

ANSI/AWWA **D103-19**
(Revision of *ANSI/AWWA D103-09*)

AWWA Standard

Factory-Coated Bolted Carbon Steel Tanks for Water Storage

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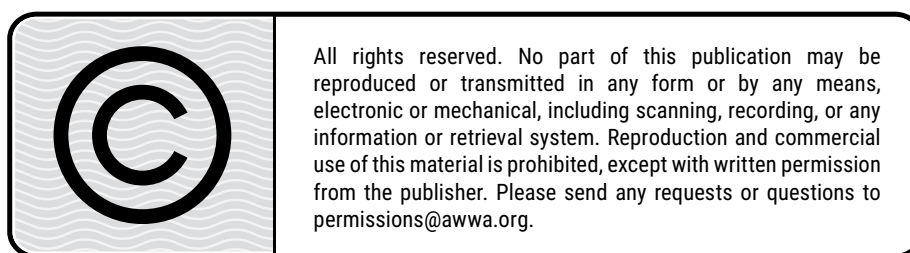
AWWA Standard

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Foreword

This foreword is for information only and is not a part of ANSI/AWWA D103.

I. Introduction.

I.A. *Background.* This standard covers factory-coated bolted carbon steel tanks for water storage and is based on the accumulated knowledge and experience of manufacturers of bolted carbon steel tanks.[†]

I.B. *History.* The first version of this standard was prepared in cooperation with the Bolted Tank Manufacturer's Association and was issued in 1980. It was prepared in response to the increasing use of bolted tanks for water storage. [ANSI/AWWA D103-80](#) was later updated and approved as [ANSI/AWWA D103-87](#) on June 14, 1987.

Subsequent editions of ANSI/AWWA D103 were approved by the AWWA Board of Directors on June 15, 1997, and Jan. 25, 2009. This edition was approved on June 7, 2019.

I.C. *Acceptance.* In May 1985, the US Environmental Protection Agency (USEPA) entered into a cooperative agreement with a consortium led by NSF International (NSF) to develop voluntary third-party consensus standards and a certification program for direct and indirect drinking water additives. Other members of the original consortium included the Water Research Foundation (formerly AwwaRF) and the Conference of State Health and Environmental Managers (COSHEM). AWWA and the Association of State Drinking Water Administrators (ASDWA) joined later.

In the United States, authority to regulate products for use in, or in contact with, drinking water rests with individual states.[‡] Local agencies may choose to impose requirements more stringent than those required by the state. To evaluate the health effects of products and drinking water additives from such products, state and local agencies may use various references, including:

1. Specific policies of the state or local agency.
2. Two standards developed under the direction of NSF,[§] NSF/ANSI 60, Drinking Water Treatment Chemicals—Health Effects, and NSF/ANSI 61, Drinking Water System Components—Health Effects.

* American National Standards Institute, 25 West 43rd Street, Fourth Floor, New York, NY 10036.

[†] The word *tanks* is used hereinafter broadly in place of the lengthy phrase *standpipes or reservoirs for water storage*.

[‡] Persons outside the United States should contact the appropriate authority having jurisdiction.

[§] NSF International, 789 North Dixboro Road, Ann Arbor, MI 48113.

3. Other references, including AWWA standards, *Food Chemicals Codex*, *Water Chemicals Codex*,^{*} and other standards considered appropriate by the state or local agency.

Various certification organizations may be involved in certifying products in accordance with NSF/ANSI 61. Individual states or local agencies have authority to accept or accredit certification organizations within their jurisdiction. Accreditation of certification organizations may vary from jurisdiction to jurisdiction.

Annex A, “Toxicology Review and Evaluation Procedures,” to NSF/ANSI 61 does not stipulate a maximum allowable level (MAL) of a contaminant for substances not regulated by a USEPA final maximum contaminant level (MCL). The MALs of an unspecified list of “unregulated contaminants” are based on toxicity testing guidelines (noncarcinogens) and risk characterization methodology (carcinogens). Use of Annex A procedures may not always be identical, depending on the certifier.

ANSI/AWWA D103 does not address additives requirements. Thus, users of this standard should consult the appropriate state or local agency having jurisdiction in order to:

1. Determine additives requirements, including applicable standards.
2. Determine the status of certifications by parties offering to certify products for contact with, or treatment of, drinking water.
3. Determine current information on product certification.

II. Special Issues.

II.A. *Purchase.* When tanks are purchased using this standard, the purchaser must specify certain basic requirements. The purchaser may desire to modify, delete, or amplify sections of this standard to suit special conditions. It is strongly recommended that such modifications, deletions, or amplifications be made by supplementing this standard rather than by rewriting or incorporating sections from this standard into a separate specification.

II.B. *Design and Construction.* The details of design and construction covered by this standard are minimum requirements. A tank cannot be represented as adhering to the provisions of ANSI/AWWA D103 if it does not meet the minimum requirements of this standard.

II.C. *Coatings.* Tanks covered by this standard shall be supplied with factory-applied coatings. Field coating is limited to repair of damaged coatings.

^{*} Both publications available from National Academy of Sciences, 500 Fifth Street, NW, Washington, DC 20001.

Tanks with factory-applied coatings and bolted construction have a long life expectancy. Regular inspection and repair of damaged or deteriorated areas may be the determining factors in the length of tank life.

II.D. *Foundations.* Tank foundations are one of the more important aspects of tank design. Detailed requirements for tank foundations are covered in Section 13 of this standard. This standard does not require the manufacturer or constructor to be responsible for the design of the tank foundation unless specified. An adequate soil investigation at the tank site, including recommendations of the type of foundation to be used, the depth of foundation required, specification and compaction of sub-base materials, and the design soil-bearing pressure, should be obtained. This information, as well as specifications for an adequate soil investigation, should be established by a qualified geotechnical engineer. A drainage inlet structure or suitable erosion protection should be provided to receive the discharge from the tank overflow. The overflow should not be connected directly to a sewer or a storm drain without an air break.

II.E. *Annual Inspection, Maintenance, and Operation.* Annual inspection and maintenance is important if maximum tank life is to be attained. Complete interior and exterior inspections should occur at least every three to five years. In particular, accumulations of dirt and weeds from around the outside base of the tank, which may trap moisture and accelerate corrosion, as well as accumulated silt inside on the floor, should be removed. Refer to [AWWA Manual M42](#), *Steel Water-Storage Tanks*, for guidance concerning inspection and maintenance.

