

American Water Works Association
ANSI/AWWA D115-95
(First Edition)



AWWA STANDARD
FOR
**CIRCULAR PRESTRESSED
CONCRETE WATER TANKS
WITH
CIRCUMFERENTIAL TENDONS**



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AMERICAN WATER WORKS ASSOCIATION

6666 West Quincy Avenue, Denver, Colorado 80235

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Foreword

This foreword is for information only and is not part of ANSI/AWWA D115-95.

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 circular prestressed concrete water storage tanks. The committee submitted a suggested specification covering wire-wound prestressed concrete tanks to NEWWA in October 1962 as a guide to those water utility people who wished to consider the use of these tanks.

The 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* in September 1970. This report referred to both wire-wound and tendon tanks. After publication of its first report in 1970, ACI Committee 344 could not reach a consensus on a combined report covering both wire-wound and tendon tanks. In 1985 the ACI Committee was divided into two subcommittees, and "interim" reports were completed in 1988 for both types of tanks. ACI did not publish these interim reports but made copies available in the hopes that a consensus could be reached on a recombined report. However, a consensus was not able to be reached, and in the spring of 1994 ACI Committee 344 was divided into two separate committees, ACI 372 and ACI 373.

I.B. *History of This Standard.* In the December 1972 issue of *Journal AWWA*, circular prestressed concrete water containment structures were 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) Standards Council on June 20, 1974, to develop an AWWA standard on circular prestressed concrete water tanks. The AWWA Standards Committee on Circular Prestressed-Concrete Water Tanks held its first meeting June 19, 1974.

After many meetings and the presentation of many differing viewpoints, this committee decided to defer work on a standard for tendon tanks and to concentrate only on a standard for wire-wound tanks. AWWA D110-86, *Standard for Wire-Wound Prestressed Concrete Tanks*, was published in 1986.

In 1988 the AWWA Standards Council authorized the formation of a new standards committee to develop a standard for tendon-type prestressed concrete tanks, with the assigned task of developing a standard for the safe, efficient use of tendon-stressing techniques for design and construction of tanks. Subsequently this new AWWA standards committee was formed and held its first meeting on June 21, 1989.

This first edition of this standard incorporates applicable work of ACI and the AWWA standards committee that developed AWWA D110-86. It contains requirements and recommendations, specifically for potable water containment structures prestressed with bonded circumferential tendons.

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 all direct and indirect drinking water additives. Other members of the original consortium included the American Water Works Association Research Foundation (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, ANSI[†]/NSF[‡] 60, Drinking Water Treatment Chemicals—Health Effects, and ANSI/NSF 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 ANSI/NSF 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.

Appendix A, “Toxicology Review and Evaluation Procedures,” to ANSI/NSF 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 Appendix A procedures may not always be identical, depending on the certifier.

AWWA D115-95 does not address additives requirements. Thus, users of this standard should consult the appropriate state or local agency having jurisdiction in order to

1. Determine additives requirements, including applicable standards.
2. Determine the status of certifications by all 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. *General.* This standard reflects a committee consensus of industry practice concerning the design, detailing, and construction of circular prestressed concrete water tanks that employ bonded circumferential prestressing tendons, placed either internally or on the wall’s surface. Recommended criteria and guidelines are presented to assist engineers in design and construction of both cast-in-place and precast concrete circular tanks using tendon prestressing, based on the specific detailed

*Persons in Canada, Mexico, and non-North American countries should contact the appropriate authority having jurisdiction.

[†]American National Standards Institute, 11 West 42nd St., New York, NY 10036.

[‡]NSF International, 3475 Plymouth Rd., Ann Arbor, MI 48106.

[§]Both publications available from National Academy of Sciences, 2102 Constitution Ave. N.W., Washington, DC 20418.

experience of the committee members. Engineering principles are tied to existing codes where applicable. Design and construction of circular prestressed concrete water tanks is complex, requiring a wide range of special knowledge and experience. This standard represents a sharing of information on the unique aspects of analysis and construction that are encountered with these types of structures.

II.B. *Site-Specific Conditions.* 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 or 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 study all factors affecting the structure carefully.

III. Use of This Standard. AWWA has no responsibility for the suitability or compatibility of the provisions of this standard to any intended application by any user. Accordingly, each user of this standard is responsible for determining that the standard's provisions are suitable for and compatible with that user's intended application.

III.A. *Purchaser Options and Alternatives.* It is not the purpose of this standard either to 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 tendon prestressed concrete tanks by one of two alternative methods.

