ANSI/AWWA C900-07
(Revision of ANSI/AWWA C900-97)

American Water Works Association

The Authoritative Resource on Safe Water®

AWWA Standard

Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 12 In. (100 mm Through 300 mm), for Water Transmission and Distribution

American Water Works Association STANDARD Since 1881

ANSI American National Standards Institute

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AWWA Standard

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AWWA unites the entire water community by developing and distributing authoritative scientific and technological knowledge. Through its members, AWWA develops industry standards for products and processes that advance public health and safety. AWWA also provides quality improvement programs for water and wastewater utilities.

Committee Personnel

The Standard C900 subcommittee that developed this standard had the following personnel at the time:

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The AWWA Standards Committee on Polyvinyl Chloride Pressure Pipe and Fittings, which reviewed and approved this standard, had the following personnel at the time of approval:

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*Alternate

Contents

All AWWA standards follow the general format indicated subsequently. Some variations from this format may be found in a particular standard.

Foreword

This foreword is for information only and is not a part of ANSI/AWWA C900.

I. Introduction.

I.A. *Background.* This standard pertains to 4-in. through 12-in. (100-mm through 300-mm) polyvinyl chloride (PVC) pressure pipe and fabricated fittings with cast-iron-pipe-equivalent (CIP) outside diameter (OD) dimensions and with wall-thickness dimension ratios (DRs) of 14, 18, and 25. Design considerations are provided in AWWA M23, *PVC Pipe—Design and Installation*, which provides detailed information on PVC pipe covered by ANSI/AWWA C900. The manual includes chapters on general properties of PVC pipe; manufacturing, testing, and inspection; pressure capacity; design factors for external forces; hydraulics; receiving, storage, and handling; testing and maintenance; and service connections (tapping). Recommended installation guidance is provided in ANSI/AWWA C605, Standard for Underground Installation of Polyvinyl Chloride (PVC) Pressure Pipe and Fittings for Water.

In addition, ANSI/AWWA C907, Standard for Injection-Molded Polyvinyl Chloride (PVC) Pressure Fittings, 4 In. Through 12 In. (100 mm Through 300 mm), for Water Distribution, provides information on injection-molded fittings for use with the PVC pipes covered by ANSI/AWWA C900.

For PVC pipe and fittings diameters greater than 12 in. (300 mm), refer to ANSI/AWWA C905, Standard for Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 14 In. Through 48 In. (350 mm Through 1,200 mm), for Water Transmission and Distribution.

I.B. *History.* This is the fifth edition of ANSI/AWWA C900.

In 1966, AWWA appointed Committee 8350-D to study and report on the adaptability of plastic pipe for use within the water industry. The committee presented its report on June 6, 1967, at AWWA's annual conference. The report included a recommendation that a task group be appointed to prepare standards for the use of plastic materials. The AWWA Standards Committee on Thermoplastic Pressure Pipe was established in 1968. The four editions of this standard were approved by the AWWA Board of Directors in June 1975, Jan. 1981, Jan. 1989, and June 1997, respectively.

In June 1988, the Thermoplastic Pressure Pipe Committee was divided into two separate committees: the Polyvinyl Chloride Pressure Pipe and Fittings Standards Committee and the Polyolefin Pressure Pipe and Fittings Standards Committee. This edition of ANSI/AWWA C900 was approved on June 24, 2007.

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 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, NSF†/ANSI‡ 60, Drinking Water Treatment Chemicals—Health Effects, and NSF/ANSI 61, Drinking Water System Components—Health Effects.

4. Other references, including AWWA standards, *Food Chemicals Codex*,§ *Water Chemicals Codex*,§ and other standards considered appropriate by the state or local agency.

Various certification organizations may be involved in certifying products in accordance with NSF/ANSI 61. Individual states or local agencies have authority to

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

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

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

§Both publications available from National Academy of Sciences, 500 Fifth Street, N.W., Washington, DC 20001.

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 C900 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. The material presented in this standard will be addressed in a revision to Manual AWWA M23 that is currently in progress. The material is published here to ensure that the users of this standard will have continuous access to the most up-to-date design information. AWWA M23 and this standard will not be compatible until AWWA M23 is revised. Where AWWA M23 does not match the standard, the intent of the standard takes precedence, and design matters in AWWA M23 that are inconsistent with this standard should be discussed with the manufacturer.

II.A. *Pipe Selection.*

II.A.1 Selection of pressure class. The minimum pressure class of the pipe or tubing selected should be equal to or greater than the system working pressure. The sum of the system working pressure and occasional surge pressure should not exceed 1.60 times the pressure class of the pipe. The system working pressure and recurring surge pressure should be analyzed using the method in appendix B. If surge pressures govern the selection of the pressure class, consideration should be given to removal of the cause of surge pressures or to the incorporation of surge suppressors in the system.

II.A.2 Recurring surge pressures. Recurring surge pressures, while present in water distribution systems, are of such low amplitude that they typically do not govern the pipe selection. When analysis is deemed necessary, the method is found in appendix B.

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.* The following items should be provided by the purchaser:

1. Standard used—that is, ANSI/AWWA C900, Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 12 In. (100 mm Through 300 mm), for Water Transmission and Distribution, of latest revision.

2. 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.

3. Details of other federal, state, or provincial, and local requirements (Sec. 4.2.1).

4. Pipe and fabricated fittings.

a. Nominal size (for example, 4 in.).

b. Working, occasional, and recurring surge pressures (Section 3).

c. Pressure class or DR (see Table 1).

d. Linear feet of each pressure class or DR for each nominal pipe size to be furnished.

e. Number, nominal size, pressure class or DR, and configuration for fittings and couplings (for example, 20, nominal 10-in., DR 18, tees).*

5. When desired, requirements such as the following should be specified in the purchase contract:

a. Standard lengths (Sec. 4.3.2.3).

b. Shipping and delivery (Sec. 6.2).

c. Affidavit of compliance (Sec. 6.3).

6. Plant inspection. If plant inspections are desired, provisions must be specified in the purchase contract (Sec. 5.3):

*NOTE: Purchase documents may allow or require the use of fittings other than those described in ANSI/AWWA C900. Some examples of compatible fittings include those covered in ANSI/AWWA Standards C907, C153, and C110.

a. Production notice. The manufacturer should be required to give adequate advance notice of when and where production of ordered materials will start.

b. Inspection aids. The manufacturer should be required to make available to the purchaser, without charge, such tools and assistance as are necessary for the inspection and handling of materials.

c. Inspection limitations. To exclude inspection of proprietary manufacturing processes, the manufacturer should be required to give advance notice to the purchaser.

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

IV. Major Revisions. Major changes made to the standard in this edition include the following:

1. The factor of safety was revised from 2.5 to 2.0.
2. The built-in surge allowance was eliminated.
3. The pressure classes were revised from 100, 150, and 200 psi (690, 950, and 1,380 kPa) to 165, 235, and 305 psi (1,140, 1,620, and 2,100 kPa), respectively.
4. Treatment of surge pressures was expanded to include occasional (emergency) surge and recurring (cyclic) surge.
5. Appendix B, Recurring (Cyclic) Surge—Figures and Design Example, was added.

