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Design of Prestressed Concrete Cylinder Pipe

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STANDARD Since 1881

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Committee Personnel

The AWWA Standards Committee on Concrete Pressure Pipe, which reaffirmed this standard without revision, had the following personnel at the time:

Wylie C. Duke, *Chair*
Richard I. Mueller, *Secretary*

User Members

K.A. Danley, Des Moines Water Works, Des Moines, Iowa
W.C. Duke, Bureau of Reclamation, Denver, Colo.
N.D. Faber, San Diego County Water Authority, Escondido, Calif.
J.C. Gehrig, Tarrant Regional Water District, Fort Worth, Tex.
W.C. HagenBurger, Beaver Water District, Lowell, Ark.
T. Peng, Metropolitan Water District of Southern California, Los Angeles, Calif.
V.D. Scutelnicu, Los Angeles Dept. of Water & Power, Los Angeles, Calif.
A.F. Williams, Louisville Water Company, Louisville, Ky.

General Interest Members

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H.H. Bardakjian, Consulting Engineer, Glendale, Calif.
W.R. Brunzell, Brunzell Associates Ltd., Wilmette, Ill.
B.C. Coltharp, Freese and Nichols Inc., Dallas, Tex.
D. Faber, (*liaison, nonvoting*), Standards Council Liaison, Faber & Associates, Columbus, Ohio
F.S. Kurtz, (*liaison, nonvoting*), Standards Engineer Liaison, AWWA, Denver, Colo.
A.S. Maughn, (*alternate*), Freese and Nichols Inc., Dallas, Tex.
R. Ortega, Aurora Technical Services LLC, Houston, Tex.
A. Rodriguez, HDR Engineering Inc., San Antonio, Tex.
J.J. Roller, CTLGroup, Skokie, Ill.
A.E. Romer, (*alternate*), AECOM, Orange, Calif.
R.F. Williams, AECOM, Miami, Fla.
M.S. Zarghamee, Simpson Gumpertz & Heger Inc., Waltham, Mass.

Producer Members

K.R. Baas, Thompson Pipe Group – Pressure, Hattiesburg, Miss.

G. Bizien, Forterra Pressure Pipe, St-Eustache, Que., Canada

K.M. Brown, Vianini Pipe Inc., Somerville, N.J.

M. DeFranco, (*alternate*), DECAST Ltd., Utopia, Ont., Canada

B.D. Keil, Northwest Pipe Company, Draper, Utah

R.D. Mielke, (*alternate*), Northwest Pipe Company, Raleigh, N.C.

R.I. Mueller, American Concrete Pressure Pipe Association, Hayden, Idaho

S. Theroux, (*alternate*), Forterra Pressure Pipe, St-Eustache, Que., Canada

J.A. Tully, DECAST Ltd., Utopia, Ont., Canada

* Alternate

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Foreword

This foreword is for information only and is not a part of ANSI/AWWA C304.*

I. Introduction.

I.A. *Background.* This standard establishes the mandatory minimum requirements for the structural design of prestressed concrete cylinder pipe (PCCP) and provides procedures that will ensure that the design requirements are satisfied.

There are two types of PCCP: (1) lined-cylinder pipe (LCP), with a core composed of a steel cylinder lined with concrete, which is subsequently prestressed with high-tensile wire wrapped directly around the steel cylinder; and (2) embedded-cylinder pipe (ECP), with a core composed of a steel cylinder encased in concrete, which is subsequently prestressed with high-tensile wire wrapped around the exterior concrete surface. The cores of both types of pipe are coated with portland-cement mortar.

Before the procedures and requirements contained in this document were developed, the design of PCCP was determined by two distinct procedures. These were designated methods A and B described in appendixes A and B of ANSI/AWWA C301-84, Prestressed Concrete Pressure Pipe, Steel-Cylinder Type, for Water and Other Liquids.