Under the first method, a qualified engineer is retained by the purchaser to design the structure and 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, such designs are referred to as *purchaser-furnished designs*.

Under the second method, the purchaser prepares performance specifications that require bidding constructors to prepare detailed project designs and specifications and to construct the tank according to the approved design. In this standard, such projects are referred to as *design-construct projects*.

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

AWWA D115-95 does not address matters related to site selection and property acquisition. It has been assumed that the purchaser will have conducted sufficient background work in the form of, for example, water system studies, predesign surveys, subsurface investigations, and preliminary design work to establish the desired tank site, volume, operating water depth, and elevations. It is also assumed the purchaser will have acquired the property, easements, and rights-of-way necessary for construction of the tank structure and associated water pipelines connecting it to the water system. Finally, it has been assumed that the purchaser will accomplish and/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, as well as 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 professional engineer specializing in soil mechanics, including allowable bearing loads, anticipated total and differential settlements, and the seismic soil profile type.

4. Structure 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, the purchaser may specify an importance factor for earthquake design as described in Sec. 4.3.1 or provide design values for the horizontal acceleration and for the spectrum velocity.

5. A groundwater drainage and collection system plan.

6. Delivery of electric power and water service to the site.

III.A.1. Information Required for Use of This Standard. The items that follow are either required information or alternative options in the standard that should be considered and covered in the purchaser's specifications, unless the purchaser intends that the choice for a particular option be left to the tank designer's discretion.

1. The standard used—that is, AWWA D115-95, Standard for Circular Prestressed Concrete Water Tanks With Circumferential Tendons.

2. The required tank capacity and either the diameter or operating water depth.

3. The size, material, location, details, cover depths, and limits of responsibility of all pipe connections.

4. The required elevation of the overflow weir and freeboard requirements.

5. The size, material, arrangement, and location of the overflow pipe.

6. Finish grade relative to the tank foundation. (Are the tank walls to be completely exposed, partially buried, or completely buried?)

7. Aboveground exterior concrete coatings or additional shotcrete cover, if required (Sec. 2.11.1 and Sec. 5.4.3).

8. Belowgrade concrete coatings, if required (Sec. 2.11.2).

9. Design loading conditions (Sec. 3.3.1, Sec. 3.3.2, Sec. 3.3.3, and Sec. 3.3.4).

10. Type of roof structure required: flat with column supports or domed (Sec. 3.8, Sec. 3.9, and Sec. 3.10).

11. Freeze protection requirements (Sec. 3.12).

12. Tank appurtenances required:

a. Arrangement of inlet–outlet piping, including cover depths (Sec. 3.13.1).

b. Whether baffles are required (Sec. 3.13.1).

c. Whether a removable silt stop is required.

d. Encasement of piping beneath the floor slab (Sec. 3.13.1.3).

e. Design rates of inflow and outflow for design of overflow and vent systems (Sec. 3.13.2.1 and Sec. 3.13.3.2).

f. Tank drain line (Sec. 3.13.2.3).

g. Water-level gauge or pressure sensor (Sec. 3.13.2.4).

h. Required roof openings and hatches (Sec. 3.13.3).

- i. Roof ventilator requirements (Sec. 3.13.3.2).
- j. Access ladder and stair requirements (Sec. 3.13.4).
- 13. Seismic zone classification (Table 4 and Uniform Building Code).
- 14. Seismic importance factor (Table 1).
- 15. Seismic soil profile coefficient (Table 3) from geotechnical foundation survey provided by the purchaser.
- 16. Type of shotcrete finish (Sec. 5.4.5.9).
- 17. Watertightness criteria (Sec. 6.1.4).

III.B. *Modification to Standard.* Any modification to the provisions, definitions, or terminology in this standard must be provided in the purchaser's specifications.

IV. Major Revisions. This is the first edition of this standard.

V. Comments. If you have any comments or questions about this standard, please call the AWWA Standards and Materials Development Department, (303) 794-7711, ext. 6283, FAX (303) 794-7310, or write to the department at 6666 W. Quincy Ave., Denver, CO 80235.