V. Comments. If you have any comments or questions about this standard, please call the AWWA Volunteer and Technical Support Group at 303.794.7711, FAX 303.795.7603, write to the group at 6666 West Quincy Avenue, Denver, CO 80235-3098, or e-mail standards@awwa.org.

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American Water Works Association

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Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 12 In. (100 mm Through 300 mm), for Water Transmission and Distribution

SECTION 1: GENERAL

Sec. 1.1 Scope

The pipe is primarily intended for use in transporting potable water in buried installations. The standard describes dimension ratios (DRs) 14, 18, and 25 for nominal pipe sizes ranging from 4 in. (100 mm) through 12 in. (300 mm). Pipe outside diameters (ODs) conform to those established for CI-equivalent ODs (CIOD). Pressure classes range from 165 psi (1,140 kPa) to 305 psi (2,100 kPa).

Sec. 1.2 Purpose

The purpose of this standard is to provide purchasers, manufacturers, and suppliers with the minimum requirements for PVC pressure pipe and fabricated fittings, 4 in. (100 mm) through 12 in. (300 mm), for water distribution and transmission.

Sec. 1.3 Application

This standard can be referenced in documents for purchasing and receiving PVC pressure pipe and fabricated fittings, 4 in. through 12 in. (100 mm through 300 mm), for water distribution and transmission. The stipulations of this standard apply when this document has been referenced and then only to PVC pressure pipe and fabricated fittings, 4 in. through 12 in. (100 mm through 300 mm), for water distribution and transmission.

SECTION 2: REFERENCES

This standard references the following documents. In their latest editions, they form a part of this standard to the extent specified within the standard. In any case of conflict, the requirements of this standard shall prevail.

ASTM* D1598—Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure.

ASTM D1599—Standard Test Method for Short-Time Hydraulic Failure Pressure of Plastic Pipe, Tubing, and Fittings.

ASTM D1784—Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds.

ASTM D2122—Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings.

ASTM D2152—Standard Test Method for Adequacy of Fusion of Extruded Poly(Vinyl Chloride) (PVC) Pipe and Molded Fittings by Acetone Immersion.

ASTM D2241—Standard Specification for Poly(Vinyl Chloride) (PVC) Pressure-Rated Pipe (SDR Series).

ASTM D2412—Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading.

ASTM D2564—Standard Specification for Solvent Cements for Poly(Vinyl Chloride) (PVC) Plastic Piping Systems.

ASTM D2837—Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials.

ASTM D2855—Standard Practice for Making Solvent-Cemented Joints with Poly(Vinyl Chloride) (PVC) Pipe and Fittings.

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

ASTM D3139—Standard Specification for Joints for Plastic Pressure Pipes Using Flexible Elastomeric Seals.

ASTM F477—Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe.

NSF* 61—Drinking Water System Components—Health Effects.

PPI† TR-3—Policies and Procedures for Developing Recommended Hydrostatic Design Stresses for Thermoplastic Pipe Materials.

SECTION 3: DEFINITIONS

The following definitions shall apply in this standard:

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

2. *Design factor (DF):* The inverse of the safety factor. It is used to reduce the hydrostatic design basis (HDB) to arrive at the hydrostatic design stress (HDS) from which the pressure class (PC) is calculated. Unless otherwise noted, the design factor used in this standard is 0.5.

NOTE: Because the effective strength of PVC materials depends on the temperature and on the duration of stress application, the effective safety factor when using a DF of 0.5 will vary with end-use conditions. For the PVC material described in this standard, the effective safety factor against sustained pressures is at least 2.0. The actual value is generally larger and depends on the magnitude of the applied transient and sustained pressures as well as on the operating temperature.

3. *Dimension ratio (DR):* The ratio of a pipe's specified average outside diameter to its specified minimum wall thickness. For US customary units, the specified average outside diameter is used for establishing pipe DR. For SI units, the minimum specified average outside diameter is used.

4. *Fabricated PVC fitting:* Fabricated fittings comprise single or multiple segments of PVC pipe cut into wedge shapes, or otherwise prepared to accept leg insertions, and joined under factory-controlled conditions to form an essentially

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

†Plastics Pipe Institute, 105 Decker Court, Suite 825, Irving, TX 75062.

homogeneous structure. Reinforcement may be applied and permanently bonded to the outside surfaces of the fitting. The different types of fittings are as follows:

a. Tees have an outstanding leg that is 90° from the running leg.

b. Crosses have two outstanding legs that are opposite each other.

c. Bends may be the standard angles (11.25°, 22.5°, 45°, and 90°) or any custom-built angle.

d. Couplings are used to join two similar-diameter pipes.

e. Reducers are used to abruptly join two different diameter pipes.

f. Adapters are to be used to join two different diameter pipes when the difference in pipe diameters is 1 in. (25 mm) or less.

g. Tapers are used to reduce hydraulic losses when joining two different diameter pipes.

5. *Hydraulic transients:* Hydraulic transients (sometimes called water hammer) are pressure fluctuations caused by a rapid change in the velocity of the water column. Hydraulic transients are the result of normal or emergency operations. The pressure fluctuations can be positive or negative and are caused by operating a valve or by starting or stopping a pump. (See surge pressure.) Hydraulic transients caused by normal pump and valve operation require the pipe system to withstand the resultant positive and negative pressures.

NOTE: For further information, see AWWA Manual M23, *PVC Pipe—Design and Installation*.

6. *Hydrostatic design basis (HDB):* The categorized long-term strength in the circumferential or hoop direction as established from long-term pressure tests in accordance with ASTM D2837. This standard requires the use of PVC compounds that qualify for an HDB rating of 4,000 psi (27.58 MPa).

7. *Hydrostatic design stress (HDS):* The maximum allowable working hoop stress in the pipe wall when the pipe is subjected to sustained long-term hydrostatic pressure. The HDS in this standard is established by multiplying the HDB by the design factor (DF) of 0.5.

8. *Inspector:* The authorized representative of the purchaser who is entrusted with the inspection of products and production records. The inspector also observes the production operations and quality-control tests to ensure that products comply with the requirements of this standard and the purchaser.

9. *Lot:* Pipe manufactured during a production run.

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

11. *Occasional (emergency or transient) surge pressure* (P_{OS}): Surge pressures caused by emergency operations, usually the result of a malfunction (such as power failure, sudden valve closure, or system component failure).

12. *Polyvinyl chloride (PVC) plastic :* PVC resin, the basic building block of PVC pipe, is a polymer derived from saltwater, air, and natural gas or petroleum. PVC resin is combined with heat stabilizers, lubricants, and other ingredients to make PVC compounds that can be extruded into pipe or molded into fittings.

13. *Pressure class (PC):* The design capacity to resist working pressure up to 73.4°F (23°C) sustained operating temperature. The methods for determining pressure class are stated in Sec. 4.7.

14. *Production run:* The length of time a particular piece of extrusion equipment is producing a certain size of pipe. NOTE: the term "production run" is not applicable to fabricated fittings.

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

16. *Recurring (cyclic) surge pressure (P_{RS}):* Surge pressures that occur frequently and are inherent to the design and operation of the system (such as normal pump startup or shutdown and normal valve opening or closure). Recurring surge pressure may occur millions of times in a piping system's lifetime.