Sufficient water replacement and circulation is necessary to prevent freezing in the tank and piping. Where low usage may result in the possibility of freezing, the water may need to be wasted or heat provided to prevent freezing. The purchaser is referred to NFPA* 22, Standard for Water Tanks for Private Fire Protection, for heater sizing. Purchasers are cautioned against allowing ice to build up for use as insulation because the ice may break loose and damage the tank.

II.F. *Disinfection Procedures.* This standard does not cover disinfecting procedures[†] (see Sec. 11.3). If the disinfecting is to be performed by the tank constructor, the purchaser must specify the disinfecting procedure to be used (see [ANSI/AWWA C652](#)).

* National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169.

[†] Various disinfection procedures are presented in [ANSI/AWWA C652](#), Disinfection of Water-Storage Facilities.

III. Use of This Standard. It is the responsibility of the user of an AWWA standard to determine that the products described in that standard are suitable for use in the particular application being considered.

III.A. Purchaser Options and Alternatives. The following information should be provided by the purchaser.

1. Standard used—that is ANSI/AWWA D103, Factory-Coated Bolted Carbon Steel Tanks for Water Storage, of latest revision.
2. Whether compliance with NSF/ANSI 61, Drinking Water System Components—Health Effects, is required.
3. Details of federal, state, and local requirements (Sec. 1.1.3).
4. Tank geometry.
 - a. Dimensions, capacity, and maximum water level (MWL) above top of foundation.
 - b. The bottom capacity level (BCL) of the tank when empty if different from the level when the tank would be emptied through the specified discharge piping.
 - c. Type of roof. Steel roof or aluminum dome.
 - d. Type of bottom. Steel tank bottom or concrete bottom with embedded steel base setting ring (Sec. 13.4.6).
 - e. Vertical distance from finished ground level to the crown of inlet and outlet pipes (pipe cover) at tank foundation (Sec. 13.7.2).
5. Tank accessories and requirements.
 - a. The type of pipe and fittings for fluid conductors and the type of pipe joint if different from that permitted in Sec. 4.9.
 - b. Locations of manholes, ladders, and accessories (Section 7). NOTE: Only one shell manhole will be provided unless the purchaser otherwise specifies (Sec. 7.1).
 - c. The number and location of pipe connections, and type and size of pipe to be accommodated.
 - d. If a removable silt stop is required (Sec. 7.2.1).
 - e. Overflow type, whether stub or to ground; size of pipe; pumping and discharge rates (Sec. 7.3).
 - f. If the exterior ladder or access to roof hatches and vents is to be omitted (Sec. 7.4).
 - g. If ladder cages, rest platforms, ladder locks, roof-ladder handrails, or other safety devices in excess of OSHA are required (Sec. 7.5).

- h. If a special screen is required for tank vent (Sec. 7.7).
 - i. If shop inspection is required, and whether certified mill-test reports are required (Sec. 11.1).
 - j. If a cathodic protection system is desired, specify the type of system (e.g., an automatically controlled impressed current cathodic protection system or a sacrificial anode cathodic protection system).
- 6. Tank design criteria.
 - a. Snow load. If snow loading is to be reduced (Sec. 5.2.4).
 - b. Wind load. Specific wind-load requirements, including whether a sliding check for self-anchored tanks is required (Sec. 5.2.6 and Sec. 15.3).
 - c. Seismic load. Risk Category for the tank, or if the seismic design is to be omitted (Sec. 5.2.1 and Sec. 14.2.1).
 - d. If seismic design of roof framing and columns is required and the amount of live loads to be used (Sec. 14.3.4.4).
 - e. Whether the site-specific seismic design procedure is required (Sec. 14.2.7).
 - f. Other loads. Equipment, platforms, walkways, and all additional loads including live, dead, static, and dynamic loads.
- 7. Foundation.
 - a. Geotechnical report. Summary of soil investigation, including foundation-design criteria (Sec. 13.2), type of foundation (Sec. 13.4), depth of foundation below existing grade, site class for seismic areas, and design soil-bearing pressure, including appropriate factor of safety.
 - b. When a pile-supported foundation is required, the pile type and the depth below existing grade (Sec. 13.5.4).
 - c. The elevation of concrete foundations above the finish grade (Sec. 13.5.1).
- 8. Field construction.
 - a. The prepared site location.
 - b. Type of road available for access to the site and whether the road is public or private.
 - c. Name of and distance to the nearest town.
 - d. Name of and distance to the nearest railroad siding.
 - e. Availability of electric power; who furnishes it and at what fee, if any; what voltage is available; whether direct or alternating current; and, if alternating current, what cycle and phase.

- f. Availability of compressed air and what pressure, volume, and fee are available, if any.
- g. Desired time for completion.
- h. Any materials furnished by the purchaser to be used by the constructor for construction of the tank.
- i. Necessary blinding fittings for leak testing.

III.B. *Information to Be Provided With the Bid.*

- 1. Detailed Submittals.
 - a. Detailed drawing of the tank with dimensions, including the diameter, shell height, height to the maximum water level (MWL), bottom, roof, coatings, details of bolted joints, accessories, ladders, and type and size of plates, members, and anchorage, as applicable.
 - b. Loads imposed on the foundation, including moment and shear under seismic and wind loading.

III.C. *Modification to Standard.* Any modification to the provisions, definitions, or terminology in this standard must be provided by the purchaser.

IV. Major Revisions. Major revisions made to the standard in this edition include the following:

- 1. Sec. 5 was revised to include risk category definitions from ASCE 7-10. Snow loads were revised to comply with ASCE 7-10.
- 2. Sec. 14 was revised so that seismic loading complies with ASCE 7-10. The site classification procedure was deleted and a reference to the procedure in ASCE 7-10 was added. Spectral response acceleration maps and the long-period transition period map were deleted and references to the maps in ASCE 7-10 were added. The vertical design acceleration was revised to include values for responses limited by buckling and responses not limited by buckling. Requirements were added for situations when the required freeboard is not provided. The slosh height equation was revised to match ASCE 7-10. The equation for allowable lateral shear for flat-bottom tanks was revised to show a service-level shear resistance similar to API 650 and ASCE 7-10.
- 3. Sec. 15 was revised so that wind loads complies with ASCE 7-10. The basic wind speed map was deleted and a reference to the basic wind speed map in ASCE 7-10 was added.

