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ANSI/AWWA D107-16
(Revision of ANSI/AWWA D107-10)

AWWA Standard

Composite Elevated Tanks for Water Storage

Effective date: Jan. 1, 2017.

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Documents

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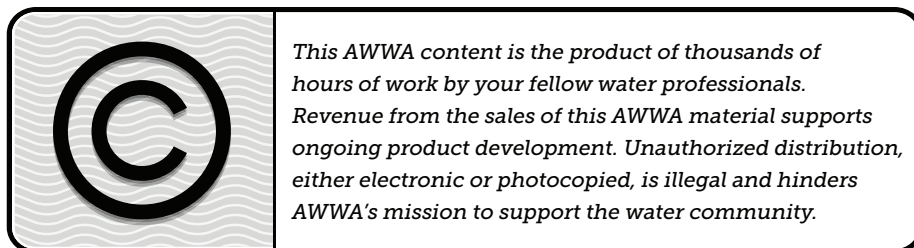
AWWA Standard

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Foreword

This foreword is for information only and is not a part of ANSI/AWWA D107.*

I. Introduction.

I.A. *Background.* A composite elevated water tank is composed of a welded steel tank for watertight containment, a single pedestal concrete support structure, a foundation, and accessories.

The AWWA Standards Committee on Composite Elevated Tanks was formed to prepare a standard for the design, construction, inspection, and testing of composite elevated tanks. ACI 371R, Guide for the Analysis, Design, and Construction of Elevated Concrete and Composite Steel-Concrete Water Storage Tanks,[†] and ANSI/AWWA D100, Welded Carbon Steel Tanks for Water Storage, are used as source documents.

Work covered by this standard is usually procured under a design-build contract. It is intended that ANSI/AWWA D107 be used as a reference standard in project documents prepared by purchasers and engineers specifying composite elevated water tanks.

I.B. *History.* The AWWA Standards Committee on Composite Elevated Tanks was formed in 1992 to prepare a standard for these structures. The first edition of ANSI/AWWA D107 was approved by the AWWA Board of Directors on Jan. 17, 2010. This edition was approved on Jan. 16, 2016.

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). The American Water Works Association (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

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

† American Concrete Institute (ACI), 38800 Country Club Drive, Farmington Hills, MI 48331.

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

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.
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 jurisdictions. 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 D107 does not address additives requirements. 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. *Applicable Building Codes.* Building codes may not have specific provisions for nonbuilding structures such as composite elevated tanks. The purchaser should make a determination as to the intent of the requirements of the applicable building codes and should specify the extent to which such building codes apply to a project. It is intended that specified building codes govern where they have more stringent requirements than this standard.

II.B. *Personnel Safety Standards.* The personnel safety requirements in this standard are based on OSHA 29 CFR, Part 1910, Occupational Safety and Health Standards, and industry practice. The user in specifying safety-related equipment,

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

† Both publications available from National Academy of Sciences, 500 Fifth Street, NW, Washington, DC 20001.

details, and design criteria should make a determination that the requirements of this standard are in compliance with current OSHA requirements and applicable building code requirements.

II.C. *Special Loading Conditions.* The purchaser should specify design requirements for service not covered by this standard, such as loads associated with surge or process tanks, or local environmental conditions more severe than those required by this standard.

II.D. *Professional Engineer (PE) Certification.* It is recommended that the engineer responsible for design be licensed in the jurisdiction where the composite elevated tank is to be constructed. The design and construction drawings should be sealed.

II.E. *Inspection and Maintenance.* Composite elevated tanks designed and constructed in accordance with the requirements of this standard can be expected to be durable structures. Steel tank construction has a satisfactory history when properly maintained, and concrete that conforms to this standard will meet the requirements for durable concrete as defined in ACI 201.2R, Guide to Durable Concrete.

An inspection of the structure and accessories is recommended approximately one year after completion. Thereafter, periodic inspection and maintenance should be performed.

II.F. *Cold Climates.* The formation of ice in the tank may result in damage to the tank or components such as piping or interior ladders. Design for this condition is beyond the scope of this standard. Reference to ice damage is to improper operation rather than an endorsement of an icing condition. The tank should be heated, insulated, or operated in a manner to prevent this condition. Water replacement, circulation, or wasting of water are operational techniques that may be used.

II.G. *Use of Interior Space.* The interior of the support structure is frequently used for mechanical rooms, storage, and parking. This space may be occupied when constructed in accordance with local building code requirements. Typical uses include fire stations and offices. Intermediate floors may be constructed to provide additional space.

II.H. *Aesthetics.* Aesthetics should be considered when planning a composite elevated tank. Minimum architectural features and finishing of exterior concrete surfaces are provided for in this standard. Painting decorative logos or color schemes on the steel tank may enhance the appearance of the structure.

II.I. *Structural Evaluation.* If construction does not meet tolerance, material, or other structural requirements of this standard, an evaluation may be performed

by the responsible design professional. When structural capacity is not compromised, repair or replacement may not be required unless other factors, such as lack-of-fit, aesthetics, or durability, require remedial action.

III. Use of This Standard.

III.A. General.

III.A.1 Disclaimer. AWWA has no responsibility for the suitability or compatibility of the provisions of this standard to any intended application by any user. Accordingly, it is the responsibility of the user of this AWWA standard to determine that the provisions described in this standard are suitable for use in the particular application being considered.

III.A.2 Minimum Requirements. ANSI/AWWA D107 is based on the collective knowledge of purchasers, consulting engineers, and constructors of composite elevated tanks. A composite elevated tank is considered to be in compliance with ANSI/AWWA D107 when the minimum requirements of this standard have been met. The purchaser may specify more stringent requirements.

III.A.3 Contract Responsibility. Procurement of composite elevated tanks is usually by design-build contracts using proprietary designs and methods of construction. The purchaser should provide project documents that describe the work to be performed.

The purchaser typically is responsible for the following:

1. A site on which the composite elevated tank is to be constructed, which should be of sufficient size to permit construction using customary methods.
2. A suitable right-of-way from the nearest public road to the construction site.
3. A geotechnical investigation, including recommendations for foundation type and associated design criteria.
4. A Federal Aviation Administration (FAA) determination with regard to siting, height, marking, and lighting requirements.
5. Water at sufficient pressure for testing and facilities for disposal after testing.
6. Purchaser-furnished materials that are to be installed by the constructor.

The constructor typically is responsible for the following:

1. Designs, drawings, and specifications for the composite elevated tank.
2. All labor, materials, equipment, supplies, and testing as required by this standard.
3. Warranting the structure against defects in material and workmanship for a period of one year from date of completion.
4. Any additional work specified in the project documents.

III.B. *Specifying ANSI/AWWA D107.*

III.B.1 Reference Standard. ANSI/AWWA D107 is a reference standard that a purchaser may cite in project documents, together with supplementary requirements for a specific project. A statement such as the following may be used to incorporate ANSI/AWWA D107 into the project documents:

“Design and construction of the composite elevated tank shall comply with the requirements of ANSI/AWWA D107, Composite Elevated Tanks for Water Storage, published by the American Water Works Association, Denver, Colorado, except as modified by the requirements of these contract documents.”

III.B.2 Information Required From Purchaser. Incorporating this standard by reference in a project specification requires that the purchaser provide the information listed in Sec. 1.3. ANSI/AWWA D107 has options that the purchaser may specify, and Section B.2 of appendix B, Table B.1, contains a comprehensive list of these options and corresponding defaults.

III.C. *Modification of Standard.* Any modification of the provisions, definitions, or terminology in this standard must be provided in the project specifications.