17. *Standard dimension ratio* (*SDR*): A dimension ratio that corresponds to one of the numbers in the standard series of preferred dimension ratios that has been established by the American Society for Testing and Materials (ASTM F412).

18. *Supplier:* The party that supplies material or services. A supplier may or may not be the manufacturer.

19. *Surge pressure (P_S):* The maximum hydraulic transient pressure increase (sometimes called water hammer) in excess of the operating pressure that is anticipated in the system as the result of sudden changes in velocity of the water column. For purposes of product selection and design, this document considers the following two types of surges:

a. Recurring (cyclic) surge pressure (P_{RS})

b. Occasional (emergency or transient) surge pressure (P_{OS})

NOTE: Occasional transients caused by emergency pump and valve operations are usually severe. The system should be designed to withstand positive and negative pressures caused by these emergency operations. Water column separation may occur if the negative pressure is reduced to the vapor pressure of the liquid. Rejoining of the separated water column typically results in a large pressure rise, which will possibly damage the pipe system. Whenever possible, water column separation should be avoided.

20. *Sustained operating temperature:* The continuous long-term temperature of the pipe wall during service. A short-term rise in service temperature above 73°F (23°C) (for example, for a few weeks during summer) does not require use of temperature coefficients for pipeline design.

21. *Working pressure (WP):* The maximum anticipated sustained operating pressure applied to the pipe exclusive of transient pressures.

SECTION 4: REQUIREMENTS

Sec. 4.1 Permeation

The selection of materials is critical for water pipe in locations where there is likelihood the pipe will be exposed to significant concentrations of pollutants composed of low-molecular-weight petroleum products or organic solvents or their vapors. Documented research has shown that pipe materials (such as polyethylene, polybutylene, polyvinyl chloride, and asbestos cement) and elastomers (such as those used in jointing gaskets and packing glands) may be subject to permeation by lower molecular weight organic solvents or petroleum products. If a water pipe must pass through such a contaminated area or an area subject to contamination, consult with the manufacturer regarding permeation of pipe walls, jointing materials, and so forth, *before* selecting materials for use in that area.

Sec. 4.2 Materials

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

4.2.2 *Pipes, couplings, and fabricated fittings.* PVC pipes, couplings, and fabricated fittings shall be made from virgin PVC resin that has been compounded to provide physical and chemical properties that equal or exceed cell class 12454 as defined in ASTM D1784. Pipe and fittings shall also qualify for a minimum hydrostatic design basis (HDB) of 4,000 psi (27.58 MPa) at 73.4°F (23°C) in accordance with the requirements of PPI TR-3.

4.2.3 *Rework materials.* Clean rework materials derived from a manufacturer's own pipe or fitting production may be used by the same manufacturer for similar purposes provided that (1) the cell classification of the rework material is identical to the material to which it will be added; (2) the rework material complies with applicable requirements of Sec. 4.2 of this standard; and (3) the finished products comply with the requirements of this standard.

4.2.4 *Certification for potable-water service.* PVC compounds and products shall be tested for chemical extractants and certified as suitable for potable-water service by an accredited testing agency acceptable to the purchaser. The basis of certification shall be the requirements specified in NSF/ANSI 61.

4.2.5 *Gaskets and lubricants.* Gaskets and lubricants intended for use with PVC pipe, couplings, and fabricated fittings shall be made from materials that are compatible with the pipe and with each other when used together. Gaskets and lubricants shall not adversely affect the potable quality of the water that is to be transported (see foreword, Sec. I.C).

4.2.5.1 Elastomeric gaskets. One gasket shall be furnished with each bell end of every pipe, fitting, and coupling. Elastomeric gaskets shall meet the requirements of ASTM F477 for high-head [50 ft (15 m) of head or higher] applications.

4.2.6 *Fabricated fitting overwrapped reinforcement.* Optional reinforcement, either PVC or non-PVC, may be applied by the manufacturer to meet the requirements of this standard.

4.2.6.1 Resin. Resins used shall be a commercial grade of unsaturated polyester resin or epoxy resin.

4.2.6.2 Glass. Glass reinforcing materials shall be commercial "E" type glass in the form of mat, continuous roving or roving fabric, or a combination of these, having a coupling agent that bonds the glass reinforcement and the resin.

Sec. 4.3 Pipe Requirements

4.3.1 *Quality of work.* When manufactured, pipe shall be homogeneous throughout; free from voids, cracks, inclusions, and other defects; and as uniform as commercially practical in color, density, and other physical properties. Pipe surfaces shall be free from nicks and significant scratches.* The joining surfaces of pipe spigots

*Scratches that extend 10 percent or more into the pipe wall shall be considered significant.

and integral-bell and sleeve-reinforced bell sockets shall be free of imperfections that might cause leakage at joints.

4.3.2 *Dimensions.*

4.3.2.1 Pipe barrel. The dimensions and tolerances of the pipe barrel shall conform with the applicable requirements listed in Table 1 when measured as specified in ASTM D2122.

4.3.2.2 Elastomeric-gasket bell ends. The dimensions of the integral bell ends shall meet one of the following requirements when measured according to ASTM D2122:

a. The bell wall thickness at any point shall conform to the dimension ratio of the pipe except in the annular gasket ring groove and bell entry lip portions where the wall shall be at least the minimum thickness of the pipe barrel (Table 1).

b. Designs not meeting the requirements of Sec. 4.3.2.2(a) shall be tested to verify that the joint assemblies qualify for a hydrostatic design basis (HDB) category of 4,000 psi (27.58 MPa) when tested in accordance with ASTM D2837 as modified in ASTM D3139.

4.3.2.3 Standard lengths. Pipe shall be provided in standard laying lengths of 20 ft ± 1 in. (6.1 m ± 25 mm), unless otherwise agreed on at time of purchase.

4.3.3 *Physical properties.*

4.3.3.1 Sustained pressure. The pipe or fabricated fitting shall not fail, balloon, burst, or weep, as defined in ASTM D1598, at the applicable sustained pressure listed in Table 2 when six specimens are tested for 1,000 hr as specified in ASTM D2241. Either free-end or restrained-end closures that are free of leaks at maximum pressure shall be used.

4.3.3.2 Burst pressure. The quick-burst strength of pipe, including any integral bell end, shall meet the applicable minimum pressure requirement listed in Table 2 when tested in accordance with the specimen and sample sizes, conditioning, and procedural requirements listed in ASTM D1599. At least three of the five test specimens shall have a portion of the required markings located at least one pipe diameter away from an end closure. For bell-end pipe, the bell shall be included as a part of at least two test specimens. The ability to attain hydrostatic pressure equal to or greater than the values in Table 2 within 60–70 sec shall indicate passing this test requirement.

4.3.3.3 Hydrostatic integrity. The pipe, including any integral bell end or affixed coupling, shall not fail, balloon, burst, or weep when subjected to an internal pressure equal to 2.0 times its designated pressure class, as listed in Table 2, for a minimum dwell time of five sec. Integral bells shall be tested with the pipe. When the test temperature (the temperature of the pipe wall) is higher than 73.4°F (23°C), the test pressure may be reduced by applying the appropriate temperature coefficient from Table 3. Test temperature shall be estimated by measuring the temperature on the pipe's outside surface within 20 min after hydrotesting is completed.

