



American Water Works
Association

ANSI/AWWA D110-13 (R18)
(Revision of ANSI/AWWA D110-04)
Reaffirmed without revisions

AWWA Standard

Wire- and Strand-Wound, Circular, Prestressed Concrete Water Tanks

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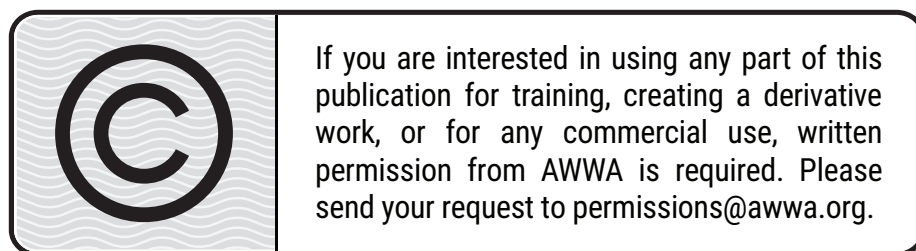
AWWA Standard

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Foreword

This foreword is for information only and is not a part of ANSI/AWWA D110.

I. Introduction.

I.A. *Background.* The New England Water Works Association (NEWWA) established a committee in 1958 to prepare a standard specification for the design and construction of prestressed concrete water-storage tanks. The committee submitted a suggested specification to NEWWA in October 1962 as a guide to those in the water industry who wished to consider the use of these tanks.

American Concrete Institute (ACI) Committee 344 concluded eight years of committee work with a report titled “Design and Construction of Circular Prestressed Concrete Structures,” published in the *ACI Journal* September 1970. This report referred primarily to wire-wound tanks.

I.B. *History.* In the December 1972 issue of *Journal AWWA*, the applicability of the ACI report to water containment structures was discussed in four articles. As a result of these articles and continued discussion on the subject, a standards committee was authorized by the American Water Works Association (AWWA) to develop an AWWA standard for circular, prestressed concrete water tanks.

An AWWA standards committee on circular, prestressed concrete water tanks was appointed and held its first meeting June 19, 1974. During its first two years, the committee studied the various types of prestressed tanks then in service or under construction and determined that most were of the wire-wound type. Therefore, the committee in 1976 was directed to limit its scope to the wire- and strand-wound prestressed tank wall design. The first edition of this standard incorporated the work of ACI Committee 344 and contained additional requirements and recommendations, specifically for potable and process water, and for wastewater containment structures. The new standard, ANSI/AWWA D110-86, Standard for Wire-Wound Circular Prestressed-Concrete Water Tanks, was approved by the AWWA Board of Directors on June 22, 1986, and had an effective date of June 1, 1987. The standard has been in use since approval by the American National Standards Institute (ANSI) on Mar. 3, 1987.

The first revision of this standard was initiated by the AWWA Standards Committee during 1990 according to AWWA Standards Council policy. The revised standard ANSI/AWWA D110-95 was approved on June 22, 1995, by the AWWA Board of

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

Directors. The next edition of the standard, ANSI/AWWA D110-04, was approved by the AWWA Board of Directors on Jan. 18, 2004. This edition, ANSI/AWWA D110-13, was approved by the AWWA Board of Directors on Jan. 20, 2013.

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

1. An advisory program formerly administered by USEPA, Office of Drinking Water, discontinued on Apr. 7, 1990.
2. Specific policies of the state or local agency.
3. 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.
4. 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

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

† NSF International, 789 N. Dixboro Road, Ann Arbor, MI 48105.

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

§ Both publications available from National Academy of Sciences, 500 Fifth Street, NW, Washington, DC 20418.

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 D110 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. Intent. This standard reflects a committee consensus of industry practice concerning the design, detailing, and construction of circular, prestressed concrete water tanks of several types, with or without vertical prestressing of the tank core wall. The horizontal prestressed reinforcement of the tank wall is accomplished by the application of helically wound high-tensile-stress wire or strand under controlled tension on the surface of the core wall, protected by shotcrete cover coats.

Recommended criteria and guidelines are presented to assist engineers in the design, construction, and inspection of tanks with shotcrete, cast-in-place concrete, or precast circular concrete core walls, with or without internal steel diaphragms, based on the successful application of these concepts in practice and the detailed experience of committee members. Engineering principles are tied to existing codes where applicable.

The intent is also to assist the designer and constructor by sharing information on the unique aspects in analysis and construction that are encountered in these types of structures.

II.B. Limitations. Because of the wide range of site-specific environments, foundation conditions, loadings, and construction conditions throughout North America, this standard should not be expected to apply universally nor to produce a cost-effective and completely maintenance-free structure in every situation. In adapting this standard to obtain the structure’s expected service life for the actual conditions that are anticipated, the purchaser and the designer of the tank are advised to carefully study all factors affecting the structure during its anticipated service life.

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. *Industry Practice and Assumptions.* It is not the purpose of this standard to either define or recommend contractual relationships or to stipulate contractual obligations, both of which are the responsibility of the purchaser. Generally, purchasers may solicit competitive bids for wire- and strand-wound circular prestressed concrete tanks by one of two methods.

According to the first method, a design professional is retained by the purchaser to prepare construction drawings, specifications, and other contract documents. Competitive bids are then solicited from constructors and suppliers for construction of the tank. In this standard, these are referred to as purchaser-furnished designs.

According to the second method, the purchaser prepares performance specifications that require bidding constructors to prepare project designs and specifications and to construct the tank according to the design. In this standard, these are referred to as design–construct projects.

While the division of information that must be covered in the purchaser’s specifications for execution of each method of contracting differs substantially, depending on who is responsible for the tank design, the information that must be supplied by the purchaser to successfully apply this standard is essentially the same.

ANSI/AWWA D110 does not address matters related to site selection and property acquisition. It is assumed that the purchaser will have conducted sufficient background work in the form of water system studies, predesign surveys, subsurface investigations, preliminary design work, etc., to establish the desired tank site, volume, operating water depth, and elevations. Further, it is assumed that the purchaser will have acquired the property, easements, and rights-of-way necessary for construction of the facility, including site access, the tank structure, and associated water pipelines connecting the tank to the water system and drainage, if required. Specifically, it has been assumed that the purchaser will arrange for or provide the following as necessary or appropriate:

1. The site on which the tank is to be built, with adequate space to permit the constructor to erect the structure using customary methods.
2. A predesign site survey and preparation of a site plan showing existing topography, property lines, approximate tank centerline location, setback, encumbrances, details of special construction features, and extent of final site grading.
3. A site geotechnical survey and foundation report, including logs of borings and test pits, soil densities, and other pertinent soil and geological information; construction criteria for any backfill that may be necessary at a particular site; and foundation design criteria prepared by a registered design professional specializing in

soil mechanics, including allowable bearing loads, anticipated total and differential settlements, and the seismic soil profile type.