Method A used a semiempirical approach based on (1) W_o , which is nine-tenths of the three-edge bearing test load that causes incipient cracking; and (2) the theoretical hydrostatic pressure, P_o, which relieves the calculated residual compression in the concrete core as a result of prestressing. The allowable combinations of three-edge bearing load and internal pressure were determined by a cubic parabola, passing through W_o and P_o , which defined the limits of these combinations. The three-edge bearing loads used in method A were converted to earth loads and transient external loads using bedding factors provided in AWWA Manual M9, *Concrete Pressure Pipe* (1979) and in the ACPA† *Concrete Pipe Design Manual* (1988).

Method B was based on a procedure that limited the maximum combined net tensile stress in pipe under static external load and internal pressure to a value equal to $7.5\sqrt{f'_c}$, where f'_c = the 28-day compressive strength of core concrete in psi ($0.62\sqrt{f'_c}$, where f'_c = the 28-day compressive strength of core concrete in MPa).

Both design methods limited the working pressure to P_o for ECP and to $0.8P_o$ for LCP, where P_o was the internal pressure required to overcome all compression in

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

† American Concrete Pipe Association, 1303 West Walnut Hill Lane, Suite 305, Irving, TX 75038.

the core concrete excluding external load. Under transient conditions, such as those produced by surge pressures and live loads, both methods permitted increased internal pressure and external load.

Although the two methods of design produced similarly conservative results that served PCCP users well for nearly half a century, a unified method of design, described in this standard, was developed to replace methods A and B.

The following objectives for the unified design procedure were established:

1. It should replace both existing methods, the semiempirical method A and the working stress method B, described in ANSI/AWWA C301-84.

2. It should be based on state-of-the-art procedures for the design and analysis of concrete and prestressed concrete structures.

3. It should account for the state of prestress in the pipe, as well as the combined effects of external loads, pipe and fluid weights, and internal pressures.

4. It should agree with the results of 40 years of experimental data gathered by the American concrete pressure-pipe industry.

5. It should preclude the onset of visible cracking under working plus transient conditions.

6. It should provide adequate safety factors based on elastic and strength limit states.

The method of calculating residual stresses in the concrete core, the steel cylinder, and the prestressing wire was updated to separately account for the effects of elastic deformation, creep, and shrinkage of concrete, and the relaxation of the prestressing wire (Zarghamee, Heger, and Dana 1988a; see appendix B). Intrinsic wire relaxation, creep factors, and shrinkage strains obtained from procedures recommended by ACI* Committee 209 (1982) (ACI 1982; see appendix B) were used in a step-by-step integration procedure (Zarghamee 1990; see appendix B) to evaluate the time-related variations of stress in the pipe elements. The results of the step-by-step integration procedure, applied to pipe in a buried environment, were used to develop simplified equations for practical design use.

Calculations of the design creep factor and shrinkage strain for buried pipe are based on the procedures recommended by ACI Committee 209. Creep and shrinkage are computed as functions of time, relative humidity, volume-to-surface ratio, age at loading, curing duration, concrete composition, and method of placement. Design values for creep factor and shrinkage strain are based on a 50-year exposure of pipe to the

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

environment to which typical pipe will be exposed. The default environment is given in the following scenario:

1. The pipe is initially stored outdoors for 270 days.
2. The pipe is buried and kept empty for 90 days.
3. The pipe is filled with water for the duration of its design life.

The periods of time given in items 1 and 2 above may be extended at the purchaser's discretion.

The design wire-relaxation factor was obtained by measuring the intrinsic loss of prestressing wire, manufactured in accordance with ASTM* A648, Specification for Steel Wire, Hard Drawn for Prestressing Concrete Pipe, under constant strain and accounting for the reduction in relaxation loss caused by creep and shrinkage.

The simplified procedure, which separately accounts for concrete creep and shrinkage and wire relaxation, complies with test results (Zarghamee, Fok, and Sikiotis 1990; see appendix B) and with prior design practice (Zarghamee, Heger, and Dana 1988b; see appendix B).

The method adopted for determining allowable combinations of internal pressure, external loads, and pipe and fluid weights is based on satisfying certain limit-states design criteria (Heger, Zarghamee, and Dana 1990; see appendix B). The purpose of using limit-states design is to ensure the serviceability of pipe for design loads and working plus transient pressures and the safety of pipe against loss of prestress and failure for loads and pressures beyond the serviceability limits.