4.3.3.4 Flattening. The flattening test procedure and failure criteria shall conform to ASTM D2412. The specified distance between the plates is 40 percent of the outside diameter of the pipe. The rate of flattening shall be uniform and such that the compression is completed within 2 to 5 min.

4.3.3.5 Extrusion quality. The pipe shall not fail when tested by the acetone-immersion method as specified in ASTM D2152.

Table 1 Dimensions, pressure classes, and dimension ratios (DRs) for PVC* pipe with cast-iron-pipe-equivalent ODs

Nominal Size	Pressure Class at 73.4°F (23°C)			OD—*in. (mm)*				Wall Thickness—*in. (mm)*			
in.	*psi*	(*kPa*)	DR	Average		Tolerance		Minimum		Tolerance	
4	165	(1,140)	25	4.800	(121.9)	±0.009	(0.23)	0.192	(4.88)	+0.023	(0.58)
4	235	(1,620)	18	4.800	(121.9)	±0.009	(0.23)	0.267	(6.78)	+0.032	(0.81)
4	305	(2,100)	14	4.800	(121.9)	±0.009	(0.23)	0.343	(8.71)	+0.041	(1.04)
6	165	(1,140)	25	6.900	(175.3)	±0.011	(0.28)	0.276	(7.01)	+0.033	(0.84)
6	235	(1,620)	18	6.900	(175.3)	±0.011	(0.28)	0.383	(9.73)	+0.046	(0.17)
6	305	(2,100)	14	6.900	(175.3)	±0.011	(0.28)	0.493	(12.52)	+0.059	(1.50)
8	165	(1,140)	25	9.050	(229.9)	±0.015	(0.38)	0.362	(9.19)	+0.043	(1.09)
8	235	(1,620)	18	9.050	(229.9)	±0.015	(0.38)	0.503	(12.78)	+0.060	(1.52)
8	305	(2,100)	14	9.050	(229.9)	±0.015	(0.38)	0.646	(16.41)	+0.078	(1.98)
10	165	(1,140)	25	11.100	(281.9)	±0.015	(0.38)	0.444	(11.28)	+0.053	(1.35)
10	235	(1,620)	18	11.100	(281.9)	±0.015	(0.38)	0.617	(15.67)	+0.074	(1.88)
10	305	(2,100)	14	11.100	(281.9)	±0.015	(0.38)	0.793	(20.14)	+0.095	(2.41)
12	165	(1,140)	25	13.200	(335.3)	±0.015	(0.38)	0.528	(13.41)	+0.063	(1.60)
12	235	(1,620)	18	13.200	(335.3)	±0.015	(0.38)	0.733	(18.62)	+0.088	(2.24)
12	305	(2,100)	14	13.200	(335.3)	±0.015	(0.38)	0.943	(23.95)	+0.113	(2.87)

*Hydrostatic design stress (HDS) = 2,000 psi.

Table 2 Pressure-test requirements

	Pressure Class		Sustained-Test Pressure		Burst-Test Pressure		Hydrostatic-Test Pressure	
DR	*psi*	*(kPa)*	*psi*	*(kPa)*	*psi*	*(kPa)*	*psi*	*(kPa)*
25	165	(1,140)	350	(2,420)	535	(3,690)	330	(2,280)
18	235	(1,620)	500	(3,450)	755	(5,210)	470	(3,240)
14	305	(2,100)	650	(4,490)	985	(6,800)	610	(4,210)

Table 3 Temperature coefficients, F_T

Pipe Temperature		Pressure Rating Reduction Coefficient
°F	(°C)	
80	(27)	0.88
90	(32)	0.75
100	(38)	0.62
110	(43)	0.50
120	(49)	0.40
130	(54)	0.30
140	(60)	0.22

Sec. 4.4 Machined Coupling Requirements

4.4.1 *Quality of work.* The body and joining surfaces of couplings machined from extruded pipe shall conform with the same requirements as specified for pipe in Sec. 4.3.

4.4.2 *Dimensions.* The computed dimension ratio (DR) of gasketed PVC couplings machined from extruded pipe shall not be greater than the DR of the pipe, except in the annular gasket space and coupling entry where the wall thickness shall be at least the minimum wall thickness of the pipe (Table 1).

4.4.3 *Burst pressure.* The quick-burst strength of couplings shall not be less than the minimum burst pressure specified for the pipe with which the couplings are designed to be used when tested as specified in Sec. 4.3.3.2.

4.4.4 *Hydrostatic integrity.* Couplings shall not fail, balloon, burst, or weep when subjected to an internal pressure equal to 2.0 times the designated pressure class of the pipe with which it is designed to be used, as listed in Table 2, for a minimum dwell time of 5 sec. When the test temperature (the temperature of the pipe wall) is higher than 73.4°F (23°C), the test pressure may be reduced by applying the appropriate temperature coefficient from Table 3. Test temperature shall be estimated by taking readings on the fitting's outside surface within 20 min after hydrotesting is completed.

4.4.5 *Standard quantities.* If elastomeric-gasketed couplings are to be used as the primary pipe-joining method, one such coupling of a corresponding size and pressure class shall be provided with each length of plain-end pipe.

Sec. 4.5 Fabricated Fitting Requirements

4.5.1 *Quality of work.* Fittings shall be fabricated from PVC pipe meeting the requirements of this standard. The component pipe segments and the bonds between them shall be free from voids, cracks, inclusions, and other defects. The joining surfaces of spigots and bells shall be free from imperfections that could cause leaks. When component segments are joined using solvent cement, the procedure shall conform with the standard practice for making pressure joints in ASTM D2855.

4.5.2 *Dimensions.*

4.5.2.1 Fitting barrel. Edge-joined segments of a fabricated fitting shall have the same dimension ratio.

4.5.2.2 Standard configurations. Standard configurations shall include customary angles for branch connections or bends. Nonstandard angles of branch connections or bends may be specified. Leg lengths shall be the minimum practical for the method of fabrication, unless otherwise specified.

4.5.2.3 Reinforcement of solvent cement joints. Fitting segments that are joined by solvent cementing shall be designed on the basis of a maximum lap shear strength of the solvent cement joint of 900 psi (6.2 MPa). Overwrapped reinforcement shall not be considered in design of the solvent cement joint.