4. Structural loading conditions, including, but not limited to, snow, wind, seismic, hydrostatic uplift, and other live loads depending on the tank's intended use; the amount of earth cover over the tank, if any; the height of backfill against the tank wall, if any; and any other special loading conditions that are anticipated or special criteria on which the tank design is to be based. If, for example, the tank is located in a high-intensity earthquake area and must continue to serve without damage following an earthquake, the purchaser may specify an importance factor for earthquake design as described in Table 2 or provide design values for the peak horizontal ground acceleration and for the spectrum velocity. In cases for which the design must consider static and dynamic earth pressures resulting from seismic shaking, the purchaser shall provide the required geotechnical data to evaluate these additional loading conditions in the tank design along with the soil site class as shown in Table 4.

5. Requirements for subdrainage and overflow collection systems.

6. The use of electric power and water service, if available, at the site.

III.B. *Purchaser Options and Alternatives.* The following information should be provided by the purchaser:

1. Whether compliance with NSF/ANSI 61, Drinking Water System Components—Health Effects, is required.

The items that follow are either required information or alternative options in the standard that should be considered and covered by the purchaser, unless the purchaser intends that the choice for a particular option be left to the tank designer's discretion.

1. The standard to be used—that is, ANSI/AWWA D110, Standard for Wire- and Strand-Wound, Circular, Prestressed Concrete Water Tanks, of latest revision.

2. The required capacity of the tank, including side water depth or diameter.

3. Requirements for subdrainage and overflow collection systems.

4. Seismic information required.

a. The Occupancy Category as indicated in ASCE 7-05.

b. Importance factor (Table 2).

c. Structural response coefficient for type of tank (Table 3).

d. Soil site class definitions (Table 4).

5. Information on access to the site for the constructor's equipment and for supply of construction materials.

6. Availability and characteristics of electric power and source of water for construction.

7. The type of roof and type or types of tank wall. Basic wall types (Sec. 1.1.1). Roof structures may be shotcrete or concrete domes (Sec. 3.6), nonprestressed concrete flat slabs supported by columns (Sec. 3.7), or other types of roofs selected by the purchaser. Preference for wet mix or dry mix for the tank wall or shotcrete cover coats (Sec. 2.2.2.2).

8. Details of other federal, state or provincial, and local requirements (Sec. 2.1).

9. Subsurface investigation and report (Sec. 3.8.4).

10. Tank appurtenances required (Sec. 3.11).

a. Specifications for any additional accessories to be provided.

b. Requirements for a water-level gauge or pressure sensor, or other level monitoring device (Sec. 3.11.2.4).

c. Size, material, and location of vents, access hatches, ladders, stairs, and manways; and locking and safety devices required (Sec. 3.11.3).

d. Whether or not a removable silt stop is required and whether baffles are provided for circulation (Sec. 3.11.7).

11. Size, material, location, details, cover depths, and limits of responsibility for all other pipe connections (Sec. 3.11.1).

12. Maximum filling (overflow) and emptying rates required (Sec. 3.11.2).

13. Size, material, arrangement, and location for the overflow pipe (Sec. 3.11.2).

14. Special exterior wall coatings or architectural treatment, if any (Sec. 3.11.6).

15. Seismic joint types (Sec. 4.2).

16. Maximum allowable stresses and reinforcement requirements (Sec. 4.6).

17. Maximum allowable coefficient of friction requirements (Sec. 4.7).

18. Foundation design requirements (Sec. 4.9).

19. The required elevation of the overflow weir and freeboard requirements (Sec. 4.10).

20. Design for seismic effects on backfill requirements (Sec. 4.11).

21. Finish grade relative to the tank foundation. (Whether or not the wall is to be completely exposed, partially buried, or completely buried.) (Sec. 4.11, Sec. 5.14)

22. Restraint cable requirements (Sec. 5.8).

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

IV. Major Revisions. This edition of the standard has been edited throughout and includes revisions to stated definitions and terms to achieve a higher degree of consistency among the various AWWA standards. The technical revisions to this

standard reflect current thinking and construction practices. These include the following:

1. A global change of references from ACI 318, Building Code Requirements for Structural Concrete, to ACI 350, Code Requirements for Environmental Engineering Concrete Structures. ACI 350 is the ACI code that deals directly with liquid-containing structures and is applicable to ANSI/AWWA D110 structures.
2. The addition of specific strength requirements for concrete slab.
3. References to “portland cement” have been changed to “cementitious material”; this change is intended to include supplemental cementitious materials such as fly ash, ground granulated blast furnace slag, and microsilica.
4. A global change of reference from “seismic cables” to “restraint cables” to reflect their use for other lateral loading conditions, such as differential backfill.
5. The elimination of Table 1 of ANSI/AWWA D110-04, Sec. 2.6, providing PVC waterstop test methods and limits, as this is directly covered by reference to Corps of Engineers CRD-C572.
6. The addition of urethane elastomer as a type of sealant and joint filler.
7. An update to the minimum design wind and seismic loads from the most recent versions of the IBC and ASCE 7.
8. The addition of construction loads as a roof design load.
9. The addition of metric equivalents to equations.
10. A clarification that the design calculations are performed by a registered design professional who is responsible for the design.
11. A reduction of the minimum roof rise-to-span ratio from 1:12 to 1:16 as a result of successful industry experience with lower-rise domes.
12. An update of the dome buckling equation to address changes in load factors.
13. The addition of requirements for compaction of cohesionless base material, such as gravel, under the floor.
14. A clarification of methods for concrete pipe encasement of under-floor pipe.
15. The addition of ultrasonic level sensors.
16. Guidance on conditions in which an interior ladder and/or wall accessway would be appropriate.
17. Incorporation of the new seismic design approach based on the IBC, ASCE 7-05 code standards, and current seismic technological advances resulting from the NEHRP research study.
18. The inclusion of urethane as a suitable material for crack injection.

19. Additional information on tank inspection, including inspector qualifications and suggested areas of inspection.

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.



American Water Works
Association

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(Revision of ANSI/AWWA D110-04)

AWWA Standard

Wire- and Strand-Wound, Circular, Prestressed Concrete Water Tanks

SECTION 1: GENERAL

Sec. 1.1 Scope

1.1.1 *Intent of standard.* The intent of this standard is to describe current recommended practice for the design, construction, inspection, and maintenance of wire- and strand-wound, circular, prestressed concrete water-containing structures with the following four types of core walls:

Type I—cast-in-place concrete with vertical prestressed reinforcement

Type II—shotcrete with a steel diaphragm

Type III—precast concrete with a steel diaphragm

Type IV—cast-in-place concrete with a steel diaphragm

1.1.2 *Items not described in standard.* This standard does not describe bonded or unbonded horizontal tendons for prestressed reinforcement of the tank wall, floor, or roof.