IV. Major Revisions. The major revisions in this edition of the standard include the following:

1. The notation and definition for maximum considered earthquake MCE_R have been revised to conform to the latest edition of ASCE* 7.
2. Seismic maps are now cited by reference to ASCE 7-10 rather than being incorporated into the standard.
3. Former Table 3, Site Classifications, has been moved to appendix A and has been renumbered as Table A.2.
4. Standard Sec. 4.2.7.8, Seismic Design Category, and appendix Sec. A.4.2.7.8, Seismic Load, have been added.
5. ASCE 7-10 wind provisions have been incorporated into the standard.
6. The gust effect factor G_f has been revised.
7. The wind map (Figure 2 of the 2010 edition) has been deleted and is now incorporated by reference to ASCE 7-10.
8. Former Tables 2a and 2b on design wind pressure have been revised and moved to appendix A as Tables A.1a and A.1b.
9. Former Table 14, Minimum Safety Factors (now Table 12), has been revised; ASTM D4945 has been added to the dynamic testing provisions.

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

10. Standard Sec. 6.3.3.8.1 and appendix Sec. A.6.3.3.8.1 have been updated to reflect current practice, similar to the provisions described in ACI 371R-08.

11. Standard Sec. 7.3.3.2 and appendix Sec. A.7.3.3 have been updated, whereby allowable compression stress values are now referenced to IBC 2012 rather than being provided in the standard.

12. Appendix Section A.2 has been added to identify specific revision years for ASCE 7 and ACI 318.

13. Determination of meridional compression strength F_L by method 2 (ANSI/AWWA D107-10, Sec. 5.3.5.3) has been eliminated. Method 3 in ANSI/AWWA D107-10 has been renamed as method 2 in this edition. Section numbers have been revised accordingly.

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 email at standards@awwa.org.



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(Revision of ANSI/AWWA D107-10)

AWWA Standard

Composite Elevated Tanks for Water Storage

SECTION 1: GENERAL

Sec. 1.1 Scope

This standard describes the design, construction, inspection, and testing of composite elevated tanks that use a welded steel tank for watertight containment and a single pedestal concrete support structure. Requirements for the steel tank, concrete support structure, foundation, and accessories are included. Site selection and procurement; tank sizing; postcommissioning inspection and maintenance; and the design, operation, and control of the water distribution system that connects to the composite elevated tank are beyond the scope of this standard.

Sec. 1.2 Purpose

The purpose of this standard is to provide minimum requirements for the design, construction, inspection, and testing of composite elevated tanks used for water storage in a water distribution system.

Sec. 1.3 Application

This standard may be referenced in project documents that address the design, construction, inspection, and testing of composite elevated tanks used for water storage. The following information is required to use this standard to specify a composite elevated tank:

1. Project location.
2. Tank capacity.
3. Maximum head range.
4. Elevation of the top capacity line (TCL) or bottom capacity line (BCL).
5. Elevation of finished grade.
6. Maximum fill rate.
7. Size of inlet/outlet pipe.

Sec. 1.4 Drawings, Calculations, and Instructions

1.4.1 *Drawings.* Construction drawings for the composite elevated tank shall be provided. Drawings shall show all features of the work, including the size and position of all structural components, the required strength or grade of all materials, and construction tolerances. Drawings of concrete elements shall show all details including construction joints, reinforcement, and splices. Drawings of steel components shall show all details of welded joints and other connections. Standard weld symbols as listed in AWS 2.4 shall be used, unless joint details are shown. The codes and standards to which the design conforms, the tank capacity, and the loads used in the design shall also be shown.

1.4.2 *Design basis documentation.* The codes and standards, methods of analysis, design coefficients, and resultant gravity, snow, wind, and seismic loads shall be documented.

1.4.3 *Operating and maintenance instructions.* Unless otherwise specified, operating and maintenance instructions shall be provided. These instructions shall include as-built drawings of the composite elevated tank, manuals and operating instructions for equipment and accessories, and minimum maintenance and inspection instructions.

Sec. 1.5 Quality Assurance

A quality assurance plan to verify that materials, fabrication, and construction conform to the design requirements shall be prepared. The plan shall include the following:

1. Procedures for exercising control of fabrication and construction.
2. Required inspections and tests.
3. Inspection and test procedures.

Sec. 1.6 Equivalence Between US Customary Units and SI-Metric Units of Nonhomogeneous Equations

Metric equivalents in the Système International d'Unités (SI) of nonhomogeneous equations presented in the standard are as follows:



Equation or Section Number	US Customary Equation	SI Equivalent Metric Equation	Variables	SI Units
Eq. 4-7	$q_s = 0.00256V_b^2$	$q_s = 0.6133V_b^2$	q_s V_b	N/m ² m/sec
Eq. 5-1	$L = \frac{2,575t}{\sqrt{w_r}} \leq 84 \text{ in.}$	$L = \frac{17.8t}{\sqrt{w_r}} \leq 2.13 \text{ m}$	L t w_r	m mm N/m ²
Eq. 6-1	$S = 15 \left(\frac{40,000}{f_s} \right) - 2.5c_c \leq 12 \left(\frac{40,000}{f_s} \right)$	$S = 380 \left(\frac{280}{f_s} \right) - 2.5c_c \leq 300 \left(\frac{280}{f_s} \right)$	S, c_c F_s	mm MPa
Eq. 6-8	$\alpha_c = 6 - \frac{2.5M_u}{V_u D_w}$ $2.0 < \alpha_c \leq 3.0$ $D\sqrt{q_z} > 2.5$	$\alpha_c = 0.37 - \frac{0.10M_u}{V_u D_w}$ $0.17 < \alpha_c \leq 0.25$ $D\sqrt{q_z} > 5.3$	$\sqrt{f'_c}$ M_u, V_u, D_w	MPa consistent units
A.4.2.6.3			q_z D	N/m ² m
Terms including $\sqrt{f'_c} f_y$				
6.3.2.2	$3\sqrt{f'_c} f_y \geq 200/f_y$	$0.25\sqrt{f'_c} f_y \geq 1.4/f_y$	$\sqrt{f'_c}$ $f'_c f_y$	MPa MPa
6.3.2.3	$5\sqrt{f'_c} f_y$	$0.42\sqrt{f'_c} f_y$		
Terms including $\sqrt{f'_c}$ and $\sqrt{f'_c} A_{cv}$				
A.6.3.2.3	$7.5 \sqrt{f'_c}$ in psi	$0.62 \sqrt{f'_c}$ in MPa	$\sqrt{f'_c}$	MPa
A.6.3.3.3	$\sqrt{f'_c} A_{cv}$	$0.083\sqrt{f'_c} A_{cv}$	f'_c A_{cv}	MPa mm ²
6.3.3.8.2	$2\sqrt{f'_c} A_{cv}$	$0.17\sqrt{f'_c} A_{cv}$		
A.6.3.3.8.2				
6.3.3.8	$8\sqrt{f'_c} A_{cv}$	$0.67\sqrt{f'_c} A_{cv}$		

SECTION 2: REFERENCES

The following standards and specifications are incorporated by reference. They form a part of this standard to the extent specified herein. Except as noted, the standard or specification in effect on the effective date of this standard shall be used.

ACI* 117—Specifications for Tolerances for Concrete Construction and Materials and Commentary.

ACI 306.1—Standard Specification for Cold Weather Concreting.

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

AISC†—Code of Standard Practice for Structural Steel Buildings and Bridges.

ANSI/AISC 360—Specification for Structural Steel Buildings.

ANSI/AWWA C200—Steel Water Pipe, 6 in. (150 mm) and Larger.

ANSI/AWWA C205—Cement–Mortar Protective Lining and Coating for Steel Water Pipe—4 in. (100 mm) and Larger—Shop Applied.

ANSI/AWWA C210—Liquid-Epoxy Coating and Linings for Steel Water Pipe and Fittings.

