

American Water Works Association
ANSI/AWWA C150/A21.50-96
(Revision of ANSI/AWWA C150/A21.50-91)



AMERICAN NATIONAL STANDARD
FOR
**THICKNESS DESIGN OF
DUCTILE-IRON PIPE**



Secretariats

AMERICAN GAS ASSOCIATION
AMERICAN WATER WORKS ASSOCIATION

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AMERICAN WATER WORKS ASSOCIATION

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Foreword

This foreword is for information only and is not a part of ANSI/AWWA C150/A21.50.

I. Introduction

I.A. *Background.* The purpose of this standard is to provide pipeline designers with a recommended design procedure and associated tabular data necessary to establish the wall thickness(es) required for buried ductile-iron pipe based on the type of pipe embedment, depths of trench cover, live load conditions, internal working pressures, and surge conditions appropriate for the specific pipeline project. Once the required wall thickness(es) has been established, the ductile-iron pipe should be specified to be manufactured in accordance with ANSI^{*}/AWWA C151/A21.51. ANSI/AWWA C151/A21.51 contains options that must be addressed in the purchaser's specifications in response to site-specific project requirements.

Although ANSI/AWWA C150/A21.50 is commonly used for designing ductile-iron pipe for services other than water, users are also directed to ASTM[†] A746, Standard Specification for Ductile Iron Gravity Sewer Pipe.

I.B. *History.* American National Standards Committee A21, Cast-Iron Pipe and Fittings, was organized in 1926 under the sponsorship of the American Gas Association (A.G.A.), the American Society for Testing and Materials (ASTM), the American Water Works Association (AWWA), and the New England Water Works Association (NEWWA). Between 1972 and 1984, the cosecretariats were A.G.A., AWWA, and NEWWA, with AWWA serving as administrative secretariat. In 1984, the committee became an AWWA committee with the name of American Water Works Association Standards Committee A21 on Ductile-Iron Pipe and Fittings. In 1988, NEWWA withdrew as a separate secretariat; however, it continues to maintain its representation on the AWWA Committee A21. The committee remains cosponsored by A.G.A. for gas-related activities.

The present scope of AWWA Committee A21 activity is the development of standards and manuals addressing ductile-iron pressure pipe for gas, water, and other liquids, and ductile-iron and gray-iron fittings for use with such pipe. These standards and manuals include design, dimensions, materials, coatings, linings, joints, accessories, and methods of inspection and testing.

The work of AWWA Committee A21 is conducted by subcommittees. The scope of Subcommittee 1, Pipe, includes the periodic review of all current A21 standards for pipe, the preparation of revisions and new standards when needed, as well as other matters pertaining to pipe standards.

The first edition of A21.50, American National Standard for the Thickness Design of Ductile-Iron Pipe, was issued in 1965, and revisions were issued in 1971, 1976, 1981, and 1991. The standard was reaffirmed without revision in 1986. Subcommittee 1 reviewed the 1991 edition and submitted a proposed revision to AWWA Standards Committee A21 in 1995.

I.C. *Acceptance.* In May 1985, the US Environmental Protection Agency (USEPA) entered into a cooperative agreement with a consortium led by NSF International

^{*}American National Standards Institute, 11 W. 42nd St., New York, NY 10036.

[†]American Society for Testing and Materials, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

(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, ANSI[†]/NSF[‡] 60, Drinking Water Treatment Chemicals—Health Effects, and ANSI/NSF 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 ANSI/NSF 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.

Appendix A, “Toxicology Review and Evaluation Procedures,” to ANSI/NSF 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 Appendix A procedures may not always be identical, depending on the certifier.

AWWA C150-96 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. Currently, there are no special issues related to this standard.

*Persons in Canada, Mexico, and non-North American countries should contact the appropriate authority having jurisdiction.

[†]American National Standards Institute, 11 W. 42nd St., New York, NY 10036.

[‡]NSF International, 3475 Plymouth Rd., Ann Arbor, MI 48106.

[§]Both publications available from National Academy of Sciences, 2102 Constitution Ave. N.W., Washington, DC 20418.

III. Use of This Standard. AWWA has no responsibility for the suitability or compatibility of the provisions of this standard to any intended application by any user. Accordingly, each user of this standard is responsible for determining that the standard's provisions are suitable for and compatible with that user's intended application.