1.1.3 *Tank contents.* This standard applies to containment structures for use with potable water or raw water of normal temperature and pH commonly found in drinking water supplies. It is not intended for use in the design of containment structures for highly aggressive waters or high-temperature waters without special consideration being given to their effects on the structure; nor is it

intended that the standard be used for the design of structures for wastewater, bulk dry storage, chemical storage, or storage of slurries.

Sec. 1.2 Definitions

In this standard, the following definitions apply:

1.2.1 *Base and top-of-wall joints.* Connections between the base of the tank's core wall and its foundation or floor slab and between the top of the wall and roof slab or dome.

Types of wall–base joints may be generally defined as follows:

1. *Anchored flexible:* Minimum restraint of radial translation and rotation, employing restraint anchor cables between the joint components to resist tangential displacement.

2. *Unanchored and uncontained, free:* Minimal restraint of radial translation and rotation.

Types of wall–roof joints in general use may be defined as follows:

1. *Reinforced nonsliding:* Fixed for restraint of radial translation and rotation.

2. *Separated:* Minimal restraint of radial translation and rotation.

1.2.2 *Capacity.* The net volume of contents that may be removed from a tank filled to the overflow level.

1.2.3 *Core wall.* That portion of the concrete or shotcrete wall that is circumferentially prestressed.

1.2.4 *Duct.* Tubing for forming internal voids in the core wall for placement of vertical prestressed reinforcement.

1.2.5 *Membrane floor.* A thin, highly reinforced, low-moment-resistant, concrete slab-on-grade designed to be a flexible watertight floor system.

1.2.6 *Mortar and grout.* Includes the following types:

1. *Cement grout:* A mixture of cementitious material (portland cement) and potable water of pourable consistency (without segregation of constituents) used to bond and provide corrosion protection to prestressed tendons in a duct.

2. *Cement mortar:* Generally, a mixture of sand, cement, and water of specified proportions.

3. *Epoxy bonding agent:* An epoxy resin normally used in repair processes to bond fresh plastic concrete mix, cement mortar, or epoxy mortar to hardened concrete.

4. *Epoxy grout:* An epoxy-resin system used to bond and provide corrosion protection to vertical prestressed tendons in a duct.

5. *Epoxy mortar*: A mixture of epoxy resin, catalyst, and fine aggregate for repair of concrete.

6. *Nonsrink grout*: A shrinkage-compensating, expansive cement grout used for concrete repair and patching of form-tie holes.

1.2.7 *Parties*. The persons, companies, or organizations generally involved in the purchase, design, and construction of circular, prestressed concrete tanks, including

1. *Constructor*: The party that provides the work and materials for placement or installation.

2. *Design-constructor*: A firm that specializes in, designs, and constructs prestressed concrete tanks.

3. *Designer*: The registered design professional responsible for the design of the tank.

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

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

6. *Purchaser's engineering agent*: The registered design professional representing the purchaser in the preparation of construction documents for the tank project or representing the purchaser during its construction.

1.2.8 *Prestressed concrete*. Concrete in which internal compressive stresses of such magnitude and distribution are introduced that the tensile stresses resulting from the service loads are counteracted to the desired degree; circumferential prestress of the tank wall is introduced herein by the helical application of high-strength steel wire or strand under controlled tension and vertical prestress is provided by post-tensioned, high-strength steel bar or strand tendons.

1.2.9 *Prestressing reinforcement*. High-strength steel used to prestress the concrete or shotcrete of the tank wall or dome roof edge ring, commonly composed of either single wires, seven-wire strands, or bars.

1. *Strand*: A symmetrically arranged and helically twisted assembly, commonly of seven high-strength steel wires, used for prestressed reinforcement or as nonprestressed restraint cables.

2. *Tendon*: High-strength strand or bar, including end anchorages, used to impart vertical prestress to the tank wall.

3. *Wire*: High-strength, cold-drawn steel wire used for prestressed reinforcement.

1.2.10 *Shotcrete.* Pneumatically applied wet- or dry-mix mortar or concrete used for the core wall or as embedment and protection of the circumferential prestressed wall reinforcement, including

1. *Cover coat:* Shotcrete applied over the wire coat of the outer layer of prestressed wire or strand.

2. *Finish coat:* The final layer of cover coat, usually placed for improved appearance.

3. *Wire coat:* Initial application of shotcrete over the prestressed wire or strand.

1.2.11 *Specifications.* A statement describing the structure to be provided and containing the details of construction materials, methods, or contractor performance required in conjunction with the construction drawings and other contract documents for the structure.

1.2.12 *Standpipe.* A cylindrical structure for water storage, based at or below grade and having a wall height greater than its diameter. Standpipes are considered a special type of tank because of generally more critical loading conditions. Use of this standard in the design and construction of standpipes is not, however, precluded.

1.2.13 *Tank.* Cylindrical structure for water storage, based at or below grade. In general, this term shall refer to a structure having a wall height equal to or less than its diameter.

1.2.14 *Waterstop.* An impervious barrier installed to prevent passage of water through a construction or expansion joint between adjacent elements of concrete or shotcrete construction.

1.2.15 *Wire or strand winding.* The helical application of a continuous wire or strand for circumferentially prestressing the wall or dome ring of a circular tank.

Sec. 1.3 References

References identified refer to the latest revision available. Standards referenced herein shall comply with the appropriate documents and test methods included and referenced in the listed standard. The following is a list of references used in this AWWA standard:

ACI* 301/301M—Specifications for Structural Concrete.

ACI 302.1R—Guide for Concrete Floor and Slab Construction.

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

ACI 304R—Guide for Measuring, Mixing, Transporting, and Placing Concrete.

ACI 305R—Guide to Hot Weather Concreting.

ACI 306R—Guide to Cold Weather Concreting.

ACI 308R—Guide to Curing Concrete.

ACI 308.1/308.1M—Specification for Curing Concrete.

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

ACI 347—Guide to Formwork for Concrete.

ACI 350/350M—Code Requirements for Environmental Engineering Concrete Structures and Commentary.

ACI 350.3—Seismic Design of Liquid-Containing Concrete Structures and Commentary.

ACI 372R—Design and Construction of Circular Wire- and Strand-Wrapped Prestressed Concrete Structures.

ACI 503.2—Standard Specification for Bonding Plastic Concrete to Hardened Concrete with a Multi-Component Epoxy Adhesive.

ACI 506R—Guide to Shotcrete.