The limit-states design procedure is based on limiting circumferential thrust and bending moment resulting from internal pressure, external loads, and pipe and fluid weights. The procedure specifies that certain limit-states design criteria are not exceeded when the pipe is subjected to working loads and pressures and to working plus transient loads and pressures.

In the design procedure, three sets of limit-states criteria are used: serviceability, elastic, and strength. To satisfy the three sets of limit-states criteria, combined loads and pressures corresponding to each of these limit states must be calculated. As a result, the combined moments and thrusts in the pipe wall corresponding to the limit states must be calculated, and both uncracked and cracked cross sections must be considered. For accurate calculation of these combined moments and thrusts, the constitutive properties of concrete and mortar in tension must be expressed correctly. A

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

trilinear model for stress–strain relationships of concrete and mortar was adopted for use in the limit-states design of PCCP.

Serviceability limit-states criteria are intended to preclude microcracking in the core and to control microcracking in the coating under working loads and pressures. These criteria are also intended to preclude visible cracking in the core and the coating under working plus transient loads and pressures. Criteria are provided for the following:

1. Core-crack control.
2. Radial-tension control.
3. Coating-crack control.
4. Core-compression control.
5. Maximum pressure.

Elastic limit states are defined to limit combined working plus transient loads and pressures so that if cracks develop in a prestressed pipe under the transient condition, the pipe will have an elastic response, preventing damage or loss of prestress. Criteria are provided for the following states:

1. Wire-stress control.
2. Steel-cylinder–stress control.

Strength limit states are defined to protect the pipe against yielding of the prestressing wire, crushing of the concrete core under external load, and tensile failure of the wire under internal pressure. Safety factors are applied to loads and pressures that produce the strength limit states. The following criteria are provided:

1. Wire yield-strength control.
2. Core compressive-strength control.
3. Burst-pressure control.
4. Coating bond-strength control.

The limit-states design procedure for PCCP subjected to the combined effects of internal pressure, external loads, and pipe and fluid weights

1. Is a rational procedure based on state-of-the-art structural engineering practice for concrete structures.
2. Uses parameters resulting from many tests of prestressed concrete pipe and its constitutive materials.
3. Is substantiated by the results of combined-load and three-edge bearing verification tests of LCP and ECP.

The standard includes tables of standard designs for prestressed concrete LCP and a design example for ECP.

I.B. *History.* The AWWA Standards Committee on Concrete Pressure Pipe supported a recommendation that a design standard be developed for PCCP to be manufactured in accordance with ANSI/AWWA C301, Prestressed Concrete Pressure Pipe, Steel-Cylinder Type, for Water and Other Liquids. On June 20, 1989, the C301 Design Subcommittee first met for the purpose of developing the design standard. At its October 1989 meeting, the AWWA Standards Council authorized a separate design standard for PCCP. The first edition of this standard, ANSI/AWWA C304, Design of Prestressed Concrete Cylinder Pipe, was approved by the Board of Directors on June 18, 1992. Subsequent editions were approved on Jan. 24, 1999, and Jan. 21, 2007. This edition was approved by the AWWA Board of Directors on Jan. 19, 2014, and it was reaffirmed without revision on Oct. 28, 2019.

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

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

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

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

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

Annex A, "Toxicology Review and Evaluation Procedures," to NSF/ANSI 61 does not stipulate a maximum allowable level (MAL) of a contaminant for substances not regulated by a USEPA final maximum contaminant level (MCL). The MALs of an unspecified list of "unregulated contaminants" are based on toxicity testing guidelines (noncarcinogens) and risk characterization methodology (carcinogens). Use of Annex A procedures may not always be identical, depending on the certifier. ANSI/AWWA C304 does not address additive requirements. Thus, users of this standard should consult the appropriate state or local agency having jurisdiction in order to

1. Determine additive 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. The information needed for selection of designs from the tables of standard designs includes:

1. Inside diameter of pipe (in. [mm]).
2. Internal working pressure (psi [kPa]).
3. Type of standard bedding.
4. Height of earth cover over the pipe (ft [m]).

