PLAINTIFF'S EXHIBIT

CT-346

ANSI A21.50–1976
(AWWA C150–76)

Revision of
A21.50–1971
(AWWA C150–71)

AMERICAN NATIONAL STANDARD

for the

THICKNESS DESIGN OF DUCTILE-IRON PIPE

SECRETARIATS

AMERICAN GAS ASSOCIATION
AMERICAN WATER WORKS ASSOCIATION
NEW ENGLAND WATER WORKS ASSOCIATION

Revised edition approved by American National Standards Institute, Inc. Aug. 4, 1976

PUBLISHED BY
AMERICAN WATER WORKS ASSOCIATION
6666 West Quincy Avenue, Denver, Colorado 80235

CTD014566

American National Standard

An American National Standard implies a consensus of those substantially concerned with its scope and provisions. An American National Standard is intended as a guide to aid the manufacturer, the consumer, and the general public. The existence of an American National Standard does not in any respect preclude anyone, whether he has approved the standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not conforming to the standard. American National Standards are subject to periodic review, and users are cautioned to obtain the latest editions. Producers of goods made in conformity with an American National Standard are encouraged to state on their own responsibility in advertising and promotion material or on tags or labels that the goods are produced in conformity with particular American National Standards.

CAUTION NOTICE. This American National Standard may be revised or withdrawn at any time. The procedures of the American National Standards Institute require that action be taken to reaffirm, revise, or withdraw this standard no later than five (5) years from the date of publication. Purchasers of American National Standards may receive current information on all standards by calling or writing the American National Standards Institute, 1430 Broadway, New York, N.Y. 10018, (212) 868–1220.

© Copyright 1976 by the American Water Works Assn.
Printed in US

CTD014567

Committee Personnel

Subcommittee 1, Pipe, which reviewed this standard, had the following personnel at that time:

EDWARD C. SEARS, *Chairman*
WALTER AMORY, *Vice-Chairman*

User Members	*Producer Members*
ROBERT S. BRYANT	ALFRED F. CASE
FRANK E. DOLSON	W. D. GOODE
GEORGE F. KEENAN	THOMAS D. HOLMES
LEONARD ORLANDO JR.	HAROLD KENNEDY JR.
JOHN E. PERRY	W. HARRY SMITH
	SIDNEY P. TEAGUE

Standards Committee A21, Cast-Iron Pipe and Fittings, which reviewed and approved this standard, had the following personnel at the time of approval:

LLOYD W. WELLER, *Chairman*
EDWARD C. SEARS, *Vice-Chairman*
JAMES B. RAMSEY, *Secretary*

Organization Represented	*Name of Representative*
American Gas Association	LEONARD ORLANDO JR.
American Society of Civil Engineers	KENNETH W. HENDERSON
American Society of Mechanical Engineers	JAMES S. VANICK
American Society for Testing and Materials	H. M. COBB*
American Water Works Association	ARNOLD M. TINKEY
	LLOYD W. WELLER
Cast Iron Pipe Research Association	THOMAS D. HOLMES
	HAROLD KENNEDY JR.
	EDWARD C. SEARS
	W. HARRY SMITH
Individual Producer	ALFRED F. CASE
Manufacturers' Standardization Society of the Valve and Fittings Industry	ABRAHAM FENSTER
New England Water Works Association	WALTER AMORY
Naval Facilities Engineering Command	STANLEY C. BAKER
Underwriters' Laboratories, Inc.	JOHN E. PERRY
Canadian Standards Association	W. F. SEMENCHUK†

* Alternate
† Liaison representative without vote

CTD014568

Table of Contents

SEC.		PAGE
Foreword		vi
Standard		
50-1	Scope	1
50-2	Procedure for Calculating Thickness	1
50-3	Design Example for Calculating Thickness	2
50-4	Design Method	3
Tables		
50.1	Earth Loads P_e, Truck Loads P_t, and Trench Loads P_v	6
50.2	Design Values for Standard Laying Conditions	8
50.3	Allowances for Casting Tolerance	8
50.4	Reduction Factors R for Truck-Load Calculations	8
0.5	Standard Thickness Classes of Ductile-Iron Pipe	10
50.6	Surface-Load Factors for Single Truck on Unpaved Road	11
50.7	Diameter-Thickness Ratios for Laying Condition Type 1	12
50.8	Diameter-Thickness Ratios for Laying Condition Type 2	14
50.9	Diameter-Thickness Ratios for Laying Condition Type 3	16
50.10	Diameter-Thickness Ratios for Laying Condition Type 4	19
50.11	Diameter-Thickness Ratios for Laying Condition Type 5	22
50.12	Thickness for Earth Load Plus Truck Load	26
50.13	Thickness for Internal Pressure	31
50.14	Rated Working Pressure and Maximum Depth of Cover	32
Figures		
1.	Standard Pipe Laying Conditions	9

CTD014569

Foreword

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

American National Standards Committee A21, Cast-Iron Pipe and Fittings, was organized in 1926 under the sponsorship of the American Gas Association, the American Society for Testing and Materials, the American Water Works Association, and the New England Water Works Association. Since 1972, the co-secretariats have been A.G.A., AWWA, and NEWWA, with AWWA serving as the administrative secretariat. The present scope of Committee A21 activity is

> Standardization of specifications for cast-iron and ductile-iron pressure pipe for gas, water and other liquids, and fittings for use with such pipe. These specifications to include design, dimensions, materials, coatings, linings, joints, accessories and methods of inspection and test.

The work of Committee A21 is conducted by subcommittees. The directive to Subcommittee 1—Pipe is that

> The scope of the subcommittee activity shall include 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, the standard for thickness design of ductile-iron pipe, was issued in 1965 and a revision was issued in 1971. Subcommittee 1 reviewed the 1971 edition and submitted a proposed revision to American National Standards Committee A21 in 1975.

Major Revisions

The basic design procedures are unchanged from the 1965 and 1971 editions. Certain design parameters have been changed to the following.

1. Trench load, which includes earth load and truck load, is expressed as vertical pressure in pounds per square inch. Earth loads for all pipe sizes are based on the prism load concept. Truck load is based on a single AASHTO* H-20 truck with 16 000-lb wheel load and 1.5 impact factor. Truck load is included at all depths of cover. In addition to tabulated truck loads, equations are included for complete calculation of truck loads.
2. The design ring bending stress is 48 000 psi, which provides safety factors under trench loading of at least 1.5 based on ring yield strength, and at least 2.0 based on ultimate strength of the material.
3. The design pipe deflection is 3 per cent of the outside diameter. Tests have shown that 3 per cent deflection is permissible without causing any damage to cement linings of ductile-iron pipe.
4. The standard laying conditions have been expanded to include five types. Types 1, 2, and 5 replace A, B, and S, respectively, in A21.50–1971. Types 3 and 4 have been added to provide a wider selection of laying conditions.
5. The design for internal pressure is based on a 2.0 safety factor. The design pressure is obtained by adding 100-psi surge allowance to the working pressure and multiplying the sum by the 2.0 safety factor. (If anticipated surge pressures are greater than 100

* American Association of State Highway and Transportation Officials.

CTD014570

psi, the maximum anticipated pressure must be used.) The resulting design pressure is then applied to the minimum yield strength in tension of 42 000 psi.

6. The standard thickness classes have been renumbered. Class 1 becomes Class 51, Class 2 becomes Class 52, and so on. Class 50 has been added for 6–54-in. pipe and Class 51 has been expanded to include 3–12-in. pipe.

7. The tables have been modified to reflect the preceding changes. Also, a table has been added to show rated working pressure and maximum depth of cover for all the standard laying conditions and standard thickness classes.

CTD014571

ANSI A21.50–1976
(AWWA C150–76)

Revision of
A21.50–1971
(AWWA C150–71)

American National Standard

for the

Thickness Design of Ductile-Iron Pipe

Sec. 50–1—Scope

This standard covers the thickness design of ductile-iron pipe complying with the requirements of ANSI A21.51 (AWWA, C151), "Ductile-Iron Pipe, Centrifugally Cast in Metal Molds or Sand-Lined Molds for Water or Other Liquids."

Section 50–2 outlines the design procedure and Sec. 50–3 gives a design example.

Section 50–4 explains the bases of design.

As opposed to using procedures in Sec. 50–2 or 50–4, the designer may reference Tables 12–14 directly.

Table 12 lists thicknesses for standard laying conditions and depths of cover up to 32 ft.

Table 13 lists thicknesses for 150–350 psi water working pressure.

The greater thickness from Table 12 or 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 thickness classes.

Sec. 50–2—Procedure for Calculating Thickness

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

50–2.1 *Step 1—Design for trench load.*

a. Determine trench load P_t. Table 1 gives trench load, including earth load, P_e, plus truck load P_t, for 2.5–32 ft cover.

b. Determine the standard laying condition from the descriptions in Table 2 and select the appropriate table for diameter–thickness ratios from Tables 7–11. 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 7–11 and locate the tabulated trench load, P_t, nearest to the calculated P_t from paragraph 50–2.1.a. (If the calculated P_t is halfway between two tabulated values, use the larger P_t value.)

CTD014572

Select the corresponding $\frac{D}{t}$ value for this P_s.

Divide the pipe's outside diameter D (Table 5) by the $\frac{D}{t}$ value to obtain the net thickness t.

d. For deflection design, enter the column headed "Deflection Design" in the appropriate table of Tables 7–11 and locate the tabulated trench load, P_s, nearest to the calculated P_s from paragraph 50–2.1.a. (If the calculated P_s is less than the minimum P_s listed in the table, design for trench load is not controlled by deflection and this determination need not be completed.) If the calculated P_s is halfway between two tabulated values, use the larger P_s value.

Select the corresponding $\frac{D}{t_1}$ value for this P_s.

Divide the pipe's outside diameter D (Table 5) by the $\frac{D}{t_1}$ value to obtain minimum manufacturing thickness t_1. Deduct 0.08-in. service allowance to obtain net thickness t.

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.

50–2.2 *Step 2—Design for internal pressure.* Calculate the net thickness required for internal pressure using the equation for hoop stress:

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

in which t is net thickness in inches; P_i is the design internal pressure, which is equal to the safety factor of 2.0 times the sum of working pressure (P_w) in pounds per square inch, plus 100 psi surge allowance (P_s) for water pipe. That is, $P_i = 2.0\ (P_w + P_s)$. If anticipated surge pressures are greater than 100 psi, then the maximum anticipated pressure must be used. D is outside diameter of pipe in inches, and S is minimum yield strength in tension (42 000 psi).

50–2.3 *Step 3—Selection of net thickness and addition of allowances.*

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

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

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

50–2.4 *Step 4—Selection of standard thickness and class.* Use the total calculated thickness from Sec. 50–2.3.c to select a standard class thickness from Table 5. Select the standard thickness nearest to the calculated thickness. When the calculated thickness is halfway between two standard thicknesses, select the larger of the two.

In specifying and ordering pipe, use the class number listed in Table 5 for this standard thickness.

Sec. 50–3—Design Example for Calculating Thickness

PROBLEM: Calculate the thickness for 30-in. ductile-iron pipe laid on a flat-bottom trench with backfill lightly consolidated to centerline of pipe, laying condition Type 2, under 10 ft of cover for a working pressure of 200 psi.