III.A. Purchaser Options and Alternatives. As noted in Sec. I.A of the foreword, ANSI/AWWA C151/A21.51 contains options that must be addressed in the purchaser's specifications in response to site-specific requirements for ductile-iron pipe.

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

1. The format has been changed to AWWA standard style.
2. The acceptance clause (Sec. I.C) has been revised to approved wording.
3. The truck load equation (Eq 5) and the surface load factor (Eq 6) have been modified to allow for a correct distribution of units.
4. Table 6, Surface load factors for single truck on unpaved road, has been changed to match the revised surface load factor equation (Eq 6).
5. The statement concerning surge allowance in the hoop stress formula (Sec. 4.1.2 and Sec. 4.2.2) has been modified to note that if anticipated surge pressures are other than 100 psi (689 kPa), the actual anticipated pressure should be used.

V. Comments. If you have any comments or questions about this standard, please call the AWWA Standards and Materials Development Department, (303) 794-7711 ext. 6283, FAX (303) 795-1440, or write to the department at 6666 W. Quincy Ave., Denver, CO 80235.



AMERICAN NATIONAL STANDARD FOR THICKNESS DESIGN OF DUCTILE-IRON PIPE

SECTION 1: GENERAL

Sec. 1.1 Scope

This standard covers the thickness design of ductile-iron pipe complying with the requirements of ANSI^{*}/AWWA C151/A21.51, Ductile-Iron Pipe, Centrifugally Cast, for Water.

Section 4.1 outlines the design procedure and Sec. 4.2 gives a design example.

Section 4.3 explains the basis of design.

As opposed to using procedures in Sec. 4.1 or Sec. 4.3, the designer may reference Tables 12 through 14 directly.

Table 12 lists thicknesses for standard laying conditions and certain depths of cover.

Table 13 lists thicknesses for 150 psi–350 psi (1,034 kPa–2,413 kPa)[†] water working pressure.

The greater thickness from Table 12 or Table 13 for given trench load or internal pressure should be used.

Table 14 lists working pressures and maximum depths of cover for standard laying conditions and standard pressure classes.

Table 15 lists special thickness classes of ductile-iron pipe.

^{*}American National Standards Institute Inc., 11 W. 42nd St., New York, NY 10036.

[†]Metric conversions given in this standard are direct conversions of US customary units and are not those specified in International Organization for Standardization (ISO) standards.

Sec. 1.2 Purpose

The main purpose of this standard is to provide the minimum requirements for the thickness design of ductile-iron pipe, including basis of design and design procedure.

Sec. 1.3 Application

This standard can be referenced in specifications for the thickness design of ductile-iron pipe. The stipulations of this standard apply when this document has been referenced and then only to the thickness design of ductile-iron pipe.

SECTION 2: REFERENCES

This standard references the following documents. In their latest editions, these documents 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 T99—Standard Method of Test for the Moisture-Density Relations of Soils Using a 5.5 lb (2.5 kg) rammer, 12 in. (305 mm) drop.

ANSI/AWWA C151/A21.51—American National Standard for Ductile-Iron Pipe, Centrifugally Cast, for Water.

ASTM* A746—Standard Specification for Ductile Iron Gravity Sewer Pipe.

SECTION 3: DEFINITIONS

This standard has no applicable information for this section.

SECTION 4: REQUIREMENTS

Sec. 4.1 Procedure for Calculating Thickness

The thickness of ductile-iron pipe is determined by considering trench load and internal pressure separately.

4.1.1 Step 1—Design for trench load.

a. Determine trench load P_v . Table 1 gives trench load, including earth load P_e , plus truck load P_t , for 2.5 ft–32 ft (0.8 m–9.8 m) cover.

b. Determine the standard laying condition from the descriptions in Table 2 and select the appropriate table for diameter–thickness ratios from Tables 7 through 11. Each table lists diameter–thickness ratios calculated for both bending stress and deflection over a range of trench loads.

c. For bending-stress design, enter the column headed “Bending-Stress Design” in the appropriate table of Tables 7 through 11, and locate the tabulated trench load P_v nearest to the calculated P_v from Sec. 4.1.1.a. (If the calculated P_v is halfway between two tabulated values, use the larger P_v value.)

*American Society for Testing and Materials, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

Select the corresponding D/t value for this P_v .

