ANSI/AWWA A100-15
(Revision of ANSI/AWWA A100-06)

American Water Works Association
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AWWA Standard

Water Wells

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STANDARD Since 1881

AWWA Standard

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Contents

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

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Foreword

This foreword is for information only and is not a part of ANSI/AWWA A100.*

I. Introduction.

I.A. *Background.* This standard was originally used more as a specification than as a standard. Subsequent changes have been directed at developing a true standard as opposed to a specification.

This standard is designed primarily for vertical wells for municipal and industrial water supply.

I.B. *History.* The first edition of this standard was approved by the AWWA Board of Directors on May 10, 1946, and was titled "Standard Specifications for Deep Wells," with the designation 4A1-1946. Amendments to Sec. 1-1.1, Sec. 1-3.2, and Sec. 1-3.3 of that standard were approved by the board on Oct. 1, 1946, and the standard was redesignated AWWA A100-46. Subsequently, a number of minor editorial changes were made; a recommended procedure for sealing abandoned wells was added as appendix Sec. A1-13; and the standard was published on June 18, 1952, titled "Standard for Deep Wells." The standard was revised on Jan. 26, 1958, and was adopted jointly by AWWA and the National Water Well Association (NWWA). The standard was revised again in 1966. In 1984, the standard was reorganized substantially and revised to be a standard for well construction, rather than a specification, and republished under the title "Standard for Water Wells." The standard was again revised in 1990 and 1997. The ninth edition was approved by the AWWA Board of Directors on Feb. 12, 2006. This edition was approved on June 7, 2015.

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

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

In the United States, authority to regulate products for use in, or in contact with, drinking water rests with individual states.* Local agencies may choose to impose requirements more stringent than those required by the state. To evaluate the health effects of products and drinking water additives from such products, state and local agencies may use various references, including

1. An advisory program formerly administered by USEPA, Office of Drinking Water, discontinued on Apr. 7, 1990.
2. Specific policies of the state or local agency.
3. Two standards developed under the direction of NSF†: NSF/ANSI 60, Drinking Water Treatment Chemicals—Health Effects, and NSF/ANSI 61, Drinking Water System Components—Health Effects.
4. Other references, including AWWA standards, *Food Chemicals Codex*, *Water Chemicals Codex*,‡ and other standards considered appropriate by the state or local agency.

Various certification organizations may be involved in certifying products in accordance with NSF/ANSI 61. Individual states or local agencies have authority to accept or accredit certification organizations within their 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 A100 does not address additives requirements. Users of this standard should consult the appropriate state or local agency having jurisdiction in order to

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

* 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.

II. Special Issues.

II.A. *Screen Capacity.* The physical conditions of aquifers, as well as the experience and practice related to their utilization as groundwater resources, vary between well sites and geographic regions. Historically, a common practice for sizing well-screen length and diameter was based on screen open area and inlet velocity (entrance velocity). However, the recommended upper limit for this screen inlet velocity has varied greatly among designers and remains a subject of considerable technical debate. Many designers have, for various technical reasons, limited well-screen entrance velocities to not exceed 0.1 ft/sec (0.03 m/sec). Others have used and demonstrated successful well designs and installations with velocities substantially exceeding 0.1 ft/sec (0.03 m/sec), and the previous edition of this standard proposed an upper limit of entrance velocity of 1.5 ft/sec (0.46 m/sec).

Based on a significant body of ongoing research within the groundwater industry, the committee recognizes as part of this current standard that there is no singular uniquely defined criterion for permissible velocity through the screen slot openings that is solely suitable for designing a well screen without consideration of the aquifer characteristics and the manner of well construction. In particular, the aspects of flow surrounding the well screen in the filter and at the filter–aquifer interface are known to play a prominent role in the well's performance and are, in fact, more influential than screen entrance velocity in determining screen dimensions. Similarly, the sizing of screen length and diameter are greatly influenced by the aquifer thickness, stratigraphic layering, and pump size. Accordingly, the applicable design approach must be regarded as a multifaceted and dynamic problem. Within this context, the current edition of the standard no longer recommends screen design solely on the basis of screen entrance velocity criterion (Sec. 4.5.3).

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 information should be provided by the purchaser:

1. Standard used—that is, ANSI/AWWA A100, Water Wells, 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. Scope of the exploratory investigation (Sec. 4.2.1).
4. Whether additional formation samples are needed (Sec. 4.2.2.2).

5. Time, place, and mode of sample delivery (Sec. 4.2.2.5).

6. Type of geophysical log desired, if any (Sec. 4.2.3).

7. Details of other federal, state or provincial, and local requirements (Sec. 4.3).

8. Options for type of casing material (Sec. 4.3.4).

9. Whether the purchaser wants to specify temporary casings (Sec. 4.4.1).

10. Minimum casing wall thickness (Sec. 4.4.5).

11. Determination of the capacity of the well screen by careful evaluation of the composition of the aquifer. (The well-screen selection should be made by a qualified professional engineer, hydrogeologist, or well-drilling constructor.) (See Sec. 4.5, appendix L, and Sec. II.A, Screen Capacity, of the foreword.)

12. Maximum rate of flow from well (Sec. 4.5.2 and 4.5.3).

13. Available options for screen construction (Sec. 4.5.7).

14. Requirements for approval of gravel filter sampling (Sec. 4.6.3).

15. Alternate-alignment tolerance (Sec. 4.7.9.4 and appendix D).

16. The depth of the completed well, which defines the lower limit to which construction tolerances are to be applied (Sec. 4.7.9.5).

17. Height of well casing above ground level (Sec. 4.7.10.3).

18. Flow rate and protocol for performance testing (Sec. 5.1 and Sec. E.4.2 in appendix E).

19. Accuracy of water-level measurements (Sec. E.2.2 in appendix E).

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 revisions made to the standard in this edition include the following:

1. Added applicable definitions for the following: *manufacturer*, *naturally developed wells*, and *supplier*.

2. Material Requirements (Sec. 4.3) were updated to add NSF/ANSI 61 (Sec. 4.3.1) and Toxicity Levels (Sec. 4.3.2) requirements for all materials.

3. The water–cement ratio of neat cement grout when using bentonite additive is clarified in Sec. 4.3.7.1.1.

4. Provisions requiring current laboratory analysis and quality assurance of gravel filter materials delivered to jobsite are provided in Sec. 4.6.3.

5. Disinfection requirements for well casing above the standing water level (Sec. 4.9.2) are clarified.

6. Ability to reject materials not complying with the requirements of this standard were added in Sec. 5.3.

7. Provision for purchaser to require an Affidavit of Compliance that the well is in compliance with this standard (Sec. 6.1) has been added.

8. Methods of measuring operating parameters during well development were updated in appendix E, including clarification of the Electric-Sounder Method (Sec. E.4.3.1) and addition of Pressure Transducer Method (Sec. E.4.3.2).

9. Table K.4 was updated to correctly define standard dimension ratio and to add parameters for the 24-in. nominal size.

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.

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AWWA Standard

Water Wells

SECTION 1: GENERAL

Sec. 1.1 Scope

This standard describes the minimum requirements for vertical water supply wells.

Sec. 1.2 Purpose

The purpose of this standard is to provide the minimum requirements for water wells, including consideration of the influences of geologic and hydrologic conditions and water quality and well construction.

Sec. 1.3 Application

This standard can be referenced in specifications for constructing water wells and can be used as a guide for vertical water supply wells. The stipulations of this standard apply when this document has been referenced and only to water wells used in water supply service applications. Application of this standard is not limited by well depth.

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.

ANSI*/AWWA B100—Granular Filtration Material.

ANSI/AWWA C200—Steel Water Pipe—6 In. (150 mm) and Larger.

ANSI/AWWA C206—Field Welding of Steel Water Pipe.

ANSI/AWWA C654—Disinfection of Wells.

API† Spec 5L—Specification for Line Pipe.

API RP 13B-2—Recommended Practice for Field Testing Oil-Based Drilling Fluids.

API Spec. 10A—Specification for Cements and Materials for Well Cementing.

ASTM‡ A53/A53M—Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless.

ASTM A139/A139M—Standard Specification for Electric-Fusion (Arc)-Welded Steel Pipe (NPS 4 and Over).

ASTM A606/A606M—Standard Specification for Steel, Sheet and Strip, High-Strength, Low-Alloy, Hot-Rolled and Cold-Rolled, With Improved Atmospheric Corrosion Resistance.

ASTM A778—Standard Specification for Welded, Unannealed Austenitic Stainless Steel Tubular Products.

ASTM C33/C33M—Standard Specification for Concrete Aggregates.

ASTM C136/C136M—Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.

ASTM C150/C150M—Standard Specification for Portland Cement.

ASTM D75/D75M—Standard Practice for Sampling Aggregates.

ASTM F480—Standard Specification for Thermoplastic Well Casing Pipe and Couplings Made in Standard Dimension Ratios (SDR), SCH 40 and SCH 80.

NSF/ANSI 60—Drinking Water Treatment Chemicals—Health Effects.

NSF/ANSI 61—Drinking Water System Components—Health Effects.

* American National Standards Institute, 25 West 43rd Street, Fourth Floor, New York, NY 10035.

† American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005.

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

SECTION 3: DEFINITIONS

The following definitions shall apply in this standard:

1. *Abandoned well:* A well, the purpose or use of which has been permanently discontinued or a well in such a state of disrepair that its purpose or use cannot be reasonably achieved.

2. *Air line:* A small-diameter pipe or tube installed in the well and charged with air for the purpose of measuring the water level.

3. *Alignment:* The horizontal deviation between the actual well centerline and a straight line representing the desired undeviating centerline.

4. *Annular space:* The space between two generally concentric, cylindrical structures, such as between two casings or between a casing and borehole.

5. *Aquifer:* A geologic formation, group of formations, or part of a formation that contains water in its voids or pores that may be used as a source of water supply.

6. *Artesian well:* A well in an aquifer where the groundwater is confined under pressure, so that the water level in the well will stand above the top of the aquifer.

7. *Bailer:* A driller's tool made from pipe with a flapper or foot valve in the bottom, used to remove cuttings, sediments, or water from the borehole or well.

8. *Casing:* A pipe installed in the well borehole to maintain the well opening.

9. *Consolidated formation:* Hard rock–material strata of sedimentary-, igneous-, or metamorphic-type rock.

10. *Constructor:* The party that furnishes the work and materials for placement or installation.

11. *Drawdown:* The difference in elevation between the static and pumping water levels.

12. *Gravel-packed well:* A well in which gravel is placed in the annular space of the well adjacent to the screen section.

13. *Groundwater:* Subsurface water occurring below the water table.

14. *Grout:* A fluid mixture of portland cement and water of a consistency that can be forced through a pipe and placed as required or a fluid mixture of high-solids bentonite and water mixed in accordance with the manufacturer's instructions (see Sec. 4.3.7).

15. *Laminar flow:* Movement of fluid particles in essentially parallel paths.

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

17. *Naturally developed well:* A well in which screen slot openings or perforations are placed in direct contact with surrounding aquifer materials, without any intervening artificial filter or gravel.

18. *Plumbness:* The horizontal deviation (drift) of the well centerline from the imaginary vertical centerline.

19. *Pumping level:* The water level in the well when pumping is in progress.

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

21. *Specific capacity:* The ratio of the discharge rate to the unit of drawdown it produces, measured inside the well (gallons per minute per foot [liters per minute per meter] of drawdown).

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

23. *Test hole:* Drilled hole used to obtain information on geologic and hydrologic conditions.

24. *Tremie pipe:* A tubular device that carries materials to designated depths in the hole (also known as *gravel feedline* in gravel-packed wells).

25. *Unconsolidated formation:* Loose soft rock–material strata of sedimentary-, igneous-, or metamorphic-type rock, which includes sand, gravel, and mixtures of sand and gravel.

26. *Uniformity coefficient:* A ratio of the sieve-size opening that will pass just 60 percent of a representative sample of the filter material divided by the sieve-size opening that will pass just 10 percent of the material.

27. *Unit capacity:* For well screens, the discharge rate-per-unit surface area of the screen face through which flow occurs (gallons per minute per square foot [liters per minute per square meter]).

28. *Well efficiency (E):* The ratio of actual to theoretical specific capacity.

29. *Well screen:* A cylindrical filtering device used to stabilize the aquifer or gravel pack while allowing the flow of water into the casing and permitting development of the screened formation.

SECTION 4: REQUIREMENTS

Sec. 4.1 General

The requirements that follow for construction, development, and testing for permanent vertical water wells are the minimum requirements for the water supply industry.

4.1.1 *Permits.* Required permits shall be obtained and complied with.

4.1.1.1 Purchaser. Unless otherwise specified, the purchaser shall be responsible for providing all government and other permits that are required to be signed by the purchaser.

4.1.1.2 Constructor. The constructor or bidder shall be responsible for meeting applicable governmental requirements that are in existence on the date of the bid opening and that are designated as the responsibility of the constructor, unless otherwise provided for by the purchaser.

4.1.2 *Submittals.* Certifications and reports shall be submitted as required in other sections of this standard and as required by the purchaser.

4.1.3 *Protection of groundwater.* All reasonably necessary precautions shall be taken during construction of the well to ensure that contaminants do not reach the subsurface environment.

Sec. 4.2 Investigation of Geologic and Hydrologic Conditions and Groundwater Quality

4.2.1 *General.* The purpose of this section is to present considerations pertaining to the collection, evaluation, and reporting of data that have been developed from the investigations necessary to establish the site-specific geologic and hydrologic conditions and groundwater-quality parameters. It is intended that these considerations apply equally to exploratory programs and to the drilling of production wells. Groundwater investigations sometimes involve drilling one or more test wells before construction of the final production well is begun.

Reliable information regarding specific geologic materials and aquifer conditions at the site is necessary to establish the optimum design for various elements of the final production well. The surest way to characterize the formations beneath the site is to drill through them, obtaining samples while drilling and recording the data collected.

In addition to the information derived from test-well drilling and test pumping, there are a variety of geophysical logging methods that can provide useful information. The extent and cost of the exploratory and test drilling programs must be balanced against the difficulty in obtaining potable water in a site-specific area, the quantity and quality of the water sought, the use and nature of the well or wells, and the anticipated cost of the permanent well and appurtenances.

The purchaser shall define the scope of the exploratory investigation, including any geophysical logging desired.

4.2.1.1 Purpose of test holes and test wells. Test holes provide hydrogeologic information on aquifers and, if completed with casing and screen, serve as observation wells. Test wells are pumped to provide information on aquifer properties and water quality. Step-drawdown tests conducted in test wells facilitate the design of production wells.

4.2.2 *Formation sampling.*

4.2.2.1 Frequency of sampling. Formation samples shall be obtained at a maximum interval not exceeding 10 ft (3.05 m) and at each change in formation. Particular care shall be taken when collecting samples from expected producing zones.

4.2.2.2 Additional samples. At the direction of the purchaser, additional samples should be obtained at a maximum interval of 5 ft (1.52 m), as required from expected producing zones.

4.2.2.3 Collection and marking. Samples shall be collected, dried, and preserved in separate containers of at least 1.1-lb (500-g) capacity for each interval. Containers shall be plainly marked with well designation, purchaser, location, depth interval, sampling method, sampler type, and the date and time the sample was taken.

4.2.2.4 Storage of samples. The constructor shall be responsible for the safe storage of formation samples until such time as they are accepted by the purchaser.

4.2.2.5 Sample delivery. Time, place, and mode of delivery shall be as directed by the purchaser.

4.2.3 *Geophysical logging.* Various geophysical logs are commercially available and may be required at the discretion of the purchaser (see appendix I). The geophysical borehole logs may provide qualitative information on aquifer types and characteristics.

4.2.4 *Water sampling and analyses.*

4.2.4.1 Water sampling. Water samples shall be taken for chemical analyses from each aquifer designated as a possible source for development. The method used to collect samples shall not contaminate the aquifer.

4.2.4.2 Water analyses. When designated, the analyses of the water shall be done according to the requirements of Sec. 5.2. Temperature, pH, specific conductance, and dissolved gases shall be determined by field test and recorded.

4.2.5 *Reports.*

4.2.5.1 Driller's log. During drilling and completion of the well, the constructor shall maintain a complete log, setting forth the following items as they apply:

1. Reference point for all depth measurements.
2. Depth at which each change of formation occurs.
3. Depth at which the first water was encountered, when applicable to the drilling method.
4. Location and thickness of each aquifer.
5. Identification of the stratigraphy and lithology encountered in the borehole.
6. Depth interval from which each water and formation sample was taken.
7. Depth for each borehole diameter.
8. Depth to the static water level (SWL) and observable changes in SWL with well depth.
9. Total depth of completed well.
10. Location limits of lost circulation zones.
11. Depth of the surface or sanitary seal.
12. Nominal hole diameter of the well bore above and below the casing seal.
13. Quantity, type, and mixture of the grout installed for the seal.
14. Depth, length, diameter, wall thickness, material, and the type of connection of the well casing.
15. Well-screen type, diameter, wall thickness, material, aperture size and orientation, type of connection, and depth interval in the borehole.
16. For gravel-packed wells, the interval, height, thickness, grain size of gravel material used, the gravel pack to formation grain-size ratio, and the source or supplier and the supplier's product number.
17. Capacity of the well, pump installed, and the observed drawdown during testing.
18. Sealing off of water-bearing strata, if any, and the exact location thereof.

Table 1 USGS grain-size classification

	Grain-Size Range	
	in.	*(mm)*
Boulder	≥10.08	(≥256)
Cobble	2.52–10.08	(64–256)
Very coarse gravel	1.26–2.52	(32–64)
Coarse gravel	0.63–1.26	(16–32)
Medium gravel	0.31–0.63	(8–16)
Fine gravel	0.16–0.31	(4–8)
Granule (very fine gravel)	0.08–0.16	(2–4)
Very coarse sand	0.04–0.08	(1–2)
Coarse sand	0.02–0.04	(0.5–1)
Medium sand	0.01–0.02	(0.25–0.5)
Fine sand	0.005–0.01	(0.125–0.25)
Very fine sand	0.002–0.005	(0.063–0.125)
Silt	0.0002–0.002	(0.004–0.063)
Clay	<0.0002	(<0.004)

19. Rate of penetration. During the drilling of the hole, a time log shall be maintained showing the rate of penetration, as well as the types of bits used in each portion of the hole.

20. All other pertinent information specified by the purchaser.

4.2.5.2 Stratigraphic log. The stratigraphic log shall be prepared to accompany the set of drilling samples, noting (1) depth; (2) strata thickness; (3) lithology, including size, range, and shape of constituent particles, as well as smoothness, rock type, and rate of penetration; and (4) such special notes as might be helpful. The description shall conform to the US Geological Survey (USGS) standard gradation of grain sizes shown in Table 1.

4.2.6 *Identification of principal aquifers.*

4.2.6.1 Identification of principal aquifers using geophysical borehole logs. Principal aquifers occurring throughout the depth of a well shall be identified using interpretation of results generated by geophysical borehole logging devices. Identification shall be made by a qualified engineer, hydrogeologist, or well constructor.

4.2.6.2 Identification of principal aquifers using formation samples. Differentiation of principal aquifers in a well shall be determined on the basis of formation samples obtained.

Sec. 4.3 Material Requirements

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

4.3.1 *NSF/ANSI 61.* Components used in well systems shall, if specified by the purchaser, be certified as suitable for contact with, or treatment of, drinking water by an accredited certification organization in accordance with NSF/ANSI 61.

4.3.2 *Toxicity levels.* Products and components must not leach toxic substances into the water that is distributed to the public or the environment in their intended use. Disposal methods for residuals and used components that meet applicable regulatory requirements shall be available. Evaluation shall be accomplished in accordance with requirements that are no less restrictive than those listed in NSF/ANSI 60 or NSF/ANSI 61, respectively, if specified by the purchaser. Certification shall be accomplished by a certification organization accredited by the American National Standards Institute

4.3.3 *Drilling-fluid materials.* Drilling fluids are used in the process of drilling to facilitate the removal of formation cuttings and to stabilize the borehole during drilling and completion operations.

4.3.3.1 Types of drilling fluids. The following types of drilling fluids are acceptable for water-well drilling:

1. Freshwater-based drilling fluids.
2. Air-based drilling fluids.

4.3.3.2 Fluid additives. Acceptable additives to drilling fluids are as follows:

1. Dissolved additives
   a. Mud-thinning agents
   b. Inorganic phosphates
   c. Surfactants
   d. Drilling detergents
   e. Foaming agents
   f. Natural and synthetic polymers
2. Nondissolved additives
   a. Native solids (clays and sand)

Table 2 Water-well casing materials

A. Manufacturing standards for single-ply carbon-steel well casing:	
ANSI/AWWA C200	
API Spec. 5L	
ASTM A53 Grade B	
ASTM A139 Grade B	
B. Manufacturing standards for alternative single-ply well-casing materials:	
Casing Material	*Manufacturing Standard*
Carbon steel	ASTM A139 Grade B
Copper-bearing steel	ASTM A139 Grade B with the additional requirement that the steel contain a minimum of 0.20% copper
High-strength low-alloy steel	ASTM A606 Type 4
Stainless steel	ASTM A778
Plastic	ASTM F480
C. Two-ply steel-casing material properties:	
Chemical Composition, Percent:	
Carbon	0.20–0.30
Manganese	0.85–1.30
Phosphorus	0.05 maximum
Sulfur	0.05 maximum
Silicon	0.12 maximum
Copper	0.20 minimum
Physical Properties:	
Yield strength, psi (MPa)	55,000–70,000 (379–483)
Ultimate strength, psi (MPa)	80,000–95,000 (552–655)
Elongation, percent in 8 in. (200 mm)	17–25
Rockwell "B" harness	80–90
Elastic ratio	69:73

b. Bentonite

c. Density-increasing materials

d. Loss-circulation materials (not to be used in the production zone)

4.3.4 *Casing materials.* All casing material shall be new and shall conform to one of the manufacturing standards listed in Table 2. It shall be the responsibility of the constructor to ensure that the purchaser is provided with documented mill certifications by the manufacturer of the casing.

4.3.4.1 Two-ply casing. Two-ply casing shall be fabricated from high-strength corrosion-resistant steel with the minimum material properties set forth in Table 2. Two-ply casing shall be made of inner and outer sections, each 4 ft (1.2 m) in length. Longitudinal seams of the sections shall be welded and processed so that the outer casing fits snugly to the inner casing. The ends of the sections shall be lathe-trimmed square to the longitudinal axis so that the fit around the entire circumference will be snug when the ends are placed together. The circumferential joints of the inner sections shall be placed midway between the circumferential joints of the outer sections. After assembly, each outer circumferential joint shall be electrically welded.