4.5.3 *Segment joint quality.*

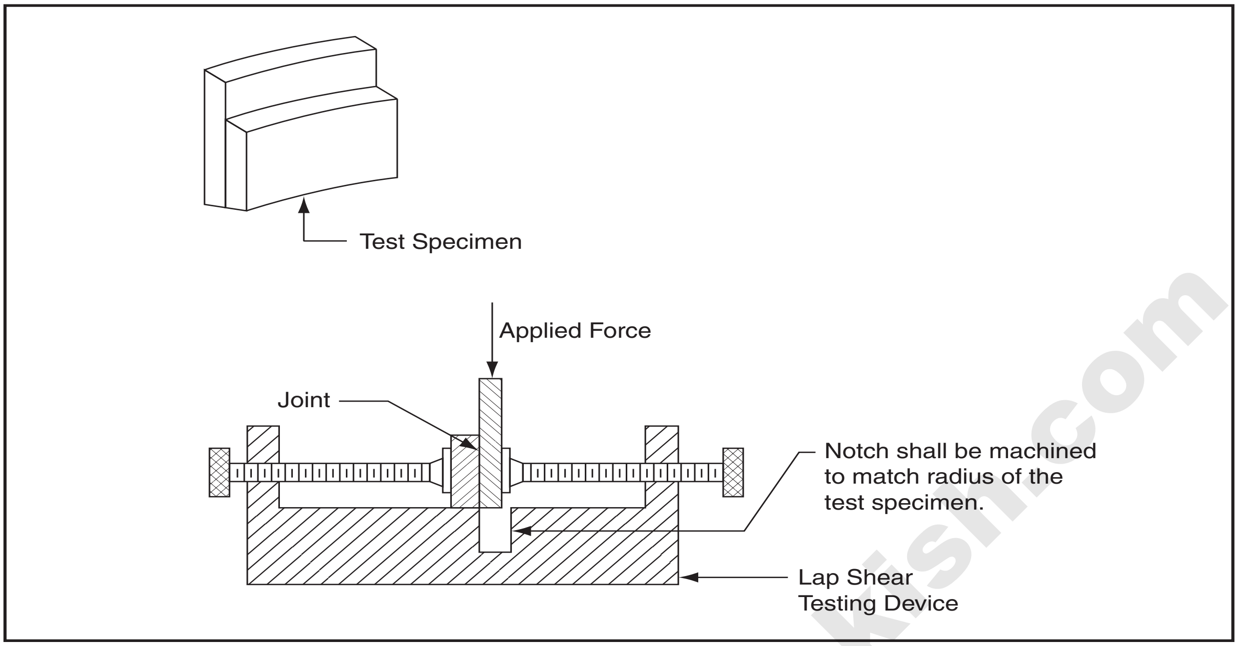

Figure 1 Lap shear test

4.5.3.1 Butt-fusion or thermal weld. A suitable probe, energized with 25,000 V, shall be swept along the joint line approximately 0.1 in. (3 mm) away from the PVC surface of the joined segments on the side opposite to the grounding medium. The grounding medium shall be a metallic conductor held against the seam surface opposite the probe. For thermally welded seams other than butt-fusion, the test shall be conducted only after the first 20 percent or less of the weld thickness is applied. Any discontinuity in the segment joint is indicated by the jump of an arc (sparking) from the probe tip and shall be cause for rejection of the fitting until such a time that the weld is repaired.

4.5.3.2 Solvent cemented bond quality. Specimens for lap shear testing shall be prepared in accordance with the requirements of ASTM D2564, except as modified in this standard. The test specimens shall be obtained from a sample solvent cemented joint produced by solvent cementing component pipe segments identical to those to be used to fabricate fittings. After at least a 72-hr solvent cement curing time at 73.4 ± 3.6°F (23 ± 2°C), three specimens shall be tested per segment joint. Each specimen shall be a section of the segment joint measuring approximately 1 in. × 2 in. (25 mm × 50 mm) and shall not include any overwrapping reinforcement. A portion of each test specimen shall be machined off as needed to obtain a specimen similar to that shown in Figure 1. After placing the specimen in a testing device similar to that shown in Figure 1, apply the force at a shear speed of 0.05 in./min (1.25 mm/min). The minimum average lap shear strength of the three specimens shall be 900 psi (6.2 MPa).

NOTE: Where mechanical joint restraint devices are used to control thrust movements of fabricated fittings, consult with the fittings manufacturer to determine the tensile thrust limitations for the specific sizes, configurations, and pressure classes specified.

4.5.4 *Pressure test.* The fabricated fitting shall not fail, balloon, burst, or weep when subjected to an internal pressure equal to 2.0 times the pressure class shown in Table 2 for a minimum of 2 hr.

Sec. 4.6 Joint Requirements

Bell-end pipe, couplings, and fittings designed for making PVC joints using elastomeric gaskets to effect the pressure seal shall be tested as assembled joints and shall meet the laboratory performance requirements specified in ASTM D3139. (These are qualifying test requirements to determine proper design and performance of specimen joints.)

Sec. 4.7 Pressure-Class Designations

4.7.1 *Pressure class.* This standard classifies pipe in accordance with its pressure class (*PC*). The following expression, commonly known as the ISO equation, is used to calculate the pressure class:

$$PC = \left[\frac{2}{DR - 1}\right] \times HDB \times DF \qquad \text{(Eq 1)}$$

Where:

PC = Pressure class, psi

DR = Dimension ratio = D_o/t

D_o = Average outside diameter, in.

t = Minimum pipe wall thickness, in.

HDB = Hydrostatic design basis, 4,000 psi

DF = 0.5; design factor or inverse of safety factor; includes consideration of degree of safety and the variables, including limited surge effects in the end application

4.7.1.1 Temperature. For pipe that meets the requirements of this standard, the PC denotes the maximum working pressure rating for water at 73°F (23°C). When higher sustained operating temperatures are anticipated, the pipe's *PC* shall be reduced by the appropriate temperature-compensating multiplier (F_T) found in Table 3.

4.7.1.2 Maximum pressure. In all cases the maximum anticipated working pressure cannot exceed the pipe's pressure class times the temperature coefficient.

$$WP < PC \times F_T \qquad \text{(Eq 2)}$$

4.7.1.3 Pressure class ratings. Pressure class ratings for pipe described in this standard are given in Table 1. The *PC* values listed are the maximum working pressure ratings of pipe made and classified in accordance with this standard. They assume that the pipe is not subject to surge pressures or hydraulic transients above the working pressure in excess of those defined in Sec. 4.7.1.4 and the pipe's sustained operating temperature is at or below 73.4°F (23°C).

4.7.1.4 Surge pressure allowance. Previous editions of this standard have included a built-in generic surge allowance or occasional surge pressure capacity equivalent to a 2-fps (0.6-m/s) velocity change. This edition of the standard has removed this surge allowance in favor of expanded coverage of the two types of surge pressure: occasional and recurring. These changes are intended to allow the user to analyze surge conditions specific to their project.

4.7.1.4.1 Occasional surge pressure (P_{OS}) is a typical design parameter for most municipal water systems. Mathematically, occasional surge pressure is a simple concept that is easily accommodated by use of short-term pressure ratings or occasional surge pressure capacities found in Table 4.

4.7.1.4.2 Occasional surge pressure capacity ($WP + P_{OS}$) or short-term pressure rating is the sum of the maximum anticipated working pressure and maximum anticipated occasional surge pressure. Occasional surge pressure capacity cannot exceed the short-term pressure rating, which is 1.60 times the pipe's pressure class times F_T. The defined occasional surge pressure capacities and corresponding allowable velocity changes are provided in Table 4.

$$WP + P_{OS} < 1.60 \times PC \times F_T \qquad \text{(Eq 3)}$$

4.7.1.4.3 Recurring surge pressure (P_{RS}) develops high-frequency, high-amplitude surge conditions that are not typically a design issue for municipal water systems, but may need to be considered. Pipe selection or design to accommodate recurring surge pressure is a function of three variables and thus does not lend itself to tabular treatment. The body of the standard contains a limited discussion that is supplemented by a design example in appendix B.

