



**American Water Works
Association**

The Authoritative Resource on Safe Water®

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AWWA Standard

Tendon-Prestressed Concrete Water Tanks



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Foreword

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

I. Introduction.

I.A. *Background.* The New England Water Works Association (NEWWA) established a committee in 1958 to prepare a standard 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 until a consensus could be reached on a recombined report. However, a consensus could not 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.* In the December 1972 issue of *AWWA Journal*, 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 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. ANSI/AWWA D110-86, Standard for Wire-Wound Prestressed Concrete Tanks, was published in 1986.

*ACI International, 38800 Country Club Drive, Farmington Hills, MI 48331.

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, under its first chair, Ib Falk Jorgensen.

The first edition of this standard was published in 1996 and incorporated applicable work of ACI and the AWWA standards committee, which developed ANSI/AWWA D110-86. It contained requirements and recommendations, specifically for potable water containment structures prestressed with bonded circumferential tendons.

This second edition is expanded to include tendon prestressed tanks of rectangular and other shapes, as well as circular. It was approved on Feb. 12, 2006.

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 consortium included the American Water Works Association Research Foundation (AwwaRF), 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.

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

[†] NSF International, 789 North Dixboro Rd., Ann Arbor, MI 48105.

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

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

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

II. Special Issues.

II.A. *General.* This standard reflects a committee consensus of industry practice concerning the design, detailing, and construction of prestressed concrete water tanks that employ horizontal 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 tanks using tendon prestressing, based on the specific detailed experience of the committee members. Engineering principles are tied to existing codes where applicable. Design and construction of 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 in these types of structures.

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

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 universally apply or to produce a cost-effective and 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 factors affecting the structure.

II.C. *Use of Horizontal Unbonded Tendons.* The owner must rely on the judgement of the project engineer to determine if the use of bonded or unbonded tendons is in the owner's best interest, taking into account the unique design and site conditions of each tank.

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

III.A. *Purchaser Options and Alternatives.* 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, these are referred to as *purchaser-furnished designs*.

Under the second method, the purchaser prepares performance specifications which require bidding constructors to prepare detailed project designs and specifications and construct the tank according to the approved 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 project type 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 D115 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 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 pipelines connecting it to the system. Finally, it has been assumed that the purchaser will accomplish and/or provide the following as necessary or appropriate:

1. Whether compliance with NSF/ANSI 61, Drinking Water System Components—Health Effects, is required, in addition to the requirements of the Safe Drinking Water Act.

2. The site on which the tank is to be built, with adequate space to permit the constructor to erect the structure using customary methods.

3. 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.

4. A site geotechnical survey and foundation report, including logs of borings and test pits, 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 professional engineer specializing in soil mechanics, including allowable bearing loads, anticipated total and differential settlements, and the seismic soil profile type.

5. 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.

6. A groundwater drainage and collection system plan.

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

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

III.A.1. Information Required for Use of This Standard. The items which follow are either required information or alternative options in the standard that should

be considered and covered in the purchase documents, 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 ANSI/AWWA D115, Tendon-Prestressed Concrete Water Tanks.

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

3. The size, material, location, details, cover depths, and limits of responsibility of 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. 2.12.1 and Sec. 5.4.3).

8. Below-grade concrete coatings, if required (Sec. 2.12.2).

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. Whether a removable silt stop is required.

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

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

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

14. Seismic Importance Factor (Table 1) (Sec. 4.1).

15. Seismic Soil Profile Coefficient (Table 3) from geotechnical foundation survey provided by the purchaser (Sec. 4.1).

16. Seismic Zone Classification (Table 4 and Uniform Building Code) (Sec. 4.1).
17. Type of shotcrete finish (Sec. 5.4.5.9).
18. Watertightness criteria (Sec. 6.1.4).

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

V. Major Revisions. The second edition of this standard incorporates the following major revisions:

1. The Standard ANSI/AWWA D115 title is changed from “Circular Prestressed Concrete Water Tanks With Circumferential Tendons” to “Tendon-Prestressed Concrete Water Tanks.”
2. The scope of the standard is expanded to include rectangular and other non-circular shapes as may be applicable (oblong, rectangular with rounded corners, etc.) and to allow the use of unbonded tendons as provided for in this standard.
3. Section 1 references have been updated.
4. Section 2 material standards are updated for cement grout, aggregates, admixtures, reinforcement, sheathing, bearing pads, and shrinkage compensating grout.
5. Section 3 design standards are updated for wall footings, floors, walls, vertical reinforcement, construction joints, and concrete and shotcrete cover.
6. Section 4 seismic design calculations are removed from the standard and replaced with references to appropriate ACI on Standards.
7. Section 5 construction procedures are updated for tendon ducts, grouting, and shotcreting.