4.3.5 *Well-screen material.* To reduce the possibility of corrosion, metallic well screen and its fittings should be fabricated of the same material. This material shall be AISI* Type 304 stainless steel unless otherwise specified. A manufacturer's certification of materials shall be provided to the purchaser by the contractor.

4.3.6 *Gravel-pack material requirements and impurity limits.*

4.3.6.1 Specific gravity. The gravel-pack material shall have an average specific gravity of not less than 2.5.

4.3.6.2 Minimum specific gravity. Not more than 1 percent, by weight, of the material shall have a specific gravity of 2.25 or less.

4.3.6.3 Nonround pieces. Thin, flat, or elongated pieces the maximum dimension of which exceeds three times the minimum shall not be in excess of 2 percent, by weight.

4.3.6.4 Acid solubles. Not more than 5 percent of the gravel shall be soluble in hydrochloric acid.

4.3.6.5 Washed material. The material shall be washed and free of shale, mica, clay, dirt, loam, and organic impurities of any kind.

4.3.6.6 Metals. The material shall contain no iron, manganese, copper, lead, or other heavy metals in a form or quantity that will adversely affect the quality of the well water.

4.3.6.7 Gradation. Tests for gradation of gravel-pack material shall be performed according to the method of testing specified in ASTM C136.

4.3.6.8 Gravel-pack to formation ratio. The ratio of grain size of gravel-pack material to formation material shall range from 6:1 to 4:1. Usually, the fiftieth or the seventieth percentiles of the grain sizes retained of both materials are compared.

* American Iron and Steel Institute, 1140 Connecticut Avenue, Suite 705, Washington, DC 20036.

4.3.6.9 Uniformity coefficient. The uniformity coefficient of the gravel pack shall not exceed 2.5.

4.3.6.10 Distribution curve. The size-distribution curve of the gravel pack shall parallel the central part of the formation-sand distribution curve for formation sands having a uniformity coefficient less than 2.5.

4.3.6.11 Site-specific selection. No two vertical water supply wells are exactly the same. Therefore, gravel-pack materials and methods of placement must be selected on a site-specific basis. The gravel-pack materials and the thickness of the gravel pack should be based on all of the information available, including production formation data, well screen, and gravel-pack materials that are practically and economically available. Purchasers, constructors, engineers, and others involved in vertical production water well design are urged to consult the various appendixes of this standard. They also are urged to consult reference books, such as the US Environmental Protection Agency's (USEPA's) *Manual of Water Well Construction Practices* (EPA-570/9-75-001), Johnson Screen's (Bilfinger Water Technologies Inc.)* *Ground Water and Wells*, and Roscoe Moss Company's† *Handbook of Ground Water Development*.

4.3.7 *Grouting and sealing materials.* The listed materials are commonly used for sealing wells. The purchaser must select sealing material on a site-specific basis.

4.3.7.1 Neat cement. Neat cement shall consist of a mixture of API Spec. 10, Class A (similar to ASTM C150, Type I) or Class B (similar to ASTM C150, Type II) and water in the ratio of not more than 6.0 gal (22.8 L) of water per 94-lb (42.6-kg) sack of cement weighing approximately 118 lb/ft^3 (1,880 kg/m^3).

4.3.7.1.1 A maximum of 6 percent, by dry weight, unbeneficiated (not enhanced or "high yield") bentonite may be added to the neat cement grout. With bentonite additive, the mixture of cement and water should begin at the base ratio of 5.2 gal (19.7 L) of water per 94-lb (42.6-kg) sack of cement plus an additional 0.65 (2.5 L) gal of water per sack of cement for each 1 percent bentonite additive. Note also that the bentonite contribution to the mixture is affected by the mixing protocol, that is, whether the bentonite is mixed dry with the dry cement prior to adding mixing water or instead is added first to the mixing water (prehydrated) prior to the addition of cement. Prehydrated bentonite generates more effect, such

* Johnson Screens, 1950 Old Hwy 8 NW, St. Paul, MN 55112.
† Roscoe Moss Company, 4360 Worth Street, Los Angeles, CA 90063.

that 1 percent of bentonite added first to the mixing water (prehydrated) has the same effect as 3.6 percent of bentonite by dry weight mixed first with the dry cement. The additional gallons of mixing water required (0.65 gal of water for each 1 percent bentonite dry mixed) must be selected with consideration to the different mixing protocols and the relative effect of the bentonite in each protocol.

4.3.7.1.2 Class B (Type II) cement is resistant to moderate sulfate aggression (sulfate concentrations of 150 to 1,500 mg/L in groundwater). Hydrogeologic conditions in which ASTM C150 Type V cement (for sulfate concentrations exceeding 1,500 mg/L) might be considered would be encountered only infrequently for water supply wells.

4.3.7.2 Concrete. Concrete shall contain 5.3 sacks of ASTM C150, Type 1 or Type 2 portland cement per cubic yard (0.76 m^3) of concrete and a maximum of 7 gal (26.5 L) of water per 94-lb (42.6-kg) sack of cement. The maximum slump shall be 4 in. (102 mm). The aggregate shall consist of 47 percent sand and 53 percent coarse aggregate, conforming to ASTM C33.

4.3.7.2.1 The maximum size aggregate should be 0.75 in. (19 mm).

4.3.7.2.2 Concrete seal shall not be placed in an annular space having a radial thickness of less than 3 in. (76 mm).

4.3.7.3 Bentonite grout. Bentonite grout shall consist of a high-solids bentonite grout and water mixture with a minimum of 20 percent solids, mixed and placed in accordance with the manufacturer's written instructions. Conventional bentonite drilling clay and water mixtures are not allowed. Such products shall not impart harmful characteristics to the well and shall be mixed and placed according to the manufacturer's instructions.

4.3.7.4 Sand–cement grout. Sand–cement grout shall consist of a mixture of ASTM C150, Type 2 cement, sand, and water in the proportion of not more than 2 parts, by weight, of sand to 1 part of cement with not more than 6 gal (22.7 L) of water per 94-lb (42.6-kg) sack of cement.

Sec. 4.4 Well Casing

4.4.1 *General.* This section sets forth standards applicable to permanent casings for water wells. Selection of temporary casings used only for construction is left to the constructor unless otherwise specified by the purchaser.

4.4.2 *Permeation.* The selection of materials is critical for well casing in locations where there is likelihood the well casing will be exposed to significant concentrations of pollutants consisting of low-molecular-weight petroleum products or organic solvents or their vapors. Research has documented that casing materials such

Table 3 Standard well-casing sizes for wells

Maximum Diameter of Pump Assembly*		Minimum (Actual) Inside Diameter (ID) of Well Casing	
in.	*(mm)*	*in.*	*(mm)*
4	(101.6)	6	(152.4)
5	(127.0)	8	(203.2)
6	(152.4)	10	(254.0)
8	(203.2)	12	(304.8)
10	(254.0)	13	(330.2)
12	(304.8)	14	(355.6)
14	(355.6)	16	(406.4)
16	(406.4)	20	(508.0)
18	(457.2)	22	(558.8)
20	(508.0)	24	(609.6)
22	(558.8)	26	(652.6)

* For pumps larger than 22 in. (558.8 mm) in diameter, casing diameter shall be at least two nominal sizes larger than the diameter of the pump being installed.

as polyethylene, polybutylene, polyvinyl chloride, and asbestos cement and elastomers, such as used in jointing gaskets and packing glands, may be subject to permeation by lower-molecular-weight organic solvents or petroleum products. If well casing extends through such a contaminated area or an area subject to contamination, consult with the manufacturer regarding permeation of casing materials and associated factors *before* selecting materials for use in that area.

4.4.3 *Permanent casings.* Permanent well casings shall be continuous and watertight from top to bottom of the installed casing, except for well screens.

4.4.4 *Casing diameter.* Casings shall meet the minimum diameter requirements given in Table 3.

4.4.5 *Casing wall thickness.* Well-casing wall thickness specified by the purchaser shall be sufficient to withstand anticipated formation and hydrostatic pressures and mechanical forces imposed on the casing during its installation, well development, and use. The minimum wall thickness tables (Tables 4 and 5) represent a committee judgment with respect to the minimum wall thickness normally necessary in the absence of unusual stresses to be placed on the casing in the course of installation and well development, corrosion, or use. Depths of well casing deeper than listed in Tables 4 and 5 are not precluded but require a careful study of casing collapse strength. Selection of casing wall thickness merits analysis and judgment by

Table 4 Minimum thickness for steel well casing—single casing

Depth of Casing *ft (m)*	Nominal Casing Diameter—*in. (mm)*									
	8 (203)	10 (254)	12 (305)	14 (356)	16 (406)	18 (457)	20 (508)	22 (559)	24 (610)	30 (762)
0–100	¼	¼	¼	¼	¼	¼	¼	5⁄16	5⁄16	5⁄16
(0–30)	(6.35)	(6.35)	(6.35)	(6.35)	(6.35)	(6.35)	(6.35)	(7.94)	(7.94)	(7.94)
100–200	¼	¼	¼	¼	¼	¼	¼	5⁄16	5⁄16	5⁄16
(30–60)	(6.35)	(6.35)	(6.35)	(6.35)	(6.35)	(6.35)	(6.35)	(7.94)	(7.94)	(7.94)
200–300	¼	¼	¼	¼	¼	5⁄16	5⁄16	5⁄16	5⁄16	⅜
(60–90)	(6.35)	(6.35)	(6.35)	(6.35)	(6.35)	(7.94)	(7.94)	(7.94)	(7.94)	(9.52)
300–400	¼	¼	¼	¼	5⁄16	5⁄16	5⁄16	5⁄16	⅜	⅜
(90–120)	(6.35)	(6.35)	(6.35)	(6.35)	(7.94)	(7.94)	(7.94)	(7.94)	(9.52)	(9.52)
400–600	¼	¼	¼	¼	5⁄16	5⁄16	5⁄16	⅜	⅜	7⁄16
(120–180)	(6.35)	(6.35)	(6.35)	(6.35)	(7.94)	(7.94)	(7.94)	(9.52)	(9.52)	(11.11)
600–800	¼	¼	¼	5⁄16	5⁄16	5⁄16	⅜	⅜	⅜	7⁄16
(180–240)	(6.35)	(6.35)	(6.35)	(7.94)	(7.94)	(7.94)	(9.52)	(9.52)	(9.52)	(11.11)
800–1,000	¼	¼	¼	5⁄16	5⁄16	5⁄16	⅜	7⁄16	7⁄16	½
(240–300)	(6.35)	(6.35)	(6.35)	(7.94)	(7.94)	(7.94)	(9.52)	(11.11)	(11.11)	(12.70)
1,000–1,500	¼	5⁄16	5⁄16	5⁄16	⅜	⅜	⅜	7⁄16	*	*
(300–450)	(6.35)	(7.94)	(7.94)	(7.94)	(9.52)	(9.52)	(9.52)	(11.11)	—	—
1,500–2,000	¼	5⁄16	5⁄16	5⁄16	⅜	⅜	7⁄16	7⁄16	*	*
(450–600)	(6.35)	(7.94)	(7.94)	(7.94)	(9.52)	(9.52)	(11.11)	(11.11)	—	—

*Reference Section 4.4.5 of A100-15 regarding thickness of well casings.

Table 5 Minimum thickness for two-ply steel well casing*

Depth of Casing *ft (m)*	Diameter—*in. (mm)*								
	10 (254)	12 (305)	14 (356)	16 (406)	18 (457)	20 (508)	22 (559)	24 (610)	30 (762)
0–100	12	12	12	12	10	10	10	10	8
(0–30)	(2.66)	(2.66)	(2.66)	(2.66)	(3.42)	(3.42)	(3.42)	(3.42)	(4.18)
100–200	12	12	12	10	10	10	10	8	8
(30–60)	(2.66)	(2.66)	(2.66)	(3.42)	(3.42)	(3.42)	(3.42)	(4.18)	(4.18)
200–300	12	12	10	10	10	10	8	8	8
(60–90)	(2.66)	(2.66)	(3.42)	(3.42)	(3.42)	(3.42)	(4.18)	(4.18)	(4.18)
300–400	12	12	10	10	10	8	8	8	8
(90–120)	(2.66)	(2.66)	(3.42)	(3.42)	(3.42)	(4.18)	(4.18)	(4.18)	(4.18)
400–600	10	10	10	10	8	8	8	8	8
(120–180)	(3.42)	(3.42)	(3.42)	(3.42)	(4.18)	(4.18)	(4.18)	(4.18)	(4.18)
600–800	10	10	10	8	8	8	6	6	6
(180–240)	(3.42)	(3.42)	(3.42)	(4.18)	(4.18)	(4.18)	(4.94)	(4.94)	(4.94)
800–1,000	10	8	8	8	8	6	6	6	6
(240–300)	(3.42)	(4.18)	(4.18)	(4.18)	(4.18)	(4.94)	(4.94)	(4.94)	(4.94)

*Values are US standard steel thickness gauge (mm).

experienced, qualified engineers and drilling experts. Actual wall thickness should, in each instance, be based on an analysis of the anticipated stresses to which the casing will be subjected during each phase of construction and any pertinent state or local requirements. An appropriate corrosion allowance shall be included.

4.4.5.1 Minimum thickness for carbon-steel casing. The purchaser shall specify the minimum wall thickness for carbon-steel casing.

4.4.5.2 Minimum thickness for plastic casing. The purchaser shall specify the minimum wall thickness of plastic casing.

Sec. 4.5 Well Screens

4.5.1 *General.* This section sets forth standards for screens to be used for water wells. All available information on the character of the water-bearing formation must be evaluated for proper well design. The screen length required to ensure a highly efficient well is determined by the thickness and hydrologic character of the aquifer.

4.5.2 *Screen diameter.* The diameter of the selected well screen shall not be less than the minimum size needed to maintain a vertical velocity within the screen barrel of not greater than 4 ft/sec (1.22 m/sec), based on the maximum well flow in gallons per minute specified by the purchaser. If it is anticipated that the pump setting will be into or below the screen, the minimum inside diameter of the screen shall conform to Table 3.

4.5.3 *Screen length.* The length of screen most appropriate for the well's construction must be selected with regard to the aquifer's thickness and stratigraphic layering, in addition to the various hydraulic factors affecting a well's performance. Where possible, the portion of the aquifer exposed to the screen should be sufficient to minimize the effects of partial penetration. In unconfined aquifers, the length and position of the screen required to negate partial penetration must be balanced against limiting the available drawdown. Stratigraphic layers varying in coarseness and permeability also may influence the length and position of screen selected.

The use of screen entrance velocity as one hydraulic consideration is discussed in appendix L. Although screen entrance velocity has been used for many years as the primary hydraulic factor for selection of screen length, the lack of consensus regarding the most appropriate entrance velocity for design discourages its use as the sole criterion. Other aspects affecting the well screen's hydraulic performance are discussed in Sec. 4.5.4.

4.5.4 *Other considerations.* As discussed in the foreword of this standard (Sec. II.A), hydraulic factors other than screen entrance velocity, such as approach velocities, turbulent versus laminar flow, and velocity distribution along the screen, are regarded as being of equal or greater influence on the performance of a well screen. In general, these factors vary with the specific discharge (flow per unit area) at the screen face and at the filter–aquifer interface, regardless of the well screen's open area. The user of this standard is encouraged to incorporate these additional design considerations during selection of screen length, as well as for establishing the diameters of the screen and borehole. By using these various additional considerations during design, the range of design options and performance can be better defined, from which the most appropriate well construction can be selected.

4.5.5 *Screen-aperture size.*

4.5.5.1 Naturally developed wells. In naturally developed wells, screen apertures shall be sized according to the following criteria:

1. Where the uniformity coefficient of the formation is greater than 6, the screen aperture shall be sized to retain 30 to 40 percent of the aquifer sample.
2. Where the uniformity coefficient of the formation is less than 6, the screen aperture shall be sized to retain 40 to 50 percent of the aquifer sample.
3. If the water in the formation is corrosive or the accuracy of the aquifer sample is in doubt, a size shall be selected that will retain 10 percent more than is indicated in items 1 and 2 in Sec. 4.5.5.1.
4. Where fine sand overlies coarse sand, use the fine-sand aperture size for the top 2 ft (0.61 m) of the underlying coarse sand. The coarse-sand aperture size shall not be larger than twice the fine-sand aperture size.

4.5.5.2 Gravel-packed wells. For gravel-packed wells, the screen-aperture openings shall be sized to retain between 80 and 95 percent of gravel-pack material.

4.5.5.3 Total aperture area. The total aperture area of most commercial well screens is normally sufficient to achieve satisfactory well performance and efficiency. In general, well capacity does not directly correspond to variations in aperture area among manufacturers and methods of screen construction. This concept is discussed further in appendix L.

4.5.6 *Screen strength.* Screens shall be designed to minimize the possibility of damage during installation, development, and use.

4.5.7 *Screen construction.* The purchaser's specifications shall dictate the type of well-screen construction using one of the following methods:

4.5.7.1 Punched- or louvered-pipe screens. Openings shall be punched in the casing screens in such a way that no material is removed from the casing wall. The spacing and size of openings shall be uniform.

4.5.7.2 Wire-wound continuous-slot screens. Continuous-slot wire-wound well screens shall be fabricated by circumferentially wrapping a triangular-shaped wire around an array of equally spaced rods. Each juncture between the horizontal wire and the vertical rods shall be fusion welded underwater for maximum strength. The wire shape must produce inlet slots with sharp outer edges, widening inwardly to minimize clogging. Screen-end fittings shall be fabricated of the same material as the screen body and shall be securely welded to each section.

4.5.7.3 Perforated-pipe base screens. Pipe conforming to the well-casing standards specified in Sec. 4.4 shall be perforated with uniformly spaced and sized openings. Telescoped over this shall be a continuous-slot screen of AISI Type 304 stainless steel identical in construction to the requirements of Sec. 4.5.7.2.

4.5.8 *Screen joints.* Joints between screen sections and blank casing shall be welded or threaded and coupled. If welded, the welding rod shall be of equal quality to the most noble metal. The joint shall be watertight, straight, and as strong as the screen.

4.5.9 *Screen-to-casing seals.* The screen or screen casing shall be sealed to the well casing by one of the following methods:

4.5.9.1 Elastomeric seals. For naturally developed wells, a nonmetallic seal of neoprene or rubber made to fit the casing surrounding the screen shall be attached to the screen or screen casing to effect the seal. The screen or screen casing shall extend at least 5 ft (1.52 m) into the exterior casing.

4.5.9.2 Grout seal. If an elastomeric seal is not used on naturally developed wells, the space between the screen casing and casing surrounding the screen shall be filled with grout to form a seal at least 3-in. (76-mm) thick and 3 ft (0.91 m) in length. The screen casing shall extend at least 5 ft (1.52 m) into the casing surrounding the screen.

4.5.9.3 Gravel-pack screen casing seal. Where the construction of the well is the gravel-packed type, and the screen casing extends at least 50 ft (15.2 m) into the casing above, and the space between the two is filled with gravel, no other seal will be required unless special local conditions warrant it or if it is required by local, state, or federal regulations. When the screen casing does not extend at least 50 ft (15.2 m) into the casing, a grout seal of at least 3 ft (0.91 m) in length shall be placed to fill the space between the two casings.

4.5.10 *Continuous casing and screen.* When the screen and casing are one continuous unit, joints may be of any of the types approved for casing in Sec. 4.7.4.1 and 4.5.8.

4.5.10.1 Bottom of screen seals. The bottom of the deepest screen or screen sump shall be sealed by any one of the following methods.

4.5.10.1.1 Threaded or welded plate. A threaded or welded plate shall be installed at the bottom of the screen or screen sump. The plate shall be made of the same material as that used for the screen or the screen sump to which the plate is attached.

4.5.10.1.2 Self-closing valve. A self-closing valve shall be installed at the bottom of the screen or screen sump and then shall be covered by a cement plug at least 1 ft (0.30 m) in depth.

Sec. 4.6 Gravel Pack

4.6.1 *General.* This section covers water-well construction where the gravel-pack material is installed in the annular space between the screen (and casing) and borehole for the purpose of stabilizing the formation.

4.6.2 *Gravel-pack thickness and location.* Selection of the gravel-pack thickness surrounding the screen is dependent on individual aquifer characteristics, and should be based on individual site-specific aquifer information and construction criteria. The minimum thickness to allow for proper placement of gravel-pack material shall be 3 in. (77 mm), and the maximum gravel-pack thickness usually does not exceed 12 in. (305 mm).

Gravel-pack material shall be placed in the annular space adjacent to the well screens and shall extend above the screen at least 20 ft (6.10 m), subject to local regulatory requirements.

4.6.3 *Gravel-pack samples.* Samples of gravel pack, including sieve analysis, shall be approved by the purchaser in advance of delivery and placement.

4.6.3.1 Grain-size distribution. Grain-size distribution information provided by the supplier shall be based on sampling and sieve analysis completed within 90 days of submittal of this information to purchaser. If supplier does not have available sieve analyses from within this period, then supplier shall provide purchaser a representative sample for analysis by an independent laboratory.

4.6.3.1.1 All samples shall be plainly labeled to indicate the source of the material, the date, and the name of the supplier.

4.6.3.2 Gravel-filter materials should be delivered to the jobsite sufficiently in advance of their scheduled emplacement in the well to allow for inspection and confirmation that the supplied grain-size distribution complies with that required for construction of the well. Prior to emplacement, representative composite samples equivalent to at least one sample for each 3 yd^3 (2.3 m^3) of filter material delivered, but no less than two samples regardless of volume, should be collected and submitted to an independent laboratory for sieve analyses.

4.6.3.3 Method of sampling. Methods of sampling shall be according to ASTM D75 and ANSI/AWWA B100. Particular care is required to obtain representative composite samples from bulk shipments and large filter bags (e.g., bags of 1 yd^3 or 1 m^3 in size). ANSI/AWWA B100 suggests several protocols for representative sampling, by collecting samples from the center of the filter container using a thief sampler or by dumping portions of the filter materials in an open top box and compositing.

4.6.4 *Delivery and storage.* The gravel-pack material shall be delivered to the well site on approval by the purchaser.

4.6.4.1 Bag or bulk delivery. The material may be delivered in bags or in bulk.

4.6.4.2 Contaminated material. Gravel-pack material that comes in contact with the ground surface shall not be used, and all materials shall be protected from contamination until installed.