ANSI/AWWA C213—Fusion-Bonded Epoxy Coating and Linings for Steel Water Pipe and Fittings.

ANSI/AWWA C220—Stainless-Steel Pipe, ½ in. (13 mm) and Larger.

ANSI/AWWA C652—Disinfection of Water-Storage Facilities.

ANSI/AWWA D100—Welded Carbon Steel Tanks for Water Storage.

ANSI/AWWA D102—Coating Steel Water-Storage Tanks.

API‡ Standard 650—Welded Tanks for Oil Storage.

ASCE§ 7—Minimum Design Loads for Buildings and Other Structures.

ASCE 20—Standard Guidelines for the Design and Installation of Pile Foundations.

ASME¶—Boiler and Pressure Vessel Code, Section V—Nondestructive Examination, Article 2.

* American Concrete Institute, 38800 Country Club Drive, Farmington Hills, MI 48331.

† American Institute of Steel Construction, 1 East Wacker Drive, Suite 700, 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, 3 Park Avenue, New York, NY 10016.

ASME—Boiler and Pressure Vessel Code, Section VIII, Division 1—Rules for Construction of Pressure Vessels.

ASME—Boiler and Pressure Vessel Code, Section IX—Welding, Brazing, and Fusing Qualifications.

ASNT*—Recommended Practice No. SNT-TC-1A: Personnel Qualification and Certification in Nondestructive Testing.

ASTM[†] A6/A6M—Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling.

ASTM A20/A20M—Standard Specification for General Requirements for Steel Plates for Pressure Vessels.

ASTM A36/A36—Standard Specification for Carbon Structural Steel.

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

ASTM A435/A435M—Standard Specification for Straight-Beam Ultrasonic Examination of Steel Plates.

ASTM A516/A516M—Standard Specification for Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service.

ASTM A537/A537M—Standard Specification for Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel.

ASTM A572/A572—Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel.

ASTM A573/A573M—Standard Specification for Structural Carbon Steel Plates of Improved Toughness.

ASTM C31/C31M—Standard Practice for Making and Curing Concrete Test Specimens in the Field.

ASTM C33/C33M—Standard Specification for Concrete Aggregates.

ASTM C39/C39M—Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.

ASTM C42/C42M—Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete.

ASTM C138/C138M—Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete.

* American Society of Nondestructive Testing, P.O. Box 28518, 1711 Arlingate Lane, Columbus, OH 43228.

† American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

ASTM C143/C143M—Standard Test Method for Slump of Hydraulic-Cement Concrete.

ASTM C172/C172M—Standard Practice for Sampling Freshly Mixed Concrete.

ASTM C173/C173M—Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method.

ASTM C231/C231M—Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method.

ASTM C309—Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete.

ASTM C597—Standard Test Method for Pulse Velocity Through Concrete.

ASTM C805/C805M—Standard Test Method for Rebound Number of Hardened Concrete.

ASTM C1064/C1064M—Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete.

ASTM C1077—Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation.

ASTM D698—Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft³ [600 kN-m/m³]).

ASTM D1143/D1143M—Standard Test Methods for Deep Foundations Under Static Axial Compressive Load.

ASTM D4945—Standard Test Method for High-Strain Dynamic Testing of Deep Foundations.

ASTM E329—Standard Specification for Agencies Engaged in Construction Inspection, Testing, or Special Inspection.

AWS 2.4—Standard Symbols for Welding, Brazing, and Nondestructive Examination.

AWS* B2.1/B2.1M-BMG—Base Metal Grouping for Welding Procedure and Performance Qualification.

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

AWS D1.4/D1.4M—Structural Welding Code—Reinforcing Steel.

AWS QC1—Standard for AWS Certification of Welding Inspectors.

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

CAN/CSA* W178.2—Certification of Welding Inspectors.

CSA G40.20-13/G40.21—General Requirements for Rolled or Welded Structural Quality Steel/Structural Quality Steel.

NEMA† 250—Enclosures for Electrical Equipment (1,000 Volts Maximum).

NFPA‡ 70—National Electrical Code®.

NFPA 780—Standard for the Installation of Lightning Protection Systems.

OSHA§—Occupational Safety and Health Standards, 29 CFR, Part 1910.

PCI¶ MNL 116—Manual for Quality Control for Plants and Production of Precast and Prestressed Concrete Products.

SECTION 3: DEFINITIONS

The following definitions are used in this standard:

1. *Active fault*: A fault determined to be active from properly substantiated data (e.g., most recent mapping of faults by the US Geological Survey).
2. *Bottom capacity line (BCL)*: The elevation above which the tank capacity is contained, not lower than the top of the inlet/outlet pipe or silt stop, if provided.
3. *Capacity*: The net volume contained between the bottom capacity line and top capacity line.
4. *Characteristic earthquake*: An earthquake assessed for an active fault having a magnitude equal to the best estimate of the maximum magnitude capable of occurring on the fault but not less than the largest magnitude that has occurred historically on the fault.
5. *Composite elevated tank*: The entire structure: foundation, concrete support structure, steel tank, and accessories.
6. *Concrete support structure*: All concrete elements above the top of the foundation that provide primary support of the tank.
7. *Deep foundation*: Piles and pile cap that transfer load from the concrete support structure to soil or rock strata by end bearing, by skin friction or adhesion, or by both.

* Canadian Standards Association, 5060 Spectrum Way, Suite 100, Mississauga, ON, Canada L4W 5N6.

† National Electrical Manufacturers Association, 1300 North 17th Street, Suite 1752, Rosslyn, VA 22209.

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

§ Occupational Safety and Health Administration, 200 Constitution Avenue, NW, Washington, DC 20210.

¶ Precast/Prestressed Concrete Institute, 209 West Jackson Boulevard, Suite 500, Chicago, IL 60606.

8. *Interface region:* Those portions of the support wall, tank floor, ring-beam, and steel tank affected by the transfer of forces from the tank floor and steel tank to the support wall.

9. *Intermediate floor:* A structural floor located above the slab-on-grade.

10. *Manufacturer:* The party that manufactures, fabricates, or produces materials or products.

11. *Pile:* Driven, augered, or drilled foundation elements that transfer load from the pile cap to soil or rock strata by end bearing, by skin friction or adhesion, or by both.

12. *Pile cap:* Concrete element that transfers load from the concrete support structure to the supporting piles.

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

14. *Ringbeam:* Concrete element connecting the support wall, tank floor, and steel tank.

15. *Risk-targeted maximum considered earthquake (MCE_R) ground motion response acceleration:* The most severe earthquake effects considered by this standard as defined in Sec. 4.2.7.5.2 and Sec. 4.2.7.6.2.

16. *Rustication:* A shallow indentation formed in the concrete surface to provide an architectural effect.

17. *Shallow foundation:* Concrete element that transfers load from the concrete support structure directly to soil or rock.

18. *Steel liner or liner:* Nonstructural welded steel plate placed over a concrete tank floor and welded to the steel tank to provide a watertight container. Considered part of the steel tank.

19. *Steel tank or tank:* Circular welded steel structure composed of a roof, shell outside the support wall, liner or structural bottom, and elements that attach the steel tank to the concrete support structure.

20. *Support wall or wall:* Concrete wall supporting the steel tank that extends from the foundation to the interface region.

21. *Tank floor:* The structural element that supports the tank contents inside the support wall.

22. *Top capacity line (TCL):* The elevation of the lip of the overflow.

SECTION 4: GENERAL REQUIREMENTS FOR ANALYSIS AND DESIGN

Sec. 4.1 General

4.1.1 *Scope.* This section covers design loads and general requirements for analysis and design.

