Designation: A746 – 09 (Reapproved 2014)

# Standard Specification for Ductile Iron Gravity Sewer Pipe[1]

This standard is issued under the fixed designation A746; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This specification covers 4 to 64-in. ductile iron gravity sewer pipe centrifugally cast with push-on joints. This specification may be used for pipe with other types of joints, as may be agreed upon at the time of purchase.

1.2 This specification covers trench load design procedures for both cement-lined pipe and flexible-lined pipe. Maximum depth of cover tables are included for both types of linings.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D3282 Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes

E8 Test Methods for Tension Testing of Metallic Materials

E23 Test Methods for Notched Bar Impact Testing of Metallic Materials

2.2 *ANSI/AWWA Standards:*

C104/A21.4 Cement Mortar Lining for Ductile-Iron Pipe and Fittings for Water[3]

C111/A21.11 Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings[3]

C150/A21.50 Thickness Design of Ductile-Iron Pipe[3]

C600 Installation of Ductile-Iron Water Mains and Their Appurtenances

2.3 *ASCE Standards:*

Manuals and Reports on Engineering Practice, No. 37, (WCPF Manual of Practice No. 9). "Design and Construction of Sanitary and Storm Sewers"[4]

2.4 *AASHTO Standard:*

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

## 3. Terminology

3.1 *Symbols:*

3.1.1 *A*—outside radius of pipe,

$$ft = \frac{D}{24}$$

$$\left( \text{in metres} = \frac{D}{2000} \right)$$

3.1.2 *a*—conversion factor, lb/ft$^2$ to psi = 144 (kN/m$^2$ to kPa = 1)

3.1.3 *B*—1.5 ft (0.457 m)

3.1.4 *b*—Effective pipe length: 36 in. (0.914 m)

3.1.5 *C*—surface load factor, Table 1

3.1.6 *D*—outside diameter, in., Table 2

3.1.7 *E*—modulus of elasticity, 24 × 10$^6$ psi (165.5 × 10$^6$ kPa)

3.1.8 *E'*—modulus of soil reaction, psi, Table 3

3.1.9 *F*—impact factor, 1.5

3.1.10 *f*—design bending stress, 48 000 psi (331 × 10$^3$ kPa)

3.1.11 *H*—depth of cover, ft (m)

3.1.12 $K_b$— bending moment coefficient, Table 3

3.1.13 $K_x$— deflection coefficient, Table 3

3.1.14 *P*—wheel load, 16 000 lb (7257 kg)

3.1.15 $P_e$— earth load, psi (kPa)

3.1.16 $P_t$— truck load, psi (kPa)

3.1.17 $P_v$— trench load, psi (kPa) = $P_e + P_t$

3.1.18 *R*—reduction factor which takes into account the fact that the part of the pipe directly below the wheels is aided in

[1] This specification is under the jurisdiction of ASTM Committee A04 on Iron Castings and is the direct responsibility of Subcommittee A04.12 on Pipes and Tubes.

Current edition approved Oct. 1, 2014. Published October 2014. Originally approved in 1977. Last previous edition approved in 2009 as A746 – 09. DOI: 10.1520/A0746-09R14.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] Available from American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191, http://www.asce.org.

**TABLE 1 Surface Load Factors for Single Truck on Unpaved Road**

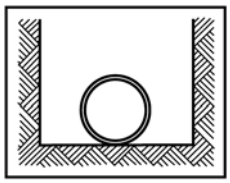
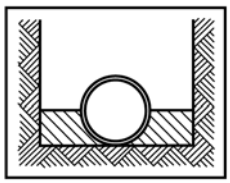
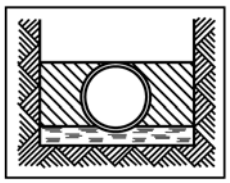
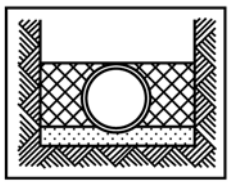
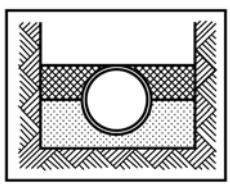
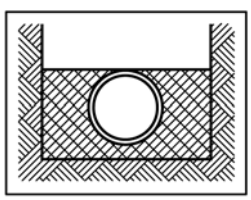
| Depth of Cover ft | Pipe Size—in. 3 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|---|---|
| | Surface Load Factor—C | | | | | | | | |
| 2.5 | 0.0589 | 0.0713 | 0.1020 | 0.1328 | 0.1615 | 0.1901 | 0.2178 | 0.2443 | 0.2698 |
| 3 | 0.0437 | 0.0530 | 0.0759 | 0.0990 | 0.1207 | 0.1424 | 0.1637 | 0.1843 | 0.2044 |
| 4 | 0.0265 | 0.0321 | 0.0460 | 0.0602 | 0.0736 | 0.0871 | 0.1005 | 0.1136 | 0.1265 |
| 5 | 0.0176 | 0.0213 | 0.0306 | 0.0401 | 0.0490 | 0.0581 | 0.0672 | 0.0761 | 0.0849 |
| 6 | 0.0125 | 0.0151 | 0.0217 | 0.0284 | 0.0348 | 0.0413 | 0.0478 | 0.0542 | 0.0606 |
| 7 | 0.0093 | 0.0113 | 0.0162 | 0.0212 | 0.0260 | 0.0308 | 0.0357 | 0.0405 | 0.0453 |
| 8 | 0.0072 | 0.0087 | 0.0125 | 0.0164 | 0.0201 | 0.0238 | 0.0276 | 0.0313 | 0.0350 |
| 9 | 0.0057 | 0.0069 | 0.0099 | 0.0130 | 0.0160 | 0.0190 | 0.0219 | 0.0249 | 0.0279 |
| 10 | 0.0046 | 0.0056 | 0.0081 | 0.0106 | 0.0130 | 0.0154 | 0.0179 | 0.0203 | 0.0227 |
| 12 | 0.0032 | 0.0039 | 0.0056 | 0.0074 | 0.0091 | 0.0108 | 0.0125 | 0.0142 | 0.0159 |
| 14 | 0.0024 | 0.0029 | 0.0042 | 0.0055 | 0.0067 | 0.0080 | 0.0092 | 0.0105 | 0.0117 |
| 16 | 0.0018 | 0.0022 | 0.0032 | 0.0042 | 0.0051 | 0.0061 | 0.0071 | 0.0080 | 0.0090 |
| 20 | 0.0012 | 0.0014 | 0.0020 | 0.0027 | 0.0033 | 0.0039 | 0.0045 | 0.0052 | 0.0058 |
| 24 | 0.0008 | 0.0010 | 0.0014 | 0.0019 | 0.0023 | 0.0027 | 0.0032 | 0.0036 | 0.0040 |
| 28 | 0.0006 | 0.0007 | 0.0010 | 0.0014 | 0.0017 | 0.0020 | 0.0023 | 0.0026 | 0.0030 |
| 32 | 0.0005 | 0.0006 | 0.0008 | 0.0011 | 0.0013 | 0.0015 | 0.0018 | 0.0020 | 0.0023 |
| Depth of Cover ft | Pipe Size—in. 20 | 24 | 30 | 36 | 42 | 48 | 54 | 60 | 64 |
| | Surface Load Factor—C | | | | | | | | |
| 2.5 | 0.2941 | 0.3390 | 0.3962 | 0.4437 | 0.4813 | 0.5115 | 0.5366 | 0.5488 | 0.5592 |
| 3 | 0.2237 | 0.2602 | 0.3085 | 0.3507 | 0.3857 | 0.4153 | 0.4412 | 0.4543 | 0.4657 |
| 4 | 0.1391 | 0.1635 | 0.1972 | 0.2284 | 0.2559 | 0.2808 | 0.3040 | 0.3164 | 0.3277 |
| 5 | 0.0936 | 0.1106 | 0.1347 | 0.1576 | 0.1786 | 0.1982 | 0.2173 | 0.2278 | 0.2377 |
| 6 | 0.0669 | 0.0793 | 0.0970 | 0.1143 | 0.1304 | 0.1458 | 0.1612 | 0.1698 | 0.1781 |
| 7 | 0.0500 | 0.0594 | 0.0730 | 0.0863 | 0.0988 | 0.1111 | 0.1235 | 0.1306 | 0.1374 |
| 8 | 0.0387 | 0.0461 | 0.0567 | 0.0672 | 0.0773 | 0.0871 | 0.0973 | 0.1031 | 0.1088 |
| 9 | 0.0309 | 0.0367 | 0.0453 | 0.0538 | 0.0620 | 0.0700 | 0.0784 | 0.0833 | 0.0880 |
| 10 | 0.0251 | 0.0299 | 0.0370 | 0.0440 | 0.0507 | 0.0574 | 0.0644 | 0.0685 | 0.0725 |
| 12 | 0.0176 | 0.0210 | 0.0259 | 0.0309 | 0.0357 | 0.0405 | 0.0456 | 0.0486 | 0.0515 |
| 14 | 0.0130 | 0.0155 | 0.0192 | 0.0229 | 0.0265 | 0.0301 | 0.0339 | 0.0362 | 0.0384 |
| 16 | 0.0100 | 0.0119 | 0.0147 | 0.0176 | 0.0204 | 0.0232 | 0.0262 | 0.0279 | 0.0297 |
| 20 | 0.0064 | 0.0076 | 0.0095 | 0.0113 | 0.0131 | 0.0149 | 0.0169 | 0.0181 | 0.0192 |
| 24 | 0.0045 | 0.0053 | 0.0066 | 0.0079 | 0.0091 | 0.0104 | 0.0118 | 0.0126 | 0.0134 |
| 28 | 0.0033 | 0.0039 | 0.0049 | 0.0058 | 0.0067 | 0.0077 | 0.0087 | 0.0093 | 0.0099 |
| 32 | 0.0025 | 0.0030 | 0.0037 | 0.0044 | 0.0052 | 0.0059 | 0.0067 | 0.0071 | 0.0076 |