Sec. 4.7 Well Construction

4.7.1 *General.* Methods of construction and well configuration shall be selected based on aquifer configuration, intended well use, and local experience and regulations. (Typical types of well construction are covered in appendix J.)

4.7.2 *Drilling methods.* Wells used for water supply are normally constructed by drilling. Drilling may consist of the cable-tool method or the direct or reverse rotary method.

4.7.2.1 Cable-tool method. With the cable-tool (percussion) method, drilling is accomplished by the breaking or crushing action of reciprocating drill tools suspended from the drilling machine on a wire line.

4.7.2.1.1 Depending on formation stability, an open hole can be drilled before installation of the casing and screen, or the casing can be installed coincident with drilling.

4.7.2.1.2 Seals and methods of sealing are discussed in Sec. 4.5.9 and 4.7.8.

4.7.2.1.3 Drive shoes are discussed in Sec. 4.7.4.2.

4.7.2.2 Rotary method. Rotary drilling is accomplished by the cutting, grinding, and rotary action of a rotating drill bit forced against the bottom of the hole. The material displaced by the bit is removed by the circulating drilling fluid.

4.7.3 *Drilling-fluid properties and tests.* During the drilling operation, when additives to freshwater are used, drilling-fluid properties shall be maintained within limits that will allow their complete removal from the water produced from the well, if necessary, and shall not damage the potential capacity, efficiency, or quality of the well. Drilling-fluid properties shall be maintained during normal drilling operations within the following limits using test procedures conforming to API RP 13B-2:

1. Weight (fluid density)—limits: 70–85 lb/ft^3 (1,121–1,362 kg/m^3); test equipment: mud balance.

2. Viscosity—limits: 32–40 sec/qt (30–38 sec/L) [clear water 26 sec/qt (25 sec/L)]; test equipment: 1-quart mud cup, Marsh funnel, stopwatch.

3. Filtration (wall cake and filtration loss)—limits: 3⁄32 in. (2.38 mm) with maximum 20 cc water loss in 30 minutes; test equipment: filter press, graduated cylinder, stopwatch.

4. Sand content (solids larger than 200 mesh)—limits: 2–4 percent, by volume; test equipment: sand-content set.

4.7.3.1 Frequency of drilling-fluid property tests. Drilling-fluid properties shall be tested once for every 50 ft (15.2 m) of hole drilled or 4 hours of circulating time, whichever is more frequent.

4.7.3.2 Recording. The drilling-fluid properties set forth in this standard shall be measured and recorded.

4.7.4 *Well-casing installation.* The method of well-casing installation shall be at the option of the drilling constructor, provided the installation meets the requirements of Sec. 4.7.9 and the installation process does not alter the shape, size, configuration, or strength of the casing.

4.7.4.1 Casing joints. Casing joints shall be of the types listed in Table 6.

Table 6 Casing joints

Casing Material	Type of Joint	Standard
Steel	Welded or threaded and coupled	ANSI/AWWA C206*
Plastic	Threaded and coupled, solvent-welded, or spline locked	ASTM F480
Two-ply	Welded	ANSI/AWWA C206

*C206 covers field welding only.

4.7.4.2 Drive shoes. Special steel drive shoes used when the casing is pushed or driven shall be heat-treated (Rockwell C Hardness 30-32) SAE 1040 steel ring or equivalent.

4.7.4.3 Sealing of well casing. Well casing shall be sealed in accordance with Sec. 4.7.8.

4.7.5 *Well-screen installation.* Well screens installed in gravel-pack wells shall be centered in the hole. A sufficient number of centralizing devices shall be used to ensure concentricity.

4.7.6 *Gravel-pack installation.*

4.7.6.1 Placement. Gravel shall be placed to ensure continuity of the gravel pack without bridging, voids, or segregation (see appendix B).

4.7.6.2 Drilling fluid. Before the introduction of gravel pack, the drilling fluid shall be reconditioned, unless different properties are needed to protect the well, until it has the following properties:

1. Weight—a maximum of 68 lb/ft^3 (1,083 kg/m^3).
2. Viscosity—a maximum of 30 sec/qt (28 sec/L), determined by the API Marsh funnel test.
3. Sand content of fluid in the system—a maximum of 1 percent, by volume.

4.7.6.3 Unusual drilling conditions. Where aquifer conditions make it necessary to continue drilling operations with drilling fluid that does not meet these standards, the drilling constructor shall be responsible for the complete removal of drilling fluid and development of the well.

4.7.7 *Gravel-pack disinfection.* The gravel pack, as it is installed, shall be disinfected according to Sec. 4.9.

4.7.8 *Grouting and sealing requirements.*

4.7.8.1 General. Sealing consists of filling the annular space between the casing and borehole with a substance that forms an impermeable seal.

4.7.8.2 Sealing requirements. All wells shall be sealed to a 50-ft (15.2-m) depth or more, unless required otherwise by state or local regulatory agencies, to prevent the entrance of water from any source other than from the aquifers selected.

4.7.8.3 Thickness of annular seal. The annular space around the conductor and well casing, from the surface to the designated depth, shall be grouted and shall not be less than 3 in. (77 mm) in radial thickness or 6 in. (152 mm) in net diametrical difference. This may be reduced to 1½ in. (19 mm) in radial thickness or 3 in. (77 mm) in net diametrical difference if the pressure grouting from the bottom upward is performed using cement tubing or the Halliburton method. This procedure shall be followed regardless of the drilling method.

4.7.8.4 Sealing of uncompleted borehole. The sealing of an uncompleted borehole shall be performed according to the requirements set forth in Sec. 4.10.

4.7.8.5 Sealing of select zones. All zones containing water of undesirable quality or zones to be protected but excluded from final well completion shall be grouted from a point at least 5 ft (1.52 m) above the zone to a point at least 5 ft (1.52 m) below the zone.

4.7.8.6 Sealing of production casing. If no other sealing has occurred, the requirements of Sec. 4.7.8.2 shall be applied to the production casing.

4.7.8.7 Methods of placement. Grouting or sealing shall be performed under pressure from the bottom upward in a continuous operation to ensure a complete seal of the annular space between the casing and the borehole (see appendix C).

4.7.9 *Plumbness and alignment.*

4.7.9.1 General. Plumbness and alignment of all water wells must permit the successful installation and long-term operation of the permanent pumping equipment installed in the well. Tolerances presented in the following sections are for wells equipped with line-shaft pumps. Wells equipped with other types of pumps do not require as accurate alignment or plumbness. Generally speaking, pumps without a line shaft will operate satisfactorily if they can be freely installed in the well.

4.7.9.2 Plumbness tolerance. The maximum allowable horizontal deviation (drift) of the well from the vertical shall not exceed 0.0067 times the smallest inside diameter of that part of the well being tested per foot (0.305 m) of depth (see appendix D).

4.7.9.3 Alignment tolerance. The maximum misalignment, or "dogleg," permissible is one that will allow a 40-ft (12.19-m) long section of pipe, or a dummy, to pass freely through it. The outside diameter of the pipe or dummy should be no smaller than ½ in. (12.7 mm) less than the inside diameter of the casing or hole being tested. If a dummy is used to test, it should have a minimum of three rings 12-in. (304.8-mm) wide, located at the top, bottom, and center on a rigid frame.

4.7.9.4 Alternate-alignment tolerance. Alternate-alignment tolerance may be specified by the purchaser after consideration of depth, formations, casing straightness, well diameter versus pump diameter, and local experience (see appendix D). The maximum allowable horizontal distance between the actual well centerline and a straight line representing the proposed pump centerline (this line being constructed to minimize the horizontal distance between the two centerlines) shall not exceed one-half of the difference between the inside diameter of the casing or hole in that part of the well being tested and the desired maximum outside diameter of the proposed pump to be installed (see Table 3).

4.7.9.5 Depth of applied tolerances. The tolerances set forth in Sec. 4.7.9.2, 4.7.9.3, and 4.7.9.4 shall apply from the top of the well to the maximum depth specified for the tolerance requirements. Generally, this will be the maximum depth to which the pump may be lowered in the future.

4.7.10 *Well-site considerations.*

4.7.10.1 Security of well site. At all times during the progress of the work, the constructor shall use reasonable precautions to prevent either tampering with the well or the entrance of foreign material or surface water into the well.

4.7.10.2 Temporary capping of well. On completion of the well, the constructor shall install a suitable threaded, flanged, or welded cap or compression seal to prevent foreign material from entering the well.

4.7.10.3 Height of casing aboveground. Unless otherwise specified by the purchaser, the casing shall extend not less than 24 in. (610 mm) above the final ground-level elevation and not less than 24 in. (610 mm) above the 100-year flood level of record, whichever is higher.

4.7.10.4 Equipment placement. Any appurtenances that will permit direct, open access to the well shall also meet the height requirements of Sec. 4.7.10.3 and shall be sealed or screened to prevent entrance of foreign matter, surface water, or contaminants into the well.

4.7.10.5 Site grading. The ground immediately surrounding the well casing shall be sloped away from the well to prevent surface runoff from collecting around the completed well.

4.7.11 *Final report.* In addition to the items covered under Sec. 4.2.5, the following items pertaining to the completed well shall be included in the final report.

4.7.11.1 Gravel-filter material emplacement. The quantity of gravel installed shall be reported (see appendix E, Sec. E.3.1).

4.7.11.2 Records. Development and testing records as set forth in Sec. 5.1.2 and appendix E, Sec. E.3, shall be included.

Sec. 4.8 Well Development

4.8.1 *General.* Well development* consists of the application of appropriate techniques designed to bring the well to its maximum discharge capacity with attendant optimization of well efficiency, specific capacity, stabilization of aquifer material, and control of sand and suspended solids. Casing and screen diameters, length of screen, and character of the formations are among the many determining factors in selecting applicable methods of well development. It is practically impossible to anticipate exactly how a well will respond to development and how long it will take to achieve adequate development. Because requests for bids on a lump-sum basis for development may result in unsatisfactory work, it is recommended that the purchaser provide for development at the design discharge until the desired parameters described above are achieved (see appendix E).

4.8.2 *Completing development.* Development shall continue until the following conditions have been met:

1. Sand content shall average not more than 5 mg/L for a complete pumping cycle of 2-hour duration when pumping at the design-discharge capacity (see appendix E, Sec. E.2.3).

2. No fewer than 10 measurements shall be taken at equal intervals to permit plotting of sand content as a function of time and production rate and to determine the average sand content for each cycle.

3. Development shall continue as long as the well's specific capacity continues to increase significantly.

Sec. 4.9 Well Disinfection

4.9.1 *General.* The well shall be disinfected to remove bacteriological contamination that may cause the well-water supply to be unsafe for human consumption. For disinfection procedures, refer to ANSI/AWWA C654.

4.9.2 *Disinfection.* The chlorine solution used for disinfecting the well shall be of such volume and strength and shall be so applied that a concentration of at least 50 mg/L of available chlorine shall be obtained for the entire water depth of the well, and this solution shall remain in the well for a period of at least 12 hours. The inside of the well casing above the standing water level also shall be washed with a chlorine solution of comparable concentration.

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* For more information, refer to appendix E and to the *Manual of Water Well Construction Practices*, EPA-570/9-75-001, USEPA, Washington, D.C. (1975).

4.9.2.1 Overdosing requirement. If the samples collected after disinfection in Sec. 4.9.2 show bacteriological contamination, the constructor shall prepare and apply to the entire depth of the well a total volume of the chlorine solution of at least 100 mg/L of available chlorine equal to at least four times the volume of water in the well. The constructor shall allow this solution to remain in the well for a period of at least 24 hours.

Sec. 4.10 Decommissioning of Test Holes, Partially Completed Wells, and Abandoned Wells

4.10.1 *General.* Test holes, test wells, partially completed wells, and abandoned wells shall be sealed. The guiding principle to follow in sealing abandoned wells is the restoration, as far as feasible, of the controlling geological conditions that existed before the test hole or the well was drilled or constructed.

4.10.1.1 Need for sealing wells. Wells need to be sealed for the following reasons:

1. To eliminate physical hazards.
2. To prevent contamination of groundwater.
3. To conserve yield and hydrostatic head of aquifers.
4. To prevent commingling of waters.

4.10.2 *Sealing requirements.* Before sealing operations are initiated, the hole or well shall be measured for depth and checked for obstructions.

4.10.2.1 Casing removal. Removal of casing from some wells may be necessary to ensure placement of an effective seal.

4.10.2.2 Exception to casing removal. If the casing cannot be readily removed, it may need to be perforated to ensure the proper sealing required.

4.10.2.3 Sealing materials and placement. Concrete, cement grout, bentonite, or sealing clay shall be used as primary sealing materials and shall be placed from the bottom upward by methods that will avoid segregation or dilution of material.

4.10.3 *Records of decommissioning procedures.* Complete, accurate records shall be kept of the entire decommissioning procedure.

4.10.3.1 Depths sealed. The depth of each layer of all sealing and backfilling materials shall be recorded.

4.10.3.2 Quantity of sealing materials used. The quantity of sealing materials used shall be recorded.

4.10.3.3 Changes recorded. Any changes in the well made during the sealing, such as perforating casing, shall be recorded in detail.

SECTION 5: VERIFICATION

Sec. 5.1 Performance Testing

5.1.1 *General.* Tests for well performance* are necessary to determine well capacity, drawdown, long-term production capabilities, and permanent pump-sizing parameters and to secure water samples for analysis.

5.1.1.1 The maximum sand content during pumping shall meet the requirements of Sec. 4.8.2.

5.1.2 *Testing methods.* A test pump and flow-rate and water-level measuring devices shall be used for test pumping (see appendix E, Well Development).

5.1.2.1 Step-drawdown tests. Step-drawdown tests should be conducted to characterize well performance at varying rates and to determine the general parameters for constant-rate pumping tests. The well shall be pumped at incrementally increasing rates, with each step consistent in duration. The elapsed time and the length of each discharge step shall be long enough to develop indication of a straight-line trend on a plot of drawdown versus logarithm of time since pumping began.

5.1.2.2 Constant-rate tests. After the step-drawdown test, a constant-rate pumping test shall be conducted at a designated capacity of at least the design or rated capacity of the well, or greater, if required by the approving authority. The well should be pumped at a constant rate at least until a straight-line trend is observed on a plot of water level versus the logarithm of time since pumping began. Recovery time of the pumping well and any observation wells to be used in the constant-rate test should be such that a straight-line trend is observed in all of the wells on a plot of the water level versus the logarithm of time. Results of the constant-rate pumping test shall be used to design the permanent well-pumping equipment (see appendix G).

5.1.2.3 Water-level measurements. Water-level measurements shall be obtained before, during, and after the pumping test in order to acquire background information (static water levels), the effects of pumping (pumping water levels), and a profile of the recovery of the water level from the pumping level to the original state. The measurement frequency of water levels during pumping shall be such that adequate definition of the time–drawdown data is made available.

* For more information, refer to the appendix and to the *Manual of Water Well Construction Practices*, EPA-570/9-75-001, USEPA, Washington, D.C. (1975).

5.1.2.4 Pumping-test interruption. The constructor shall conduct any pumping tests specified by the purchaser without any interruptions or fluctuations that may affect the accuracy of the required pumping results.

5.1.2.5 Records and reports. The constructor shall maintain all records and shall submit to the purchaser accurate written reports regarding water levels, pumping rates, time intervals, and other pertinent details on the testing of the production well and all observation wells used in the test period.

Sec. 5.2 Water Quality Testing

5.2.1 *General considerations.* Water quality shall be determined by analyses of water samples collected from the well. The analyses shall be performed by a laboratory acceptable to the appropriate regulatory agency. All analyses shall be performed according to methods prescribed by regulatory agencies having jurisdiction over the well construction.

5.2.2 *Sampling procedures.* The procedures outlined in the latest edition of USEPA's *Manual of Methods for Chemical Analysis of Water and Wastes** shall be followed.

5.2.2.1 Field tests. Water temperatures, pH, specific conductance, dissolved oxygen, and other pertinent dissolved gases if applicable shall be determined from samples collected and analyzed in the field.

5.2.2.2 Samples for local-regulation tests. Water samples shall be taken near the end of the constant-rate pumping test for chemical analyses as required by the purchaser or local regulations.

Sec. 5.3 Basis of Rejection

Material not complying with the requirements of this standard and the purchaser's documents may be rejected. Repairs, replacements, and retesting shall be accomplished in accordance with the purchaser's documents.

SECTION 6: DELIVERY

Sec. 6.1 Affidavit of Compliance

The purchaser may require an affidavit from the manufacturer that the well provided complies with applicable requirements of this standard.

* USEPA, *Manual of Methods for Chemical Analysis of Water and Wastes*, EPA-625/6-74-003, Office of Technology Transfer, USEPA, Washington, D.C. (1974).

APPENDIX A

Bibliography

This appendix is for information only and is not a part of ANSI/AWWA A100.

The following references are not listed in ANSI/AWWA A100 but are provided in this appendix as sources of additional information:

APHA, AWWA, and WEF. 2012. *Standard Methods for the Examination of Water and Wastewater.* 22nd ed. Washington, D.C.: APHA, AWWA, and WEF.

Johnson Screens (Bilfinger Water Technologies Inc.). 2007. *Groundwater and Wells*, 3rd ed. St. Paul, Minn.: Johnson Screens.

Lehr, J., S. Hurlburt, B. Gallagher, and J. Voytek (National Water Well Association). 1988. *Design and Construction of Water Wells—A Guide for Engineers.* New York: Van Nostrand Reinhold Company.

Roscoe Moss Company. 1990. *Handbook of Ground Water Development.* New York: John Wiley & Sons.

US Environmental Protection Agency. 1975. *Manual of Water Well Construction Practices* (EPA-570/9-75-001). Washington, D.C.: USEPA.

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APPENDIX B

Gravel-Pack Installation Methods

This appendix is for information only and is not a part of ANSI/AWWA A100.

SECTION B.1: GENERAL

The selected method for installing gravel pack (as described in Sec. 4.6 and Sec. 4.7.6) downhole should provide a graded envelope of relatively uniform thickness, without segregation or voids, completely filling the annulus within the borehole surrounding the production casing (blank/screen). Gravel pack is installed to maintain the integrity of the borehole to prevent collapse of the aquifer formation materials against the production casing. Gravel pack, properly installed, provides a filter for the formation particles allowing for relatively sand-free water to be pumped from the completed production well.

Any of the methods listed, or related variations thereof, may be selected on a site-specific basis suited for the type of well construction used. Each of the methods listed has advantages and disadvantages. A description of each method of installation is provided in the bibliography reference publications.

To preserve water quality and prevent contamination of the well, all gravel-pack materials require disinfection with a minimum 50-mg/L free-chlorine strength solution of potable water during installation.

SECTION B.2: POURED FROM THE SURFACE WITH DIRECT CIRCULATION

When the assembled casing and screen are centered in the borehole, tubing or drill pipe with two close-fitting swabs shall be inserted, one swab located near the bottom of the screen and the other near the surface in the blank casing. Clear water shall be introduced into the fluid system until the requirements of Sec. 4.7.6.2 have been met. The gravel shall be placed from the surface through a funnel or orifice in the annular space between the borehole and casing. Swabbing and circulating shall be continued during placement until the gravel pack is completely in place. Before this operation begins, the constructor shall make adequate preparations to ensure that circulation will be continuous.

SECTION B.3: PUMPED THROUGH GRAVEL FEED LINE WITH DIRECT CIRCULATION

When the assembled casing and screen are centered in the borehole, preparations for the installation of gravel pack shall be made according to the requirements of Sec. 4.7.6.2 and Sec. B.2. The filter pack shall be placed by pumping through a feed line, or tremie, that extends to the bottom of the casing annulus. The feed line shall be gradually withdrawn as the filter pack is placed.

SECTION B.4: POURED FROM THE SURFACE WITH REVERSE CIRCULATION

When the assembled casing and screen are centered in the borehole, the return-flow pipe shall be installed with suction near the bottom of the screen. Circulation down the annulus between the casing screen and borehole and back through the return-flow pipe to the surface shall be started and the circulating-fluid properties shall be controlled to meet the requirements of Sec. 4.7.6.2. The velocity of the descending stream shall be adjusted to approximately the slip velocity of the particles in the gravel pack.

SECTION B.5: PUMPED UNDER PRESSURE FROM THE SURFACE WITH REVERSE CIRCULATION

When the assembled casing and screen are centered in the borehole, the return-flow pipe shall be installed with suction near the bottom of the screen. The annulus between the return-flow pipe and the casing at the surface shall be sealed and the filter pack pumped under pressure into the annulus at the surface. Placement shall be according to the requirements of Sec. B.4.

SECTION B.6: CROSS-OVER METHOD

Casing and screen shall be installed with a crossover-sub tool attached to the top of the section and to the drill pipe required for placement. An extension pipe shall extend from the sub to the bottom of the screen. Circulating- and drilling-fluid conditioning shall be according to Sec. 4.7.6.2. The gravel pack shall be pumped through the drill pipe to the crossover sub and into the annulus between the screen and borehole.

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APPENDIX C

Grouting and Sealing—Methods of Placement

This appendix is for information only and is not a part of ANSI/AWWA A100.

SECTION C.1: TREMIE METHOD

Grout material shall be placed by tremie pouring (after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions). When making a tremie pour, the tremie pipe shall be lowered to the bottom of the zone being grouted and raised slowly as the grout material is introduced. The tremie pipe shall be kept full continuously from start to finish of the grouting procedure, and the discharge end of the tremie pipe shall be continuously submerged in the grout until the zone to be grouted is completely filled.

SECTION C.2: POSITIVE DISPLACEMENT—EXTERIOR METHOD

Grout material shall be placed by a positive-displacement method after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions. Grout shall be injected in the annular space between the inner casing and either the outer casing or the borehole. The grout pipe shall extend from the surface to the bottom of the zone to be grouted.

Grout shall be placed, from bottom to top, in one continuous operation. The grout pipe may be slowly raised as the grout is placed, but the discharge end of the grout pipe shall be submerged in the emplaced grout at all times until grouting is completed. The grout pipe shall be maintained full, to the surface, at all times until grouting is completed in the entire specified zone. In the event that grouting operations are interrupted for any reason, the bottom of the pipe shall be raised above the grout level and shall not be resubmerged until air and water have been displaced from the grout pipe and the pipe has been flushed clean with clear water.