4.1.2 *Notation.*

4.1.2.1 *Loads.* The following symbols and notation represent applied loads in Sec. 4.3:

D = dead load

E_h = horizontal seismic load effect

E_v = vertical seismic load effect

F = water load

G = eccentric load due to dead and water loads

L = live load on intermediate floors

S = larger of snow load or roof live load

T = creep, shrinkage, differential settlement, or temperature effects

W = wind load

4.1.2.2 *Variables.* The following symbols and notation represent variables in Sec. 4.1 and 4.2:

A_f = vertical projected area of a portion of the structure, ft²

C_f = wind force drag coefficient

C_r = roof slope factor

C_s = seismic response coefficient

C_u = coefficient for upper limit on calculated period

d_s = height of the seismic sloshing wave, ft

D_F = Diameter of the free water surface, ft

D_w = mean diameter of support wall, in.

e_g = vertical load eccentricity, in.

e_o = minimum vertical load eccentricity, in.

E_c = modulus of elasticity of concrete, psi

f_{ca} = average service level compression stress in the support wall due to gravity loads for load combination S1.1, psi

F_a = acceleration-based site coefficient at short period

F_i = portion of factored seismic force V acting at level i , lb

- F_v = velocity-based site coefficient at 1-second period
 F_w = wind force acting on a portion of the structure, lb
 F_x = portion of factored seismic force V acting at level x , lb
 g = acceleration due to gravity
 G_f = wind gust effect factor
 h/D = wind force drag coefficient height-to-diameter ratio
 H_F = equivalent height of a cylinder with diameter D_F containing the total stored water volume, ft
 I = importance factor
 K_z = wind velocity exposure coefficient evaluated at height z
 l_g = distance from base to centroid of stored water, in.
 l_{ga} = distance from base to TCL minus one-half the operating head range; approximate distance from base to centroid of stored water, in.
 l_i = distance from base to level of F_i , ft
 l_w = distance from base to top of concrete support wall, ft
 l_x = distance from base to level of F_x , ft
 M_o = factored seismic moment at base, ft-lb
 M_x = factored seismic moment at level x , ft-lb
 $\overline{N}$ = average field standard penetration resistance for the top 100 ft (30 m)
 $\overline{N}_{ch}$ = average standard penetration resistance for cohesionless soil layers for the top 100 ft (30 m)
 p_g = ground snow load, psf
 p_z = wind pressure at height z above ground level, psf
 q_s = wind velocity pressure, psf
 R = response modification coefficient
 S_a = design spectral response acceleration at any period
 S_{ac} = spectral acceleration of the sloshing liquid (convective component) based on the sloshing period T_c and 0.5 percent damping
 S_{aM} = site-specific MCE_R spectral response acceleration at any period
 S_{DS} = design, 5 percent damped, spectral response acceleration parameter at short periods
 S_{D1} = design, 5 percent damped, spectral response acceleration parameter at a period of 1 second
 S_{MS} = the MCE_R , 5 percent damped, spectral response acceleration parameter at short periods adjusted for site class effects
 S_{M1} = the MCE_R , 5 percent damped, spectral response acceleration parameter at a period of 1 second adjusted for site class effects

- S_S = mapped MCE_R , 5 percent damped, spectral response acceleration parameter at short periods as defined in Sec. 4.2.7.5.1
 S_1 = mapped MCE_R , 5 percent damped, spectral response acceleration parameter at a period of 1 second as defined in Sec. 4.2.7.5.1
 $\bar{s}_u$ = average undrained shear strength in top 100 ft (30 m), psf
 T = fundamental period of vibration of the structure, sec
 T_a = approximate fundamental period of vibration of the structure, sec
 T_c = natural period of the first (convective) mode of sloshing, sec
 T_L = long-period transition period determined from chapter 22 of ASCE 7, sec
 $\bar{v}_s$ = average shear wave velocity at small shear strains in top 100 ft (30 m), ft/sec
 V = total design seismic lateral force or shear at the base, lb
 V_b = basic wind speed, mph
 w_f = uniformly distributed flat roof snow load, psf
 w_i = portion of total mass the centroid of which is at level i , a distance l_i above the base, lb
 w_s = uniformly distributed sloped roof snow load, psf
 w_x = portion of effective seismic weight W the centroid of which is at level x , a distance l_x above the base, lb
 W = effective seismic weight, lb
 z = height above ground level, ft
 z_g = nominal height of the atmospheric boundary layer, ft
 α = 3-second gust speed power law exponent
 θ_g = estimated foundation tilt, degrees
 θ_r = roof slope at a point measured from the horizontal, degrees

Sec. 4.2 Design Loads

4.2.1 *Minimum loads.* The structure shall be designed for the loads defined in this standard, unless larger loads are specified.

4.2.2 *Dead load.* Dead load shall be the weight of all permanent structural components, attachments, and equipment. Unit weight of material shall be based on test data of materials, when available. Otherwise, unit weights shall be 490 lb/ft³ (7,850 kg/m³) for steel, 150 lb/ft³ (2,400 kg/m³) for reinforced concrete, and 100 lb/ft³ (1,600 kg/m³) for soil.

4.2.3 *Water load.* Water load shall be the weight of the water when the tank is filled to the TCL. The unit weight for water shall be 62.4 lb/ft³ (1,000 kg/m³).

4.2.4 *Live load.* Distributed and concentrated live loads acting on the tank roof, access areas, elevated platforms, and intermediate floors shall be in accordance with ASCE 7 unless otherwise specified.

4.2.5 *Snow load.*

4.2.5.1 *Scope.* This section defines minimum service snow loads for design. It is applicable to conical roofs and curved roofs that concave downward without steps or abrupt changes in elevation.

4.2.5.2 *Ground snow load.* Ground snow load p_g shall be based on an extreme value statistical analysis of weather records using a 2 percent annual probability of exceedance (a 50-year mean recurrence interval). In the contiguous United States and Alaska the ground snow load p_g shall be determined from ASCE 7 Figure 7-1, “Ground Snow Loads, p_g , for the United States (lb/ft²).”

4.2.5.3 *Flat roof snow load.* Unless otherwise specified, the uniformly distributed snow load w_f acting on a flat roof shall be

$$w_f = 0.9 p_g \geq 25 \text{ psf (1.2 kPa)} \quad \text{for } p_g > 20 \text{ psf (960 Pa)} \quad (\text{Eq 4-1a})$$

$$w_f = 1.2 p_g \geq 15 \text{ psf (720 Pa)} \quad \text{for } p_g \leq 20 \text{ psf (960 Pa)} \quad (\text{Eq 4-1b})$$

4.2.5.4 *Sloped roof snow load.* Portions of the tank having a slope θ_r greater than 70 degrees shall be considered free of snow load. The sloped roof snow load w_s at any point on the roof shall be

$$w_s = C_r w_f \quad (\text{Eq 4-2})$$

where:

$$C_r = 1.75 - \theta_r / 40 \quad 0 < C_r \leq 1 \quad (\text{Eq 4-3})$$

For curved roofs, the distribution of snow load may be assumed to vary linearly between roof slopes of 30 degrees and 70 degrees.

4.2.6 *Wind load.*

4.2.6.1 *Scope.* This section defines the minimum factored wind loads for design of the main wind-force-resisting system. Larger wind loads shall be used when specified.

4.2.6.2 *Basic wind speed.* Basic wind speed V_b shall be based on a 3-second gust speed at 33 ft (10 m) above ground corresponding to approximately a 3 percent probability of exceedance in 50 years (mean recurrence interval = 1,700 years). In the contiguous United States and Alaska, the basic wind speed V_b shall be determined from ASCE 7-10, Figure 26.5-1B, “Basic Wind Speeds for Risk Category III and IV Buildings and Other Structures,” and shall not be less than 120 mph (54 m/sec).

In special wind regions and areas outside the contiguous United States and Alaska, determine basic wind speed in accordance with ASCE 7-10, Sec. 26.5-2 and 26.5-3.