ACI 506.2—Specification for Shotcrete.

ACI 515.1R—Guide to the Use of Waterproofing, Dampproofing, Protective and Decorative Barrier Systems for Concrete.

ACI SP-2—Manual of Concrete Inspection, Tenth Edition.

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

ASCE* 7-05—Minimum Design Loads for Buildings and Other Structures.

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

ASTM† A185/A185M—Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete.

ASTM A416/A416M—Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete.

ASTM A421/A421M—Standard Specification for Uncoated Stress-Relieved Steel Wire for Prestressed Concrete.

ASTM A475—Standard Specification for Zinc-Coated Steel Wire Strand.

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

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

ASTM A641/A641M—Standard Specification for Zinc-Coated (Galvanized) Carbon Steel Wire.

ASTM A648—Standard Specification for Steel Wire, Hard Drawn for Prestressing Concrete Pipe.

ASTM A653/A653M—Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process.

ASTM A722/A722M—Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete.

ASTM A821/A821M—Standard Specification for Steel Wire, Hard-Drawn for Prestressed Concrete Tanks.

ASTM A882/A882M—Standard Specification for Filled Epoxy-Coated Seven-Wire Prestressing Steel Strand.

ASTM A1008/1008M—Standard Specification for Steel, Sheet, Cold-Rolled, Carbon, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy with Improved Formability, Solution Hardened, and Bake Hardenable.

ASTM C836/C836M—Standard Specification for High Solids Content, Cold Liquid-Applied Elastomeric Waterproofing Membrane for Use with Separate Wearing Course.

ASTM C881/C881M—Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete.

ASTM C882/C882M—Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear.

ASTM C920—Standard Specification for Elastomeric Joint Sealants.

ASTM C957/C957M—Standard Specification for High-Solids Content, Cold Liquid-Applied Elastomeric Waterproofing Membrane with Integral Wearing Surface.

ASTM C1107/C1107M—Standard Specification for Packaged Dry, Hydraulic-Cement Grout (Nonshrink).

ASTM C1218/C1218M—Standard Test Method for Water-Soluble Chloride in Mortar and Concrete.

ASTM D695—Standard Test Method for Compressive Properties of Rigid Plastics.

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

ASTM D1056—Standard Specification for Flexible Cellular Materials—Sponge or Expanded Rubber.

ASTM D1556—Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method.

ASTM D1557—Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft³) (2,700 kN-m/m³).

ASTM D1566—Standard Terminology Relating to Rubber.

ASTM D1752—Standard Specification for Preformed Sponge Rubber Cork and Recycled PVC Expansion Joint Fillers for Concrete Paving and Structural Construction.

ASTM D2000—Standard Classification System for Rubber Products in Automotive Applications.

ASTM D2240—Standard Test Method for Rubber Property—Durometer Hardness.

ASTM D2922—Standard Test Method for Density of Soil and Soil Aggregate in Place by Nuclear Methods (Shallow Depth).

ASTM D4253—Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table.

ASTM D4254—Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density.

ASTM D6938—Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth).

Fed Spec.* SS-S-210A—Sealing Compound, Preformed Plastic, for Expansion Joints and Pipe Joints.

Handbook of Molded and Extruded Rubber.[†]

ICC[‡] IBC—International Building Code.

Uniform Building Code.[§]

Post-Tensioning Manual.[¶] Sixth Edition, 2006.

US Army Corps of Engineers Spec.** CRD-C572—Corps of Engineers Specifications for Polyvinylchloride Waterstop.

Zia, P., H.K. Preston, N.L. Scott, and E.B. Workman. 1979. Estimating Prestress Losses. *Concrete International*, 1(6): 32–38.

* Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120.

† Goodyear Tire and Rubber Company, 1144 East Market Street, Akron, OH 44316.

‡ International Code Council, 5203 Leesburg Pike, Suite 600, Falls Church, VA 22041.

§ International Conference of Building Officials (ICBO), 5360 Workman Mill Rd., Whittier, CA 90601.

¶ Post-Tensioning Institute, 38800 Country Club Drive, Farmington Hills, MI 48331.

** Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120.

SECTION 2: MATERIALS

Sec. 2.1 Materials

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

Sec. 2.2 Concrete and Shotcrete

2.2.1 *General.* The quality of concrete and shotcrete is of great importance to the structural integrity, reliability, durability, and watertightness of the completed tank. Therefore, care shall be taken throughout the tank construction to maintain close quality control of the source materials, mix proportions, forming, embedded items, placement, finishing, curing, and other details of the work. Concrete or shotcrete in potable-water tanks in contact with water shall

1. Be dense, well consolidated, and low in permeability, to retain water and enhance the serviceability, strength, and durability of the tank.

2. Provide a highly alkaline environment to prevent corrosion of embedded steel reinforcement.

3. Provide a surface that is uniform and well formed to facilitate cleaning and reduce maintenance. A smooth-form finish as specified in ACI 301/301M for formed concrete, a light broom or nozzle finish for shotcrete, and a light broom finish for precast panels are acceptable, provided good workmanship standards are observed.

2.2.2 *Concrete and shotcrete materials.* Concrete and shotcrete materials shall conform to the requirements of ACI 301/301M, ACI 350, and ACI 506.2 as modified herein. The mix proportions shall meet the strength requirements and physical properties of the purchaser's specifications. The minimum 28-day compressive strength of concrete shall be 4,000 psi (28 MPa) in walls, structural floors and roofs and 3,500 psi (24 MPa) in membrane floors. For corrosion protection of the steel reinforcement, concrete or shotcrete used in the core wall, top slab, or dome, and shotcrete for covering prestressed wire or strand, shall not contain water-soluble chloride ions in excess of 0.06 percent of the weight of the cement in the mix as determined by ASTM C1218/C1218M.

Concrete subjected to freeze–thaw cycling shall be air entrained according to ACI 301/301M. Wet-mix shotcrete for dome roofs in areas subjected to freeze–

thaw cycles shall be air entrained with an air content of 5 to 8 percent at the pump. Dry-mix shotcrete shall not be used in domes subject to freeze–thaw cycles.

2.2.2.1 *Shotcrete coat.* Shotcrete coat used for covering prestressed wire or strand shall consist of not more than three parts sand to one part cementitious material by weight; additional coats of shotcrete shall consist of not more than four parts sand to one part cementitious material by weight.

2.2.2.2 *Shotcrete mix.* Either the wet-mix or dry-mix process may be used for shotcreting unless the specifications require the use of a specific process. Shotcrete shall be proportioned for a 28-day compressive strength equal to that for which the core wall is designed but not less than 4,500 psi (31 MPa) unless otherwise specified.