SECTION C.3: INTERIOR METHOD—WITHOUT PLUG

Grout shall be placed in the annulus by forcing the grout down a drop pipe that is installed inside the casing, out the bottom of the casing, and then up to the ground surface outside the casing. The drop pipe shall extend airtight, through a sealed cap on the casing head of the well casing to a point no more than 5 ft (1.52 m) above the bottom of the casing.

The casing head shall be equipped with a relief valve, and the drop pipe shall be equipped at the top with a valve permitting injection of water and grout. The lower end of the drop pipe and the casing shall be open. Clean water shall be injected down the drop pipe until it returns through the casing-head relief valve. The relief valve is closed, and the injection of water is continued until it flows from the borehole outside of the casing. Sufficient circulation shall be established in the annular space to clear obstructions. Without significant interruption, grout shall be substituted for water and injected, in a continuous manner, down the drop pipe until it returns to the surface outside of the casing. The minimum amount of water necessary shall be injected into the drop pipe to flush the grout from it. The valve on top of the drop pipe shall be closed and a constant pressure maintained on the inside of the drop pipe and casing for at least 24 hours, or until the grout has set.

SECTION C.4: POSITIVE PLACEMENT, INTERIOR METHOD—DRILLABLE PLUG

Grout shall be placed in the annulus through the casing interior (after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions). A measured quantity of grout, 30 percent in excess of the theoretical volume of the annulus, shall be pumped into the capped casing. The casing shall be uncapped, a drillable plug inserted on top of the grout, and the casing recapped. A measured volume of water, equal to the volume of the casing, shall be pumped into the casing, forcing the plug to the bottom of the casing and the grout into the annular space surrounding the casing. Pressure shall be maintained until such time as a sample of the grout indicates a satisfactory set.

SECTION C.5: PLACEMENT THROUGH FLOAT SHOE ATTACHED TO BOTTOM OF CASING

Grout shall be placed through a drillable float shoe attached to the bottom of the casing (after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions). Tubing or pipe shall be run to the float shoe and connected by a bayonet fitting, left-hand thread coupling, or similar release mechanism. Water or other drilling fluid shall be circulated through the tubing and up through the annular space outside the casing. When the annular space has been flushed, grout shall be pumped into the annular space surrounding the casing. Pumping shall continue until the entire zone to be grouted is filled. Pressure shall be maintained inside the tubing until initial set.

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APPENDIX D

Plumbness and Alignment—Procedure for Testing

This appendix is for information only and is not a part of ANSI/AWWA A100.

SECTION D.1: PROCEDURE FOR TESTING

The alternate-alignment tolerance method presented in appendix D is a straightforward elementary method that is easy to perform in the field. The procedure of lowering a cylindrical plummet (see Figure D.1) into the well to the specified depth applies to obtaining data for the plumbness tolerance as well as the alternate-alignment tolerance. Although new methods of checking plumbness and alignment are becoming available, such as gyroscopic or laser methods, most of these are offered through specialist service companies and still remain relatively unproven.

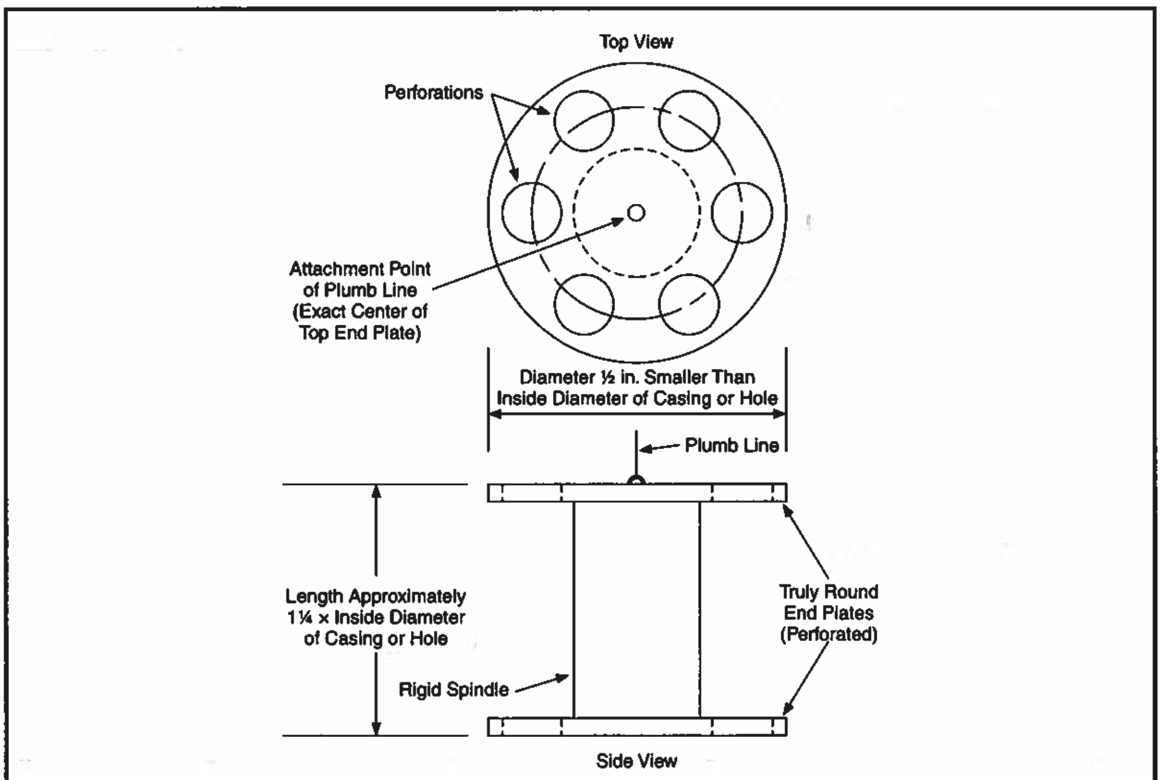


Figure D.1 Details of cylindrical plummet

SECTION D.2: APPARATUS REQUIRED FOR PLUMBNESS AND ALIGNMENT TESTS

Sec. D.2.1 Plummet

The plummet shall consist of a rigid spindle with round plates at both ends. The outer diameter of the end plates shall be 0.5 in. (13 mm) smaller than the inside diameter of that part of the casing or hole being tested. The distance between end plates shall be approximately 1.25 times the diameter of that part of the casing or hole being tested. The plummet shall be heavy enough to keep the plumb line taut. The plumb line is attached to the plummet at the exact center of the top end plate and shall be of uniform diameter.

Sec. D.2.2 Apex

The apex shall be stationary with a recommended minimum height of 10 ft (3.05 m) above the casing or hole (Figure D.2).

Sec. D.2.3 Pulley

The pulley shall be suitable for running the plumb line and plummet being used.

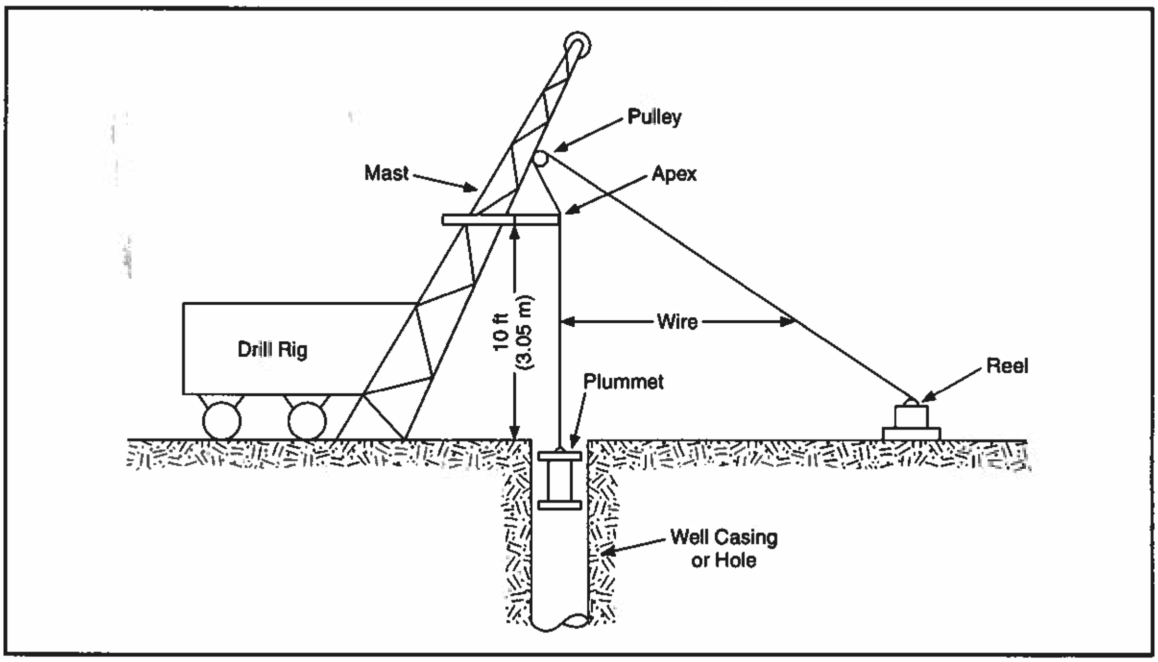


Figure D.2 Suspension of the plummet using drill rig

SECTION D.3: PROCEDURE FOR TEST MEASUREMENTS

Plumbness and alignment are determined by lowering the plummet a maximum of 10 ft (3.05 m) at a time and measuring the horizontal deflection of the plumb line from the center of the top of the casing or hole at each interval. If during the field measurements there is reason to suspect that the plummet is approaching the maximum allowable deviation, it may be prudent to take more frequent measurements. The horizontal deflection shall be measured in two planes, 90° from each other.

SECTION D.4: DETERMINATION OF DRIFT (HORIZONTAL DEVIATION)

The drift (horizontal deviation) of the casing or hole at each recorded depth shall be calculated by using the following formula:

$$\text{drift} = \frac{\text{deflection (height + depth)}}{\text{height}} \qquad \text{(Eq D.1)}$$

Where:

drift = calculated horizontal deviation of casing or hole from the vertical, in. (mm)

deflection = measured horizontal deflection of the plumb line from center of the top of casing or hole, in. (mm)

height = height of apex above the top of casing or hole, in ft (m)

depth = depth of plummet below the top of casing or hole, in ft (m)

The calculated drift of the casing or hole at the depth intervals recorded in Figure D.3 should be plotted as shown in Figure D.4.

SECTION D.5: ITEMS TO BE PROVIDED BY CONSTRUCTOR

The following items are to be provided to the purchaser by the constructor as part of the testing procedure for well plumbness and alignment.

1. Test sheet—written statement covering details of the plumbness and alignment test data (see Figure D.3).

Details of Plumbness and Alignment Test Well No. 1 Date: 3-21-15 *Size of Hole or Casing = 19¼ in., ID; Size of Plummet = 18¾ in., OD;* *Height of Apex Above Top of Well = 10.0 ft*								
Depth of Plummet Below Top of Well *ft*	Horizontal Deflection of Plumb Line—*ft*				Calculated Drift of Well—*ft*			
	North	South	East	West	North	South	East	West
10	0.010		0	0.0000	0.020		0	0.0000
20	0.010			0.010	0.030			0.030
30	0.010			0.015	0.040			0.060
40	0.010			0.015	0.050			0.075
50	0.010			0.015	0.060			0.090
60	0.005			0.015	0.035			0.105
70	0.005			0.015	0.040			0.120
80	0.005			0.020	0.045			0.180
90	0.005			0.020	0.050			0.200
100	0.005			0.020	0.055			0.220
110	0.005			0.010	0.060			0.120
120	0.005			0.010	0.065			0.130
130	0	0		0.005	0	0		0.070
140		0.005	0	0		0.075	0	0
150		0.010	0	0		0.160	0	0
160		0.010		0.005		0.170		0.085
170		0.010		0.005		0.180		0.090
180		0.010		0.010		0.190		0.190
190		0.010		0.010		0.200		0.200
200		0.010		0.010		0.210		0.210

Figure D.3 Plumbness and alignment test data sheet

2. Well diagram—longitudinal projections of actual well centerline and proposed pump centerline (see Figure D.4).

3. Plumbness graph—calculated drift of the well-casing centerline from vertical (see Figure D.5).

4. Alignment graph—horizontal deviations of actual well-casing centerline from proposed pump centerline (see Figure D.6).

5. Diagram—a diagram showing the effective well diameter and the determination of the largest pump that can be inserted into the well without bending (see Figure D.7).

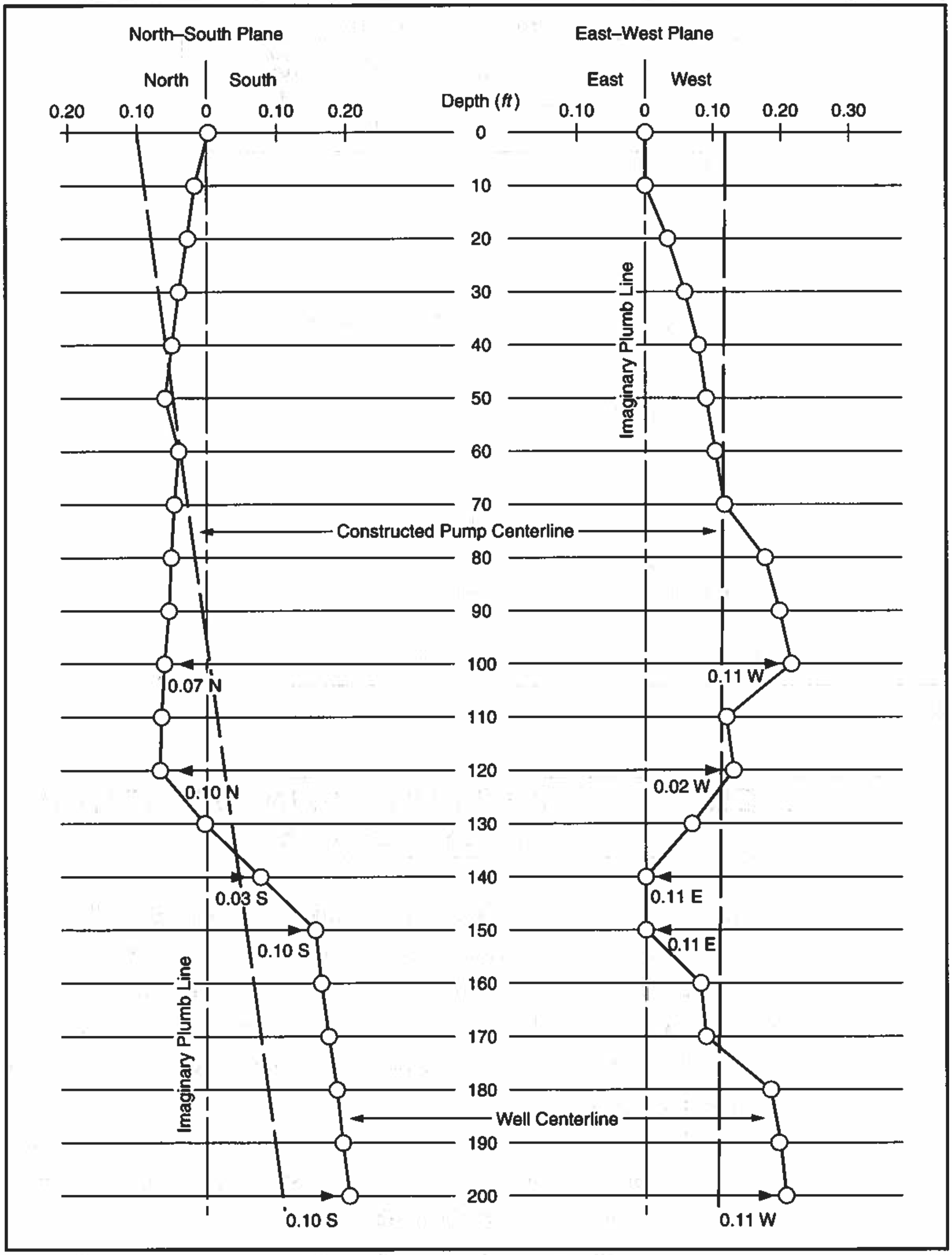
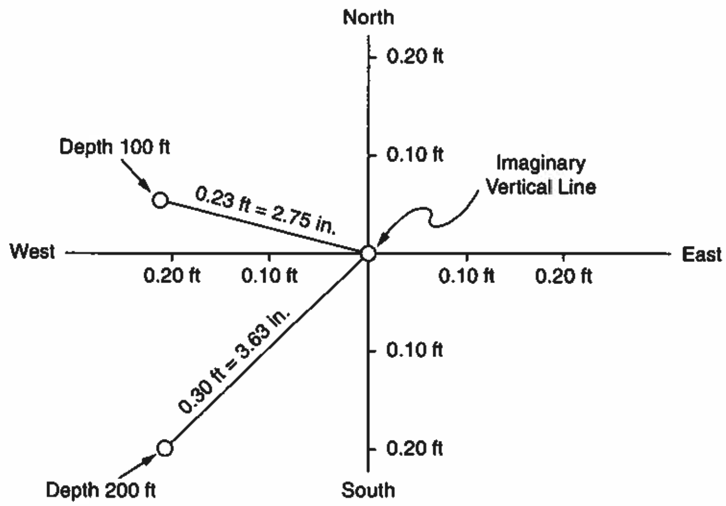


Figure D.4 Longitudinal projections of well and constructed pump centerlines on north–south and east–west vertical planes

Drift Is Greatest at Depths 100 ft and 200 ft

Depth *ft*	Actual Drift *in.*	Allowed Drift* *in.*
100	2.75	12.83
200	3.63	25.66

*For 19.250-in. ID casing.



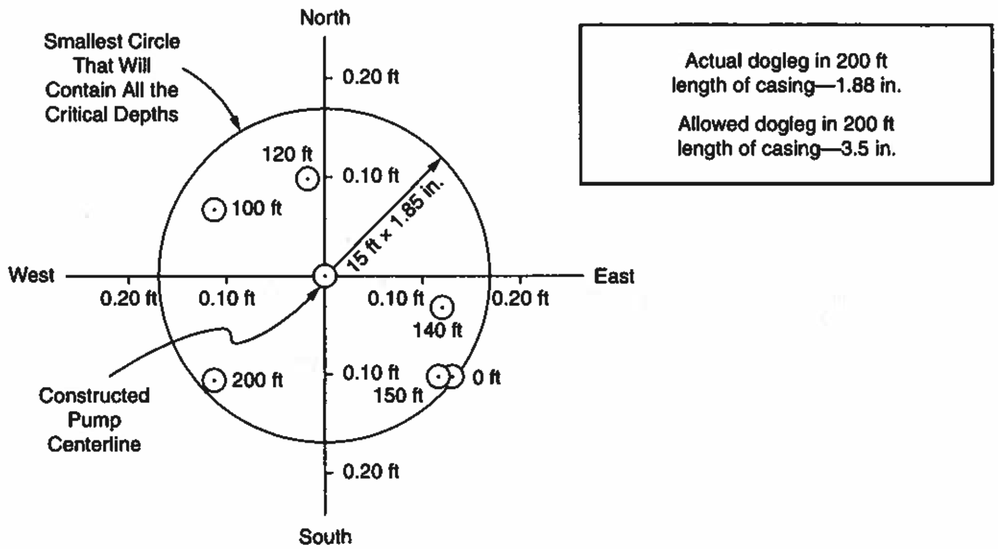
NOTE: This well meets the specifications for plumbness.

Figure D.5 Graphic representation of requirements of plumbness in Sec. 4.7.9

SECTION D.6: PLOTTING AND INTERPRETATION OF TEST RESULTS

The calculated drift of the well at the recorded depth intervals shall be plotted on cross-section format in two planes, 90° from each other, as shown in Figure D.4. First, plot the calculated horizontal deviations in one plane, called the *north–south plane*, and then in the other plane 90° from the first, called the *east–west plane*. The lines obtained by connecting the plotted points represent the actual well centerline in each plane.

Straight lines representing the pump centerline shall be constructed on the same cross-section format in the north–south and east–west planes again, as shown in Figure D.4. Working first with the north–south plane, construct a straight line representing the pump centerline from top to bottom of the section of casing or hole that was tested. Make any adjustments necessary so that the horizontal distance from this line to any plotted point on the well centerline is a minimum. This



Vertical alignment specification for 19.250-in. ID casing and 12.25-in. OD pump:

Maximum allowable horizontal distance between the actual well centerline and a straight line representing the pump centerline, this line being constructed so as to minimize the horizontal distance between the two centerlines, shall not exceed 3.5 in. (one-half the difference between the ID of that part of the well being tested—19.250 in.—and the desired maximum OD of the pump—12.25 in.: 19.250 − 12.25 = 7.0, one-half of 7.0 equals 3.5).

Misalignment Radius = 1.88 in.

This figure is the maximum horizontal distance between well centerline and a straight line representing the pump centerline, this line being constructed so as to minimize the horizontal distance between the two centerlines. This figure can be considered a measurement of the maximum dogleg of the well.

Misalignment Diameter = 3.75 in.

This figure is the difference between well ID and the largest pump OD that can be inserted into the well without bending. This figure can be considered a measurement of the loss in effective diameter of the well.

NOTE: This well meets the specifications for alignment.

Figure D.6 Graphic representation of requirements for alignment in Sec. 4.7.9

line is the optimum position for the pump in the north–south plane. Repeat this procedure for the east–west plane. The resulting graph is a longitudinal projection of well and constructed pump centerlines.

A graph of horizontal deviations of well centerline from pump centerline shall be drawn as shown in Figure D.6. Construct a set of perpendicular axes, labeling the endpoints to indicate direction. The intersection of these axes, referred to as the *origin*, represents the optimum position of the proposed pump centerline in a horizontal plane, at any depth, as previously positioned in Figure D.4.