**TABLE 2 Nominal Thicknesses for Standard Pressure Classes of Ductile-Iron Pipe**

| Size, in. | Outside Diameter, in. (mm) | Pressure Class 150 | 200 | 250 | 300 | 350 |
|---|---|---|---|---|---|---|
| | | Nominal Thickness, in. (mm) | | | | |
| 3 | 3.96 (100.6) | . . . | . . . | . . . | . . . | 0.25[A] (6.4) |
| 4 | 4.80 (121.9) | . . . | . . . | . . . | . . . | 0.25[A] (6.4) |
| 6 | 6.90 (175.3) | . . . | . . . | . . . | . . . | 0.25[A] (6.4) |
| 8 | 9.05 (229.9) | . . . | . . . | . . . | . . . | 0.25[A] (6.4) |
| 10 | 11.10 (281.9) | . . . | . . . | . . . | . . . | 0.26 (6.6) |
| 12 | 13.20 (335.3) | . . . | . . . | . . . | . . . | 0.28 (7.1) |
| 14 | 15.30 (388.6) | . . . | . . . | 0.28 (7.1) | 0.30 (7.6) | 0.31 (7.9) |
| 16 | 17.40 (442.0) | . . . | . . . | 0.30 (7.6) | 0.32 (8.1) | 0.34 (8.6) |
| 18 | 19.50 (495.3) | . . . | . . . | 0.31 (7.9) | 0.34 (8.6) | 0.36 (9.1) |
| 20 | 21.60 (548.6) | . . . | . . . | 0.33 (8.4) | 0.36 (9.1) | 0.38 (9.7) |
| 24 | 25.80 (655.3) | . . . | 0.33 (8.4) | 0.37 (9.4) | 0.40 (10.2) | 0.43 (10.9) |
| 30 | 32.00 (812.8) | 0.34 (8.6) | 0.38 (9.7) | 0.42 (10.7) | 0.45 (11.4) | 0.49 (12.4) |
| 36 | 38.30 (972.8) | 0.38 (9.7) | 0.42 (10.7) | 0.47 (11.9) | 0.51 (12.9) | 0.56 (14.2) |
| 42 | 44.50 (1130.3) | 0.41 (10.4) | 0.47 (11.9) | 0.52 (13.2) | 0.57 (14.5) | 0.63 (16.0) |
| 48 | 50.80 (1290.3) | 0.46 (11.7) | 0.52 (13.2) | 0.58 (14.7) | 0.64 (16.3) | 0.70 (17.8) |
| 54 | 57.56 (1450.3) | 0.51 (12.9) | 0.58 (14.7) | 0.65 (16.5) | 0.72 (18.3) | 0.79 (20.1) |
| 60 | 61.61 (1564.9) | 0.54 (13.7) | 0.61 (15.5) | 0.68 (17.3) | 0.76 (19.3) | 0.83 (21.1) |
| 64 | 65.67 (1668.0) | 0.56 (14.2) | 0.64 (16.3) | 0.72 (18.3) | 0.80 (20.3) | 0.87 (22.1) |

[A] Calculated thicknesses for these sizes and pressure ratings are less than those shown above. Presently these are the lowest nominal thicknesses available in these sizes.

**TABLE 3 Design Values for Standard Laying Conditions[A]**

| Laying Condition | Description | E' psi[B] | Bedding Angle, ° | $K_b$ | $K_x$ |
|---|---|---|---|---|---|
|  Type 1 | Flat-bottom trench[C] loose backfill.[D] | 150 | 30 | 0.235 | 0.108 |
|  Type 2 | Flat-bottom trench[C] Backfill lightly consolidated to centerline of pipe. | 300 | 45 | 0.210 | 0.105 |
|  Type 3 | Pipe bedded in 4-in. (102 mm) min loose soil[E] 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 ⅛ pipe diameter, 4-in. (102 mm) min. Backfill compacted to top of pipe. (Approximately 80 percent Standard Proctor, AASHTO T-99)[F] | 500 | 90 | 0.157 | 0.096 |
|  Type 5 | Pipe bedded in compacted granular material to centerline of pipe, 4 in. (102 mm) minimum under pipe. Compacted granular[G] or select[E] material to top of pipe. (Approximately 90 percent Standard Proctor, AASHTO T-99) | 700 | 150 | 0.128 | 0.085 |
|  Type “Deep Bury” | Pipe bedded to the top of the pipe with angular graded stone (¼ - to 1½ - in.) or well-graded gravel . Minimum under pipe. Compact the angular graded stone or well-graded gravel to top of pipe. (Approximately 95 percent Standard Proctor, AASHTO T-99) | 1500 | 150 | 0.128 | 0.085 |

[A] 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.
[B] 1 psi = 6.894757 kPa.
[C] Flat-bottom is defined as undisturbed earth.
[D] For pipe 14 in. (350 mm) and larger, consideration should be given to use of laying conditions other than Type 1.
[E] Loose soil or select material is defined as native soil excavated from the trench, free of rocks, foreign materials, and frozen earth.
[F] American Association of State Highway and Transportation Officials, 444 N. Capitol Street, N.W., Suite 225, Washington D.C. 20001.
[G] Granular materials are defined per AASHTO Soil Classification System (Classification D2487), with the exception that gravel bedding and gravel backfill adjacent to the pipe is limited to 2 in. maximum particle size per ANSI/AWWA C600.

carrying the truck load by adjacent parts of the pipe that receive little or no load from the wheels, Table 4

3.1.19 *t*—net thickness, in. (mm)

3.1.20 $t_l$—minimum manufacturing thickness, in., $t + 0.08$, (in mm, $t + 2.0$)

3.1.21 *w*—soil weight, 120 lb/ft$^3$ (18.85 kN/m$^3$)

3.1.22 $\Delta X$—design deflection, in. (mm),

$[\Delta X = 0.03\ D]$, or $[(\Delta X = 0.05\ D)$ for flexible linings$]$

## 4. General Requirements

4.1 The pipe shall be ductile iron in accordance with Section 9.

4.2 Push-on joints shall comply with all applicable requirements of ANSI/AWWA C111/A21.11.

Pipe with other types of joints shall comply with the joint dimensions and weights agreed upon at the time of purchase, but in all other respects shall fulfill the requirements of this specification.

4.3 Unless otherwise specified, pipe shall have a nominal length of 18 or 20 ft (5.5 or 6.1 m). A maximum of 20 % of the total number of pipe of each size specified in an order may be furnished as much as 24 in. (610 mm) shorter than the nominal laying length, and an additional 10 % may be furnished as much as 6 in. (152 mm) shorter than the nominal laying length.

## 5. Tolerances or Permitted Variations

5.1 *Dimensions*—The spigot end, bell, and socket of the pipe and the accessories shall be gaged with suitable gages at sufficiently frequent intervals to assure that the dimensions comply with the requirements of this specification. The smallest inside diameter (ID) of the sockets and the outside diameter (OD) of the spigot ends shall be tested with circular gauges. Other socket dimensions shall be gauged as may be appropriate.

5.2 *Thickness*—Minus thickness tolerances of pipe shall not exceed those shown in Table 5.

NOTE 1—An additional minus tolerance of 0.02 in. (0.5 mm) shall be permitted along the barrel of the pipe for a distance not to exceed 12 in. (305 mm).

5.3 *Weight*— The weight of any single pipe shall not be less than the tabulated weight by more than 6 % for pipe 12 in. or smaller in diameter, or by more than 5 % for pipe larger than 12 in. in diameter.

**TABLE 5 Allowances for Casting Tolerance**

| Size, in. | Casting Tolerance, in. (mm) |
|---|---|
| 3–8 | 0.05 (1.3) |
| 10–12 | 0.06 (1.5) |
| 14–42 | 0.07 (1.8) |
| 48 | 0.08 (2.0) |
| 54–64 | 0.09 (2.3) |

## 6. Coating and Lining

6.1 *Outside Coating*—The outside coating for use under normal conditions shall be a shop applied coating approximately 1 mil (0.025 mm) thick. The coating shall be applied to the outside of all pipe, unless otherwise specified. The finished coating shall be continuous and smooth, neither brittle when cold, nor sticky when exposed to the sun, and shall be strongly adherent to the pipe.

6.2 *Cement-Mortar Linings*—Unless otherwise specified, the lining shall be cement-mortar in accordance with ANSI/AWWA C104/A21.4.

6.3 *Special Linings*—For severely aggressive wastes, other types of linings may be available. Such special linings shall be specified in the invitation for bids and on the purchase order.

## 7. Pipe Design

7.1 *Step 1*—Design for trench load.

7.1.1 Determine the trench load, $P_v$. Table 6 gives the trench load, including the earth load, $P_e$, plus the truck load, $P_t$, for 2.5 to 32 ft (0.76 to 9.75 m) of cover.

7.1.2 Determine the standard laying condition from the descriptions in Table 3 and select the appropriate table for diameter-thickness ratios from Tables 7-12. Each table lists diameter-thickness ratios calculated for both bending and deflection over a range of trench loads.