V. Comments. If you have any comments or questions about this standard, please call AWWA Engineering and Technical Services at 303.794.7711, FAX at 303.795.7603, write to the department at 6666 West Quincy Avenue, Denver, CO 80235-3098, or e-mail at standards@awwa.org.



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ANSI/AWWA D103-19
(Revision of [ANSI/AWWA D103-09](#))

AWWA Standard

Factory-Coated Bolted Carbon Steel Tanks for Water Storage

SECTION 1: GENERAL

Sec. 1.1 Scope

The purpose of this standard is to provide minimum requirements for the design, construction, inspection, and testing of new cylindrical, factory-coated, bolted carbon steel tanks for the storage of water. This standard is only applicable to tanks with a base elevation substantially at ground level.

1.1.1 *Tank roofs.* All tanks storing potable water shall have roofs. Roofs may be column-supported, self-supported, or aluminum dome. Tanks storing nonpotable water may be constructed without roofs.

1.1.2 *Items not described.* This standard does not cover all details of design and construction. Details that are not addressed shall be designed and constructed to be as adequate and as safe as those that would otherwise be provided under this standard. This standard is not applicable to tanks of corrugated construction. This standard is not applicable to tanks constructed of stacked plates or sheets laminated to form multiple layers.

1.1.3 *Local requirements.* This standard is not intended to cover storage tanks erected in areas subject to regulations more stringent than the requirements contained within this standard. In such cases, this standard should be followed where it does not conflict with local requirements. Where more stringent local,

municipal, county, or state government requirements apply, such requirements shall be specified, and this standard shall be interpreted to supplement them.

Sec. 1.2 Drawings to Be Provided

Construction drawings for the foundation and tank shall be provided. Where foundation and tank designs are performed by separate parties, each party shall provide construction drawings in accordance with the particular portion of the tank facility for which they have design responsibility. For tanks with anchor bolts or base-setting rings, the tank designer shall provide details of the required embedment, water stops, additional concrete reinforcement, and minimum required concrete strength. Details of all bolted joints shall be referenced on the tank construction drawings.

SECTION 2: REFERENCES

This standard references the following documents. In their latest editions, or as specified, they form a part of this standard to the extent specified within the standard. In any case of conflict, the requirements of this standard shall prevail.

AA* ADM—*Aluminum Design Manual*, 2015.

AA ASD—*Aluminum Standards and Data*, 2013.

AA SPC-18—Standards for Aluminum Sand and Permanent Mold Castings, 15th Edition, 2008.

ACI[†] 301-10—Specifications for Structural Concrete.

ACI 318-14—Building Code Requirements for Structural Concrete and Commentary.

ACI 349-06—Code Requirements for Nuclear Safety-Related Concrete Structures.

AISI[‡] 1010—Carbon Steel—Plates; Structural Shapes; Rolled Floor Plates; Steel Sheet Piling.

AISI S100—North American Specification for the Design of Cold-Formed Steel Structural Members.

AISI T-192—Steel Plate Engineering Data—Volume 1, Steel Tanks for Liquid Storage

* The Aluminum Association, 1400 Crystal Drive, Suite 430, Arlington, VA 22202.

[†] American Concrete Institute, 38800 Country Club Drive, Farmington Hills, MI 48331.

[‡] American Iron and Steel Institute, 1140 Connecticut Ave., NW, Suite 705, Washington, DC 20036.

AISI T-192—Steel Plate Engineering Data—Volume 2, Useful Information on the Design of Plate Structures

ANSI^{*}/AISC[†] 360—Specification for Structural Steel Buildings.

[ANSI/AWWA C652](#)—Disinfection of Water-Storage Facilities.

[ANSI/AWWA D104](#)—Automatically Controlled, Impressed-Current Cathodic Protection for the Interior Submerged Surfaces of Steel Water Storage Tanks.

[ANSI/AWWA D106](#)—Sacrificial Anode Cathodic Protection Systems for the Interior Submerged Surfaces of Steel Water Storage Tanks.

[ANSI/AWWA D108](#)—Aluminum Dome Roofs for Water Storage Facilities.

API[‡] SPEC 5L, 45th Edition, 2012—Specification for Line Pipe.

API SPEC 12B, 16th Edition, 2014—Specification for Bolted Tanks for Storage of Production Liquids.

ASCE[§] 7-10—Minimum Design Loads for Buildings and Other Structures.

ASME[¶] B16.5-13—Pipe Flanges and Flanged Fittings: NPS ½ through 24 Metric/Inch Standard.

[ASTM^{**} A6/A6M](#)—Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling.

[ASTM A27/A27M](#)—Standard Specification for Steel Castings, Carbon, for General Application.

[ASTM A36/A36M](#)—Standard Specification for Carbon Structural Steel.

[ASTM A48/A48M](#)—Standard Specification for Gray Iron Castings.

[ASTM A53/A53M](#)—Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless.

[ASTM A105/A105M](#)—Standard Specification for Carbon Steel Forgings for Piping Applications.

[ASTM A106/A106M](#)—Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service.

[ASTM A123/A123M-15](#)—Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products.

* American National Standards Institute, 25 West 43rd Street, Fourth Floor, New York, NY 10036.

† American Institute of Steel Construction, 130 East Randolph, Suite 2000, Chicago, IL 60601.

‡ American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005.

§ American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, VA 20191.

¶ American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016.

** ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

[ASTM A139/A139M](#)—Standard Specification for Electric-Fusion (Arc)-Welded Steel Pipe (NPS 4 and Over).

[ASTM A153/A153M](#)—Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware.

[ASTM A181/A181M](#)—Standard Specification for Carbon Steel Forgings, for General-Purpose Piping.

[ASTM A194/A194M](#)—Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both.

[ASTM A216/A216M](#)—Standard Specification for Steel Castings, Carbon, Suitable for Fusion Welding, for High-Temperature Service.

[ASTM A240/A240M](#)—Standard Specification for Chromium and Chromium–Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications.

[ASTM A283/A283M](#)—Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates.

[ASTM A307](#)—Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60,000 PSI Tensile Strength.

[ASTM A500/A500M](#)—Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes.

[ASTM A501/A501M](#)—Standard Specification for Hot-Formed Welded and Seamless Carbon Steel Structural Tubing.

[ASTM A563-15](#)—Standard Specification for Carbon and Alloy Steel Nuts.