2.2.3 *Cement mortar.* Mortar used for repair of concrete, encasement of waterstop, and patching form tie holes shall consist of not more than three parts sand to one part portland cement by weight and shall conform to the requirements of ACI 301/301M. Mortar shall not contain water-soluble chloride ions in excess of 0.06 percent of the weight of the cement in the mortar. Shrinkage-compensating mortars (nonshrink grout) shall be of the nonmetallic type as specified in Sec. 2.2.5.

2.2.4 *Cement grout.* Cement grout used for grouted or bonded vertical tendons in ducts shall contain not more than 0.45 parts water to one part portland cement by weight (approximately 5 gal [19 L] per sack of cement) and shall not contain water-soluble chloride ions in excess of 0.06 percent of the weight of the cement in the grout. Cement grout for tendons shall contain admixtures to reduce bleeding and grout settlement and shall be used according to the manufacturer's recommendation for this application.

2.2.5 *Nonshrink grout.* Nonshrink cement grout used for repair of honeycomb and other concrete repair and for patching form tie holes shall be a non-hydrogen-gas-liberating, nonmetallic grout meeting the requirements of ASTM C1107/C1107M, grade A or C, for nonshrink grout. This grout is not to be used for bonding of prestressed tendons or to come into contact with the wire or strand prestressed reinforcement.

Sec. 2.3 Mixing Water

Mixing water shall conform to the requirements of ACI 350.

Sec. 2.4 Admixtures

Admixtures shall comply with the requirements of ACI 301/301M or ACI 506.2 and shall not contain more than trace amounts of chlorides, fluorides, sulfides,

or nitrates because of their possible corrosive effect on the prestressed reinforcement. Materials in contact with potable water shall not impart taste, odor, or toxic chemicals to the water. All admixtures used in the concrete shall be compatible.

Sec. 2.5 Reinforcement

2.5.1 *Nonprestressed reinforcement.*

2.5.1.1 Bars and fabric. Deformed billet-steel bars; epoxy-coated steel bars; fabricated deformed steel bar mats; and steel welded-wire fabric, plain or deformed, for concrete reinforcement shall conform to the requirements of ACI 350 and the applicable ASTM standards referenced therein.

2.5.1.2 Strand. Strand for restraint cables shall meet the requirements of ASTM A416/A416M for seven-wire prestressing steel strand. The strand shall be protected with a fusion-bonded epoxy coating, grit-impregnated on the surface, conforming to ASTM A882/A882M, or it shall be galvanized. Galvanized strand shall meet the requirements of ASTM A416/A416M prior to galvanizing. The zinc coating for galvanizing shall meet the requirements of ASTM A641/A641M or ASTM A475, with a minimum weight per unit of uncoated wire surface of class A of these standards. Only hot-dipped galvanizing shall be permitted.

2.5.1.3 Steel-sheet diaphragms. Steel-sheet diaphragms for use as impervious membranes in the walls of prestressed concrete tanks shall be vertically ribbed with adjacent and opposing channels. The base of the channels (see Figure 1) shall be wider than the throat, thus providing a mechanical keyway anchorage between the inner and outer concrete or shotcrete. Uncoated steel sheet shall comply with ASTM A1008/A1008M, and hot-dipped galvanized sheet shall comply with ASTM A653/A653M. Diaphragm steel thickness shall be a minimum of 26 gauge with a minimum thickness of 0.017 in. (0.43 mm). Weight of zinc coating, where specified, shall be not less than G 90 of Table 1 of ASTM A653/A653M. The diaphragm sheets shall be continuous for the full height of the tank.

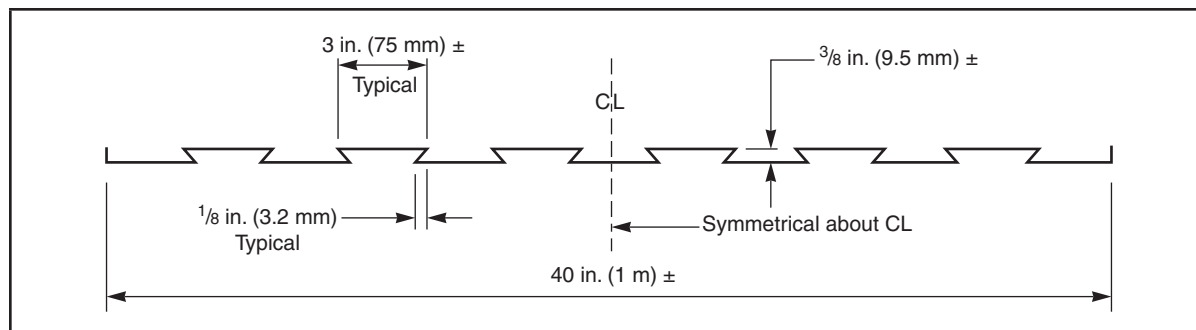


Figure 1 Example diaphragm sheet

2.5.2 *Prestressed reinforcement.*

2.5.2.1 Uncoated wire and strand. Uncoated prestressing wire and strand shall conform to the requirements of ACI 350 and the following applicable ASTM standards: hard-drawn steel wire to be helically wrapped, maintaining tension by mechanical means, shall conform to the requirements of ASTM A821/A821M; ASTM A648, class II; or ASTM A421/A421M, type WA. Steel wire, hard-drawn to be helically wrapped on the structure employing a wire-drawing die for back tension, shall conform to the requirements of ASTM A821/A821M. Steel prestressing strand shall conform to the requirements of ASTM A416/A416M.

2.5.2.2 Galvanized wire and strand. Galvanized prestressing wire and strand to be helically wrapped and tensioned shall meet the requirements of ASTM A821/A821M; ASTM A648, class II; or ASTM A421/A421M, type WA, for wire; and ASTM A416/A416M for strand. Zinc coating for galvanizing shall meet the requirements of ASTM A641/A641M or ASTM A475, with a minimum weight per unit area of uncoated wire surface of 0.85 oz/ft² (259 g/m²) or of class A of these standards. Only hot-dipped galvanizing shall be permitted.

2.5.2.3 Where galvanized wire is stressed on the structure by drawing through a die, the zinc coating remaining after stressing shall be a minimum of 0.50 oz/ft² (150 g/m²) of wire surface.

2.5.2.4 Splices. Splices for horizontal prestressed reinforcement shall be ferrous material compatible with the reinforcement and shall develop the full strength of the wire or strand. Anchor clamps and other accessories in contact with the prestressing elements may be galvanized or epoxy-coated iron or steel. Wire splice and anchorage accessories shall not weaken or otherwise compromise the prestressed reinforcement.