7.1.3 Refer to the column headed " Bending-Stress Design" in the appropriate table of Tables 7-12, and locate the tabulated trench load $P_v$ from Sec. 7.1.1. If the calculated $P_v$ is halfway between two tabulated values, use the larger $P_v$ value. Select the corresponding *D/t* value for this $P_v$. Divide the pipe's outside diameter *D* (Table 2) by the *D/t* value to obtain the net thickness t required for bending stress design.

7.2 *Step 2*—Addition of service allowance.

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

**TABLE 4 Reduction Factors (R) for Truck Load Calculations**

| Size, in. | Depth of Cover, ft (m) | | | |
|---|---|---|---|---|
| | <4 (1.2) | 4 to 7 (1.2 to 2.1) | >7 to 10 (2.4 to 3.0) | >10 (3.0) |
| | Reduction Factor | | | |
| 3 to 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 to 30 | 0.81 | 0.85 | 0.95 | 1.00 |
| 36 to 64 | 0.80 | 0.85 | 0.90 | 1.00 |

**TABLE 6 Earth Loads ($P_e$) Truck Loads ($P_t$) and Trench Loads ($P_v$), psi[A]**

| Depth of Cover, ft (m) | $P_e$ | 3-in. Pipe | | 4-in. Pipe | | 6-in. Pipe | | 8-in. Pipe | | 10-in. Pipe | | 12-in. Pipe | | 14-in. Pipe | | 16-in. Pipe | | 18-in. Pipe | | 20-in. Pipe | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $P_t$ | $P_v$ | $P_t$ | $P_v$ | $P_t$ | $P_v$ | $P_t$ | $P_v$ | $P_t$ | $P_v$ | $P_t$ | $P_v$ | $P_t$ | $P_v$ | $P_t$ | $P_v$ | $P_t$ | $P_v$ | $P_t$ | $P_v$ |
| 2.5 (0.8) | 2.1 | 9.9 | 12.0 | 9.9 | 12.0 | 9.9 | 12.0 | 9.8 | 11.9 | 9.7 | 11.8 | 9.6 | 11.7 | 8.7 | 10.8 | 8.2 | 10.3 | 7.8 | 9.9 | 7.5 | 9.6 |
| 3 (0.9) | 2.5 | 7.4 | 9.9 | 7.4 | 9.9 | 7.3 | 9.8 | 7.3 | 9.8 | 7.2 | 9.7 | 7.2 | 9.7 | 6.6 | 9.1 | 6.2 | 8.7 | 5.9 | 8.4 | 5.7 | 8.2 |
| 4 (1.2) | 3.3 | 4.4 | 7.7 | 4.5 | 7.8 | 4.4 | 7.7 | 4.4 | 7.7 | 4.4 | 7.7 | 4.4 | 7.7 | 4.4 | 7.7 | 4.1 | 7.4 | 3.9 | 7.2 | 3.9 | 7.2 |
| 5 (1.5) | 4.2 | 3.0 | 7.2 | 3.0 | 7.2 | 3.0 | 7.2 | 3.0 | 7.2 | 2.9 | 7.1 | 2.9 | 7.1 | 2.9 | 7.1 | 2.8 | 7.0 | 2.6 | 6.8 | 2.6 | 6.8 |
| 6 (1.8) | 5.0 | 2.1 | 7.1 | 2.1 | 7.1 | 2.1 | 7.1 | 2.1 | 7.1 | 2.1 | 7.1 | 2.1 | 7.1 | 2.1 | 7.1 | 2.0 | 7.0 | 1.9 | 6.9 | 1.9 | 6.9 |
| 7 (2.1) | 5.8 | 1.6 | 7.4 | 1.6 | 7.4 | 1.6 | 7.4 | 1.6 | 7.4 | 1.6 | 7.4 | 1.6 | 7.4 | 1.6 | 7.4 | 1.5 | 7.3 | 1.4 | 7.2 | 1.4 | 7.2 |
| 8 (2.4) | 6.7 | 1.2 | 7.9 | 1.2 | 7.9 | 1.2 | 7.9 | 1.2 | 7.9 | 1.2 | 7.9 | 1.2 | 7.9 | 1.2 | 7.9 | 1.2 | 7.9 | 1.2 | 7.9 | 1.1 | 7.8 |
| 9 (2.7) | 7.5 | 1.0 | 8.5 | 1.0 | 8.5 | 1.0 | 8.5 | 1.0 | 8.5 | 1.0 | 8.5 | 1.0 | 8.5 | 1.0 | 8.5 | 1.0 | 8.5 | 1.0 | 8.5 | 0.9 | 8.4 |
| 10 (3.0) | 8.3 | 0.8 | 9.1 | 0.8 | 9.1 | 0.8 | 9.1 | 0.8 | 9.1 | 0.8 | 9.1 | 0.8 | 9.1 | 0.8 | 9.1 | 0.8 | 9.1 | 0.8 | 9.1 | 0.7 | 9.0 |
| 12 (3.7) | 10.0 | 0.6 | 10.6 | 0.6 | 10.6 | 0.6 | 10.6 | 0.6 | 10.6 | 0.5 | 10.5 | 0.5 | 10.5 | 0.5 | 10.5 | 0.5 | 10.5 | 0.5 | 10.5 | 0.5 | 10.5 |
| 14 (4.3) | 11.7 | 0.4 | 12.1 | 0.4 | 12.1 | 0.4 | 12.1 | 0.4 | 12.1 | 0.4 | 12.1 | 0.4 | 12.1 | 0.4 | 12.1 | 0.4 | 12.1 | 0.4 | 12.1 | 0.4 | 12.1 |
| 16 (4.9) | 13.3 | 0.3 | 13.6 | 0.3 | 13.6 | 0.3 | 13.6 | 0.3 | 13.6 | 0.3 | 13.6 | 0.3 | 13.6 | 0.3 | 13.6 | 0.3 | 13.6 | 0.3 | 13.6 | 0.3 | 13.6 |
| 20 (6.1) | 16.7 | 0.2 | 16.9 | 0.2 | 16.9 | 0.2 | 16.9 | 0.2 | 16.9 | 0.2 | 16.9 | 0.2 | 16.9 | 0.2 | 16.9 | 0.2 | 16.9 | 0.2 | 16.9 | 0.2 | 16.9 |
| 24 (7.3) | 20.0 | 0.2 | 20.2 | 0.1 | 20.1 | 0.1 | 20.1 | 0.1 | 20.1 | 0.1 | 20.1 | 0.1 | 20.1 | 0.1 | 20.1 | 0.1 | 20.1 | 0.1 | 20.1 | 0.1 | 20.1 |
| 28 (8.5) | 23.3 | 0.1 | 23.4 | 0.1 | 23.4 | 0.1 | 23.4 | 0.1 | 23.4 | 0.1 | 23.4 | 0.1 | 23.4 | 0.1 | 23.4 | 0.1 | 23.4 | 0.1 | 23.4 | 0.1 | 23.4 |
| 32 (9.8) | 26.7 | 0.1 | 26.8 | 0.1 | 26.8 | 0.1 | 26.8 | 0.1 | 26.8 | 0.1 | 26.8 | 0.1 | 26.8 | 0.1 | 26.8 | 0.1 | 26.8 | 0.1 | 26.8 | 0.1 | 26.8 |

| Depth of Cover, ft (m) | $P_e$ | 24-in. Pipe | | 30-in. Pipe | | 36-in. Pipe | | 42-in. Pipe | | 48-in. Pipe | | 54-in. Pipe | | 60-in. Pipe | | 64-in. Pipe | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $P_t$ | $P_v$ | $P_t$ | $P_v$ | $P_t$ | $P_v$ | $P_t$ | $P_v$ | $P_t$ | $P_v$ | $P_t$ | $P_v$ | $P_t$ | $P_v$ | $P_t$ | $P_v$ |
| 2.5 (0.8) | 2.1 | 7.1 | 9.2 | 6.7 | 8.8 | 6.2 | 8.3 | 5.8 | 7.9 | 5.4 | 7.5 | 5.0 | 7.1 | 4.8 | 6.9 | 4.5 | 6.6 |
| 3 (0.9) | 2.5 | 5.4 | 7.9 | 5.2 | 7.7 | 4.9 | 7.4 | 4.6 | 7.1 | 4.4 | 6.9 | 4.1 | 6.6 | 3.9 | 6.4 | 3.8 | 6.3 |
| 4 (1.2) | 3.3 | 3.6 | 6.9 | 3.5 | 6.8 | 3.4 | 6.7 | 3.3 | 6.6 | 3.1 | 6.4 | 3.0 | 6.3 | 2.9 | 6.2 | 2.8 | 6.1 |
| 5 (1.5) | 4.2 | 2.4 | 6.6 | 2.4 | 6.6 | 2.3 | 6.5 | 2.3 | 6.5 | 2.2 | 6.4 | 2.1 | 6.3 | 2.1 | 6.3 | 2.1 | 6.3 |
| 6 (1.8) | 5.0 | 1.7 | 6.7 | 1.7 | 6.7 | 1.7 | 6.7 | 1.7 | 6.7 | 1.6 | 6.6 | 1.6 | 6.6 | 1.6 | 6.6 | 1.5 | 6.5 |
| 7 (2.1) | 5.8 | 1.3 | 7.1 | 1.3 | 7.1 | 1.3 | 7.1 | 1.3 | 7.1 | 1.2 | 7.0 | 1.2 | 7.0 | 1.2 | 7.0 | 1.2 | 7.0 |
| 8 (2.4) | 6.7 | 1.1 | 7.8 | 1.1 | 7.8 | 1.1 | 7.8 | 1.0 | 7.7 | 1.0 | 7.7 | 1.0 | 7.7 | 1.0 | 7.7 | 1.0 | 7.7 |
| 9 (2.7) | 7.5 | 0.9 | 8.4 | 0.9 | 8.4 | 0.8 | 8.3 | 0.8 | 8.3 | 0.8 | 8.3 | 0.8 | 8.3 | 0.8 | 8.3 | 0.8 | 8.3 |
| 10 (3.0) | 8.3 | 0.7 | 9.0 | 0.7 | 9.0 | 0.7 | 9.0 | 0.7 | 9.0 | 0.7 | 9.0 | 0.7 | 9.0 | 0.7 | 9.0 | 0.7 | 9.0 |
| 12 (3.7) | 10.0 | 0.5 | 10.5 | 0.5 | 10.5 | 0.5 | 10.5 | 0.5 | 10.5 | 0.5 | 10.5 | 0.5 | 10.5 | 0.5 | 10.5 | 0.5 | 10.5 |
| 14 (4.3) | 11.7 | 0.4 | 12.1 | 0.4 | 12.1 | 0.4 | 12.1 | 0.4 | 12.1 | 0.4 | 12.1 | 0.4 | 12.1 | 0.4 | 12.1 | 0.4 | 12.1 |
| 16 (4.9) | 13.3 | 0.3 | 13.6 | 0.3 | 13.6 | 0.3 | 13.6 | 0.3 | 13.6 | 0.3 | 13.6 | 0.3 | 13.6 | 0.3 | 13.6 | 0.3 | 13.6 |
| 20 (8.1) | 16.7 | 0.2 | 16.9 | 0.2 | 16.9 | 0.2 | 16.9 | 0.2 | 16.9 | 0.2 | 16.9 | 0.2 | 16.9 | 0.2 | 16.9 | 0.2 | 16.9 |
| 24 (7.3) | 20.0 | 0.1 | 20.1 | 0.1 | 20.1 | 0.1 | 20.1 | 0.1 | 20.1 | 0.1 | 20.1 | 0.1 | 20.1 | 0.1 | 20.1 | 0.1 | 20.1 |
| 28 (8.5) | 23.3 | 0.1 | 23.4 | 0.1 | 23.4 | 0.1 | 23.4 | 0.1 | 23.4 | 0.1 | 23.4 | 0.1 | 23.4 | 0.1 | 23.4 | 0.1 | 23.4 |
| 32 (9.8) | 26.7 | 0.1 | 26.8 | 0.1 | 26.8 | 0.1 | 26.8 | 0.1 | 26.8 | 0.1 | 26.8 | 0.1 | 26.8 | 0.1 | 26.8 | 0.1 | 26.8 |

