendix Q or Appendix R, the more conservative requirements shall apply.
Special provisions for refrigerated tanks requiring performance level designs are contained in Section L.4.

L.3.1 Force Reduction Factor

The response modification factor for ground supported, liquid storage tanks designed and detailed to these provisions shall be less than or equal to the values shown in Table L-1Q or L-1R, as applicable.

Table L-1Q—Force Reduction Factors for ASD Methods, Appendix Q Tanks

<table>
<thead>
<tr>
<th>Anchorage System</th>
<th>$R_{wi}$, (impulsive)</th>
<th>$R_{wc}$, (convective)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Tank:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel (nickel, or stainless)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-anchored</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Mechanically-anchored</td>
<td>1.75</td>
<td>1.0</td>
</tr>
<tr>
<td>Aluminum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-anchored</td>
<td>1.25</td>
<td>1.0</td>
</tr>
<tr>
<td>Mechanically-anchored</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Outer Tank (Empty):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-anchored</td>
<td>2.0</td>
<td>n/a</td>
</tr>
<tr>
<td>Mechanically-anchored</td>
<td>2.0</td>
<td>n/a</td>
</tr>
</tbody>
</table>

NOTE: The above $R_w$ factors are applied for CLE (or SSE) event. For OLE (or OBE), the elastic design ($R_w = 1.0$) is used.

Table L-1R—Force Reduction Factors for ASD Methods, Appendix R Tanks

<table>
<thead>
<tr>
<th>Anchorage System</th>
<th>$R_{wi}$, (impulsive)</th>
<th>$R_{wc}$, (convective)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Tank:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-anchored</td>
<td>2.25</td>
<td>1.5</td>
</tr>
<tr>
<td>Mechanically-anchored</td>
<td>2.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Outer Tank (Empty):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-anchored</td>
<td>2.0</td>
<td>n/a</td>
</tr>
<tr>
<td>Mechanically-anchored</td>
<td>2.0</td>
<td>n/a</td>
</tr>
</tbody>
</table>

The inner and outer tanks may be decoupled for seismic design of the tank and anchorage and assumed to act independently. However, if the inner and outer tanks are supported by a common foundation, the seismic foundation loading shall be calculated using the lesser response modification values for either the inner tank or outer tank for both tanks and a dynamic analysis shall be performed to determine the combined effect.

L.3.2 Resistance to Design Loads

L.3.2.1 Allowable Stresses

For Appendix R tanks, design allowable stresses shall be per API 620, Section R.3.3.

For Appendix Q tanks, design allowable stresses shall be per API 620, Section Q.3.3.

L.3.2.2 Annular Bottom Plates

Thickness shall be per API 650, Appendix E (with loads modified by requirements of this appendix) plus corrosion allowance unless a thickness increase is required for compliance with Appendix R or Appendix Q. Annular plate width shall be per API 650, Appendix E (with loads modified by requirements of this appendix) unless a width increase is
required for compliance with Appendix R or Appendix Q. Thickness used for determination of API 650, Appendix E width shall be based on the thickness required for seismic product hold down.

L.3.2.3 Resistance to Sliding

The tank system, whether self-anchored or mechanically-anchored, shall be configured such that the overall horizontal shear force at the base of the tank does not exceed the friction capacity as defined in API 650, Section E.7.6. Mechanical anchorage shall not be used to resist sliding.

L.3.2.4 Insulation Load

For tanks designed and constructed with an outer tank containing loose fill insulation in the annular space between the tanks, the insulation weight shall be divided equally to the inner and outer tank wall for seismic lateral loads unless a more rigorous analysis is performed to determine the distribution. The insulation within the annular space shall not be used to calculate resistance to overturning. Insulation on the roof or suspended deck shall be applied to the tank supporting the load at the point or center of gravity of attachment and may be used to resist overturning.

For single wall tanks with insulation or double wall tanks with the insulation adhered to the plate surface, the additional weight of the insulation shall be included and may be included in the tank weight, \( w_i \), used to resist overturning. The insulation weight shall also be included in the definition of the terms, \( W_T \) and \( W_{RS} \).

Modify Equation (E.6.1-2) of API 650, Appendix E as shown in Equation (L-1):

\[
V_i = A_i(W_i + W_f + W_i + W_{ai} + W_{ai})
\]

Modify Equation (E.6.1.5-1) and Equation (E.6.1.5-2) of API 650, Appendix E as shown in Equation (L-2) and Equation (L-3):

\[
\text{Ringwall Moment, } M_{rw}:
\]

\[
M_{rw} = \sqrt{[A_i(W_iX_i + W_fX_i + W_rX_i + W_{ai}X_{ai} + W_{ai}X_{ai})]^2 + [A_i(W_rX_i)]^2}
\]

\[
\text{Slab Moment, } M_s:
\]

\[
M_s = \sqrt{[A_i(W_iX_i + W_fX_i + W_rX_i + W_{ai}X_{ai} + W_{ai}X_{ai})]^2 + [A_i(W_rX_i)]^2}
\]

L.3.2.5 Additional Roof Loads

When \( S_{DS} > 0.33g \) and the tank is classified as SUG III; and equipment loads such as pumps, platforms, piping platforms supported directly by the roof exceed 25 % of the combined weight of the roof and shell, \( W_r + W_s \), a dynamic analysis shall be performed to determine the effective roof load and the amplified roof acceleration for the design of the roof, roof supports and superstructure supported by or suspended from the roof.

L.3.2.6 Alternate Performance Basis Design

If the governing regulations or project documents require the tank system to be designed for an operating level earthquake or to consider aftershocks, the provisions in L.4 may be used. Adjustment may be required to the definition of the ground motion (i.e. different recurrence interval).

If base isolation of the tank system is permitted, the requirements of L.4.5 shall apply.
L.4 Special Provisions for Tanks Requiring Performance Level Designs

This section is applicable to refrigerated tanks built to API 620, Appendix Q with supplemental seismic design methods addressing an operating level earthquake (OLE), sometimes referred to as OBE, a contingency level earthquake (CLE), sometimes referred to as SSE, and an aftershock level earthquake (ALE) when required by regulations or the Purchaser.

The performance basis objectives for the ground motions are as follows.

a) OLE—the tank system will remain operational with only minor repair required. The tank system should be capable of withstanding multiple events with this ground motion without significant damage.

b) CLE—the primary liquid container will survive and contain the liquid (with only minor leaks permitted) to protect the public but extensive damage may occur and the tank system may not be repairable after this event. This is assumed to be a singular event in the design life of the tank system.

c) ALE—the primary liquid container is assumed to be damaged by the CLE event and the secondary containment system is containing the liquid. The secondary containment is intended to survive multiple aftershocks of the ALE ground motion with minor damage and leaks.

The requirements of API 650, Appendix E, and L.3 of this standard apply unless modified herein.

L.4.1 Ground Motions

The definition of the ground motions to be used with the OLE, CLE and ALE events may vary depending on regulations for the specific location. Within the U.S. federal regulations 49 CFR 193 and NFPA 59A are the primary regulatory and standard documents for storage tanks. The user is referred to those documents or similar regulatory documents when the tank is located outside the U.S., for ground motion definitions to be used with this appendix.

Vertical earthquake shall be considered.

A site-specific response spectrum is required for tanks located in regions where peak ground acceleration is greater than 0.15g or $S_s$ is greater than 0.3g unless otherwise specified.

The exception in API 650, Section E.4.6.2 limiting the upper value of the spectral acceleration, $S_{la}^*$ under specific tank configurations is not applicable.

Current U.S. requirements are based on a response spectrum with 5 % damping. If the site specific regulations require a different damping value, and a site-specific spectrum is not required, the following factors may be applied to the impulsive spectral component to adjust the 5 % damped values to other values of damping. The convective multiplier, $K$, from API 650, Appendix E is unchanged and equal to 1.5. Alternative adjustment factors to damping ratios are permitted providing they are based on local geotechnical data and rational analysis.

<table>
<thead>
<tr>
<th>Damping Ratio</th>
<th>Adjustment Factor, $K_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 %</td>
<td>0.45</td>
</tr>
<tr>
<td>10 %</td>
<td>0.6</td>
</tr>
<tr>
<td>5 %</td>
<td>1.0</td>
</tr>
<tr>
<td>2 %</td>
<td>1.65</td>
</tr>
<tr>
<td>1 %</td>
<td>2.0</td>
</tr>
<tr>
<td>0.5 %</td>
<td>2.2</td>
</tr>
</tbody>
</table>
L.4.2 Operating Level Earthquake (OLE)

Unless otherwise defined by the governing local regulations, the operating level earthquake ground motion shall be defined as the motion due to an event with a 10 % probability of exceedence within a 50-year period (a 475-year recurrence interval).

L.4.2.1 OLE Definition Based on Appendix E, ASCE 7 Method

To utilize API 650, Section E.4 to define the OLE ground motion, the following modifications shall be made based on the provisions in this appendix.

1) Re-define the following terms for OLE only:

- $S_S$ is mapped, 10 % PE50 earthquake from the USGS data, 5-percent-damped, spectral response acceleration parameter at short periods (0.2 sec), % g;
- $S_1$ is mapped, 10 % PE50 earthquake from the USGS data, 5-percent-damped, spectral response acceleration parameter at a period of one second, % g.

2) The scaling factor, $Q$, is not applicable.

3) API 650, Appendix E, Equation (E.4.6.1-2) and Equation (E.4.6.1-3), do not apply.

4) Equation (E.4.6.1-1) shall be modified:

$$ A_i = K_F s_s $$

5) Equation (E.4.6.1-4) and Equation (E.4.6.1-5) shall be modified:

When, $T_C \leq T_L$:

$$ A_c = K_S S_{d1} \left( \frac{T_c}{T_s} \right) = 2.5 K_F s_s \left( \frac{T_c}{T_s} \right) \leq A_i $$

When, $T_C > T_L$:

$$ A_c = K_S S_{d1} \left( \frac{T_L}{T_s} \right) = 2.5 K_F s_s \left( \frac{T_L}{T_s} \right) \leq A_i $$

L.4.2.2 Adjustment Factors

Unless specifically permitted by the regulations, the OLE design forces shall not be adjusted by an importance factor, $I$, or force reduction factor, $R$. Nor shall the forces be reduced by the 0.7 multiplier (1/1.4) commonly applied to convert contingency level events to ASD methods.

L.4.2.3 Damping

Unless otherwise defined by regulatory requirements, the damping ratio for the impulsive spectral accelerations shall be 5 %.
L.4.2.4 Soil Structure Interaction

Soil structure interaction per API 650, Section E.6.1.6 may be used for OLE design providing the damping ratio does not exceed 10%.

L.4.2.5 Allowable Stresses

Design allowable stresses shall be per API 620, Section Q.3.3, including the 33% increase permitted for earthquake loads.

L.4.2.6 Self-anchored Inner Tank

The anchorage ratio for a self-anchored inner tank, $J$, shall not exceed 1.0 for the OLE design combination to limit uplift and stresses in the annular plate and corner weld.