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AWWA STANDARD FOR CIRCULAR PRESTRESSED CONCRETE WATER TANKS WITH CIRCUMFERENTIAL TENDONS

SECTION 1: GENERAL

Sec. 1.1 Scope

This standard covers current and recommended practice for the design, construction, and field observations of circular prestressed concrete tanks using tendons for circumferential prestressing. This standard covers tanks using bonded circumferential (horizontal) prestressing tendons in the wall or on the wall's exterior surface. This standard does not cover tanks using unbonded circumferential (horizontal) prestressing tendons in the wall or on the wall's exterior surface. This standard also covers the use of bonded or unbonded prestressing tendons, or conventional reinforcing, vertically in the wall and in the floor and roof. This standard applies to containment structures for use with potable water or raw water.

Sec. 1.2 Definitions

The following definitions shall apply in this standard.

1.2.1 *Parties*: The persons, companies, or organizations generally involved in the purchase, design, and construction of circular prestressed concrete tanks. These include:

1. *Bidder*: the party from whom bids for construction of the tank are solicited or received (by the purchaser).
2. *Constructor*: the party that furnishes the work and materials for placement or installation (in providing the tank for the purchaser).
3. *Design constructor*: the firm that specializes in design and construction of circular prestressed concrete tanks. (The firm shall have an experienced registered

professional engineer who will assume responsibility for the design of such tanks on its staff, in its employ, or under contract.)

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

5. *Prestresser*: the person, company, or organization that applies the prestressing forces to the tank.

6. *Purchaser*: the person, company, or organization that purchases any materials or work to be performed (in the design and construction of the tank).

7. *Purchaser's engineer*: the registered professional engineer representing the purchaser in the design of the tank and/or during its construction.

1.2.2 *Core wall*: That portion of a concrete wall that is circumferentially prestressed.

1.2.3 *Horizontal wall joints*: Connection between the tank's core wall and its foundation or floor slab or roof or dome. Types of joints may be generally defined as shown in Sec. 1.2.4.

1.2.4 *Joint restraint conditions*: Top and bottom boundary conditions for the cylindrical shell wall.

1. *Hinged*: full restraint of radial translation and negligible restraint of rotation.

2. *Fixed*: full restraint of radial translation and full restraint of rotation.

3. *Partially fixed*: full restraint of radial translation and partial restraint of rotation.

4. *Unrestrained*: limited restraint of radial translation and negligible restraint of rotation.

5. *Changing restraint*: a joint of a different type during and after prestressing. An example is a joint that is unrestrained during prestressing but is hinged after prestressing. The change in joint type is a result of grout installation, which prevents radial translation after prestressing.

1.2.5 *Membrane floor*: A highly reinforced (see Sec. 3.6), low-moment resistant, slab-on-grade designed to be a flexible watertight floor system.

1.2.6 *Shotcrete*: Pneumatically applied mortar conforming with ACI 506.2.

1.2.7 *Shotcrete cover*: Shotcrete covering external tendons.

1. *Tendon coat*: initial application of shotcrete between and over the tendon.

2. *Body coat(s)*: the remainder of the shotcrete cover.

3. *Cover coat*: the tendon coat plus the body coat.

1.2.8 *Tendon*: High-strength steel elements, such as strands or bars, used to impart compressive stress to concrete. In pretensioned concrete, the tendon is just the bare strand. In posttensioned concrete, the tendon includes the complete assembly consisting of end anchorages or couplers, prestressing steel and any coating materials, and sheathing filled with corrosion-inhibiting material or ducts filled with grout.

1. *Anchorage*: In posttensioning, a device or assembly used to transfer the tendon force to the concrete.

2. *Bonded tendon*: A prestressing tendon that is bonded to the concrete section with cement grouting or shotcrete. In a bonded internal tendon, the prestressing steel is bonded continuously to the concrete section through the duct corrugations after stressing and cement grouting. External tendons are bonded to the concrete wall section by the shotcrete cover.

3. *Circumferential tendon*: A tendon that goes around the tank circumference. Circumferential tendons shall be bonded using cement grout or shotcrete.