2.5.2.5 Vertical tendons. Tendons for vertical prestressed reinforcement of cast-in-place concrete core walls shall consist of high-strength strand or bars conforming to the requirements of ACI 350 and the material requirements of ASTM A416/A416M or ASTM A722/A722M. Tendon anchorages may be galvanized or epoxy coated for additional corrosion protection.

2.5.3 *Steel corrosion inhibitor.* Temporary corrosion protection of vertical prestressed reinforcement left in the ducts for more than 10 days before grouting shall be provided by volatile or vapor-phase inhibitors. These inhibitors are applied in solid form (a fine white powder) or liquid form that vaporizes and coats the surface of the prestressing steel with a stable organic nitrate that prevents corrosion

by passivating the metal. The corrosion inhibitor shall have no deleterious effect on the steel or bond strength between the cement or epoxy-resin grout and steel; and the corrosion inhibitor shall not prevent future corrosion protection of the prestressing steel by the grout.

Sec. 2.6 Elastomeric Materials

2.6.1 *Waterstops.* Waterstops shall be composed of plastic or other materials suitable for the intended use.

2.6.1.1 *Plastic waterstops.* Plastic waterstops shall be extruded from an elastomeric plastic material of which the basic resin is polyvinyl chloride (PVC). The PVC compound shall contain no scrapped or reclaimed material or pigment. The profile of the waterstop and its size shall be suitable for the hydrostatic pressure and movements to which it is exposed. The waterstop shall meet, as a minimum, the requirements of CRD-C572. Tests assuring conformity to these requirements shall either be made on material delivered to the jobsite or be certified by the manufacturer. Splices to the waterstop shall be according to the manufacturers' recommendations, or as detailed by the design professional and subject to review by the purchaser's representative.

2.6.2 *Bearing pads.* Bearing pads used in the floor-to-wall and wall-to-roof joints shall consist of neoprene, natural rubber, or polyvinyl chloride.

2.6.2.1 *Neoprene bearing pads.* Neoprene bearing pads shall have a minimum ultimate tensile strength of 1,500 psi (10.3 MPa), a minimum elongation of 500 percent, a maximum compressive set of 50 percent, and a hardness of 40 to 50 durometer according to ASTM D2240. Neoprene bearing pads shall contain only virgin crystallization-resistant polychloroprene as the raw polymer and the physical properties shall comply with ASTM D2000, line call-out M 2 BC 410 A1 4 B14 for 40-durometer material.

2.6.2.2 *Natural-rubber bearing pads.* Natural-rubber bearing pads shall contain only virgin natural polyisoprene as the raw polymer, and the physical properties shall comply with ASTM D2000, line call-out M 4 AA 4 14 A1 3.

2.6.2.3 *Polyvinyl chloride bearing pads.* Polyvinyl chloride for bearing pads shall meet the requirements of CRD-C572 for tanks in cold-weather regions.

2.6.3 *Sponge filler.* Sponge filler shall be closed-cell neoprene or rubber conforming to ASTM D1752, type 1, or to the requirements of ASTM D1056, types 2A1 through 2A4.

Sec. 2.7 Duct Material

2.7.1 *Grouted tendons.* Duct material for grouted vertical wall tendons shall be flexible or semiflexible steel or polyvinyl chloride pipe or tubing and shall be sufficiently strong to retain its shape and location during placement and vibration of the concrete. The inside diameter of the duct to be filled with portland-cement grout shall be a minimum of $\frac{3}{8}$ in. (9.5 mm) greater than the nominal diameter of the bar tendon, or the inside area of the duct shall be twice the area of the prestressed strand tendon. If the duct is to be filled with pumped epoxy, the annular space around the tendon may be reduced to the minimum size that will permit easy insertion of the tendon. Ducts shall be so constructed and sealed as to positively prevent the entrance of cement paste from the concrete and shall be equipped with suitable fittings and tubing at the base and top for flushing and pumping the grout or epoxy.

2.7.2 *Bonded tendons.* Duct material for fully bonded vertical tendons shall be semiflexible steel or corrugated polyvinyl duct. In addition to the requirements of Sec. 2.7.1, the duct shall be capable of transferring the stress from the tendon by bond or shear through the duct to the concrete along its full length.

Sec. 2.8 Concrete and Shotcrete Coatings

2.8.1 *Above grade.* In some cases, such as tanks located in areas subject to salt spray or other corrosive environments, coatings may be desired to seal the exterior surface of above-grade concrete and shotcrete dome roofs and shotcrete protection for the circumferential prestressed reinforcement. Coatings suitable for sealing the exterior of the tank shall be permeable to water vapor. Suitable coatings include rubber base (polyvinyl chloride-latex and polymeric vinyl-acrylic), acrylic elastomer and acrylic emulsion paints, and cementitious waterproofing compounds.

2.8.2 *Below grade.* Coatings are recommended for sealing the exterior surface of below-grade tanks where additional protection against aggressive soils is required. Coatings suitable for sealing the exterior of the tank wall include coal-tar epoxies and bitumastic compounds specifically formulated for this purpose.

2.8.3 *Other aggressive environments.* Additional information on exterior coatings and seal coats for an aggressive environment may be found in ACI 350 and ACI 515.1R.

Sec. 2.9 Sealants and Joint Fillers

2.9.1 *Sealant for steel diaphragm joints.* Sealants used in joints shall be polysulfide, polyurethane, urethane elastomer, or epoxy and shall provide watertightness under full tank head.

2.9.2 Polysulfide sealant. Polysulfide sealant shall be a two- (or more) component elastomeric compound of the appropriate type meeting the requirements of ASTM C920, type M, and shall have permanent characteristics of bond-to-metal or concrete surfaces, flexibility, and resistance to extrusion caused by hydrostatic pressure. Air-cured sealants shall not be used. The grade and class shall be appropriate for the intended use as recommended by the manufacturer.

2.9.3 Polyurethane sealant. Polyurethane elastomeric sealant used in interior tank construction joints and movement joints at the base of the wall, or in floor or roof slab joints shall meet the requirements of ASTM C920, class 25, of appropriate type and grade for permanent bond-to-concrete surfaces, flexibility, and resistance to extrusion caused by hydrostatic pressure. The sealant shall be multicomponent type M, of grade P for pourable, and grade NS for nonsag or gunnable. Sealant shall not impart taste, odor, or toxic chemicals to potable water.

2.9.4 Preformed bitumen joint filler. Preformed bitumen compound plastic joint filler for use in exterior movement joints shall be of the appropriate type conforming to Fed. Spec. SS-S-210A. Such filler or sealing compound shall not be used in interior floor, wall, or roof joints in contact with potable-water tank contents, or where the material may leach into the tank contents.