50–3.1 *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, $P_s = P_e + P_t$ = 9.0 psi

CTD014573

b. Select Table 8 for diameter-thickness ratios for laying condition Type 2.

c. Entering P_v of 9.0 psi in Table 8, the bending stress design requires $\frac{D}{t}$ of 128. From Table 5, diameter D of 30-in. pipe is 32.00 in.

Net thickness t for bending stress $= \frac{D}{\frac{D}{t}} = \frac{32.00}{128} = 0.25$ in.

d. Also, from Table 8, the deflection design requires $\frac{D}{t_1}$ of 108.

Minimum thickness t_1 for deflection design $= \frac{D}{\frac{D}{t_1}} = \frac{32.00}{108} = 0.30$ in.

Deduct service allowance -0.08 in.

Net thickness t for deflection control 0.22 in

e. The larger net thickness is 0.25 in., obtained by the design for bending stress.

50–3.2 *Step 2—Design for internal pressure.*

P_i = 2.0 (Working pressure + 100 psi surge allowance)

(If anticipated surge pressures are greater than 100 psi, then the actual anticipated pressures must be used.)

$P_i = 2.0\ (200 + 100)$
$= 600$ psi

$t = \frac{P_i D}{2S} = \frac{600 \times 32.00}{2 \times 42\,000} = 0.23$ in.

Net thickness t for internal pressure is 0.23 in.

50–3.3 *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 0.25 in. is selected.

Net thickness	= 0.25 in.
Service allowance	= 0.08 in.
Minimum thickness	= 0.33 in.
Casting tolerance	= 0.07 in.
Total calculated thickness	= 0.40 in.

50–3.4 *Step 4—Selection of standard thickness and class.* The total calculated thickness of 0.40 in. is nearest to 0.39, Class 50, in Table 5. Therefore, Class 50 is selected for specifying and ordering.

Sec. 50–4—Design Method

50–4.1 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 tolerance to obtain the total calculated thickness.

The standard thickness and the thickness class for specifying and ordering are selected from a table of standard class thicknesses.

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

50–4.2 *Trench load*, P_v. Trench load is expressed as vertical pressure in pounds per square inch, and is equal to the sum of earth load P_e and truck load P_t.

50–4.3 *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/cu ft. If the designer antici-

CTD014574

pates additional loads because of frost, the design load should be increased accordingly.

50–4.4 *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 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.

50–4.5 *Design for trench load.* Tables 7–11, the tables of diameter–thickness ratios used to design for trench load, were computed by Eq 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, 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 per cent 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 7–11 may be compiled for laying conditions other than those shown in this standard by calculating the trench loads P_t for a series of diameter–thickness ratios, $\frac{D}{t}$ and $\frac{D}{t_1}$, using Eq 2 and 3 with values of E', K_b, and K_x appropriate to the bedding and backfill conditions.

Design Equations

$$t = \frac{P_t D}{2S} \tag{1}$$

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

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

$$P_t = \frac{wH}{144} = \frac{120H}{144} = \frac{H}{1.2} \tag{4}$$

$$P_t = \frac{C \cdot R \cdot P \cdot F}{12D} \tag{5}$$

$$C = \frac{1}{3} - \frac{2}{3\pi}\arcsin\left[H\sqrt{\frac{A^2 + H^2 + 1.5^2}{(A^2 + H^2)(H^2 + 1.5^2)}}\right] + \frac{AH}{\pi\sqrt{A^2 + H^2 + 1.5^2}}\left[\frac{1}{A^2 + H^2} + \frac{1}{H^2 + 1.5^2}\right] \tag{6}$$

CTD014575

Explanation of Symbols for Equations

A = Outside radius of pipe in feet = $\frac{D}{24}$
C = Surface load factor (Table 6)
D = Outside diameter in inches (Table 5)
E = Modulus of elasticity (24×10^6 psi)
E' = Modulus of soil reaction in pounds per square inch (Table 2)
F = Impact factor—1.5
f = Design bending stress—48 000 psi
H = Depth of cover in feet
K_b = Bending moment coefficient (Table 2)
K_x = Deflection coefficient (Table 2)
P = Wheel load—16 000 lb
P_e = Earth load in pounds per square inch
P_i = Design internal pressure in pounds per square inch = 2.0 (working pressure + 100 psi surge allowance)
P_t = Truck load in pounds per square inch
P_v = Trench load in pounds per square inch = $P_e + P_t$
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 (Table 4)
S = Minimum yield strength in tension—42 000 psi
t = Net thickness in inches
t_1 = Minimum thickness in inches ($t + 0.08$)
w = Soil weight—120 pounds per cubic foot
ΔX = Design deflection in inches $\left(\frac{\Delta X}{D} = 0.03\right)$

NOTE: In Eq 6, angles are in radians.

CTD014576

TABLE 50.1

Earth Loads P_e, *Truck Loads* P_t, *and Trench Loads* P_v—psi

Depth of Cover ft	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 ft	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	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

CTD014577

TABLE 50.1—(*cont.*)

Depth of Cover *ft*	P_e	18-in. Pipe		20-in. Pipe		24-in. Pipe		30-in. Pipe	
		P_i	P_e	P_i	P_e	P_i	P_e	P_i	P_e
2.5	2.1	7.8	9.9	7.5	9.6	7.1	9.2	6.7	8.8
3	2.5	5.9	8.4	5.7	8.2	5.4	7.9	5.2	7.7
4	3.3	3.9	7.2	3.9	7.2	3.6	6.9	3.5	6.8
5	4.2	2.6	6.8	2.6	6.8	2.4	6.6	2.4	6.6
6	5.0	1.9	6.9	1.9	6.9	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
8	6.7	1.2	7.9	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
10	8.3	0.8	9.1	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
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

Depth of Cover *ft*	P_e	36-in. Pipe		42-in. Pipe		48-in. Pipe		54-in. Pipe	
		P_i	P_e	P_i	P_e	P_i	P_e	P_i	P_e
2.5	2.1	6.2	8.3	5.8	7.9	5.4	7.5	5.0	7.1
3	2.5	4.9	7.4	4.6	7.1	4.4	6.9	4.1	6.6
4	3.3	3.4	6.7	3.3	6.6	3.1	6.4	3.0	6.3
5	4.2	2.3	6.5	2.3	6.5	2.2	6.4	2.1	6.3
6	5.0	1.7	6.7	1.7	6.7	1.6	6.6	1.6	6.6
7	5.8	1.3	7.1	1.3	7.1	1.2	7.0	1.2	7.0
8	6.7	1.1	7.8	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
10	8.3	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
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

CTD014578

TABLE 50.2

Design Values for Standard Laying Conditions

Laying Condition*	Description	E'	Bedding Angle *deg*	K_1	K_2
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. (Approx. 80 per cent 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. (Approx. 90 per cent Standard Proctor, AASHTO T-99)**	700	150	0.128	0.085

* See Fig. 1.
† For pipe 30 in. 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, "Moisture Density Relations of Soils Using a 5.5 lb (2.5 kg) Rammer 12-in. (305-mm) Drop."

TABLE 50.3

Allowances for Casting Tolerance

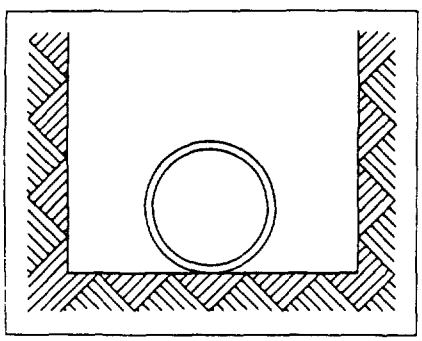
Size *in.*	Casting Tolerance *in.*
3–8	0.05
10–12	0.06
14–42	0.07
48	0.08
54	0.09

TABLE 50.4

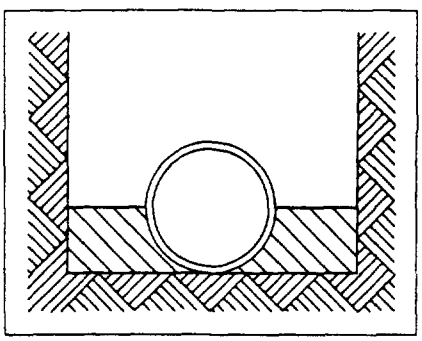
Reduction Factors R *for Truck Load Calculations*

Size *in.*	Depth of Cover—*ft*			
	<4	4–7	8–10	>10
	Reduction Factor			
3–12	1.00	1.00	1.00	1.00
14	0.92	1.00	1.00	1.00
16	0.88	0.95	1.00	1.00
18	0.85	0.90	1.00	1.00
20	0.83	0.90	0.95	1.00
24–30	0.81	0.85	0.95	1.00
36–54	0.80	0.85	0.90	1.00

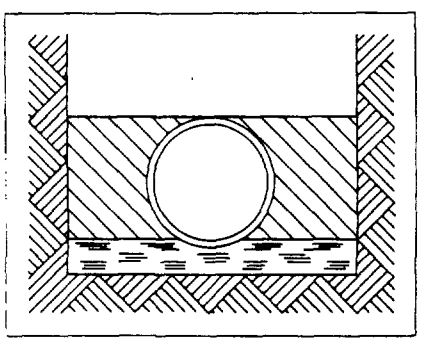
CTD014579



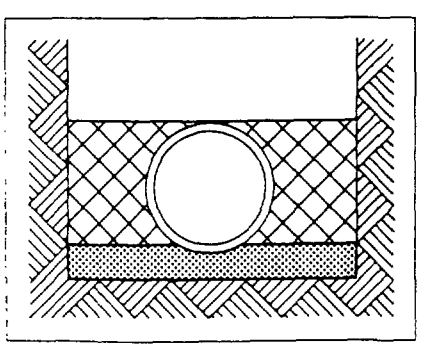
Type 1



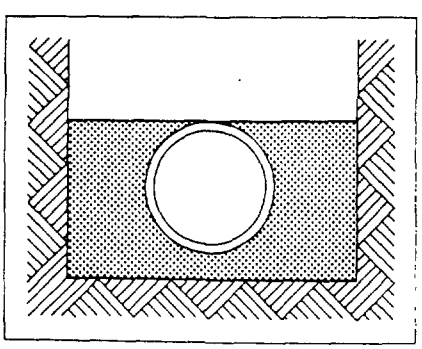
Type 2



Type 3



Type 4



Type 5

Figure 1. Standard Pipe Laying Conditions

See Table 2

CTD014580

TABLE 50.5

Standard Thickness Classes of Ductile-Iron Pipe

Size *in.*	Outside Diameter—*in.*	Thickness Class						
		50	51	52	53	54	55	56
		Thickness—*in.*						
3	3.96	—	0.25	0.28	0.31	0.34	0.37	0.40
4	4.80	—	0.26	0.29	0.32	0.35	0.38	0.41
6	6.90	0.25	0.28	0.31	0.34	0.37	0.40	0.43
8	9.05	0.27	0.30	0.33	0.36	0.39	0.42	0.45
10	11.10	0.29	0.32	0.35	0.38	0.41	0.44	0.47
12	13.20	0.31	0.34	0.37	0.40	0.43	0.46	0.49
14	15.30	0.33	0.36	0.39	0.42	0.45	0.48	0.51
16	17.40	0.34	0.37	0.40	0.43	0.46	0.49	0.52
18	19.50	0.35	0.38	0.41	0.44	0.47	0.50	0.53
20	21.60	0.36	0.39	0.42	0.45	0.48	0.51	0.54
24	25.80	0.38	0.41	0.44	0.47	0.50	0.53	0.56
30	32.00	0.39	0.43	0.47	0.51	0.55	0.59	0.63
36	38.30	0.43	0.48	0.53	0.58	0.63	0.68	0.73
42	44.50	0.47	0.53	0.59	0.65	0.71	0.77	0.83
48	50.80	0.51	0.58	0.65	0.72	0.79	0.86	0.93
54	57.10	0.57	0.65	0.73	0.81	0.89	0.97	1.05