4.2.6.3 Design wind force. Total factored wind force acting on the main wind-force-resisting system is the sum of the forces F_w acting on each portion of the structure determined by Eq 4-4.

The wind force F_w acting on any portion of the structure is

$$F_w = C_f p_z A_f \quad \text{not less than 48 psf (2,300 Pa) times } C_f A_f \quad (\text{Eq 4-4})$$

NOTE: Design wind pressure $C_f p_z$ used in Eq 4-4 corresponding to a basic wind speed V_b of 120 mph (54 m/sec) may be determined from Tables A.1a and A.1b in appendix A.

The wind force drag coefficient C_f is

$$C_f = 0.5 + \frac{h/D - 1}{60} \quad 0.5 \leq C_f \leq 0.6 \quad (\text{Eq 4-5})$$

The ratio of structure height-to-diameter ratio h/D in Eq 4-5 shall be calculated using:

- Height h measured from grade to a point on the roof, where roof slope θ_r is 30 degrees or less
- Diameter D equal to maximum tank diameter

Wind pressure p_z at height z above ground level is

$$p_z = q_s G_f K_z \quad (\text{Eq 4-6})$$

Wind velocity pressure q_s is

$$q_s = 0.00256 V_b^2 \quad (\text{Eq 4-7})$$

Wind gust effect factor G_f is 0.85 for structure period 1.0 second or less, and G_f is 1.0 when structure period exceeds 1.0 second.

Velocity exposure height coefficient K_z shall be determined by Eq 4-8a/4-8b or from ASCE 7 Table 6-3. Unless otherwise specified, Exposure Category C shall be used.

$$K_z = 2.01 (z/z_g)^{2/\alpha} \quad \text{for } z_{15} \leq z \leq z_g \quad (\text{Eq 4-8a})$$

$$K_z = 2.01 (z_{15}/z_g)^{2/\alpha} \quad \text{for } z < z_{15} \quad (\text{Eq 4-8b})$$

where $z_{15} = 15$ ft (4.6 m), and values of α and z_g are from Table 1.

4.2.6.4 Other wind loads. Wind forces acting on specified accessories or other components attached to the composite elevated tank shall be considered.

1. Minimum wind forces acting on projecting accessories or components shall comply with ASCE 7. These loads may be neglected in design of the main

Table 1 Coefficients for calculation of velocity exposure height coefficient K_z

Exposure Category	α	z_g	
		<i>ft</i>	<i>(m)</i>
C	9.5	900	(274.32)
D	11.5	700	(213.36)

wind-force-resisting system when they increase overturning moment by 5 percent or less.

2. Minimum wind forces on shrouds that totally enclose the structure for environmental protection shall be based on basic wind speed V_b of 67 mph (30 m/s), acting on projected area of tank height by a width equal to maximum tank diameter plus 6 ft (1.8 m).

Supporting elements and connections for projecting accessories or components shall have sufficient strength to resist applied wind loads.

4.2.7 *Seismic design criteria.*

4.2.7.1 *Scope.* This section defines criteria to be used in design of the main lateral-force-resisting system. Seismic analysis is not required where mapped maximum spectral response acceleration at 1-second period S_1 is less than or equal to $0.04g$ and mapped maximum spectral response acceleration at short periods S_S is less than or equal to $0.15g$.

4.2.7.2 *Site classification.* The site class shall be determined in accordance with the classification procedure given in chapter 20 of ASCE 7.

4.2.7.3 *Site coefficients.* Site coefficients F_a and F_v shall be determined from Tables 2a and 2b, respectively. For intermediate values of S_S and S_1 , the higher value or straight-line interpolation may be used to determine coefficients F_a and F_v .

4.2.7.4 *Ground motions.* Ground motions shall be determined in accordance with Sec. 4.2.7.5 or Sec. 4.2.7.6. For structures on Site Class F sites, ground motions shall be determined by site-specific procedures in accordance with Sec. 4.2.7.6.

4.2.7.5 *General procedure.* Risk-targeted maximum considered earthquake (MCE_R) and design spectral response.

Table 2a Site coefficient F_a

Site Class	Mapped Maximum Considered Earthquake Spectral Response Acceleration Parameter at Short Period				
	$S_S \leq 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.0$	$S_S \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	Site-specific response analysis required; see Sec. 4.2.7.6.				

Table 2b Site coefficient F_v

Site Class	Mapped Maximum Considered Earthquake Spectral Response Acceleration Parameter at 1-Second Period				
	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \geq 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	Site-specific response analysis required; see Sec. 4.2.7.6.				

4.2.7.5.1 Mapped acceleration parameters.* Ground motion acceleration shall be based on a 2 percent probability of exceedance in 50 years with 5 percent critical damping. The mapped risk-adjusted maximum considered earthquake spectral response acceleration parameters S_S and S_1 shall be determined from the USGS Earthquake Hazards Program—National Seismic Hazard Mapping Project, 2008 database for Site Class B. Alternatively, S_S and S_1 may be determined by interpolation from MCE_R maps in chapter 22 of ASCE 7.

4.2.7.5.2 Maximum considered earthquake. Maximum considered earthquake spectral response acceleration at short periods S_{MS} and at 1-second period S_{M1} adjusted for site class effects are

* Values of mapped acceleration parameters and seismic design parameters are provided at the USGS Web site at earthquake.usgs.gov/designmaps, or through the SEI Web site at content.seiinstitute.org.

$$S_{MS} = F_a S_S \quad (\text{Eq 4-9a})$$

$$S_{M1} = F_v S_1 \quad (\text{Eq 4-9b})$$

4.2.7.5.3 Design spectral response acceleration. Design spectral response acceleration at short periods S_{DS} and at 1-second period S_{D1} are

$$S_{DS} = \frac{2}{3} S_{MS} \quad (\text{Eq 4-10a})$$

$$S_{D1} = \frac{2}{3} S_{M1} \quad (\text{Eq 4-10b})$$

Where a design response spectrum is required and site-specific procedures are not used, the design spectral acceleration at any period is

$$S_a = S_{D1}/T \leq S_{DS} \quad (\text{Eq 4-11})$$

4.2.7.6 Site-specific procedure. Risk-targeted maximum considered earthquake (MCE_R) and design spectral response.

4.2.7.6.1 Ground motion hazard analysis. When site-specific ground motions are used or required, a ground motion hazard analysis for the site shall be performed in accordance with chapter 21 of ASCE 7 and documented in a report. Site-specific MCE_R spectral response acceleration at any period shall be determined using probabilistic procedures or deterministic procedures, or both. Probabilistic MCE_R spectral response accelerations at each period shall be based on a 2 percent probability of exceedance in 50 years with 5 percent critical damping. Deterministic MCE_R response accelerations at each period shall be taken as 150 percent of the largest median 5 percent damped spectral acceleration computed at that period for characteristic earthquakes on all known active faults within the region.

4.2.7.6.2 Risk-targeted maximum considered earthquake (MCE_R). Site-specific MCE_R spectral response acceleration at any period S_{aM} shall be taken as the lesser of the spectral response accelerations from the probabilistic MCE_R and the deterministic MCE_R . The deterministic MCE_R ground motion response spectrum ordinates shall not be less than the value determined by Eq 4-12.

$$S_{aM} = 0.6 F_v / T \leq 1.5 F_a \quad (\text{Eq 4-12})$$

For Site Class F sites, values of F_a and F_v used in Eq 4-12 shall be for Site Class E from Tables 2a and 2b, respectively.

4.2.7.6.3 Site-specific design spectral response acceleration. Site-specific design spectral response acceleration S_a is the larger of 80 percent of the value determined by Eq 4-11 and the value determined from Eq 4-13.

$$S_a = (\frac{2}{3}) S_{aM} \quad (\text{Eq 4-13})$$

Site-specific MCE_R spectral response acceleration at any period S_{aM} is in accordance with Sec. 4.2.7.6.2.