L.4.2.7 Foundation Stability

The overturning ratio defined in API 650, Section E.6.2.3, Equation (E.6.2.3-1) shall be equal to or greater than 3.0 for the defined OLE event.

L.4.2.8 Inner Tank Freeboard

Freeboard shall be provided for the OLE event in accordance with the following where the terms are as defined in API 650, Appendix E:

$$\delta_s = 0.42DAf + h_s$$

An additional shell height, $h_{\text{sh}}$, shall be added to the calculated value above the sloshing height as required by the governing regulations. The minimum value of $h_s$ for the OLE event shall be 300 mm (1ft).

If provided, the site-specific response spectrum may be used to determine the effective spectral acceleration, $A_f$, in lieu of using the $T_L$ values in API 650, Appendix E.

Alternative sloshing height calculation methods may be used if approved by the regulatory body providing the calculated sloshing height is not less than 80% of the value required by these provisions.

L.4.2.9 Piping Flexibility

Piping, piping supports, support foundations and superstructures supporting piping attached to the tank shall be designed for the piping displacements in API 650, Table E-8. A 33% increase in stress is permitted.

L.4.2.10 Sliding Resistance

The calculated sliding force at the base of the tank shall not exceed $V_s$. The maximum coefficient of friction, $\mu$, shall be $(\tan 30^\circ/1.5)$ where 1.5 is the factor of safety against sliding. The coefficient of friction selected shall consider the materials underlying the tank bottom. Anchorage may not be used to resist sliding. If the sliding force exceeds the allowable, the tank shall be re-configured.

L.4.2.11 Connections with Adjacent Structures

The calculated or tabular displacements in API 650, Section E.7.8 shall be amplified by 1.25 for OLE.
L.4.2.12 Bottom and Shell Support

The tank under-bottom insulation shall be designed to resist the combined pressures from the product load, the overturning seismic load and the vertical seismic load. These seismic pressures may be combined by SRSS.

The bearing ring under the shell shall be designed to resist the calculated OLE peak compressive force in the tank shell due to overturning (see API 650, Section E.6.2.2), including dead and live loads. A 33 % increase in allowable bearing stress is permitted.

L.4.3 Contingency Level Earthquake (CLE)

Unless otherwise defined by the governing local regulations, the contingency level earthquake ground motion shall be defined as the motion due to an event with a 2 % probability of exceedence within a 50-year period (a 2475-year recurrence interval) which is the maximum considered earthquake in API 650, Appendix E and ASCE 7.

L.4.3.1 CLE Definition Based on API 650, Appendix E, ASCE 7 Method

To utilize API 650, Section E.4 to define the CLE ground motion, the following modifications shall be made based on the provisions in this appendix:

1) the scaling factor, $Q$, is not applicable and may be set equal to a value of 1.0;

2) the response modification factor shall be as defined in Table L1-Q or Table L1-R as applicable;

3) the importance factor, $I$, shall be taken as 1.0.

L.4.3.2 Inner Tank Freeboard

Freeboard shall be provided in accordance with L.4.2.8 except the value of $h_s$ shall be taken as zero unless required by the governing regulations.

L.4.3.3 Sliding Resistance

The calculated sliding force at the base of the tank shall not exceed $V_s$. The maximum coefficient of friction, $\mu$, shall be $\tan 30^\circ$. The coefficient of friction selected shall consider the materials underlying the tank bottom. Anchorage may not be used to resist sliding. If the sliding force exceeds the allowable, the tank shall be re-configured.

L.4.3.4 Damping

The damping ratio for soil-structure interaction shall not exceed 20 %.

L.4.4 Aftershock Level Earthquake (ALE)

This design case shall be applicable only when regulations or project documents specifically require the tank system to be designed or evaluated for aftershocks.

Unless otherwise defined by the governing local regulations, the aftershock level earthquake (ALE) ground motion shall be defined as the motion due to an event with a 2 % probability of exceedence within a 50-year period (a 2475-year recurrence interval), which is the maximum considered earthquake in API 650, Appendix E and ASCE 7, with the spectral values reduced by 50 %.

If the outer tank is not designed as a secondary containment (i.e. it serves as vapor barrier and pressure boundary only and is not constructed of API 620 material suitable for the inner tank), then no design or evaluation for ALE is required by these provisions for the inner or outer tank.
If the outer tank is designed as the secondary containment (i.e. constructed of API 620 materials suitable for the inner tank and designed for the product hydrostatic pressure), the outer tank, foundation and anchorage shall be designed for the ALE assuming the inner tank no longer exists and all of the liquid is contained by the outer tank system and the following provisions apply.

**L.4.4.1 Modification Factors**

The secondary containment shall be designed for ALE while containing liquid using an importance factor equal to 1.0 and response modification values in Table L-1Q or Table L-1R as applicable for the inner tank.

**L.4.4.2 Damping**

Unless otherwise defined by regulatory requirements, the damping ratio for the impulsive spectral accelerations shall be 5%.

**L.4.4.3 Soil Structure Interaction**

Soil structure interaction per API 650, Section E.6.1.6 may be used for ALE design.

**L.4.4.4 Allowable Stresses**

Design allowable stresses shall be per API 620, Section Q.3.3, including the 33% increase permitted for earthquake loads.

**L.4.5 Base isolation**

Base isolation systems may be used to alter the tank response to the design ground motions providing:

1) the inner and outer tanks are both isolated on a common foundation to avoid excessive differential displacements between the tanks and connecting internals;

2) the anchorage, internal and external piping, insulation and other attached equipment are designed for the larger differential deformations associated with an isolated system;

3) a site-specific response spectrum is mandatory and includes the long term periods necessary to define the system response;

4) all external piping connections to the isolated system are designed for the calculated displacements for the actual ground motions (no \( I \) or \( R \) modifications);

5) the design is peer reviewed for technical adequacy by an independent party knowledgeable in the design and behavior of base-isolation systems; or, the design is verified by scaled shake-table tests or 3-dimensional non-linear analysis applying simultaneous horizontal and vertical time histories fit to the design OLE and CLE spectra and including the supporting soil and isolators.
Q.6.5 Production Welding Procedures

The production welding procedures and the production welding shall conform to the requirements of the procedure qualification tests within the following limitations:

a) Individual weld layer thickness shall not be substantially greater than that used in the procedure qualification test.

b) Electrodes shall be of the same AWS classification and shall be of the same nominal size or smaller.

c) The nominal preheat and interpass temperatures shall be the same.

Q.6.6 Production Weld Tests

Q.6.6.1 Production weld test plates shall be welded for primary-component butt-welded shell plates when welding procedure qualifications are required to be impact tested per Q.6.2 and Q.6.3. The number of production weld tests shall be based on the requirements of Q.6.6.3 and Q.6.6.4. The locations impact tested (i.e., HAZ and/or weld deposits) shall likewise be the same as required for weld procedure qualifications per Q.6.2 and Q.6.3. Weld testing shall be in accordance with Q.6.6.5. Test plates shall be made from plates produced only from the heats that are used to produce the shell plates for the tank.

Q.6.6.2 Test plates shall be welded using the same qualified welding procedure and electrodes that are required for the tank shell plate joints. The test plates need not be welded as an extension of the tank shell joint but shall be welded in the required qualifying positions.

Q.6.6.3 One test weld shall be made on a set of plates from each specification and grade of plate material, using a thickness that would qualify for all thicknesses in the shell. Each test welded of thickness $t$ shall qualify for plate thicknesses from $2t$ down to $\frac{t}{2}$, but not less than $\frac{5}{8}$ in. For plate thicknesses less than $\frac{5}{8}$ in., a test weld shall be made for the thinnest shell plate to be welded; this test weld will qualify plate thicknesses from $t$ up to $2t$.

Q.6.6.4 Test welds shall be made for each position and for each process used in welding the tank shell except for the following:

a) A manual or semi-automatic vertical test weld will qualify manual or semi-automatic welding using the same weld process in all positions.

b) A semi-automatic vertical test weld will qualify machine welding using the same weld process in all positions.

c) Test welds are not required for machine welded circumferential joints in cylindrical shells.

Q.6.6.5 The impact specimens and testing procedure shall conform to Q.6.2.1 through Q.6.2.5 for 9% and 5% nickel steel. The impact specimens and testing procedure shall conform to Q.6.3.3 for austenitic stainless steel welds deposited for service below –200°F.

Q.6.6.6 By agreement between the Purchaser and the Manufacturer, production test welds for the first tank shall satisfy the requirements of this paragraph for similar tanks at the same location if the tanks are fabricated within 6 months of the time the impact tests were made and found satisfactory and the same weld procedure specifications are used.
Q.7 Requirements for Fabrication, Openings, and Inspection

Q.7.1 Welding of Primary Components

Q.7.1.1 The following primary components shall be joined with double butt-welds that have complete penetration and complete fusion except as noted:

a) Longitudinal and circumferential shell joints and joints that connect the annular bottom plates together. When approved by Purchaser, these may be welded from a single side provided temporary non-fusible backing is used with complete penetration and complete fusion. Both sides of the joint shall be 100% visually examined as specified in 7.15.5.

b) Joints that connect sections of compression rings and sections of shell stiffeners together. Backup bars may be used for these joints with complete penetration and complete fusion detail.

c) Joints around the periphery of a shell insert plate.

d) Joints that connect the shell to the bottom, unless a method of leak checking is used (see Q.8.2.1), in which case double fillet welds are acceptable (see Q.8.2.2).

Q.7.1.2 Fillet welds shall be made in the manner described in Q.7.1.2.1 through Q.7.1.2.3.

Q.7.1.2.1 All primary components joined together by fillet welds shall have a minimum of two passes, except aluminum material and as permitted for stiffening ring attachment to shell (see Q.3.5.4).

Q.7.1.2.2 Outer tank bottom components exposed to vaporized liquefied gas and joined together by fillet welds shall have a minimum of two passes.

Q.7.1.2.3 For 9% nickel material, sandblasting or other adequate means must be used to remove mill scale from all plate edges and surfaces before fillet welds in contact with the refrigerated liquid and vaporized liquefied gas are welded. Sandblasting, or other adequate means, is required to remove slag from the first welding pass if coated electrodes are used.

Q.7.1.2.4 Slip-on flanges may be used where specifically approved by the Purchaser.

Q.7.1.3 Butt-welds in piping nozzles, manway necks, and pipe fittings, including weld neck flanges, shall be made using double butt-welded joints. When accessibility does not permit the use of double butt-welded joints, single butt-welded joints that ensure full penetration through the root of the joint are permitted.

Q.7.2 Connections in Primary Components

Q.7.2.1 All connections located in primary components shall have complete penetration and complete fusion.

Q.7.2.2 Acceptable types of welded opening connections are shown in Figure 5-8, Panels a, b, c, g, h, m, and o.

Q.7.2.3 Flanges for nozzles and manways shall be in accordance with this standard; however, the material shall comply with the requirements of Q.2.1 or Q.2.2.