[A] 1 psi = 6.894757 kPa.

7.3 *Step 3*—Check deflection.

7.3.1 Refer to the column headed "Deflection Check" in the appropriate table of Tables 7-12 and locate the tabulated trench load $P_v$ from 7.1.1. If the calculated $P_v$ is between two tabulated values, use the larger $P_v$ value. (If the calculated $P_v$ is less than the minimum $P_v$ listed in the table, the deflection does not govern – proceed to Step 4). Select the corresponding $D/t_1$ value for this $P_v$. Divide the pipe's outside diameter $D$ (Table 2) by the $D/t_1$ value to obtain the minimum thickness $t_1$ required for deflection. Compare this value to the required minimum thickness $t_1$ from 7.2.1. If the $t_1$ required for deflection is less than the $t_1$ from 7.2.1, then deflection does not govern – proceed to Step 4. If the $t_1$ required for deflection is greater than the $t_1$ from 7.2.1, then deflection governs and the minimum thickness $t_1$ required for deflection should be used in Step 4.

7.4 *Step 4*—Add the casting allowance.

7.4.1 Add the casting allowance from Table 5 to the minimum manufacturing thickness $t_1$. The resulting thickness is the total calculated thickness.

7.5 *Step 5*—Selection of nominal thickness and standard pressure class.

7.5.1 Use the total calculated thickness from 7.4.1 to select a standard pressure-class thickness from Table 2. When the calculated thickness is between two nominal thicknesses, select the larger of the two. When specifying and ordering pipe, specify the pressure class listed in Table 2 corresponding to this nominal thickness.

NOTE 2—On specific projects, manufacturers may be willing to furnish pipe with thicknesses that fall between standard classes.

7.6 *Alternative procedure*

7.6.1 The appropriate standard pressure class may also be determined by using the Design Equations in 7.9.

7.7 *Design Example*—Calculate the thickness for 24-in. (610-mm) cement-lined ductile iron pipe bedded in loose soil for a minimum depth of 4 in. (100 mm), backfill lightly consolidated to the top of pipe, Laying Condition Type 3, under 10 ft (3 m) of cover.

7.7.1 *Step 1*—Design for Trench Load.

7.7.1.1

Earth load, Table 6, $P_e$ = 10.0 psi
Truck load, Table 6, $P_t$ = 0.5 psi
Trench load, $P_v = P_e + P_t$ = 10.5 psi

7.7.1.2 Select Table 9 for diameter-thickness ratios for laying condition Type 3.

7.7.1.3 Entering $P_v$ of 10.5 psi in Table 9, the bending-stress design requires $D/t$ of 144. From Table 2, diameter $D$ of 24-in. pipe is 25.80 in.

Net thickness, $t$, for bending stress = $D/(D/t)$ = 25.80 / 144 = 0.18 in.

**TABLE 7 Diameter-Thickness Ratios for Laying Condition Type 1**

NOTE 1—$E' = 150$ psi[A] $K_b = 0.235$ $K_x = 0.108$

| Trench Load $P_v$, psi[A] | | | | Trench Load $P_v$, psi[A] | | | |
|---|---|---|---|---|---|---|---|
| Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ | Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ |
| 5.17 | 3.89 | 6.48 | 150 | 10.37 | 8.85 | 14.74 | 90 |
| 5.21 | 3.91 | 6.52 | 149 | 10.55 | 9.06 | 15.11 | 89 |
| 5.26 | 3.94 | 6.57 | 148 | 10.74 | 9.29 | 15.48 | 88 |
| 5.30 | 3.97 | 6.62 | 147 | 10.93 | 9.53 | 15.88 | 87 |
| 5.35 | 4.00 | 6.67 | 146 | 11.13 | 9.78 | 16.30 | 86 |
| 5.40 | 4.03 | 6.72 | 145 | 11.34 | 10.04 | 16.73 | 85 |
| 5.45 | 4.06 | 6.77 | 144 | 11.55 | 10.31 | 17.19 | 84 |
| 5.49 | 4.09 | 6.82 | 143 | 11.78 | 10.60 | 17.67 | 83 |
| 5.54 | 4.13 | 6.88 | 142 | 12.01 | 10.90 | 18.17 | 82 |
| 5.59 | 4.16 | 6.94 | 141 | 12.25 | 11.22 | 18.70 | 81 |
| 5.65 | 4.20 | 6.99 | 140 | 12.50 | 11.56 | 19.26 | 80 |
| 5.70 | 4.23 | 7.05 | 139 | 12.76 | 11.91 | 19.85 | 79 |
| 5.75 | 4.27 | 7.12 | 138 | 13.03 | 12.28 | 20.46 | 78 |
| 5.80 | 4.31 | 7.18 | 137 | 13.31 | 12.67 | 21.11 | 77 |
| 5.86 | 4.35 | 7.25 | 136 | 13.60 | 13.08 | 21.79 | 76 |
| 5.91 | 4.39 | 7.31 | 135 | 13.91 | 13.51 | 22.52 | 75 |
| 5.97 | 4.43 | 7.38 | 134 | 14.23 | 13.97 | 23.28 | 74 |
| 6.03 | 4.47 | 7.46 | 133 | 14.56 | 14.45 | 24.08 | 73 |
| 6.09 | 4.52 | 7.53 | 132 | 14.91 | 14.96 | 24.93 | 72 |
| 6.15 | 4.56 | 7.61 | 131 | 15.27 | 15.50 | 25.83 | 71 |
| 6.21 | 4.61 | 7.69 | 130 | 15.65 | 16.07 | 26.78 | 70 |
| 6.27 | 4.66 | 7.77 | 129 | 16.05 | 16.68 | 27.79 | 69 |
| 6.33 | 4.71 | 7.85 | 128 | 16.46 | 17.32 | 28.86 | 68 |
| 6.40 | 4.76 | 7.94 | 127 | 16.89 | 18.00 | 30.00 | 67 |
| 6.46 | 4.82 | 8.03 | 126 | 17.35 | 18.73 | 31.21 | 66 |
| 6.53 | 4.87 | 8.12 | 125 | 17.83 | 19.50 | 32.49 | 65 |
| 6.60 | 4.93 | 8.22 | 124 | 18.33 | 20.32 | 33.86 | 64 |
| 6.67 | 4.99 | 8.32 | 123 | 18.85 | 21.19 | 35.32 | 63 |
| 6.74 | 5.05 | 8.42 | 122 | 19.40 | 22.12 | 36.87 | 62 |
| 6.82 | 5.11 | 8.52 | 121 | 19.98 | 23.12 | 38.53 | 61 |
| 6.89 | 5.18 | 8.63 | 120 | 20.59 | 24.18 | 40.30 | 60 |
| 6.97 | 5.25 | 8.74 | 119 | 21.23 | 25.32 | 42.20 | 59 |
| 7.05 | 5.32 | 8.86 | 118 | 21.91 | 26.54 | 44.23 | 58 |
| 7.13 | 5.39 | 8.98 | 117 | 22.63 | 27.85 | 46.42 | 57 |
| 7.21 | 5.46 | 9.11 | 116 | 23.38 | 29.26 | 48.76 | 56 |
| 7.29 | 5.54 | 9.24 | 115 | 24.18 | 30.77 | 51.28 | 55 |
| 7.38 | 5.62 | 9.37 | 114 | 25.02 | 32.39 | 53.99 | 54 |
| 7.47 | 5.71 | 9.51 | 113 | 25.92 | 34.15 | 56.92 | 53 |
| 7.56 | 5.79 | 9.65 | 112 | 26.86 | 36.05 | 60.08 | 52 |
| 7.65 | 5.88 | 9.80 | 111 | 27.87 | 38.10 | 63.50 | 51 |
| 7.75 | 5.97 | 9.96 | 110 | 28.94 | 40.32 | 67.20 | 50 |
| 7.85 | 6.07 | 10.12 | 109 | 30.07 | 42.73 | 71.22 | 49 |
| 7.95 | 6.17 | 10.28 | 108 | 31.28 | 45.35 | 75.58 | 48 |
| 8.05 | 6.27 | 10.46 | 107 | 32.57 | 48.20 | 80.34 | 47 |
| 8.16 | 6.38 | 10.63 | 106 | 33.95 | 51.31 | 85.52 | 46 |
| 8.27 | 6.49 | 10.82 | 105 | 35.42 | 54.72 | 91.19 | 45 |
| 8.38 | 6.61 | 11.01 | 104 | 37.00 | 58.44 | 97.40 | 44 |
| 8.49 | 6.73 | 11.22 | 103 | 38.69 | 62.53 | 104.22 | 43 |
| 8.61 | 6.86 | 11.43 | 102 | 40.50 | 67.03 | 111.71 | 42 |
| 8.74 | 6.99 | 11.64 | 101 | 42.46 | 71.99 | 119.98 | 41 |
| 8.86 | 7.12 | 11.87 | 100 | 44.56 | 77.47 | 129.11 | 40 |
| 8.99 | 7.26 | 12.11 | 99 | 46.84 | 83.54 | 139.23 | 39 |
| 9.13 | 7.41 | 12.35 | 98 | 49.30 | 90.28 | 150.47 | 38 |
| 9.27 | 7.57 | 12.61 | 97 | 51.96 | 97.80 | 163.00 | 37 |
| 9.41 | 7.73 | 12.88 | 96 | 54.86 | 106.20 | 177.00 | 36 |
| 9.56 | 7.89 | 13.15 | 95 | 58.02 | 115.62 | 192.70 | 35 |
| 9.71 | 8.07 | 13.45 | 94 | 61.46 | 126.21 | 210.36 | 34 |
| 9.87 | 8.25 | 13.75 | 93 | 65.23 | 138.18 | 230.29 | 33 |