2.9.5 Epoxy sealant. Epoxy sealants shall be suitable for bonding to concrete, shotcrete, and steel, and shall be suitable for sealing the vertical joints between sheets of steel diaphragms. Epoxy sealants shall conform to the requirements of ASTM C881/C881M, type III, grade 1, and shall be a 100 percent solids, moisture-insensitive, low-modulus epoxy system. When pumped, maximum viscosity of the epoxy shall be 10 poise (1 Pa·s) at 77°F (25°C).

2.9.6 Polyurethane filler. Polyurethane filler used to fill voids between components in the wall base joint and seal around waterstops, base pads, restraint cable sleeves, and sponge fillers shall meet the requirements of ASTM C920, class 25, for single- or multiple-component types S or M, grade P or NS, as appropriate for the intended use.

2.9.7 Urethane elastomer sealant. Elastomer sealants shall be suitable for bonding to concrete, shotcrete, and steel, and shall be suitable for sealing the vertical joints between sheets of steel diaphragms. Urethane sealants shall be two component and conform to ASTM C836/C836M and ASTM C957/C957M, suitable for use in constant immersion. Sealant shall be suitable for potable water contact up to 180°F (82°C).

Sec. 2.10 Epoxy Bonding Agent

Epoxy resin used for increasing the bond of fresh, plastic concrete or mortars to hardened concrete shall be a two-component, 100 percent solids, moisture-insensitive epoxy adhesive meeting the requirements of ASTM C881/C881M, type II, grade 2, as specified in ACI 503.2. The bonding agent shall produce a bond strength, as determined by ASTM C882/C882M, greater than 1,500 psi (10.3 MPa), 14 days after the plastic concrete is placed. Epoxy in contact with potable water shall not impart taste or odor, or leach toxic trace elements into the water.

Sec. 2.11 Epoxy Mortar and Grout

2.11.1 *Epoxy mortar.* Epoxy mortar used for concrete repair shall be a noncorrosive and noncontaminating mixture of epoxy resin, catalyst, and fine aggregate proportioned in strict accordance with the manufacturer's instructions for the product and its intended use.

2.11.2 *Epoxy-resin grout.* Epoxy-resin grout used for corrosion protection of prestressed vertical tendons or for bonding the reinforcement within the duct shall be a two-component, moisture-insensitive, resin bonding system conforming to ASTM C881, of the type, grade, and class recommended by the manufacturer as suitable for these applications.

Sec. 2.12 Form Coatings

The form coating for concrete surfaces that will be in contact with potable water shall be of an organic base and shall be nonstaining and nontoxic.

SECTION 3: DESIGN

Sec. 3.1 Notation*

Notation used in various equations presented in Section 3 are defined as follows:

A_{ds} = total area of prestressing wires or strand for dome ring area, in in.² (mm²), see Sec. 3.6.5

d = distance from face of support in in. (mm)

D = dead load in psf (N/m²)

E_c = short-term modulus of elasticity of concrete or shotcrete in psi (Pa)

* Caution should be used to be consistent throughout with use of units.

- E_v = vertical seismic load corresponding to the maximum design vertical spectral acceleration in lb (N) (see Sec. 3.6.3.1)
- f'_c = specified 28-day compressive cylinder strength of concrete or shotcrete in psi (Pa). (Refer to Sec. 5.3.4 for control of shotcrete strength)
- f_c = permissible compressive concrete or shotcrete stress in psi (Pa)
- f_{ci}' = specified compressive cylinder strength of concrete or shotcrete (Refer to Sec. 5.6.2.5) at time of prestressing in psi (Pa)
- f_{pu} = specified ultimate tensile strength of steel prestressing wire, strand, or high-strength bars in psi (Pa)
- f_{se} = effective stress in prestressed reinforcement after losses in psi (Pa)
- f_{si} = maximum permissible initial stress in prestressed reinforcement before losses in psi (Pa)
- f_t = flexural tensile stress in extreme fiber of the core wall in psi (Pa)
- l_d = development length for bond in in. (mm)
- L = roof live load in psf (N/m²), in accordance with ASCE 7
- P_u = factored (uniformly distributed) unit dead and live design load on dome shell in lb/ft² (N/m²)
- r_d = mean radius of dome shell in ft (m)
- r_i = average maximum radius of curvature over a dome imperfection area in ft (m)
- S = snow load in psf (N/m²), in accordance with ASCE 7
- t_c = core-wall thickness in in. (mm)
- t_d = dome-shell thickness in in. (mm)
- u = nominal bond stress in concrete or shotcrete in psi (Pa)
- V_c = nominal shear stress in concrete or shotcrete in psi (Pa)
- V_{max} = maximum shear stress in reinforced section in psi (Pa)
- W = total dead and live load on dome, exclusive of dome ring in lb (N)
- β_c = buckling reduction factor for creep, nonlinearity, and cracking of concrete
- β_i = buckling reduction factor for geometrical imperfections from a true spherical surface, such as local increases in radius
- ω = half central angle of dome shell in degrees
- ϕ = buckling resistance factor

Sec. 3.2 Design Method

Tank design shall be based on elastic analysis methods and shall take into account effects of all loads and prestressing forces during and after tensioning, and conditions of edge restraint at wall junctions with floor and roof. Stresses shall

not exceed allowable service stresses specified in Sec. 3.4. Consideration shall also be given to the effects of all loads and load combinations, including stresses induced by temperature and moisture gradients. The recommendations herein pertain to service-load conditions and serviceability requirements. However, to ensure the safety of the structure, the design must also meet the strength requirements of this standard and ACI 350. All applicable sections of the latest edition of ACI 350, including supplements and the chapters describing precast and prestressed concrete, shall be followed except when supplemented or modified by provisions of this standard.

Sec. 3.3 Design Loads

Loads indicated in this section are those most frequently encountered in prestressed concrete tank design and shall be included in the design calculations. Loadings, including prestressing forces and their placement, shall follow governing codes.

3.3.1 *Wall design loads.*

3.3.1.1 Internal pressure—the pressure from water at maximum overflow level.

3.3.1.2 Dead loads, including all attached accessories and appurtenances.

3.3.1.3 Backfill loading—the lateral pressure from earth backfill, symmetrical or asymmetrical. Net lateral loads, including those caused by unequal backfill, shall be determined by rational methods of soil mechanics based on foundation and soils investigations. Surcharge loads on backfilled surfaces shall be considered.

Backfill pressure shall not be used to reduce the amount of prestressing force required for resisting internal water pressure. Backfill forces shall be based on soil parameters established by a registered design professional experienced in soils.

3.3.1.4 Minimum design loadings for wind and earthquake. These loadings shall conform to requirements of local building codes applicable to the site. These might include the applicable sections of the International Building Code or ASCE 7. Seismic design criteria for prestressed concrete tanks are stated in Section 4 as appropriate.

