



**American Water Works
Association**

The Authoritative Resource on Safe WaterSM

ANSI/AWWA C403-05
(Revision of ANSI/AWWA C403-00)

AWWA Standard

The Selection of Asbestos– Cement Transmission Pipe, Sizes 18 In. Through 42 In. (450 mm Through 1,050 mm), for Water Supply Service



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WITHDRAWN

Contents

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

SEC.	PAGE	SEC.	PAGE
Foreword		4.7	Design Criteria and Use of Pipe Selection Charts 29
I	Introduction..... ix	4.8	Type of Pipe 53
I.A	Background..... ix	5	Verification 56
I.B	History..... ix	6	Delivery 56
I.C	Acceptance xi	Appendixes	
II	Special Issues..... xii	A	Friction Loss of Head Chart— Coefficient of Flow, $C=140$ 57
III	Use of This Standard xiii	B	Surge Pressure Analysis
III.A	Purchaser Options and Alternatives..... xiii	B.1	Water Hammer or Surge 59
III.B	Modification to Standard..... xiii	B.2	Water Hammer Analysis..... 60
IV	Major Revisions xiii	B.3	Valve Closure..... 61
V	Comments xiv	B.4	Pumped Systems..... 64
Standard		B.5	Methods of Control..... 65
1	General	B.6	Surge Calculation Example 67
1.1	Scope 1	B.7	Air in Pipelines 68
1.2	Purpose 2	C	Frictional Power Requirements 71
1.3	Application 2	Figures	
2	References 2	1	Classes of Bedding for Conduits in Trench 8
3	Definitions, Symbols, and Abbreviations 3	2	Load Pressure Curve 10
4	Requirements	3	Assembly for Three-edge, V-Shaped Crushing Strength Test 10
4.1	Permeation..... 6	4	Classification of Construction Techniques..... 12
4.2	Pressure Classes..... 6		
4.3	Installation 7		
4.4	General Design 7		
4.5	External Loads 11		
4.6	Hydrostatic Pressure 28		

SEC.	PAGE	SEC.	PAGE
5	Values of C_d for Trench Conditions 13	14G	Combined Loading Curves for 33-In. Transmission Pipe 36
6	Embankment Conditions..... 18	14H	Combined Loading Curves for 36-In. Transmission Pipe 37
7	Value of C_c for Positive Projecting Pipe..... 18	14I	Combined Loading Curves for 39-In. Transmission Pipe 38
8	Values of B_d/B_c at Which the Trench and Positive Projecting Pipe Equations Give Equal Loads..... 20	14J	Combined Loading Curves for 42-In. Transmission Pipe 39
9	Values of C_n for Negative Projecting Pipe and Imperfect Ditch Conditions 21	14A(m)	Combined Loading Curves for 450-mm Transmission Pipe..... 40
10A	Positive Projecting Pipe Projection Ratio $p = x/B_c$ 21	14B(m)	Combined Loading Curves for 500-mm Transmission Pipe..... 41
10B	Negative Projecting Pipe Projection Ratio $p' = x/B_d$ 21	14C(m)	Combined Loading Curves for 525-mm Transmission Pipe..... 42
11	Projection Ratio p' for the Imperfect Trench Embankment Condition..... 22	14D(m)	Combined Loading Curves for 600-mm Transmission Pipe..... 43
12	Values of C_T for Tunnel Conditions 24	14E(m)	Combined Loading Curves for 675-mm Transmission Pipe..... 44
13	Superimposed Loads 25	14F(m)	Combined Loading Curves for 750-mm Transmission Pipe..... 45
14A	Combined Loading Curves for 18-In. Transmission Pipe 30	14G(m)	Combined Loading Curves for 825-mm Transmission Pipe..... 46
14B	Combined Loading Curves for 20-In. Transmission Pipe 31	14H(m)	Combined Loading Curves for 900-mm Transmission Pipe..... 47
14C	Combined Loading Curves for 21-In. Transmission Pipe 32	14I(m)	Combined Loading Curves for 975-mm Transmission Pipe..... 48
14D	Combined Loading Curves for 24-In. Transmission Pipe 33	14J(m)	Combined Loading Curves for 1,050-mm Transmission Pipe... 49
14E	Combined Loading Curves for 27-In. Transmission Pipe 34	A.1	Friction Loss of Head Chart— Coefficient of Flow, $C = 140$ 57
14F	Combined Loading Curves for 30-In. Transmission Pipe 35	B.1	Time (T_E) = Effective for Full Cutoff Uniformly at Maximum Rate 62
		C.1	Yearly Power Cost to Compensate for Friction Loss of Head 72

SEC.	PAGE	SEC.	PAGE
<i>Tables</i>		7	Minimum Safety Factors for Use With Asbestos–Cement Transmission Pipe Selection..... 51
1	Earth Loads (lb/lin ft)..... 14	8	Asbestos–Cement Pipe Type Recommended for Internal Water Aggressiveness..... 53
2	Recommended Safe Design Values of c for Tunnel Conditions 23	9	Aggressiveness of Nonsulfate Acidic Soils to Asbestos–Cement Pipe 54
3	Concentrated Superimposed Wheel Load W_{sc} (measured in lb/ft [kN/m]) on Asbestos–Cement Transmission Pipe—Single Wheel = 16,000 lb (7,250 kg) 26	10	Chemical Resistance of Asbestos– Cement Pipe to Nonacid (pH ≥ 7.0) Soluble Sulfates in Water and Soils..... 54
4	Values of Load Coefficients C_s 27	11	Sulfate Aggressiveness in Water and Soil..... 55
5	Impact Factors F 28	C.1	Present Worth of an Income of \$1.00 Per Year for the Next N Years 73
6	Design Internal Pressure and Design External Load Intercepts for Use With Selection Curves for Transmission Pipe 50		

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Foreword

This foreword is for information only and is not a part of ANSI/AWWA C403.

I. Introduction.

I.A. *Background.* Asbestos–cement pipe was originally introduced into the North American market in 1931. At that time, asbestos cement (an intimate mixture of Portland cement and asbestos fibers) was a relatively new pipe material. Experience with asbestos–cement pipe was limited to only a few years at installations in several European countries, particularly Italy. During the years following its North American introduction, a record of successful experience was established in the United States and other North American countries. In 1949, AWWA established a standards committee to develop a standard for asbestos–cement pressure pipe.

I.B. *History.* The original AWWA committee developed a standard for asbestos–cement water pipe, designated AWWA C400-53T, Tentative Standard for Asbestos–Cement Water Pipe, which was approved by the AWWA Board of Directors as tentative on May 15, 1953. In 1958, the committee was reactivated as Committee 8340D on Asbestos–Cement Pipe. This committee produced a revised tentative standard adopted by AWWA as AWWA C400-64T, Tentative Standard for Asbestos–Cement Pipe, on Jan. 27, 1964. This edition was advanced to standard without revision under the designation AWWA C400-65, Standard for Asbestos–Cement Water Pipe, on July 2, 1965.

The committee concluded that an installation guide was desirable to advise pipe users of certain important requirements of the inspection, handling, installation, and field-testing of asbestos–cement pressure pipe. The committee submitted its final draft in 1963, and it received approval as tentative, AWWA C603-64T, on Jan. 27, 1964. It was advanced to standard without revision on Aug. 9, 1965, and designated as AWWA C603-65.