[ASTM A568/A568M](#)—Standard Specification for Steel, Sheet, Carbon, Structural, and High-Strength, Low-Alloy, Hot-Rolled and Cold-Rolled, General Requirements for.

[ASTM A572/A572M](#)—Standard Specification for High-Strength Low-Alloy Columbium–Vanadium Structural Steel.

[ASTM A656/A656M](#)—Standard Specification for Hot-Rolled Structural Steel, High-Strength Low-Alloy Plate with Improved Formability.

[ASTM A668/A668M](#)—Standard Specification for Steel Forgings, Carbon and Alloy, for General Industrial Use.

[ASTM A992/A992M](#)—Standard Specification for Structural Steel Shapes.

[ASTM A1011/A1011M](#)—Standard Specification for Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy with Improved Formability, and Ultra-High Strength.

[ASTM B695](#)—Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel.

[ASTM D395](#)—Standard Test Methods for Rubber Property—Compression Set.

[ASTM D412](#)—Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension.

[ASTM D471](#)—Standard Test Method for Rubber Property—Effect of Liquids.

[ASTM D573](#)—Standard Test Method for Rubber—Deterioration in an Air Oven.

[ASTM D1171](#)—Standard Test Method for Rubber Deterioration—Surface Ozone Cracking Outdoors or Chamber (Triangular Specimens).

[ASTM D1229](#)—Standard Test Method for Rubber Property—Compression Set at Low Temperatures.

[ASTM D1751](#)—Standard Specification for Preformed Expansion Joint Filler for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types).

[ASTM D2240](#)—Standard Test Method for Rubber Property—Durometer Hardness.

[ASTM D4752](#)—Standard Test Method for Measuring MEK Resistance of Ethyl Silicate (Inorganic) Zinc-Rich Primers by Solvent Rub.

[ASTM D5162](#)—Standard Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates.

[ASTM D5402](#)—Standard Practice for Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs.

[ASTM F1554](#)—Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength.

[ASTM F3125](#)—Standard Specification for High Strength Structural Bolts, Steel and Alloy Steel, Heat Treated, 120 ksi (830 MPa) and 150 ksi (1040 MPa) Minimum Tensile Strength, Inch and Metric Dimensions.

AWS* A5.1/A5.1M—Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding.

AWS D1.1/D1.1M—*Structural Welding Code—Steel*.

AWS D1.2/D1.2M—*Structural Welding Code—Aluminum*.

* American Welding Society, 550 NW LeJeune Road, Miami, FL 33126.

AWS D1.6/D1.6M—*Structural Welding Code—Stainless Steel*.

ICC*—2015 International Building Code.

NACE[†] SP0188—Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates.

NFPA[‡] 22 2013—Standard for Water Tanks for Private Fire Protection.

NSF[§]/ANSI 61—Drinking Water System Components—Health Effects.

OSHA[¶]—Occupational Safety and Health Standards, 29 CFR, Part 1910.

SAE^{**} J429—Mechanical and Material Requirements for Externally Threaded Fasteners.

SAE J995—Mechanical and Material Requirements for Steel Nuts.

SSPC^{††}-SP 8—Pickling.

SSPC-SP 10/NACE No. 2—Near-White Metal Blast Cleaning.

SECTION 3: DEFINITIONS

The following definitions shall apply in this standard:

1. *BCL*: See *Water levels*.
2. *Capacity*: The net volume, in gallons (liters), that may be removed from a tank filled to the maximum operating level (MOL) and emptied to the bottom capacity level (BCL), unless otherwise specified. The BCL and MOL are defined below under *Water levels*.
3. *Constructor*: The party that furnishes the work and materials for placement and installation.
4. *Head range*: The vertical distance between the MOL and BCL.
5. *Manufacturer*: The party that manufactures, fabricates, or produces materials or products.
6. *MOL*: See *Water levels*.
7. *MWL*: See *Water levels*.

* International Code Council, 500 New Jersey Avenue, NW, 6th Floor, Washington, DC 20001.

† NACE International, 1440 South Creek Drive, Houston, TX 77084.

‡ National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169.

§ NSF International, 789 North Dixboro Road, Ann Arbor, MI 48105.

¶ Occupational Safety and Health Administration, 200 Constitution Ave. NW, Washington, DC 20210.

** SAE International, 400 Commonwealth Drive, Warrendale, PA 15096.

†† Society for Protective Coatings, 800 Trumbull Dr., Pittsburgh, PA 15205.

8. *Purchaser*: The person, company, or organization that purchases any materials or work to be performed.

9. *Reservoir*: A ground-supported, flat-bottom cylindrical tank having a shell height equal to or smaller than its diameter.

10. *Standpipe*: A ground-supported, flat-bottom cylindrical tank having a shell height greater than its diameter.

11. *Tank*: A standpipe or a reservoir used for water storage.

12. *Water levels*: The following water levels are used in this standard:

12.1 Bottom capacity level (BCL): The water level above which the specified capacity is provided. The BCL shall be the water level in the tank shell when the tank is emptied through the specified discharge fittings, unless otherwise specified.

12.2 Maximum operating level (MOL): The specified maximum water level under normal operating conditions and the upper limit for calculating the specified operating capacity (head range) of the tank. The MOL shall be taken as the maximum water level (MWL), unless otherwise specified.

12.3 Maximum water level (MWL): The water level defined by the flow line of the overflow pipe or lip of the weir unless otherwise specified.

SECTION 4: MATERIALS

Sec. 4.1 General

All materials to be incorporated in any structure to meet the provisions of this standard shall be new, previously unused, and in first-class condition and shall comply with all of the requirements of this standard. Steel materials of unidentified analysis may be used if they are tested and found to comply with all of the physical, dimensional, and chemical requirements of a material that is acceptable for use under this standard. A report showing the test results shall be provided when mill test reports are specified.

Materials shall comply with the Safe Drinking Water Act and federal regulations for potable water and wastewater systems as applicable.

Sec. 4.2 Bolts, Nuts, and Anchor Bolts

4.2.1 *Carbon steel bolts and nuts*. Carbon steel bolts shall conform to the requirements of [ASTM A307](#), [ASTM F3125](#), SAE J429 grade 2, SAE J429

grade 5, SAE J429 grade 8, or API SPEC 12B. Carbon steel nuts shall be suitable for use with selected bolt and shall conform to API SPEC 12B, SAE J995 grade 2, SAE J995 grade 5, SAE J995 grade 8, [ASTM A194/A194M](#), or [ASTM A563](#).