4. *Corrosion-inhibiting materials*:
 - a. Cement grout: A portland cement mix produced to inhibit corrosion and transfer bond in the ducts of bonded internal tendons.
 - b. Grease coating: Grease with corrosion-inhibiting additives that leaves no voids between the strand and sheathing in an unbonded tendon.
 - c. Galvanizing: Zinc coating.
 - d. Epoxy coatings: Factory-applied epoxy coatings, with or without grit for bond.
 - e. Shotcrete cover coat: Shotcrete covering for external tendons (see Sec. 1.2.7).
5. *Coupler*: A device that joins two pieces of a tendon.
6. *Ducts*: Corrugated tubing for forming internal voids in the concrete for the bonded prestressing.
7. *Prestressing steel*: High-strength steel used to prestress concrete; commonly seven-wire strands, bars, or groups of strands.
8. *Sheathing*: Extruded polyethylene or polypropylene enclosures in which greased, post-tensioning tendons are encased and waterproofed.
9. *Unbonded tendon*: A tendon encased in a corrosion-inhibiting material (grease) and sheathing that is not bonded continuously to the concrete section but is anchored at each end after prestressing.
- 1.2.9 *Specifications*: A document describing the requirements for the structure that is to be provided and containing the details of construction materials, methods, or constructor performance required in conjunction with the construction drawings and other contract documents for the structure.
- 1.2.10 *Standpipe*: A cylindrical structure for water storage 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.
- 1.2.11 *Tank*: A 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.
- 1.2.12 *Waterstop*: An impervious barrier installed to prevent passage of water through a construction or expansion joint between adjacent elements of concrete or shotcrete construction.
- 1.2.13 *Prestressing*: The application of compressive stresses to concrete through tendons prior to application of loads, such as filling with water.
- 1.2.14 *Epoxy bonding agent*: An epoxy used in repair processes to bond fresh, plastic concrete mix, mortar, or epoxy mortar to hardened concrete.
- 1.2.15 *Epoxy mortar*: An epoxy mix used for repair of concrete.

Sec. 1.3 References

References identified refer to the latest revision available. The following is a list of references used in this AWWA standard:

- ACI* 301—Specifications for Structural Concrete.
- ACI 302.1R—Guide for Concrete Floor and Slab Construction.
- ACI 304R—Guide for Measuring, Mixing, Transporting, and Placing Concrete.

*American Concrete Institute, 22400 W. Seven Mile Rd., P.O. Box 19150, Detroit, MI 48219.

- ACI 305R—Hot Weather Concreting.
 ACI 306R—Cold Weather Concreting.
 ACI 308—Standard Practice for Curing Concrete.
 ACI 318—Building Code Requirements for Reinforced Concrete.
 ACI 344R-T—Design and Construction of Circular Prestressed Concrete Structures With Circumferential Tendons.
 ACI 344R-W—Design and Construction of Circular Wire and Strand Wrapped Prestressed Concrete Structures.
 ACI 347—Recommended Practice for Concrete Formwork.
 ACI 350R—Environmental Engineering Concrete Structures.
 ACI 503.2—Standard Specification for Bonding Plastic Concrete to Hardened Concrete With a Multi-Component Epoxy Adhesive.
 ACI 504R—Guide to Sealing Joints in Concrete Structures.
 ACI 506R—Recommended Practice for Shotcreting.
 ACI 506.2—Specifications for Materials, Proportioning, and Application of Shotcrete.
 ACI 515R—A Guide to the Use of Waterproofing, Dampproofing, Protective and Decorative Barrier Systems for Concrete.
 ACI SP-2—ACI Manual of Concrete Inspection.
 ASCE* 7—Minimum Design Load(s) for Buildings and Other Structures.
 ASTM† A416—Standard Specification for Uncoated Seven-Wire Stress-Relieved Steel Strand for Prestressed Concrete.
 ASTM A475—Standard Specification for Zinc-Coated Steel Wire Strand.
 ASTM A586—Standard Specification for Zinc-Coated Parallel and Helical Steel Wire Structural Strand.
 ASTM A603—Standard Specification for Zinc-Coated Steel Structural Wire Rope.
 ASTM A615—Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement.
 ASTM A722—Standard Specifications for Uncoated High-Strength Steel Bar for Prestressed Concrete.
 ASTM A775—Standard Specification for Epoxy-Coated Reinforcing Steel Bars.
 ASTM A882—Standard Specification for Epoxy-Coated Seven-Wire Prestressing Steel Strand.
 ASTM C881—Standard Specification for Epoxy-Resin-Base Bonding System for Concrete.
 ASTM C882—Standard Test Method for Bond Strength of Epoxy-Resin Systems Used in Concrete.
 ASTM C900—Standard Test Method for Pullout Strength of Hardened Concrete.
 ASTM C920—Standard Specification for Elastomeric Joint Sealants.
 ASTM C928—Standard Specification for Packaged, Dry, Rapid Hardening Cementitious Materials for Concrete Repairs.
 ASTM C939—Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete.
 ASTM D395—Standard Test Methods for Rubber Property-Compression Set.

*American Society of Civil Engineers, 345 E. 47 St., New York, NY 10017-2398.