**TABLE 7** *Continued*

| Trench Load $P_v$, psi[A] | | | | Trench Load $P_v$, psi[A] | | | |
|---|---|---|---|---|---|---|---|
| Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ | Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ |
| 10.03 | 8.44 | 14.07 | 92 | 69.36 | 151.73 | 252.88 | 32 |
| 10.20 | 8.64 | 14.40 | 91 | 73.92 | 167.15 | 278.58 | 31 |
| | | | | 78.94 | 184.77 | 307.96 | 30 |

[A] 1 psi = 6.894757 kPa.
[B] The $D/t$ 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 $D/t$ should be used.
[C] Maximum 3 % deflection is recommended for rigid or semirigid linings such as cement mortar.
[D] Maximum 5 % deflection is recommended for flexible linings such as asphaltic and plastic.

7.7.2 *Step 2*—Addition of service allowances.

7.7.2.1 Net thickness is given by the design for trench load, Step 1, or 0.18 in.

| | | |
|---|---|---|
| Net thickness | = | 0.18 in. |
| Service allowance | = | 0.08 in. |
| Minimum manfacturing thickness | = | 0.26 in. |

7.7.3 *Step 3*—Check deflection.

7.7.3.1 Entering $P_v$ of 10.5 psi in Table 9, the "Deflection Check" requires $D/t_1$ of 118. Minimum thickness $t_1$ for deflection design = $D/(D/t_1)$ = 25.80/118 = 0.22 in. This minimum thickness, 0.22 in., is less than the minimum thickness calculated in 7.7.2.1 above (0.26 in.); therefore, deflection does not govern.

7.7.4 *Step 4*—Add the casting allowance.

7.7.4.1

| | | |
|---|---|---|
| Minimum manufacturing thickness | = | 0.26 in. |
| Casting allowance | = | 0.07 in. |
| Total calculated thickness | = | 0.33 in. |

7.7.5 *Step 5*—Selection of nominal thickness and standard pressure class.

7.7.5.1 The total calculated thickness of 0.33 in. is the same as 0.33 in., Class 200, in Table 2. Therefore, Class 200 (0.33 in.) is selected for specifying and ordering.

7.8 *Design Method:*

7.8.1 Calculations are made for the thickness required to resist the bending stress caused by trench load.

7.8.2 To this net thickness is added a service allowance to obtain the minimum thickness $t_1$.

7.8.3 The minimum thickness required for deflection is then calculated and compared to $t_1$. The larger of the two is selected as the minimum manufacturing thickness. To this minimum manufacturing thickness is added a casting allowance to obtain the total calculated thickness.

7.8.4 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 2).

7.8.5 The reverse of the above procedure is used to determine the maximum depth of cover for pipe of a given pressure-class.

7.8.6 *Trench Load, $P_v$*—Trench load is expressed as vertical pressure, psi, and is equal to the sum of earth load, $P_e$, and truck load, $P_t$.

7.8.7 *Earth Load, $P_e$*—Earth load is computed by Eq 3 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/ft$^3$ (18.85 kN/m$^3$). If the designer anticipates additional loads, the design load should be increased accordingly.

7.8.8 *Truck Load, $P_t$*—The truck loads shown in Table 6 were computed by Eq 4 using the surface load factors in Table 1 and the reduction factors R from Table 4 for a single AASHTO H-20 truck on an unpaved road or flexible pavement, 16 000-lbf (71 kN) wheel load and 1.5 impact factor. The surface load factors in Table 1 were calculated by Eq 5 for a single concentrated wheel load centered over an effective pipe length of 3 ft (0.91 m).

7.8.9 *Design for Trench Load*—Tables 7-12, the diameter-thickness ratios tables used to design for trench load, were computed by Eqs 1 and Eqs 2. Equation 1 is based on the bending stress at the bottom of the pipe. The design bending stress, $f$, is 48 000 psi (331 MPa) which provides at least a 1.5 safety factor based on minimum ring yield strength and 2.0 safety factor based on ultimate strength. Equation 2 is based on the deflection of the pipe ring section. The design deflection $\Delta_x$ is 3 % of the outside diameter of the pipe for cement-lined pipe and 5 % for pipe with flexible linings. Design values of the trench parameters, $E'$, $K_b$, and $K_x$ are given in Table 3.

7.8.10 Tables similar to Tables 7-12 may be compiled for laying conditions other than those shown in this specification by calculating the trench loads, $P_v$, for a series of diameter-thickness ratios, $D/t$ and $D/t_1$, using Eqs 1 and Eqs 2 with values of $E'$, $K_b$, and $K_x$ appropriate to the bedding and backfill conditions.

7.9 *Design Equations:*

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

$$P_v = \frac{\frac{\Delta X}{D}}{12K_x}\left[\frac{8E}{\left(\frac{D}{t_1}-1\right)^3}+.732\,E'\right] \quad (2)$$