CTD014581

TABLE 50.6

Surface Load Factors for Single Truck on Unpaved Road

Depth of Cover *ft*	Pipe Size—*in.*							
	3	4	6	8	10	12	14	16
	Surface Load Factor—*C*							
2.5	0.0196	0.0238	0.0340	0.0443	0.0538	0.0634	0.0726	0.0814
3	0.0146	0.0177	0.0253	0.0330	0.0402	0.0475	0.0546	0.0614
4	0.0088	0.0107	0.0153	0.0201	0.0245	0.0290	0.0335	0.0379
5	0.0059	0.0071	0.0102	0.0134	0.0163	0.0194	0.0224	0.0254
6	0.0042	0.0050	0.0072	0.0095	0.0116	0.0138	0.0159	0.0181
7	0.0031	0.0038	0.0054	0.0071	0.0087	0.0103	0.0119	0.0135
8	0.0024	0.0029	0.0042	0.0055	0.0067	0.0079	0.0092	0.0104
9	0.0019	0.0023	0.0033	0.0043	0.0053	0.0063	0.0073	0.0083
10	0.0015	0.0019	0.0027	0.0035	0.0043	0.0051	0.0060	0.0068
12	0.0011	0.0013	0.0019	0.0025	0.0030	0.0036	0.0042	0.0047
14	0.0008	0.0010	0.0014	0.0018	0.0022	0.0027	0.0031	0.0035
16	0.0006	0.0007	0.0011	0.0014	0.0017	0.0020	0.0024	0.0027
20	0.0004	0.0005	0.0007	0.0009	0.0011	0.0013	0.0015	0.0017
24	0.0003	0.0003	0.0005	0.0006	0.0008	0.0009	0.0011	0.0012
28	0.0002	0.0002	0.0003	0.0005	0.0006	0.0007	0.0008	0.0009
32	0.0002	0.0002	0.0003	0.0003	0.0004	0.0005	0.0006	0.0007

Depth of Cover *ft*	Pipe Size—*in.*							
	18	20	24	30	36	42	48	54
	Surface Load Factor—*C*							
2.5	0.0899	0.0980	0.1130	0.1321	0.1479	0.1604	0.1705	0.1784
3	0.0681	0.0746	0.0867	0.1028	0.1169	0.1286	0.1384	0.1466
4	0.0422	0.0464	0.0545	0.0657	0.0761	0.0853	0.0936	0.1008
5	0.0283	0.0312	0.0369	0.0449	0.0525	0.0595	0.0661	0.0720
6	0.0202	0.0223	0.0264	0.0323	0.0381	0.0435	0.0486	0.0534
7	0.0151	0.0167	0.0198	0.0243	0.0288	0.0329	0.0370	0.0409
8	0.0117	0.0129	0.0154	0.0189	0.0224	0.0258	0.0290	0.0322
9	0.0093	0.0103	0.0122	0.0151	0.0179	0.0206	0.0233	0.0259
10	0.0076	0.0084	0.0100	0.0123	0.0147	0.0169	0.0191	0.0213
12	0.0053	0.0059	0.0070	0.0086	0.0103	0.0119	0.0135	0.0151
14	0.0039	0.0043	0.0052	0.0064	0.0076	0.0088	0.0100	0.0112
16	0.0030	0.0033	0.0040	0.0049	0.0059	0.0068	0.0077	0.0087
20	0.0019	0.0021	0.0025	0.0032	0.0038	0.0044	0.0050	0.0056
24	0.0013	0.0015	0.0018	0.0022	0.0026	0.0030	0.0035	0.0039
28	0.0010	0.0011	0.0013	0.0016	0.0019	0.0022	0.0026	0.0029
32	0.0008	0.0008	0.0010	0.0012	0.0015	0.0017	0.0020	0.0022

CTD014582

TABLE 50.7

*Diameter-Thickness Ratios for Laying Condition Type 1**

Trench Load (P_r)—*psi*			Trench Load (P_s)—*psi*		
Bending Stress Design	Deflection Design	$\frac{Dt}{i}$ or $\frac{D}{I_1}$	Bending Stress Design	Deflection Design	$\frac{Dt}{i}$ or $\frac{D}{I_1}$
4.40	3.46	170	6.33	4.71	128
4.43	3.48	169	6.40	4.76	127
4.46	3.50	168	6.46	4.82	126
4.50	3.51	167			
4.54	3.53	166	6.53	4 87	125
			6.60	4.93	124
4.57	3.55	165	6.67	4.99	123
4.61	3.57	164	6.74	5.05	122
4.64	3.59	163	6.82	5.11	121
4.68	3.61	162			
4.72	3.63	161	6.89	5.18	120
			6.97	5.25	119
4.76	3.65	160	7.05	5.32	118
4.80	3.67	159	7.13	5.39	117
4.84	3.69	158	7.21	5.46	116
4.88	3.71	157			
4.92	3.74	156	7.29	5.54	115
			7.38	5.62	114
4.96	3.76	155	7.47	5.71	113
5.00	3.78	154	7.56	5.79	112
5.04	3.81	153	7.65	5.88	111
5.08	3.83	152			
5.13	3.86	151	7.75	5.97	110
			7.85	6.07	109
5.17	3.89	150	7.95	6.17	108
5.21	3.91	149	8.05	6.27	107
5.26	3.94	148	8.16	6.38	106
5.30	3.97	147			
5.35	4.00	146	8 27	6.49	105
			8.38	6.61	104
5.40	4.03	145	8.49	6.73	103
5.45	4.06	144	8.61	6.86	102
5.49	4.09	143	8.74	6.99	101
5.54	4.13	142			
5.59	4.16	141	8.86	7.12	100
			8.99	7.26	99
5.65	4.20	140	9.13	7.41	98
5.70	4.23	139	9.27	7.57	97
5.75	4.27	138	9.41	7.73	96
5.80	4.31	137			
5.86	4.35	136	9.56	7.89	95
			9.71	8.07	94
5.91	4.39	135	9.87	8.25	93
5.97	4.43	134	10.03	8.44	92
6.03	4.47	133	10.20	8.64	91
6.09	4.52	132			
6.15	4.56	131	10.37	8.85	90
			10.55	9.06	89
6.21	4.61	130	10.74	9.29	88
6.27	4.66	129	10.93	9.53	87
			11.13	9.78	86

CTD014583

TABLE 50.7—(*cont.*)

Trench Load (P_t)—*psi*			Trench Load (P_t)—*psi*		
Bending Stress Design	Deflection Design	$\frac{Dt}{i}$ or $\frac{D}{I_t}$	Bending Stress Design	Deflection Design	$\frac{Dt}{i}$ or $\frac{D}{I_t}$
11.34	10.04	85	21.91	26.54	58
11.55	10.31	84	22.63	27.85	57
11.78	10.60	83	23.38	29.26	56
12.01	10.90	82			
12.25	11.22	81	24.18	30.77	55
			25.02	32.39	54
12.50	11.56	80	25.92	34.15	53
12.76	11.91	79	26.86	36.05	52
13.03	12.28	78	27.87	38.10	51
13.31	12.67	77			
13.60	13.08	76	28.94	40.32	50
			30.07	42.73	49
13.91	13.51	75	31.28	45.35	48
14.23	13.97	74	32.57	48.20	47
14.56	14.45	73	33.95	51.31	46
14.91	14.96	72			
15.27	15.50	71	35.42	54.72	45
			37.00	58.44	44
15.65	16.07	70	38.69	62.53	43
16.05	16.68	69	40.50	67.03	42
16.46	17.32	68	42.46	71.99	41
16.89	18.00	67			
17.35	18.73	66	44.56	77.47	40
			46.84	83.54	39
17.83	19.50	65	49.30	90.28	38
18.33	20.32	64	51.96	97.80	37
18.85	21.19	63	54.86	106.20	36
19.40	22.12	62			
19.98	23.12	61	58.02	115.62	35
			61.46	126.21	34
			65.23	138.18	33
20.59	24.18	60	69.36	151.73	32
21.23	25.32	59	73.92	167.15	31

* $E' = 150$; $K_b = 0.235$; $K_s = 0.108$.

† The $\frac{D}{t}$ for the tabulated P_t nearest to the calculated P_t is selected; when the calculated P_t is halfway between two tabulated values, the smaller $\frac{D}{t}$ should be used.

CTD014584

TABLE 50.8

*Diameter-Thickness Ratios for Laying Condition Type 2**

Trench Load (P_v)—psi			Trench Load (P_v)—psi		
Bending Stress Design	Deflection Design	$\frac{Dt}{i}$ or $\frac{D}{t_1}$	Bending Stress Design	Deflection Design	$\frac{Dt}{i}$ or $\frac{D}{t_1}$
6.29	6.18	170	8.99	7.46	128
6.34	6.19	169	9.07	7.51	127
6.39	6.21	168	9.16	7.57	126
6.44	6.23	167			
6.50	6.25	166	9.25	7.63	125
			9.33	7.69	124
6.55	6.26	165	9.42	7.75	123
6.60	6.28	164	9.51	7.81	122
6.66	6.30	163	9.60	7.87	121
6.71	6.32	162			
6.77	6.34	161	9.70	7.94	120
			9.79	8.01	119
6.82	6.37	160	9.89	8.08	118
6.88	6.39	159	9.99	8.16	117
6.94	6.41	158	10.09	8.23	116
6.99	6.43	157			
7.05	6.46	156	10.19	8.31	115
			10.29	8.40	114
7.11	6.48	155	10.40	8.48	113
7.17	6.50	154	10.51	8.57	112
7.23	6.53	153	10.62	8.66	111
7.29	6.56	152			
7.35	6.58	151	10.73	8.76	110
			10.84	8.86	109
7.42	6.61	150	10.96	8.96	108
7.48	6.64	149	11.08	9.07	107
7.54	6.67	148	11.21	9.18	106
7.61	6.70	147			
7.67	6.73	146	11.33	9.29	105
			11.46	9.41	104
7.74	6.76	145	11.59	9.54	103
7.80	6.79	144	11.73	9.67	102
7.87	6.83	143	11.87	9.80	101
7.94	6.86	142			
8.01	6.89	141	12.01	9.94	100
			12.16	10.09	99
8.08	6.93	140	12.31	10.24	98
8.15	6.97	139	12.46	10.40	97
8.22	7.01	138	12.62	10.56	96
8.29	7.05	137			
8.37	7.09	136	12.79	10.73	95
			12.96	10.91	94
8.44	7.13	135	13.13	11.10	93
8.52	7.17	134	13.31	11.29	92
8.59	7.22	133	13.49	11.50	91
8.67	7.26	132			
8.75	7.31	131	13.68	11.71	90
			13.88	11.94	89
8.83	7.36	130	14.08	12.17	88
8.91	7.41	129	14.30	12.42	87
			14.51	12.67	86