Transfer the horizontal distances between the proposed pump centerline and the well centerline from Figure D.4 onto Figure D.6, and label each transferred point according to depth. Be sure to transfer each point to its proper quadrant on

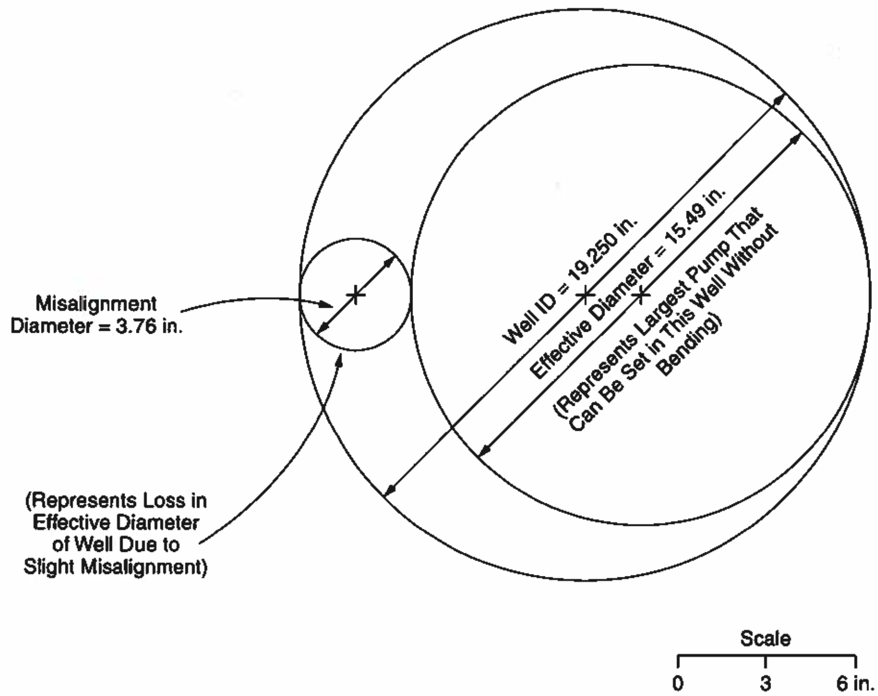


Figure D.7 Relationship between misalignment diameter from Figure D.6, effective diameter of the well, and inside diameter of the well

Figure D.6. To save time, only the critical depths may be considered (depths where the greatest horizontal distances between the two centerlines are involved).

When completed, Figure D.6 shows the relationship between the actual well centerline and the proposed pump centerline at critical depths for this particular proposed pump-centerline location. In other words, Figure D.6 can be considered a view directly down the proposed pump centerline as positioned in Figure D.4, showing the varying locations of the well center with depths.

Finally, using the origin as center, draw the smallest circle that will contain all the plotted points. The diameter of this circle is equal to the difference between the well inside diameter and the largest pump outside diameter that can be inserted into the well without bending (see Figure D.7) when the pump is positioned as in Figure D.4.

One-half the diameter of this circle is equal to the maximum horizontal distance between the well centerline and a straight line representing the pump centerline, this line being constructed so as to minimize the horizontal distance between the two centerlines. Figure D.6 will reveal which depths are most critical for pump clearance.

APPENDIX E

Well Development

This appendix is for information only and is not a part of ANSI/AWWA A100.

SECTION E.1: WELL DEVELOPMENT PROCEDURE

A variety of methods can be applied for preliminary development of wells, including such commonly used techniques as bailing, surging, flushing, pumping, jetting, and airlifting. Following the use of one or more of these preliminary methods, a well pump shall be used for final development and for testing development.

Sec. E.1.1 Test-Pump Capacity

The pump and prime mover shall have a capacity in excess of the anticipated lift and final production capacity of the well. The pump shall be set to a depth in excess of the anticipated pumping level.

Sec. E.1.2 Variable Discharge Rates

The development equipment and method used shall permit variable pumping discharge rates.

Sec. E.1.3 Discharge Piping

The discharge piping provided shall be of sufficient diameter and length to conduct water to a point designated by the purchaser, and shall include orifices, meters, or other devices that will accurately measure the discharge rate. The discharge piping shall also include a valve or other appropriate device for controlling or regulating the discharge rate.

SECTION E.2: MEASUREMENT OF OPERATING PARAMETERS DURING DEVELOPMENT

Sec. E.2.1 Discharge Rate

The device used to measure the pump discharge rate shall have a minimum accuracy of 95 percent.

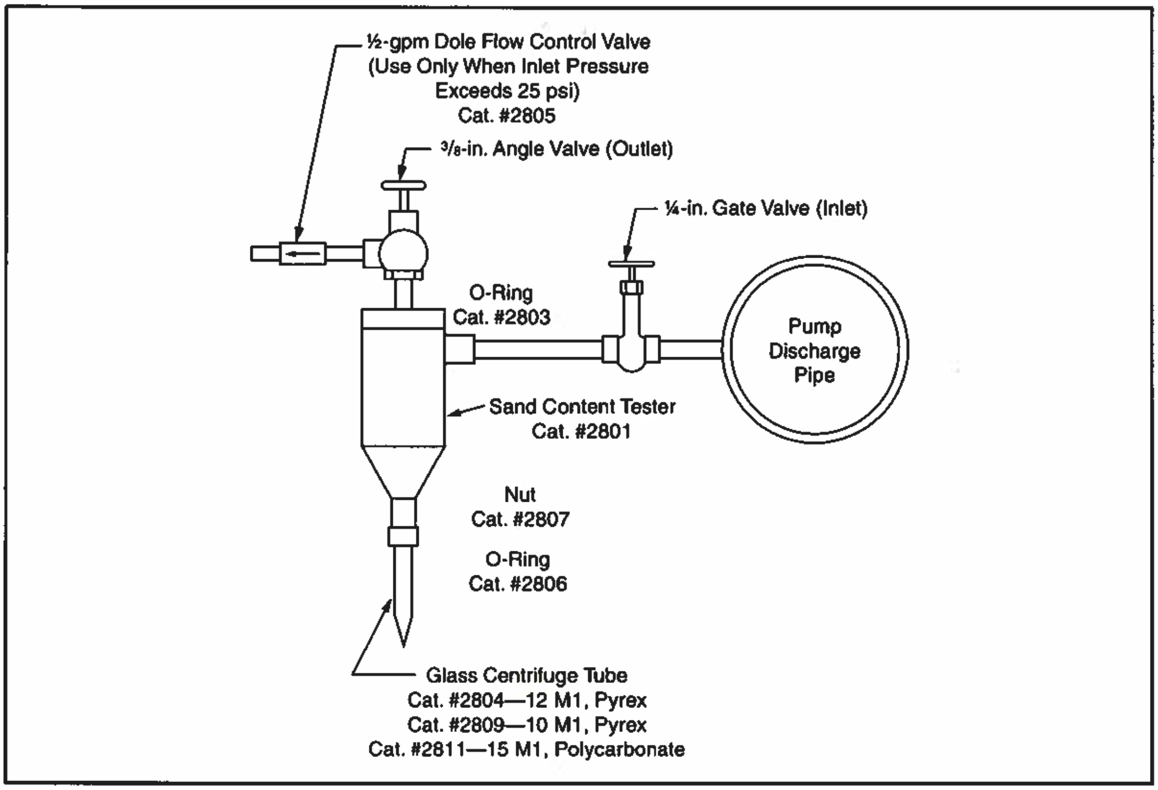


Figure E.1 Rossum sand sampler

Sec. E.2.2 Water Elevations

Water elevations in the well shall be measured to the accuracy specified by the purchaser at each of the various pumping rates (see Sec. 5.1 Performance Testing and Sec. 5.1.2.3 Water-Level Measurements).

Sec. E.2.3 Measurement of Sand Content

Sand content shall be measured with a centrifugal sand sampler as described in the article "Control of Sand in Water Systems."*

Sec. E.2.4 Installation of Sand Sampler

The installation of the sampler should be according to Figure E.1.

SECTION E.3: DEVELOPMENT RECORDS

Complete records of all development work shall be maintained.

* Rossum, J.R., "Control of Sand in Water Systems," *Jour. AWWA*, 46:2:123 (February 1954).

Sec. E.3.1 Quantity of Gravel

For gravel-pack wells, the quantity of gravel added during development shall be recorded.

Sec. E.3.2 Data to Record

The following data shall be included in the work record:

1. Quantity and description of material brought into the well.
2. Static and pumping water levels.
3. Methods of measurement.
4. Duration of each operation.
5. Observation of results.
6. Pump discharge rates and specific capacity.
7. Sand content as a function of pump discharge rates and time.
8. Sand content as a function of pump discharge rates and specific capacity.
9. All other pertinent information.

SECTION E.4: METHODS OF MEASURING OPERATING PARAMETERS DURING DEVELOPMENT

Sec. E.4.1 Step-Drawdown Test Method

Step-drawdown tests shall be conducted to characterize well performance at varying rates and to determine the general parameters for a constant-rate pumping test. The well shall be pumped at a minimum of at least three incrementally increasing rates. The duration of each discharge step shall be consistent and of sufficient elapsed time to develop indication of a straight-line trend on a plot of drawdown versus logarithm of time since pumping began.

Sec. E.4.2 Constant-Rate Tests

After the step-drawdown test, the well shall be allowed to recover until water levels return to approximately static conditions. After recovery, a constant-rate test shall be conducted at a designated capacity to determine the trend of drawdown versus prolonged time of pumping at the pumped well and any observation wells.

E.4.2.1 *Pumping well.* The pumping well shall be pumped at a constant rate until a straight-line trend is observed on a plot of water level versus the logarithm of time since pumping began.

E.4.2.2 *Recovery time.* Recovery time of the pumping well and any observation wells to be used in the test should be such that a straight-line trend is observed in all of the wells on a plot of water level versus the logarithm of time since pumping stopped.

Sec. E.4.3 Water-Level Measurements

Water-level measurements shall be obtained before, during, and after the pumping test in order to acquire background information (static water levels), the effects of pumping (pumping water levels), and a profile of the recovery of the water level from the pumping level to the original state. The measurement frequency of water levels during pumping and recovery shall be such that adequate definition of the drawdown and recovery trends is achieved. Methods commonly used to measure water levels include electric sounders, pressure transducers, chalked steel tapes, and air lines.

E.4.3.1 *Electric-sounder method.* The electric water-level sounder uses a probe with two electrodes attached to a permanently marked polyethylene tape on a reel with meter. When the probe at the bottom of the tape contacts water, the circuit is complete, activating a buzzer or light on the meter, and the corresponding depth is read accordingly. If the level cannot be measured accurately due to cascading water, a 0.5-in. (13-mm) or larger diameter pipe shall be installed in the well from the surface to 2 ft (0.61 m) above the pump bowl to permit the installation and operation of an electric sounder.

E.4.3.2 *Pressure transducer method.* Pressure transducers are used for full-time monitoring of water level by measuring hydrostatic pressure at the transducer, which is converted to an electrical output recorded by data loggers. The transducers can be programmed to measure and record water levels for desired intervals during the period of testing.

E.4.3.3 *Air-line method.* A tube, free of air leaks, shall be installed in the well with the development pump, terminating at least 5 ft (1.5 m) above the pump intake. The tube shall have an accurate altitude gauge and an air valve attached to it at the surface. The vertical distance from the bottom of the air line to the center of the gauge shall be recorded. The line shall then be charged with air under pressure until the gauge will read no higher. The water level in the well shall be computed by subtracting the altitude registered on the gauge from the known length of the line.

Sec. E.4.4 Measurement of Sand Content

Measurement of sand content may be accomplished by the installation of the Rossum centrifugal sand sampler according to Figure E.1.* The sample line shall tap the discharge pipe as close to the pump head as possible to ensure that flow is sufficiently turbulent to keep the sand uniformly distributed in the stream. The purchaser may specify other methods acceptable to local regulatory agencies.

* See Rossum, J.R., "Control of Sand in Water Systems," *Jour. AWWA*, 46:2:123 (February 1954).

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APPENDIX F

Water Sampling—Suggested Methods

This appendix is for information only and is not a part of ANSI/AWWA A100.

SECTION F.1: GENERAL

Collecting aquifer water samples, when deemed appropriate, should be carried out with techniques that will deliver as truly a representative sample as possible. Evaluation of laboratory analysis may influence design specifications or forecast future maintenance requirements.

SECTION F.2: A WELL IN A CONSOLIDATED FORMATION

The well shall be equipped with an assembly that includes an inner perforated pipe with the bottom plugged and a packer located above and below the target aquifer. The inner pipe shall be pumped at a rate of at least 10 gpm (0.67 L/sec) until a clear sample is obtained for analysis. This step shall be repeated for each aquifer. Pumping shall be done by mechanical means. Air- or gas-lift pumping is not recommended for sampling purposes as the air or gas may compromise the results. Air-lift pumping may be used for development prior to sampling.

SECTION F.3: A WELL IN AN UNCONSOLIDATED FORMATION

The well shall be equipped with an assembly that consists of a wound screen 2 ft (0.6 m) in length set opposite each potential aquifer. Gravel shall be placed around the screen or clear water shall be pumped via reverse flow through the screen to cause the formation to collapse onto the screen. A well point may be driven into the undisturbed aquifer as an alternative. Water shall then be pumped at 10 gpm (0.67 L/sec), or more, until clear, at which time a sample shall be taken. This shall be repeated for each aquifer intended for use. Pumping shall be done by mechanical means. Air- or gas-lift pumping is not recommended for sampling purposes as the air or gas may compromise the results. Air-lift pumping may be used for development prior to sampling.

APPENDIX G

Factors Influencing the Duration of Pumping Test

This appendix is for information only and is not a part of ANSI/AWWA A100.

SECTION G.1: GENERAL

The length of time that the final pumping test shall run depends entirely on local conditions and geological conditions, but the duration should be sufficient to allow pumping influence to encounter any potential recharge sources and nearby aquifer boundaries. In general, the pump should be operated at a uniform rate for a period ranging from 12 hours to 72 hours. It is recommended that, as a minimum, a 24-hour test be conducted on all municipal wells in artesian aquifers and a 72-hour test be conducted for water-table aquifers. Testing should continue to equilibrium conditions and, if necessary, the recommended test duration should be extended until the pumping level stabilizes. If stabilization is not possible, the test shall not be terminated until a consistent pumping level trend is observed, and the failure to reach equilibrium shall be recorded.

SECTION G.2: LOCAL EXPERIENCE

Pumping tests may be modified in areas in which substantial experience regarding geological and hydrological conditions is available.

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APPENDIX H

Decommissioning of Test Holes, Partially Completed Wells, and Abandoned Completed Wells

This appendix is for information only and is not a part of ANSI/AWWA A100.

SECTION H.1: GENERAL

The recommendations contained in this appendix pertain to wells and test holes in consolidated and unconsolidated formations. Each sealing job should be considered as individual in nature, and methods and materials should be determined only after carefully considering the objectives outlined in the standard.

SECTION H.2: WELLS IN UNCONSOLIDATED FORMATIONS

Normally, test holes, partially completed wells, and abandoned completed wells extending only into unconsolidated formations near the surface and containing water under water-table conditions can be adequately sealed by filling with concrete, grout, bentonite, or sealing clay. In the event that the water-bearing formation consists of coarse gravel and producing wells are located nearby, care must be taken to select sealing materials that will not affect the producing wells. Concrete may be used if the producing wells can be shut down for a sufficient time to allow the concrete to set without the cement washing out. Disinfected clean sand or gravel may also be used as fill material opposite the water-bearing formation. The remainder of the well, especially the upper portion, should be filled with concrete, cement grout, bentonite, or sealing clay to exclude surface water. The last method, using clay as the upper sealing material, is especially applicable to large-diameter abandoned wells.

In gravel-packed, gravel-envelope, or other wells in which coarse material has been added around the inner casing to within 20 ft to 30 ft (6.1 m to 9.1 m) of the surface, the sealing outside the casing is very important. This sealing may sometimes require removal of the gravel or perforation of the casing, to ensure that the well or hole is sealed to a minimum depth of 50 ft (15.2 m) from the surface.

SECTION H.3: WELLS IN CREVICED FORMATIONS

Test holes, partially completed wells, and abandoned completed wells that penetrate limestone or other creviced or channelized rock formations lying immediately below the surface deposits should preferably be filled with concrete or grout, to ensure permanence of the seal. The use of clay or sand in such wells is not desirable because fine-grained fill material may be displaced by the flow of water through crevices or channels. If limited vertical movement of water in the formation will not affect the quality or quantity of water in nearby producing wells, alternate layers of coarse stone and concrete may be used for fill material through the water-producing horizon. Otherwise only concrete or grout should be used. The portion of the well between a point 10 ft to 20 ft (3.0 m to 6.1 m) below and a point 10 ft to 20 ft (3.0 m to 6.1 m) above the creviced formation should be sealed. Clay or sand may be used to fill the upper part of the well to within 50 ft (15.2 m) of ground level. The upper 50 ft (15.2 m) should be sealed with concrete, grout, bentonite, or sealing clay.

SECTION H.4: WELLS IN NONCREVICED ROCK FORMATIONS

Test holes, partially completed wells, and abandoned completed wells encountering noncreviced sandstone or other water-bearing consolidated formations below the surface deposits may be satisfactorily sealed by filling the entire depth with clay, provided there is no movement of water in the well. Disinfected clean sand may also be used through the sandstone up to a point 10 ft to 20 ft (3.0 m to 6.1 m) below the bottom of the casing. The upper portion of this type of well should be filled with concrete, grout, bentonite, or sealing clay to provide an effective seal against entrance of surface water. If there is an appreciable amount of upward flow, pressure grouting or pumping of concrete is advisable.

SECTION H.5: MULTIPLE-AQUIFER WELLS

Some special problems may develop in sealing wells extending into more than one aquifer. If required, these wells should be filled and sealed in such a way that the commingling of water from one aquifer to another is prevented. If no appreciable movement of water is encountered, filling with concrete, grout, or alternate layers of these materials and sand will prove satisfactory. When velocities are high, the procedures outlined in Sec. H.6 are recommended. If alternate concrete plugs or bridges are used, they should be placed in known nonproducing horizons or, if locations of the nonproducing horizons are not known, at frequent intervals. Where the casing is not grouted or the formation is noncaving, it may be necessary to break, slit, or perforate the casing to fill any annular space on the outside.

SECTION H.6: WELLS WITH ARTESIAN FLOW

The sealing of test holes, partially completed wells, and abandoned completed wells that have water moving between aquifers or to the surface requires special attention. Frequently, the movement of water may be sufficient to make sealing by gravity placement of concrete, grout, bentonite, or sealing clay impractical. In such wells, large stone aggregate (not more than one-third of the diameter of the hole) or a well packer will be needed to restrict the flow and thereby permit the gravity placement of sealing material above the formation producing the flow. If preshaped or precast plugs are used, they should be several times longer than the diameter of the well to prevent tilting.

Because it is very important in wells of this type to prevent circulation between formations or loss of water to the surface or to the annular space outside the casing, it is recommended that pressure grouting or pumping of concrete, using the minimum quantity of water that will permit handling, be used.

In wells in which the hydrostatic head producing flow to the surface is low, the movement of water may be arrested by extending the well casing to an elevation above the artesian-pressure surface. Previously described sealing methods suitable to the geologic conditions can then be used.

SECTION H.7: SEALING MATERIALS

A number of materials can be used for sealing wells satisfactorily. They include concrete, grout, bentonite, sealing clay, sand, or combinations of these materials, and are mentioned in this appendix. Each material has certain characteristics and distinctive properties; therefore, one material may be especially suited for doing a particular job. The selection of the material must be based on the construction of the well, the nature of the formations penetrated, the material and equipment available, the location of the well with respect to possible sources of contamination, the pH of the water and its effect on the sealing material, and the cost of doing the work.

Generally, concrete is used for filling the upper part of the well or water-bearing formations, for plugging short sections of casings, or for filling large-diameter wells. It may be cheaper to use than grout and it makes a stronger plug or seal. However, concrete will not penetrate thin seams, crevices, or interstices. Furthermore, proper care must be taken during the placement of concrete to ensure that the aggregate does not separate from the cement.

Grout is far superior for sealing small openings, for penetrating any annular space outside of casings, and for filling voids in the surrounding formation. When applied under pressure, it is strongly favored for sealing wells under artesian pressure or for wells that penetrate more than one aquifer.

Clay, as a heavy mud-laden or special clay fluid applied under pressure, has most of the advantages of grout. Its use is preferred by some competent authorities, particularly for sealing artesian wells. Others feel that it may, under some conditions, eventually be carried away into the surrounding formations.

Clay in a relatively dry state, clay and sand, or sand alone may be used advantageously as sealing materials, particularly under water-table conditions where diameters are large, depths are great, formations are caving, and where there is no need to penetrate openings in casings, liners, or formations, or to obtain a watertight seal at any given spot.

Frequently, combinations of these materials are necessary. The more expensive materials are used when strength, penetration, or watertightness are needed. The less expensive materials are used for the remainder of the well. Further advances in the approach to sealing materials have led to grout being mixed commonly with bentonite clays and various aggregates to achieve superior results and lower costs.

APPENDIX I

Geophysical Borehole Logs

This appendix is for information only and is not a part of ANSI/AWWA A100.

Some of the geophysical logs available include the following:

Geophysical Log Type		Type of Information
Resistivity		
Short normal	(16 in.)	Aquifer boundaries and thickness
Long normal	(64 in.)	Porosity
Lateral	(6 ft)	Clay and shale content
Spontaneous potential		Delineation of clay and sand beds
Gamma-ray		Radioactivity
Gamma-ray neutron		Gases
Acoustic (sonic)		Cement bond
Radioactive nuclides (uranium, potassium, and thorium)		Finite identification of radioactive materials
Porosity		Lithology and effective porosity
Temperature		Movement of water in hole and cement bond
Caliper		Hole diameter for size and volume
Formation tester		Formation water samples and hydrostatic pressure
Sidewall coring		Formation samples
Mechanical drift inclinometer		Borehole drift/alignment
Continuous alignment/magnetic multishot with gyroscope		Alignment direction and dogleg severity
Casing potential profile		Cathodic protection
Television camera survey		Videotape/pictures of well completion
Fluid movement (spinner survey)		Vertical movement of water in well
Penetration		Rate of drilling penetration

NOTE: The geophysical logs listed are generic. Wire-line service companies use proprietary trade names for these services.

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APPENDIX J

Types of Wells

This appendix is for information only and is not a part of ANSI/AWWA A100.

SECTION J.1: GENERAL

It is impossible to describe all of the types of wells being constructed. Furthermore, numerous variations of each type exist, depending on production requirements and the geological/hydrological environment. For any given site, the selection of the basic type of well most appropriate and the design of that type must be based on an examination of all available data.

In selecting the type of well to be constructed, the following criteria should be considered:

1. The well should be designed so that it will seal off water-bearing formations that are or may be contaminated or formations that have undesirable characteristics.
2. Well efficiency, specific capacity, and control of sand and turbidity should be optimized to permit production at the required rates with minimum operating cost.
3. Materials selected for completion should be designed to meet longevity requirements for the specific environment.