Divide the pipe's outside diameter D (Table 5) by the D/t value to obtain net thickness t .

d. For deflection design, enter the column headed "Deflection Design" in the appropriate table of Tables 7 through 11, and locate the tabulated trench load P_v nearest to the calculated P_v from Sec. 4.1.1.a. (If the calculated P_v is less than the minimum P_v listed in the table, design for trench load is not controlled by deflection and this determination need not be completed.) If the calculated P_v is halfway between two tabulated values, use the larger P_v value.

Select the corresponding D/t_1 value for this P_v .

Divide the pipe's outside diameter D (Table 5) by the D/t_1 value to obtain minimum manufacturing thickness t_1 . Deduct 0.08 in. (2.0 mm) service allowance to obtain net thickness t .

NOTE: Service allowance equals 0.08 in. (2.0 mm) for all sizes of ductile-iron pipe.

e. Compare the net thicknesses from steps c and d and select the larger of the two. This will be the net thickness required for trench load.

4.1.2 *Step 2—Design for internal pressure.* Calculate the net thickness required for internal pressure using the equation for hoop stress:

$$t = \frac{P_i D}{2S}$$

Where:

t = net thickness, in. (mm)

P_i = design internal pressure, psi (kPa) = 2 ($P_w + P_s$)

P_w = working pressure, psi (kPa)

P_s = surge allowance, 100* psi (689 kPa)

D = outside diameter of pipe, in. (mm)

S = minimum yield strength in tension = 42,000 psi (289,590 kPa)

*If anticipated surge pressures are other than 100 psi (689 kPa), the actual anticipated pressure should be used.)

4.1.3 *Step 3—Selection of net thickness and addition of allowances.*

a. Select the net thickness t from step 1 or step 2, whichever thickness is larger.

b. Add the service allowance of 0.08 in. (2.0 mm) to the net thickness t . The resulting thickness is the minimum manufacturing thickness t_1 .

c. Add the casting allowance from Table 3 to the minimum manufacturing thickness t_1 . The resulting thickness is the total calculated thickness.

4.1.4 *Step 4—Selection of standard pressure class.* Use the total calculated thickness from Sec. 4.1.3.c to select a standard pressure-class thickness from Table 5. When the calculated thickness is between two nominal thicknesses, select the larger of the two.

When specifying and ordering pipe, use the pressure class listed in Table 5 for this nominal thickness.

NOTE: On specific projects, manufacturers may be willing to furnish pipe with thicknesses that fall between standard classes.

4.1.5 *Alternative procedure.* The appropriate standard pressure class may also be determined by using the Design Equations in Sec. 4.3.

Sec. 4.2 Design Example for Calculating Thickness

Problem: Calculate the thickness for 30-in. (762-mm) ductile-iron pipe bedded in loose soil for a minimum depth of 4 in. (100 mm), backfill lightly consolidated to top of pipe, laying condition Type 3, under 10 ft (3 m) of cover for a working pressure of 150 psi (1,034 kPa).

4.2.1 Step 1—Design for trench load.

- a. Earth load (Table 1) P_e = 8.3 psi
- Truck load (Table 1) P_t = 0.7 psi
- Trench load, $P_v = P_e + P_t$ = 9.0 psi

b. Select Table 9 for diameter–thickness ratios for laying condition Type 3.

c. Entering P_v of 9.0 psi in Table 9, the bending-stress design requires D/t of 163. From Table 5, diameter D of 30-in. pipe is 32.00 in.

Net thickness t for bending stress = $D/(D/t) = 32.00/163 = 0.20$ in.

d. Also, from Table 9, the deflection design requires D/t_1 of 136.

Minimum manufacturing thickness t_1 for deflection design:

$$t_1 = \frac{D}{\frac{D}{t_1}} = \frac{32.00}{136} = 0.24 \text{ in.}$$

Deduct service allowance = −0.08 in.

Net thickness t for deflection control = 0.16 in.

e. The larger net thickness is 0.20 in., obtained by the design for bending stress.

4.2.2 Step 2—Design for internal pressure.

$P_i = 2.0 (P_w + P_s) = 2.0$ (working pressure + 100 psi surge allowance)

(If anticipated surge pressures are other than 100 psi [689 kPa], then the actual anticipated pressures should be used.)

$$P_i = 2.0 (150 + 100) = 500 \text{ psi}$$

$$t = \frac{P_i D}{2S} = \frac{500 \times 32.00}{2 \times 42,000} = 0.19 \text{ in.}$$

Net thickness t for internal pressure is 0.19 in.

4.2.3 Step 3—Selection of net thickness and addition of allowances. The larger of the thicknesses is given by the design for trench load, Step 1, and 0.20 in. is selected.