The standard criteria used in the design selection tables are summarized in Sec. 9.4 preceding the design selection tables. If different design criteria are required by the purchaser, they should be specified by the purchaser, stated in the contract documents, and accounted for in the design of the pipe.

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.* For LCP designs not included in the standard design tables and for all ECP designs, the design procedures specified in the standard must be implemented. For this purpose, the following information is to be provided by the purchaser:

1. Inside diameter of pipe (in. [mm]).
2. Fluid unit weight (lb/ft^3 [kg/m^3]) if a fluid other than fresh water is required.
3. Height of earth cover over the pipe (ft [m]) or external dead load (lb/ft [kg/m]).

4. External surcharge load (lb/ft [kg/m]).

5. External transient load (lb/ft [kg/m]) if loading other than AASHTO* HS20 loading is required.

6. Internal working pressure (psi [kPa]).

7. Internal transient pressure (psi [kPa]).

8. Internal field-test pressure (psi [kPa]).

9. Installation requirements.

10. Time period of exposure to outdoor environment (days) if more than 270 days.

11. Relative humidity of the outdoor environment.

12. Time exposure of pipe to burial environment before water filling (days) if more than 90 days.

III.A.1 *Information to Be Provided by the Pipe Manufacturer.* In addition to the information listed above (Sec. III.A), the following information is to be provided by the pipe manufacturer:

1. Outside diameter of the steel cylinder (in. [mm]).
2. Thickness of the steel cylinder (in. [mm]).
3. Diameter of prestressing wire (in. [mm]).
4. Class of prestressing wire (II or III).
5. Number of layers of prestressing wire (one, two, or three).
6. Coating thickness over the prestressing wire (in. [mm]).
7. Coating thickness between layers of prestressing wire (in. [mm]).
8. Concrete 28-day compressive strength (psi [MPa]).
9. Concrete modulus of elasticity multiplier, if less than 0.9.
10. Concrete creep factor multiplier, if greater than 1.1.
11. Concrete shrinkage strain multiplier, if greater than 1.1.
12. Prestressing wire intrinsic relaxation multiplier, if greater than 1.1.

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

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

* American Association of State Highway and Transportation Officials, 444 North Capitol Street NW, Suite 249, Washington, DC 20001.

1. In Sec. 2.3.1.1, the unit weights for concrete and mortar have been changed from 150 and 144 lb/ft^3 (2,403 and 2,307 kg/m^3) to 145 and 140 lb/ft^3 (2,323 and 2,243 kg/m^3), respectively, to match the unit weights in Sec. 5.3.4 and 5.4.3.

2. In Sec. 2.3.1.3, an alternate criterion has been added for surcharge load computed in accordance with recognized and documented analytical procedures based on soil–pipe interaction.

3. In Sec. 5.5.1, the design yield strength of the steel cylinder in tension has been changed from 33,000 psi to 36,000 psi (227 to 248 MPa).

4. Numerous editorial improvements and reference updates have been made throughout the standard.

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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AWWA Standard

Design of Prestressed Concrete Cylinder Pipe

SECTION 1: GENERAL

Sec. 1.1 Scope

This standard defines the methods to be used in the structural design of buried prestressed concrete cylinder pipe (PCCP) under internal pressure. These methods are provided for the design of pipe subjected to the effects of working, transient, and field-test load and internal pressure combinations.

The design procedures of this standard are applicable to lined-cylinder pipe (LCP) having inside diameters of 16 in. through 60 in. (410 mm through 1,520 mm) and to embedded-cylinder pipe (ECP) having inside diameters of 24 in. (610 mm) and larger.

The design for longitudinal hydrostatic thrust restraint of prestressed concrete cylinder pipe is not addressed in this standard. See AWWA Manual M9, *Concrete Pressure Pipe*, for information on this topic.

Sec. 1.2 References

Standard requirements for the manufacture of PCCP are contained in ANSI*/AWWA C301, Prestressed Concrete Pressure Pipe, Steel-Cylinder Type. Procedures

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