**TABLE 8 Diameter-Thickness Ratios for Laying Condition Type 2**

NOTE 1—$E' = 300$ psi[A] $K_b = 0.210$ $K_x = 0.105$

| Trench Load $P_v$, psi[A] | | | | Trench Load $P_v$, psi[A] | | | |
|---|---|---|---|---|---|---|---|
| Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ | Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ |
| 7.42 | 6.61 | 11.02 | 150 | 13.68 | 11.71 | 19.52 | 90 |
| 7.48 | 6.64 | 11.06 | 149 | 13.88 | 11.94 | 19.89 | 89 |
| 7.54 | 6.67 | 11.11 | 148 | 14.08 | 12.17 | 20.28 | 88 |
| 7.61 | 6.70 | 11.16 | 147 | 14.30 | 12.42 | 20.69 | 87 |
| 7.67 | 6.73 | 11.21 | 146 | 14.51 | 12.67 | 21.12 | 86 |
| 7.74 | 6.76 | 11.27 | 145 | 14.74 | 12.94 | 21.57 | 85 |
| 7.80 | 6.79 | 11.32 | 144 | 14.97 | 13.22 | 22.04 | 84 |
| 7.87 | 6.83 | 11.38 | 143 | 15.21 | 13.52 | 22.53 | 83 |
| 7.94 | 6.86 | 11.43 | 142 | 15.46 | 13.83 | 23.05 | 82 |
| 8.01 | 6.89 | 11.49 | 141 | 15.72 | 14.16 | 23.60 | 81 |
| 8.08 | 6.93 | 11.55 | 140 | 15.99 | 14.50 | 24.17 | 80 |
| 8.15 | 6.97 | 11.61 | 139 | 16.28 | 14.86 | 24.77 | 79 |
| 8.22 | 7.01 | 11.68 | 138 | 16.57 | 15.24 | 25.40 | 78 |
| 8.29 | 7.05 | 11.74 | 137 | 16.87 | 15.64 | 26.07 | 77 |
| 8.37 | 7.09 | 11.81 | 136 | 17.19 | 16.06 | 26.77 | 76 |
| 8.44 | 7.13 | 11.88 | 135 | 17.52 | 16.51 | 27.52 | 75 |
| 8.52 | 7.17 | 11.95 | 134 | 17.86 | 16.98 | 28.30 | 74 |
| 8.59 | 7.22 | 12.03 | 133 | 18.22 | 17.48 | 29.13 | 73 |
| 8.67 | 7.26 | 12.10 | 132 | 18.59 | 18.00 | 30.00 | 72 |
| 8.75 | 7.31 | 12.18 | 131 | 18.98 | 18.56 | 30.93 | 71 |
| 8.83 | 7.36 | 12.26 | 130 | 19.39 | 19.14 | 31.91 | 70 |
| 8.91 | 7.41 | 12.35 | 129 | 19.82 | 19.77 | 32.95 | 69 |
| 8.99 | 7.46 | 12.43 | 128 | 20.27 | 20.43 | 34.05 | 68 |
| 9.07 | 7.51 | 12.52 | 127 | 20.73 | 21.13 | 35.22 | 67 |
| 9.16 | 7.57 | 12.62 | 126 | 21.23 | 21.87 | 36.46 | 66 |
| 9.25 | 7.63 | 12.71 | 125 | 21.74 | 22.67 | 37.78 | 65 |
| 9.33 | 7.69 | 12.81 | 124 | 22.28 | 23.51 | 39.18 | 64 |
| 9.42 | 7.75 | 12.91 | 123 | 22.85 | 24.41 | 40.68 | 63 |
| 9.51 | 7.81 | 13.02 | 122 | 23.45 | 25.37 | 42.28 | 62 |
| 9.60 | 7.87 | 13.12 | 121 | 24.07 | 26.39 | 43.99 | 61 |
| 9.70 | 7.94 | 13.24 | 120 | 24.74 | 27.49 | 45.81 | 60 |
| 9.79 | 8.01 | 13.35 | 119 | 25.43 | 28.66 | 47.76 | 59 |
| 9.89 | 8.08 | 13.47 | 118 | 26.17 | 29.91 | 49.86 | 58 |
| 9.99 | 8.16 | 13.60 | 117 | 26.95 | 31.26 | 52.10 | 57 |
| 10.09 | 8.23 | 13.72 | 116 | 27.77 | 32.71 | 54.51 | 56 |
| 10.19 | 8.31 | 13.86 | 115 | 28.64 | 34.26 | 57.10 | 55 |
| 10.29 | 8.40 | 13.99 | 114 | 29.56 | 35.93 | 59.89 | 54 |
| 10.40 | 8.48 | 14.14 | 113 | 30.53 | 37.74 | 62.90 | 53 |
| 10.51 | 8.57 | 14.29 | 112 | 31.57 | 39.69 | 66.15 | 52 |
| 10.62 | 8.66 | 14.44 | 111 | 32.67 | 41.80 | 69.67 | 51 |
| 10.73 | 8.76 | 14.60 | 110 | 33.84 | 44.09 | 73.48 | 50 |
| 10.84 | 8.86 | 14.76 | 109 | 35.08 | 46.56 | 77.61 | 49 |
| 10.96 | 8.96 | 14.93 | 108 | 36.41 | 49.26 | 82.10 | 48 |
| 11.08 | 9.07 | 15.11 | 107 | 37.83 | 52.19 | 86.99 | 47 |
| 11.21 | 9.18 | 15.30 | 106 | 39.34 | 55.40 | 92.33 | 46 |
| 11.33 | 9.29 | 15.49 | 105 | 40.96 | 58.89 | 98.16 | 45 |
| 11.46 | 9.41 | 15.69 | 104 | 42.70 | 62.73 | 104.54 | 44 |
| 11.59 | 9.54 | 15.89 | 103 | 44.57 | 66.93 | 111.55 | 43 |
| 11.73 | 9.67 | 16.11 | 102 | 46.57 | 71.56 | 119.26 | 42 |
| 11.87 | 9.80 | 16.33 | 101 | 48.73 | 76.66 | 127.76 | 41 |
| 12.01 | 9.94 | 16.57 | 100 | 51.06 | 82.29 | 137.16 | 40 |
| 12.16 | 10.09 | 16.81 | 99 | 53.57 | 88.54 | 147.57 | 39 |
| 12.31 | 10.24 | 17.06 | 98 | 56.30 | 95.48 | 159.13 | 38 |
| 12.46 | 10.40 | 17.33 | 97 | 59.25 | 103.21 | 172.02 | 37 |
| 12.62 | 10.56 | 17.60 | 96 | 62.46 | 111.85 | 186.42 | 36 |
| 12.79 | 10.73 | 17.89 | 95 | 65.96 | 121.54 | 202.56 | 35 |
| 12.96 | 10.91 | 18.19 | 94 | 69.79 | 132.44 | 220.73 | 34 |
| 13.13 | 11.10 | 18.50 | 93 | 73.98 | 144.74 | 241.23 | 33 |

**TABLE 8** *Continued*

| Trench Load $P_v$, psi[A] | | | | Trench Load $P_v$, psi[A] | | | |
|---|---|---|---|---|---|---|---|
| Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ | Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ |
| 13.31 | 11.29 | 18.82 | 92 | 78.57 | 158.68 | 264.46 | 32 |
| 13.49 | 11.50 | 19.17 | 91 | 83.64 | 174.54 | 290.90 | 31 |
| | | | | 89.23 | 192.67 | 321.11 | 30 |

[A] 1 psi = 6.894757 kPa.
[B] The $D/t$ 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 $D/t$ should be used.
[C] Maximum 3 % deflection is recommended for rigid or semirigid linings such as cement mortar.
[D] Maximum 5 % deflection is recommended for flexible linings such as asphaltic and plastic.

$$P_e = \frac{wH}{a} \tag{3}$$

$$P_t = RF\,\frac{CP}{bD} \tag{4}$$

$$C = 1 - \frac{2}{\pi}\arcsin\left[\, H\sqrt{\frac{A^2+B^2+H^2}{(A^2+H^2)(H^2+B^2)}}\,\right] + \frac{2}{\pi}\left(\frac{A\cdot H\cdot B}{\sqrt{A^2+H^2+B^2}}\right)\left(\frac{1}{A^2+H^2}+\frac{1}{B^2+H^2}\right) \tag{5}$$

NOTE 3—In Eq 5, angles are in radians.

## 8. Hydrostatic Test

8.1 Each pipe shall be subjected to a hydrostatic test of not less than 500 psi (3.45 MPa). This test may be performed either before or after the outside coating and inside coating have been applied, but shall be performed before the application of cement-mortar lining or of a special lining.

8.2 The pipe shall be under the full test pressure for at least 5 s. Suitable controls and recording devices shall be provided so that the test pressure and duration are adequately ascertained. Any pipe that leaks or does not withstand the test pressure shall be rejected.

8.3 In addition to the hydrostatic test before application of a cement-mortar lining or special lining, the pipe may be retested, at the manufacturer's option, after the application of such a lining.

## 9. Acceptance Tests

9.1 The standard acceptance tests for the physical characteristics of the pipe shall be as follows:

9.2 *Tension Test*—Unless otherwise specified by the purchaser, a tension test specimen shall be cut longitudinally or circumferentially from the midsection of the pipe wall. In case of dispute, the test specimen shall be cut longitudinally. This specimen shall be machined and tested in accordance with Fig. 1 and Test Methods E8. The yield strength shall be determined by the 0.2 % offset, halt-of-pointer, or extension-under-load methods. If check tests are to be made, the 0.2 % offset method shall be used. All specimens shall be tested at room temperature 70 ± 10°F (21 ± 6°C).

9.2.1 *Acceptable Values*—The acceptance values for test specimens shall be as follows:

| | |
|---|---|
| Grade of Iron: | 60–42–10 |
| Minimum tensile strength, psi (MPa) | 60 000 (413.7) |
| Minimum yield strength, psi (MPa): | 42 000 (289.6) |
| Minimum elongation, %: | 10 |

9.3 *Charpy Impact Test*—Tests shall be made in accordance with Test Methods E23, except that dimensions of the specimens shall be 0.500 in. (12.70 mm) by full thickness of pipe wall. Unless otherwise specified by the purchaser, the Charpy notched impact test specimen shall be in accordance with Fig. 2 except that it may be cut circumferentially. In case of dispute, the specimen shall be cut in accordance with Fig. 2. If the pipe wall thickness exceeds 0.40 in. (10.2 mm), the Charpy impact specimen may be machined to a nominal thickness of 0.40 in. In all tests, impact values are to be corrected to a standard wall thickness, $t_s$ = 0.40 in., by calculation as follows:

$$\text{Impact value (corrected)} = \frac{t_s}{t} \times \text{impact value (actual)}$$

where: $t$ = the thickness of the specimen, in. (mm).

The Charpy impact test machine anvil shall not be moved to compensate for the variation of cross-section dimensions of the test specimens.

9.3.1 *Acceptance Value*—The corrected acceptance value for notched impact test specimens shall be a minimum of 7 ft·lbf (9.49 J) for tests conducted at 70 ± 10°F (21 ± 6°C).

9.4 *Sampling*— At least one tension sample shall be taken during each casting period of approximately 3 h. At least one 70 ± 10°F (21 ± 6°C) Charpy impact sample shall be taken during each operating hour. Samples shall be selected to properly represent extremes of pipe diameters and wall thicknesses.

## 10. Additional Control Tests by Manufacturer

10.1 An additional low-temperature impact test shall be made from at least 10 % of the sample coupons taken for the required 70 ± 10°F (21 ± 6°C) Charpy impact test specified in 9.4 to check compliance with a minimum corrected value of 3 ft·lbf (4 J) for tests conducted at –40°F ± 2°F (–40°C ± 1°C). Test specimens shall be prepared and tested in accordance with 9.3.