†American Society for Testing and Materials, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

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

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

ASTM D1752—Standard Specification for Preformed Sponge Rubber and Cork 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 D4258—Standard Practice for Surface Cleaning Concrete for Coating.

ASTM D4259—Standard Practice for Abrading Concrete.

AWWA C652—Standard Standard for Disinfection of Water-Storage Facilities.

Fed. Spec.* SS-S-210A—Sealing Compound for Expansion Joints.

Fed. Spec. TT-S-227—Polysulfide Sealant.

US Army Corps of Engineers Spec. CRD-C572—Specification for PVC Waterstops.*
Handbook of Molded and Extruded Rubber.†

PCI‡ Manual 116—Quality Control.

PTI§ Post-Tensioned Commercial and Industrial Floors.

PTI Post-Tensioning Manual, Fifth Edition.

PTI Field Procedures Manual for Unbonded Single Strand Tendons.

PTI Manual for Certification of Plants Producing Unbonded Single Strand Tendons.

PTI Specification for Unbonded Single Strand Tendons.

Uniform Building Code.**

SECTION 2: MATERIALS

Sec. 2.1 Concrete and Shotcrete

2.1.1 *General.* The quality of concrete or shotcrete is of great importance to a tendon tank's structural integrity and watertightness. Therefore, care shall be taken throughout the construction to maintain close quality control of the materials, proportions, forming, embedded items, placement, finishing, curing, and other details of the work. In the context of watertightness, the aggregates used in concrete and shotcrete are impermeable and the permeability coefficient of cement paste having a water-cement ratio of 0.45 is about 10^{-14} m/s (appendix A, Ref. 12). This renders uncracked, properly placed concrete and shotcrete essentially impermeable, less than 1 gal/year (3.78 L/year) through the wall of a typical 5-mil (18.9-ML) gal tank.

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

†Goodyear Tire and Rubber Company, Akron, OH.

‡Precast/Prestressed Concrete Institute, 175 W. Jackson Blvd., Chicago, IL 60604.

§Post-Tensioning Institute, 1717 W. Northern Ave., Suite 218, Phoenix, AZ 85021.

**International Conference of Building Officials, 5360 S. Workman Mill Rd., Whittier, CA 90601.

Concrete and shotcrete in water tanks that will be in contact with the stored water shall:

1. Be dense and of very low permeability in order to retain water, minimize potential contamination of the water supply, and provide corrosion protection for the reinforcement steel.

2. Provide a surface that will facilitate cleaning and reduce maintenance. A smooth formed wall finish for cast-in-place concrete, as defined by ACI 301, and precast panels of good workmanship standards will be acceptable.

2.1.2 Concrete and shotcrete materials. Concrete and shotcrete materials shall conform to the recommendations of ACI 301, ACI 350R, and ACI 506.2 except as modified herein. The mix proportions shall be submitted to the purchaser and shall meet the strength and other requirements of the specifications. Prestressed concrete or shotcrete cover coats for external tendons, including aggregates and admixtures, and cement grout in contact with internal tendons shall not contain water-soluble chloride ions in excess of 0.06 percent of the weight of the cement in the mix. Concrete or shotcrete subject to freezing shall be air-entrained.

2.1.2.1 Concrete. Concrete shall be proportioned for a maximum water–cement ratio of 0.45 and other properties in accordance with ACI 350R. Fly ash or other pozzolans that do not decrease durability are recommended for decreased permeability but are not required as a part of this standard. When pozzolans are part of the mixture, the water–cementitious materials ratio shall be 0.45 or less based on the cement plus pozzolans. Concrete shall be protected from deterioration that can be caused by contact with aggressive soils and other subsurface conditions. Requirements for the concrete shall be established based on the expected conditions. Criteria for the evaluation of sulfate conditions are covered in ACI 350R.

2.1.2.2 Shotcrete. Shotcrete in contact with prestressing tendons shall consist of not more than three parts sand to one part portland cement by weight; other shotcrete shall not contain more than four parts sand to one part cement by weight. Either the wet-mix or dry-mix process referred to in ACI 506R may be used for shotcrete unless the specifications require the use of a specific process, except that dry-mix shotcrete shall not be used in domes subject to freezing cycles. Wet-mix shotcrete for domes in areas subjected to freezing shall be air-entrained with an in-place air content of 5 percent or greater. Shotcrete shall be proportioned for a 28-day strength equal to or exceeding that for which the core wall is designed, but not less than 4,500 psi (31 MPa) unless otherwise specified.