Q.7.3 Postweld Heat Treatment

Q.7.3.1 Cold-formed 9% and 5% nickel plates shall be postweld heat treated (or stress relieved) when the extreme fiber strain from cold forming exceeds 3%. Cold-formed 201LN stainless steel shall be reheat-treated in accordance
Q.7.7 Inspection of Butt-welds in Piping

Q.7.7.1 Butt-welds in piping and in pipe fittings within the limitations of 1.3.2 (including the annular space of double-wall tanks) shall be inspected in conformance with Q.7.7.2 through Q.7.7.6.

Q.7.7.2 Longitudinal welded joints in piping that contains liquid shall be completely radiographed except for manufactured pipe welded without filler metal, 12 in. or less in diameter, which is tested hydrostatically or by eddy current to ASTM requirements.

Q.7.7.3 Longitudinal welded joints in piping that contains vapor shall be completely radiographed except for manufactured pipe welded without filler metal, 18 in. or less in diameter, which is tested hydrostatically or by eddy current to ASTM requirements.

Q.7.7.4 Thirty percent of the circumferential welded joints in all piping shall be 100% radiographed.

Q.7.7.5 Butt-welded joints used to fabricate tank fittings shall be completely radiographed.

Q.7.7.6 Lines carrying liquid shall be hydrostatically or pneumatically pressurized at a minimum pressure of 35 lbf/in.² and butt welded joints shall be simultaneously visually examined (hydrostatic) or solution film tested (pneumatic) for tightness. If manufactured pipe has been hydrostatically tested previously to ASTM requirements, then only circumferential welds need to be examined.

Notes:
1) One circumferential spot examination shall be performed in the first 10 ft for each welding operator of each type and thickness. After the first 10 ft, without regard to the number of welders, one circumferential spot examination shall be performed between each longitudinal joint on the course below.
2) One longitudinal spot examination shall be performed in the first 10 ft for each welder or welding operator of each type and thickness. After the first 10 ft, without regard to the number of welders, one longitudinal spot examination shall be performed in each longitudinal joint.
3) Longitudinal joints shall be 100% examined.
4) All intersections of joints shall be examined.

Figure Q-2—Radiographic/Ultrasonic Examination Requirements for Butt-welded Shell Joints in Cylindrical Flat-bottom Tanks
Q.7.8 Permanent Attachments

All permanent structural attachments welded directly to 9% and 5% nickel steel shall be of the same material or of an austenitic stainless steel type that cannot be hardened by heat treatment.

Q.7.9 Non-pressure Parts

Welds for pads, lifting lugs, and other nonpressure parts, as well as temporary lugs for alignment and scaffolding attached to primary components, shall be made in full compliance with a welding procedure qualified in accordance with Q.6.1. Lugs attached for erection purposes shall be removed, and any significant projections of weld metal shall be ground to a smooth contour. Plate that is gouged or torn in removing the lugs shall be repaired using a qualified procedure and then ground to a smooth contour. Where such repairs are made in primary components, the area shall be inspected by the liquid-penetrant method. A visual inspection is adequate for repairs in secondary components.

Q.7.10 Repairs to Welded Joints

When repairs are made to welded joints, including the welds in Q.7.9, the repair procedure shall be in accordance with a qualified welding procedure.

Q.7.11 Marking of Materials

Q.7.11.1 Material for primary components shall be marked so that the individual components can be related back to the mill test report. For aluminum materials, a certificate of conformance shall be provided in place of a mill test report stating that the material has been sampled, tested, and inspected in accordance with the specifications and has met the requirements.

Q.7.11.2 All mill markings shall be in accordance with the requirements of ASTM A20 and ASTM A480 as applicable. All material markings performed by the tank Manufacturer shall be in accordance with the requirements of Sections 7.7 and Q.7.11.1.

Q.7.11.3 Under some conditions, marking material that contains carbon or heavy-metal compounds can cause corrosion of aluminum. Chalk, wax-base crayons, or marking inks with organic coloring are usually satisfactory.

Q.7.12 Construction Practices

Excessive hammering should be avoided on primary components so that the material is not hardened or severely dented. Any objectionable local thinning caused by hammering can be repaired by welding using a qualified procedure, followed by grinding. The extent of rework for any repair that is permissible must be agreed to between the Purchaser and the Manufacturer. If the rework is determined to have been excessive, the reworked area should be cut out and replaced.

Q.7.13 Protection of Plates during Shipping and Storage

Plates shall be adequately protected during shipping and storage to avoid damage to plate surfaces and edges from handling (scratches, gouge marks, etc.) and from environmental conditions (corrosion, pitting, etc.).

Q.7.13.1 Plates shall be protected from moisture or stored in inclined position to prevent water from collecting and standing on surface.

Q.7.13.2 Nine percent and five percent nickel plates which are exposed to humid or corrosive atmosphere shall be sand or grit blasted and coated with a suitable coating. The Purchaser shall specify when plates are exposed to humid or corrosive atmosphere.
Q.10.4.4 When the anchorage is designed to meet the requirements of Q.3.6.4.2, the foundation should be designed to resist the uplift that results from three times the design pressure with the tank full to the design liquid level. When designing to any of the conditions in this paragraph, it is permissible to utilize friction between the soil and the vertical face of the ringwall and all of the effective liquid weight.

Q.11 Marking

Q.11.1 Data on Nameplate

The data required to be marked on the tank by the Manufacturer is listed in 8.1 and shall indicate that the tank has been constructed in accordance with Appendix Q.

Q.11.2 Location of Nameplate

In addition to the requirements of 8.1, the nameplate shall be attached to the tank at an accessible location if it is outside of any insulation or protective covering of the tank. The nameplate for the inner tank shall be located on the outer tank wall but shall refer to the inner tank. The nameplate, if any, for the outer tank of a double-wall tank shall be located adjacent to the nameplate of the inner tank and shall refer to the outer tank.

Q.12 Reference Standards

For rules and requirements not covered in this appendix or in the basic rules of this standard, the following documents should be referred to for the type of material used in the tank:

a) For 9% and 5% nickel steels, Part UHT in Section VIII of the ASME Code.

b) For stainless steel, Part UHA in Section VIII of the ASME Code.

c) For aluminum, Part UNF in Section VIII of the ASME Code and ASME B96.1.

< Notes moved to Figure Q-2 >
Appendix R
Low-pressure Storage Tanks for Refrigerated Products

R.1 Scope

R.1.1 General

The provisions in this appendix form a guide for the materials, design, and fabrication of tanks to be used for the storage of refrigerated products.

The requirements for a basic API 620 tank are superseded by any requirements of this appendix; all other requirements for an API 620 tank shall apply.

A refrigerated tank may be a single-wall insulated tank or a double-wall tank that consists of an inner tank for storing the refrigerated liquid and an outer tank that encloses an insulation space (which usually has a lower gas pressure) around the inner tank. A double-wall tank is a composite tank, and the outer tank is not required to contain the product of the inner tank. In a double-wall tank, differences in materials, design, and testing exist between the inner and outer tanks.

R.1.2 Pressure Range

The provisions in this appendix apply to all design pressures within the scope of this standard.

R.1.3 Temperature Range

The provisions in this appendix are considered suitable for design metal temperatures from +40°F to -60°F, inclusive.

R.1.4 Primary Components

R.1.4.1 In general, primary components include those components whose failure would result in leakage of the liquid being stored, those exposed to the refrigerated temperature, and those subject to thermal shock. Further definitions of such components are provided in R.1.4.2 and R.1.4.3.

R.1.4.2 The primary components shall include, but will not be limited to, the following parts of a single-wall tank or of the inner tank in a double-wall tank: shell plates; bottom plates; knuckle plates; compression rings; and shell manways and nozzles including reinforcement, shell anchors, piping, tubing, forgings, and bolting. Roof nozzles in contact with the refrigerated liquid shall be considered primary components.

R.1.4.3 The primary components shall also include those parts of a single-wall or an inner tank that are not in contact with the refrigerated liquid but are subject to the refrigerated temperature. Such components include roof plates, roof manways and nozzles with their reinforcements, roof-supporting structural members, and shell stiffeners when the combined tensile and primary bending stresses in these components under design conditions are greater than 6000 lbf/in.².

R.1.5 Secondary Components

Secondary components are those whose failure would not result in leakage of the liquid being stored. Secondary components also include those components that are not in contact with the refrigerated liquid but are subject to the refrigerated temperature vapors and have a combined tensile and primary bending stress under design conditions that does not exceed 6000 lbf/in.². Secondary components that could be designed within this reduced stress are roof plates, including roof manways and nozzles with their reinforcement, roof-supporting structural members, and shell stiffeners.
R.1.6 Basic Components

Basic components are those that contain the vaporized liquefied gas from the stored refrigerated liquid but primarily operate at atmospheric temperatures because of insulation system design and natural ambient heating. These components shall comply with the basic rules of this standard. Examples of such components are the outer wall and roofs of double-wall tanks and roof components above an internally insulated suspended deck.

R.2 Materials

The materials requirements are based on the storage of refrigerated products at the design metal temperature.

R.2.1 Primary Components

R.2.1.1 General

Materials for primary components shall comply with the requirements of Tables R-1 and R-2. All primary components shall be impact tested in accordance with R.2.1.2 through R.2.1.4.

R.2.1.2 Impact Test Requirements for Plates

R.2.1.2.1 Impact testing of plates, including structural members made of plate, shall comply with Table R-1.

R.2.1.2.2 Impact test specimens shall be taken transverse to the direction of final plate rolling.

R.2.1.2.3 The Charpy V-notch test shall be used, and the minimum impact value at the design metal temperature shall be as given in Table R-2. For subsize specimen acceptance criteria, see ASTM A20. An impact test temperature lower than the design metal temperature may be used by the Manufacturer, but in such a case the impact values at the test temperature must comply with Table R-2.

R.2.1.2.4 All other impact requirements of ASTM A20, Supplementary Requirement S5, shall apply for all materials listed in Table R-2, including specifications that do not refer to ASTM A20.

R.2.1.2.5 When as-rolled plate material complies with impact test requirements as specified here, the material need not be normalized. If, as with ASTM A516, the specification prohibits impact test without normalizing but otherwise permits as-rolled plates, the material may be ordered in accordance with the above provision and identified as “MOD” for this API modification.

R.2.1.3 Impact Requirements for Pipe, Bolting, and Forgings

The impact tests for pipe (including structural members made of pipe), bolting, and forgings, shall be in accordance with ASTM specifications referred to in Table R-1.

Piping materials made according to ASTM A333 and A350 may be used at design metal temperatures no lower than the impact test temperature required by the ASTM specification for the applicable material grade without additional impact tests. For temperatures below those allowed by the ASTM specification, the following paragraph shall apply.