4.2.2 *Galvanizing.* Hot-dip galvanizing of fasteners shall conform to [ASTM A153/A153M](#), class C. Mechanical galvanizing of fasteners shall conform to [ASTM B695](#), class 50. Mechanical galvanizing is permitted for [ASTM F3125](#), SAE J429 grade 8, and SAE J995 grade 8 fasteners, provided that proper procedures are followed to prevent or eliminate hydrogen embrittlement. [ASTM F3125](#), SAE J429 grade 8, and SAE J995 grade 8 high-strength fasteners shall not be hot-dip galvanized.

4.2.3 *Carbon steel anchor bolts.* Carbon steel anchor bolts shall conform to the requirements of [ASTM A36/A36M](#), or [ASTM F1554](#) grade 36 or 55.

Sec. 4.3 Foundation-Reinforcing Steel

Reinforcing steel in foundations shall comply with the requirements of ACI 318.

Sec. 4.4 Plates and Sheets

Carbon steel plate and sheet materials shall be open-hearth, electric-furnace, or basic-oxygen-process steel conforming to any of the following ASTM specifications: [A36/A36M](#); [A283/A283M](#), grade C or D; [A1011/A1011M](#), grade 30, 33, 36, 40, 45, 50, 55, 60, 65, or 70; [A572/A572M](#), grade 42, 50, 55, 60, or 65; [A656/A656M](#), grade 50, 60, or 70.

Plates and sheets may be provided on the weight basis, with permissible underrun according to the tolerance table for plates ordered to weight published in [ASTM A6/A6M](#). For sheets ordered to weight published in [ASTM A568/A568M](#), no underrun is permitted.

Materials conforming to [ASTM A1011/A1011M](#) with a designation CS, DS, or UHSS shall not be used. No grade, type, or class of [ASTM A1011/A1011M](#) material shall be used where the ratio of published minimum yield strength to published minimum tensile strength exceeds 0.85. For [ASTM A656/A656M](#) grade 60 and grade 70 material, the ratio of the actual yield strength to the actual tensile strength shall not exceed 0.85 as confirmed by mill test reports.

Steel grades designating a published minimum yield strength of 50,000 psi or greater shall not be used for shell sheets or plates on 15-ft or smaller-diameter tanks that have form-flanged connections.

Sec. 4.5 Structural Shapes

4.5.1 *Carbon steel.* Hot-rolled carbon steel structural shapes for use under the provisions of this standard shall conform to [ASTM A6/A6M](#). Material shall conform to [ASTM A36/A36M](#), [A572/A572M](#) grade 50, [A992/A992M](#), or AISI 1010. Additionally, [ASTM A992/A992M](#) is acceptable for carbon steel wide flange and other structural shapes.

4.5.2 *Aluminum.* Aluminum shapes of a suitable alloy for load and service requirements may be used for portions of the tank not in contact with water. The design of all aluminum members shall be in accordance with AA ADM (Allowable Stress Design) and to the loads specified in Section 5 of this standard. Aluminum in contact with dissimilar metals shall be properly isolated to prevent galvanic corrosion.

4.5.3 *Tubular.* Tubular steel structural shapes may be used for columns and other structural components. Carbon steel tubular structural members shall comply with one of the following specifications:

1. Cold-formed square and rectangular carbon steel structural tubing shall comply with [ASTM A500/A500M](#).
2. Hot-formed square and rectangular carbon steel tubing shall comply with [ASTM A501/A501M](#).

4.5.3.1 Structural tubing with a circular cross section may be manufactured from plates of any of the specifications permitted in Sec. 4.4, provided the welding and other manufacturing processes are in compliance with all sections of this standard.

4.5.3.2 Carbon steel pipe may be used as tubular structural members, provided it complies with [ASTM A139/A139M](#), grade B; [ASTM A53/A53M](#), type E or S, grade B; [ASTM A106/A106M](#), grade B; or API SPEC 5L, grade B, and provided the minimum thickness of any such material shall comply with the design requirements regardless of the thickness tolerances in any of these specifications. Some pipe specifications allow thickness underruns as high as 12.5 percent. The appropriate specification shall be consulted for allowable underrun and for adjustments made in thickness to ensure that minimum design thicknesses are met.

Sec. 4.6 Castings

Iron castings shall conform to [ASTM A48/A48M](#), class 30. Steel castings shall conform to [ASTM A216/A216M](#), grade WCB, or [ASTM A27/A27M](#), grade 60-30 (full annealed). Aluminum castings shall conform to AA SPC-18.

Sec. 4.7 Forgings

4.7.1 *Forgings from plate and sheet materials.* Forgings from plate and sheet materials shall conform to the plate and sheet materials permitted under Sec. 4.4.

4.7.2 *Forgings from other than plate or sheet materials.* Forgings from other than plate or sheet materials shall conform to [ASTM A668/A668M](#), class E.

4.7.3 *Forged and rolled pipe flanges.* Carbon steel forged and rolled pipe flanges shall conform to [ASTM A181/A181M](#), class 60; [ASTM A105/A105M](#); or ASME B16.5.

Sec. 4.8 Electrodes

Manual, shielded-metal, arc-welding electrodes shall conform to the requirements of AWS A5.1/A5.1M. Welding electrodes shall be of any E60XX or E70XX classification suitable for the electric current characteristics, the position of welding, and other conditions of intended use. Welding electrodes for other welding processes shall conform to applicable AWS specifications for filler metal.

Sec. 4.9 Pipe and Fittings for Fluid Conductors

Inlet, outlet, overflow, and other pipes, and all fittings for fluid use shall be specified. Carbon steel pipe shall conform to [ASTM A53/A53M](#) type E or S, grade B; [ASTM A106/A106M](#); or API SPEC 5L. When specified, pipe for fluid conductors smaller than 6-in. nominal diameter may be constructed of stainless steel and shall conform to [ASTM A240/A240M](#) 300 series. Other types of pipe may be specified, provided they conform to recognized national or industry standards. Unless otherwise specified, joints may be either screwed or flanged.

Sec. 4.10 Gaskets and Sealants

The manufacturer shall use gaskets or sealants or a combination of both in accordance with the following requirements. Gasket and sealant material in contact with stored potable water shall be tested and certified for potable water contact in accordance with the requirements of NSF/ANSI 61, when specified.