2.1.3 Cement mortar. Mortar used for repair of concrete and encasement of waterstops 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. 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.

2.1.4 Cement grout. Cement grout used for bonded tendons shall contain not more than 0.45 parts water to 1 part portland cement by weight (approximately 4.5 gal (17 L) per sack of cement). Cement grout for tendons shall contain admixtures, used in accordance with the manufacturer's recommendations, to prevent bleeding or grout settlement. Cement grout shall not contain water-soluble chloride ions in excess of 0.06 percent of the weight of the cement in the mix.

Sec. 2.2 Mixing Water

Mixing water shall conform to the requirements of ACI 318 and shall be potable.

Sec. 2.3 Admixtures

Admixtures shall comply with the requirements of ACI 301 or ACI 506.2 and shall not contain chlorides, fluorides, sulfides, or nitrates, in more than trace amounts, because of the possible corrosive effect of those substances on the prestressed reinforcement. Materials in contact with potable water shall not impart taste, odor, or toxic chemicals to the water. All admixtures shall be compatible.

Sec. 2.4 Reinforcement

2.4.1 *Nonprestressed reinforcement.*

2.4.1.1 Reinforcing bars shall conform to the requirements of ASTM A615 and ACI 318. Epoxy-coated bars shall be in accordance with ASTM A775.

2.4.1.2 Strand or dowel bars used for seismic ties in joints shall be epoxy coated with grit or deformations for bond, or galvanized. Epoxy-coated strand shall be in accordance with ASTM A882. Galvanized strand or bars shall conform to ASTM A416 or to ASTM A475, ASTM A586, ASTM A603, or ASTM A615 prior to coating. Zinc coating shall be 0.85 oz/ft² (0.26 kg/m²) in accordance with ASTM A475, Table 4, class B.

2.4.2 *Prestressed reinforcement.*

2.4.2.1 Prestressed tendons shall conform to the requirements of Sec. 3.5.5 of ACI 318. In addition to ACI 318, materials shall conform to ASTM A416, ASTM A722, ASTM A882, and applicable sections of the PTI Post-Tensioning Manual.

2.4.2.2 Epoxy-coated or galvanized prestressing strand shall conform to the minimum elongation requirements of ASTM A416. Zinc coating shall be 0.85 oz/ft² (0.26 kg/m²) in accordance with ASTM A475, Table 4, class B, and shall be used to provide long-term corrosion protection.

2.4.2.3 Anchorages or couplers for prestressed reinforcement shall conform to the requirements of ACI 318 and the PTI specifications. They shall be ferrous material compatible with the reinforcement and shall develop at least 95 percent of the full strength of the strand. Anchorages and other accessories in contact with the prestressing elements may be galvanized or epoxy- or plastic-coated iron or steel.

Sec. 2.5 Ducts

Duct material for tendons may be flexible, semiflexible, or rigid steel, or corrugated or smooth polyvinyl chloride (PVC) or polyethylene as appropriate for bonded or unbonded tendons. Ducts shall be sufficiently strong to retain their shape during construction and shall be mortartight.

Sec. 2.6 Sheathing

Sheathing for unbonded single strand tendons shall conform to ACI 318 and the Post-Tensioning Institute's Specification for Unbonded Single Strand Tendons for tendons in an aggressive (corrosive) environment. The sheathing for unbonded single strand tendons shall be of virgin high-density polyethylene or polypropylene, and it shall be produced by the seamless extrusion process over corrosion-preventive grease that leaves no air pockets and has a thickness of at least 40 mil (1.02 mm) with no negative tolerance. A watertight plastic sleeve filled with corrosion-preventive grease shall connect the sheathing to the anchorage. The anchorages for single strand tendons shall be capped at the wedge cavity with a nonmetallic watertight cover. The complete dead-end anchorage assembly shall be installed at the plant. Capped stressing or dead-end cavities shall be filled with grease. The encapsulated tendon

assembly shall remain watertight. The anchorage itself may also be protected either by epoxy coating or by encasement in a plastic covering. Unbonded single-strand tendons shall be fabricated at a plant certified by the PTI Plant Certification Program for Unbonded Tendons.