- Net thickness = 0.20 in.
- Service allowance = 0.08 in.
- Minimum manufacturing thickness = 0.28 in.
- Casting allowance = 0.07 in.
- Total calculated thickness = 0.35 in.

4.2.4 *Step 4—Selection of nominal thickness and standard pressure class.* The total calculated thickness of 0.35 in. is larger than 0.34 in., Class 150. Therefore, Class 200 is selected for specifying and ordering.

Sec. 4.3 Design Method

4.3.1 *Ductile-iron pipe thickness.* The thickness of ductile-iron pipe is determined by considering trench load and internal pressure separately.

Calculations are made for the thicknesses required to resist the bending stress and the deflection caused by trench load. The larger of the two is selected as the thickness required to resist trench load. Calculations are then made for the thickness required to resist the hoop stress of internal pressure.

The larger of these is selected as the net design thickness. To this net thickness is added a service allowance to obtain the minimum manufacturing thickness and a casting allowance to obtain the total calculated thickness.

The nominal thickness and the standard pressure class for specifying and ordering are selected from the table of nominal thicknesses for standard pressure classes (Table 5).

The reverse of the preceding procedure is used to determine the rated working pressure and maximum depth of cover for pipe of a given pressure class.

4.3.2 *Trench load P_v .* Trench load is expressed as vertical pressure in pounds per square inch (kilopascals) and is equal to the sum of earth load P_e and truck load P_t .

4.3.3 *Earth load P_e .* Earth load is computed by Eq 4 for the weight of the unit prism of soil with a height equal to the distance from the top of the pipe to the ground surface. The unit weight of backfill soil is taken to be 120 lb/ft³ (18.85 kN/m³). If the designer anticipates additional loads, the design load should be increased accordingly.

4.3.4 *Truck load P_t .* The truck loads shown in Table 1 were computed by Eq 5 using the surface-load factors in Table 6 and the reduction factors R from Table 4 for a single AASHTO H-20 truck on unpaved road or flexible pavement, 16,000-lb (71,170-N) wheel load, and 1.5 impact factor. The surface-load factors in Table 6 were calculated by Eq 6 for a single concentrated wheel load centered over an effective pipe length of 3 ft (0.914 m).

4.3.5 *Design for trench load.* Tables 7 through 11, the diameter–thickness ratios tables used to design for trench load, were computed with Eqs 2 and 3. Equation 2 is based on the bending stress at the bottom of the pipe. The design-bending stress f is 48,000 psi (331×10^3 kPa), which provides at least a 1.5 safety factor based on minimum ring yield strength and a 2.0 safety factor based on ultimate strength. Equation 3 is based on the deflection of the pipe ring section. The design deflection Δx is 3 percent of the outside diameter of the pipe, which is well below the deflection that might damage cement linings. Design values of the trench parameters E' , K_b , and K_x are given in Table 2.

Tables similar to Tables 7 through 11 may be compiled for laying conditions other than those shown in this standard by calculating the trench loads P_v for a series of diameter–thickness ratios, D/t and D/t_1 , using Eqs 2 and 3 with values of E' , K_b , and K_x appropriate to the bedding and backfill conditions.

Design Equations

$$t = \frac{P_i D}{2S} \quad (\text{Eq 1})$$

$$P_v = \frac{f}{3 \left(\frac{D}{t} \right) \left(\frac{D}{t} - 1 \right) \left[K_b - \frac{K_x}{\frac{8E}{E' \left(\frac{D}{t} - 1 \right)^3} + 0.732} \right]} \quad (\text{Eq 2})$$

$$P_v = \frac{\frac{\Delta x}{D}}{12 K_x} \left[\frac{8E}{\left(\frac{D}{t_1} - 1 \right)^3} + 0.732 E' \right] \quad (\text{Eq 3})$$

$$P_e = \frac{wH}{a} \quad (\text{Eq 4})$$

$$P_t = RF \frac{CP}{bD} \quad (\text{Eq 5})$$

$$C = 1 - \frac{2}{\pi} \arcsin \left(H \sqrt{\frac{A^2 + B^2 + H^2}{(A^2 + H^2)(B^2 + H^2)}} \right) + \frac{2}{\pi} \left(\frac{A \cdot H \cdot B}{\sqrt{A^2 + H^2} \sqrt{B^2 + H^2}} \right) \left(\frac{1}{A^2 + H^2} + \frac{1}{B^2 + H^2} \right) \quad (\text{Eq 6})$$

NOTE: In Eq 6, angles are in radians.