CTD014585

TABLE 50.8—(*cont.*)

Trench Load (P_v)—*psi*			Trench Load (P_v)—*psi*		
Bending Stress Design	Deflection Design	$\frac{D}{t}$† or $\frac{D}{t_1}$	Bending Stress Design	Deflection Design	$\frac{D}{t}$† or $\frac{D}{t_1}$
14.74	12.94	85	26.95	31.26	57
14.97	13.22	84	27.77	32.71	56
15.21	13.52	83			
15.46	13.83	82	28.64	34.26	55
15.72	14.16	81	29.56	35.93	54
			30.53	37.74	53
15.99	14.50	80	31.57	39.69	52
16.28	14.86	79	32.67	41.80	51
16.57	15.24	78			
16.87	15.64	77	33.84	44.09	50
17.19	16.06	76	35.08	46.56	49
			36.41	49.26	48
17.52	16.51	75	37.83	52.19	47
17.86	16.98	74	39.34	55.40	46
18.22	17.48	73			
18.59	18.00	72	40.96	58.89	45
18.98	18.56	71	42.70	62.73	44
			44.57	66.93	43
19.39	19.14	70	46.57	71.56	42
19.82	19.77	69	48.73	76.66	41
20.27	20.43	68			
20.73	21.13	67	51.06	82.29	40
21.23	21.87	66	53.57	88.54	39
			56.30	95.48	38
21.74	22.67	65	59.25	103.21	37
22.28	23.51	64	62.46	111.85	36
22.85	24.41	63			
23.45	25.37	62	65.96	121.54	35
24.07	26.39	61	69.79	132.44	34
			73.98	144.74	33
24.74	27.49	60	78.57	158.68	32
25.43	28.66	59	83.64	174.54	31
26.17	29.91	58			

* $E' = 300$; $K_b = 0.210$; $K_s = 0.105$.

† The $\frac{D}{t}$ for the tabulated P_v nearest to the calculated P_v is selected; when the calculated P_v is halfway between two tabulated values, the smaller $\frac{D}{t}$ should be used.

CTD014586

TABLE 50.9

*Diameter-Thickness Ratios for Laying Condition Type 3**

Trench Load (P_v)—*psi*			Trench Load (P_v)—*psi*		
Bending Stress Design	Deflection Design	$\frac{Dt}{t}$ or $\frac{D}{t_1}$	Bending Stress Design	Deflection Design	$\frac{Dt}{t}$ or $\frac{D}{t_1}$
3.25	7.26	310	5.62	7.52	226
3.29	7.27	308	5.70	7.53	224
3.33	7.27	306	5.79	7.54	222
3.37	7.27	304			
3.41	7.28	302	5.87	7.55	220
			5.96	7.56	218
3.45	7.28	300	6.04	7.58	216
3.49	7.28	298	6.13	7.59	214
3.54	7.29	296	6.22	7.60	212
3.58	7.29	294			
3.63	7.30	292	6.32	7.62	210
			6.41	7.63	208
3.67	7.30	290	6.51	7.65	206
3.72	7.30	288	6.60	7.66	204
3.76	7.31	286	6.70	7.68	202
3.81	7.31	284			
3.86	7.32	282	6.80	7.70	200
			6.91	7.72	198
3.91	7.32	280	7.01	7.74	196
3.96	7.33	278	7.12	7.76	194
4.01	7.33	276	7.22	7.78	192
4.06	7.34	274			
4.11	7.34	272	7.33	7.80	190
			7.45	7.82	188
4.17	7.35	270	7.56	7.84	186
4.22	7.35	268	7.68	7.87	184
4.28	7.36	266	7.80	7.89	182
4.33	7.36	264			
4.39	7.37	262	7.92	7.92	180
			8.04	7.95	178
4.45	7.38	260	8.16	7.98	176
4.51	7.38	258	8.29	8.01	174
4.57	7.39	256	8.42	8.04	172
4.63	7.39	254			
4.69	7.40	252	8.55	8.07	170
			8.62	8.09	169
4.76	7.41	250	8.69	8.11	168
4.82	7.42	248	8.75	8.13	167
4.89	7.42	246	8.82	8.14	166
4.96	7.43	244			
5.03	7.44	242	8.89	8.16	165
			8.96	8.18	164
5.10	7.45	240	9.03	8.20	163
5.17	7.46	238	9.10	8.22	162
5.24	7.47	236	9.17	8.24	161
5.31	7.48	234			
5.39	7.48	232	9.25	8.27	160
			9.32	8.29	159
5.47	7.49	230	9.39	8.31	158
5.54	7.51	228	9.47	8.33	157
			9.54	8.36	156

CTD014587

TABLE 50.9—(*cont.*)

Trench Load (P_v)—*psi*			Trench Load (P_v)—*psi*		
Bending Stress Design	Deflection Design	$\frac{Dt}{i}$ or $\frac{D}{I_1}$	Bending Stress Design	Deflection Design	$\frac{Dt}{i}$ or $\frac{D}{I_1}$
9.62	8.38	155	13.71	10.51	112
9.69	8.41	154	13.83	10.61	111
9.77	8.43	153			
9.85	8.46	152	13.96	10.71	110
9.92	8.49	151	14.09	10.81	109
			14.22	10.91	108
10.00	8.52	150	14.36	11.02	107
10.08	8.54	149	14.50	11.13	106
10.16	8.57	148			
10.24	8.60	147	14.64	11.25	105
10.33	8 64	146	14.78	11.37	104
			14.93	11.50	103
10.41	8.67	145	15.08	11.63	102
10.49	8.70	144	15.23	11.77	101
10.58	8.73	143			
10.66	8.77	142	15.39	11.91	100
10.75	8.81	141	15.55	12.06	99
			15.71	12.21	98
10.83	8.84	140	15.88	12.37	97
10.92	8.88	139	16.06	12.54	96
11.01	8.92	138			
11.10	8.96	137	16.23	12.72	95
11.19	9.00	136	16.42	12.90	94
			16.61	13.09	93
11.28	9.04	135	16.80	13.29	92
11.37	9.09	134	17.00	13.50	91
11 46	9.13	133			
11.56	9.18	132	17.21	13.72	90
11.65	9.23	131	17.42	13.95	89
			17.64	14.18	88
11.75	9.28	130	17.86	14.43	87
11.84	9.33	129	18.10	14.70	86
11.94	9.38	128			
12.04	9.44	127	18.34	14.97	85
12.14	9.49	126	18.59	15.26	84
			18.85	15.56	83
12.25	9.55	125	19.12	15.88	82
12.35	9.61	124	19.40	16.21	81
12.45	9.67	123			
12.56	9.74	122	19.68	16.56	80
12.67	9.80	121	19.99	16.93	79
			20.30	17.31	78
12.78	9.87	120	20.62	17.72	77
12.89	9.94	119	20.96	18.15	76
13.00	10.02	118			
13.11	10.09	117	21.31	18.61	75
13.23	10.17	116	21.68	19.09	74
			22.07	19.59	73
13.34	10.25	115	22.47	20.13	72
13.46	10.34	114	22.88	20.69	71
13.58	10.42	113			

CTD014588

TABLE 50.9—(*cont.*)

Trench Load (P_e)—*psi*			Trench Load (P_e)—*psi*		
Bending Stress Design	Deflection Design	$\frac{D}{t}$† or $\frac{D}{I_1}$	Bending Stress Design	Deflection Design	$\frac{D}{t}$† or $\frac{D}{I_1}$
23.32	21.29	70	38.97	46.72	50
23.78	21.93	69	40.33	49.25	49
24.26	22.60	68	41.78	51.99	48
24.76	23.32	67	43.33	54.98	47
25.29	24.08	66	44.98	58.25	46
25.85	24.88	65	46.76	61.81	45
26.43	25.74	64	48.66	65.72	44
27.04	26.66	63	50.71	70.01	43
27.68	27.64	62	52.91	74.72	42
28.36	28.68	61	55.28	79.92	41
29.08	29.80	60	57.84	85.67	40
29.83	30.99	59	60.61	92.04	39
30.63	32.27	58	63.61	99.11	38
31.47	33.64	57	66.86	106.99	37
32.36	35.12	56	70.40	115.80	36
33.31	36.70	55	74.27	125.67	35
34.30	38.41	54	78.49	136.78	34
35.37	40.25	53	83.11	149.32	33
36.49	42.24	52	88.19	163.54	32
37.69	44.39	51	93.79	179.71	31

* $E' = 400$; $K_b = 0.189$; $K_s = 0.103$.

† The $\frac{D}{t}$ for the tabulated P_e nearest to the calculated P_e is selected; when the calculated P_e is halfway between two tabulated values, the smaller $\frac{D}{t}$ should be used.

CTD014589

TABLE 50.10

*Diameter-Thickness Ratios for Laying Condition Type 4**

Trench Load (P_e)—*psi*			Trench Load (P_e)—*psi*		
Bending Stress Design	Deflection Design	$\frac{Dt}{t}$ or $\frac{D}{t_1}$	Bending Stress Design	Deflection Design	$\frac{Dt}{t}$ or $\frac{D}{t_1}$
5.93	9.70	310	9.95	9.97	226
6.00	9.70	308	10.08	9.98	224
6.07	9.71	306	10.21	9.99	222
6.14	9.71	304			
6.21	9.71	302	10.35	10.01	220
			10.49	10.02	218
6.29	9.72	300	10.62	10.03	216
6.36	9.72	298	10.77	10.05	214
6.43	9.73	296	10.91	10.06	212
6.51	9.73	294			
6.59	9.73	292	11.05	10.08	210
			11.20	10.09	208
6.67	9.74	290	11.35	10.11	206
6.74	9.74	288	11.50	10.13	204
6.83	9.75	286	11.66	10.15	202
6.91	9.75	284			
6.99	9.76	282	11.81	10.17	200
			11.97	10.19	198
7.08	9.76	280	12.13	10.21	196
7.16	9.77	278	12.29	10.23	194
7.25	9.77	276	12.45	10.25	192
7.34	9.78	274			
7.43	9.78	272	12.62	10.27	190
			12.79	10.30	188
7.52	9.79	270	12.96	10.32	186
7.61	9.79	268	13.13	10.35	184
7.71	9.80	266	13.30	10.37	182
7.80	9.81	264			
7.90	9.81	262	13.48	10.40	180
			13.66	10.43	178
8.00	9.82	260	13.84	10.46	176
8.10	9.83	258	14.02	10.50	174
8.20	9.83	256	14.20	10.53	172
8.31	9.84	254			
8.41	9.85	252	14.39	10.57	170
			14.48	10.59	169
8.52	9.86	250	14.57	10.60	168
8.63	9.86	248	14.67	10.62	167
8.74	9.87	246	14.76	10.64	166
8.85	9.88	244			
8.97	9.89	242	14.86	10.66	165
			14.96	10.69	164
9.08	9.90	240	15.05	10.71	163
9.20	9.91	238	15.15	10.73	162
9.32	9.92	236	15.25	10.75	161
9.44	9.93	234	15.34	10.78	160
9.57	9.94	232	15.44	10.80	159
			15.54	10.82	158
9.69	9.95	230	15.64	10.85	157
9.82	9.96	228	15.74	10.87	156