4.10.1 *Gaskets.* Gasket material shall be of adequate tensile strength and resilience to obtain a leakproof seal at all seams and joints. Gasket material shall be resistant to weather and ozone exposure as designated by [ASTM D1171](#). Physical requirements are described in Table 1.

4.10.2 *Sealants.* Sealants shall comply with the following:

1. Resistance to temperature. The sealant shall remain flexible when in continuous operation over a temperature range of -40°F to $+170^{\circ}\text{F}$ (-40°C to $+77^{\circ}\text{C}$).

Table 1 Physical requirements for gasket material*

Description	Strip and Extruded Gasket Material
Tensile strength, initial, psi minimum, ASTM D412	1,200 psi (8.3 MPa)
Tensile strength after oven aging as percent of initial, minimum, ASTM D573	70%
Tensile strength after immersion in distilled water as percent of initial, minimum, ASTM D471	60%
Ultimate elongation, initial, percent of minimum, ASTM D412	175%
Ultimate elongation after oven aging as percent of initial, minimum, ASTM D573	70%
Hardness, Shore A, ASTM D2240	75±5
Hardness change Shore A, after oven aging, ASTM D573	7
Compression set as maximum percent of original, after oven aging, ASTM D395	40%
Low-temperature compression set as maximum percent of original, ASTM D1229	60%
Tear strength, pounds per inch	160 lb/in. (28 kN/m)

* Dimensions and tolerances shall be as specified by the manufacturer for the specific tank requirements.

2. Weatherability. The sealant shall be resistant to hardening and cracking. The sealant shall be essentially solid and contain no plasticizers or extenders that could cause shrinkage due to weathering. The sealant shall be resistant to ozone and ultraviolet light.

3. Chemical resistance. The sealant shall be suitable for contact with potable water without chemical extraction to water and shall not swell or degrade under normal water-storage conditions.

4. Material specification. The sealant shall be suitable for use on potable water-contact surfaces and shall meet NSF/ANSI 61 requirements where in contact with stored potable water, when specified.

5. Primers for sealant. Some sealant materials require the use of a primer on metal or glass for maximum adhesion. Most of these primers contain a volatile solvent. After evaporation of the solvent, the primer shall meet NSF/ANSI 61 requirements where in contact with stored potable water, when specified.

SECTION 5: GENERAL DESIGN

Sec. 5.1 Types of Joints

5.1.1 *Bolted joints.* All vertical, horizontal, shell-to-roof, and shell-to-bottom plates or sheets shall be field-bolted. Bolt holes shall be shop-punched or drilled for field assembly. The bolted joints between roof, shell, and bottom sheets and plates that are required to contain water or to be weathertight shall be sealed with suitable gasket material, sealant, or gasket material and sealant as required to make a watertight joint (see Sec. 4.10). The tank manufacturer's erection procedures shall be followed.

5.1.2 *Welded joints.* Welding may be used to join shop-fabricated subassemblies that are subsequently bolted into place in the field. Vertical joints in the tank shell shall not be welded.

Sec. 5.2 Design Loads

The following loads shall be considered in the design of tank structures and foundations.

5.2.1 *Risk category.* Risk category is a categorization of the structure for the determination of snow, wind, and seismic loads based on the risk associated with unacceptable performance. The structure shall be classified one of the following risk categories and the risk category shall be specified. Risk Category IV shall be used if none is specified.

5.2.1.1 Risk Category II. All structures other than those included in Risk Categories III and IV.

5.2.1.2 Risk Category III. Structures where failure could pose a substantial risk to human life. Structures not included in Risk Category IV that have the potential to cause substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure.

5.2.1.3 Risk Category IV. Structures designated as essential facilities. Structures required to maintain the functionality of other Risk Category IV structures.

5.2.2 *Dead load.* Dead load shall be the estimated weight of all permanent construction and fittings. The unit weights used shall be 490 lb/ft³ (7,850 kg/m³) for steel and 144 lb/ft³ (2,310 kg/m³) for concrete.

5.2.3 *Water load.* Water load shall be the weight of all of the liquid when the tank is filled to maximum water level (MWL). Unit weight used for water shall be 62.4 lb/ft³ (1,000 kg/m³), except as noted in Section 14 for seismic design.

5.2.4 *Snow load.* Snow load shall be in accordance with ASCE 7, except as modified herein.

5.2.4.1 *Ground snow load.* Ground snow load p_g shall be in accordance with ASCE 7, Figure 7-1 and Table 7-1. Ground snow load shall be specified for areas designated C_s and for sites at elevations above the limits indicated in ASCE 7, Figure 7-1. Ground snow load determination for such sites shall be based on an extreme value statistical analysis of data available in the vicinity of the site using a value with a 2 percent annual probability of being exceeded (50-year mean recurrence interval). Snow loads are zero for Hawaii, except in mountainous regions. Snow load shall be specified for mountainous regions of Hawaii.

5.2.4.2 *Flat roof snow load.* Flat roof snow load p_f shall be determined using the equation

$$p_f = 0.7C_eC_tI_s p_g \quad (\text{Eq 5-1})^*$$

where:

p_f = flat roof snow load, in pounds per square foot

C_e = exposure factor

= 0.9 for wind Exposure C

= 0.8 for wind Exposure D

C_t = thermal factor

= 1.2 for unheated and open structures

I_s = importance factor for snow load

= 1.0 for Risk Category II structures

= 1.1 for Risk Category III structures

= 1.2 for Risk Category IV structures

p_g = ground snow load, in pounds per square foot

* For equivalent metric equation, see Sec. 5.11.

5.2.4.3 *Sloped roof snow load.* Sloped roof snow load p_s shall be zero for portions of the roof with a roof angle θ_r equal to or greater than 70 degrees. For portions of the roof with a roof angle less than 70 degrees, the sloped roof snow load shall be determined using the following equations

$$C_s = \frac{70 - \theta_r}{55}, 0 \leq C_s \leq 1 \quad (\text{Eq 5-2})$$

$$p_s = C_s p_f \quad (\text{Eq 5-3})$$

where:

p_s = sloped roof snow load, in pounds per square foot

C_s = slope factor based on cold roofs with unobstructed slippery surfaces that will allow snow to slide

θ_r = roof angle measured as the angle between the tangent of the roof and the horizontal at the point of consideration, in degrees

5.2.4.4 *Minimum snow load for sloped roofs.* The minimum snow load shall only apply to monoslope and conical roofs with a roof angle θ_r less than 15 degrees and portions of double-curved roofs with a roof angle less than 15 degrees. Where the ground snow load p_g is equal to or less than 20 lb/ft² (0.96 kN/m²), the minimum snow load shall be $I_s p_g$. Where the ground snow load is greater than 20 lb/ft² (0.96 kN/m²), the minimum snow load shall be $20 I_s$.