Sec. 4.4 Explanation of Symbols Used in Design Equations

- A = Outside radius of pipe. For A in feet, D in inches: $A = D/24$
(For A in metres, D in millimetres: $A = D/2,000$)
- a = Conversion factor. For pounds per square foot to pounds per square inch:
 $a = 144$ (For kilonewtons per square metre to kilopascals: $a = 1$)
- B = 1.5 ft (0.457 m)
- b = Effective pipe length: 36 in. (0.914 m)
- C = Surface load factor: see Table 6.
- D = Outside diameter, in inches (millimetres): see Table 5.
- E = Modulus of elasticity: 24×10^6 psi (165.5×10^6 kPa)
- E' = Modulus of soil reaction, in pounds per square inch (kilopascals):
see Table 2.
- F = Impact factor: 1.5
- f = Design bending stress: 48,000 psi (331×10^3 kPa)
- H = Depth of cover, in feet (metres)
- K_b = Bending moment coefficient: see Table 2.

- K_x = Deflection coefficient: see Table 2.
 P = Wheel load: 16,000 lb (71,170 N)
 P_e = Earth load, in pounds per square inch (kilopascals)
 P_i = Design internal pressure, in pounds per square inch (kilopascals):
 $P_i = 2$ (working pressure + 100 psi [689 kPa] surge allowance)
 P_t = Truck load, in pounds per square inch (kilopascals)
 P_v = Trench load, in pounds per square inch (kilopascals): $P_v = P_e + P_t$
 R = Reduction factor, which takes account of the fact that the part of the pipe directly below the wheels is aided in carrying the truck load by adjacent parts of the pipe that receive little or no load from the wheels: see Table 4.
 S = Minimum yield strength in tension: 42,000 psi (289,590 kPa)
 t = Net thickness, in inches (millimetres)
 t_1 = Minimum manufacturing thickness, in inches: $t_1 = t + 0.08$
(in millimetres: $t_1 = t + 2$)
 w = Soil weight: 120 lb/ft³ (18.85 kN/m³)
 Δx = Design deflection, in inches (millimetres): $\Delta x = 0.03D$

Sec. 4.5 Special Thickness Classes

For design conditions not covered in Tables 12, 13, and 14, special (formerly standard) thickness classes shown in Table 15 continue to be available.

SECTION 5: VERIFICATION

This standard has no applicable information for this section.

SECTION 6: DELIVERY

This standard has no applicable information for this section.

Table 1 Earth loads P_e , truck loads P_t , and trench loads P_v —psi

Depth of Cover <i>ft</i>	P_e	3-in. Pipe		4-in. Pipe		6-in. Pipe		8-in. Pipe	
		P_t	P_v	P_t	P_v	P_t	P_v	P_t	P_v
2.5	2.1	9.9	12.0	9.9	12.0	9.9	12.0	9.8	11.9
3	2.5	7.4	9.9	7.4	9.9	7.3	9.8	7.3	9.8
4	3.3	4.4	7.7	4.5	7.8	4.4	7.7	4.4	7.7
5	4.2	3.0	7.2	3.0	7.2	3.0	7.2	3.0	7.2
6	5.0	2.1	7.1	2.1	7.1	2.1	7.1	2.1	7.1
7	5.8	1.6	7.4	1.6	7.4	1.6	7.4	1.6	7.4
8	6.7	1.2	7.9	1.2	7.9	1.2	7.9	1.2	7.9
9	7.5	1.0	8.5	1.0	8.5	1.0	8.5	1.0	8.5
10	8.3	0.8	9.1	0.8	9.1	0.8	9.1	0.8	9.1
12	10.0	0.6	10.6	0.6	10.6	0.6	10.6	0.6	10.6
14	11.7	0.4	12.1	0.4	12.1	0.4	12.1	0.4	12.1
16	13.3	0.3	13.6	0.3	13.6	0.3	13.6	0.3	13.6
20	16.7	0.2	16.9	0.2	16.9	0.2	16.9	0.2	16.9
24	20.0	0.2	20.2	0.1	20.1	0.1	20.1	0.1	20.1
28	23.3	0.1	23.4	0.1	23.4	0.1	23.4	0.1	23.4
32	26.7	0.1	26.8	0.1	26.8	0.1	26.8	0.1	26.8
Depth of Cover <i>ft</i>	P_e	10-in. Pipe		12-in. Pipe		14-in. Pipe		16-in. Pipe	
		P_t	P_v	P_t	P_v	P_t	P_v	P_t	P_v
2.5	2.1	9.7	11.8	9.6	11.7	8.7	10.8	8.2	10.3
3	2.5	7.2	9.7	7.2	9.7	6.6	9.1	6.2	8.7
4	3.3	4.4	7.7	4.4	7.7	4.4	7.7	4.1	7.4
5	4.2	2.9	7.1	2.9	7.1	2.9	7.1	2.8	7.0
6	5.0	2.1	7.1	2.1	7.1	2.1	7.1	2.0	7.0
7	5.8	1.6	7.4	1.6	7.4	1.6	7.4	1.5	7.3
8	6.7	1.2	7.9	1.2	7.9	1.2	7.9	1.2	7.9
9	7.5	1.0	8.5	1.0	8.5	1.0	8.5	1.0	8.5
10	8.3	0.8	9.1	0.8	9.1	0.8	9.1	0.8	9.1
12	10.0	0.5	10.5	0.5	10.5	0.5	10.5	0.5	10.5
14	11.7	0.4	12.1	0.4	12.1	0.4	12.1	0.4	12.1
16	13.3	0.3	13.6	0.3	13.6	0.3	13.6	0.3	13.6
20	16.7	0.2	16.9	0.2	16.9	0.2	16.9	0.2	16.9
24	20.0	0.1	20.1	0.1	20.1	0.1	20.1	0.1	20.1
28	23.3	0.1	23.4	0.1	23.4	0.1	23.4	0.1	23.4
32	26.7	0.1	26.8	0.1	26.8	0.1	26.8	0.1	26.8