10.2 In addition, the manufacturer shall conduct such other tests as may be necessary to ensure compliance with this specification.

**TABLE 9 Diameter-Thickness Ratios for Laying Condition Type 3**

NOTE 1—$E' = 400$ psi[A] $K_b = 0.189$ $K_x = 0.103$

| Trench Load $P_v$, psi[A] | | | | Trench Load $P_v$, psi[A] | | | |
|---|---|---|---|---|---|---|---|
| Bending Stress Design | Deflection Check | | $D/t$[B] or $D/t_1$ | Bending Stress Design | Deflection Check | | $D/t$[B] or $D/t_1$ |
| | 3 %[C] max | 5 %[D] max | | | 3 %[C] max | 5 %[D] max | |
| 10.00 | 8.52 | 14.19 | 150 | 17.21 | 13.72 | 22.86 | 90 |
| 10.08 | 8.54 | 14.24 | 149 | 17.42 | 13.95 | 23.24 | 89 |
| 10.16 | 8.57 | 14.29 | 148 | 17.64 | 14.18 | 23.64 | 88 |
| 10.24 | 8.60 | 14.34 | 147 | 17.86 | 14.43 | 24.06 | 87 |
| 10.33 | 8.64 | 14.39 | 146 | 18.10 | 14.70 | 24.49 | 86 |
| 10.41 | 8.67 | 14.45 | 145 | 18.34 | 14.97 | 24.95 | 85 |
| 10.49 | 8.70 | 14.50 | 144 | 18.59 | 15.26 | 25.43 | 84 |
| 10.58 | 8.73 | 14.56 | 143 | 18.85 | 15.56 | 25.93 | 83 |
| 10.66 | 8.77 | 14.62 | 142 | 19.12 | 15.88 | 26.46 | 82 |
| 10.75 | 8.81 | 14.68 | 141 | 19.40 | 16.21 | 27.01 | 81 |
| 10.83 | 8.84 | 14.74 | 140 | 19.68 | 16.56 | 27.60 | 80 |
| 10.92 | 8.88 | 14.80 | 139 | 19.99 | 16.93 | 28.21 | 79 |
| 11.01 | 8.92 | 14.87 | 138 | 20.30 | 17.31 | 28.86 | 78 |
| 11.10 | 8.96 | 14.93 | 137 | 20.62 | 17.72 | 29.54 | 77 |
| 11.19 | 9.00 | 15.00 | 136 | 20.96 | 18.15 | 30.26 | 76 |
| 11.28 | 9.04 | 15.07 | 135 | 21.31 | 18.61 | 31.01 | 75 |
| 11.37 | 9.09 | 15.15 | 134 | 21.68 | 19.09 | 31.81 | 74 |
| 11.46 | 9.13 | 15.22 | 133 | 22.07 | 19.59 | 32.65 | 73 |
| 11.56 | 9.18 | 15.30 | 132 | 22.47 | 20.13 | 33.55 | 72 |
| 11.65 | 9.23 | 15.38 | 131 | 22.88 | 20.69 | 34.49 | 71 |
| 11.75 | 9.28 | 15.46 | 130 | 23.32 | 21.29 | 35.49 | 70 |
| 11.84 | 9.33 | 15.55 | 129 | 23.78 | 21.93 | 36.55 | 69 |
| 11.94 | 9.38 | 15.64 | 128 | 24.26 | 22.60 | 37.67 | 68 |
| 12.04 | 9.44 | 15.73 | 127 | 24.76 | 23.32 | 38.86 | 67 |
| 12.14 | 9.49 | 15.82 | 126 | 25.29 | 24.08 | 40.13 | 66 |
| 12.25 | 9.55 | 15.92 | 125 | 25.85 | 24.88 | 41.47 | 65 |
| 12.35 | 9.61 | 16.02 | 124 | 26.43 | 25.74 | 42.91 | 64 |
| 12.45 | 9.67 | 16.12 | 123 | 27.04 | 26.66 | 44.43 | 63 |
| 12.56 | 9.74 | 16.23 | 122 | 27.68 | 27.64 | 46.06 | 62 |
| 12.67 | 9.80 | 16.34 | 121 | 28.36 | 28.68 | 47.80 | 61 |
| 12.78 | 9.87 | 16.45 | 120 | 29.08 | 29.80 | 49.66 | 60 |
| 12.89 | 9.94 | 16.57 | 119 | 29.83 | 30.99 | 51.65 | 59 |
| 13.00 | 10.02 | 16.69 | 118 | 30.63 | 32.27 | 53.78 | 58 |
| 13.11 | 10.09 | 16.82 | 117 | 31.47 | 33.64 | 56.07 | 57 |
| 13.23 | 10.17 | 16.95 | 116 | 32.36 | 35.12 | 58.53 | 56 |
| 13.34 | 10.25 | 17.09 | 115 | 33.31 | 36.70 | 61.17 | 55 |
| 13.46 | 10.34 | 17.23 | 114 | 34.30 | 38.41 | 64.02 | 54 |
| 13.58 | 10.42 | 17.37 | 113 | 35.37 | 40.25 | 67.08 | 53 |
| 13.71 | 10.51 | 17.52 | 112 | 36.49 | 42.24 | 70.40 | 52 |
| 13.83 | 10.61 | 17.68 | 111 | 37.69 | 44.39 | 73.98 | 51 |
| 13.96 | 10.71 | 17.84 | 110 | 38.97 | 46.72 | 77.86 | 50 |
| 14.09 | 10.81 | 18.01 | 109 | 40.33 | 49.25 | 82.08 | 49 |
| 14.22 | 10.91 | 18.18 | 108 | 41.78 | 51.99 | 86.65 | 48 |
| 14.36 | 11.02 | 18.37 | 107 | 43.33 | 54.98 | 91.64 | 47 |
| 14.50 | 11.13 | 18.55 | 106 | 44.98 | 58.25 | 97.08 | 46 |
| 14.64 | 11.25 | 18.75 | 105 | 46.76 | 61.81 | 103.02 | 45 |
| 14.78 | 11.37 | 18.95 | 104 | 48.66 | 65.72 | 109.53 | 44 |
| 14.93 | 11.50 | 19.16 | 103 | 50.71 | 70.01 | 116.68 | 43 |
| 15.08 | 11.63 | 19.38 | 102 | 52.91 | 74.72 | 124.54 | 42 |
| 15.23 | 11.77 | 19.61 | 101 | 55.28 | 79.92 | 133.20 | 41 |
| 15.39 | 11.91 | 19.85 | 100 | 57.84 | 85.67 | 142.78 | 40 |
| 15.55 | 12.06 | 20.10 | 99 | 60.61 | 92.04 | 153.39 | 39 |
| 15.71 | 12.21 | 20.35 | 98 | 63.61 | 99.11 | 165.18 | 38 |
| 15.88 | 12.37 | 20.62 | 97 | 66.86 | 106.99 | 178.32 | 37 |
| 16.06 | 12.54 | 20.90 | 96 | 70.40 | 115.80 | 193.00 | 36 |
| 16.23 | 12.72 | 21.20 | 95 | 74.27 | 125.67 | 209.46 | 35 |
| 16.42 | 12.90 | 21.50 | 94 | 78.49 | 136.78 | 227.97 | 34 |
| 16.61 | 13.09 | 21.82 | 93 | 83.11 | 149.32 | 248.87 | 33 |

**TABLE 9** *Continued*

| Trench Load $P_v$, psi[A] | | | | Trench Load $P_v$, psi[A] | | | |
|---|---|---|---|---|---|---|---|
| Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ | Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ |
| 16.80 | 13.29 | 22.15 | 92 | 88.19 | 163.54 | 272.56 | 32 |
| 17.00 | 13.50 | 22.50 | 91 | 93.79 | 179.71 | 299.51 | 31 |
| | | | | 99.97 | 198.18 | 330.31 | 30 |

[A] 1 psi = 6.894757 kPa.
[B] The $D/t$ 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 $D/t$ should be used.
[C] Maximum 3 % deflection is recommended for rigid or semirigid linings such as cement mortar.
[D] Maximum 5 % deflection is recommended for flexible linings such as asphaltic and plastic.

## 11. Additional Tests Required by Purchaser

11.1 When tests other than those required in this specification are required by the purchaser, such tests shall be specified in the purchaser's specifications.

## 12. Inspection and Certification by Manufacturer

12.1 The manufacturer shall establish the necessary quality-control and inspection practice to ensure compliance with this specification.

12.2 The manufacturer shall, if required on the purchaser's specifications, furnish a sworn statement that the inspection and all of the specified tests have been made and that all results thereof comply with the requirements of this specification.

12.3 All pipes shall be without defects that could impair service. Repairing of defects by welding or other methods shall not be allowed if such repairs could adversely affect the serviceability of the pipe or its capability to meet strength requirements of this specification.

## 13. Defective Specimens and Retests

13.1 When any mechanical test specimen shows defective machining or lack of continuity of metal, it shall be discarded and replaced by another specimen. When any sound test specimen fails to meet the specified mechanical property requirements, the lot of pipe from which the specimen was obtained shall be separated from acceptable pipe. The lot may be either retested, re-heat treated as necessary and retested, or rejected. A retest shall be made on two additional sound test specimens taken from the same lot as the specimen that failed. Pipe that are heat-treated, or retested, or both, shall meet the requirements of 5.1, 9, and 10.

## 14. Inspection by Purchaser

14.1 If the purchaser desires to inspect pipe at the manufacturer's plant, the purchaser shall so state in the purchaser's specifications and describe the conditions (such as time and the extent of inspection) under which the inspection shall be made.