SECTION J.2: BASIC TYPES OF WELLS

In general, the following types of wells prevail in construction of public water-supply wells in North America. The listed well types and those shown in the figures are not presented in any order of preference and are not the only types of wells that may be satisfactorily used. The type of well selected must be site specific and will depend on the intended use, capacity, pump requirements, available aquifers, local and state rules and requirements, and drilling techniques locally available. It is also possible to combine more than one type in a single well.

Sec. J.2.1 Type 1

Gravel-packed well with conductor casing grouted in place and gravel envelope extending to surface (Figure J.1).

Sec. J.2.2 Type 2

Gravel-packed well with well casing cemented in place and gravel envelope terminated above the top of the screen with gravel feed line (Figure J.2).

Sec. J.2.3 Type 3

Gravel-packed well with telescoped screen, well casing cemented in place, and gravel envelope terminated above the top of the screen (Figure J.3).

Sec. J.2.4 Type 4

Naturally developed well with telescoped screen, well pump-housing casing driven or jacked into place, and the conductor sealed as locally required (Figure J.4).

Sec. J.2.5 Type 5

Naturally developed well with telescoped screen, temporary casing driven or jacked into place, and pump-housing casing sealed in to prevent contamination (Figure J.5).

Sec. J.2.6 Type 6

Naturally developed well with well casing advanced by driving or jacking and perforated in place (Figure J.6).

Sec. J.2.7 Type 7

Gravel-packed well with under-reamed borehole for screen and pump-housing casing cemented in place (Figure J.7).

Sec. J.2.8 Type 8

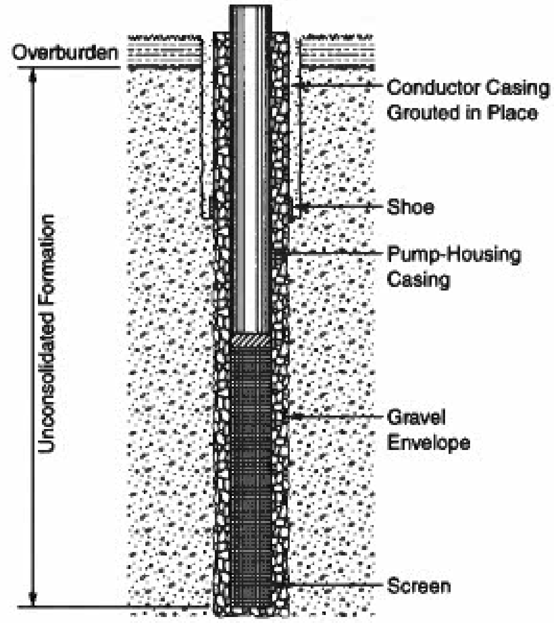
Gravel-packed well with under-reamed borehole for screens in multiple unconsolidated aquifers (Figure J.8).

Sec. J.2.9 Type 9

Well with open hole completion in consolidated rock and well casing cemented in place (Figure J.9).

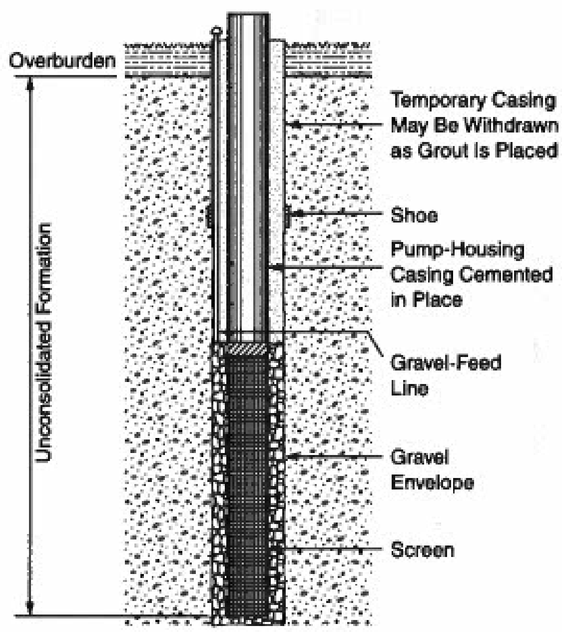
Sec. J.2.10 Type 10

Gravel-packed well completed in consolidated rock with well casing cemented in place (Figure J.10).



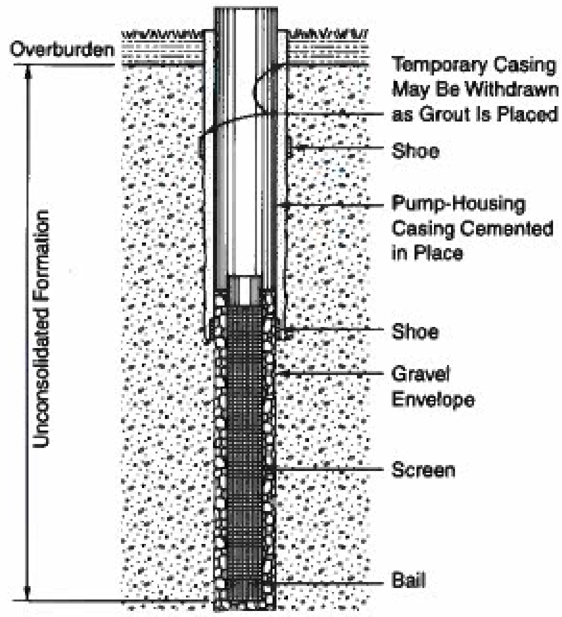
Gravel-packed well with conductor casing grouted in place and gravel envelope extending to surface.

Figure J.1 Type 1



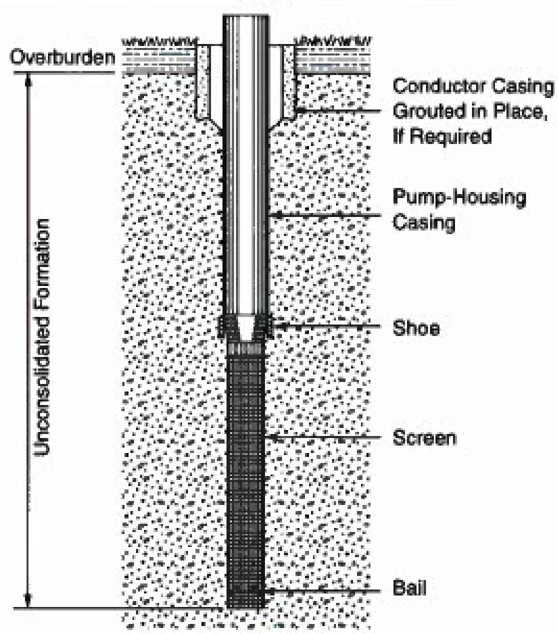
Gravel-packed well with well casing cemented in place and gravel envelope terminated above the top of the screen with gravel feed line.

Figure J.2 Type 2



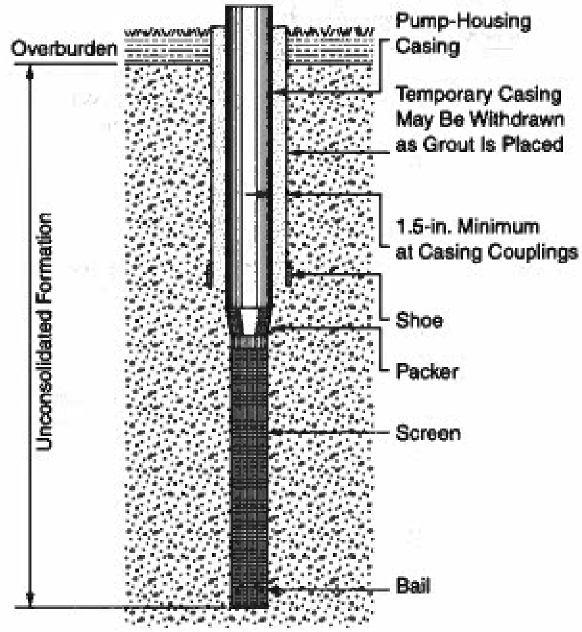
Gravel-packed well with telescoped screen, well casing cemented in place, and gravel envelope terminated above the top of screen.

Figure J.3 Type 3



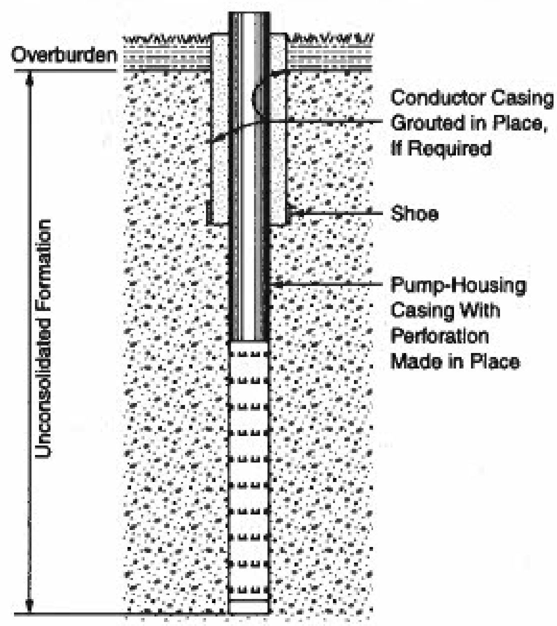
Naturally developed well with telescoped screen, well pump-housing casing driven or jacked into place, and the conductor sealed as locally required.

Figure J.4 Type 4



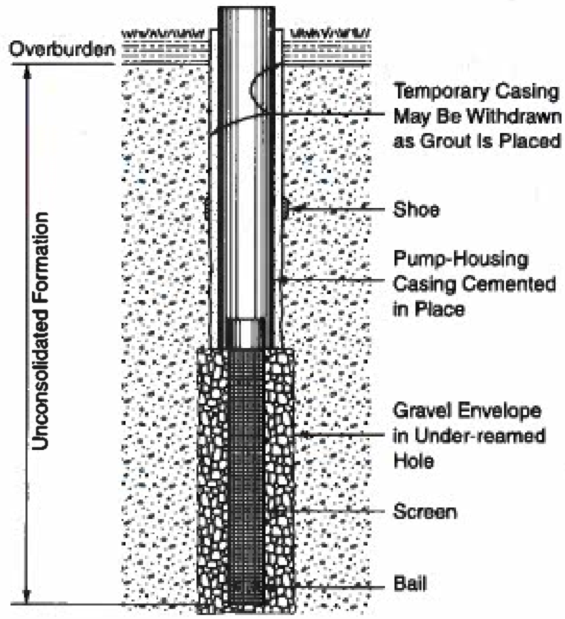
Naturally developed well with telescoped screen, temporary casing driven or jacked into place, and the pump-housing casing sealed in to prevent contamination.

Figure J.5 Type 5



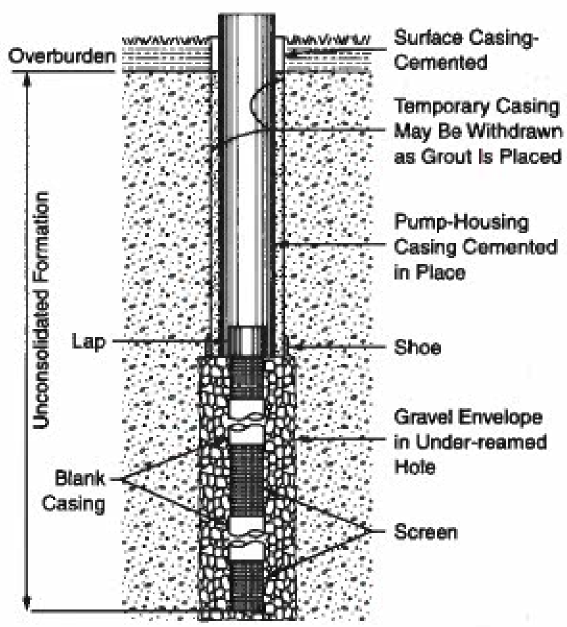
Naturally developed well with well casing advanced by driving or jacking and perforated in place.

Figure J.6 Type 6



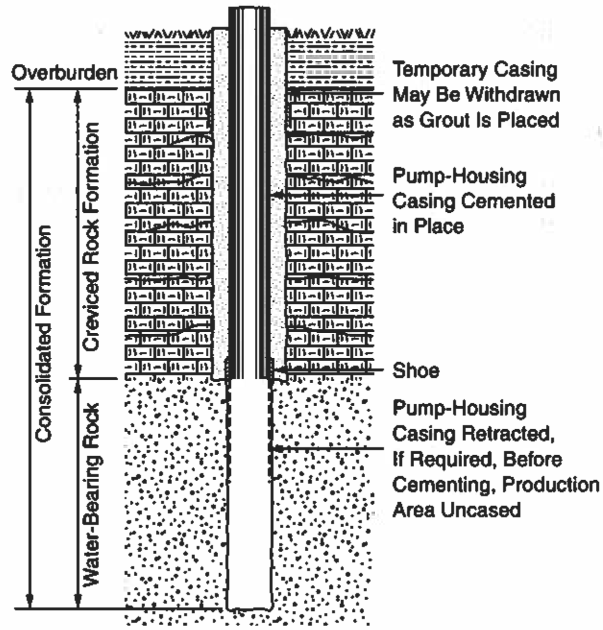
Gravel-packed well with under-reamed borehole for screen and pump-housing casing cemented in place.

Figure J.7 Type 7



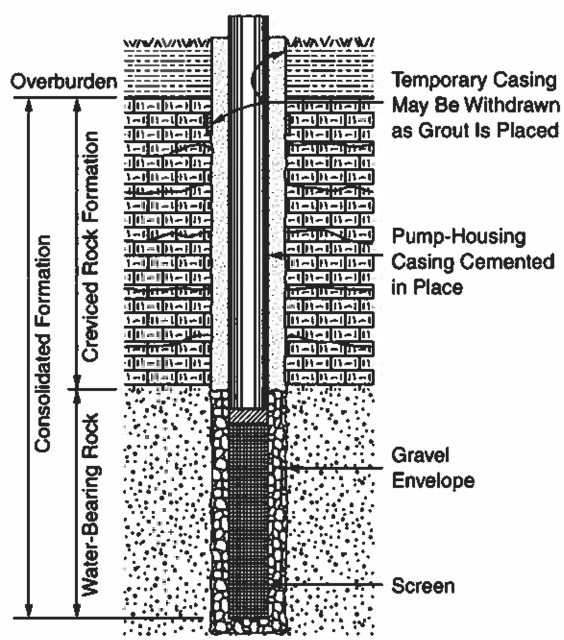
Gravel-packed well with under-reamed borehole for screens in multiple unconsolidated aquifers.

Figure J.8 Type 8



Well with open hole completion in consolidated rock and well casing cemented in place.

Figure J.9 Type 9



Gravel-packed well completed in consolidated rock with well casing cemented in place.

Figure J.10 Type 10

Sec. J.2.11 Type 11

Open hole or screened well completion in an artesian aquifer where piezometric level is above the ground elevation (Figure J.11).

Sec. J.2.12 Type 12

Naturally developed well with screen and well casing installed in place in an open hole. Blank casing in non–water-bearing formation is optional (Figure J.12).

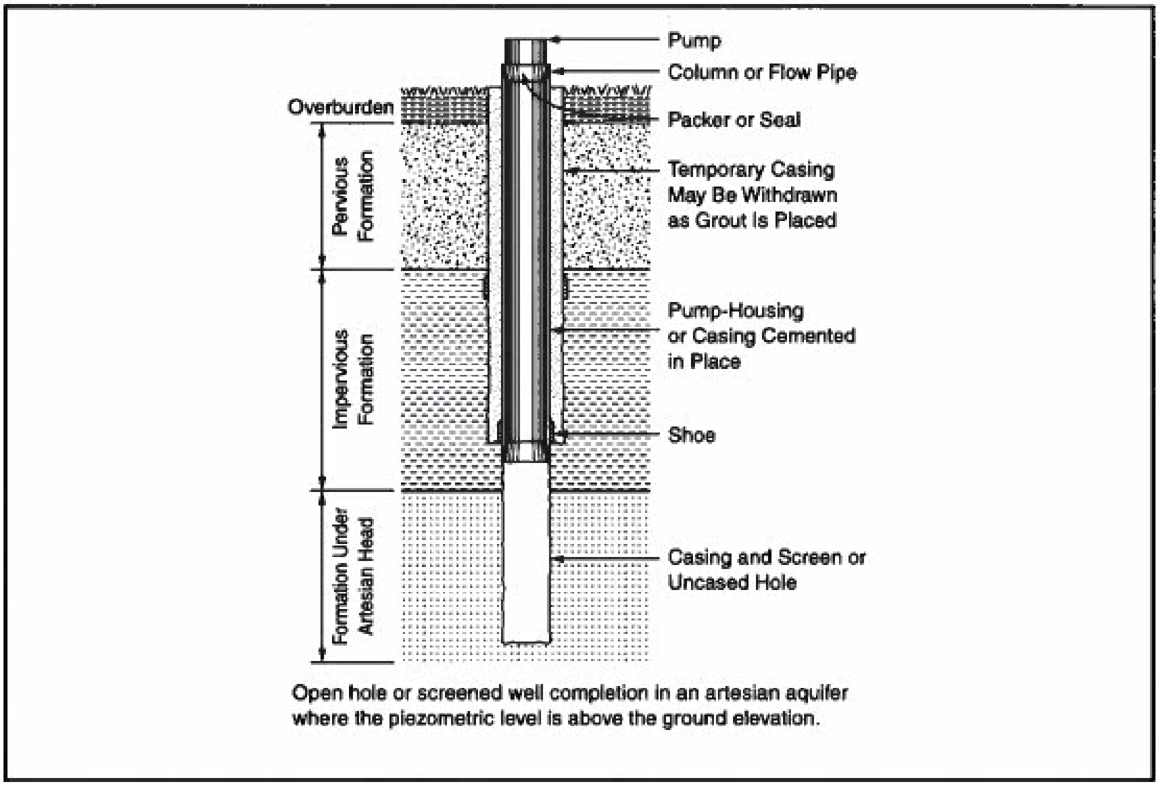


Figure J.11 Type 11

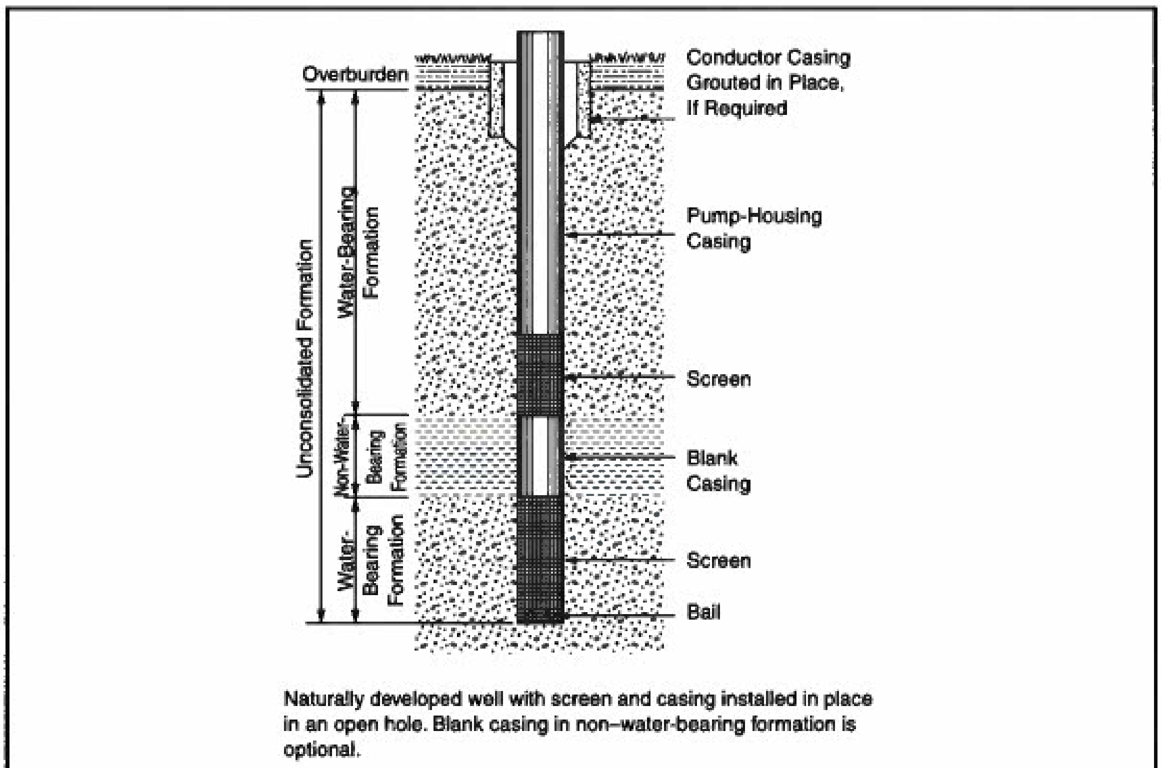


Figure J.12 Type 12

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APPENDIX K

Collapse Strength of Well Casing

This appendix is for information only and is not a part of ANSI/AWWA A100.

SECTION K.1: GENERAL

The minimum wall thickness tables for single-ply and two-ply steel well casing (Tables 4 and 5 in Sec. 4.4 of the standard) represent the committee's judgment regarding the minimum wall thicknesses normally necessary for various steel casing sizes and well depths. Tables 4 and 5 of the standard are based on the assumption that no unusual stresses will be placed on the casing during installation, well development, or well operation. The actual wall thickness required for each well project should be based on a careful analysis of conditions, expected loads, and resultant stresses to which the casing will be subjected (see Sec. 4.4.5).

Tables K.1 through K.4 may be used to assist in the determination of wall thickness requirements for several alternative well-casing materials. When well depths exceed those listed in Tables 4 and 5 of the standard, Tables K.1 and K.2 may be used to assist in determination of the wall thickness required for single-ply steel well casing, and Table K.3 may be used for two-ply steel casing. Table K.4 provides similar information for polyvinyl chloride (PVC) casing.