VI. Comments. If you have any comments or questions about this standard, please call the AWWA Volunteer & Technical Support Group, at 303.794.7711, FAX at 303.794.7603, write to the group at 6666 West Quincy Avenue, Denver, CO 80235-3098, or e-mail standards@awwa.org.

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AWWA Standard

Tendon-Prestressed Concrete Water Tanks

SECTION 1: GENERAL

Sec. 1.1 Scope

This standard describes current and recommended practice for the design, construction, and field observations of concrete tanks using tendons for prestressing. This standard applies to containment structures for use with potable water, raw water, or wastewater.

Sec. 1.2 Definitions

The following definitions shall apply in this standard:

1. *Core wall:* That portion of a concrete wall that is horizontally prestressed.
2. *Epoxy bonding agent:* An epoxy used in repair processes to bond fresh, plastic concrete mix, mortar, or epoxy mortar to hardened concrete.
3. *Epoxy mortar:* An epoxy mix used for repair of concrete.
4. *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 Figures 2 and 3.

5. *Joint restraint conditions:* Top and bottom boundary conditions for the core wall.

a. Changing restraint: A joint may be 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.

b. Fixed: Full restraint of radial translation and full restraint of rotation.

c. Hinged: Full restraint of radial translation and negligible restraint of rotation.

d. Partially fixed: Full restraint of radial translation and partial restraint of rotation.

e. Unrestrained: Limited restraint of radial translation and negligible restraint of rotation.

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

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

a. Bidder: The party from whom bids for construction of the tank are solicited or received by the purchaser.

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

c. Design/build constructor: The firm that specializes in design and construction of 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.

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

e. Prestresser: The person, company, or organization that applies the prestressing forces to the tank.

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

g. Purchaser's engineer: The registered professional engineer representing the purchaser in the design of the tank and during its construction.

- h. **Supplier:** The party that supplies material or services. A supplier may or may not be the manufacturer.
- 8. **Prestressing:** The application of compressive stresses to concrete through tendons prior to application of loads such as filling with water.
- 9. **Shotcrete:** Pneumatically applied mortar conforming with ACI* 506.2.
- 10. **Shotcrete cover:** Shotcrete covering external tendons.
 - a. **Tendon coat:** Initial application of shotcrete between and over the tendon.
 - b. **Body coat(s):** The remainder of the shotcrete cover.
 - c. **Cover coat:** The tendon coat plus the body coat.
- 11. **Specifications:** A document describing the requirements for the structure 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.
- 12. **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.
- 13. **Tank:** A structure for water storage, based above, at, or below grade. In general, this term refers to a structure having a wall height equal to or less than its diameter or least plan dimension.
- 14. **Tendon:** High-strength steel elements, such as strands or bars, used to impart compressive stress to concrete. In pretensioned concrete, the tendon is only the bare strand. In post-tensioned 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.
 - a. **Anchorage:** In post-tensioning, a device or assembly used to transfer the tendon force to the concrete.
 - b. **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.

* ACI International, 38800 Country Club Drive, Farmington Hills, MI 48331.

- c. Circumferential tendon: A horizontal tendon in a circular tank.
 - d. Corrosion-inhibiting materials:
 - d.1. Cement grout: A portland cement mix produced to inhibit corrosion and transfer bond in the ducts of bonded internal tendons.
 - d.2. Epoxy coatings: Factory-applied epoxy coatings, with or without grit for bond.
 - d.3. Galvanizing: Zinc coating.
 - d.4. Grease coating: Grease with corrosion-inhibiting additives that leaves no voids between the strand and sheathing in an unbonded tendon.
 - d.5. Shotcrete cover coat: Shotcrete covering for external tendons (see Sec. 1.2.10).
 - e. Coupler: A device that joins two pieces of a tendon.
 - f. Ducts: Corrugated tubing for forming internal voids in the concrete for the bonded prestressing.
 - g. Prestressing steel: High-strength steel used to prestress concrete; commonly seven-wire strands, bars, or groups of strands.
 - h. Sheathing: Extruded polyethylene or polypropylene enclosures in which greased, post-tensioning tendons are encased and waterproofed.
 - i. Unbonded tendon: A tendon encased in a corrosion-inhibiting material (grease) and a sheathing that is not bonded continuously to the concrete section but anchored at each end after prestressing. Tendons may be unbonded to the extent allowed by ACI 350.
15. *Waterstop*: An impervious barrier installed to prevent passage of water through a construction or expansion joint between adjacent elements of concrete or shotcrete construction.