NOTE: To convert inches (in.) to millimetres (mm), multiply by 25.4; to convert feet (ft) to metres (m), multiply by 0.3048; to convert pounds per square inch (psi) to kilopascals (kPa), multiply by 6.895.

Table continued next page.

Table 1 Earth loads P_e , truck loads P_t , and trench loads P_v —psi (continued)

Depth of Cover <i>ft</i>	P_e	18-in. Pipe		20-in. Pipe		24-in. Pipe		30-in. Pipe		36-in. Pipe	
		P_t	P_v	P_t	P_v	P_t	P_v	P_t	P_v	P_t	P_v
2.5	2.1	7.8	9.9	7.5	9.6	7.1	9.2	6.7	8.8	6.2	8.3
3	2.5	5.9	8.4	5.7	8.2	5.4	7.9	5.2	7.7	4.9	7.4
4	3.3	3.9	7.2	3.9	7.2	3.6	6.9	3.5	6.8	3.4	6.7
5	4.2	2.6	6.8	2.6	6.8	2.4	6.6	2.4	6.6	2.3	6.5
6	5.0	1.9	6.9	1.9	6.9	1.7	6.7	1.7	6.7	1.7	6.7
7	5.8	1.4	7.2	1.4	7.2	1.3	7.1	1.3	7.1	1.3	7.1
8	6.7	1.2	7.9	1.1	7.8	1.1	7.8	1.1	7.8	1.1	7.8
9	7.5	1.0	8.5	0.9	8.4	0.9	8.4	0.9	8.4	0.8	8.3
10	8.3	0.8	9.1	0.7	9.0	0.7	9.0	0.7	9.0	0.7	9.0
12	10.0	0.5	10.5	0.5	10.5	0.5	10.5	0.5	10.5	0.5	10.5
14	11.7	0.4	12.1	0.4	12.1	0.4	12.1	0.4	12.1	0.4	12.1
16	13.3	0.3	13.6	0.3	13.6	0.3	13.6	0.3	13.6	0.3	13.6
20	16.7	0.2	16.9	0.2	16.9	0.2	16.9	0.2	16.9	0.2	16.9
24	20.0	0.1	20.1	0.1	20.1	0.1	20.1	0.1	20.1	0.1	20.1
28	23.3	0.1	23.4	0.1	23.4	0.1	23.4	0.1	23.4	0.1	23.4
32	26.7	0.1	26.8	0.1	26.8	0.1	26.8	0.1	26.8	0.1	26.8
Depth of Cover <i>ft</i>	P_e	42-in. Pipe		48-in. Pipe		54-in. Pipe		60-in. Pipe		64-in. Pipe	
		P_t	P_v	P_t	P_v	P_t	P_v	P_t	P_v	P_t	P_v
2.5	2.1	5.8	7.9	5.4	7.5	5.0	7.1	4.8	6.9	4.5	6.6
3	2.5	4.6	7.1	4.4	6.9	4.1	6.6	3.9	6.4	3.8	6.3
4	3.3	3.3	6.6	3.1	6.4	3.0	6.3	2.9	6.2	2.8	6.1
5	4.2	2.3	6.5	2.2	6.4	2.1	6.3	2.1	6.3	2.1	6.3
6	5.0	1.7	6.7	1.6	6.6	1.6	6.6	1.6	6.6	1.5	6.5
7	5.8	1.3	7.1	1.2	7.0	1.2	7.0	1.2	7.0	1.2	7.0
8	6.7	1.0	7.7	1.0	7.7	1.0	7.7	1.0	7.7	1.0	7.7
9	7.5	0.8	8.3	0.8	8.3	0.8	8.3	0.8	8.3	0.8	8.3
10	8.3	0.7	9.0	0.7	9.0	0.7	9.0	0.7	9.0	0.7	9.0
12	10.0	0.5	10.5	0.5	10.5	0.5	10.5	0.5	10.5	0.5	10.5
14	11.7	0.4	12.1	0.4	12.1	0.4	12.1	0.4	12.1	0.4	12.1
16	13.3	0.3	13.6	0.3	13.6	0.3	13.6	0.3	13.6	0.3	13.6
20	16.7	0.2	16.9	0.2	16.9	0.2	16.9	0.2	16.9	0.2	16.9
24	20.0	0.1	20.1	0.1	20.1	0.1	20.1	0.1	20.1	0.1	20.1
28	23.3	0.1	23.4	0.1	23.4	0.1	23.4	0.1	23.4	0.1	23.4
32	26.7	0.1	26.8	0.1	26.8	0.1	26.8	0.1	26.8	0.1	26.8