In 1968, the committee was reactivated as the Standards Committee on Asbestos–Cement Pipe to review and revise all AWWA standards on asbestos–cement pipe. The committee produced a revised standard designated as AWWA C400-72, Standard for Asbestos–Cement Pressure Pipe for Water and Other Liquids, which was approved on Jan. 31, 1972.

AWWA C401-64, Standard Practice for the Selection of Asbestos–Cement Water Pipe (originally designated AWWA Handbook H2), was first approved by the

AWWA Board of Directors on Jan. 27, 1964. Although it described pipe sizes up to and including 36 in. (900 mm), the standard was primarily intended for use with asbestos–cement pipe in smaller distribution sizes (4 in. through 16 in. [100 mm through 400 mm]).

During 1972 and 1973, the committee was reorganized and enlarged to include representatives of national organizations interested in the scope of the committee and wanting to participate in the work. The reorganized committee reaffirmed AWWA C400-72 without revision so that it could be presented to the American National Standards Institute for designation as an American National Standard. The reaffirmed standard was published as AWWA C400-73 under the same title.

In 1975, the committee produced a revised standard designated AWWA C400-75, Standard for Asbestos–Cement Pressure Pipe, 4 In. Through 24 In., for Water and Other Liquids, which was approved on Jan. 26, 1975.

The asbestos–cement pipe manufacturers developed a new series of large pipe classifications designed to give greater freedom of selection to design engineers. This was of particular significance for large-diameter pipeline projects where the savings in material cost can exceed the increased cost resulting from more detailed design, better control of methods of installation, and provision of surge controls, when justified.

To provide the user with a ready reference and specification for this type of pipe, known as transmission pipe, the committee also produced the first edition of AWWA C402-75, Standard for Asbestos–Cement Transmission Pipe, 18 In. Through 42 In., for Water and Other Liquids, which was approved on Jan. 26, 1975.

The possibility of confusion between the two 1975 standards, AWWA C400 and AWWA C402, was carefully reviewed by the committee. The results were AWWA C402-77, which describes sizes 18 in. through 42 in. (450 mm through 1,050 mm), and AWWA C400-77, which describes sizes 4 in. through 16 in. (100 mm through 400 mm). There is now no overlap of sizes.

Consequently, it was desirable to revise AWWA C401-64 so that it would be compatible with AWWA C400-77 and to develop a new pipe selection standard to be compatible with AWWA C402-77. AWWA C401-77, Standard Practice for the Selection of Asbestos–Cement Distribution Pipe, 4 In. Through 16 In., for Water and Other Liquids, and ANSI/AWWA C403-78, Standard Practice for the Selection of Asbestos–Cement Transmission and Feeder Main Pipe, Sizes 18 In. Through 42 In., were approved in May 1977 and January 1978, respectively. The 1978 edition of ANSI/AWWA C403 was revised to include the three-edge, vee-shaped bearing method

for crush testing, revision of bedding condition descriptions and load factors used in calculating earth loads to correspond with those contained in ASCE Manual of Practice 37, *Design and Construction of Sanitary and Storm Sewers*,^{*} and revision of the crush values for pipe. That revision was approved by the AWWA Board of Directors on Jan. 30, 1984, and designated AWWA C403-84. The third revision of this standard was approved by the Board of Directors on Jan. 29, 1989. The fourth edition was approved by the AWWA Board of Directors on June 17, 1995. The fifth edition was approved by the AWWA Board of Directors on Jan. 23, 2000. This sixth edition was approved by the AWWA Board of Directors on Jan. 16, 2005.

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

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

1. An advisory program formerly administered by USEPA, Office of Drinking Water, discontinued on Apr. 7, 1990.
2. Specific policies of the state or local agency.
3. Two standards developed under the direction of NSF, NSF[‡]/ANSI[§] 60, Drinking Water Treatment Chemicals—Health Effects, and NSF/ANSI 61, Drinking Water System Components—Health Effects.

^{*}Available from American Society of Civil Engineers, 1801 Alexander Bell Dr., Reston, VA 20191.

[†]Persons outside the US should contact the appropriate authority having jurisdiction.

[‡]NSF International, 789 N. Dixboro Rd., Ann Arbor, MI 48105.

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

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

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

Annex A, “Toxicology Review and Evaluation Procedures,” to NSF/ANSI 61 does not stipulate a maximum allowable level (MAL) of a contaminant for substances not regulated by a USEPA final maximum contaminant level (MCL). The MALs of an unspecified list of “unregulated contaminants” are based on toxicity testing guidelines (noncarcinogens) and risk characterization methodology (carcinogens). Use of Annex A procedures may not always be identical, depending on the certifier.

ANSI/AWWA C403 does not address additives requirements. Thus, users of this standard should consult the appropriate state or local agency having jurisdiction in order to

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

II. Special Issues.

This standard provides for pipe sizes ranging from 18 in. (450 mm) through 42 in. (1,050 mm). The purpose of this standard is to provide guidance in the selection of asbestos–cement pressure pipe, manufactured in accordance with ANSI/AWWA C402 and installed in accordance with ANSI/AWWA C603. In addition to the physical strength parameters addressed in the standard, it is recommended that the user collect site-specific data on water chemistry both for the internal water to be carried by the pipe and external groundwater conditions, and the chemistry of the soil in which the pipe is to be installed. Criteria for various water and soil chemistry parameters that affect asbestos–cement pipe are discussed.

Occupational Safety and Health Administration (OSHA) standards for workplace exposure to airborne asbestos particles should be reviewed by the purchaser for

^{*}Both publications available from National Academy of Sciences, 500 Fifth St., N.W., Washington, DC 20001.

regulatory requirements related to the protection of workers engaged in the handling and installation of asbestos–cement pipe. The current standard makes the employer responsible for ensuring that employee exposures to airborne asbestos fiber concentrations do not exceed stringent exposure limits. The OSHA construction standard on asbestos, 29 CFR 1926, prescribes initial air monitoring and other compliance measures. The OSHA requirements apply to the manufacture, shipping, handling, installation, and repair of asbestos–cement pipe and appurtenances. It is recommended that users and prospective users of asbestos–cement pipe familiarize themselves with the current OSHA asbestos work practice standards.

The AWWA handbook *Work Practices for Asbestos-Cement Pipe* (1995) was developed to assist in the compliance with United States federal asbestos workplace standards when shipping, receiving, handling, and assembling asbestos-cement pipe. These recommended work practices were designed to achieve safe jobsite conditions when working with asbestos-cement pipe.

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

III.A. Purchaser Options and Alternatives. The following items should be included in the purchaser's specifications:

1. The standard used—that is, ANSI/AWWA C403, Standard for the Selection of Asbestos–Cement Transmission Pipe, Sizes 18 In. Through 42 In. (450 mm Through 1,050 mm), for Water Supply Service, of latest revision.

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

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

1. Information on determining the type of pipe to be used under various soil and water conditions has been moved from Sec. II of the Foreword to the body of the standard (Sec. 4.8). The Scope of the standard has been updated to reflect this change (Sec. 1.1).

2. Class C bedding with shaped bottom and Class D bedding have been removed, so as to show only the recommended bedding conditions (Sec. 4.4.1 and Figure 1).

V. Comments. If you have any comments or questions about this standard, please call the AWWA Volunteer and Technical Support Group at (303) 794-7711, FAX (303) 795-7603, or write to the group at 6666 West Quincy Avenue, Denver, CO 80235-3098, or e-mail at standards@awwa.org.