Sec. 2.7 Elastomeric Materials

2.7.1 *Waterstops.*

2.7.1.1 PVC waterstops. PVC waterstops shall be composed of ribbed virgin polyvinyl chloride meeting the requirements of CRD-C572 for tanks in cold-weather regions. Splices shall be made in accordance with the manufacturer's recommendations subject to review by the purchaser. Tests ensuring conformity to the specification shall either be made on material delivered to the jobsite or be certified by an independent testing laboratory. Plastic waterstops shall have a minimum ultimate tensile strength of 2,000 psi (13.78 MPa), an ultimate elongation of 350 percent, and shore hardness of 70 to 80 durometer.

2.7.1.2 Adhesive waterstops. Preformed plastic adhesive waterstops shall conform to Federal Specification SS-S-210A. Other adhesive waterstops acceptable to the purchaser may be used.

2.7.2 *Bearing pads.* Bearing pads used to permanently support loads in floor-to-wall or wall-to-roof joints shall consist of neoprene, polyvinyl chloride, or other material acceptable to the purchaser. Temporary shims under precast panels that are subsequently grouted into nonmoving joints may be asphalt-impregnated cork or other materials acceptable to the purchaser.

2.7.2.1 Neoprene. Neoprene bearing pads shall have a minimum ultimate tensile strength of 1,500 psi (10.5 MPa), a minimum elongation of 500 percent (ASTM D412), and a maximum compressive set of 15 percent (ASTM D395) with a hardness of 30 to 50 durometer in accordance with 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 M2BC4105A14B14, for 40-durometer material.

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

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

Sec. 2.8 Epoxy Bonding Agent

Epoxy 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, type II, grade 2, as specified in ACI 503.2. The bonding agent shall produce a bond strength, as determined by ASTM C882, greater than 1,500 psi (10 MPa) 14 days after the plastic concrete is placed. Epoxy in contact with potable water shall not impart taste or odor or leach trace elements into the water.

Sec. 2.9 Nonshrink Grout

Nonshrink grout shall meet all of the requirements of ASTM C928 and ASTM C939. This grout is used to fill stressing pockets at tendon anchorages and to repair honeycombed concrete or other repairs.

Sec. 2.10 Steel Corrosion Inhibitor

Temporary corrosion protection of prestressing steel left in the ducts for more than 10 days prior to grouting shall be provided by volatile or vapor phase inhibitors. These inhibitors are usually applied in solid form (a fine white powder) that vaporizes and coats the surface of the prestressing steel with a stable organic nitrate, which prevents corrosion by passivating the metal. The corrosion inhibitor shall have no deleterious effect on the steel or bond strength between the grout and steel, and it shall not prevent future corrosion protection of the prestressing steel by the grout.

Sec. 2.11 Concrete Coatings

2.11.1 *Above grade.* In some cases, such as tanks located in areas subject to salt spray, coatings may be desired (1) to seal the exterior surface of above-grade concrete and shotcrete domes and (2) shotcrete protection for external tendons. Coatings suitable for sealing the exterior of the tank shall be permeable to water vapor. Suitable coatings include latex-acrylics and modified-acrylate elastomers. Increasing the total thickness of the shotcrete cover coat by an additional shotcrete coat (see Sec. 5.4.3) also increases the corrosion protection.

2.11.2 *Below grade.* Coatings are recommended to seal the exterior surface of below-grade tanks for protection against aggressive soils. Coatings suitable for sealing the exterior of the tank wall include coal-tar epoxies and bitumastic compounds.

2.11.3 *Additional information.* Additional information on coatings for concrete may be found in ACI 515R.

2.11.4 *Form coatings.* For concrete surfaces that will be in contact with potable water, the form coating shall be of an organic base and be nonstaining and nontoxic.

Sec. 2.12 Sealants

Sealants are used in construction joints and movement joints at the base of the wall. Polyurethane elastomeric sealants shall meet the requirements of ASTM C920.

SECTION 3: DESIGN

Sec. 3.1 Notation*

A_{ds}	= total area of prestressing steel for dome ring (area)
b	= unit width (linear)
d	= distance from face of support (linear)
D	= unit dead load (force per unit area)
E_c	= $57,000 \sqrt{f'_c}$ short-term modulus of elasticity of normal-weight concrete or shotcrete (force per unit area, psi)
f'_c	= specified 28-day compressive cylinder strength of concrete or shotcrete (force per unit area)
f'_{ci}	= specified compressive cylinder strength of concrete at time of prestressing (force per unit area)

*Caution should be used to be consistent throughout with respect to units.