Table K.1 Collapse strength of steel well casing

Nominal Diameter		Wall Thickness			Outside Diameter		Inside Diameter		Weight		Collapsing Strength			
in.	*(mm)*	*in.*	*in.*	*(mm)*	*in.*	*(mm)*	*in.*	*(mm)*	*lb/ft*	*(kg/m)*	*psi*	*ft water*	*(kg/cm²)*	*(m water)*
8	(203)	¼	0.250	(6.35)	8.625	(219.08)	8.125	(206.38)	22.36	(33.28)	755.54	1,745.29	(53.20)	(531.96)
8	(203)	5⁄16	0.3125	(7.94)			8.000	(203.20)	27.74	(41.29)	1,191.21	2,751.70	(83.87)	(838.72)
10	(254)	¼	0.250	(6.35)	10.750	(273.05)	10.250	(260.35)	28.04	(41.72)	461.08	1,065.10	(32.46)	(324.64)
10	(254)	5⁄16	0.3125	(7.94)			10.125	(257.18)	34.84	(51.84)	760.25	1,756.18	(53.53)	(535.28)
12	(304)	¼	0.250	(6.35)	12.750	(323.85)	12.250	(311.15)	33.38	(49.67)	306.09	707.06	(21.55)	(215.51)
12	(304)	5⁄16	0.3125	(7.94)			12.125	(307.98)	41.51	(61.78)	520.68	1,202.78	(36.66)	(366.61)
14	(355)	¼	0.250	(6.35)	14.000	(355.60)	13.500	(342.90)	36.71	(54.64)	242.43	560.02	(17.07)	(170.69)
14	(355)	5⁄16	0.3125	(7.94)			13.375	(339.73)	45.68	(67.98)	418.68	967.15	(29.48)	(294.79)
14	(355)	⅜	0.375	(9.53)			13.250	(336.55)	54.57	(81.21)	636.10	1,469.39	(44.79)	(447.87)
14	(355)	¼	0.250	(6.35)	14.500	(368.30)	14.000	(355.60)	38.05	(56.62)	221.82	512.41	(15.62)	(156.18)
14	(355)	5⁄16	0.3125	(7.94)			13.875	(352.43)	47.35	(70.47)	385.11	889.59	(27.11)	(271.15)
14	(355)	⅜	0.375	(9.53)			13.750	(349.25)	56.57	(84.19)	588.19	1,358.72	(41.41)	(414.14)
16	(406)	¼	0.250	(6.35)	16.000	(406.40)	15.500	(393.70)	42.05	(62.58)	172.25	397.90	(12.13)	(121.28)
16	(406)	5⁄16	0.3125	(7.94)			15.375	(390.53)	52.36	(77.92)	303.15	700.27	(21.34)	(213.44)
16	(406)	⅜	0.375	(9.53)			15.250	(387.35)	62.58	(93.13)	469.53	1,084.62	(33.06)	(330.59)
16	(406)	¼	0.250	(6.35)	16.625	(422.28)	16.125	(409.58)	43.72	(65.07)	155.89	360.11	(10.98)	(109.76)
16	(406)	5⁄16	0.3125	(7.94)			16.000	(406.40)	54.44	(81.02)	275.69	636.84	(19.41)	(194.11)
16	(406)	⅜	0.375	(9.53)			15.875	(403.23)	65.08	(96.85)	429.18	991.40	(30.22)	(302.18)
18	(457)	¼	0.250	(6.35)	18.000	(457.20)	17.500	(444.50)	47.39	(70.53)	126.48	292.16	(8.90)	(89.05)

(Table continued next page)

Table K.1 Collapse strength of steel well casing (continued)

Nominal Diameter		Wall Thickness			Outside Diameter		Inside Diameter		Weight		Collapsing Strength			
in.	*(mm)*	*in.*	*in.*	*(mm)*	*in.*	*(mm)*	*in.*	*(mm)*	*lb/ft*	*(kg/m)*	*psi*	*ft water*	*(kg/cm²)*	*(m water)*
18	(457)	5⁄16	0.3125	(7.94)			17.375	(441.33)	59.03	(87.85)	225.76	521.49	(15.90)	(158.95)
18	(457)	3⁄8	0.375	(9.53)			17.250	(438.15)	70.59	(105.05)	354.92	819.86	(24.99)	(249.89)
18	(457)	1⁄4	0.250	(6.35)	18.625	(473.08)	18.125	(460.38)	49.06	(73.01)	115.51	266.84	(8.13)	(81.33)
18	(457)	5⁄16	0.3125	(7.94)			18.000	(457.20)	61.12	(90.96)	206.95	478.05	(14.57)	(145.71)
18	(457)	3⁄8	0.375	(9.53)			17.875	(454.03)	73.09	(108.77)	326.64	754.54	(23.00)	(229.98)
20	(508)	1⁄4	0.250	(6.35)	20.000	(508.00)	19.500	(495.30)	52.73	(78.48)	95.46	220.52	(6.72)	(67.21)
20	(508)	5⁄16	0.3125	(7.94)			19.375	(442.13)	65.71	(97.79)	172.25	397.90	(12.13)	(121.28)
20	(508)	3⁄8	0.3750	(9.53)			19.250	(488.95)	78.60	(116.97)	273.98	632.89	(19.29)	(192.90)
20	(508)	7⁄16	0.4375	(11.11)			19.125	(485.78)	91.41	(136.03)	399.05	921.82	(28.10)	(280.97)
20	(508)	1⁄4	0.2500	(6.35)	20.625	(523.88)	20.125	(511.18)	54.40	(80.96)	87.86	202.96	(6.19)	(61.86)
20	(508)	5⁄16	0.3125	(7.94)			20.000	(508.00)	67.79	(100.89)	159.00	367.28	(11.19)	(111.95)
20	(508)	3⁄8	0.3750	(9.53)			19.875	(504.83)	81.10	(120.69)	253.68	586.00	(17.86)	(178.61)
20	(508)	7⁄16	0.4375	(11.11)			19.750	(501.65)	94.33	(140.38)	370.69	856.31	(26.10)	(261.00)
22	(559)	1⁄4	0.2500	(6.35)	22.00	(558.80)	21.500	(546.10)	58.07	(86.42)	73.75	170.37	(5.19)	(51.93)
22	(559)	5⁄16	0.3125	(7.94)			21.375	(542.93)	72.38	(107.72)	134.22	310.05	(9.45)	(94.50)
22	(559)	3⁄8	0.3750	(9.53)			21.250	(539.75)	86.61	(128.89)	215.46	497.71	(15.17)	(151.70)
22	(559)	7⁄16	0.4375	(11.11)			21.125	(536.58)	100.75	(149.94)	316.88	732.00	(22.31)	(223.11)
22	(559)	1⁄4	0.2500	(6.35)	22.50	(571.50)	22.000	(558.80)	59.41	(88.41)	69.37	160.25	(4.88)	(48.84)
22	(559)	5⁄16	0.3125	(7.94)			21.875	(555.63)	74.05	(110.20)	126.48	292.16	(8.90)	(89.05)

(Table continued next page)

Table K.1 Collapse strength of steel well casing (continued)

Nominal Diameter		Wall Thickness			Outside Diameter		Inside Diameter		Weight		Collapsing Strength			
in.	*(mm)*	*in.*	*in.*	*(mm)*	*in.*	*(mm)*	*in.*	*(mm)*	*lb/ft*	*(kg/m)*	*psi*	*ft water*	*(kg/cm²)*	*(m water)*
22	(559)	⅜	0.3750	(9.53)			21.750	(552.45)	88.61	(131.87)	203.44	469.94	(14.32)	(143.24)
22	(559)	7⁄16	0.4375	(11.11)			21.625	(549.28)	103.09	(153.41)	299.84	692.62	(21.11)	(211.11)
24	(610)	¼	0.2500	(6.35)	24.00	(609.60)	23.500	(596.90)	63.41	(94.37)	58.13	134.28	(4.09)	(40.93)
24	(610)	5⁄16	0.3125	(7.94)			23.375	(593.73)	79.06	(117.65)	106.51	246.04	(7.50)	(74.99)
24	(610)	⅜	0.3750	(9.53)			23.250	(590.55)	94.62	(140.81)	172.25	397.90	(12.13)	(121.28)
24	(610)	7⁄16	0.4375	(11.11)			23.125	(587.38)	110.10	(163.84)	255.34	589.84	(17.98)	(179.78)
24	(610)	¼	0.2500	(6.35)	24.50	(622.30)	24.000	(609.60)	64.75	(96.36)	54.92	126.88	(3.87)	(38.67)
24	(610)	5⁄16	0.3125	(7.94)			23.875	(606.43)	80.73	(120.14)	100.79	232.82	(7.10)	(70.96)
24	(610)	⅜	0.3750	(9.53)			23.750	(603.25)	96.62	(143.79)	163.26	377.13	(11.49)	(114.95)
24	(610)	7⁄16	0.4375	(11.11)			23.625	(600.08)	112.43	(167.32)	242.43	560.02	(17.07)	(170.69)
26	(660)	¼	0.2500	(6.35)	26.00	(660.40)	25.500	(647.70)	68.75	(102.32)	46.61	107.67	(3.28)	(32.82)
26	(660)	5⁄16	0.3125	(7.94)			25.375	(644.53)	85.73	(127.59)	85.88	198.38	(6.05)	(60.47)
26	(660)	⅜	0.3750	(9.53)			25.250	(641.35)	102.63	(152.73)	139.73	322.78	(9.84)	(98.38)
26	(660)	7⁄16	0.4375	(11.11)			25.125	(638.18)	119.44	(177.75)	208.48	481.59	(14.68)	(146.79)
26	(660)	¼	0.2500	(6.35)	26.50	(673.10)	26.000	(660.40)	70.09	(104.30)	44.21	102.13	(3.11)	(31.13)
26	(660)	5⁄16	0.3125	(7.94)			25.875	(657.23)	87.40	(130.07)	81.56	188.41	(5.74)	(57.43)
26	(660)	⅜	0.3750	(9.53)			25.750	(654.05)	104.63	(155.71)	132.89	306.97	(9.36)	(93.56)
26	(660)	7⁄16	0.4375	(11.11)			25.625	(650.88)	121.78	(181.23)	198.55	458.66	(13.98)	(139.80)
28	(711)	¼	0.2500	(6.35)	28.00	(711.20)	27.500	(698.50)	74.09	(110.26)	37.94	87.63	(2.67)	(26.71)

(Table continued next page)

Table K.1 Collapse strength of steel well casing (continued)

Nominal Diameter		Wall Thickness			Outside Diameter		Inside Diameter		Weight		Collapsing Strength			
in.	*(mm)*	*in.*	*in.*	*(mm)*	*in.*	*(mm)*	*in.*	*(mm)*	*lb/ft*	*(kg/m)*	*psi*	*ft water*	*(kg/cm²)*	*(m water)*
28	(711)	5⁄16	0.3125	(7.94)			27.375	(695.33)	92.41	(137.52)	70.22	162.21	(4.94)	(49.44)
28	(711)	3⁄8	0.3750	(9.53)			27.250	(692.15)	110.64	(164.65)	114.83	265.25	(8.08)	(80.85)
28	(711)	7⁄16	0.4375	(11.11)			27.125	(688.98)	128.79	(191.66)	172.25	397.90	(12.13)	(121.28)
28	(711)	1⁄4	0.2500	(6.35)	28.50	(723.90)	28.000	(711.20)	75.43	(112.25)	36.11	83.41	(2.54)	(25.42)
28	(711)	5⁄16	0.3125	(7.94)			27.875	(708.03)	94.08	(140.00)	66.91	154.55	(4.71)	(47.11)
28	(711)	3⁄8	0.3750	(9.53)			27.750	(704.85)	112.64	(167.63)	109.53	253.02	(7.71)	(77.12)
28	(711)	7⁄16	0.4375	(11.11)			27.625	(701.68)	131.12	(195.14)	164.51	380.01	(11.58)	(115.83)
30	(762)	1⁄4	0.2500	(6.35)	30.000	(762.00)	29.500	(749.30)	79.43	(118.21)	31.28	72.26	(2.20)	(22.02)
30	(762)	5⁄16	0.3125	(7.94)			29.375	(746.13)	99.08	(147.45)	58.13	134.28	(4.09)	(40.93)
30	(762)	3⁄8	0.3750	(9.53)			29.250	(742.95)	118.65	(176.57)	95.46	220.52	(6.72)	(67.21)
30	(762)	7⁄16	0.4375	(11.11)			29.125	(739.78)	138.13	(205.57)	143.85	332.20	(10.13)	(101.28)
30	(762)	1⁄2	0.5000	(12.70)			29.000	(736.60)	157.53	(234.44)	203.44	469.94	(14.32)	(143.24)
30	(762)	1⁄4	0.2500	(6.35)	30.50	(774.70)	30.000	(762.00)	80.77	(120.20)	29.86	68.99	(2.10)	(21.03)
30	(762)	5⁄16	0.3125	(7.94)			29.875	(758.83)	100.75	(149.94)	55.55	128.31	(3.91)	(39.11)
30	(762)	3⁄8	0.3750	(9.53)			29.750	(755.65)	120.65	(179.55)	91.31	210.91	(6.43)	(64.29)
30	(762)	7⁄16	0.4375	(11.11)			29.625	(752.48)	140.47	(209.04)	137.73	318.15	(9.70)	(96.97)
30	(762)	1⁄2	0.5000	(12.70)			29.500	(749.30)	160.20	(238.41)	194.99	450.43	(13.73)	(137.29)

Table K.2 Axial-compressive strength and tensile strength of steel well casing

Nominal Diameter		Wall Thickness			Outside Diameter		Inside Diameter		Axial-Compressive Strength		Tensile Strength	
in.	*(mm)*	*in.*	*in.*	*(mm)*	*in.*	*(mm)*	*in.*	*(mm)*	*tons*	*(kg)**	*tons*	*(kg)*
8	(203)	¼	0.2500	(6.35)	8.625	(219.08)	8.125	(206.38)	115.11	(104,426.03)	197.33	(179,014.76)
8	(203)	5⁄16	0.3125	(7.94)			8.000	(203.20)	142.81	(129,555.05)	244.82	(222,096.96)
10	(254)	¼	0.2500	(6.35)	10.750	(273.05)	10.250	(260.35)	144.32	(130,924.90)	247.40	(224,437.49)
10	(254)	5⁄16	0.3125	(7.94)			10.125	(257.18)	179.32	(162,676.36)	307.41	(278,877.65)
12	(304)	¼	0.2500	(6.35)	12.750	(323.85)	12.250	(311.15)	171.81	(155,863.40)	294.52	(267,184.04)
12	(304)	5⁄16	0.3125	(7.94)			12.125	(307.98)	213.68	(193,847.23)	366.31	(332,310.83)
14	(355)	¼	0.2500	(6.35)	14.00	(355.60)	13.500	(342.90)	188.99	(171,448.84)	323.98	(293,909.70)
14	(355)	5⁄16	0.3125	(7.94)			13.375	(339.73)	235.16	(213,333.55)	403.13	(365,713.37)
14	(355)	⅜	0.3750	(9.53)			13.250	(336.55)	280.90	(254,828.18)	481.55	(436,854.79)
14	(355)	¼	0.2500	(6.35)	14.50	(368.30)	14.000	(355.60)	195.86	(177,681.20)	335.76	(304,596.33)
14	(355)	5⁄16	0.3125	(7.94)			13.875	(352.43)	243.75	(221,126.27)	417.86	(379,076.20)
14	(355)	⅜	0.3750	(9.53)			13.750	(349.25)	291.21	(264,181.26)	499.22	(452,884.75)
16	(406)	¼	0.2500	(6.35)	16.00	(406.40)	15.500	(393.70)	216.48	(196,387.34)	371.10	(336,656.24)
16	(406)	5⁄16	0.3125	(7.94)			15.375	(390.53)	269.52	(244,504.42)	462.04	(419,155.62)
16	(406)	⅜	0.3750	(9.53)			15.250	(387.35)	322.14	(292,240.48)	552.23	(500,974.61)
16	(406)	¼	0.2500	(6.35)	16.625	(422.28)	16.125	(409.58)	225.07	(204,180.06)	385.83	(350,019.07)
16	(406)	5⁄16	0.3125	(7.94)			16.000	(406.40)	280.26	(254,247.58)	480.44	(435,847.82)
16	(406)	⅜	0.3750	(9.53)			15.875	(403.23)	335.02	(303,925.02)	574.32	(521,014.32)
18	(457)	¼	0.2500	(6.35)	18.00	(457.20)	17.500	(444.50)	243.96	(221,316.78)	418.22	(379,402.79)

*Conversion factor used: 1 ton (2,000 lb) = 907.1847 kg.

(Table continued next page)

Table K.2 Axial-compressive strength and tensile strength of steel well casing (continued)

Nominal Diameter		Wall Thickness			Outside Diameter		Inside Diameter		Axial-Compressive Strength		Tensile Strength	
in.	*(mm)*	*in.*	*in.*	*(mm)*	*in.*	*(mm)*	*in.*	*(mm)*	*tons*	*(kg)**	*tons*	*(kg)*
18	(457)	5⁄16	0.3125	(7.94)			17.375	(441.33)	303.88	(275,675.29)	520.94	(472,588.80)
18	(457)	3⁄8	0.3750	(9.53)			17.250	(438.15)	363.37	(329,643.70)	622.92	(565,103.49)
18	(457)	1⁄4	0.2500	(6.35)	18.625	(473.08)	18.125	(460.38)	252.55	(229,109.50)	432.95	(392,765.62)
18	(457)	5⁄16	0.3125	(7.94)			18.000	(457.20)	314.62	(285,418.45)	539.35	(489,290.07)
18	(457)	3⁄8	0.3750	(9.53)			17.875	(454.03)	376.25	(341,328.24)	645.01	(585,143.20)
20	(508)	1⁄4	0.2500	(6.35)	20.00	(508.00)	19.500	(495.30)	271.45	(246,255.29)	465.35	(422,158.40)
20	(508)	5⁄16	0.3125	(7.94)			19.375	(492.13)	338.24	(306,846.15)	579.84	(526,021.98)
20	(508)	3⁄8	0.3750	(9.53)			19.250	(488.95)	404.60	(367,046.93)	693.60	(629,223.31)
20	(508)	7⁄16	0.4375	(11.11)			19.125	(485.78)	470.53	(426,857.62)	806.63	(731,762.39)
20	(508)	1⁄4	0.2500	(6.35)	20.625	(523.88)	20.125	(511.18)	280.04	(254,048.00)	480.07	(435,512.16)
20	(508)	5⁄16	0.3125	(7.94)			20.000	(508.00)	348.98	(316,589.32)	598.25	(542,723.25)
20	(508)	3⁄8	0.3750	(9.53)			19.875	(504.83)	417.49	(378,740.54)	715.69	(649,263.02)
20	(508)	7⁄16	0.4375	(11.11)			19.750	(501.65)	485.57	(440,501.67)	832.40	(755,140.54)
22	(559)	1⁄4	0.2500	(6.35)	22.00	(558.80)	21.500	(546.10)	298.94	(271,193.79)	512.47	(464,904.94)
22	(559)	5⁄16	0.3125	(7.94)			21.375	(542.93)	372.60	(338,017.02)	638.75	(579,464.23)
22	(559)	3⁄8	0.3750	(9.53)			21.250	(539.75)	445.84	(404,459.23)	764.29	(693,352.19)
22	(559)	7⁄16	0.4375	(11.11)			21.125	(536.58)	518.64	(470,502.27)	889.10	(806,577.92)
22	(559)	1⁄4	0.2500	(6.35)	22.50	(571.50)	22.000	(558.80)	305.81	(277,426.15)	524.25	(475,591.58)
22	(559)	5⁄16	0.3125	(7.94)			21.875	(555.63)	381.19	(345,809.74)	653.48	(592,827.06)

*Conversion factor used: 1 ton (2,000 lb) = 907.1847 kg.

(Table continued next page)

Table K.2 Axial-compressive strength and tensile strength of steel well casing (continued)

Nominal Diameter		Wall Thickness			Outside Diameter		Inside Diameter		Axial-Compressive Strength		Tensile Strength	
in.	*(mm)*	*in.*	*in.*	*(mm)*	*in.*	*(mm)*	*in.*	*(mm)*	*tons*	*(kg)**	*tons*	*(kg)*
22	(559)	3⁄8	0.3750	(9.53)			21.750	(552.45)	456.14	(413,803.23)	781.96	(709,382.15)
22	(559)	7⁄16	0.4375	(11.11)			21.625	(549.28)	530.67	(481,415.70)	909.71	(825,274.99)
24	(610)	1⁄4	0.2500	(6.35)	24.00	(609.60)	23.500	(596.90)	326.43	(296,132.30)	559.60	(507,660.56)
24	(610)	5⁄16	0.3125	(7.94)			23.375	(593.73)	406.97	(369,196.96)	697.65	(632,897.41)
24	(610)	3⁄8	0.3750	(9.53)			23.250	(590.55)	487.07	(441,862.45)	834.98	(757,481.08)
24	(610)	7⁄16	0.4375	(11.11)			23.125	(587.38)	566.74	(514,137.86)	971.56	(881,384.37)
24	(610)	1⁄4	0.2500	(6.35)	24.50	(622.30)	24.000	(609.60)	333.30	(302,364.66)	571.38	(518,347.19)
24	(610)	5⁄16	0.3125	(7.94)			23.875	(606.43)	415.56	(376,989.67)	712.38	(646,260.24)
24	(610)	3⁄8	0.3750	(9.53)			23.750	(603.25)	497.38	(451,215.53)	852.65	(773,511.03)
24	(610)	7⁄16	0.4375	(11.11)			23.625	(600.08)	578.77	(525,051.29)	992.18	(900,090.52)
26	(660)	1⁄4	0.2500	(6.35)	26.00	(660.40)	25.500	(647.70)	353.92	(321,070.81)	606.72	(550,407.10)
26	(660)	5⁄16	0.3125	(7.94)			25.375	(644.53)	441.33	(400,367.82)	756.56	(686,339.66)
26	(660)	3⁄8	0.3750	(9.53)			25.250	(641.35)	528.30	(479,265.68)	905.66	(821,600.90)
26	(660)	7⁄16	0.4375	(11.11)			25.125	(638.18)	614.85	(557,782.51)	1,054.03	(956,199.89)
26	(660)	1⁄4	0.2500	(6.35)	26.50	(673.10)	26.000	(660.40)	360.79	(327,303.17)	618.50	(561,093.74)
26	(660)	5⁄16	0.3125	(7.94)			25.875	(657.23)	449.92	(408,160.54)	771.29	(699,702.49)
26	(660)	3⁄8	0.3750	(9.53)			25.750	(654.05)	538.61	(488,618.75)	923.33	(837,630.85)
26	(660)	7⁄16	0.4375	(11.11)			25.625	(650.88)	626.88	(568,695.94)	1,074.65	(974,906.04)
28	(711)	1⁄4	0.2500	(6.35)	28.00	(711.20)	27.500	(698.50)	381.41	(346,009.32)	653.84	(593,153.64)

*Conversion factor used: 1 ton (2,000 lb) = 907.1847 kg.