4.2.7.6.4 Site-specific acceleration parameters. Site-specific design spectral response acceleration parameters at short periods and at 1 second are

- S_{DS} is the spectral acceleration S_a obtained from Sec. 4.2.7.6.3 at a period of 0.2 seconds, but not less than the larger of 90 percent of the peak spectral acceleration S_a at any period greater than 0.2 seconds, and 80 percent of the value obtained from Eq 4.10a.
- S_{D1} is the larger value of spectral acceleration S_a obtained from Sec. 4.2.7.6.3 at 1 second and two times the spectral acceleration S_a at 2 seconds, but not less than 80 percent of the value obtained from Eq 4.10b.

4.2.7.7 Importance factor. An importance factor I of 1.5 shall be used for seismic loads. The importance factor I may be reduced to 1.25 when the structure is not an essential facility used for fire protection or potable water supply.

4.2.7.8 Seismic design category (SDC). Determine seismic design category in accordance with Sec. 11.6 of ASCE 7 when required for design or detailing of elements not expressly covered in the standard. Sites where S_S is 0.15g or less and S_1 is 0.04g or less shall be assigned to SDC A.

4.2.8 Seismic load.

4.2.8.1 Scope. This section defines the minimum factored seismic loads for design of the main lateral-force-resisting system.

4.2.8.2 Seismic load effects.

4.2.8.2.1 Vertical. Factored vertical seismic load effect E_v due to vertical acceleration at the base shall not be less than

$$E_v = 0.2 S_{DS} W \quad (\text{Eq 4-14})$$

The seismic coefficient S_{DS} is in accordance with Sec. 4.2.7.5.3 or Sec. 4.2.7.6.4, and the effective seismic weight W is in accordance with Sec. 4.2.8.3.1.

Vertical distribution of E_v is proportional to the vertical distribution of the structure weight.

4.2.8.2.2 Horizontal. Factored horizontal seismic load effect E_h , the shear and the resulting moment acting on any horizontal section of the structure, shall be determined in accordance with Sec. 4.2.8.4 and Sec. 4.2.8.5.

4.2.8.2.3 *P*-delta effects. *P*-delta effects may be ignored when the increase in seismic overturning moment is less than 10 percent of the moment without *P*-delta effects.

4.2.8.3 Seismic base shear. Factored seismic base shear V acting in any direction shall be in accordance with Sec. 4.2.8.3.1 and Sec. 4.2.8.3.2.

4.2.8.3.1 Equivalent lateral force procedure. The equivalent lateral force procedure may be used for all structures and shall be based on a fixed-base, single degree-of-freedom model. All mass, including the water, shall be considered rigid.

Factored seismic base shear V is

$$V = C_s W \quad (\text{Eq 4-15})$$

Seismic response coefficient C_s is the larger value determined from Equations 4-16a through 4-16c.

$$C_s = \frac{S_a I}{R} \quad (\text{Eq 4-16a})$$

The value of S_a used in Eq 4-16a is for design spectral response acceleration determined in Sec. 4.2.7.5.3 or Sec. 4.2.7.6.3 at fundamental structure period T from Sec. 4.2.8.7.

The seismic response coefficient C_s shall not be less than

$$C_s = 0.044 S_{DS} I \geq 0.01 \quad (\text{Eq 4-16b})$$

The value of S_{DS} in Eq 4-16b is from Sec. 4.2.7.5.3 or Sec. 4.2.7.6.4.

When S_1 determined in Sec. 4.2.7.5.1 is equal to or greater than 0.6g, seismic response coefficient C_s shall not be less than

$$C_s = \frac{0.5 S_1 I}{R} \quad (\text{Eq 4-16c})$$

Effective seismic weight W shall include dead load above the base; water load; and 25 percent of live load from intermediate floors.

Importance factor I is determined in Sec. 4.2.7.7.

4.2.8.3.2 Alternative procedures. Analysis complying with Sec. 15.7.10 of ASCE 7 may be used in lieu of the equivalent lateral force procedure of Sec. 4.2.8.3.1 to determine seismic base shear V .

When soil-structure interaction is used, the effective damping factor for the structure-foundation system shall be computed using the procedure provided in ASCE 7, chapter 19, but shall not exceed 15 percent.

Fluid-structure interaction may be used when the following requirements are met:

1. The sloshing period is greater than three times the natural period of the tank with confined liquid (rigid mass) and supporting structure.
2. The sloshing mechanism (percentage of convective mass and centroid) is determined for the specific configuration of the tank by detailed fluid-structure interaction analysis or testing.
3. The response modification factor for the convective component is 1.5 or less, and the spectral acceleration of the convective component is based on 0.5 percent damping.

Factored base shear V determined by alternative procedures shall not be less than $0.75C_sW$. Seismic response coefficient C_s and effective seismic weight W shall be determined by the equivalent lateral force procedure of Sec. 4.2.8.3.1.

4.2.8.4 Seismic force distribution. Factored seismic base shear V shall be distributed over the height of the structure in proportion to the structure weight by

$$F_x = V \frac{w_x}{\sum_{i=1}^n w_i} \quad (\text{Eq 4-17})$$

4.2.8.5 Seismic moment.

4.2.8.5.1 Overturning moment at base. Factored base overturning moment M_o is

$$M_o = \sum_{i=1}^n (F_i l_x) \quad (\text{Eq 4-18})$$

4.2.8.5.2 Seismic moment at level x . Factored seismic moment M_x acting at any level of the structure is the larger of

$$M_x = \sum_{i=1}^x F_i (l_i - l_x) \quad (\text{Eq 4-19a})$$

or

$$M_x = M_o \left(1 - 0.75 \frac{l_x}{l_w} \right) \quad (\text{Eq 4-19b})$$

4.2.8.6 Response modification coefficient. The response modification coefficient R used in design shall not exceed 3.0.

4.2.8.7 Structure period.

4.2.8.7.1 Fundamental period. The fundamental period of vibration T of the structure shall be established using the elastic structural properties and deformational characteristics of the resisting elements in a properly substantiated analysis.

The period T used to calculate the seismic response coefficient C_s in Sec. 4.2.8.3.1 shall be determined from the lesser of

$$T \leq C_u T_a \quad (\text{Eq 4-20a})$$

or

$$T \leq 2.5 \text{ seconds} \quad (\text{Eq 4-20b})$$

4.2.8.7.2 Approximate fundamental period. The approximate fundamental period T_a shall be determined from one of the following equations:

$$T_a = \frac{10.26 l_g}{D_w} \sqrt{\frac{f_{ca} l_g}{E_c g}} \quad (\text{Eq 4-21a})$$

$$T_a = \frac{0.16 l_{ga}}{D_w} \sqrt{\frac{l_g}{g}} \quad (\text{Eq 4-21b})$$

Terms D_w , E_c , f_{ca} , g , l_g , and l_{ga} are in consistent units.

4.2.8.7.3 Coefficient for upper limit on calculated period. The coefficient for upper limit on calculated period C_u shall be determined from Table 3.

4.2.8.8 Sloshing. Sloshing of stored water due to seismic acceleration shall be considered by

- Providing minimum freeboard in accordance with Sec. 4.2.8.8.1; or
- Designing the roof and supporting structure to contain the sloshing water.

4.2.8.8.1 Minimum freeboard. Minimum freeboard shall comply with the following where seismic design is required:

- Not less than the sloshing wave height d_s for Risk Category IV structures.
- Not less than $0.7d_s$ for Risk Category III structures when $S_{DS} > 0.33g$.
- No minimum freeboard is required for Risk Category III structures when

$S_{DS} \leq 0.33g$.