For all other materials, the impact test temperature shall be at least 30°F colder than the design metal temperature. Alternately, materials impact tested at the design metal temperature or lower with Charpy impact test energy value of 25 ft-lb (average), 20 ft-lb (minimum) are acceptable for design metal temperatures above –40°F. Materials with an energy value of 30 ft-lb (average), 25 ft-lb (minimum) are acceptable for design metal temperatures of –40°F or lower.
### R.2.1.4 Impact Requirements for Controlled-rolled or Thermo-mechanical Control Process (TMCP) Plates

Subject to the approval of the Purchaser, controlled-rolled or TMCP plates (material produced by a mechanical-thermal rolling process designed to enhance the notch toughness) may be used where normalized plates are required. Each plate, as rolled, shall be Charpy V-notch tested to the requirements of R.2.1.2.

### R.2.1.5 Impact Requirements for Structural Shapes

Impact test for structural shapes listed in Table R-1 shall be made in accordance with ASTM A673 on a piece-testing frequency. Impact values, in foot-pounds, shall be 25 minimum average of 3 and 20 minimum individual at a temperature no warmer than the design metal temperature.

### R.2.2 Basic and Secondary Components

Materials for basic and secondary components shall comply with R.2.2.1 and R.2.2.2.

#### R.2.2.1 Material for the outer tank and for the roof that contains the vaporized liquefied gas but is primarily subjected to atmospheric temperatures may conform to one of the following:

a) Table 4-1 for design metal temperatures down to –35°F (lowest 1-day mean ambient temperature of –35°F) without impact test unless they are required by Table 4-1 or by the Purchaser.

---

**Table R-1—Material for Primary Components**

<table>
<thead>
<tr>
<th>Component</th>
<th>Materials</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate</td>
<td>Refer to R.2.1.2</td>
<td>1 and 2</td>
</tr>
<tr>
<td>Pipe</td>
<td>ASTM A333 (seamless only)</td>
<td>2 and 3</td>
</tr>
<tr>
<td>Structural members</td>
<td>Plate or pipe as listed above</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Structural shapes</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>ASTM A36 Mod 1</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>ASTM A131 Grades CS, D, and E</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASTM A633 Grade A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CSA G40.21 Grades 38WT, 44WT and 50WT</td>
<td></td>
</tr>
<tr>
<td>Forgings</td>
<td>ASTM A350</td>
<td>2 and 3</td>
</tr>
<tr>
<td>Bolts</td>
<td>ASTM A320 Grade L7</td>
<td>3</td>
</tr>
</tbody>
</table>

**Notes:**

1. See R.2.1.4.
2. Type 304 or 304L stainless steel material, as permitted in Table Q-1 may be used at the maximum allowable stress values permitted by Table Q-3. Impact tests of this material are not required. Welding procedures shall be qualified in accordance with the more restrictive requirements of R.6.1 and Q.6.3 as applicable to the base materials and welding material.
3. See R.2.1.3.
4. See R.2.1.5.
5. Normalized, if necessary, to meet the required minimum Charpy V-notch impact values.
6. See 4.5 for a complete description of this material.
b) Table R-3 for design metal temperatures down to –60°F without impact tests unless they are required by Table R-4 or by the Purchaser.

c) If approved by the Purchaser, the material may be selected by the requirements of 4.2.2.

R.2.2.2 Material for the outer tank that does not contain the vaporized liquefied gas may conform to any of the approved materials listed in Table 4-1. Consideration of the design metal temperature is not required if the actual stress in the outer tank does not exceed one-half the allowable tensile design stress for the material.

Table R-2—Minimum Charpy V-notch Impacta Requirements for Primary-component Plate Specimens (Transverse) and Weld Specimens Including the Heat-affected Zone

<table>
<thead>
<tr>
<th>Specification Number</th>
<th>Grade</th>
<th>Range in Thickness (in.)</th>
<th>Plate Impact Valueb (ft-lb)</th>
<th>Weld Impact Value (ft-lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Average</td>
<td>Individual</td>
</tr>
<tr>
<td>ASTM A131</td>
<td>Cs c</td>
<td>3/16 – 1 1/2</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>ASTM A516</td>
<td>55 and 60</td>
<td>3/16 – 2</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>ASTM A516</td>
<td>65 and 70</td>
<td>3/16 – 2</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>ASTM A516</td>
<td>65 and 70 Mod 1d</td>
<td>3/16 – 2</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>ASTM A516</td>
<td>65 and 70 Mod 2d</td>
<td>3/16 – 2</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>ASTM A841</td>
<td>1</td>
<td>3/16 – 2</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>ASTM A537</td>
<td>1</td>
<td>3/16 – 2</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>ASTM A537</td>
<td>2</td>
<td>3/16 – 2</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>ASTM A662</td>
<td>B and C</td>
<td>3/16 – 2</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>ASTM A678</td>
<td>A c</td>
<td>3/16 – 1 1/2</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>ASTM A678</td>
<td>B c</td>
<td>3/16 – 2</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>ASTM A737</td>
<td>B</td>
<td>3/16 – 2</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>ASTM A841</td>
<td>1</td>
<td>3/16 – 2</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>ISO 630</td>
<td>E 355 Quality</td>
<td>3/16 – 2</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>CSA G40.21</td>
<td>38WT c,d,e</td>
<td>3/16 – 2</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>CSA G40.21</td>
<td>44WT c,d,e</td>
<td>3/16 – 2</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>CSA G40.21</td>
<td>50wt c,d,e</td>
<td>3/16 – 2</td>
<td>25</td>
<td>20</td>
</tr>
</tbody>
</table>

Notes:

a See R.2.1.2.

b For design metal temperatures of –40°F and lower, the plate impact values shall be raised 5 ft-lb.

c The frequencies of testing for mechanical and chemical properties shall be at least equal to those of ASTM A20.

d See 4.2.3 for a complete description of this material.

e The steel shall be fully killed and made with fine-grain practice.
Table R-5—Minimum Charpy V-notch Impact Requirements for Secondary-component Plate Specimens (Transverse)

<table>
<thead>
<tr>
<th>Group</th>
<th>Specification Number</th>
<th>Grade</th>
<th>Range in Thickness (in.)</th>
<th>Impact Valuea (foot-lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (semikilled)</td>
<td>A 36 Mod 2b</td>
<td>3/16 – 1</td>
<td>13, 9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A 131 B</td>
<td>3/16 – 1</td>
<td>13, 9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ISO 630 Fe 430 Quality C</td>
<td>3/16 – 11/2</td>
<td>13, 9</td>
<td></td>
</tr>
<tr>
<td>II (fully killed)</td>
<td>A 573 58c</td>
<td>3/16 – 11/2</td>
<td>15, 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A 131 CS</td>
<td>3/16 – 11/2</td>
<td>15, 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A 516 55 and 60</td>
<td>3/16 – 2</td>
<td>15, 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A 516 55 and 60d</td>
<td>3/16 – 1/2</td>
<td>15, 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ISO 630 Fe 430 Quality Dc</td>
<td>3/16 – 11/2</td>
<td>15, 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CSA G40.21 38WT</td>
<td>3/16 – 2</td>
<td>15, 10</td>
<td></td>
</tr>
<tr>
<td>III (fully killed and high strength)</td>
<td>A 573 65 and 70</td>
<td>3/16 – 2</td>
<td>15, 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A 516 65 and 70</td>
<td>3/16 – 2</td>
<td>15, 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A 516 65 and 70 Mod 1b</td>
<td>3/16 – 2</td>
<td>15, 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A 516 65 and 70 Mod 2b</td>
<td>3/16 – 2</td>
<td>15, 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A 537 1</td>
<td>3/16 – 2</td>
<td>15, 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A 537 2</td>
<td>3/16 – 2</td>
<td>20, 15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A 633 C and D</td>
<td>3/16 – 2</td>
<td>15, 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A 662 B</td>
<td>3/16 – 2</td>
<td>15, 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A 678 A</td>
<td>3/16 – 11/2</td>
<td>20, 15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A 678 B</td>
<td>3/16 – 2</td>
<td>20, 15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ISO 630 Fe 52 Quality Dc</td>
<td>3/16 – 2</td>
<td>15, 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CSA G40.21 44WT</td>
<td>3/16 – 2</td>
<td>15, 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A 841 1</td>
<td>3/16 – 2</td>
<td>15, 10</td>
<td></td>
</tr>
</tbody>
</table>

Notes:

aThe 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 values at the test temperature must comply with Table R-5. 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.

bSee 4.2.3 for a complete description of this material.

cThe steel shall be fully killed and made with fine-grain practice, without normalizing, for thicknesses of 3/16 in. – 11/2 in.

dThe manganese content shall be in the range from 0.85% to 1.20% by ladle analysis.

R.3.4.2 The thickness of the annular bottom plates shall be not less than the thicknesses listed in Table R-6.

R.3.4.3 The ring of annular plates shall have a circular outside circumference, but may have a regular polygonal shape inside the tank shell with the number of sides equal to the number of annular plates. These pieces shall be butt-welded in accordance with R.7.1.1, Item b.

R.3.4.4 The plates of the first shell course shall be attached to the annular bottom plates by welds as required by 5.9.5 except when a full penetration weld is used or required (see R.7.1.1).

R.3.4.5 Butt-welds in annular plates shall be not closer than 12 in. from any vertical weld in the tank shell.

R.3.4.6 Three-plate laps or butt-weld junctions in the tank bottom shall be not closer than 12 in. from each other and/or the butt-welds of the annular plate.
R.3.5 Shell Stiffening Rings for Tanks That Contain Liquid

R.3.5.1 Internal or external shell stiffening rings may be required to maintain roundness when the tank is subjected to wind, vacuum, or other specified loads. When stiffening rings are required, the stiffener-to-shell weld details shall be in accordance with Figure R-1 and R.3.5.2 through R.3.5.5.

R.3.5.2 The stiffener ring and backing strip, if used, are primary components, and they shall comply with the requirements of R.2.1. The stiffener ring may be fabricated from plate using an intermittent weld on alternating sides between the web and the flange.

R.3.5.3 One rat hole with a minimum radius of 3/4 in. shall be provided at each longitudinal shell joint and ring juncture weld (see Figure R-1).

R.3.5.4 All fillet welds shall consist of a minimum of two passes. The ends of the fillet welds shall be 2 in. from the rat hole (see Figure R-1), and these welds shall be deposited by starting 2 in. from the rat hole and welding away from the rat hole. An acceptable alternative to stopping fillet welds 2 in. short of the rat hole would be to weld continuously through the rat hole from one side of the stiffener to the opposite side. All craters in fillet welds shall be repaired by back welding.

R.3.5.5 Any joints between the adjacent sections of stiffening rings, as shown in Figure R-1, shall be made so that the required moment of inertia of the combined ring-shell section is provided. Weld joints between adjacent sections shall be made with full-thickness and full-penetration butt-welds. Stiffening-ring butt-welds may employ metal backing strips. Backing strips and the associated welding shall be made in a manner that provides a smooth contour in the rat hole and all other weld joints ends. All weld passes shall be started at the rat hole and other weld joint ends and shall be completed by moving away from these ends. Passes shall be overlapped away from the edge to provide a smooth continuous weld.