5.2.5 *Roof live load.* The minimum roof live load shall be 15 lb/ft² (720 N/m²).

5.2.6 *Wind load.* Refer to Section 15 of this standard for wind load design. When so specified, wind loads may be omitted for structures completely enclosed within buildings.

5.2.7 *Seismic load.* Structures shall be designed for seismic loads as defined in Section 14 of this standard. Exception: Structures located where mapped spectral response acceleration at 1-s period S_1 is less than or equal to $0.04g$ and the mapped short period spectral response acceleration S_s is less than or equal to $0.15g$ do not require design for seismic loads. See Section 14 for definitions.

5.2.8 *Platform and ladder load.* A vertical load (and only one such load in each case) shall be applied as follows: 1,000 lb (4.4 kN) to each platform; 500 lb (2.2 kN) to any 10 ft² (0.93 m²) area on the tank roof; 500 lb (2.2 kN) on each vertical section of the ladder. All structural parts and connections shall be

properly proportioned to withstand such loads. The aforementioned load need not be combined with the snow load specified in Sec. 5.2.4, but it shall be combined with the dead load. The platform and roof plating may deflect between structural supports in order to support the loading.

Sec. 5.3 Design Criteria

With the exception of other criteria specifically provided for elsewhere in this standard, the structural design of all standpipes and reservoirs shall be in compliance with the following: AISI S100 (ASD provisions) and ANSI/AISC 360 (ASD provisions).

5.3.1 *Allowable stresses increased by one-third.* Except as specified otherwise, for members subjected to loads produced by wind or seismic forces, acting alone or in combination with the design dead and water loads, the allowable stresses may be increased by one-third, provided the required section computed on this basis is not less than that required for the design dead and water load computed without the one-third allowable stress increase.

5.3.2 *Effect of glass-fused coatings firing process on steel strength.* The design of structural components with glass-fused-to-steel coatings shall take into account the reduction in strength properties of the steel due to the firing process of the glass coatings, and details of such effects shall be submitted when specified. The effect of the glass-fused-to-steel coating process shall be assessed and monitored over a period of time using a regular and documented testing program from which steel strength properties can be predicted with a 95 percent confidence level. The 95 percent confidence level refers to the 95 percent confidence interval, which is the statistically calculated range within which there is a 95 percent probability that the true value of a parameter will fall.

5.3.2.1 Reduced strength properties for components with glass-fused-to-steel coatings. The modified steel properties F'_y and F'_u shall be the minimum values established for the particular specification and grade of steel through the regular and documented testing program as identified in Sec. 5.3.2 or, alternatively, where regular and documented testing is not carried out, the values of F'_y and F'_u shall be taken as 70 percent of the minimum published yield strength, F_y , and 70 percent of the minimum published tensile strength, F_u , respectively, of the selected material.

5.3.2.2 Application of reduced strength properties. For components with glass-fused-to-steel coatings, design of the components shall utilize the lesser of the applicable modified steel properties F'_y and F'_u and the minimum published

yield strength and minimum published tensile strength, F_y and F_u , respectively. Reduced strength properties only apply to structural elements of the tank that have undergone the glass-fused-to-steel coating process.

Sec. 5.4 Tank Shell

In the design of the tank shell, the hydrostatic water pressure at the lower edge of each ring of sheets or plates in the tank shell shall be assumed to act undiminished on the entire area of the ring.

5.4.1 *Shell thickness.* When the net tensile stress governs, the thickness of cylindrical shell plates stressed by pressure of the tank contents shall be calculated by the formula

$$t = \frac{2.6 H D S G}{f_t (S - d)} \quad (\text{Eq 5-4})^*$$

where:

- t = shell plate thickness in inches
- H = height of liquid from the top capacity line just to overflow to the bottom of the shell course being designed in feet
- D = tank diameter in feet
- S = bolt spacing in line perpendicular to line of stress in inches
- G = specific gravity of liquid (1.0 for water)
- f_t = allowable tensile stress in pounds per square inch (Sec. 5.5.3)
- d = bolt-hole diameter in inches

5.4.2 *Compressive stress.* The allowable compressive stress in each ring of sheets or plates under wind or earthquake loading combined with dead load shall be determined by the formula

$$f_s = 15,000 \left(\frac{2}{3} \right) \left(100 \frac{t}{R} \right) \times \left[2 - \left(\frac{2}{3} \right) \left(100 \frac{t}{R} \right) \right] \leq 15,000 \quad (\text{Eq 5-5})^*$$

where:

- f_s = allowable compressive stress in pounds per square inch
- t = shell thickness in inches
- R = shell radius in inches

* For equivalent metric equation, see Sec. 5.11.

Sec. 5.5 Bolted Joints

In the design of bolted joints, the effect of the gasket and sealant shall be neglected, provided the compressed thickness of the gasket or sealant does not exceed $\frac{1}{16}$ in. (1.6 mm).

5.5.1 *Minimum spacing.* The center-to-center distance between bolts shall not be less than $2d$, where d is the diameter of the bolt, in inches (millimeters). The distance from the center of any bolt to an edge or seam shall not be less than 0.75 in. In no case shall the center-to-center or edge-to-center distance be less than

$$\frac{P}{0.6 F_y t} \text{ inches (m)} \quad (\text{Eq 5-6})$$

where:

P = force transmitted by the bolt, lb (kN)

F_y = published minimum yield strength of the sheet or plate, psi (MPa)

t = thickness of the thinner sheet or plate in the joint connection, in. (mm)

5.5.2 *Multiple bolt lines.* When multiple bolt lines are used, the effective net section area shall not be taken as greater than 85 percent of the gross area.