CTD014590

TABLE 50.10—(*cont.*)

Trench Load (P_v)—*psi*			Trench Load (P_v)—*psi*		
Bending Stress Design	Deflection Design	$\frac{Dt}{i}$ or $\frac{D}{i_1}$	Bending Stress Design	Deflection Design	$\frac{Dt}{i}$ or $\frac{D}{i_1}$
15.84	10.90	155	20.69	13.19	112
15.94	10.93	154	20.82	13.29	111
16.04	10.96	153			
16.14	10.98	152	20.96	13.39	110
16.24	11.01	151	21.10	13.50	109
			21.24	13.61	108
16.34	11.04	150	21.39	13.73	107
16.45	11.07	149	21.54	13.85	106
16.55	11.11	148			
16.65	11.14	147	21.69	13.98	105
16.76	11.17	146	21.84	14.11	104
			22.00	14.24	103
16.86	11.21	145	22.16	14.38	102
16.96	11.24	144	22.32	14.53	101
17.07	11.28	143			
17.18	11.31	142	22.49	14.68	100
17.28	11.35	141	22.66	14.84	99
			22.83	15.01	98
17.39	11.39	140	23.01	15.18	97
17.50	11.43	139	23.20	15.36	96
17.60	11.48	138			
17.71	11.52	137	23.38	15.55	95
17.82	11.56	136	23.58	15.75	94
			23.78	15.95	93
17.93	11.61	135	23.99	16.17	92
18.04	11.66	134	24.20	16.39	91
18.15	11.71	133			
18.26	11.76	132	24.42	16.62	90
18.37	11.81	131	24.64	16.87	89
			24.88	17.12	88
18.49	11.86	130	25.12	17.39	87
18.60	11.92	129	25.37	17.67	86
18.72	11.97	128			
18.83	12.03	127	25.63	17.97	85
18.95	12.09	126	25.90	18.28	84
			26.18	18.60	83
19.06	12.15	125	26.47	18.94	82
19.18	12.22	124	26.77	19.30	81
19.30	12.28	123			
19.42	12.35	122	27.09	19.67	80
19.54	12.42	121	27.42	20.07	79
			27.76	20.48	78
19.66	12.50	120	28.11	20.92	77
19.78	12.57	119	28.49	21.38	76
19.91	12.65	118			
20.04	12.73	117	28.87	21.87	75
20.16	12.82	116	29.28	22.38	74
			29.70	22.93	73
20.29	12.91	115	30.15	23.50	72
20.42	13.00	114	30.62	24.11	71
20.55	13.09	113			

CTD014591

TABLE 50.10—(*cont.*)

Trench Load (P_v)—*psi*			Trench Load (P_v)—*psi*		
Bending Stress Design	Deflection Design	$\frac{D}{t}$† or $\frac{D}{t_1}$	Bending Stress Design	Deflection Design	$\frac{D}{t}$† or $\frac{D}{t_1}$
31.11	24.75	70	49.11	52.03	50
31.62	25.43	69	50.70	54.74	49
32.16	26.16	68	52.41	57.69	48
32.72	26.92	67	54.23	60.90	47
33.32	27.74	66	56.18	64.40	46
33.95	28.60	65	58.27	68.23	45
34.61	29.53	64	60.52	72.42	44
35.30	30.51	63	62.93	77.02	43
36.04	31.56	62	65.54	82.08	42
36.81	32.68	61	68.35	87.66	41
37.63	33.88	60	71.39	93.82	40
38.50	35.16	59	74.67	100.65	39
39.42	36.53	58	78.24	108.24	38
40.39	38.00	57	82.11	116.70	37
41.42	39.58	56	86.33	126.15	36
42.51	41.28	55	90.93	136.74	35
43.67	43.12	54	95.97	148.66	34
44.91	45.09	53	101.49	162.12	33
46.22	47.22	52	107.56	177.37	32
47.62	49.53	51	114.25	194.72	31

* $E' = 500$; $K_b = 0.157$; $K_x = 0.096$.

† The $\frac{D}{t}$ for the tabulated P_v nearest to the calculated P_v is selected; when the calculated P_v is halfway between two tabulated values, the smaller $\frac{D}{t}$ should be used.

CTD014592

TABLE 50.11

*Diameter–Thickness Ratios for Laying Condition Type 5**

Trench Load (P_t)—psi			Trench Load (P_t)—psi		
Bending Stress Design	Deflection Design	$\frac{Dt}{I}$ or $\frac{D}{t_1}$	Bending Stress Design	Deflection Design	$\frac{Dt}{I}$ or $\frac{D}{t_1}$
3.06	15.09	660	6.41	15.13	450
3.10	15.09	655	6.54	15.14	445
3.15	15.09	650	6.68	15.14	440
3.20	15.09	645			
3.25	15.09	640	6.83	15.14	435
			6.98	15.14	430
3.30	15.09	635	7.13	15.14	425
3.35	15.09	630	7.29	15.15	420
3.40	15.09	625	7.46	15.15	415
3.46	15.09	620			
3.51	15.09	615	7.63	15.15	410
			7.80	15.16	405
3.57	15.10	610	7.98	15.16	400
3.63	15.10	605	8.17	15.16	395
3.68	15.10	600	8.36	15.17	390
3.75	15.10	595			
3.81	15.10	590	8.56	15.17	385
			8.77	15.17	380
3.87	15.10	585	8.98	15.18	375
3.94	15.10	580	9.20	15.18	370
4.00	15.10	575	9.43	15.19	365
4.07	15.10	570			
4.14	15.10	565	9.66	15.19	360
			9.91	15.20	355
4.21	15.10	560	10.16	15.20	350
4.29	15.10	555	10.42	15.21	345
4.36	15.10	550	10.69	15.22	340
4.44	15.11	545			
4.52	15.11	540	10.97	15.22	335
			11.26	15.23	330
4.60	15.11	535	11.56	15.24	325
4.69	15.11	530	11.87	15.24	320
4.77	15.11	525	12.19	15.25	315
4.86	15.11	520			
4.95	15.11	515	12.52	15.26	310
			12.66	15.27	308
5.05	15.11	510	12.80	15.27	306
5.14	15.11	505	12.94	15.27	304
5.24	15.12	500	13.08	15.28	302
5.35	15.12	495			
5.45	15.12	490	13.23	15.28	300
			13.37	15.29	298
5.56	15.12	485	13.52	15.29	296
5.67	15.12	480	13.67	15.30	294
5.78	15.12	475	13.83	15.30	292
5.90	15.13	470			
6.02	15.13	465	13.98	15.30	290
			14.14	15.31	288
6.15	15.13	460	14.30	15.31	286
6.28	15.13	455	14.46	15.32	284
			14.62	15.33	282

CTD014593

TABLE 50.11—(*cont.*)

Trench Load (P_e)—*psi*			Trench Load (P_e)—*psi*		
Bending Stress Design	Deflection Design	$\frac{Dt}{t}$ or $\frac{D}{I_1}$	Bending Stress Design	Deflection Design	$\frac{Dt}{t}$ or $\frac{D}{I_1}$
14.79	15.33	280	24.24	15.86	194
14.96	15.34	278	24.50	15.88	192
15.13	15.34	276			
15.30	15.35	274	24.77	15.91	190
15.48	15.35	272	25.04	15.93	188
			25.31	15.96	186
15.65	15.36	270	25.59	15.99	184
15.83	15.37	268	25.86	16.02	182
16.02	15.37	266			
16.20	15.38	264	26.13	16.06	180
16.39	15.39	262	26.41	16.09	178
			26.68	16.12	176
16.58	15.40	260	26.96	16.16	174
16.77	15.40	258	27.23	16.20	172
16.97	15.41	256			
17.16	15.42	254	27.51	16.24	170
17.36	15.43	252	27.65	16.26	169
			27.78	16.28	168
17.57	15.44	250	27.92	16.31	167
17.77	15.45	248	28.06	16.33	166
17.98	15.45	246			
18.19	15.46	244	28.19	16.35	165
18.40	15.47	242	28.33	16.37	164
			28.47	16.40	163
18.62	15.48	240	28.60	16.42	162
18.84	15.49	238	28.74	16.45	161
19.06	15.51	236			
19.28	15.52	234	28.87	16.48	160
19.51	15.53	232	29.01	16.50	159
			29.15	16.53	158
19.73	15.54	230	29.28	16.56	157
19.97	15.55	228	29.41	16.59	156
20.20	15.57	226			
20.43	15.58	224	29.55	16.62	155
20.67	15.59	222	29.68	16.65	154
			29.82	16.68	153
20.91	15.61	220	29.95	16.71	152
21.16	15.62	218	30.08	16.74	151
21.40	15.64	216			
21.65	15.65	214	30.21	16.78	150
21.90	15.67	212	30.34	16.81	149
			30.48	16.85	148
22.15	15.69	210	30.61	16.89	147
22.40	15.71	208	30.74	16.92	146
22.66	15.73	206			
22.92	15.75	204	30.87	16.96	145
23.18	15.77	202	30.99	17.00	144
			31.12	17.04	143
23.44	15.79	200	31.25	17.09	142
23.70	15.81	198	31.38	17.13	141
23.97	15.83	196			

CTD014594

TABLE 50.11—(*cont.*)

Trench Load (P_e)—*psi*			Trench Load (P_e)—*psi*		
Bending Stress Design	Deflection Design	$\frac{D\dagger}{t}$ or $\frac{D}{t_1}$	Bending Stress Design	Deflection Design	$\frac{D\dagger}{t}$ or $\frac{D}{t_1}$
31.50	17.17	140	37.01	21.45	97
31.63	17.22	139	37.17	21.66	96
31.76	17.27	138			
31.88	17.32	137	37.34	21.87	95
32.01	17.37	136	37.52	22.09	94
			37.70	22.32	93
32.13	17.42	135	37.89	22.56	92
32.25	17.47	134	38.08	22.82	91
32.38	17.53	133			
32.50	17.58	132	38.28	23.08	90
32.62	17.64	131	38.49	23.36	89
			38.71	23.65	88
32.75	17.70	130	38.93	23.95	87
32.87	17.76	129	39.17	24.27	86
32.99	17.83	128			
33.11	17.89	127	39.41	24.60	85
33.23	17.96	126	39.67	24.95	84
			39.94	25.31	83
33.35	18.03	125	40.22	25.70	82
33.47	18.11	124	40.51	26.10	81
33.59	18.18	123			
33.71	18.26	122	40.82	26.52	80
33.83	18.34	121	41.14	26.97	79
			41.48	27.44	78
33.95	18.42	120	41.84	27.93	77
34.07	18.51	119	42.21	28.46	76
34.19	18.60	118			
34.31	18.69	117	42.60	29.01	75
34.43	18.78	116	43.02	29.59	74
			43.45	30.20	73
34.55	18.88	115	43.92	30.85	72
34.68	18.98	114	44.40	31.53	71
34.80	19.09	113			
34.92	19.20	112	44.91	32.26	70
35.05	19.31	111	45.46	33.03	69
			46.03	33.85	68
35.17	19.43	110	46.64	34.71	67
35.30	19.55	109	47.28	35.63	66
35.43	19.68	108			
35.56	19.81	107	47.96	36.61	65
35.69	19.95	106	48.68	37.65	64
			49.44	38.77	63
35.83	20.09	105	50.25	39.95	62
35.96	20.24	104	51.11	41.21	61
36.10	20.39	103			
36.25	20.55	102	52.02	42.57	60
36.39	20.72	101	52.99	44.01	59
			54.02	45.56	58
36.54	20.89	100	55.12	47.23	57
36.69	21.07	99	56.28	49.01	56
36.85	21.26	98			