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.
- ACI 305R—Hot Weather Concreting.
- ACI 306R—Cold Weather Concreting.
- ACI 308—Standard Practice for Curing Concrete.

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

ACI 347—Guide to Formwork for Concrete.

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

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

ACI 372W—Design and Construction of Circular Wire and Strand Wrapped Prestressed Concrete Structures and Commentary.

ACI 373—Design and Construction of Circular Prestressed Concrete Structures with Circumferential Tendons.

ACI 423.6—Specification for Unbonded Single-Strand Tendons and Commentary.

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

ACI 504R—Guide to Joint Sealants in Concrete Structures.

ACI 506R—Guide to Shotcrete.

ACI 506.2—Specification for Shotcrete.

ACI SP-2—ACI Manual of Concrete Inspection.

ANSI^{*}/AWWA C652—Disinfection of Water-Storage Facilities.

ASCE[†] 7—Minimum Design Load(s) for Buildings and Other Structures.

ASTM[‡] A416—Standard Specification for Steel Strand Uncoated Seven-Wire 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 Carbon-Steel Bars for Concrete Reinforcement.

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

[†]American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, VA 20191.

[‡]ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

ASTM A722—Standard Specifications for Uncoated High-Strength Steel Bar for Prestressed Concrete.

ASTM A775—Standard Specification for Epoxy-Coated Steel Bars Reinforcing.

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

ASTM C260—Standard Specification for Air-Entraining Admixtures for Concrete.

ASTM C494—Standard Specification for Chemical Admixtures for Concrete.

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

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

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 (Flow Cone Method).

ASTM D395—Standard Test Methods for Rubber Property—Compression Set.

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.

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

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

PCI* Manual 116—Manual for Quality Control for Plants and Production of Structural Precoat.

PTI† *Field Procedures Manual for Unbonded Single Strand Tendons.*

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

PTI Post-Tensioned Commercial and Industrial Floors.

PTI Post-Tensioning Manual.

PTI Specification for Grouting of Post-Tensioned Structures.

PTI Specification for Unbonded Single Strand Tendons.

US Army Corps of Engineers Spec. CRD-C572—Specification for PVC Waterstops.

ICBO‡ Uniform Building Code.

SECTION 2: MATERIALS

Sec. 2.1 Materials

Materials shall comply with the requirements of the Safe Drinking Water Act and other federal requirements.

Sec. 2.2 Concrete and Shotcrete

2.2.1 *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 per year (3.78 L/year) through the walls and floor of a typical 5-mil gal tank (18.9-ML).

*Precast/Prestressed Concrete Institute, 209 W. Jackson Blvd., Ste. 500, Chicago, IL 60606.

†Post-Tensioning Institute, 8601 North Black Canyon Highway, Suite 103, Phoenix, AZ 85021.

‡International Conference of Building Officials, 5360 Workman Mill Road, 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.

2.2.2 Concrete and shotcrete materials. Concrete and shotcrete materials shall conform to the recommendations of ACI 301, ACI 318, ACI 350, 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.

2.2.2.1 Concrete. Concrete shall be proportioned for a maximum water–cementitious materials ratio of 0.42 and other properties in accordance with ACI 350. 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 0.42 or less based on the cement-plus pozzolans. Concrete shall be protected from deterioration that can be caused by freezing and thawing, contact with aggressive soils and other environmental or subsurface conditions. The requirements for the concrete shall be established based on the expected conditions. The criteria for the evaluation of sulfate conditions are covered in ACI 350.

2.2.2.2 Shotcrete. Shotcrete in contact with prestressing tendons shall consist of not more than three parts sand and to one part portland cement plus pozzolans by weight; other shotcrete shall not contain more than four parts sand to one part cement plus pozzolans 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 and thawing cycles. Wet-mix shotcrete for domes in areas subjected to freezing and thawing 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).

2.2.3 Cement mortar. Mortar used for 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.

2.2.4 Cement grout. Cement grout used for bonded tendons shall contain not more than 0.45 parts water to one part portland cement by weight (approximately 4.5 gal [17 L] per sack of cement) and shall conform to PTI Specification for Grouting of Post-Tensioned Structures for grout Classes B, C, or D, as applicable. Cement grout for tendons shall contain admixtures, used in accordance with the manufacturer's recommendations and the PTI Specification for Grouting of Post-Tensioned Structures, 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.

2.2.4.1 Aggregates. Aggregates, if used, in grouts shall pass a 1.18 mm (No. 16) sieve.

Sec. 2.3 Mixing Water

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

Sec. 2.4 Admixtures

Admixtures shall comply with the requirements of ACI 301, ACI 506.2, or ASTM C494 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. Admixtures shall be compatible with the cement, mineral additives, other admixtures, and potable water, when applicable.