Height of the sloshing wave d_s shall be computed by

Table 3 Coefficient for upper limit on calculated period C_u *

Design Spectral Response Acceleration at 1 second, S_{D1}	Coefficient C_u
≥ 0.4	1.4
0.3	1.4
0.2	1.5
0.15	1.6
≤ 0.1	1.7

* Interpolation may be used for intermediate values.

$$d_s = 0.5 D_F I S_{ac} \quad (\text{Eq 4-22})$$

Spectral acceleration of the sloshing liquid S_{ac} is the smaller value from Eq 4-23a and Eq 4-23b. Equation 4-23b is applicable only when the long-period transition period T_L is determined and $T_c > T_L$.

$$S_{ac} = 1.5 S_{D1}/T_c \leq 1.5 S_{DS} \quad (\text{Eq 4-23a})$$

$$S_{ac} = 1.5 S_{D1} T_L/(T_c)^2 \quad (\text{Eq 4-23b})$$

Natural period of the first (convective) mode of sloshing T_c is computed by

$$T_c = 2\pi \sqrt{\frac{D_F}{3.68 \tanh(3.68 H_F/D_F)}} \quad (\text{Eq 4-24})$$

4.2.9 Other loads.

4.2.9.1 Vertical load eccentricity. Eccentricity of dead and water loads that cause additional overturning moments to the structure as a whole shall be accounted for in the design. The additional overturning moment is the dead and water loads times the eccentricity e_g . Eccentricity e_g shall not be taken less than

$$e_g \geq e_o + \frac{l_g}{400} \quad (\text{Eq 4-25a})$$

The minimum vertical load eccentricity e_o is 1 in. (25 mm). Where tilting of the structure due to nonuniform settlement is estimated to exceed $1/800$, the eccentricity e_g shall not be taken less than

$$e_g \geq e_o + l_g \left(\frac{1}{800} + \tan \theta_g \right) \quad (\text{Eq 4-25b})$$

4.2.9.2 Construction loads. Temporary loads resulting from construction activity shall be considered in the design of structural components.

4.2.9.3 Future construction. When future construction such as the addition of intermediate floors is specified, the load effects shall be included in the original design. Future construction dead and live loads shall be included in the Group 1 load combinations (see Sec. 4.3.3.1 and Sec. 4.3.4.1). Only that portion of the dead load existing at the time of original construction shall be included in the Group 2 load combinations (see Sec. 4.3.3.2 and Sec. 4.3.4.2).

Sec. 4.3 Analysis and Design

4.3.1 Analysis. The design of the composite elevated tank and its components shall be based on the results of a detailed structural analysis, which shall provide the applicable axial loads, shears, and moments to be used in design. Methods of analysis may be based on classical theory, simplified mathematical models, or

numerical solutions using finite element, finite differences, or numerical integration techniques. The analysis shall consider the effects of restraint at the boundaries of shell elements.

4.3.2 Design methods. Design the steel tank by the working stress method using the unfactored load combinations in Sec. 4.3.3. Design the concrete support structure and concrete foundation by the strength design method to resist the factored load combinations in Sec. 4.3.4. Size the foundations using the unfactored load combinations in Sec. 4.3.3 in accordance with Sec. 7.3.1.

4.3.3 Unfactored load combinations. Load combinations for the working stress method shall comply with the following:

4.3.3.1 Group 1 load combinations. The allowable load shall not be less than

Load combination:	S1.1	$D + F$
	S1.2	$D + F + G + S + L$
	S1.3	$D + F + G + L + 0.6W$
	S1.4	$D + F + G + L + 0.7E_h + 0.7E_v$

4.3.3.2 Group 2 load combinations. Where D , L , or F reduce the effect of W , E_h , or E_v , as in uplift produced by overturning moment, the allowable load shall not be less than

Load combination:	S2.1	$D + 0.6W$
	S2.2	$D + F + 0.7E_h + 0.7E_v$

4.3.3.3 Differential settlement, creep, shrinkage, and temperature. Where structural effects of differential settlement, creep, shrinkage, or temperature effects are significant, $1.0T$ shall be included with load combinations S1.1 and S1.2, and $0.75T$ shall be included with load combinations S1.3 and S1.4. Where structural effects T are significant, $0.75T$ shall be included with Group 2 load combinations when T is additive to W , E_h , or E_v .

4.3.4 Factored load combinations. Load factors and load combinations for the strength design method shall comply with the following:

4.3.4.1 Group 1 load combinations. Where the structural effects of applied loads are cumulative, the required strength shall not be less than

Load combination:	U1.1	$1.4(D + F)$
	U1.2	$1.2(D + G) + 1.5F + 1.6(S + L)$
	U1.3	$1.2(D + F) + 0.5(S + G) + L + W$
	U1.4	$1.2(D + F) + 0.5G + L + E_h + E_v$

4.3.4.2 Group 2 load combinations. Where D , L , or F reduce the effect of W , E_h , or E_v , as in uplift produced by overturning moment, the required strength shall not be less than

$$\begin{array}{ll} \text{Load combination:} & \text{U2.1} \quad 0.9 D + W \\ & \text{U2.2} \quad 0.9 D + F + E_h + E_v \end{array}$$

4.3.4.3 Differential settlement, creep, shrinkage, and temperature. Where structural effects of differential settlement, creep, shrinkage, or temperature effects are significant, $1.2T$ shall be included with load combinations U1.2 and U1.3, and $1.0T$ shall be included with load combination U1.4. Where structural effects T are significant, $1.0T$ shall be included with Group 2 load combinations when T is additive to W , E_h , or E_v .

SECTION 5: STEEL TANK

Sec. 5.1 General

5.1.1 *Scope.* This section covers materials, design, and construction of the steel tank.

5.1.2 *Notation.* The following symbols are used to represent variables in this section:

A_1 = loaded area, in.²

A_2 = area of the lower base of the largest frustrum contained within the supporting concrete, having side slopes of 1 vertical to 2 horizontal and loaded area A_1 for its upper base, in.²

C_p = elastic buckling coefficient for pressure stabilization

C_o = elastic buckling coefficient

D_s = diameter of cylindrical shell, in.

f'_c = specified compressive strength of concrete, psi

e_x = local imperfection tolerance, in.

E_s = modulus of elasticity of steel, psi

f_h = circumferential membrane tension stress due to hydrostatic pressure, psi

F_{cr} = critical buckling strength, psi

F_L = meridional compression strength, psi

F_{xe} = maximum meridional compression strength, psi

F_y = minimum yield point or minimum yield strength specified in referenced material standards, psi

F_p = allowable bearing stress on concrete, psi

K_o = meridional compression strength factor

L = centerline spacing of rafters at maximum radius, in.

L_x = gauge length for measuring local imperfections, in.

p = hydrostatic pressure at point under consideration, psi

R = radius of the shell, normal to the plate at the point under consideration and measured from the centerline of the plate to the axis of revolution, in.

$(R/t)_c$ = radius-to-thickness ratio at which buckling changes from elastic to inelastic

t = plate thickness less the specified corrosion allowance, in.

t_{base} = plate thickness determined by Eq 5-3a and 5-3b with F_y equal to 36,000 psi (248 MPa), in.

w_r = roof design load, psf

η = plasticity reduction factor

5.1.3 Configuration. Provide an all-welded steel tank comprising one or more axisymmetric shell courses and a roof. Provide welded steel plate liners over concrete floors.

5.1.4 Modulus of elasticity. Modulus of elasticity E_s for steel used in design shall be 29,000,000 psi (200 GPa).

Sec. 5.2 Material Requirements

5.2.1 General. All materials incorporated into the steel tank shall be previously unused. Unless otherwise specified, materials shall comply with the requirements of this standard.