NOTE: To convert inches (in.) to millimetres (mm), multiply by 25.4; to convert feet (ft) to metres (m), multiply by 0.3048; to convert pounds per square inch (psi) to kilopascals (kPa), multiply by 6.895.

Table 2 Design values for standard laying conditions

Laying Condition*	Description	E' psi	Bedding Angle deg	K_b	K_x
Type 1 [†]	Flat-bottom trench. [‡] Loose backfill.	150	30	0.235	0.108
Type 2	Flat-bottom trench. Backfill lightly consolidated to centerline of pipe.	300	45	0.210	0.105
Type 3	Pipe-bedded in 4-in.-minimum loose soil. [§] Backfill lightly consolidated to top of pipe.	400	60	0.189	0.103
Type 4	Pipe bedded in sand, gravel, or crushed stone to depth of $\frac{1}{8}$ pipe diameter. 4-in. minimum. Backfill compacted to top of pipe. (Approximately 80 percent Standard Proctor, AASHTO T-99)**	500	90	0.157	0.096
Type 5	Pipe bedded to its centerline in compacted granular material, 4-in. minimum under pipe. Compacted granular or select material [§] to top of pipe. (Approximately 90 percent Standard Proctor, AASHTO T-99)**	700	150	0.128	0.085

NOTES:

1) Consideration of the pipe-zone embedment conditions included in this table may be influenced by factors other than pipe strength. For additional information see ANSI/AWWA C600, Standard for Installation of Ductile-Iron Water Mains and Their Appurtenances.

2) To convert pounds per square inch (psi) to kilopascals (kPa), multiply by 6.895.

*See Figure 1.

[†]For pipe 14 in. (356 mm) and larger, consideration should be given to the use of laying conditions other than Type 1.

[‡]Flat-bottom is defined as "undisturbed earth."

[§]Loose soil or select material is defined as "native soil excavated from the trench, free of rocks, foreign material, and frozen earth."

**AASHTO T-99, "Standard Method of Test for the Moisture-Density Relations of Soils Using a 5.5 lb (2.5 kg) Rammer and a 12 in. (305 mm) Drop." Available from the American Association of State Highway and Transportation Officials, 444 N. Capital St. N.W., Washington, DC 20001.

Table 3 Allowances for casting tolerance

Size in.	Casting Allowance in.
3–8	0.05
10–12	0.06
14–42	0.07
48	0.08
54–64	0.09

NOTE: To convert inches (in.) to millimetres (mm), multiply by 25.4.