4.7.1.4.4 Recurring surge pressure capacity ($WP + P_{RS}$). Recurring surge pressure capacity is the sum of the maximum anticipated working pressure and the maximum anticipated surge pressure. Recurring surge pressure capacity cannot exceed the pipe's pressure class times the temperature coefficient.

$$WP + P_{RS} < PC \times F_T \quad \text{(Eq 4)}$$

Table 4 Allowable maximum occasional surge pressure capacity and allowable sudden changes in water velocity for pipe operating at 73°F (23°C) at working pressures expressed as percent of nominal pressure class (*PC*)*

DR	Pressure Class (PC)	Occasional Surge Pressure Capacity	Corresponding Sudden Delta V with WP = % of PC			
			100%	80%	60%	40%
	(psi)	*(psi)*	*(fps)*	*(fps)*	*(fps)*	*(fps)*
25	165	264	6.7	9.0	11.2	13.5
18	235	376	8.1	10.8	13.5	16.2
14	305	488	9.2	12.3	15.4	18.5

*The surge pressure tolerances in this table apply only to pipe and not to system components, which may have lesser tolerances. The design should consider possible system reactions and their potential effect on system components.

See Sec. 3 for definitions of recurring and occasional surge pressures.

A pipe may sometimes be subjected to net negative internal pressure because of the individual or combined effect of internal negative transients and external forces (such as water table). When this situation exists, refer to the supplier for information on the hydraulic collapse resistance of the pipeline.

4.7.2 *Fabricated fittings.* Fabricated PVC fittings meeting the requirements of this standard shall have the pressure class designations listed in Table 1 that are equal to or less than the pressure for the dimension ratio of the pipe used in their fabrication. The determination of pressure classes and safety factors for fabricated fittings shall follow the method given in Sec. 4.7.1 for pipe meeting the requirements of this standard, ignoring the effect of any overwrap reinforcement.

SECTION 5: VERIFICATION

Sec. 5.1 Quality Control and Qualification Test Requirements

The manufacturer shall take adequate measures in the production of extruded PVC pipe, couplings, and fabricated fittings to ensure product compliance with the requirements of this standard. The pipe, couplings, and fabricated fittings shall be tested at 73.4 ± 3.6°F (23 ± 2°C), unless otherwise specified, in accordance with the requirements of Sec. 4.3, 4.4, 4.5, and 4.6 at intervals as required in this standard.

5.1.1 *Pipe dimensions.* The dimensions of pipe produced from each extrusion outlet, and the bell or sleeve-reinforced bell of pipe with such ends, shall be measured in accordance with Sec. 4.3.2 at the beginning of production of each specific material and each size. Thereafter, one specimen from each extrusion outlet shall be measured each hour.

5.1.2 *Coupling dimensions.* The dimensions of machined couplings shall be measured in accordance with Sec. 4.4.2 at the beginning of production of each specific material and each size. Thereafter, one specimen shall be measured each hour.

5.1.3 *Sustained pressure.* At the beginning of a production run and semi-annually thereafter, specimens of 4-in. (100-mm) or 6-in. (150-mm) pipe and of 8-in. (200-mm) or larger pipe that are made from each PVC pressure pipe commercial compound (i.e., material) shall be tested in accordance with Sec. 4.3.3.1. (These tests are for qualification of the compound and the extrusion process—not for quality control of the product.)

5.1.4 *Pipe burst strength.* The quick-burst strength of pipe produced from each extrusion outlet shall be tested in accordance with Sec. 4.3.3.2 at the beginning of a production run of each specific material and each size. Thereafter, one specimen from each extrusion outlet shall be tested every 24 hr.

5.1.5 *Coupling burst strength.* The quick-burst strength of machined couplings shall be tested in accordance with Sec. 4.4.3 at the beginning of a production run of each specific material and each size. Thereafter, one specimen shall be tested every 8 hr.

5.1.6 *Flattening capability.* The flattening capability of pipe shall be tested in accordance with Sec. 4.3.3.4 at the beginning of a production run from each extrusion outlet for each specific material and each size. The test shall be run immediately following any change from establishing running conditions that could affect extrusion quality. Thereafter, one specimen from each extrusion outlet shall be tested every 8 hr.

5.1.7 *Extrusion quality.* The pipe produced from each extrusion outlet shall be tested in accordance with Sec. 4.3.3.5 at the beginning of a production run of each specific material and each size. The test shall also be run immediately following any change from established running conditions that could affect extrusion quality.

5.1.8 *Fitting segment fusion.* Each fitting manufactured using the butt-fusion or thermal welding method of segment joining shall be tested in accordance with Sec. 4.5.3.1.

5.1.9 *Fitting segment solvent cemented bond quality.* Where solvent cement is used to join fitting segments, the quality of the bond shall be tested in accordance with Sec. 4.5.3.2 at startup and once every 200 fittings produced using this procedure. Testing shall also be required when changing the PVC cement product, brand, or surface preparation used in the process prior to any fittings made using the alternative product(s). Failure to meet the requirements of Sec. 4.5.3.2 or Sec. 4.5.4 shall result in the rejection or testing of fittings manufactured since the last successful test.

5.1.10 *Fabricated fitting pressure tests.*

5.1.10.1 Qualification pressure test. For a specific production run process and whenever the production run process is changed, a representative fabricated fitting specimen shall be subjected to a sustained pressure test in accordance with Sec. 4.3.3.1. A representative specimen shall be the most critically stressed fitting configuration. (NOTE: Critical stresses generally occur where fitting segments are joined together.)

5.1.10.2 Quality control pressure test. Each fitting size and configuration shall be tested once for every 50 fittings of the same configuration produced or when the fabrication process changes.

5.1.11 *Provision for test failure.* When any PVC product fails to meet a requirement specified in this standard or in a referenced standard, additional tests shall be performed to determine which products are acceptable of those produced since the last favorable test. Products that fail to meet any requirement shall be rejected.

5.1.12 *Hydrostatic proof test for pipe.* Each length of pipe shall be proof tested in accordance with Sec. 4.3.3.3.

5.1.13 *Hydrostatic proof test for machined couplings.* Each separate machined coupling shall be proof tested in accordance with Sec. 4.4.4.

5.1.14 *Optional test frequency.* The purchaser or supplier may allow the manufacturer to conduct hydrostatic proof tests for pipes or couplings at test frequencies other than required in Sec. 5.1.12 and 5.1.13. Each purchaser in the distribution chain shall be notified if this option is used.

Sec. 5.2 Quality-Control Records

The manufacturer shall maintain, for a period of not less than two years, a record of quality-control tests and shall, if requested, submit the pertinent record to the purchaser.

Sec. 5.3 Plant Inspection

5.3.1 *Plant access.* The purchaser's inspector shall have access at reasonable times to those parts of a manufacturer's plant that are necessary to ensure that products comply with requirements.

5.3.2 *Responsibility for compliance.* Plant inspection by the purchaser or the omission of such inspections shall not relieve the manufacturer of the responsibility to provide materials complying with the applicable requirements of this standard.

SECTION 6: DELIVERY

Sec. 6.1 Marking

6.1.1 *General.* Pipe, couplings, and fittings shall bear identification markings that will remain legible during normal handling, storage, and installation. The markings shall be applied in a manner that will not reduce the strength of any product described by this standard.