5.2.2 Steel plate. Steel plate shall conform to the requirements of Table 4. Thickness limits apply to shell elements where primary membrane tension or compression stress exceeds 6,000 psi (41 MPa).

5.2.3 Other structural steel. Other steel materials and products shall comply with requirements of ANSI/AISC 360.

5.2.4 Filler metals and welding consumables. Filler metals and welding consumables shall be as required by weld procedure specifications in Sec. 5.4.

Sec. 5.3 Analysis and Design

5.3.1 Analysis. Perform analysis to determine the following:

1. In-plane membrane forces in shell elements and boundary elements such as tension and compression rings, where shear and flexure are not significant and membrane theory of shells is applicable.
2. Axial load, shear, and flexure in other elements.



Table 4 Steel plate requirements

Specification	Grade	Minimum Yield Strength, F_y		Maximum Thickness, Tension		Maximum Thickness, Compression	
		(<i>psi</i>)	(<i>MPa</i>)	(<i>in.</i>)	(<i>mm</i>)	(<i>in.</i>)	(<i>mm</i>)
ASTM A36	—	36,000	248	2*	51*	4*,†,‡,§	100*,†,‡,§
ASTM A516	60	32,000	221	1½	38	4†	100†
	65	35,000	241	1½	38	4†	100†
	70	38,000	262	1½	38	4†	100†
ASTM A537	CL 1	50,000	345	1½	38	2½†	64†
ASTM A572	42	42,000	290	1½*	38*	4*,†	100*,†
	50	50,000	345	1½*	38*	4*,†	100*,†
ASTM A573	58	32,000	221	1½	38	1½	38
	65	35,000	241	1½	38	1½	38
	70	42,000	290	1½	38	1½	38
CSA G40.21	38W	38,000	262	2	51	4†	100†
	44W	44,000	303	2	51	4†	100†
	50W	50,000	345	2	51	4†	100†

* Comply with supplementary requirement S91 (silicon killed and fine grain practice) for thicknesses greater than 1½ in. (38 mm).

† Comply with supplementary requirement S8 (ultrasonic examination in accordance with ASTM A435) for thicknesses greater than 2 in. (51 mm).

‡ Comply with supplementary requirement S97 (steel shall be other than rimmed or capped).

§ Normalize for thicknesses greater than 2 in. (51 mm).

5.3.2 General design requirements.

5.3.2.1 Design method. Design the steel tank by the working stress method using the unfactored load combinations in Sec. 4.3.3, except as permitted in Sec. 5.3.4.4. Allowable stresses may be increased by one-third for load combinations in Sec. 4.3.3 that include wind or seismic loads.

5.3.2.2 Minimum thickness. Unless otherwise specified, minimum thickness of steel tank components shall be:

1. Parts not in contact with water: ⅜ in. (4.76 mm).
2. Parts in contact with water: ¼ in. (6.35 mm).
3. Shell plate thickness controlled by Sec. 5.3.5: ⅜ in. (9.52 mm).
4. Cylindrical shells: $D_s/6,000$, not less than ¼ in. (6.35 mm).

For structural members, thickness is defined as the mean thickness of flanges.

5.3.2.3 Corrosion allowance. Unless otherwise specified, corrosion allowance is not required. Corrosion allowance shall be added to the calculated thickness of specified elements.

5.3.3 Design of welds.

5.3.3.1 General. Calculated stress in welds shall not exceed allowable stresses in Sec. 5.3.3.2 times joint efficiency factor in Sec. 5.3.3.3.

5.3.3.2 Allowable stress. Allowable stresses in welds are

1. Tension or compression on effective weld area of groove welds: same as the base metal in Table 5.

2. Shear on effective area of groove and fillet welds: 0.3 times nominal tensile strength of weld metal for filler metals matching base metal strength. Stress on fillet welds shall be considered as shear regardless of direction of load application.

5.3.3.3 Joint efficiency factors. Joint efficiency factors are

1. Tension normal to effective area of groove welds: 0.80.

2. Shear on effective area of groove and fillet welds: 0.75.

3. Compression normal to effective area of groove welds, and tension or compression parallel to effective area of groove welds: 1.0.

5.3.3.4 Effective area of welds. Effective area of a weld is the weld length times effective weld size. Effective weld size shall be

1. Complete joint penetration groove welds: thickness of the thinner part joined.

2. Partial joint penetration groove welds with bevel or V-joints: depth of chamfer minus $\frac{1}{8}$ in. (3.18 mm).

Table 5 Allowable stresses in shell plates and structural components

Item	Allowable Stress*	
	(psi)	(MPa)
Shell plates:		
Membrane tension	$0.5F_y \leq 18,000$	$0.5F_y \leq 124$
Membrane compression	$0.5F_L^\dagger \leq 18,000$	$0.5F_L^\dagger \leq 124$
In-plane shear	$0.4F_y \leq 14,400$	$0.4F_y \leq 99.3$
Tension and compression rings	$0.5F_y \leq 15,000$	$0.5F_y \leq 103$
Structural members and connections	AISC	AISC
Bending in base plates and roof plates	$0.67F_y \leq 24,000$	$0.67F_y \leq 165$

* See applicable joint efficiency in Sec. 5.3.3.3.

† F_L is determined in Sec. 5.3.5.1.

3. Fillet welds: throat of weld defined as the shortest distance from the joint root to face of weld.

5.3.3.5 Weld joint details. Weld joint details shall comply with the following:

1. Shell plates in contact with water shall be butt welded with continuous complete joint penetration welds.

2. Unless otherwise specified, all exposed joints on the tank interior and exterior shall be continuously welded with structural welds or seal welds. Seal welds shall be continuous and of sufficient size to prevent cracking.

3. Maximum thickness of plate connected by lap welds is $\frac{3}{8}$ in. (9.52 mm). Plate laps shall be minimum 1 in. (25 mm) and maximum 4 in. (100 mm) for single-welded lap joints. Minimum plate lap for double-welded lap joints subjected to calculated stress is five times the thickness of the thinner part joined.

4. Minimum length of fillet weld is the greater of four times the nominal weld size or $1\frac{1}{2}$ in. (38 mm). Maximum size of fillet weld along edge of a connected part is the edge thickness for material less than $\frac{1}{4}$ -in. (6.35-mm) thick, and the edge thickness minus $\frac{1}{16}$ in. (1.59 mm) for material $\frac{1}{4}$ -in. (6.35-mm) thick or greater.

5. Minimum size of structural fillet welds and partial penetration groove welds shall comply with Table 6. Minimum size of seal welds is $\frac{1}{8}$ in. (3.18 mm).

6. Welding to steel members embedded in concrete shall not detrimentally affect the connected parts.

5.3.4 Design of shell plates and structural components.

5.3.4.1 General. Calculated stress in shell plate and structural components shall not exceed allowable stresses in Table 5.

Table 6 Minimum size of fillet and partial joint penetration welds

Base Metal Thickness*		Minimum Weld Size†	
(in.)	(mm)	(in.)	(mm)
To $\frac{1}{2}$ inclusive	To 12.7 inclusive	$\frac{3}{16}$	4.76
Over $\frac{1}{2}$ to $\frac{3}{4}$	Over 12.7 to 19	$\frac{1}{4}$	6.35
Over $\frac{3}{4}$ to $1\frac{1}{2}$	Over 19 to 38	$\frac{5}{16}$	7.94
Over $1\frac{1}{2}$ to $2\frac{1}{4}$	Over 38 to 57	$\frac{3}{8}$	9.52
Over $2\frac{1}{4}$ to 6	Over 57 to 150	$\frac{1}{2}$	12.7

* Thickness of thicker part joined.

† Fillet weld size need not exceed thickness of thinner part joined.