5.5.3 *Tension on the net section.* The tensile stress on the net section of a bolted connection shall not exceed the lesser of the values determined by the following formulas:

$$f_t = 0.6 F_y (1.0 - 0.9r + 3rd / s) \leq 0.6 F_y \quad (\text{Eq 5-7})$$

or

$$f_t = 0.40 F_u \quad (\text{Eq 5-8})$$

where:

f_t = allowable tensile stress, psi (MPa)

F_y = published minimum yield strength of the sheet or plate, psi (MPa)

r = force transmitted by the bolt or bolts at the section considered, divided by the tensile force in the member at that section. If r is less than 0.2, it may be taken to equal zero.

d = diameter of bolt in inches (mm)

s = spacing of bolts perpendicular to line of stress in inches (mm)

F_u = published minimum ultimate strength of the sheet or plate, psi (MPa)

5.5.4 *Hole bearing stress.* The hole bearing stress on the area $d \times t$ shall not exceed $1.35F_y$. The symbols d and F_y are as defined in Sec. 5.5.3; t is the thickness of the sheet or plate under consideration.

5.5.5 *Bolt shear.* Shear on bolts in live and dead loads shall not exceed the value as determined from the formula

$$f_v = F_u(0.6)(0.9) / 2.2 \leq 0.25F_u \quad (\text{Eq 5-9})$$

where:

f_v = allowable shear stress to the affected area, whether tensile stress area or gross area, psi (MPa)

F_u = published minimum tensile strength of bolt, psi (MPa)

5.5.6 *Bolt tension.* The tensile stress on the tensile stress area of bolts, other than anchor bolts, shall not exceed the lesser of the following:

$$f_t = 0.6F_y \quad (\text{Eq 5-10})$$

or

$$f_t = F_u / 2.2 \quad (\text{Eq 5-11})$$

where:

f_t = allowable tensile stress of the bolt, psi (MPa)

F_y = published minimum yield strength of the bolt, psi (MPa)

F_u = published minimum tensile strength of the bolt, psi (MPa)

5.5.7 *Tensile Straps.* Horizontal joints on tanks with formed flange construction could require tensile straps to transfer vertical tension loads. The design procedure in Sec. 15.5 shall be utilized to determine if tensile straps are required for these joints to resist forces generated under load combinations including either wind or seismic loads, or both.

Sec. 5.6 Weld Design

5.6.1 *Structural joints.* Welded structural joints shall be proportioned so that the stresses on a section through the throat of the weld, exclusive of weld reinforcement, do not exceed the following percentages of the allowable tensile stress of the structural material joined.

5.6.1.1 Groove welds. Tension, 85 percent; compression, 100 percent; shear, 75 percent.

5.6.1.2 Fillet welds. Transverse shear, 65 percent; longitudinal shear, 50 percent; varying shear for circular weldments, 60 percent.

NOTE: Stress in a fillet weld shall be considered as shear on the throat, for any direction of the applied load. The throat of a fillet weld shall be assumed as 0.707 times the length of the shorter leg of the fillet weld having a flat or slightly convex profile.

Sec. 5.7 Roof Supports

Roof supports or stiffeners, if used, shall be designed in accordance with the current specifications of ANSI/AISC 360-10, with the following stipulations or exceptions:

1. The roof sheet shall be assumed to provide the necessary lateral support of roof rafters from the friction between the roof plates and rafter compression flange, with the following exceptions:

- a. Trusses and open-web joists used as rafters.
- b. Rafters having a nominal depth greater than 15 in. (380 mm).
- c. Rafters having a slope greater than 2 in 12.

2. The roof rafter and purlin depth may be less than $f_b/600,000$ ($f_b/4,140$) times the span length, provided the roof slope is $\frac{3}{4}$ in 12 or greater. The symbol f_b is the bending unit stress in pounds per square inch (MPa), equal to the bending moment divided by the section modulus of the member.

3. The maximum slenderness ratio KL/r for the column supporting rafters shall be 175. The notation L is the laterally unsupported length of the column, in inches (mm), and r is the least radius of gyration, in inches (mm).

4. Roof trusses shall be placed above the top capacity level in climates where ice may form. No part shall project below the top capacity level.

5. Roof rafters shall be placed above the top capacity level. No part shall project below the top capacity level.

6. The maximum spacing between roof supports shall be determined by the formula

$$L = (300F_y t^2 / W)^{1/2} \leq 60 \quad (\text{Eq 5-12})^*$$

where:

L = maximum centerline spacing, in.

F_y = published minimum yield strength of the roof sheet, psi

* For equivalent metric equation, see Sec. 5.11.

t = roof sheet thickness, in.

W = roof dead load plus live load acting on roof surface, lb/ft²

7. Self-supporting dome roof constructed of aluminum shall comply with the requirements of [ANSI/AWWA D108](#).

Sec. 5.8 Steel Thickness

Steel thicknesses shall comply with the following:

1. Roof sheets having a slope of 1 in 2.75 or greater shall have a minimum thickness of 0.070 in. (1.8 mm) where the tank diameter does not exceed 35 ft (10.7 m), and a minimum thickness of 0.094 in. (2.4 mm) where the tank diameter is greater than 35 ft (10.7 m).

2. Roof sheets having a slope less than 1 in 2.75, regardless of tank diameter, shall have a minimum thickness of 0.094 in. (2.4 mm).

3. The minimum thickness of the bottom sheets shall be 0.094 in. (2.4 mm).

4. The maximum thickness of formed flange shell plates shall be 0.3125 in. (7.9 mm); the minimum thickness shall be 0.094 in. (2.4 mm).

5. The maximum thickness of flat panel shell plates shall be 0.50 in. (12.7 mm); the minimum thickness shall be 0.094 in. (2.4 mm).

6. Tank components fabricated from [ASTM A1011](#) material shall be less than 0.230 in. thickness.

7. Plates and sheets shall not be stacked or laminated together to form multiple layers to achieve a given design thickness.

Sec. 5.9 Foundation Anchor Bolts

5.9.1 General.

5.9.1.1 Required anchorage. Anchor bolts shall be provided when the wind or seismic loads exceed the limits for self-anchored tanks. (Refer to Section 14 for seismic loads and Section 15 for wind loads.)

5.9.1.2 Spacing.

5.9.1.2.1 Maximum anchor bolt spacing shall be 10 ft (3 m). Anchored tanks shall have a minimum quantity of five anchor bolts.

5.9.1.2.2 The pullout value of the anchor bolts shall be adjusted for anchor spacing and edge distance.

5.9.1.2.3 Anchor bolts shall be evenly spaced except where interference with tank openings or tank accessories does not permit. At locations where tank openings or tank accessories interfere with one or two anchors, no more than two anchors adjacent to the interference may be moved a maximum of 50 percent of