CTD014595

TABLE 50.11—(*cont.*)

Trench Load (P_e)—*psi*			Trench Load (P_e)—*psi*		
Bending Stress Design	Deflection Design	$\frac{Dt}{t}$ or $\frac{D}{t_1}$	Bending Stress Design	Deflection Design	$\frac{Dt}{t}$ or $\frac{D}{t_1}$
57.53	50.93	55	84.50	97.01	42
58.86	53.00	54	87.85	103.31	41
60.28	55.23	53			
61.79	57.64	52			
63.41	60.25	51	91.47	110.27	40
			95.40	117.98	39
65.14	63.07	50	99.67	126.56	38
67.00	66.13	49	104.32	136.11	37
68.99	69.46	48	109.40	146.78	36
71.12	73.09	47			
73.41	77.04	46	114.94	158.75	35
			121.02	172.21	34
75.88	81.36	45	127.69	187.41	33
78.54	86.10	44	135.03	204.63	32
81.40	91.29	43	143.14	224.22	31

* $E' = 700$; $K_b = 0.128$; $K_s = 0.085$.

† The $\frac{D}{t}$ for the tabulated P_e nearest to the calculated P_e is selected; when the calculated P_e is halfway between two tabulated values, the smaller $\frac{D}{t}$ should be used.

CTD014596

TABLE 50.12

Thickness for Earth Load Plus Truck Load

Size in.	Depth of Cover ft	Laying Condition									
		Type 1		Type 2		Type 3		Type 4		Type 5	
		Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class
3	2.5	0.18	51	0.17	51	0.16	51	0.15	51	0.14	51
	3	0.17	51	0.16	51	0.16	51	0.15	51	0.14	51
	4	0.17	51	0.16	51	0.15	51	0.14	51	0.14	51
	5	0.16	51	0.16	51	0.15	51	0.14	51	0.14	51
	6	0.16	51	0.16	51	0.15	51	0.14	51	0.14	51
	7	0.16	51	0.16	51	0.15	51	0.14	51	0.14	51
	8	0.17	51	0.16	51	0.15	51	0.15	51	0.14	51
	9	0.17	51	0.16	51	0.15	51	0.15	51	0.14	51
	10	0.17	51	0.16	51	0.15	51	0.15	51	0.14	51
	12	0.17	51	0.17	51	0.16	51	0.15	51	0.14	51
	14	0.18	51	0.17	51	0.16	51	0.15	51	0.14	51
	16	0.18	51	0.17	51	0.17	51	0.15	51	0.14	51
	20	0.19	51	0.18	51	0.17	51	0.16	51	0.15	51
	24	0.19	51	0.19	51	0.18	51	0.16	51	0.15	51
	28	0.20	51	0.19	51	0.19	51	0.17	51	0.15	51
	32	0.21	51	0.20	51	0.19	51	0.18	51	0.15	51
4	2.5	0.19	51	0.18	51	0.17	51	0.15	51	0.15	51
	3	0.18	51	0.17	51	0.16	51	0.15	51	0.14	51
	4	0.17	51	0.16	51	0.16	51	0.15	51	0.14	51
	5	0.17	51	0.16	51	0.15	51	0.15	51	0.14	51
	6	0.17	51	0.16	51	0.15	51	0.15	51	0.14	51
	7	0.17	51	0.16	51	0.16	51	0.15	51	0.14	51
	8	0.17	51	0.16	51	0.16	51	0.15	51	0.14	51
	9	0.18	51	0.17	51	0.16	51	0.15	51	0.14	51
	10	0.18	51	0.17	51	0.16	51	0.15	51	0.14	51
	12	0.18	51	0.17	51	0.16	51	0.15	51	0.14	51
	14	0.19	51	0.18	51	0.17	51	0.15	51	0.15	51
	16	0.19	51	0.18	51	0.17	51	0.16	51	0.15	51
	20	0.20	51	0.19	51	0.18	51	0.16	51	0.15	51
	24	0.21	51	0.20	51	0.19	51	0.17	51	0.15	51
	28	0.22	51	0.21	51	0.20	51	0.18	51	0.15	51
	32	0.22	51	0.21	51	0.21	51	0.19	51	0.16	51
6	2.5	0.21	50	0.20	50	0.18	50	0.16	50	0.15	50
	3	0.20	50	0.19	50	0.18	50	0.16	50	0.15	50
	4	0.19	50	0.18	50	0.17	50	0.16	50	0.15	50
	5	0.19	50	0.17	50	0.17	50	0.15	50	0.15	50
	6	0.19	50	0.17	50	0.17	50	0.15	50	0.15	50
	7	0.19	50	0.18	50	0.17	50	0.16	50	0.15	50
	8	0.19	50	0.18	50	0.17	50	0.16	50	0.15	50
	9	0.20	50	0.18	50	0.17	50	0.16	50	0.15	50
	10	0.20	50	0.18	50	0.17	50	0.16	50	0.15	50
	12	0.21	50	0.19	50	0.18	50	0.16	50	0.15	50
	14	0.21	50	0.20	50	0.18	50	0.17	50	0.15	50
	16	0.22	50	0.21	50	0.19	50	0.17	50	0.15	50
	20	0.23	50	0.22	50	0.21	50	0.18	50	0 16	50
	24	0.24	50	0.23	50	0.22	50	0.19	50	0.16	50
	28	0.25	50	0.24	50	0.23	50	0.20	50	0.16	50
	32	0.26	50	0.25	50	0.24	50	0.22	50	0.17	50

* Total calculated thickness includes service allowance and casting tolerance added to net thickness.

CTD014597

TABLE 50.12—(*cont.*)

Size *in.*	Depth of Cover *ft*	Laying Condition									
		Type 1		Type 2		Type 3		Type 4		Type 5	
		Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class
8	2.5	0.24	50	0.22	50	0.20	50	0.18	50	0.16	50
	3	0.23	50	0.21	50	0.19	50	0.17	50	0.16	50
	4	0.21	50	0.19	50	0.18	50	0.16	50	0.15	50
	5	0.21	50	0.19	50	0.18	50	0.16	50	0.15	50
	6	0.21	50	0.19	50	0.18	50	0.16	50	0.15	50
	7	0.21	50	0.19	50	0.18	50	0.16	50	0.15	50
	8	0.21	50	0.19	50	0.18	50	0.16	50	0.15	50
	9	0.22	50	0.20	50	0.18	50	0.17	50	0.15	50
	10	0.22	50	0.20	50	0.19	50	0.17	50	0.15	50
	12	0.23	50	0.21	50	0.19	50	0.17	50	0.16	50
	14	0.24	50	0.22	50	0.20	50	0.18	50	0.16	50
	16	0.25	50	0.23	50	0.21	50	0.18	50	0.16	50
	20	0.27	50	0.25	50	0.23	50	0.19	50	0.17	50
	24	0.28	50	0.26	50	0.24	50	0.21	50	0.17	50
	28	0.29	51	0.28	50	0.26	50	0.23	50	0.18	50
	32	0.30	51	0.29	51	0.27	50	0.24	50	0.18	50
10	2.5	0.27	50	0.25	50	0.23	50	0.20	50	0.17	50
	3	0.26	50	0.23	50	0.21	50	0.19	50	0.17	50
	4	0.24	50	0.22	50	0.20	50	0.18	50	0.17	50
	5	0.23	50	0.21	50	0.20	50	0.18	50	0.17	50
	6	0.23	50	0.21	50	0.20	50	0.18	50	0.17	50
	7	0.24	50	0.21	50	0.20	50	0.18	50	0.17	50
	8	0.24	50	0.22	50	0.20	50	0.18	50	0.17	50
	9	0.25	50	0.22	50	0.20	50	0.18	50	0.17	50
	10	0.25	50	0.23	50	0.21	50	0.19	50	0.17	50
	12	0.26	50	0.24	50	0.22	50	0.19	50	0.17	50
	14	0.28	50	0.25	50	0.23	50	0.20	50	0.18	50
	16	0.29	50	0.26	50	0.24	50	0.20	50	0.18	50
	20	0.31	51	0.28	50	0.26	50	0.22	50	0.18	50
	24	0.32	51	0.30	50	0.28	50	0.24	50	0.19	50
	28	0.34	52	0.32	51	0.30	50	0.26	50	0.20	50
	32	0.35	52	0.33	51	0.32	51	0.28	50	0.20	50
12	2.5	0.30	50	0.27	50	0.24	50	0.21	50	0.18	50
	3	0.28	50	0.25	50	0.23	50	0.20	50	0.18	50
	4	0.26	50	0.23	50	0.21	50	0.19	50	0.17	50
	5	0.25	50	0.23	50	0.21	50	0.19	50	0.17	50
	6	0.25	50	0.23	50	0.21	50	0.19	50	0.17	50
	7	0.26	50	0.23	50	0.21	50	0.19	50	0.17	50
	8	0.26	50	0.23	50	0.21	50	0.19	50	0.17	50
	9	0.27	50	0.24	50	0.22	50	0.19	50	0.17	50
	10	0.27	50	0.24	50	0.22	50	0.20	50	0.18	50
	12	0.29	50	0.26	50	0.23	50	0.20	50	0.18	50
	14	0.30	50	0.27	50	0.24	50	0.21	50	0.18	50
	16	0.31	50	0.29	50	0.26	50	0.21	50	0.18	50
	20	0.34	51	0.31	50	0.28	50	0.23	50	0.19	50
	24	0.36	52	0.33	51	0.31	50	0.25	50	0.20	50
	28	0.38	52	0.35	51	0.33	51	0.28	50	0.21	50
	32	0.39	53	0.37	52	0.35	51	0.30	50	0.23	50

* Total calculated thickness includes service allowance and casting tolerance added to net thickness.