3.3.1.5 Construction loads. Effects of construction, including loads resulting from equipment, materials, and construction methods to be used.

3.3.1.6 Hydrostatic load. External hydrostatic pressure on the floor and wall, including flood and wave loads, if any.

3.3.1.7 Operating loads and system surges.

3.3.1.8 Thermal and moisture loads. Thermal and moisture gradients as follows:

1. Radially, through the thickness of the wall.
2. Vertically, that occur between the buried and exposed portion of the wall.
3. Between the wall and roof or floor.

3.3.1.9 Prestressing loads. Effects on the wall caused by the application of prestressing forces, including those caused by nonuniform distribution of prestressing forces temporarily induced during the stressing operations and in the completed structure.

3.3.2 *Roof design loads.*

- 3.3.2.1 Dead loads, including sustained surcharges.
- 3.3.2.2 Earth, snow or ice, and other live loads.
- 3.3.2.3 Construction loads.
- 3.3.2.4 Wind loads.
- 3.3.2.5 Earthquake loads.
- 3.3.2.6 Appurtenance loads.
- 3.3.2.7 Operational loads, if any.
- 3.3.2.8 Loads created by roof openings.

3.3.3 *Floor design loads.*

- 3.3.3.1 Dead loads.
- 3.3.3.2 Water loads.
- 3.3.3.3 Earthquake loads.
- 3.3.3.4 Uplift caused by groundwater or expansive soils.
- 3.3.3.5 Radial forces from the base of the tank wall.
- 3.3.3.6 Differential and total settlement.
- 3.3.3.7 Construction loads.

3.3.4 *Control of loads.* Consideration shall also be given to the following load control techniques and their safety margins:

- 3.3.4.1 Overflow systems.
- 3.3.4.2 Venting.
- 3.3.4.3 Internal freeboard to provide room for sloshing during an earthquake.
- 3.3.4.4 Perimeter and underfloor drainage systems to limit hydrostatic pressures.
- 3.3.4.5 Drainage. Provisions for drainage of surface water from earth backfill and roof runoff away from the structure, or use of a free-draining granular backfill or composite drainage panels adjacent to the wall, should be considered for reducing hydrostatic loading on the exterior face of the tank wall and floor.

Sec. 3.4 Allowable Stresses

3.4.1 *Concrete and shotcrete.* Service-load stresses shall be limited to provide protection against leakage into or out of the tank and against corrosion of the reinforcement. Cracking under predominantly flexural stresses shall be controlled to limit crack depth and width. The stresses for concrete and shotcrete shall not exceed the values indicated in Table 1.

3.4.2 *Prestressed reinforcement.*

3.4.2.1 Maximum permissible initial prestress. Maximum permissible initial stress f_{si} in any wire or strand on the wall, or in vertical threaded bar prestressed reinforcement, shall not exceed $0.75f_{pu}$. Maximum initial stress for anchored strands in vertical prestressed reinforcement, after anchorage and elastic losses, shall not exceed $0.70f_{pu}$.

Table 1 Allowable stresses in concrete and shotcrete

Description	Notation	Allowable Stresses*
Compression: horizontal or vertical in extreme fiber.	f_c	$0.55f'_c$ initial; $0.45f'_c$ final.
Tension: vertical, in extreme fiber of all tanks without a diaphragm. All tanks without a diaphragm shall be vertically prestressed.	f_t	Vertical flexural tensile stresses to be reduced to zero by vertical prestressing as in Sec. 3.5.3 or taken by the auxiliary nonprestressed reinforcement at the stresses in paragraphs of Sec. 3.4.3.
Tension: vertical in tanks with a diaphragm.	f_t	100 percent of the tensile force shall be taken by the reinforcing steel or diaphragm at the stresses specified in the paragraphs of Sec. 3.4.3.
Shear: as a measure of diagonal tension at a distance d from the face of the support, psi. Members with no web reinforcement.	V_c	$1.1\sqrt{f'_c}$
Members with vertical or inclined web reinforcement,	V_{max}	$5\sqrt{f'_c}$ (Increased stress allowed for properly designed reinforcement.)
Slabs with footings: peripheral shear.	V_c	$2\sqrt{f'_c}$
Development length and bonding reinforcement: deformed bars and welded wire fabric	l_d	Development length l_d shall be computed as a measure of bond resistance according to recommendations of ACI 350.
Steel diaphragm: nominal bond stress in concrete or shotcrete	u	$2.5\sqrt{f'_c}$ (See Sec. 3.4.3.1)

*Coefficients shown are for values of f'_c expressed in pounds per square inch (psi). Refer to Sec. 3.1 for definition of notation.

Table 1M Metric Conversion

A. Shear in members with no web reinforcement:

$$V_c = 1.1\sqrt{f'_c}$$

$$[V_c = 92\sqrt{f'_c}] \text{ in SI system}$$

B. Shear in members with vertical or inclined web reinforcement:

$$V_{max} = 5\sqrt{f'_c}$$

$$[V_{max} = 415\sqrt{f'_c}] \text{ in SI system}$$

C. Peripheral shear in slabs and footings:

$$V_c = 2\sqrt{f'_c}$$

$$[V_c = 170\sqrt{f'_c}] \text{ in SI system}$$

D. Steel diaphragm—nominal bond stress in concrete or shotcrete:

$$u = 2.5\sqrt{f'_c}$$

$$[u = 210\sqrt{f'_c}] \text{ in SI system}$$

3.4.2.2 Long-term stress loss. Long-term stress losses caused by shrinkage and creep of concrete or shotcrete and relaxation in prestressed reinforcement shall be calculated according to the recommendations in Zia et al. (1979)* or assumed to be 25,000 psi (170 MPa).

3.4.2.3 Maximum design stress. Maximum design stress in prestressed wire, strand, or high-strength bars f_{se} for structures subject to full design load, after deduction for stress losses, shall not exceed $0.65f_{pu}$.

3.4.3 *Nonprestressed reinforcement.* Nonprestressed reinforcement shall be designed according to the requirements of the Alternate Design Method in ACI 350. The strength requirements of ACI 350 shall also be satisfied. Because crack control is of paramount importance to prestressed concrete structures, additional nonprestressed reinforcement is often used in areas of localized stress to control cracking and preclude the contained liquid from reaching the prestressing elements. Low stress in reinforcement at service loads is good insurance against undesirable performance of these structures. Recommended maximum stresses and spacing for deformed bars, as provided in ACI 350, shall not be exceeded.

* Zia, P., H.K. Preston, N.L. Scott, and E.B. Workman. 1979. Estimating Prestress Losses. *Concrete International*, 1(6): 32–38.