R.3.6 Tank Anchorage

R.3.6.1 In addition to the loads in R.4, R.5.1, and R.5.2, the anchorage for the tank that contains liquid, whether it be a single-wall tank or the inner tank of a double-wall tank, shall be designed to meet the requirements of R.3.6.2 through R.3.6.5.

R.3.6.2 The anchorage shall accommodate movement of the tank wall and bottom caused by thermal changes.
**Figure R-1—Typical Stiffening-ring Weld Details**

**R.3.6.3** The Manufacturer and the Purchaser should consider using stainless steel anchorage materials, or they should provide for corrosion allowance when carbon steels are used. Material for tank anchorage shall meet the requirements for primary components given in R.2.1.

**R.3.6.4** For anchored flat-bottom tanks, the anchorage shall be designed as described in R.3.6.4.1 through R.3.6.4.3.

**R.3.6.4.1** When the topshell course is the minimum thickness indicated in Table 5-6, the minimum anchorage shall be designed for normal loads as specified by the Purchaser and by this standard. See 5.11.2.3 for the allowable stress.

**R.3.6.4.2** When the topshell course is thickened beyond minimum thickness provided in Table 5-6 or as in Figure 5-6, details f and g, or when a knuckle is used, the minimum anchorage shall be designed for three times the internal design pressure. The allowable stress for this loading is 90% of the minimum specified yield strength of the anchorage material.

**R.3.6.4.3** As an alternative to R.3.6.4.2, the Purchaser may specify a combination of normal anchorage design (see R.3.6.4.1) and emergency venting. The Purchaser shall specify required emergency venting discharge rates considering upset conditions including those addressed in API 2000 (see 9.2 and K.1).

**R.3.6.5** The foundation design loading for R.3.6.4 is described in R.10.5.3.

**R.4 Design of a Single-wall Tank**

The Purchaser shall specify the design metal temperature and pressures (internal and external), specific gravity of the contents to be stored, roof live load, wind load, earthquake load where applicable, and corrosion allowance, if any. The insulation load shall be considered.
R.5 Design of a Double-wall Tank

R.5.1 Design Specifications

The outer bottom, shell, and roof of a double-wall tank shall enclose an insulating space around the bottom, shell, and roof of the inner tank that contains the stored liquid. The annular space shall be maintained at a low positive pressure, which necessitates that the enclosure be vaportight. The Purchaser shall specify the design metal temperature and pressures (internal and external) of both the inner and outer tanks, specific gravity of the contents to be stored, roof live load, wind load, earthquake load where applicable, and corrosion allowance, if any. The static insulation pressure and pressures from expansion and contraction of the insulation shall be considered.

R.5.2 Combination of Design Loads

The inner tank shall be designed for the most critical combinations of loading that result from internal pressure and liquid head, the static insulation pressure, the insulation pressure as the inner tank expands after an in-service period, and the purging or operating pressure of the space between the inner and outer tank shells. The outer wall shall be designed for the purging and operating pressure of the space between the inner and outer tank shells and for the loading for insulation, the pressure of wind forces, and roof loading.

R.5.3 Outer Tank

R.5.3.1 The outer tank bottom, shell, and roof shall be a minimum nominal thickness of 3/16 in. (7.65 lb/ft²).

R.5.3.2 The outer tank bottom, shell, and roof not in contact with the vaporized liquefied gas may be of single-welded lap or of single-welded partial penetration butt construction when the thickness does not exceed 3/8 in. Such single side welds shall be made from the outside to prevent corrosion and the entrance of moisture. At any thickness, it may be of single-welded butt construction from either side with full penetration and fusion or double-welded butt construction without necessarily having full fusion and penetration.

R.5.3.3 When in contact with the vaporized liquefied gas, the outer tank bottom, shell, and roof shall conform to the lap- or butt-welded construction described elsewhere in this standard.

R.6 Welding Procedures

These rules shall apply only to the primary components of the tank. The secondary components shall be welded in accordance with the basic rules of this standard.

R.6.1 Welding Procedure Qualification

R.6.1.1 The qualification of welding procedures shall conform to 6.7. For primary components (see R.2.1), impact tests are also required for each welding procedure (with exceptions for Type 304 or 304L stainless steel described in Table R-1, Note 2). Charpy V-notch specimens that conform to ASTM E23 shall be taken from the weld metal and from the heat-affected zone of the welding procedure qualification test plates or duplicate test plates.

R.6.1.2 Weld metal impact specimens shall be taken across the weld with the notch in the weld metal. The specimen shall be oriented so that the notch is normal to the surface of the material. One face of the specimen shall be substantially parallel to and within 1/16 in. of the surface.

R.6.1.3 Heat-affected-zone impact specimens shall be taken across the weld and as near the surface of the material as is practicable. The specimens shall be of sufficient length to locate, after etching, the notch in the heat-affected zone. The notch shall be cut approximately normal to the material surface to include as much heat-affected zone material as possible in the resulting fracture.

R.6.1.4 Impact test specimens shall be tested at the design metal temperature or at a lower temperature, as agreed upon by the Purchaser and the Manufacturer.
R.6.1.5 The required impact values of the weld and heat-affected zone shall be as given in Table R-2.

R.6.2 Production Welding Procedures

The production welding procedures and the production welding shall conform to the requirements of the procedure qualification tests within the following limitations:

a) Individual weld layer thickness shall not be substantially greater than that used in the procedure qualification test.
b) Electrodes shall be of the same size and American Welding Society (AWS) classification.
c) The nominal preheat and interpass temperatures shall be the same.

R.6.3 Production Weld Tests

R.6.3.1 Production weld test plates shall be welded and tested for primary-component, butt-welded shell plates when welding procedure qualifications are required to be impact tested per paragraph R.6.1.1. The number of production weld tests shall be based on the requirements of R.6.3.3 and R.6.3.4. Weld testing shall be in accordance with R.6.3.5. Test plates shall be made from plates produced only from the heats used to produce the shell plates for the tank.

R.6.3.2 Test plates shall be welded using the same qualified welding procedure and electrodes as required for the tank shell plate joints. The test plates need not be welded as an extension of the tank shell joint but shall be welded in the required qualifying positions.

R.6.3.3 One test weld shall be made on a set of plates from each specification and grade of plate material, using a thickness that would qualify for all thicknesses in the shell. Each test welded of thickness $t$ shall qualify for plate thicknesses from $2t$ down to $\frac{t}{2}$, but not less than $\frac{5}{8}$ in. For plate thicknesses less than $\frac{5}{8}$ in., a test weld shall be made for the thinnest shell plate to be welded; this test weld will qualify the plate thickness from $t$ up to $2t$.

R.6.3.4 Test welds shall be made for each position and for each process used in welding the tank shell except for the following:

a) A manual or semi-automatic vertical test weld will qualify manual or semi-automatic welding using the same weld process in all positions.
b) A semi-automatic vertical test weld will qualify machine welding using the same weld process in all positions.
c) Test welds are not required for machine welded circumferential joints in cylindrical shells.

R.6.3.5 The impact specimens and testing procedure shall conform to R.6.1.2 through R.6.1.5.

R.6.3.6 By agreement between the Purchaser and the Manufacturer, production weld test plates for the first tank shall satisfy the requirements of this paragraph for similar tanks at the same location if the tanks are fabricated within six months of the time the impact tests were made and found satisfactory and the same weld procedure specifications are used.
R.7 Requirements for Fabrication, Openings, and Inspection

R.7.1 Welding of Primary Components

R.7.1.1 The following primary components shall be joined with double butt-welds that have complete penetration and complete fusion except as noted:

a) Longitudinal and circumferential shell joints and joints that connect the annular bottom plates together. When approved by Purchaser, these may be welded from a single side provided temporary non-fusible backing is used with complete penetration and complete fusion. Both sides of the joint shall be 100% visually examined as specified in 7.15.5.

b) Joints that connect sections of compression rings and sections of shell stiffeners together. Backup bars may be used for these joints with complete penetration and complete fusion details.

c) Joints around the periphery of a shell insert plate.

d) Joints that connect the shell to the bottom, unless a method of leak checking is used (see R.8.2.3); in that case, double fillet welds are acceptable.

e) Joints that connect nozzle and manhole necks to flanges.

f) Butt-welds in piping nozzles, manway necks, and pipe fittings, including weld neck flanges, shall be made using double butt-welded joints. When accessibility does not permit the use of double butt-welded joints, single butt-welded joints that ensure full penetration through the root of the joint are permitted.

R.7.1.2 All primary components joined together by fillet welds shall have a minimum of two passes.

R.7.1.3 Slip-on flanges may be used where specifically approved by the Purchaser.

R.7.2 Welding of Connections in Primary Components

All opening connections located in primary components shall have complete penetration and complete fusion. Acceptable types of welded opening connections are shown in Figure 5-8, Panels a, b, c, g, h, m, and o.

R.7.3 Postweld Heat Treatment

R.7.3.1 In primary components, all opening connections shall be welded into the shell plate or a thickened insert plate, and the welded assembly shall be stress relieved prior to installation in the tank unless one of the following exceptions is fulfilled:

a) The stress level in the plate, under the design conditions, does not exceed 10% of the minimum tensile strength of the plate material. The opening shall be reinforced for the low stress.

b) The impact tests on the material and welding fulfill the requirements of R.2.1.2 and Table R-2, and the thickness of the material is less than 5/8 in. for any diameter of connection or less than 1 1/4 in. for connections that have a nominal diameter less than 12 in. The thickness of the nozzle neck without stress relief shall be limited to the value of \( (D + 50)/120 \), as described in 5.25.3.

c) Opening reinforcement is made from forgings similar in configuration to Figure 5-8, Panels o-1, o-2, o-3, and o-4.

R.7.3.2 The stress-relieving requirements of 5.25 shall still be mandatory for both primary and secondary components.
R.7.3.3 When used in stress relieved assemblies, the material of TMCP steel A 841 shall be represented by test specimens that have been subjected to the same heat treatment as that used for the stress relieved assembly.

R.7.4 Spacing of Connections and Welds

In primary components, all opening connections in a shell plate shall conform to the requirements of R.7.4.1 through R.7.4.3 for the spacing of butt and fillet welds.

R.7.4.1 The butt-weld around the periphery of a thickened insert plate or the fillet weld around the periphery of a reinforcing plate shall be at least the greater of 10 times the shell thickness or 12 in. from any butt-welded shell seams except where the completed periphery weld has been stress relieved prior to the welding of the adjacent butt-welded shell seams. Where stress relief has been performed, the spacing from the periphery weld to a shell butt-weld shall be at least 6 in. from the longitudinal or meridional joints or 3 in. from the circumferential or latitudinal joints if in either case the spacing is not less than 3 times the shell thickness. These rules shall also apply to the bottom-to-shell joint; however, as an alternative, the insert plate or reinforcing plate may extend to and intersect the bottom-to-shell joint at approximately 90°. The stress-relieving requirements do not apply to the weld to the bottom or annular plate.

R.7.4.2 In cylindrical tank walls, the longitudinal weld joints in adjacent shell courses, including compression ring welds, shall be offset from each other a minimum distance of 12 in.