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AWWA Standard

The Selection of Asbestos–Cement Transmission Pipe, Sizes 18 In. Through 42 In. (450 mm Through 1,050 mm), for Water Supply Service

SECTION 1: GENERAL

Sec. 1.1 Scope

This standard has been prepared so that design engineers may determine the correct pressure classification of asbestos–cement transmission pipe to use under various combinations of internal pressure (static, operating, and surge) and external load (earth and superimposed live loads). Combined loading curves depicting the relationship between hydrostatic loading and external loading capabilities are included to expedite the selection of the correct pipe strength classification. This standard also presents criteria for determining the type of pipe to be used under various soil and water conditions.

NOTE: Information to assist the engineer in selecting the most economical size of pipe is in the appendixes. Appendix A contains a friction loss of head chart based on the Hazen and Williams formula. Appendix B is a detailed analysis of surge pressure factors. Appendix C includes tables to assist the engineer in determining the

yearly power costs to overcome loss of head caused by friction. The appendixes are for information only and are not a part of ANSI/AWWA C403.

Sec. 1.2 Purpose

The purpose of this standard is to provide purchasers, manufacturers, and constructors with the minimum requirements for selecting asbestos–cement transmission pipe, sizes 18 in. through 42 in. (450 mm through 1,050 mm), for water supply service, including design, design criteria, and loads.

Sec. 1.3 Application

This standard can be referenced in specifications for purchasing and receiving asbestos–cement transmission pipe. This standard can be used as a guide for selecting this type of pipe. The stipulations of this standard apply when this document has been referenced and only to asbestos–cement transmission pipe, 18 in. through 42 in. (450 mm through 1,050 mm).

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.

AASHTO^{*} T-99—Standard Methods of Test for the Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5-lb (2.49 kg) Rammer and 12-in. (304.8 mm) Drop.

ANSI[†]/AWWA C401—The Selection of Asbestos–Cement Pressure Pipe, 4 In. Through 16 In. (100 mm Through 400 mm), for Water Distribution Systems.

ANSI/AWWA C402—Asbestos–Cement Transmission Pipe, 18 In. Through 42 In. (450 mm Through 1,050 mm), for Water Supply Service.

ANSI/AWWA C603—Installation of Asbestos–Cement Pressure Pipe.

ASTM[‡] C500—Standard Test Methods for Asbestos–Cement Pipe.

^{*}American Association of State Highway and Transportation Officials, 444 North Capital St., N.W., Ste. 249, Washington, DC 20001.

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

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

ASTM D698—Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft³ [600 kN-m/m³]).

ASTM D4253—Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table.

ASTM D4254—Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density.

1969. *Design and Construction of Sanitary and Storm Sewers*. Manual of Engineering Practices No. 37, American Society of Civil Engineers.*

Kerr, S.L. 1948. Practical Aspects of Water Hammer. *Journal AWWA*, 40:6:599.

Marston, A. 1930. The Theory of External Loads on Closed Conduits in the Light of Latest Experiments. Bull. 96. Ames, Iowa: Iowa State College of Engineering, Experimental Station.†

Schlick, W.J. 1940. Supporting Strengths for Cast-Iron Pipe for Water and Gas Service. Bull. 146. Ames, Iowa: Iowa State College of Engineering, Experimental Station.

SECTION 3: DEFINITIONS, SYMBOLS, AND ABBREVIATIONS

The following definitions, symbols, and abbreviations shall apply in this standard:

B_c = outside diameter of a pipe, in feet (meters).

B_d = width of trench measured at the top of pipe, in feet (meters).

BF = bedding factor, which is a load factor correlating three-edge, V-shaped bearing test loads to field loads associated with specific bedding conditions.

B_T = maximum width of a tunnel excavation, in feet (meters).

c = coefficient of soil cohesion, in pounds per square foot (kilonewtons per square meter).

C = load coefficient dependent upon construction conditions in Marston's equation.

*American Society of Civil Engineers, 1801 Alexander Bell Dr., Reston, VA 20191.

†College of Engineering, 104 Marston Hall, Iowa State University, Ames, IA 50011.

- C_c = load coefficient for the positive projecting embankment condition. It is a function of the ratio H/B_c , the projection ratio p , and the settlement ratio r_{sd} .
- C_d = load coefficient for the trench condition. It is a function of the ratio H/B_d and the backfill material.
- C_n = load coefficient for the negative projecting embankment condition, as well as the imperfect trench condition. It is a function of the ratio H/B_d , projection ratio p' , and the settlement ratio r_{sd} .
- C_s = load coefficient for concentrated or distributed superimposed loads. It is a function of the ratio $B_c/2H$ and the ratio $L/2H$ for concentrated loads, or the ratio $D/2H$ and the ratio $M/2H$ for distributed loads.
- C_T = load coefficient for tunnel conditions. It is a function of the ratio H/B_T and the type of soil surrounding the tunnel.
- d = inside diameter of a pipe, in feet (meters).
- D = width of the area over which the distributed superimposed load acts, in feet (meters).
- F = impact factor.
- g = acceleration of gravity.
- H = depth of cover, in feet (meters), for all conditions except the tunnel condition. For the tunnel condition, H is the distance from the ground surface to the top of the tunnel excavation, in feet (meters).
- k = Rankine's ratio of lateral earth pressure to vertical pressure.
- L = effective length of the pipe, in feet (meters). For pipe less than 3 ft (1 m), the actual length of the section should be used. For all other lengths, an effective length of 3 ft (1 m) should be used.
- M = length of the area over which the distributed superimposed load acts, in feet (meters).
- P = internal pressure, in pounds per square inch (kilopascals), that the pipe will withstand when no external load exists.
- P_c = concentrated load, in pounds (kilonewtons^{*}).
- P_d = distributed load, in pounds per square foot (kilonewtons per square meter^{*}).

^{*}NOTE: P_c and P_d are loads measured as a mass. However, to use them in equations using SI units, the mass unit must be converted to force by multiplying by 9.8062 (g, the acceleration of gravity).

P_o = static, working, or operating pressure, in pounds per square inch (kilopascals).

P_s = surge pressure or water hammer, in pounds per square inch (kilopascals).

P_T = total internal pressure, in pounds per square inch (kilopascals), above which, in combination with some external load W_T applied in three-edge, V-shaped bearing, the pipe will withstand.

p = projection ratio for the positive projecting embankment condition. It is defined as the ratio of the distance that the top of the pipe projects above the original ground surface, in feet (meters), to the outside diameter of the pipe, in feet (meters) (see Figure 10A).

p' = projection ratio for the negative projecting and imperfect trench condition. It is defined as the ratio of the vertical distance from the original ground surface down to the top of the pipe, in feet (meters), divided by the width of the trench, in feet (meters), for negative projection, and as the ratio of the vertical distance from the top of the excavated trench down to the top of the pipe, in feet (meters), divided by the diameter of the pipe, in feet (meters), for the imperfect trench condition (see Figures 10B and 11).

r_{sd} = settlement ratio for positive projection, negative projection, and imperfect trench conditions.

RSA = ratio of the area of steel to the area at the pipe invert for reinforced concrete cradle bedding or the area at the crown of the pipe for concrete arch bedding.

SF = safety factor.

μ = coefficient of internal friction of backfill material.

μ' = coefficient of friction between backfill material and the trench wall.