6.1.2 *Pipe.* Marking on pipe shall include the following and shall be applied at intervals of not more than 5 ft (1.5 m):

a. Nominal size in inches and OD base (for example, 4 CI).

b. PVC.

c. Dimension ratio (for example, DR 25).

d. AWWA pressure class (for example, PC 165).

e. Test pressure for hydrotested pipe (for example, T330) or if not tested, "NOT HYDROSTATIC PROOF TESTED."

f. AWWA designation number for this standard (ANSI/AWWA C900).

g. Manufacturer's name or trademark and production run record or lot code.

h. Seal (mark) of the testing agency verifying the suitability of the pipe material for potable-water service (Sec. 4.2.4).

6.1.3 *Couplings and fabricated fittings.* Marking on couplings and fabricated fittings shall include the following:

a. Nominal size OD base and deflection angle if applicable (for example, 8 in. × 4 in. or 8-in. 45°).

b. PVC.

c. AWWA pressure class (for example, PC 165).

d. AWWA designation number for this standard (ANSI/AWWA C900-07).

e. Manufacturer's name or trademark.

f. Seal (mark) of the testing agency verifying the suitability of the coupling or fitting for potable-water service (Sec. 4.2.4).

Sec. 6.2 Shipping and Delivery

6.2.1 *Shipping.* Pipe, couplings, and fabricated fittings shall, unless otherwise required by the purchaser, be prepared for standard commercial shipment.

6.2.2 *Delivery.* Pipe, couplings, and fabricated fittings that do not comply with the applicable requirements of this standard or that are damaged when received shall be replaced by the manufacturer or supplier at the agreed point of delivery.

Sec. 6.3 Affidavit of Compliance

The manufacturer shall, if so specified by the purchaser, provide an affidavit that delivered materials comply with the requirements of this standard and of the purchaser.

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APPENDIX A

Bibliography

This appendix is for information only and is not a part of ANSI/AWWA C900.

1. ANSI/AWWA C605—Underground Installation of Polyvinyl Chloride (PVC) Pressure Pipe and Fittings for Water.

2. ANSI/AWWA C905—Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 14 in. Through 48 in. (350 mm Through 1,200 mm), for Water Transmission and Distribution.

3. ANSI/AWWA C907—Injection-Molded Polyvinyl Chloride (PVC) Pressure Fittings, 4 In. Through 12 in. (100 mm Through 300 mm), for Water Distribution.

4. AWWA Manual M23, *PVC Pipe—Design and Installation,* second edition, AWWA, Denver, Colo. (2002).

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APPENDIX B

Recurring (Cyclic) Surge—Figures and Design Example

This appendix is for information only and is not a part of ANSI/AWWA C900.

SECTION B.1: DISCUSSION

Cyclic surge design is presented in terms of allowable cycles to failure as the quantity to which a safety factor is applied. The safety factor on cycles to failure is 2.0 (corresponding to a design factor of 0.5).

Cyclic surge design is a function of three variables: mean (average) stress, stress amplitude, and number of cycles to failure:

1. From Figure B.1, "mean (average) stress" is the hoop stress caused by the static working pressure in the pipe. The surge pressure will cycle above and below this value.

2. Also from Figure B.1, "Stress amplitude" is the increase in hoop stress caused by the cyclic surge pressure.

3. "Number of cycles to failure" is the value determined in Figure B.2. This value must be at least equal to the safety factor times the anticipated number of surge cycles.

SECTION B.2: DESIGN EXAMPLE

Project conditions (as determined by designer):

Pipe diameter = 8 in.

Working pressure (WP) = 160 psi

Recurring surge

Anticipated cycles per day = 55

Factor of safety on number of cycles = 2.0

Design life = 50 years

Anticipated recurring surge pressure (P_{RS}) = ±30 psi

Occasional surge

Anticipated occasional instantaneous change in flow velocity = 7 fps
Sustained operating temperature = 60°F

Pipe dimension ratio:

Try DR 18.

PC = 235 psi (Table 1)

Occasional surge pressure per 1 fps instantaneous flow change is 17.4 psi.

(Reference: AWWA Manual M23, *PVC Pipe—Design and Installation*)

Analysis:

Step 1: Check temperature considerations.

Operating temperature does not exceed 73°F.

$F_T = 1$ (Table 3)

Therefore, pressure-rating reduction is not necessary, $PC = 235$ psi

Step 2: Check working pressure versus pressure class.

Working pressure: 160 psi

Working pressure cannot exceed allowable pressure of $PC \times F_T$ (Eq 2)

Allowable pressure = 235 psi × 1.00 = 235 psi > 160 psi working pressure

Result: DR 18 OK for working pressure

Step 3: Check occasional surge pressure capacity, $WP + P_{OS}$

Anticipated occasional surge pressure, P_{OS}

= 17.4 psi / (1 ft/sec) × 7 ft/sec = 122 psi

Anticipated occasional surge pressure, $WP + P_{OS}$

= 160 psi + 122 psi = 282 psi

Allowable occasional surge pressure capacity, $1.60 \times PC \times F_T$ (Eq 3)

= 1.60 × 235 psi × 1 = 376 psi

Checking allowable versus anticipated

376 psi > 282 psi anticipated

Result: DR 18 OK for occasional surge pressure

Step 4: Check recurring surge pressure capacity, $WP + P_{RS}$

Design pressures:

Maximum design pressure, $P_{max} = (WP + P_{RS}) = 160$ psi + 30 psi
= 190 psi

Minimum design pressure, $P_{min} = (WP - P_{RS}) = 160$ psi – 30 psi
= 130 psi

Design stresses:

Mean hoop stress (Figure B.1) = $(P_{max} + P_{min})(\text{DR} - 1)/4$
= (190 psi + 130 psi)(18 – 1)/4 = 1,360 psi

Stress amplitude (Figure B.1) = $(P_{max} - P_{min})(\text{DR} - 1)/4$
= (190 psi – 130 psi)(18 – 1)/4 = 255 psi

Number of cycles:

Anticipated # of cycles = (# cycles/day) ×
(365 days/year) × (Design Life in Years)
= 55 × 365 × 50 = 1.0E+06 cycles

Factor of safety = 2.0

Required number of cycles = 2 × 1.0E+06

Actual number of cycles to failure (Figure B.2) = 2.1E+07 cycles

Check allowable versus required cycles

Allowable 2.1E+07 cycles > 2.1E+06 cycles required

Result: DR 18 OK for recurring surge

Conclusion: DR 18 pipe is adequate for the design conditions.