R.7.4.3 Radial weld joints in a compression ring shall not be closer than 12 in. from any vertical weld.

R.7.5 Inspection of Welds by Magnetic-particle or Liquid-penetrant Methods

The following primary-component welds shall be inspected, using the magnetic-particle method (see 7.15) for carbon steel and the liquid-penetrant method (see 7.15) for stainless steel, after stress relieving, if any, and before the hydrostatic test of the tank.

a) All longitudinal and circumferential butt-welds that are not completely radiographed. Inspection shall be on both sides of the joint.

b) The welded joint that joins the cylindrical wall of the tank to the bottom annular plates.

c) All welds of opening connections that are not completely radiographed, including nozzle and manhole neck welds and neck-to-flange welds. Inspection shall also include the root pass and every 1/2 in. of thickness of deposited weld metal (see 5.27.11) as welding progresses.

d) All welds of attachments to primary components such as stiffeners, compression rings, clips, and other nonpressure parts.

e) All welded joints on which backing strips are to remain shall also be examined after the first two layers (or beads) of weld metal have been deposited.

R.7.6 Radiographic/Ultrasonic Examination of Butt-welds in Plates

Primary-component butt-welds shall be examined by radiographic or ultrasonic methods. When the term "examination" is used in section R.7.6 and its subsections, it shall be understood to refer to radiographic or ultrasonic examination. The extent of the examination shall be as described in R.7.6.1 through R.7.6.6. When the examination is by the ultrasonic method, it shall be done in accordance with the requirements of Appendix U.

R.7.6.1 Butt-welds in all tank wall courses subjected to a maximum actual operating membrane tensile stress perpendicular to the welded joint that is greater than 0.1 times the specified minimum tensile strength of the plate material shall be completely examined.
R.7.6.2 Butt-welds in all tank wall courses subjected to a maximum actual operating membrane tensile stress perpendicular to the welded joint that is less than or equal to 0.1 times the specified minimum tensile strength of the plate material shall be examined in accordance with Figure R-2.

R.7.6.3 Butt-welds around the periphery of a thickened insert plate shall be completely examined. This does not include the weld that joins the insert plate with the bottom plate of a flat-bottom tank.

R.7.6.4 Butt-welds at all three-plate junctions in the tank wall shall be examined except in the case of a flat bottom (wall) supported uniformly by the foundation. This does not include the shell-to-bottom weld of a flat-bottom tank. See Figure R-2 for minimum examination dimensions.

R.7.6.5 Twenty-five percent of the butt-welded annular plate radial joints shall be spot examined for a minimum length of 6 in. The location shall be under the tank shell at the outer edge of the joint.

R.7.6.6 Twenty-five percent of the butt-welded compression bar radial joints shall be spot examined for a minimum length of 6 in. except as required by 5.26.4.3.

R.7.7 Inspection of Butt-welds in Piping

R.7.7.1 Butt-welds in piping and in pipe fittings within the limitations of 1.3.2, including the annular space of double-wall tanks, shall be inspected in conformance with R.7.7.2 through R.7.7.6.

R.7.7.2 Longitudinal welded joints in piping that contains liquid shall be completely radiographed except for welds in manufactured pipe welded without filler metal, 12 in. or less in diameter, which is tested hydrostatically or by eddy current to ASTM requirements.

R.7.7.3 Longitudinal welded joints in piping that contains vapor shall be completely radiographed except for welds in manufactured pipe welded without filler metal, 18 in. or less in diameter, which is tested hydrostatically or by eddy current to ASTM requirements.

R.7.7.4 Ten percent of the circumferential welded joints in all piping shall be completely radiographed.

R.7.7.5 Butt-welded joints used to fabricate tank fittings shall be completely radiographed.

R.7.7.6 Lines carrying liquid shall be hydrostatically or pneumatically pressurized at a minimum pressure of 35 lbf/in.² and butt welded joints shall be simultaneously visually examined (hydrostatic) or solution film tested (pneumatic) for tightness. If manufactured pipe has been hydrostatically tested previously to ASTM requirements, then only circumferential welds need to be examined.

R.7.8 Nonpressure Parts

Welds for pads, lifting lugs, and other nonpressure parts, as well as temporary lugs for alignment and scaffolding attached to primary components, shall be made in full compliance with a welding procedure qualified in accordance with R.6.1. Lugs attached for erection purposes shall be removed by the grinding of all remaining welds followed by magnetic-particle examination. Plate that is gouged or torn in removing the lugs shall be repaired using a qualified procedure, followed by grinding. Where such repairs are made in primary components, the area shall be inspected using the magnetic-particle method. A visual inspection is adequate for repaired areas in secondary components.

R.8 Testing the Tank in Contact with Liquid Contents

The provisions stated in this section are testing requirements for the tank refrigerated by the liquid contents. The provisions in R.9 cover the outer tank that is not in contact with the refrigerated liquid and is subjected to a higher temperature that approaches atmospheric.
R.8.1 General Procedure

A thorough check for tightness and structural adequacy is essential for a single-wall tank or for an inner tank of a double-wall tank. Except as permitted by R.8.5, the test shall be conducted after the entire tank is complete, but before the insulation is applied. The hydrostatic test shall be performed by filling the tank with water to the design liquid level and applying an overload air pressure of 1.25 times the pressure for which the vapor space is designed. The hydrostatic test shall not produce a membrane tensile stress in any part of the tank exceeding 85% of the minimum specified yield strength or 55% of the minimum specified tensile strength of the material.

R.8.2 Test Preliminaries

Before the tank is filled with water, the procedures described in R.8.2.1 through R.8.2.5 shall be completed.

R.8.2.1 All welded joints in the bottom of the tank shall be inspected by applying a solution film to the welds and pulling a partial vacuum of at least 3 lbf/in.² gauge above the welds by means of a vacuum box with a transparent top.

R.8.2.2 Complete penetration and complete fusion welds that join the cylindrical wall to the tank bottom shall be inspected by applying a solution film to the welds and pulling a partial vacuum of at least 3 lbf/in.² gauge above the welds by means of a vacuum box with a transparent top.

R.8.2.3 When the weld in R.8.2.2 does not have complete penetration and complete fusion, the initial weld passes, inside and outside of the shell, shall have all slag and non-metals removed from the surface of the welds and the
welds examined visually. After completion of the inside and outside fillet or partial penetration welds, the welds shall be tested by pressurizing the volume between the inside and outside welds with air pressure to 15 lbf/in.² gauge and applying a solution film to both welds. To assure that the air pressure reaches all parts of the welds, a sealed blockage in the annular passage between the inside and outside welds must be provided by welding at one or more points. Additionally, a small pipe coupling communicating with the volume between the welds must be welded on each side of and adjacent to the blockages. The air supply must be connected at one end and a pressure gauge connected to a coupling on the other end of the segment under test.

R.8.2.4 The attachment welding around all reinforced openings in the bottom, shell, and roof shall be inspected by applying air pressure of 15 lbf/in.² gauge behind the reinforcement plates and simultaneously applying a solution film to the welds. The test holes in the reinforcing plates shall be left open.

R.8.2.5 The attachment fillet welds around bottom openings, which do not permit the application of air pressure behind the reinforcing plate, shall be inspected by applying a solution film and by a vacuum box inspection.

R.8.3 Hydrostatic Test

The provisions described in R.8.3.1 through R.8.3.5 shall apply during and after water filling for the hydrostatic test.

R.8.3.1 The tank shall be vented to the atmosphere when it is filled with or emptied of water.

R.8.3.2 During water filling, the elevations of at least four equidistant points at the bottom of the tank shell and on top of the ringwall or slab shall be checked. Differential settlement, or uniform settlement of substantial magnitude, requires an immediate stop to water filling. Any further filling with water will depend on an evaluation of the measured settlement.

R.8.3.3 The tank shall be filled with water to the design liquid level. In the case of settlement, as stated in R.8.3.2, an appropriate corrective action shall be taken before further filling or, alternatively the design liquid level shall be reduced to the actual maximum test water level.

R.8.3.4 After the tank is filled with water and before the pneumatic test pressure is applied, anchor bolts or anchor straps, if provided, shall be tightened against the hold-down brackets.

R.8.3.5 All welds in the shell, including the corner weld between the shell and the bottom, shall be visually checked for tightness.

R.8.4 Pneumatic Pressure

R.8.4.1 An air pressure equal to 1.25 times the pressure for which the vapor space is designed shall be applied to the enclosed space above the water level. In the case of a double-wall tank with an open-top inner tank, where the air pressure acts against the outer tank and the inner tank is thus not stressed by the air pressure, the inner tank may be emptied of water before the pneumatic pressure testing begins.

R.8.4.2 The test pressure shall be held for 1 hour.

R.8.4.3 The air pressure shall be reduced until the design pressure is reached.

R.8.4.4 Above the water level, all welded joints, welds around openings, and piping joints shall be checked with a solution film. A visual inspection may be substituted for the solution-film inspection of the welded joints if they have been previously checked with a vacuum box. Above the water level, the solution-film inspection shall be made of all welds around openings, all piping joints, and the compression-ring welds, including the attachment welds to the roof and shell.

R.8.4.5 The opening pressure or vacuum of the pressure relief and vacuum relief valves shall be checked by pumping air above the water level and releasing the pressure, then partially withdrawing water from the tank.

R.8.4.6 After the tank has been emptied of water and is at atmospheric pressure, the anchorage, if provided, shall be rechecked for tightness against the hold-down brackets.
Appendix S
Austenitic Stainless Steel Storage Tanks

S.1 Scope

S.1.1 This appendix covers materials, design, fabrication, erection, and testing requirements for aboveground, welded, austenitic stainless steel storage tanks constructed of material grades 304, 304L, 316, 316L, 317, and 317L. This appendix does not cover stainless steel clad plate or strip lined construction.

S.1.2 This appendix applies only to tanks in non-refrigerated service. For stainless steel tanks in refrigerated service, refer to Appendix Q of this standard. Minimum design metal temperature of the non-refrigerated tanks in the scope of the appendix is not limited. Maximum design metal temperature shall be limited as given in 1.2.2. For the purposes of this appendix, the design temperature shall be the maximum operating temperature as specified by the Purchaser. Ambient temperature tanks (non-heated) shall have a design temperature of 40°C (100°F). It is cautioned that exothermic reactions occurring inside unheated storage tanks can produce temperatures exceeding 40°C (100°F).

S.1.3 This appendix is intended to provide the petroleum industry, chemical industry, and other users with tanks of safe design for containment of fluids within the design limits.

S.1.4 The minimum thicknesses in this appendix do not contain any allowance for corrosion.

S.1.5 This appendix states only the requirements that differ from the basic rules in this standard. For requirements not stated, the basic rules must be followed.

S.2 Materials

S.2.1 Selection and Ordering

S.2.1.1 Materials shall be in accordance with Table S-1.

S.2.1.2 Selection of the type/grade of stainless steel depends on the service and environment to which it will be exposed and the effects of fabrication processes. The Purchaser shall select the type/grade.