W = external load, in pounds per linear foot (kilonewtons per linear meter) of pipe, in the three-edge, V-shaped bearing test that the pipe will withstand when no hydrostatic pressure exists.

W_E = total earth load, in pounds per linear foot (kilonewtons per linear meter), to which the pipe is subjected.

W_s = total superimposed load, in pounds per linear foot (kilonewtons per linear meter) of pipe, transmitted through the burial environment to the pipe by factors other than the earth loads.

W_{sc} = concentrated superimposed load, in pounds per linear foot (kilonewtons per linear meter) of pipe, transmitted through the burial environment to the pipe by factors other than the earth loads.

W_{sd} = distributed superimposed load, in pounds per linear foot (kilonewtons per linear meter) of pipe, transmitted through the burial environment to the pipe by factors other than the earth loads.

W_T = total external load, in pounds per linear foot (kilonewtons per linear meter) of pipe, applied in three-edge, V-shaped bearing above which, in combination with some internal pressure P_T , the pipe will withstand.

w_e = weight of earth, in pounds per cubic foot (kilonewtons per cubic meter^{*}).

SECTION 4: REQUIREMENTS

Sec. 4.1 Permeation

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

Sec. 4.2 Pressure Classes

The pipe strength classifications of 30, 35, 40, 45, 50, 60, 70, 80, and 90 refer to the similarly numbered classes specified in ANSI/AWWA C402.

^{*}Density, as used in the equations in this standard, refers to force exerted per unit volume under the acceleration of gravity, rather than mass per unit volume. Where true density is known in pounds per cubic foot, that value should be used in equations using US customary units; where true density is known in kilograms per cubic meter, it must be converted to newtons per cubic meter by multiplying by 9.8062 (g, the acceleration of gravity) before the value is used in equations using SI units.

Sec. 4.3 Installation

Detailed coverage of the installation of asbestos-cement pipe can be found in ANSI/AWWA C603.

Sec. 4.4 General Design

4.4.1 *Strength and design factors.* The strength of asbestos-cement transmission pipe must be sufficient to withstand the combined forces of all types of internal pressures (static, operating, and surge) and external loadings (earth, live, and impact). Sound engineering practice also requires that adequate safety factors be applied to strength requirements to ensure performance under other than ideal or calculated loading conditions. The magnitude of these safety factors is inversely proportional to the confidence that the designer has in engineering estimates of actual operating conditions. Safety factors are included in Sec. 4.7.2.

4.4.1.1 Bedding conditions. The bedding conditions described below and shown in Figure 1 have been selected as representative of typical installation conditions encountered in the field.

4.4.1.1.1 Class A—concrete cradle or concrete arch bedding. This class of bedding may take either of the following two forms:

a. Concrete cradle. The pipe shall be bedded in a monolithic cradle of plain or reinforced concrete having a minimum thickness of one-fourth the inside pipe diameter (minimum of 4 in. [100 mm]) under the barrel and extending up the sides for a height equal to one-fourth the outside diameter. The cradle shall have a width at least equal to the outside diameter of the pipe barrel plus 8 in. (200 mm). Backfill shall be compacted above the cradle and extending to 12 in. (300 mm) above the crown of the pipe. The load factor for class A concrete cradle bedding is 2.2 for plain concrete with lightly compacted (85 percent to 95 percent proctor or 40 percent to 70 percent relative density) backfill; 2.8 for plain concrete with carefully compacted (greater than 95 percent proctor or greater than 70 percent relative density) backfill; and 3.4 for reinforced concrete with $RSA = 0.4$ percent, in which RSA is the ratio of the contact area of steel to the area at the pipe invert.

b. Concrete arch. The pipe shall be embedded in carefully compacted granular material having a minimum thickness of one-fourth the outside pipe diameter (minimum of 4 in. [100 mm]) between barrel and bottom of trench excavation and extending halfway up the sides of the pipe. The top half of the pipe shall be covered with a monolithic plain or reinforced concrete arch having a minimum thickness of

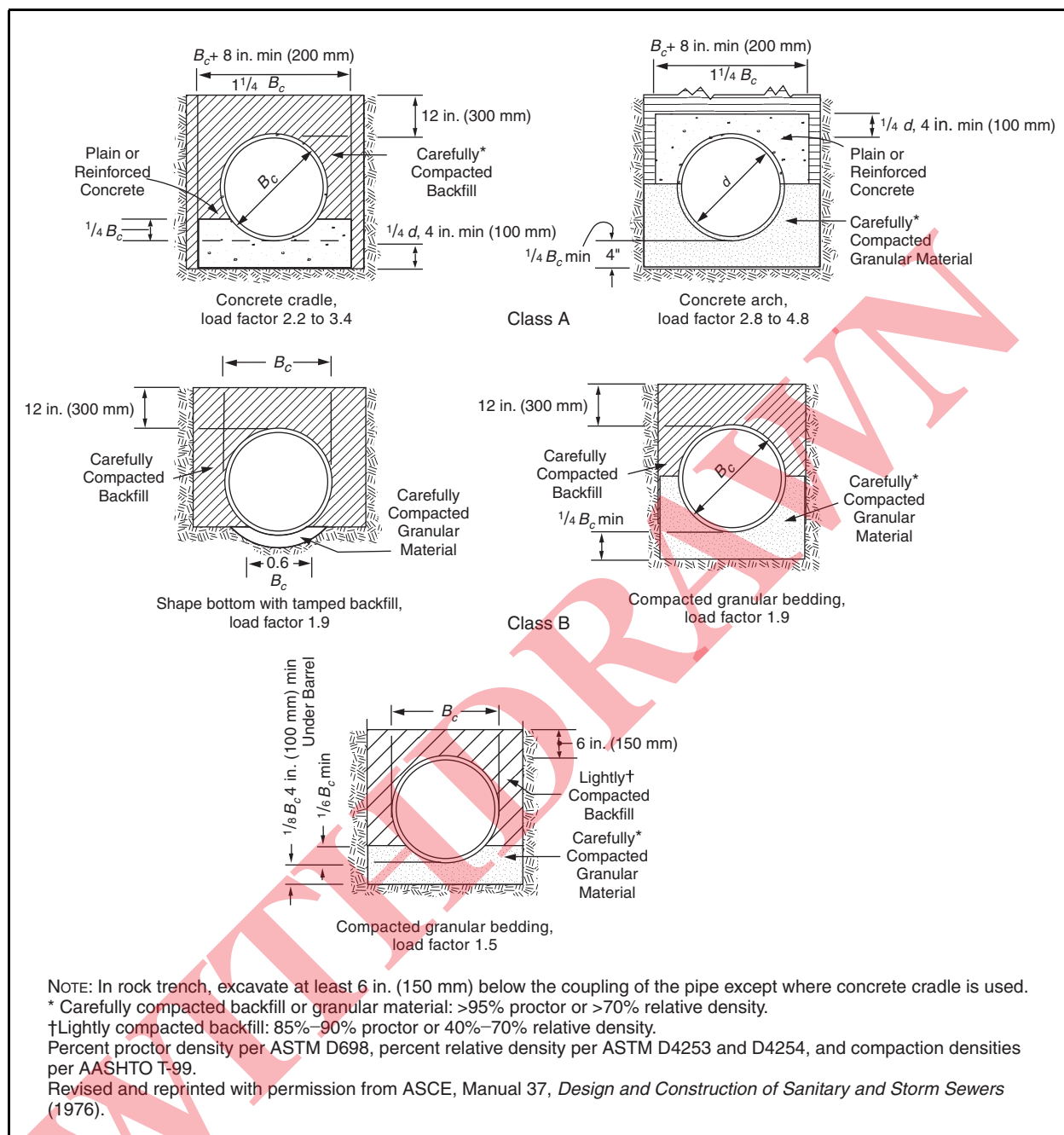


Figure 1 Classes of bedding for conduits in trench

one-fourth the inside diameter (minimum of 4 in. [100 mm]) at the crown and having a minimum width equal to the outside pipe diameter plus 8 in. (200 mm). The load factor for class A concrete arch-type bedding is 2.8 for plain concrete; up to 3.4 for reinforced concrete with RSA = 0.4 percent; and up to 4.8 for reinforced concrete with

RSA = 1.0 percent, in which RSA is the ratio of the area of steel to the area of concrete at the crown of the pipe.