f_c	= permissible compressive concrete or shotcrete stress (force per unit area)
f_{pu}	= specified ultimate tensile stress of steel prestressing strand or high-strength bars (force per unit area)
f_{se}	= effective stress in prestressed reinforcement after all losses (force per unit area)
f_{si}	= initial stress in prestressed reinforcement after friction losses but before long-term losses (force per unit area)
f_t	= tension in extreme fiber (force per unit area)
h	= depth of water contents (linear)
k	= buckling coefficient for dome shells
l_d	= development length for bond (linear)
p	= superimposed unit live load on dome shell (force per unit area)
P_{fw}	= final prestressing force for water load (force)
r	= inside radius of tank wall (linear)
r_d	= radius of dome shell (linear)
R	= inside radius of tank (linear)
S	= safety factor—dome roof buckling
t_c	= core-wall thickness (linear)
t_d	= dome shell thickness (linear)
u	= nominal bond stress in concrete or shotcrete (force per unit area)
v_c	= nominal shear stress in concrete or shotcrete (force per unit area)
v_{max}	= maximum shear stress in reinforced section (force per unit area)
W	= total dead and live load on dome, exclusive of dome ring (force)
ϕ	= capacity reduction factor
ω	= half central angle of dome shell (degrees)

Sec. 3.2 Design Method

The tank wall, roof, and floor shall be designed for service loads and checked for required strength. The wall and roof analysis shall be based on elastic analysis using either analytical or numerical (e.g., finite element) methods. Rational inelastic analysis is also permitted (e.g., in verifying the width of a crack due to temperature or moisture gradient and in seismic design). Concrete roofs shall be designed for corrosive environments in accordance with the latest edition of ACI 318 when prestressed and ACI 350R when nonprestressed. When applicable, the analysis shall account for interaction between wall and floor and between wall and roof. The analysis shall take into account all stages of loading: construction (specified or reviewed by the tank designer), service (including tank full and empty conditions), wind, seismic, and possible overloads.

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 as a minimum. Loadings, including prestressing forces and their placement, shall follow governing codes.

3.3.1 Wall design loads. Wall design loads include the following:

1. Internal pressure—the pressure from water at maximum overflow level (that level which develops the design overflow weir capacity).
2. Backfill loading—the lateral pressure from earth backfill, symmetrical or asymmetrical. Net lateral loads, including those due to unequal backfill, shall be determined by rational methods of soil mechanics based on foundation and soils

investigations. Surcharge loads on backfill surfaces shall be considered. Backfill pressure shall not be used to reduce the amount of prestressing force required for resisting internal water pressure or other loads. Backfill forces shall be based on soil parameters for the “at rest” condition as established by a soils engineer.

3. Wind and earthquake loading. Minimum design loadings for wind and earthquake shall conform to requirements of local building codes, such as the provisions of the Uniform Building Code or ASCE 7. Seismic design criteria for prestressed concrete tanks are set forth in Sec. 4 as appropriate.

4. Construction effects. All effects of construction shall be considered, including loads resulting from surcharges on backfill, equipment, materials, and construction methods to be used.

5. Prestressing initial, temporary, and final forces and effects, including (1) bending moments and compressive stresses in the wall due to nonlinear distributions of prestressing forces and (2) temporary bending moments developing during the stressing operation.

6. External hydrostatic pressure on floor and wall from groundwater, if any.

7. Appurtenance loads.

8. Ice pressures from freezing of stored water. Alternatively, see Sec. 3.12 for ice-prevention considerations in cold climates.

9. Thermal and moisture gradients, radially, through the thickness of the wall.

10. Thermal and moisture gradients, vertically, through the height of the wall, that occur between the unburied and buried portion of the wall.

11. Temperature and moisture difference between the wall and roof or floor.

12. Anticipated total and differential settlement of the structure.

13. Strand-banding effects. For openings in walls (manholes, pipes, and other types) consideration must be given to the effects of banding of strands above and below the openings.

3.3.2 *Roof design loads.* Roof design loads include the following:

1. Dead loads.
2. Earth, snow, and other live loads.
3. Wind loads.
4. Earthquake loads.
5. Appurtenance loads.
6. Operational loads.
7. Temperature and moisture loads.
8. Construction loads.
9. Roof openings.

3.3.3 *Floor design loads.* Floor design loads include the following:

1. Dead loads.
2. Water loads.
3. Earthquake loads.
4. Uplift due to groundwater or expansive soils.
5. Radial forces from the base of the tank wall.
6. Differential and total settlement.

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

1. Overflow systems.
2. Venting.
3. Under-floor drainage systems.