Admixtures conforming to ASTM C494 Types D, E, F, and G may be used in grouts. Admixtures Types F and G shall not exceed 45 oz per 100 lb (3 L per 100 kg) of portland cement. Anti-bleed admixtures used with post-tensioned grouts shall conform to PTI Specification for Grouting of Post-Tensioned Structures.

Air-entraining admixtures shall conform to the requirements of ASTM C260.

Sec. 2.5 Reinforcement

2.5.1 *Non-prestressed reinforcement.*

2.5.1.1 Rebar. Reinforcing bars shall conform to the requirements of ASTM A615 and ACI 318. The coatings on epoxy-coated bars shall be in accordance with ASTM A775.

2.5.1.2 Dowels. Strand or dowel bars used for seismic ties in joints shall be either 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.

2.5.2 *Prestressed reinforcement.*

2.5.2.1 Tendons. 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 ACI 350 and the PTI Post-Tensioning Manual.

2.5.2.2 Coatings. Epoxy-coated prestressing strand shall conform to the minimum elongation requirements of ASTM A416.

2.5.2.3 Anchors. Anchorages or couplers for prestressed reinforcement shall conform to the requirements of ACI 318 and ACI 350 and the PTI specifications. They shall be ferrous material compatible with the reinforcement and shall develop at least 95 percent of the actual breaking 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. 2.6 Ducts

Duct material for tendons may be flexible, semi-flexible, or rigid steel, or corrugated polyvinyl chloride or polyethylene. Ducts shall be sufficiently strong to retain their shape during construction and shall be mortar-tight.

Sec. 2.7 Sheathing

Sheathing for unbonded single-strand tendons shall conform to the requirements of ACI 318, ACI 350, and ACI 423.6 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 60 mil (1.50 mm) with no negative tolerance. A watertight plastic sleeve filled with corrosion-preventive grease or other means shall connect the sheathing to the anchorage such that no void spaces are left where water can accumulate. The anchorages for single-strand tendons shall be capped at the wedge cavity with a watertight cap. 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 Post-Tensioning Institute (PTI) Plant Certification Program for Unbonded Tendons.

Sec. 2.8 Elastomeric Materials

2.8.1 *Waterstops.*

2.8.1.1 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 assuring conformity shall either be made on material delivered to the job site 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.

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

2.8.2 *Bearing pads.* Bearing pads used to permanently support loads in floor-to-wall or wall-to-roof joints may consist of natural rubber, neoprene, polyvinyl chloride, or other proven materials with known physical properties that facilitate structural design. Temporary shims under precast panels that are subsequently grouted into nonmoving joints may be asphalt-impregnated cork or other materials acceptable to the purchaser.

2.8.2.1 Neoprene. Neoprene bearing pads shall have a minimum ultimate-tensile strength of 2,000 psi (14 MPa), a minimum elongation of 500 percent (ASTM D412), and a maximum compressive set of 50 percent (ASTM D395) with a hardness of Shore A 30 to 50 durometers, 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.

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

2.8.3 *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. 2.9 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. 2.10 Shrinkage Compensating Grout

Shrinkage compensating grout shall meet all of the requirements of ASTM C928 and ASTM C939. Shrinkage compensating grout shall not contain water-soluble chloride ions in excess of 0.06 percent of the weight of the cement in the mortar. Shrinkage compensating grout shall be of the nonmetallic type. This grout shall be used to fill stressing pockets at tendon anchorages and to repair honeycombed concrete or other repairs.

Sec. 2.11 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 shall not prevent future corrosion protection of the prestressing steel by the grout.

Sec. 2.12 Concrete Coatings

2.12.1 *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-acrylic 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.

2.12.2 *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.

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

2.12.4 *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. 2.13 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)

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

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)
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 crack width caused by temperature or moisture gradients 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 350 when non-prestressed. When applicable, the analysis shall account for interaction between wall and floor and between wall and roof. The analysis shall take into account 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 be in accordance with this standard and governing codes.

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

1. Internal pressure. The pressure from water at the maximum overflow level (the level that develops the design overflow weir capacity).
2. 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 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 shall conform to requirements of local building codes, such as the provisions of the Uniform Building Code or ASCE 7. The seismic loads shall conform to those provided in ACI 350.3, as modified in Section 4 of this standard.
4. Construction effects. 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 caused by non-linear distributions of prestressing forces, and (2) temporary bending moments developing during the stressing operation.