4.4.1.1.2 Class B—first-class bedding. Class B bedding may be achieved by either of the following two construction methods. The load factor for either construction method is 1.9.

a. Shaped bottom with carefully compacted backfill. The bottom of the trench excavation shall be shaped to conform to a cylindrical surface with a radius at least 2 in. (50 mm) greater than the radius to the outside of the pipe and with a width sufficient to allow six tenths of the width of the pipe barrel to be bedded in fine granular fill placed in the shaped excavation. Carefully compacted backfill shall be placed at the sides of the pipe to a thickness of at least 12 in. (300 mm) above the top of the pipe. Shaped trench bottoms are difficult to achieve under current construction techniques.

b. Compacted granular bedding with carefully compacted backfill. The pipe shall be bedded in compacted granular material placed on a flat trench bottom. The granular bedding shall have a minimum thickness of one-fourth the outside pipe diameter (minimum of 4 in. [100 mm]) and shall extend halfway up the pipe barrel at the side. The remainder of the backfill to a minimum depth of 12 in. (300 mm) over the top of the pipe shall be carefully compacted material.

4.4.1.1.3 Class C—ordinary bedding. Class C ordinary bedding shall be achieved by compacted granular bedding with a lightly compacted backfill. The pipe shall be bedded in compacted granular material placed on a flat trench bottom. The granular bedding shall have a minimum thickness of one-eighth the outside pipe diameter (minimum of 4 in. [100 mm]) under the barrel and shall extend to a minimum of one sixth of the outside diameter up the pipe barrel at the sides. The remainder of the backfill and to a minimum depth of 6 in. (150 mm) over the top of the pipe shall be filled with lightly compacted backfill. The load factor for class C bedding is 1.5.

4.4.2 *Combined loading theory.* Tests of asbestos-cement pipe under various combinations of internal pressure and external crush load applied in three-edge, V-shaped bearing (see Sec. 4.4.3) indicate that there is a relationship between the combined loads at the point of pipe fracture. This relationship can be represented by a parabolic curve as shown in Figure 2. The equation for the load pressure parabolic curve, which is known as the Schlick formula, may be expressed as the following:

$$W_T = W \sqrt{\frac{P - P_T}{P}} \quad (\text{Eq 1})$$

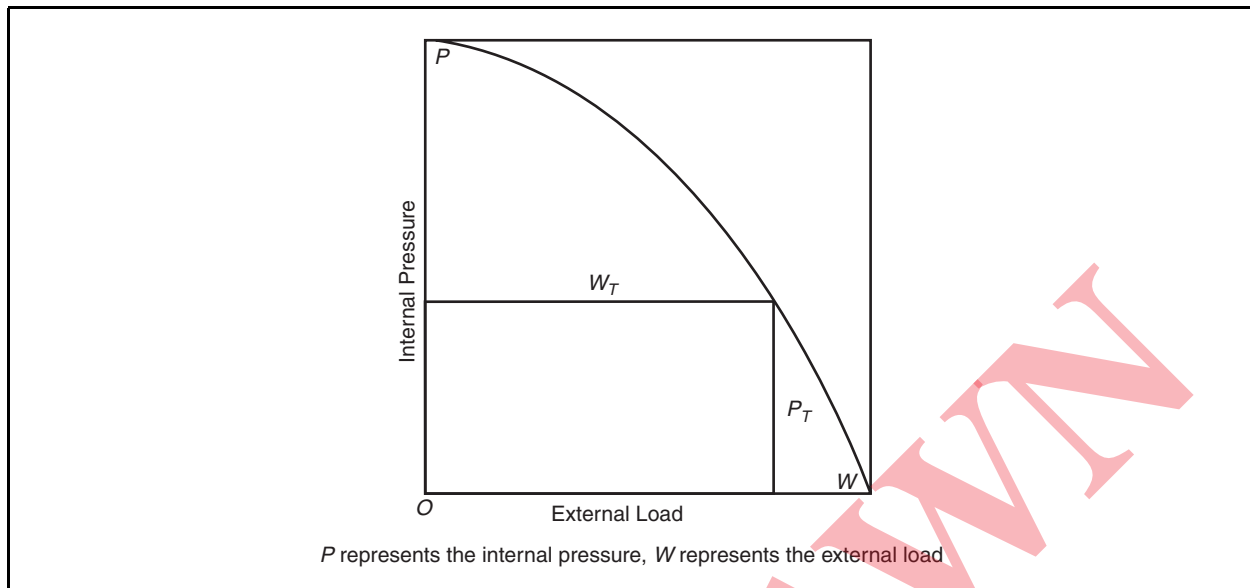


Figure 2 Load pressure curve

4.4.3 *Three-edge, V-shaped bearing load.* The combined loading curve shown in Figure 2 is calculated on the basis of crush strengths determined by laboratory tests employing the three-edge, V-shaped bearing test method (see ASTM C500 and Figure 3). Because the field-supporting strength of a pipe is influenced by the bedding conditions and by the lateral pressure acting against the sides of the pipe, it