(Table continued next page)

Table K.2 Axial-compressive strength and tensile strength of steel well casing (continued)

Nominal Diameter		Wall Thickness			Outside Diameter		Inside Diameter		Axial-Compressive Strength		Tensile Strength	
in.	*(mm)*	*in.*	*in.*	*(mm)*	*in.*	*(mm)*	*in.*	*(mm)*	*tons*	*(kg)**	*tons*	*(kg)*
28	(711)	5⁄16	0.3125	(7.94)			27.375	(695.33)	475.69	(431,538.69)	815.46	(739,772.84)
28	(711)	3⁄8	0.3750	(9.53)			27.250	(692.15)	569.54	(516,677.97)	976.35	(885,729.78)
28	(711)	7⁄16	0.4375	(11.11)			27.125	(688.98)	662.96	(601,427.17)	1,136.50	(1,031,015.41)
28	(711)	1⁄4	0.2500	(6.35)	28.50	(723.90)	28.000	(711.20)	388.28	(352,241.68)	665.62	(603,840.28)
28	(711)	5⁄16	0.3125	(7.94)			27.875	(708.03)	484.28	(439,331.41)	830.19	(753,135.67)
28	(711)	3⁄8	0.3750	(9.53)			27.750	(704.85)	579.84	(526,021.98)	994.02	(901,759.74)
28	(711)	7⁄16	0.4375	(11.11)			27.625	(701.68)	674.98	(612,331.53)	1,157.11	(1,049,712.49)
30	(762)	1⁄4	0.2500	(6.35)	30.000	(762.00)	29.500	(749.30)	408.90	(370,947.82)	700.97	(635,909.26)
30	(762)	5⁄16	0.3125	(7.94)			29.375	(746.13)	510.05	(462,709.56)	874.37	(793,215.09)
30	(762)	3⁄8	0.3750	(9.53)			29.250	(742.95)	610.77	(554,081.20)	1,047.03	(949,849.60)
30	(762)	7⁄16	0.4375	(11.11)			29.125	(739.78)	711.06	(645,062.75)	1,218.96	(1,105,821.86)
30	(762)	1⁄2	0.5000	(12.70)			29.000	(736.60)	810.92	(735,654.22)	1,390.15	(1,261,122.81)
30	(762)	1⁄4	0.2500	(6.35)	30.50	(774.70)	30.000	(762.00)	415.77	(377,180.18)	712.75	(646,595.89)
30	(762)	5⁄16	0.3125	(7.94)			29.875	(758.83)	518.64	(470,502.27)	889.10	(806,577.92)
30	(762)	3⁄8	0.3750	(9.53)			29.750	(755.65)	621.08	(563,434.27)	1,064.71	(965,888.62)
30	(762)	7⁄16	0.4375	(11.11)			29.625	(752.48)	723.09	(655,976.18)	1,239.58	(1,124,528.01)
30	(762)	1⁄2	0.5000	(12.70)			29.500	(749.30)	824.67	(748,128.01)	1,413.72	(1,282,505.15)

*Conversion factor used: 1 ton (2,000 lb) = 907.1847 kg.

Table K.3 Collapse strength and axial-compression strength of two-ply steel well casing

Nom. Diam.	US Std.	Casing Wall Thickness		Outside Diameter		Inside Diameter		Weight		Collapsing Strength				Axial-Compression Strength	
in.	Gauge	*in.*	*(mm)*	*in.*	*(mm)*	*in.*	*(mm)*	*lb/ft*	*(kg/m)*	*psi*	*ft water*	*(kg/cm²)*	*(m water)*	*tons*	*(kg)**
8	12	0.218	(5.54)	8.436	(214.27)	8.000	(203.20)	19.13	(28.47)	302.65	698.97	(21.28)	(213.05)	76.36	(69,272.62)
8	10	0.282	(7.16)	8.504	(216.00)	7.940	(201.68)	24.76	(36.85)	662.74	1,530.58	(46.60)	(466.53)	98.44	(89,303.26)
10	12	0.218	(5.54)	10.436	(265.07)	10.000	(254.00)	23.79	(35.40)	153.75	355.07	(10.81)	(108.23)	95.20	(86,363.98)
10	10	0.282	(7.16)	10.504	(266.80)	9.940	(252.48)	30.79	(45.82)	335.88	775.71	(23.61)	(236.44)	122.80	(111,402.28)
12	12	0.218	(5.54)	12.436	(315.87)	12.000	(304.80)	28.45	(42.33)	88.51	204.41	(6.22)	(62.31)	114.03	(103,446.27)
12	10	0.282	(7.16)	12.504	(317.60)	11.940	(303.28)	36.81	(54.78)	193.06	445.88	(13.57)	(135.90)	147.16	(133,501.30)
12	8	0.344	(8.74)	12.568	(319.23)	11.880	(301.75)	44.91	(66.83)	353.07	815.41	(24.82)	(248.54)	179.09	(162,467.71)
14	12	0.218	(5.54)	14.496	(368.20)	14.060	(357.12)	33.24	(49.47)	55.53	128.25	(3.90)	(39.09)	133.43	(121,045.65)
14	10	0.282	(7.16)	14.564	(369.93)	14.000	(355.60)	43.01	(64.01)	120.99	279.43	(8.51)	(85.17)	172.26	(156,271.64)
14	8	0.344	(8.74)	14.628	(371.55)	13.940	(354.08)	52.48	(78.10)	221.03	510.47	(15.54)	(155.59)	209.70	(190,236.63)
16	12	0.218	(5.54)	16.496	(419.00)	16.060	(407.92)	37.90	(56.40)	37.10	85.68	(2.61)	(26.12)	152.26	(138,127.94)
16	10	0.282	(7.16)	16.564	(420.73)	16.000	(406.40)	49.04	(72.98)	80.77	186.52	(5.68)	(56.85)	196.62	(178,370.66)
16	8	0.344	(8.74)	16.628	(422.35)	15.940	(404.88)	59.83	(89.03)	147.42	340.47	(10.36)	(103.78)	239.42	(217,198.16)
16	6	0.406	(10.31)	16.692	(423.98)	15.880	(403.35)	70.62	(105.09)	243.72	562.86	(17.14)	(171.56)	282.06	(255,880.52)
18	12	0.218	(5.54)	18.496	(469.80)	18.060	(458.72)	42.56	(63.33)	26.00	60.05	(1.83)	(18.30)	171.10	(155,219.30)
18	10	0.282	(7.16)	18.564	(471.53)	18.000	(457.20)	55.06	(81.94)	56.57	130.64	(3.98)	(39.82)	220.98	(200,469.68)
18	8	0.344	(8.74)	18.628	(473.15)	17.940	(455.68)	67.17	(99.97)	103.10	238.30	(7.25)	(72.64)	269.14	(244,159.69)

*Conversion factor used: 1 ton (2,000 lb) = 907.1847 kg.

(Table continued next page)

Table K.3 Collapse strength and axial-compression strength of two-ply steel well casing (continued)

Nom. Diam.	US Std.	Casing Wall Thickness		Outside Diameter		Inside Diameter		Weight		Collapsing Strength				Axial-Compression Strength	
in.	Gauge	*in.*	*(mm)*	*in.*	*(mm)*	*in.*	*(mm)*	*lb/ft*	*(kg/m)*	*psi*	*ft water*	*(kg/cm²)*	*(m water)*	*tons*	*(kg)**
18	6	0.406	(10.31)	18.692	(474.78)	17.880	(454.15)	79.29	(118.00)	170.48	393.71	(11.99)	(120.01)	317.14	(287,704.56)
20	12	0.218	(5.54)	20.556	(522.12)	20.120	(511.05)	47.35	(70.47)	18.92	43.70	(1.33)	(13.32)	190.50	(172,818.69)
20	10	0.282	(7.16)	20.624	(523.85)	20.060	(509.52)	61.27	(91.17)	41.14	95.02	(2.89)	(28.96)	246.08	(223,240.01)
20	8	0.344	(8.74)	20.688	(525.48)	20.000	(508.00)	74.74	(111.23)	75.02	173.25	(5.27)	(52.81)	299.75	(271,883.25)
20	6	0.406	(10.31)	20.752	(527.10)	19.940	(506.48)	88.22	(131.29)	123.88	286.09	(8.71)	(87.20)	353.27	(320,481.14)
22	10	0.282	(7.16)	22.624	(574.65)	22.060	(560.32)	67.29	(100.14)	30.86	71.26	(2.17)	(21.72)	270.44	(245,339.03)
22	8	0.344	(8.74)	22.688	(576.28)	22.000	(558.80)	82.09	(122.16)	56.24	129.87	(3.95)	(29.59)	329.47	(298,890.14)
22	6	0.406	(10.31)	22.752	(577.90)	21.940	(557.28)	96.90	(144.19)	92.82	214.38	(6.53)	(65.34)	388.34	(352,296.11)
24	10	0.282	(7.16)	24.624	(625.45)	24.060	(611.12)	73.31	(109.10)	23.73	54.80	(1.67)	(16.70)	294.80	(267,438.05)
24	8	0.344	(8.74)	24.688	(627.08)	24.000	(609.60)	89.44	(133.10)	43.23	99.85	(3.07)	(30.43)	359.19	(325,851.67)
24	6	0.406	(10.31)	24.752	(628.70)	23.940	(608.08)	105.57	(157.10)	71.34	164.76	(5.02)	(50.22)	423.42	(384,120.15)
26	10	0.282	(7.16)	26.624	(676.25)	26.060	(661.92)	79.34	(118.06)	18.64	43.05	(1.31)	(13.12)	319.17	(289,546.14)
26	8	0.344	(8.74)	26.688	(677.88)	26.000	(660.40)	96.79	(144.03)	33.95	78.41	(2.39)	(23.90)	388.91	(352,813.20)
26	6	0.406	(10.31)	26.752	(679.50)	25.940	(658.88)	114.24	(170.10)	56.01	129.35	(3.94)	(39.43)	458.49	(415,935.11)

*Conversion factor used: 1 ton (2,000 lb) = 907.1847 kg.

Table K.4 Hydraulic collapse pressure and unit weight of PVC well casing

Nominal Size *in.*	Actual OD *in.*	SDR/SCH*	Minimum Wall Thickness *in.*	Inside Diameter *in.*	Weight in Air *lb/100 ft*	Weight in Water *lb/100 ft*	RHCP† *psi*
2	2.375	SCH40	0.154	2.067	65	19	291
3	3.500	SCH40	0.216	3.068	135	39	250
4	4.500	SDR26	0.173	4.154	143	41	58
		SDR21	0.214	4.072	175	50	111
		SCH40	0.237	4.026	193	55	152
4½	4.950	SDR26	0.190	4.570	172	49	58
		SCH40	0.248	4.454	222	63	130
		SDR17	0.291	4.368	258	74	215
5	5.563	SCH80	0.375	4.813	371	106	329
		SDR26	0.214	5.135	218	62	58
		SCH40	0.258	5.047	261	74	103
		SDR21	0.265	5.033	267	76	111
		SDR17	0.327	4.909	326	93	215
6	6.625	SDR32.5	0.204	6.217	250	71	29
		SDR26	0.255	6.115	310	88	58
		SCH40	0.280	6.065	339	97	77
		SDR21	0.316	5.993	380	109	111
		SDR17	0.390	5.845	463	132	215
6.9 in. OD	6.900	SDR27.6	0.250	6.400	317	91	48
		SDR21	0.329	6.242	412	118	111
		SDR17	0.406	6.088	503	144	215
8	8.625	SDR26	0.332	7.961	525	150	58
		SDR21	0.410	7.805	642	183	111
		SDR17	0.508	7.609	786	225	215
10	10.750	SDR26	0.413	9.924	814	232	58
		SDR21	0.511	9.728	997	285	111
		SDR17	0.632	9.486	1,219	348	215
12	12.750	SDR26	0.490	11.770	1,145	327	58
		SDR21	0.606	11.538	1,403	401	111
		SDR17	0.750	11.250	1,715	490	215
14	14.000	SCH40	0.437	13.126	1,130	323	30
		SDR17	0.824	12.353	2,068	591	215
16	16.000	SCH40	0.500	15.000	1,477	422	30
		SDR26	0.616	14.768	1,806	516	58
		SDR21	0.762	14.476	2,213	632	111
		SDR17	0.941	14.118	2,701	772	215
17.4 in. OD	17.400	SDR17	1.024	15.353	3,195	913	215
24	24.000	SDR17	1.412	21.176	6,078	1,737	215

NOTE: These values listed in Table K.4 are for PVC cell classification 12454.

* SDR = Standard dimension ratio (Actual OD/Minimum Wall Thickness), SCH = Schedule

† RHCP = Resistance to hydraulic collapse pressure (per ASTM F480, Appendix X.2) based on PVC Cell Class 12454 per ASTM D1784. (NOTE: Collapse strength may be reduced by temperature rise during grouting.)

SECTION K.2: COLLAPSING STRENGTH, OR HYDRAULIC COLLAPSE PRESSURE, VALUES

The values for *collapsing strength*, or *hydraulic collapse pressure*, set forth in Table K.1 were determined by the following equation:*

$$P_e^2 - P_e\left\{\frac{2S}{\left(\frac{D_o}{t}-1\right)} + P_{cr}\left[1 + 3e\left(\frac{D_o}{t}-1\right)\right]\right\} + \left[\frac{2SP_{cr}}{\left(\frac{D_o}{r}-1\right)}\right] = 0 \quad \text{(Eq K.1)}$$

Where:

P_e = collapse pressure with ellipticity, in psi (MPa)

e = casing ellipticity = 1 percent

S = yield strength = 35,000 psi (241.3 MPa)

D_o = casing outside diameter, in in. (mm)

t = casing wall thickness, in in. (mm)

P_{cr} = theoretical collapse strength of a perfectly round tube

$$P_{cr} = \left(\frac{2E}{1-u^2}\right)\left[\frac{1}{\left(\frac{D_o}{t}-1\right)}\right]^3$$

Where:

E = Young's modulus = 30×10^6 psi (206,800 MPa)

u = Poisson's ratio = 0.3

The values for *collapsing strength* for two-ply steel well casing set forth in Table K.3 were determined from the following formula:†

$$P = \frac{0.65(62{,}600{,}000)}{\left(\frac{D}{T}\right)\left(\frac{D}{T}-1\right)^2} \quad \text{(Eq K.2)}$$

* Timoshenko, S.P., and J.M. Gere. *Theory of Elastic Stability* (p. 296, equation e), New York: McGraw-Hill (1961).

† Cates, W.H. *Water Well Casing Manual*, Consolidated Western Steel—Division of United States Steel Corporation (1955).

Where:

P = collapsing pressure, in psi (MPa)

D = nominal diameter, in in. (mm)

$T = \sqrt{t_1^2 + t_2^2}$

Where:

t_1 = wall thickness of inside casing (one-half casing wall thickness from Table K.3), in in. (mm)

t_2 = wall thickness of outside casing (one-half casing wall thickness from Table K.3), in in. (mm)

CAUTION: Equation K.2 has been empirically derived. Its validity has been established over many years by comparison with the results of test and field failure observations. Please note that this formula does not contain any safety factor. As a result, the values for collapsing strength in Table K.3 are indicative of the value at which actual failure can be expected.

SECTION K.3: CASING TENSILE STRENGTH VALUES

The values for casing tensile strength set forth in Table K.2 were determined by the following equation:

$$C_{ts} = \frac{\pi t S_t (D_o - t)}{2{,}000} \qquad \text{(Eq K.3)}$$

Where:

C_{ts} = casing tensile strength, in tons (kg)

t = casing wall thickness, in in. (mm)

S_t = tensile strength of material, 60,000 psi (413.7 MPa)

D_o = casing outside diameter, in in. (mm)

SECTION K.4: CASING AXIAL COMPRESSIVE STRENGTH VALUES

The values for casing axial compressive strength for single-ply steel casing in Table K.2 were determined by the following equation:

$$C_{as} = \frac{\pi t S_{yp}(D_o - t)}{2{,}000} \quad \text{(Eq K.4)}$$

Where:

C_{as} = casing axial compressive strength, in tons (kg)

t = casing wall thickness, in in. (mm)

S_{yp} = material yield strength, 35,000 psi (241.3 MPa)

D_o = casing outside diameter, in in. (mm)

The values for axial compressive strength set forth in Table K.3 for two-ply steel casing were determined from Eq K.5 as follows:

$$P = \frac{\pi t S_{yp}(D_i - t)}{2{,}000} \quad \text{(Eq K.5)}$$

Where:

P = compressive strength, in tons (kg)

t = single-ply thickness (one-half of casing wall thickness from Table K.3), in in. (mm) (assumes that load bears on inside shell only)

S_{yp} = minimum yield strength of two-ply casing steel = 55,000 psi (379.2 MPa)

D_i = inside diameter of casing, in in. (mm)

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APPENDIX L

Screen Length and Entrance Velocities

This appendix is for information only and is not a part of ANSI/AWWA A100.

SECTION L.1: GENERAL

As discussed in Section II.A of the foreword to this standard, the common practice historically used for sizing well-screen length and diameter was based on screen open area and entrance velocity through the screen slots. Accordingly, previous editions of the standard used this approach for determining the recommended minimum screen length. However, the recommended upper limit for the entrance velocity has varied considerably among designers. One commonly reported design recommendation limited well-screen entrance velocities to not exceed 0.1 ft/sec (0.03 m/sec). Others have advocated velocities on an order of magnitude larger or more, and the most recent edition of the standard recommended an upper limit of 1.5 ft/sec (0.46 m/sec). As demonstrated in Section L.3 below, the broad ranges of these entrance velocities and screen open areas, where used as the sole design approach, can result in large variations in recommended well-screen length. These examples are presented merely as guidelines and not as rigorous design standards.

SECTION L.2: THEORETICAL RELATIONSHIPS

The flow through well screens is quantified by the continuity equation:

$$Q = A \times V_e \qquad \text{(Eq L.1)}$$

Where:

Q = Discharge of the well, L^3/T

A = Open area of the screen through which flow occurs, L^2

V_e = Entrance velocity through the screen open area, L/T

NOTE: Units are shown in general dimensions of length (L) and time (T).

The open area of the well screen through which flow occurs can be further defined:

$$A = \frac{(A_p \times A_b \times \pi \times D \times L)}{12} \qquad \text{(Eq L.2)}$$

Where:

A = Open area of the well screen through which flow occurs, ft^2

A_p = Percentage open area of screen as per manufacturer, decimal fraction

A_b = Percent blockage of well-screen open area, decimal fraction

D = Outside diameter of well screen, in.

L = Design length of well screen, ft

The design length of the well screen can be further defined:

$$L = \frac{(12 \times Q)}{(\pi \times D \times q_{uc})} \qquad \text{(Eq L.3)}$$

Where:

Q = Discharge of the well (gpm)

q_{uc} = Unit capacity of the face of the well screen
60 × 7.48 × A_p × A_b × V_e, gpm/ft^2

V_e = Screen entrance velocity, ft/sec

Combining the above two equations:

$$L = Q / (117.5 \times D \times A_p \times A_b \times V_e) \qquad \text{(Eq L.4)}$$

SECTION L.3: DESIGN EXAMPLES

Consider the variation of minimum screen length for an 18-in. (0.45-m) diameter well producing 2,000 gpm (126 L/sec), using a common range of screen open area and entrance velocity.

Example 1: 40 percent open area and entrance velocity = 0.1 ft/sec

Design discharge rate of well (Q), gpm:	2,000
OD of well screen (D), in.:	18
Percentage open area of well screen (A_p):	0.40
Percentage blockage of well screen (A_b):	0.50
Unit capacity of screen face (q_{uc}), gpm/ft^2:	9.0
Screen entrance velocity (V_e), ft/sec:	0.1
Design length of well screen (L), ft:	47

Example 2: 40 percent open area and entrance velocity = 1.5 ft/sec

Design discharge rate of well (Q), gpm:	2,000
OD of well screen (D), in.:	18
Percentage open area of well screen (A_p):	0.40
Percentage blockage of well screen (A_b):	0.50
Unit capacity of screen face (q_{uc}), gpm/ft^2:	135
Screen entrance velocity (V_e), ft/sec:	1.5
Design length of well screen (L), ft:	3

Example 3: 3 percent open area and entrance velocity = 0.1 ft/sec

Design discharge rate of well (Q), gpm:	2,000
OD of well screen (D), in.:	18
Percentage open area of well screen (A_p):	0.03
Percentage blockage of well screen (A_b):	0.50
Unit capacity of screen face (q_{uc}), gpm/ft^2:	0.7
Screen entrance velocity (V_e), ft/sec:	0.1
Design length of well screen (L), ft:	630

Example 4: 3 percent open area and entrance velocity = 1.5 ft/sec

Design discharge rate of well (Q), gpm:	2,000
OD of well screen (D), in.:	18
Percentage open area of well screen (A_p):	0.03
Percentage blockage of well screen (A_b):	0.50
Unit capacity of screen face (q_{uc}), gpm/ft^2:	10.0
Screen entrance velocity (V_e), ft/sec:	1.5
Design length of well screen (L), ft:	42

As can be seen in the previous examples, the design length of well screen may vary widely, depending on the percentage of open area of the screen slots and the selected design screen entrance velocity. Selection of the appropriate screen length and position would undoubtedly need to consider aquifer thickness and stratigraphic layering, in conjunction with the calculations. However, two of the calculated screen lengths, 3 ft and 630 ft (in Examples 2 and 3), are relatively extreme and would likely not be used in common practice.

The other two lengths, 47 ft and 42 ft, agree reasonably well despite substantial differences in screen open area and entrance velocity. In both of these latter cases, the unit capacity of the screen surface area is relatively similar, 9 and 10 gpm/ft^2, respectively, regardless of screen open area or entrance velocity. This relative agreement corresponds to a similar flow velocity (specific discharge) through the filter and aquifer surrounding the well, as flow approaches the screen face. To the extent that this specific discharge (q_{uc}) can be derived with respect to aquifer permeability, hydraulic gradient, Reynolds number (tendency for turbulence), or other design considerations, supplemental criteria for well design can be established as part of the design process.

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