S.2.1.3 External structural attachments may be carbon steels meeting the requirements of Section 2 of this standard, providing they are protected from corrosion and the design and details consider the dissimilar properties of the materials used. (This does not include shell, roof, or bottom openings and their reinforcement.) Carbon steel attachments (e.g., clips for scaffolding) shall not be welded directly to any internal surface of the tank.

S.2.2 Packaging

Packaging stainless steel for shipment is important to its corrosion resistance. Precautions to protect the surface of the material will depend on the surface finish supplied and may vary among manufacturers. Normal packaging methods may not be sufficient to protect the material from normal shipping damage. If the intended service requires special precautions, special instructions should be specified by the purchaser.

S.2.3 Impact Testing

Impact tests are not required for austenitic stainless steel base metals.
S.3 Design

S.3.1 Operating Temperature

S.3.1.1 The Purchaser shall specify the maximum operating temperature of the tank, not to exceed the maximum temperature of 120°C (250°F) given in 5.2.

S.3.2 Maximum Tensile Stress

S.3.2.1 The maximum tensile stress shall be in accordance with 5.5.3 except Table S-2 shall be used to determine $S_{ts}$.

S.3.3 Maximum Compressive Stress

S.3.3.1 Allowable compressive stresses shall be in accordance with 5.5.4, except the allowable compressive stress shall be reduced by the ratio material modulus of elasticity at the design temperature to 200,000 Mpa (29,000,000 lbf/in.²) for values $(t – c)/R$ less than 0.0175 and by the ratio of the materials minimum yield strength at the design temperature to 205 Mpa (30,000 lbf/in.²) for values $(t – c)/R$ equal to or greater than 0.0175.

S.3.4 Maximum Allowable Stress for Structural Members and Bolts

S.3.4.1 The maximum allowable stress values for structural members shall be in accordance with Table 3-3 except the allowable stresses for compression shall be reduced by the ratio of the materials yield strength at design temperature to 205 Mpa (30,000 lbf/in.²).

---

Table S-1a—ASTM Materials for Stainless Steel Components (SI Units)

<table>
<thead>
<tr>
<th>Plates and Structural Members (Note 1)</th>
<th>Piping and Tubing Seamless or Welded (Note 2)</th>
<th>Forgings (Notes 2, 3)</th>
<th>Bolting and Bars (Notes 4, 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A240M, Type 304</td>
<td>A213M, Grade TP 304</td>
<td>A182M, Grade F 304</td>
<td>A193M, Class 1, Grades B8, B8A, and B8M</td>
</tr>
<tr>
<td>A240M, Type 304L</td>
<td>A213M, Grade TP 304L</td>
<td>A182M, Grade F 304L</td>
<td>A194M, Grades B8, B8A, B8M, and B8MA</td>
</tr>
<tr>
<td>A240M, Type 316</td>
<td>A213M, Grade TP 316</td>
<td>A182M, Grade F 316</td>
<td>A320M, Grades B8, B8A, B8M, and B8MA</td>
</tr>
<tr>
<td>A240M, Type 316L</td>
<td>A213M, Grade TP 316L</td>
<td>A182M, Grade F 316L</td>
<td>A479M, Type 304</td>
</tr>
<tr>
<td>A240M, Type 317</td>
<td>A213M, Grade TP 317</td>
<td>A182M, Grade F 317</td>
<td>A479M, Type 304L</td>
</tr>
<tr>
<td>A240M, Type 317L</td>
<td>A312M, Grade TP 304</td>
<td>A182M, Grade F 317L</td>
<td>A479M, Type 316</td>
</tr>
<tr>
<td>A240M, Type 317L</td>
<td>A213M, Grade TP 317L</td>
<td>A182M, Grade F 317L</td>
<td>A479M, Type 316L</td>
</tr>
<tr>
<td></td>
<td>A312M, Grade TP 317</td>
<td></td>
<td>A479M, Type 317</td>
</tr>
</tbody>
</table>

Notes:
1. Unless otherwise specified by the Purchaser, plate, sheet, or strip shall be furnished with a No. 1 finish and shall be hot-rolled, annealed, and descaled.
2. Carbon steel flanges and/or stub ends may be used by agreement between the Purchaser and Manufacturer, providing the design and details consider the dissimilar properties of the materials used and are suitable for the intended service.
3. Castings shall not be used unless specified by the Purchaser. If specified, castings shall meet ASTM A351 and shall be inspected in accordance with ASME Section VIII, Division 1, Appendix 7.
4. All bars in contact with the product shall be furnished in the hot-rolled, annealed, and descaled condition.
5. Other bolting materials may be used by agreement between the Purchaser and Manufacturer.
Table S-1b—ASTM Materials for Stainless Steel Components (US Customary Units)

<table>
<thead>
<tr>
<th>Plates and Structural Members (Note 1)</th>
<th>Piping and Tubing Seamless or Welded (Note 2)</th>
<th>Forgings (Notes 2, 3)</th>
<th>Bolting and Bars (Notes 4, 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A240, Type 304</td>
<td>A213, Grade TP 304</td>
<td>A182, Grade F 304</td>
<td>A193, Class 1, Grades B8, B8A, and B8M</td>
</tr>
<tr>
<td>A240, Type 304L</td>
<td>A213, Grade TP 304L</td>
<td>A182, Grade F 304L</td>
<td>A194, Grades B8, B8A, B8M, and B8MA</td>
</tr>
<tr>
<td>A240, Type 316</td>
<td>A213, Grade TP 316</td>
<td>A182, Grade F 316</td>
<td>A320, Grades B8, B8A, B8M, and B8MA</td>
</tr>
<tr>
<td>A240, Type 316L</td>
<td>A213, Grade TP 316L</td>
<td>A182, Grade F 316L</td>
<td>A479, Type 304</td>
</tr>
<tr>
<td>A240, Type 317</td>
<td>A213, Grade TP 317</td>
<td>A182, Grade F 317</td>
<td>A479, Type 304L</td>
</tr>
<tr>
<td>A240, Type 317L</td>
<td>A213, Grade TP 317L</td>
<td>A182, Grade F 317L</td>
<td>A479, Type 316</td>
</tr>
<tr>
<td></td>
<td>A312, Grade TP 304</td>
<td></td>
<td>A479, Type 316L</td>
</tr>
<tr>
<td></td>
<td>A312, Grade TP 304L</td>
<td></td>
<td>A479, Type 317</td>
</tr>
<tr>
<td></td>
<td>A312, Grade TP 316</td>
<td></td>
<td>A479, Type 317L</td>
</tr>
<tr>
<td></td>
<td>A312, Grade TP 316L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A312, Grade TP 317</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A312, Grade TP 317L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A358, Grade 304</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A358, Grade 304L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A358, Grade 316</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A358, Grade 316L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A403, Class WP 304</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A403, Class WP 304L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A403, Class WP 316</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A403, Class WP 316L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A403, Class WP 317</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A403, Class WP 317L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A403, Class WP 317L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A312, Grade TP 316L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A312, Grade TP 317L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A312, Grade TP 317L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A358, Grade 304</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A358, Grade 304L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A358, Grade 316</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A358, Grade 316L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A403, Class WP 304</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A403, Class WP 304L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A403, Class WP 316</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A403, Class WP 316L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A403, Class WP 317</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A403, Class WP 317L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A403, Class WP 317L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Unless otherwise specified by the Purchaser, plate, sheet, or strip shall be furnished with a No. 1 finish and shall be hot-rolled, annealed, and descaled.
2. Carbon steel flanges and/or stub ends may be used by agreement between the Purchaser and Manufacturer, providing the design and details consider the dissimilar properties of the materials used and are suitable for the intended service.
3. Castings shall not be used unless specified by the Purchaser. If specified, castings shall meet ASTM A351 and shall be inspected in accordance with ASME Section VIII, Division 1, Appendix 7.
4. All bars in contact with the product shall be furnished in the hot-rolled, annealed, and descaled condition.
5. Other bolting materials may be used by agreement between the Purchaser and Manufacturer.

S.3.5  Flat Bottoms of Cylindrical Tanks

S.3.5.1  The minimum thickness for bottom plates shall be 5 mm (\(\frac{3}{16}\) in.), exclusive of any corrosion allowance specified by the Purchaser.

S.3.6  Intermediate Wind Girders for Cylindrical Sidewalls

S.3.6.1  The value \(H_1\) in 5.10.6.1 shall be reduced by the ratio of the materials modulus of elasticity at the design temperature to 200,000 Mpa (29,000,000 lbf/in.\(^2\)).

S.3.6.2  The value \(W_{tr}\) in 5.10.6.2 shall be reduced by the ratio of the materials modulus of elasticity at the design temperature to 200,000 Mpa (29,000,000 lbf/in.\(^2\)).

S.3.7  Compression Rings

S.3.7.1  The value of 15,000 in equation (27) in 5.12.4.3 shall be reduced by the ratio of the material yield strength at the design temperature to 205 Mpa (30,000 lbf/in.\(^2\)).

S.3.8  Flat Cover Plates and Blind Flanges

S.3.8.1  The value s in 5.21 shall be in accordance with Table S-3.
S.3.9 Stress Relieving

S.3.9.1 The stress relieving requirements of 5.25 need not be performed unless specified by the Purchaser.

S.3.10 Flush-type Shell Connection

S.3.10.1 The value \( t_b \) in 5.27.4.5 shall be reduced by the ratio of the materials yield stress at the design temperature to 205 Mpa (30,000 lbf/in.\(^2\)).

S.4 Fabrication

S.4.1 General

Special precautions must be observed to minimize the risk of damage to the corrosion resistance of stainless steel. Stainless steel shall be handled in a manner that minimizes contact with iron or other types of steel during all phases of fabrication and construction. The following sections describe the major precautions that should be observed during fabrication and handling.

S.4.2 Storage

Storage should be under cover and removed from shop dirt, fumes, and pickling operations. If outside storage is necessary, provisions should be made for rainwater to drain and allow the material to dry. Stainless steel should not be stored in contact with carbon steel. Materials containing chlorides, including foods, beverages, oils, and greases, should not come in contact with stainless steel.

Table S-2—Maximum Allowable Stress Values for Simple Tension

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Min Yield Mpa</th>
<th>Min Tensile Mpa</th>
<th>Allowable Stress for Design Temperature Not Exceeding (( S_{ts} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mpa</td>
<td>lbf/in.(^2)</td>
<td>Mpa</td>
</tr>
<tr>
<td>304</td>
<td>205</td>
<td>30,000</td>
<td>515</td>
</tr>
<tr>
<td>304L</td>
<td>170</td>
<td>25,000</td>
<td>485</td>
</tr>
<tr>
<td>316</td>
<td>205</td>
<td>30,000</td>
<td>515</td>
</tr>
<tr>
<td>316L</td>
<td>170</td>
<td>25,000</td>
<td>485</td>
</tr>
<tr>
<td>317</td>
<td>205</td>
<td>30,000</td>
<td>515</td>
</tr>
<tr>
<td>317L</td>
<td>205</td>
<td>30,000</td>
<td>515</td>
</tr>
</tbody>
</table>

Notes:
1. \( S_{ts} \) may be interpolated between temperatures.
2. The design stress corresponds to the lesser of 0.33 of the minimum tensile strength or 0.75 of the minimum yield strength.
3. For dual certified materials (e.g., ASTM A182M/A182 Type 304L/304), use the allowable stress of the grade specified by the Purchaser.