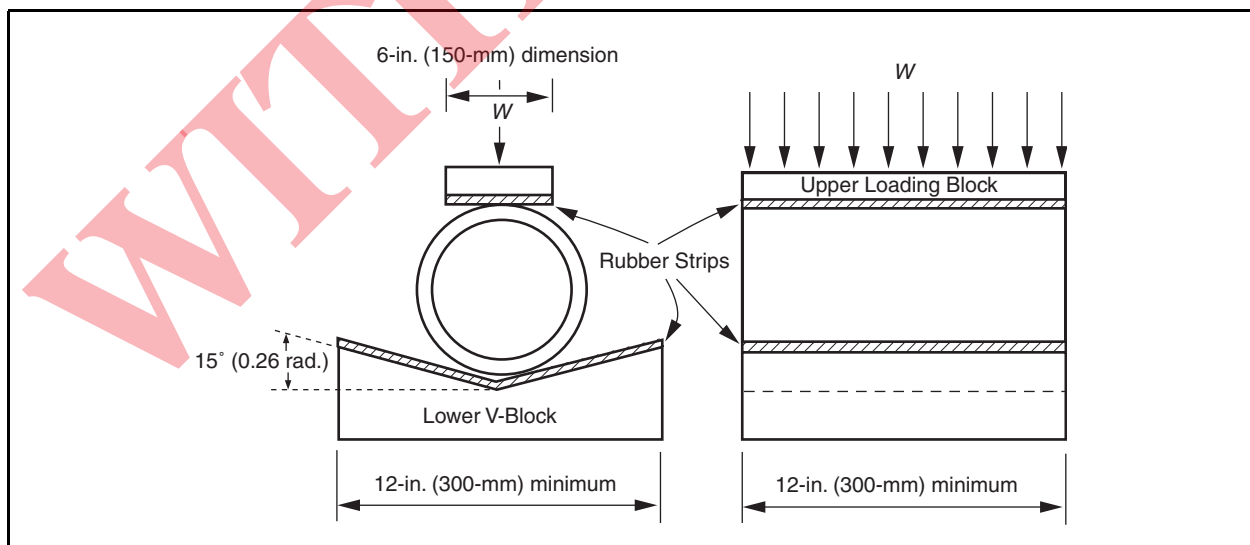


Figure 3 Assembly for three-edge, V-shaped crushing strength test

is necessary to apply a bedding load factor to the laboratory three-edge, V-shaped bearing loads to correlate them to the actual field loads. Because the external load equals the bedding factor times the V-shaped bearing load, the bedding factor equals the external load divided by the three-edge, V-shaped bearing load. Figure 1 shows the load factors to be applied for each bedding class.

Sec. 4.5 External Loads

4.5.1 *Introduction.* For the design of asbestos-cement transmission pipe, external loads W_T are defined by the following equation:

$$W_T = \frac{W_E + W_s}{(BF)} \times (SF) \quad (\text{Eq 2})$$

4.5.2 *Earth loads.* Earth loads, W_E , to which pipe is subjected, are a function of the soil density, pipe diameter, depth of cover, and construction techniques employed in laying the pipeline. They depend on the interplay between the weight of the prism of earth directly over the pipe, called the interior prism, and the frictional shearing forces, plus or minus, transferred to that interior prism by the adjacent outside prisms of earth. The magnitude of earth loads varies with the construction technique employed. There are two major construction techniques normally encountered—trench and embankment. Another technique, the tunnel condition, is not normally found but nevertheless has unique design methods that make its inclusion in this discussion necessary. Figure 4 shows these three construction techniques.

4.5.2.1 *Marston's equation.* For asbestos-cement transmission pipe design, earth loads are calculated by using the following general form of Marston's equation:*

$$W_E = CW_e(B_d)^2 \quad (\text{Eq 3})$$

Soil densities w_e range in value from 100 to 135 lb/ft³ (16 to 21 kN/m³). In the absence of actual site information, a value of 120 lb/ft³ (19 kN/m³) is recommended for asbestos-cement transmission pipe design.

*Density, as used in this equation and the following equations, actually refers to force exerted per unit volume (pounds per cubic foot or kilonewtons per meter) under the acceleration of gravity, rather than mass per unit volume. Where true density is known in pounds per cubic foot, that value should be used in equations using US customary units. Where true density is known in kilograms per cubic meter, it must be converted to newtons per cubic meter by multiplying by 9.8062 (g, the acceleration of gravity) before the value is used in equations using SI units.

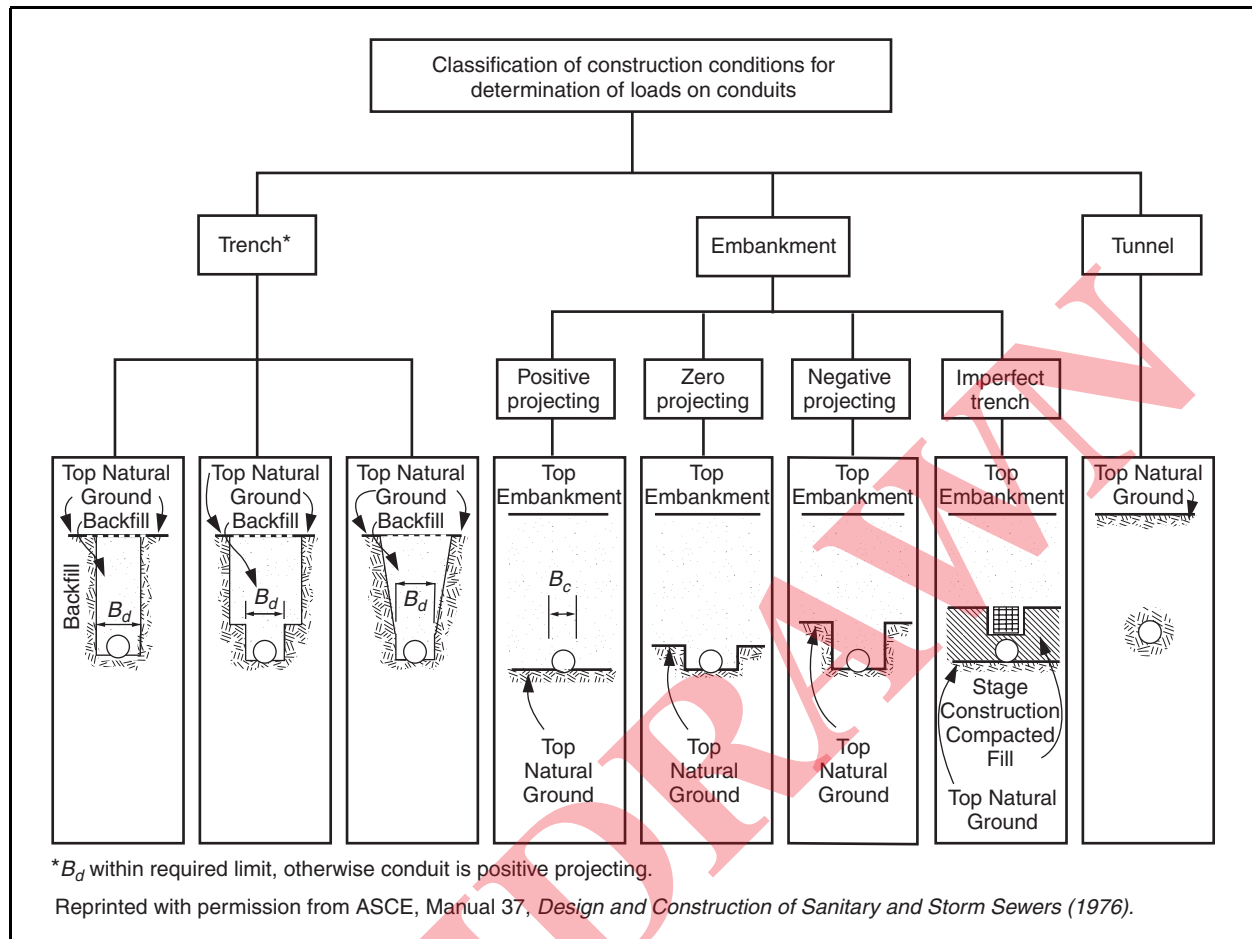


Figure 4 Classification of construction techniques

4.5.2.1.1 C is a coefficient that is dependent on the following:

1. Ratio of the height of fill to the width of trench or pipe diameter.
2. Shearing forces between the interior and adjacent earth prisms.
3. Direction and amount of relative settlement between interior and adjacent earth prisms for embankment conditions.

The calculations used to find the value of the coefficient will depend on the installation conditions employed in laying the pipe.

4.5.2.1.2 Values for B_d and C must be determined to calculate earth loads using Eq 3 for the trench, embankment, and tunnel construction techniques. The following subsections describe the different conditions and explain the methods for finding the values needed to use Marston's equation for soil loading.