CTD014598

TABLE 50.12—(*cont.*)

Size *in.*	Depth of Cover *ft*	Laying Condition									
		Type 1		Type 2		Type 3		Type 4		Type 5	
		Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class
14	2.5	0.32	50	0.29	50	0.26	50	0.22	50	0.20	50
	3	0.31	50	0.27	50	0.24	50	0.21	50	0.19	50
	4	0.29	50	0.26	50	0.23	50	0.21	50	0.19	50
	5	0.28	50	0.25	50	0.23	50	0.20	50	0.19	50
	6	0.28	50	0.25	50	0.23	50	0.20	50	0.19	50
	7	0.28	50	0.25	50	0.23	50	0.21	50	0.19	50
	8	0.29	50	0.26	50	0.23	50	0.21	50	0.19	50
	9	0.30	50	0.26	50	0.24	50	0.21	50	0.19	50
	10	0.31	50	0.27	50	0.24	50	0.21	50	0.19	50
	12	0.32	50	0.29	50	0.26	50	0.22	50	0.19	50
	14	0.34	50	0.30	50	0.27	50	0.23	50	0.20	50
	16	0.35	51	0.32	50	0.29	50	0.24	50	0.20	50
	20	0.38	52	0.35	51	0.32	50	0.26	50	0.21	50
	24	0.40	52	0.38	52	0.34	50	0.28	50	0.22	50
	28	0.42	53	0.40	52	0.37	51	0.31	50	0.24	50
	32	0.44	54	0.42	53	0.39	52	0.34	50	0.26	50
16	2.5	0.34	50	0.30	50	0.27	50	0.23	50	0.20	50
	3	0.32	50	0.28	50	0.25	50	0.22	50	0.20	50
	4	0.30	50	0.27	50	0.24	50	0.21	50	0.19	50
	5	0.30	50	0.26	50	0.24	50	0.21	50	0.19	50
	6	0.30	50	0.26	50	0.24	50	0.21	50	0.19	50
	7	0.30	50	0.26	50	0.24	50	0.21	50	0.19	50
	8	0.31	50	0.27	50	0.25	50	0.22	50	0.19	50
	9	0.32	50	0.28	50	0.25	50	0.22	50	0.20	50
	10	0.33	50	0.29	50	0.26	50	0.22	50	0.20	50
	12	0.35	50	0.31	50	0.27	50	0.23	50	0.20	50
	14	0.36	51	0.33	50	0.29	50	0.24	50	0.20	50
	16	0.38	51	0.34	50	0.30	50	0.25	50	0.21	50
	20	0.41	52	0.38	51	0.34	50	0.27	50	0.22	50
	24	0.44	53	0.41	52	0.37	51	0.30	50	0.24	50
	28	0.46	54	0.43	53	0.40	52	0.33	50	0.27	50
	32	0.48	55	0.46	54	0.43	53	0.36	51	0.29	50
18	2.5	0.36	50	0.32	50	0.28	50	0.24	50	0.20	50
	3	0.34	50	0.29	50	0.26	50	0.23	50	0.20	50
	4	0.32	50	0.28	50	0.25	50	0.22	50	0.20	50
	5	0.31	50	0.27	50	0.25	50	0.22	50	0.19	50
	6	0.31	50	0.27	50	0.25	50	0.22	50	0.19	50
	7	0.32	50	0.28	50	0.25	50	0.22	50	0.20	50
	8	0.33	50	0.29	50	0.26	50	0.22	50	0.20	50
	9	0.34	50	0.30	50	0.26	50	0.23	50	0.20	50
	10	0.35	50	0.30	50	0.27	50	0.23	50	0.20	50
	12	0.37	51	0.32	50	0.29	50	0.24	50	0.21	50
	14	0.39	51	0.35	50	0.30	50	0.25	50	0.21	50
	16	0.41	52	0.37	51	0.32	50	0.26	50	0.22	50
	20	0.44	53	0.40	52	0.36	50	0.29	50	0.23	50
	24	0.47	54	0.44	53	0.40	52	0.32	50	0.26	50
	28	0.50	55	0.46	54	0.43	53	0.36	50	0.29	50
	32	0.53	56	0.49	55	0.46	54	0.39	51	0.32	50

* Total calculated thickness includes service allowance and casting tolerance added to net thickness.

CTD014599

TABLE 50.12—(*cont.*)

Size in.	Depth of Cover ft	Laying Condition									
		Type 1		Type 2		Type 3		Type 4		Type 5	
		Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class
20	2.5	0.38	51	0.33	50	0.29	50	0.24	50	0.21	50
	3	0.35	50	0.31	50	0.27	50	0.23	50	0.20	50
	4	0.34	50	0.29	50	0.26	50	0.23	50	0.20	50
	5	0.33	50	0.28	50	0.26	50	0.23	50	0.20	50
	6	0.33	50	0.29	50	0.26	50	0.23	50	0.20	50
	7	0.34	50	0.29	50	0.26	50	0.23	50	0.20	50
	8	0.35	50	0.30	50	0.27	50	0.23	50	0.20	50
	9	0.36	50	0.31	50	0.28	50	0.24	50	0.21	50
	10	0.37	50	0.32	50	0.28	50	0.24	50	0.21	50
	12	0.39	51	0.34	50	0.30	50	0.25	50	0.21	50
	14	0.41	52	0.37	50	0.32	50	0.26	50	0.22	50
	16	0.43	52	0.39	51	0.34	50	0.27	50	0.22	50
	20	0.47	54	0.43	52	0.39	51	0.31	50	0.23	50
	24	0.50	55	0.47	54	0.42	52	0.34	50	0.28	50
	28	0.54	56	0.50	55	0.46	53	0.38	51	0.31	50
	32	0.57	—	0.53	56	0.49	54	0.42	52	0.34	50
24	2.5	0.42	51	0.35	50	0.31	50	0.26	50	0.22	50
	3	0.39	50	0.33	50	0.29	50	0.25	50	0.21	50
	4	0.37	50	0.31	50	0.28	50	0.24	50	0.21	50
	5	0.36	50	0.31	50	0.28	50	0.24	50	0.21	50
	6	0.36	50	0.31	50	0.28	50	0.24	50	0.21	50
	7	0.37	50	0.32	50	0.28	50	0.24	50	0.21	50
	8	0.39	50	0.33	50	0.29	50	0.25	50	0.21	50
	9	0.40	51	0.34	50	0.30	50	0.25	50	0.22	50
	10	0.41	51	0.35	50	0.31	50	0.26	50	0.22	50
	12	0.44	52	0.38	50	0.33	50	0.27	50	0.23	50
	14	0.46	53	0.41	51	0.35	50	0.28	50	0.23	50
	16	0.49	54	0.44	52	0.38	50	0.31	50	0.24	50
	20	0.54	55	0.49	54	0.43	52	0.36	50	0.25	50
	24	0.57	56	0.53	55	0.48	53	0.40	51	0.32	50
	28	0.61	—	0.57	56	0.52	55	0.43	52	0.36	50
	32	0.65	—	0.60	—	0.56	56	0.47	53	0.40	51
30	2.5	†	†	0.40	50	0.34	50	0.28	50	0.23	50
	3			0.37	50	0.32	50	0.27	50	0.23	50
	4			0.35	50	0.31	50	0.26	50	0.22	50
	5			0.35	50	0.31	50	0.26	50	0.22	50
	6			0.35	50	0.31	50	0.26	50	0.22	50
	7			0.36	50	0.31	50	0.26	50	0.23	50
	8			0.37	50	0.33	50	0.27	50	0.23	50
	9			0.39	50	0.34	50	0.28	50	0.23	50
	10			0.40	50	0.35	50	0.28	50	0.24	50
	12			0.44	51	0.37	50	0.30	50	0.24	50
	14			0.47	52	0.40	50	0.32	50	0.25	50
	16			0.51	53	0.43	51	0.37	50	0.26	50
	20			0.57	55	0.50	53	0.43	51	0.29	50
	24			0.62	56	0.56	54	0.48	52	0.37	50
	28			0.67	—	0.61	56	0.51	53	0.43	51
	32			0.71	—	0.66	—	0.55	54	0.47	52

* Total calculated thickness includes service allowance and casting tolerance added to net thickness.
† For pipe 30 in. and larger, consideration should be given to laying conditions other than Type 1.

CTD014600

TABLE 50.12—(*cont.*)

Size in.	Depth of Cover ft	Laying Condition									
		Type 1		Type 2		Type 3		Type 4		Type 5	
		Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class
36	2.5	†	†	0.43	50	0.37	50	0.30	50	0.25	50
	3			0.40	50	0.35	50	0.29	50	0.24	50
	4			0.39	50	0.34	50	0.28	50	0.24	50
	5			0.38	50	0.34	50	0.28	50	0.24	50
	6			0.39	50	0.34	50	0.28	50	0.24	50
	7			0.40	50	0.35	50	0.29	50	0.24	50
	8			0.42	50	0.36	50	0.30	50	0.24	50
	9			0.43	50	0.37	50	0.30	50	0.25	50
	10			0.45	50	0.38	50	0.31	50	0.25	50
	12			0.49	51	0.42	50	0.33	50	0.26	50
	14			0.54	52	0.46	51	0.37	50	0.27	50
	16			0.58	53	0.49	51	0.42	50	0.28	50
	20			0.65	54	0.57	53	0.50	51	0.33	50
	24			0.71	56	0.63	54	0.55	52	0.43	50
	28			0.77	—	0.70	55	0.60	53	0.50	51
	32			0.82	—	0.76	—	0.64	54	0.55	52
42	2.5	†	†	0.46	50	0.40	50	0.32	50	0.26	50
	3			0.44	50	0.38	50	0.31	50	0.25	50
	4			0.42	50	0.37	50	0.30	50	0.25	50
	5			0.42	50	0.37	50	0.30	50	0.25	50
	6			0.42	50	0.37	50	0.30	50	0.25	50
	7			0.44	50	0.38	50	0.31	50	0.25	50
	8			0.46	50	0.39	50	0.32	50	0.26	50
	9			0.48	50	0.41	50	0.33	50	0.26	50
	10			0.50	51	0.42	50	0.33	50	0.27	50
	12			0.55	51	0.47	50	0.35	50	0.28	50
	14			0.60	52	0.52	51	0.42	50	0.29	50
	16			0.64	53	0.56	52	0.48	50	0.30	50
	20			0.73	54	0.64	53	0.57	52	0.37	50
	24			0.80	56	0.71	54	0.63	53	0.49	50
	28			0.87	—	0.79	55	0.69	54	0.57	52
	32			0.93	—	0.86	—	0.73	54	0.63	53
48	2.5	†	†	0.50	50	0.43	50	0.35	50	0.28	50
	3			0.48	50	0.42	50	0.34	50	0.28	50
	4			0.46	50	0.40	50	0.33	50	0.27	50
	5			0.46	50	0.40	50	0.33	50	0.27	50
	6			0.47	50	0.41	50	0.33	50	0.27	50
	7			0.48	50	0.42	50	0.34	50	0.28	50
	8			0.51	50	0.44	50	0.35	50	0.28	50
	9			0.53	50	0.45	50	0.36	50	0.29	50
	10			0.56	51	0.47	50	0.37	50	0.30	50
	12			0.61	51	0.53	50	0.39	50	0.31	50
	14			0.67	52	0.59	51	0.48	50	0.32	50
	16			0.72	53	0.64	52	0.55	51	0.33	50
	20			0.82	54	0.72	53	0.65	52	0.43	50
	24			0.91	56	0.80	54	0.72	53	0.56	51
	28			0.98	—	0.89	55	0.79	54	0.65	52
	32			1.05	—	0.97	—	0.84	55	0.72	53

* Total calculated thickness includes service allowance and casting tolerance added to net thickness.
† For pipe 30 in. and larger, consideration should be given to laying conditions other than Type 1.