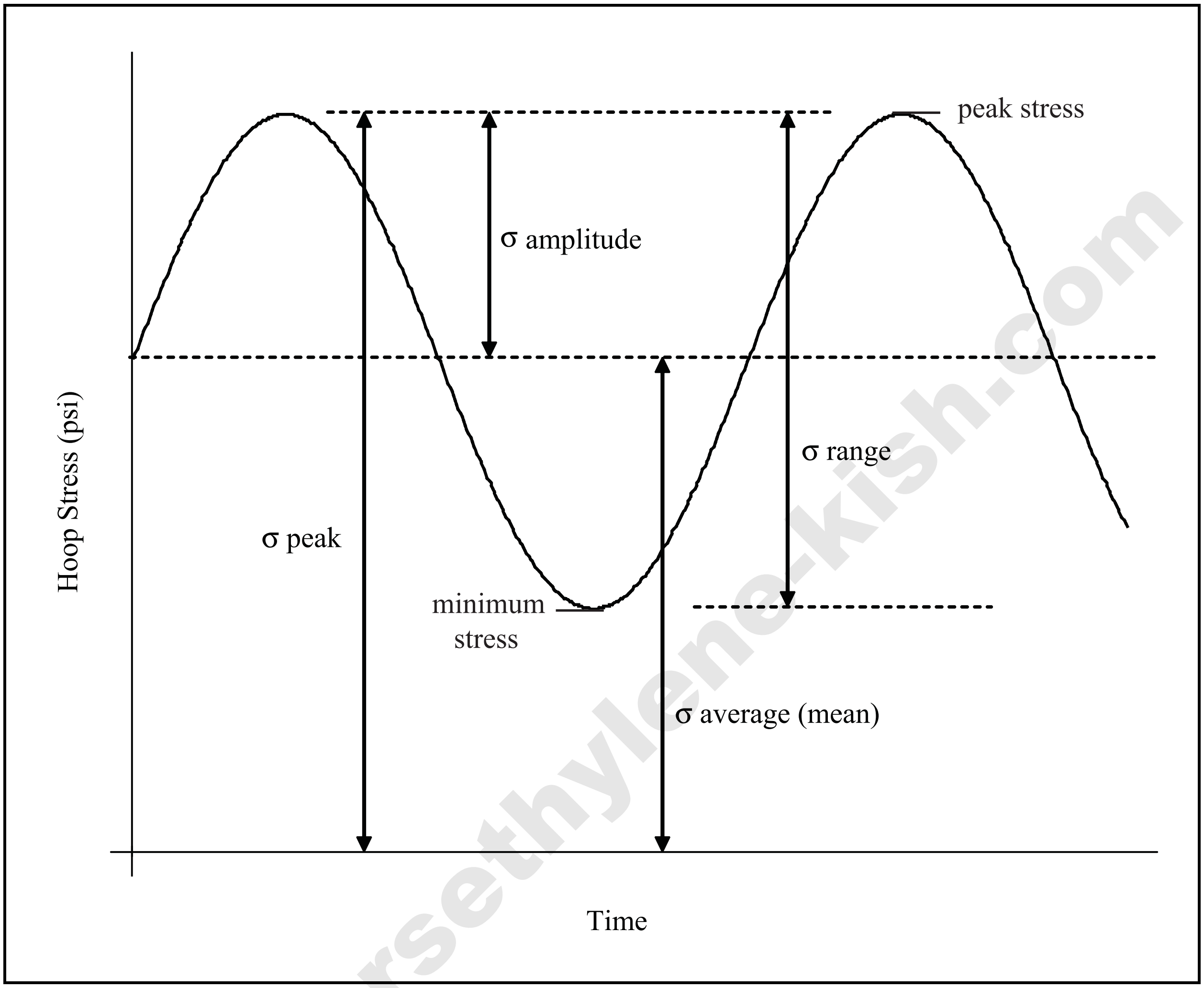

Figure B.1 Illustration of stress terms

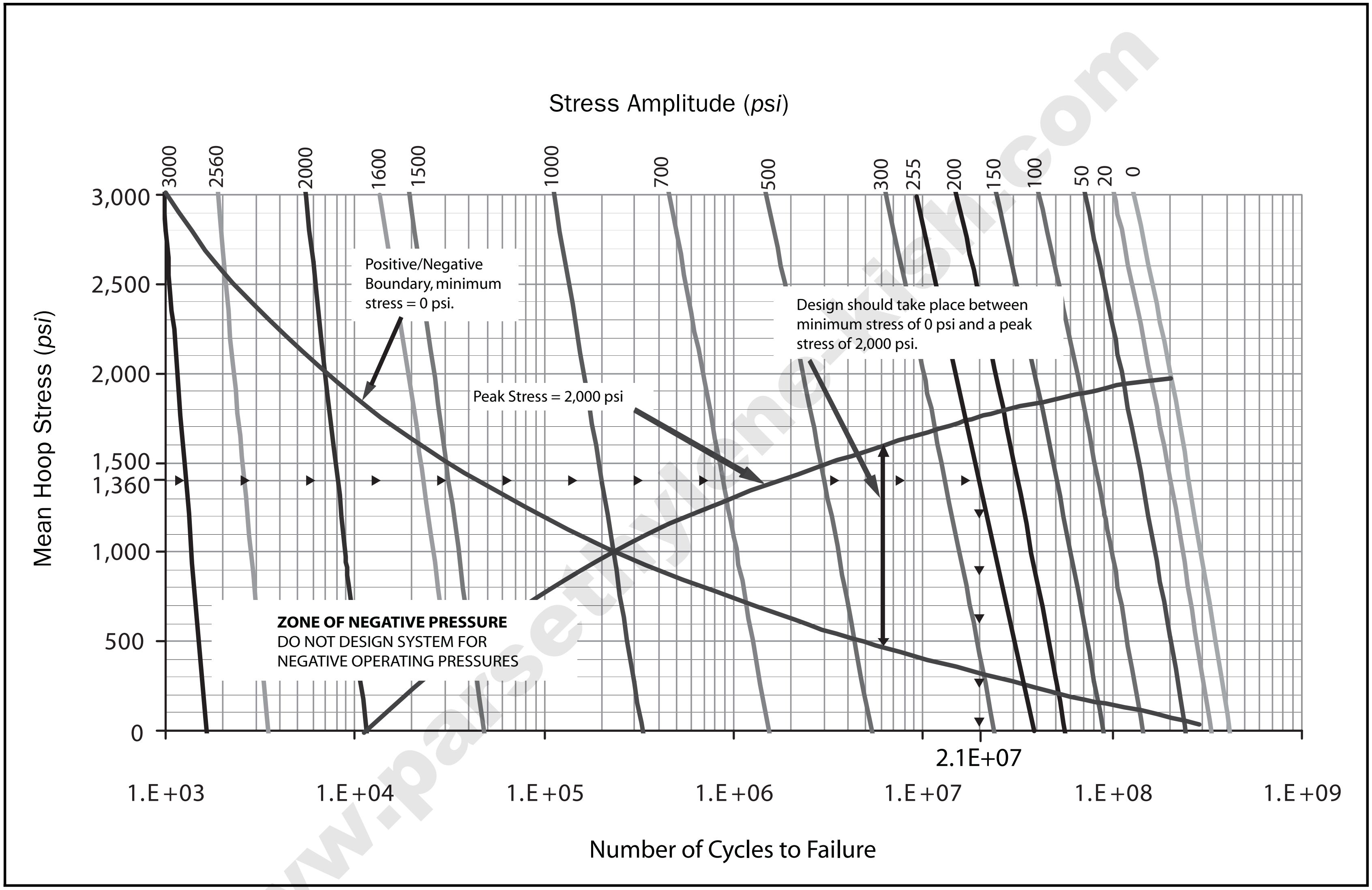

Figure B.2 Cyclic design curves

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