4.5.2.2 Trench condition. A trench condition is defined as that in which the pipe is installed in a narrow trench, generally less than two to three diameters in

width, cut in undisturbed ground, and backfilled to the original ground surface, as illustrated in Figure 4. For this condition, Eq 3 is rewritten as the following:

$$W_E = C_d w_e (B_d)^2 \quad (\text{Eq 4})$$

4.5.2.2.1 The values of C_d are obtained from Figure 5, in which curves A, B, C, D, and E take into account the friction coefficient between the backfill and the sides of the trench for the various soil compositions likely to be encountered. Curve A is for granular materials without cohesion. Curve B is for sand and gravel. Curve C is for saturated topsoil. Curve D is for clay. Curve E is for saturated clay. Table 1 contains a series of earth-load selection tables.

4.5.2.3 Embankment condition. An embankment condition is defined as either that condition where the pipe is installed in a trench that is wider than two to

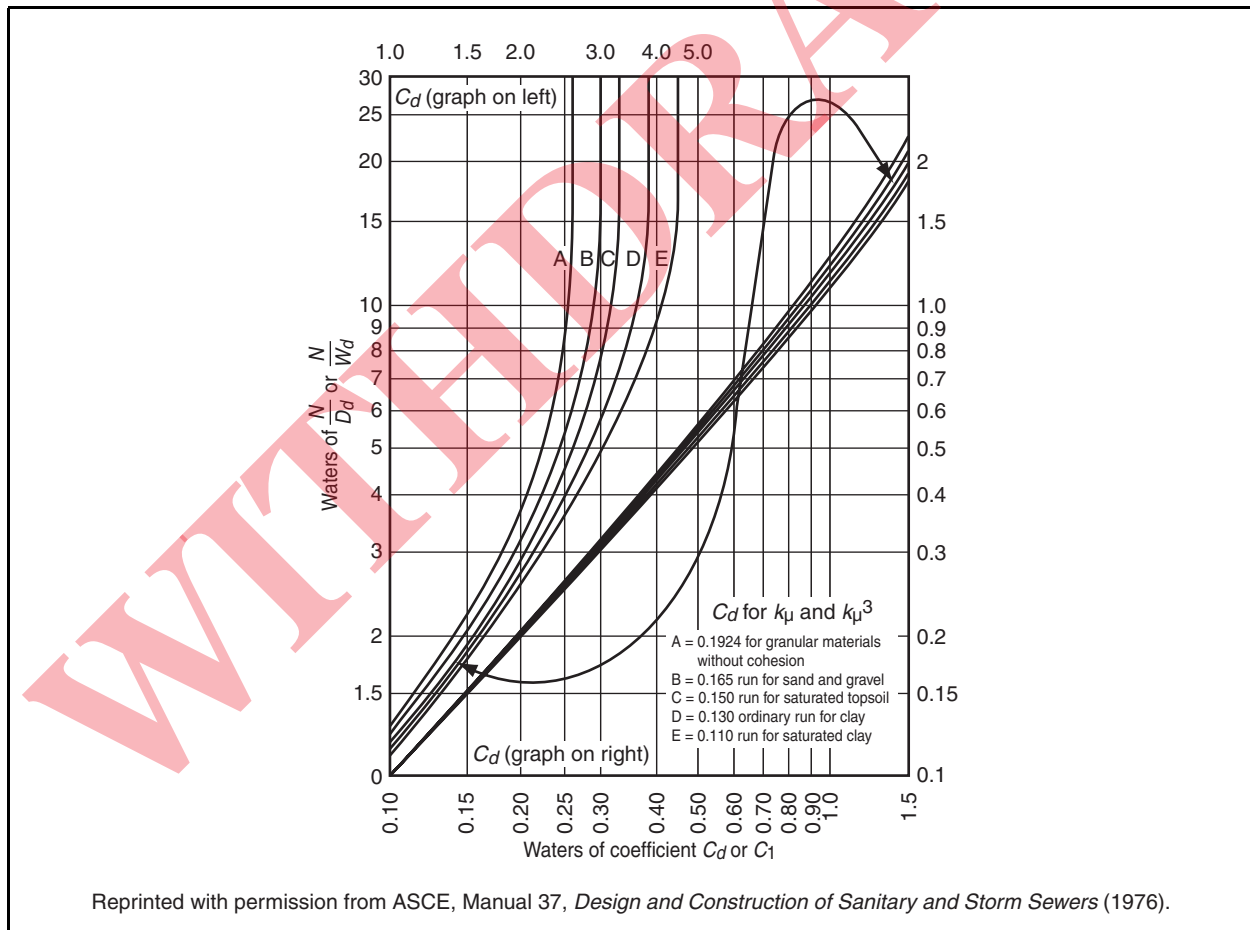


Figure 5 Values of C_d for trench conditions

Table 1 Earth loads (*lb/lin ft*)

Pipe size 18 in. ID											
Trench Cover		Trench Width, <i>ft</i>									Transition Width
<i>ft</i>	2.5	2.75	3.0	3.25	3.5	3.5	4.0	4.5	5.0	5.5	
2	490										2 ft 5 in.
2.5	640	640									2 ft 8 in.
3	810	835									2 ft 10 in.
4	1,000	1,110	1,240								3 ft 1 in.
5	1,200	1,320	1,450	1,610	1,640						3 ft 5 in.
6	1,350	1,520	1,700	1,865	2,050						3 ft 8 in.
7	1,500	1,690	1,900	2,090	2,300						3 ft 10 in.
8	1,600	1,850	2,100	2,320	2,525	2,825					4 ft 0 in.
9	1,725	2,000	2,250	2,510	2,750	3,230					4 ft 1 in.
10	1,850	2,120	2,400	2,725	2,950	3,550	3,635				4 ft 3 in.
12	2,050	2,360	2,675	3,020	3,300	4,000	4,440				4 ft 5 in.
14	2,200	2,570	2,900	3,280	3,600	4,400	5,220				4 ft 7 in.
16	2,300	2,720	3,100	3,515	3,900	4,800	5,640	6,040			4 ft 9 in.
18	2,400	2,840	3,275	4,720	4,150	5,100	6,040	6,830			5 ft 0 in.
20	2,500	3,000	3,400	4,995	4,350	5,350	6,400	7,450	7,620		5 ft 2 in.
Pipe size 20 in. ID											
Trench Cover		Trench Width, <i>ft</i>									Transition Width
<i>ft</i>	2.75	3.0	3.25	3.5	3.5	4.0	4.5	5.0	5.5		
2	545										2 ft 8 in.
2.5	705										2 ft 10 in.
3	870	890									3 ft 0 in.
4	1,110	1,250	1,330								3 ft 4 in.
5	1,320	1,450	1,610	1,750	1,770						3 ft 8 in.
6	1,520	1,700	1,865	2,050	2,210	2,220					3 ft 11 in.
7	1,690	1,900	2,090	2,300	2,515	2,655					4 ft 1 in.
8	1,850	2,100	2,320	2,525	2,765	3,000	3,095				4 ft 3 in.
9	2,000	2,250	2,510	3,750	3,040	3,300	3,545				4 ft 5 in.
10	2,120	2,400	2,725	3,950	3,240	3,650	3,980				4 ft 6 in.
12	2,380	2,675	3,020	3,300	3,660	4,000	4,660	4,310			4 ft 10 in.
14	2,570	2,900	3,280	4,600	4,050	4,400	5,200	5,760			5 ft 1 in.
16	2,720	3,100	3,515	4,900	4,350	4,800	5,640	6,450	6,640		5 ft 2 in.
18	2,840	3,275	3,720	4,150	4,620	5,100	6,040	7,060	7,500		5 ft 4 in.
20	3,000	3,400	3,995	4,350	4,860	5,350	6,400	7,450	8,410		5 ft 7 in.
Pipe size 21 in. ID											
Trench Cover		Trench Width, <i>ft</i>									Transition Width
<i>ft</i>	2.75	3.0	3.25	3.5	3.75	4.0	4.5	5.0	5.5	6.0	
2	570										2 ft 9 in.
2.5	745	730									2 ft 11 in.
3	870	915									3 ft 2 in.
4	1,110	1,250	1,330	1,380							3 ft 6 in.
5	1,320	1,450	1,610	1,750	1,360						3 ft 10 in.
6	1,520	1,700	1,865	2,050	2,210	2,325					4 ft 1 in.
7	1,690	1,900	2,090	2,300	2,515	2,700	2,795				4 ft 4 in.
8	1,850	2,100	2,320	2,525	2,765	3,000	3,250				4 ft 6 in.
9	2,000	2,250	2,510	3,750	3,040	3,300	3,725				4 ft 7 in.
10	2,120	2,400	2,725	3,950	3,240	3,550	4,140	4,210			4 ft 9 in.
12	2,360	2,675	2,020	3,300	3,660	4,000	4,660	5,160			5 ft 0 in.
14	2,570	2,900	3,280	4,600	4,050	4,400	5,200	6,000	6,100		5 ft 3 in.
16	2,720	3,100	3,515	4,900	4,350	4,800	5,540	6,450	7,020		5 ft 5 in.
18	2,340	3,275	3,720	4,150	4,620	5,100	6,040	7,050	7,950		5 ft 6 in.
20	3,000	3,400	3,995	4,350	4,880	5,350	6,400	7,450	8,460	8,920	5 ft 8 in.