S.4.3 Thermal Cutting

S.4.3.1 Thermal cutting of stainless steel shall be by the iron powder burning carbon arc or the plasma-arc method.

S.4.3.2 Thermal cutting of stainless steel may leave a heat-affected zone and intergranular carbide precipitates. This heat-affected zone may have reduced corrosion resistance unless removed by machining, grinding, or solution annealing and quenching. The Purchaser shall specify if the heat-affected zone is to be removed.
S.4.4 Forming

S.4.4.1 Stainless steels shall be formed by a cold, warm, or hot forming procedure that is non-injurious to the material.

S.4.4.2 Stainless steels may be cold formed, providing the maximum strain produced by such forming does not exceed 10% and control of forming spring-back is provided in the forming procedure.

S.4.4.3 Warm forming at 540°C (1000°F) to 650°C (1200°F) may cause intergranular carbide precipitation in 304, 316, and 317 grades of stainless steel. Unless stainless steel in this sensitized condition is acceptable for the service of the equipment, it will be necessary to use 304L, 316L, or 317L grades or to solution anneal and quench after forming. Warm forming shall be performed only with agreement of the Purchaser.

S.4.4.4 Hot forming, if required, may be performed within a temperature range of 900°C (1650°F) to 1200°C (2200°F).

Table S-3—Allowable Stresses for Plate Ring Flanges

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Allowable Stress for Design Temperatures Not Exceeding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40°C</td>
</tr>
<tr>
<td></td>
<td>Mpa</td>
</tr>
<tr>
<td>304</td>
<td>140</td>
</tr>
<tr>
<td>304L</td>
<td>117</td>
</tr>
<tr>
<td>316</td>
<td>140</td>
</tr>
<tr>
<td>316L</td>
<td>117</td>
</tr>
<tr>
<td>317</td>
<td>140</td>
</tr>
<tr>
<td>317L</td>
<td>140</td>
</tr>
</tbody>
</table>

Notes:
1. Allowable stresses may be interpolated between temperatures.
2. The allowable stresses are based on a lower level of permanent strain.
3. The design stress shall be the lesser of 0.3 of the minimum tensile strength, or 2/3 of the minimum yield strength.
4. For dual certified materials (e.g., ASTM A182M/A 182 Type 304L/304), use the allowable stress of the grade specified by the Purchaser.

Table S-4—Yield Strength Values

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Yield Strength for Design Temperature Not Exceeding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40°C</td>
</tr>
<tr>
<td></td>
<td>Mpa</td>
</tr>
<tr>
<td>304</td>
<td>205</td>
</tr>
<tr>
<td>304L</td>
<td>170</td>
</tr>
<tr>
<td>316</td>
<td>205</td>
</tr>
<tr>
<td>316L</td>
<td>170</td>
</tr>
<tr>
<td>317</td>
<td>205</td>
</tr>
<tr>
<td>317L</td>
<td>205</td>
</tr>
</tbody>
</table>

Table S-5—Modulus of Elasticity at the Design Temperature

<table>
<thead>
<tr>
<th>Modulus of Elasticity for Design Temperature Not Exceeding</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>90</td>
</tr>
<tr>
<td>120</td>
</tr>
</tbody>
</table>
S.4.4.5 Forming at temperatures between 650°C (1200°F) and 900°C (1650°F) is not permitted.

S.4.5 Cleaning

S.4.5.1 When the Purchaser requires cleaning to remove surface contaminants that may impair the normal corrosion resistance, it shall be done in accordance with ASTM A380, unless otherwise specified. Any additional cleanliness requirements for the intended service shall be specified by the Purchaser.

S.4.5.2 When welding is completed, flux residues and weld spatter shall be removed mechanically using stainless steel tools.

S.4.5.3 Removal of excess weld metal, if required, shall be done with a grinding wheel or belt that has not been previously used on other metals.

S.4.5.4 Chemical cleaners used shall not have a detrimental effect on the stainless steel and welded joints and shall be disposed of in accordance with laws and regulations governing the disposal of such chemicals. The use of chemical cleaners shall always be followed by thorough rinsing with water and drying (see S.4.9).

S.4.6 Blast Cleaning

If blast cleaning is necessary, it shall be done with sharp acicular grains of sand or grit containing not more than 2% by weight iron as free iron or iron oxide. Steel shot or sand used previously to clean nonstainless steel is not permitted.

S.4.7 Pickling

If pickling of a sensitized stainless steel is necessary, an acid mixture of nitric and hydrofluoric acids shall not be used. After pickling, the stainless steel shall be thoroughly rinsed with water and dried.

S.4.8 Passivation or Iron Freeing

When passivation or iron freeing is specified by the Purchaser, it may be achieved by treatment with nitric or citric acid. The use of hydrofluoric acid mixtures for passivation purposes is prohibited for sensitized stainless.

S.4.9 Rinsing

S.4.9.1 When cleaning and pickling or passivation is required, these operations shall be followed immediately by rinsing, not allowing the surfaces to dry between operations.

S.4.9.2 Rinse water shall be potable and shall not contain more than 200 parts per million chloride at temperatures below 40°C (100°F), or no more than 100 parts per million chloride at temperatures above 40°C (100°F) and below 65°C (150°F), unless specified otherwise by the Purchaser.

S.4.9.3 Following final rinsing, the material shall be completely dried.

S.4.10 Welding

S.4.10.1 Tanks and their structural attachments shall be welded by any of the processes permitted in 6.6.2 or by the plasma arc process. Galvanized components or components painted with zinc-rich paint shall not be welded directly to stainless steel.

S.4.10.2 Filler metal chemistry shall match the type of base metals joined. Dissimilar welds to carbon steels shall use filler metals of E 309 or higher alloy content.
Appendix U
Ultrasonic Examination in Lieu of Radiography

U.1 Purpose and Scope

This appendix provides detailed rules for the use of the ultrasonic examination (UT) method for the examination of tank seams as permitted by 5.26, R.7.6, and Q.7.6. This alternative is limited to joints where the thickness of the thinner of the two members joined is greater than or equal to 10 mm (3/8 in.).

U.2 Definitions

U.2.1 documenting: Preparation of text and/or and figures.

U.2.2 evaluation: All activities required in U.6.3 through U.6.6 to determine the acceptability of a flaw.

U.2.3 flaw: A reflector that is not geometric or metallurgical in origin that may be detectable by nondestructive testing but is not necessarily rejectable.

U.2.4 flaw categorization: Whether a flaw is a surface flaw or is a subsurface flaw (see U.6.4). Note that a flaw need not be surface breaking to be categorized as a surface flaw.

U.2.5 flaw characterization: The process of quantifying the size, location, and shape of a flaw. See U.6.3 for size and location. The only shape characterization required by this appendix is applied to the results of supplemental surface examination by MT or PT (see U.6.6.2).

U.2.6 indication: That which marks or denotes the presence of a reflector.

U.2.7 interpretation: The determination of whether an indication is relevant or nonrelevant, i.e., whether it originates from a geometric or metallurgical feature or conversely originates from a flaw (see U.6.2).

U.2.8 investigation: Activities required to determine the interpretation of an indication (see U.6.1 and U.6.2).

U.2.9 recording: The writing of ultrasonic data onto an appropriate electronic medium.

U.2.10 reflector: An interface at which an ultrasonic beam encounters a change in acoustic impedance and at which at least part of the energy is reflected.

U.3 Technique

U.3.1 The ultrasonic examination volume shall include the weld metal, plus the lesser of 25 mm (1 in.) or t of adjoining base metal on each side of the weld unless otherwise agreed upon by the Purchaser and the Manufacturer.

U.3.2 Ultrasonic examination for the detection of flaws shall be performed using automated, computer-based data acquisition except that scanning of adjacent base metal for flaws that can interfere with the examination may be performed manually. Ultrasonic examination for sizing of flaws shall be performed as described in U.6.3.1.

U.3.3 A documented examination strategy or scan plan shall be provided showing transducer placement, movement, and component coverage that provides a standardized and repeatable methodology for weld acceptance. The scan plan shall also include ultrasonic beam angle to be used, beam directions with respect to weld centerline, and tank material volume examined for each weld. The documentation shall be made available to the Owner upon request.
U.3.4 Data from the examination volume, per U.3.1, shall be recorded and/or documented as follows:

a) For automated computer-based scans, data shall be recorded using the same system essential variables, specified value or range of values, used for the demonstration of the procedure per U.4.3 below.

b) For manual scans, results shall be documented in a written report.

U.3.5 The ultrasonic examination shall be performed in accordance with a written procedure which has been reviewed and approved by the Purchaser and conforms to the requirements of Section V, Article 4, except that:

a) The calibration block shown in Figure T-434.2.1 of Section V, Article 4 shall be used, and;

b) For examination techniques that provide plate quality information (e.g., time of flight diffraction), the initial base material straight-beam examination need not be performed.

U.3.6 The examination methodology (including U.6.6) shall be demonstrated to be effective over the full weld volume. It is recognized that time of flight diffraction (TOFD) may have limitations in detection of flaws at the surface such that it may be necessary to supplement TOFD with pulse-echo techniques suitable for the detection of near-field and far-field flaws. The variety of surface and sub-surface category flaws in the test plate mandated by U.4.3.a are intended to ensure that any such limitations are adequately addressed.

U.3.7 It is recognized that in the ultrasonic inspection of joints with austenitic weld metals, initial screening for defects may be done by methods that determine flaw lengths but give only limited information on flaw height. In these cases a length and upper bound height acceptance criteria is applied (see Table U-2).

U.4 Personnel Qualifications and Training

U.4.1 Personnel Qualifications

Personnel performing and evaluating UT examinations shall be qualified and certified in accordance with their employer’s written practice. ASNT SNT-TC-IA or CP-189 shall be used as a guideline. Only Level II or III personnel shall perform UT examinations, analyze the data, or interpret the results.

U.4.2 Qualification Records

Qualification records of certified personnel shall be approved by the Manufacturer and maintained by their employer.

U.4.3 Personnel Testing

Personnel who acquire and analyze UT data shall be trained using the equipment of U.3.2, and the procedure of U.3.5 above. Additionally, they shall pass a practical examination based on the technique on a blind test plate. The testing program details shall be by agreement between the Purchaser and the inspection company, but shall in any case include the following elements as a minimum:

a) The test plate shall contain a variety of surface and sub-surface category flaws including multiple flaws described in section U.6.5. Some of the flaws shall be acceptable and others unacceptable per the applicable criteria of Tables U-1 or U-2.

b) The practical examination should cover detection, interpretation, sizing, plotting, categorization, grouping, and characterization that is sufficient to cover the cases outlined in U.6.