CTD014601

TABLE 50.12—(*cont.*)

Size *in.*	Depth of Cover *ft*	Laying Condition									
		Type 1		Type 2		Type 3		Type 4		Type 5	
		Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class
54	2.5	†	†	0.54	50	0.46	50	0.37	50	0.30	50
	3			0.52	50	0.45	50	0.37	50	0.30	50
	4			0.51	50	0.44	50	0.36	50	0.30	50
	5			0.51	50	0.44	50	0.36	50	0.30	50
	6			0.52	50	0.45	50	0.37	50	0.30	50
	7			0.53	50	0.46	50	0.37	50	0.30	50
	8			0.56	50	0.48	50	0.38	50	0.31	50
	9			0.59	50	0.50	50	0.39	50	0.32	50
	10			0.62	51	0.52	50	0.41	50	0.32	50
	12			0.68	51	0.60	50	0.43	50	0.34	50
	14			0.74	52	0.67	51	0.54	50	0.35	50
	16			0.80	53	0.72	52	0.62	51	0.36	50
	20			0.91	54	0.81	53	0.73	52	0.48	50
	24			1.01	56	0.89	54	0.81	53	0.63	51
	28			1.09	—	0.99	55	0.88	54	0.73	52
	32			1.17	—	1.08	—	0.94	55	0.81	53

* Total calculated thickness includes service allowance and casting tolerance added to net thickness.
† For pipe 30 in. and larger, consideration should be given to laying condit ons other than Type 1.

TABLE 50.13

Thickness for Internal Pressure

Pipe Size *in.*	Rated Water Working Pressure*—*psi*									
	150		200		250		300		350	
	Total Calculated Thickness *in.*†	Use Class	Total Calculated Thickness *in.*†	Use Class	Total Calculated Thickness *in.*†	Use Class	Total Calculated Thickness *in.*†	Use Class	Total Calculated Thickness *in.*†	Use Class
3	0.15	51	0.16	51	0.16	51	0.17	51	0.17	51
4	0.16	51	0.16	51	0.17	51	0.18	51	0.18	51
6	0.17	50	0.18	50	0.19	50	0.20	50	0.20	50
8	0.18	50	0.19	50	0.21	50	0.22	50	0.23	50
10	0.21	50	0.22	50	0.23	50	0.25	50	0.26	50
12	0.22	50	0.23	50	0.25	50	0.27	50	0.28	50
14	0.24	50	0.26	50	0.28	50	0.30	50	0.31	50
16	0.25	50	0.27	50	0.30	50	0.32	50	0.34	50
18	0.27	50	0.29	50	0.31	50	0.34	50	0.36	50
20	0.28	50	0.30	50	0.33	50	0.36	50	0.38	51
24	0.30	50	0.33	50	0.37	50	0.40	51	0.43	52
30	0.34	50	0.38	50	0.42	51	0.45	52	0.49	53
36	0.38	50	0.42	50	0.47	51	0.51	52	0.56	53
42	0.41	50	0.47	50	0.52	51	0.57	52	0.63	53
48	0.46	50	0.52	50	0.58	51	0.64	52	0.70	53
54	0.51	50	0.58	50	0.65	51	0.71	52	0.78	53

* These pipe are adequate for the rated working pressure plus a surge allowance of 100 psi.
† Total calculated thickness includes service allowance and casting tolerance added to net thickness.

CTD014602

TABLE 50.14

Rated Working Pressure and Maximum Depth of Cover

Pipe Size in.	Thickness Class	Nominal Thickness in.	Rated Water Working Pressure psi*	Laying Condition				
				Type 1	Type 2	Type 3	Type 4	Type 5
				Maximum Depth of Cover—ft†				
3	51	0.25	350	98	100‡	100‡	100‡	100‡
	52	0.28	350	100‡	100‡	100‡	100‡	100‡
	53	0.31	350	100‡	100‡	100‡	100‡	100‡
	54	0.34	350	100‡	100‡	100‡	100‡	100‡
	55	0.37	350	100‡	100‡	100‡	100‡	100‡
	56	0.40	350	100‡	100‡	100‡	100‡	100‡
4	51	0.26	350	76	86	96	100‡	100‡
	52	0.29	350	100‡	100‡	100‡	100‡	100‡
	53	0.32	350	100‡	100‡	100‡	100‡	100‡
	54	0.35	350	100‡	100‡	100‡	100‡	100‡
	55	0.38	350	100‡	100‡	100‡	100‡	100‡
	56	0.41	350	100‡	100‡	100‡	100‡	100‡
6	50	0.25	350	32	38	44	56	75
	51	0.28	350	49	57	64	80	100‡
	52	0.31	350	67	77	86	100‡	100‡
	53	0.34	350	91	100‡	100‡	100‡	100‡
	54	0.37	350	100‡	100‡	100‡	100‡	100‡
	55	0.40	350	100‡	100‡	100‡	100‡	100‡
	56	0.43	350	100‡	100‡	100‡	100‡	100‡
8	50	0.27	350	25	30	36	46	64
	51	0.30	350	36	42	49	61	81
	52	0.33	350	47	54	62	77	99
	53	0.36	350	64	73	82	100‡	100‡
	54	0.39	350	80	91	100‡	100‡	100‡
	55	0.42	350	98	100‡	100‡	100‡	100‡
	56	0.45	350	100‡	100‡	100‡	100‡	100‡
10	50	0.29	350	19	24	29	38	55
	51	0.32	350	27	32	38	49	66
	52	0.35	350	35	41	47	59	79
	53	0.38	350	45	52	59	74	95
	54	0.41	350	57	65	74	91	100‡
	55	0.44	350	67	77	86	100‡	100‡
	56	0.47	350	81	92	100‡	100‡	100‡
12	50	0.31	350	17	22	27	36	52
	51	0.34	350	23	28	33	43	60
	52	0.37	350	30	35	41	53	71
	53	0.40	350	36	42	49	61	81
	54	0.43	350	45	52	59	74	95
	55	0.46	350	54	62	71	87	100‡
	56	0.49	350	64	73	83	100‡	100‡

* These pipe are adequate for the rated working pressure plus a surge allowance of 100 psi. Ductile-iron pipe for working pressures higher than 350 psi is available.

† An allowance for a single H-20 truck with 1.5 impact factor is included for all depths of cover.

‡ Calculated maximum depth of cover exceeds 100 ft.

CTD014603

TABLE 50.14—(*cont.*)

Pipe Size in.	Thickness Class	Nominal Thickness in.	Rated Water Working Pressure psi*	Laying Condition				
				Type 1	Type 2	Type 3	Type 4	Type 5
				Maximum Depth of Cover—ft†				
14	50	0.33	350	15	19	24	33	49
	51	0.36	350	19	23	28	38	55
	52	0.39	350	24	29	34	44	62
	53	0.42	350	30	35	41	53	71
	54	0.45	350	36	42	49	61	81
	55	0.48	350	43	50	57	71	92
	56	0.51	350	52	59	67	83	100‡
16	50	0.34	350	13	17	21	30	47
	51	0.37	350	16	21	25	34	51
	52	0.40	350	20	25	30	40	57
	53	0.43	350	25	30	36	46	64
	54	0.46	350	30	35	41	53	71
	55	0.49	350	35	41	47	59	79
	56	0.52	350	41	48	55	68	89
18	50	0.35	350	11	15	20	29	42
	51	0.38	350	14	19	23	32	49
	52	0.41	350	18	22	27	36	53
	53	0.44	350	22	26	31	41	58
	54	0.47	350	25	30	36	46	64
	55	0.50	350	30	35	41	53	71
	56	0.53	350	35	41	47	59	79
20	50	0.36	300	10	14	18	27	38
	51	0.39	350	13	17	21	30	44
	52	0.42	350	16	20	25	34	50
	53	0.45	350	19	23	28	38	54
	54	0.48	350	22	27	32	42	59
	55	0.51	350	26	31	37	47	65
	56	0.54	350	30	35	41	53	71
24	50	0.38	250	8	12	17	23	31
	51	0.41	300	10	15	19	27	36
	52	0.44	350	13	17	21	30	41
	53	0.47	350	15	19	24	33	47
	54	0.50	350	18	22	27	36	53
	55	0.53	350	20	25	30	40	57
	56	0.56	350	24	29	34	44	61
30	50	0.39	200	§	10	14	18	25
	51	0.43	250		12	16	21	29
	52	0.47	300		14	19	24	33
	53	0.51	350		17	21	29	38
	54	0.55	350		19	24	33	44
	55	0.59	350		22	27	36	51
	56	0.63	350		26	31	41	57

* These pipe are adequate for the rated working pressure plus a surge allowance of 100 psi. Ductile-iron pipe or working pressures higher than 350 psi is available.
† An allowance for a single H-20 truck with 1.5 impact factor is included for all depths of cover.
‡ Calculated maximum depth of cover exceeds 100 ft.
§ For pipe 30 in. and larger, consideration should be given to laying conditions other than Type 1.

CTD014604

TABLE 50.14—(*cont.*)

Pipe Size *in.*	Thickness Class	Nominal Thickness *in.*	Rated Water Working Pressure *psi**	Laying Condition				
				Type 1	Type 2	Type 3	Type 4	Type 5
				Maximum Depth of Cover—*ft*†				
36	50	0.43	200	§	10	13	17	25
	51	0.48	250		12	16	20	28
	52	0.53	300		15	19	24	32
	53	0.58	350		17	21	28	37
	54	0.63	350		20	25	33	43
	55	0.68	350		23	28	37	50
	56	0.73	350		26	31	41	59
42	50	0.47	200	§	9	13	16	24
	51	0.53	250		12	15	19	27
	52	0.59	300		14	18	22	30
	53	0.65	350		17	22	27	35
	54	0.71	350		20	24	32	42
	55	0.77	350		23	28	38	48
	56	0.83	350		26	31	41	57
48	50	0.51	200	§	9	12	15	23
	51	0.58	250		12	14	18	26
	52	0.65	300		14	18	21	30
	53	0.72	350		17	21	25	34
	54	0.79	350		20	24	30	40
	55	0.86	350		23	28	37	47
	56	0.93	350		26	31	41	55
54	50	0.57	200	§	9	12	15	23
	51	0.65	250		12	14	18	25
	52	0.73	300		14	17	21	29
	53	0.81	350		17	21	25	34
	54	0.89	350		20	25	30	40
	55	0.97	350		23	28	37	47
	56	1.05	350		27	32	42	55

* These pipe are adequate for the rated working pressure plus a surge allowance of 100 psi. Ductile-iron pipe for working pressures higher than 350 psi is available.
† An allowance for a single H-20 truck with 1.5 impact factor is included for all depths of cover.
‡ Calculated maximum depth of cover exceeds 100 ft.
§ For pipe 30 in. and larger, consideration should be given to laying conditions other than Type 1.

CTD014605

3P—5M—4/78—43150

CTD014606