NOTE: Values are for clay (part D of Figure 5, $k\mu = k\mu' = 0.130$) with weight of earth taken as 120 lb/ft³ (19 kN/m³). Correction for other earth weights may be made by simple direct proportions. For corrections of other types of soils, refer to formulas in Sec. 4.5. Boldface figures indicate maximum earth load for depth of trench. To obtain earth loads in kilonewtons per meter, multiply by 0.014594.

Table 1 Earth loads (*lb/lin ft*) (continued)

Pipe size 24 in. ID											
Trench Cover		Trench Width, <i>ft</i>									Transition Width
<i>ft</i>	3.0	3.25	3.5	3.75	4.0	4.5	5.0	5.5	6.0	6.5	
2	630										3 ft 1 in.
2.5	805	810									3 ft 3 in.
3	955	1,010	1,010								3 ft 5 in.
4	1,250	1,330	1,400	1,490							3 ft 9 in.
5	1,450	1,610	1,750	1,940	2,030						4 ft 1 in.
6	1,700	1,865	2,050	2,210	2,400	2,550					4 ft 5 in.
7	1,900	2,090	2,300	2,515	2,700	3,080					4 ft 8 in.
8	2,100	2,320	2,525	2,765	3,000	3,480	3,620				4 ft 10 in.
9	2,250	2,510	2,750	3,040	3,300	3,790	4,130				5 ft 0 in.
10	2,400	2,725	2,950	3,240	3,550	4,140	4,660	4,660			5 ft 2 in.
12	2,675	3,020	3,300	3,660	4,000	4,660	5,400	5,740			5 ft 5 in.
14	2,900	3,280	3,600	4,050	4,400	5,200	6,000	6,750	6,800		5 ft 8 in.
16	3,100	3,515	3,900	4,350	4,800	5,640	6,450	7,410	7,850		5 ft 11 in.
18	3,275	3,720	4,150	4,620	5,100	6,040	7,050	8,000	8,910		6 ft 1 in.
20	3,400	3,995	4,350	4,860	5,350	6,400	7,450	8,460	9,600	10,000	6 ft 2 in.
Pipe size 27 in. ID											
Trench Cover		Trench Width, <i>ft</i>									Transition Width
<i>ft</i>	3.25	3.5	3.75	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
2	710										3 ft 5 in.
2.5	895	905									2 ft 10 in.
3	1,040	1,095									3 ft 0 in.
4	1,330	1,400	1,540	1,600							3 ft 4 in.
5	1,610	1,750	1,940	2,050	2,200						3 ft 8 in.
6	1,865	2,050	2,210	2,400	2,735						3 ft 11 in.
7	2,090	2,300	2,515	2,700	3,110	3,385					4 ft 1 in.
8	2,320	2,525	2,765	3,300	3,480	3,900	3,980				4 ft 3 in.
9	2,510	2,750	3,040	3,300	3,790	4,300	4,590				4 ft 5 in.
10	2,725	2,950	3,240	3,550	4,140	4,700	5,190				4 ft 6 in.
12	3,020	3,300	3,660	4,000	4,660	5,400	6,060	6,390			4 ft 10 in.
14	3,280	3,600	4,050	4,400	5,200	6,000	6,750	7,550	7,560		6 ft 3 in.
16	3,515	3,900	4,350	4,800	5,840	6,450	7,410	8,300	8,800		6 ft 6 in.
18	3,720	4,150	4,620	5,100	6,040	7,050	8,000	9,000	9,960	10,000	6 ft 8 in.
20	3,995	4,350	4,860	5,350	6,400	7,450	8,460	9,600	10,890	11,180	6 ft 10 in.
Pipe size 30 in. ID											
Trench Cover		Trench Width, <i>ft</i>									Transition Width
<i>ft</i>	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5		
2	755										3 ft 7 in.
2.5	965										3 ft 10 in.
3	1,150	1,185									3 ft 11 in.
4	1,400	1,675	1,680								4 ft 5 in.
5	1,750	2,050	2,335	2,340							4 ft 8 in.
6	2,050	2,400	2,800	3,005							5 ft 0 in.
7	2,300	2,700	3,110	3,500	3,665						5 ft 5 in.
8	2,525	3,000	3,480	3,900	4,320						5 ft 7 in.
9	2,750	3,300	3,790	4,300	4,840	4,980					5 ft 10 in.
10	2,950	3,550	4,140	4,700	5,260	5,660					6 ft 1 in.
12	3,300	4,000	4,660	5,400	6,060	6,800	6,990				6 ft 5 in.
14	3,600	4,400	5,200	6,000	6,750	7,550	8,320	8,320			6 ft 9 in.
16	3,900	4,800	5,640	6,450	7,410	8,300	9,210	9,610			7 ft 0 in.
18	4,150	5,100	6,040	7,050	8,000	9,000	9,960	10,980	10,980		7 ft 3 in.
20	4,350	5,350	6,400	7,450	8,460	9,600	10,980	11,890	12,300		7 ft 5 in.

NOTE: Values are for clay (part D of Figure 5, $k_{\mu} = k_{\mu'} = 0.130$) with weight of earth taken as 120 lb/ft³ (19 kN/m³). Correction for other earth weights may be made by simple direct proportions. For corrections of other types of soils, refer to formulas in Sec. 4.5. Boldface figures indicate maximum earth load for depth of trench. To obtain earth loads in kilonewtons per meter, multiply by 0.014594.