14.2 The purchaser's representative shall have free access to those areas of the manufacturer's plant that are necessary to determine compliance with this specification. The manufacturer shall make available for the use of the purchaser's representative such gages as are necessary for inspection. The manufacturer shall provide the purchaser's representative with assistance as necessary for handling of pipe.

## 15. Delivery and Acceptance

15.1 All pipe and accessories shall comply with this specification. Pipe and accessories not complying with this specification shall be replaced by the manufacturer at the agreed point of delivery. The manufacturer shall not be liable for shortages or damaged pipe after acceptance at the agreed point of delivery, except as recorded on the delivery receipt or similar document by the carrier's agent. See Tables 13-15.

## 16. Foundry Records

16.1 The results of the acceptance tests (Section 9) and low-temperature impact tests (Section 10) shall be recorded and retained for 1 year, and shall be available to the purchaser at the foundry. Written transcripts shall be furnished, if required by the purchaser's specification.

## 17. Rejection of Pipe

17.1 If the results of any physical acceptance test fail to meet the requirements of Sections 9, 10, or 13, all pipe cast in the same period shall be rejected, except as provided in Section 18.

## 18. Determining Rejection

18.1 The manufacturer may determine the amount of pipe to be rejected by making similar additional tests of pipe, of the same size as the rejected pipe, until the rejected lot is bracketed, in order of manufacture, by an acceptable test at each end of the interval in question. When pipe of one size is rejected from a casting period, the acceptability of pipe of different sizes from that same period may be established by developing the acceptance tests for these sizes as specified in Section 9.

## 19. Marking Pipe

19.1 The weight, class, or nominal thickness, and casting period shall be shown on each pipe. The manufacturer's mark, the country where cast, the year in which the pipe was produced, and the letters "DI" or "DUCTILE" shall be cast or metal stamped on the pipe and letters and numbers on pipe sizes 14 in. (356 mm) and larger shall be not less than ½ in. (13

**TABLE 10 Diameter-Thickness Ratios for Laying Condition Type 4**

NOTE 1—$E'$ = 500 psi[A] $K_b$ = 0.157 $K_x$ = 0.096

| Trench Load $P_v$, psi[A] | | | | Trench Load $P_v$, psi[A] | | | |
|---|---|---|---|---|---|---|---|
| Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ | Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ |
| 16.34 | 11.04 | 18.40 | 150 | 24.42 | 16.62 | 27.71 | 90 |
| 16.45 | 11.07 | 18.46 | 149 | 24.64 | 16.87 | 28.11 | 89 |
| 16.55 | 11.11 | 18.51 | 148 | 24.88 | 17.12 | 28.54 | 88 |
| 16.65 | 11.14 | 18.56 | 147 | 25.12 | 17.39 | 28.99 | 87 |
| 16.76 | 11.17 | 18.62 | 146 | 25.37 | 17.67 | 29.45 | 86 |
| 16.86 | 11.21 | 18.68 | 145 | 25.63 | 17.97 | 29.95 | 85 |
| 16.96 | 11.24 | 18.74 | 144 | 25.90 | 18.28 | 30.46 | 84 |
| 17.07 | 11.28 | 18.80 | 143 | 26.18 | 18.60 | 31.00 | 83 |
| 17.18 | 11.31 | 18.86 | 142 | 26.47 | 18.94 | 31.57 | 82 |
| 17.28 | 11.35 | 18.92 | 141 | 26.77 | 19.30 | 32.16 | 81 |
| 17.39 | 11.39 | 18.99 | 140 | 27.09 | 19.67 | 32.79 | 80 |
| 17.50 | 11.43 | 19.06 | 139 | 27.42 | 20.07 | 33.45 | 79 |
| 17.60 | 11.48 | 19.13 | 138 | 27.76 | 20.48 | 34.14 | 78 |
| 17.71 | 11.52 | 19.20 | 137 | 28.11 | 20.92 | 34.87 | 77 |
| 17.82 | 11.56 | 19.27 | 136 | 28.49 | 21.38 | 35.64 | 76 |
| 17.93 | 11.61 | 19.35 | 135 | 28.87 | 21.87 | 36.45 | 75 |
| 18.04 | 11.66 | 19.43 | 134 | 29.28 | 22.38 | 37.31 | 74 |
| 18.15 | 11.71 | 19.51 | 133 | 29.70 | 22.93 | 38.21 | 73 |
| 18.26 | 11.76 | 19.59 | 132 | 30.15 | 23.50 | 39.17 | 72 |
| 18.37 | 11.81 | 19.68 | 131 | 30.62 | 24.11 | 40.18 | 71 |
| 18.49 | 11.86 | 19.77 | 130 | 31.11 | 24.75 | 41.25 | 70 |
| 18.60 | 11.92 | 19.86 | 129 | 31.62 | 25.43 | 42.39 | 69 |
| 18.72 | 11.97 | 19.95 | 128 | 32.16 | 26.16 | 43.59 | 68 |
| 18.83 | 12.03 | 20.05 | 127 | 32.72 | 26.92 | 44.87 | 67 |
| 18.95 | 12.09 | 20.15 | 126 | 33.32 | 27.74 | 46.23 | 66 |
| 19.06 | 12.15 | 20.26 | 125 | 33.95 | 28.60 | 47.67 | 65 |
| 19.18 | 12.22 | 20.36 | 124 | 34.61 | 29.53 | 49.21 | 64 |
| 19.30 | 12.28 | 20.47 | 123 | 35.30 | 30.51 | 50.85 | 63 |
| 19.42 | 12.35 | 20.59 | 122 | 36.04 | 31.56 | 52.60 | 62 |
| 19.54 | 12.42 | 20.71 | 121 | 36.81 | 32.68 | 54.47 | 61 |
| 19.66 | 12.50 | 20.83 | 120 | 37.63 | 33.88 | 56.46 | 60 |
| 19.78 | 12.57 | 20.96 | 119 | 38.50 | 35.16 | 58.60 | 59 |
| 19.91 | 12.65 | 21.09 | 118 | 39.42 | 36.53 | 60.88 | 58 |
| 20.04 | 12.73 | 21.22 | 117 | 40.39 | 38.00 | 63.34 | 57 |
| 20.16 | 12.82 | 21.36 | 116 | 41.42 | 39.58 | 65.97 | 56 |
| 20.29 | 12.91 | 21.51 | 115 | 42.51 | 41.28 | 68.81 | 55 |
| 20.42 | 13.00 | 21.66 | 114 | 43.67 | 43.12 | 71.86 | 54 |
| 20.55 | 13.09 | 21.82 | 113 | 44.91 | 45.09 | 75.15 | 53 |
| 20.69 | 13.19 | 21.98 | 112 | 46.22 | 47.22 | 78.71 | 52 |
| 20.82 | 13.29 | 22.15 | 111 | 47.62 | 49.53 | 82.55 | 51 |
| 20.96 | 13.39 | 22.32 | 110 | 49.11 | 52.03 | 86.72 | 50 |
| 21.10 | 13.50 | 22.50 | 109 | 50.70 | 54.74 | 91.24 | 49 |
| 21.24 | 13.61 | 22.69 | 108 | 52.41 | 57.69 | 96.15 | 48 |
| 21.39 | 13.73 | 22.88 | 107 | 54.23 | 60.90 | 101.50 | 47 |
| 21.54 | 13.85 | 23.08 | 106 | 56.18 | 64.40 | 107.33 | 46 |
| 21.69 | 13.98 | 23.29 | 105 | 58.27 | 68.23 | 113.71 | 45 |
| 21.84 | 14.11 | 23.51 | 104 | 60.52 | 72.42 | 120.70 | 44 |
| 22.00 | 14.24 | 23.74 | 103 | 62.93 | 77.02 | 128.36 | 43 |
| 22.16 | 14.38 | 23.97 | 102 | 65.54 | 82.08 | 136.80 | 42 |
| 22.32 | 14.53 | 24.22 | 101 | 68.35 | 87.66 | 146.09 | 41 |
| 22.49 | 14.68 | 24.47 | 100 | 71.39 | 93.82 | 156.37 | 40 |
| 22.66 | 14.84 | 24.74 | 99 | 74.67 | 100.65 | 167.75 | 39 |
| 22.83 | 15.01 | 25.02 | 98 | 78.24 | 108.24 | 180.40 | 38 |
| 23.01 | 15.18 | 25.30 | 97 | 82.11 | 116.70 | 194.50 | 37 |
| 23.20 | 15.36 | 25.61 | 96 | 86.33 | 126.15 | 210.25 | 36 |
| 23.38 | 15.55 | 25.92 | 95 | 90.93 | 136.74 | 227.91 | 35 |
| 23.58 | 15.75 | 26.25 | 94 | 95.97 | 148.66 | 247.77 | 34 |
| 23.78 | 15.95 | 26.59 | 93 | 101.49 | 162.12 | 270.20 | 33 |

**TABLE 10** *Continued*

| Trench Load $P_v$, psi[A] | | | | Trench Load $P_v$, psi[A] | | | |
|---|---|---|---|---|---|---|---|
| Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ | Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ |
| 23.99 | 16.17 | 26.94 | 92 | 107.56 | 177.37 | 295.61 | 32 |
| 24.20 | 16.39 | 27.32 | 91 | 114.25 | 194.72 | 324.53 | 31 |
| | | | | 121.65 | 214.54 | 357.57 | 30 |

[A] 1 psi = 6.894757 kPa.
[B] The $D/t$ 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 $D/t$ should be used.
[C] Maximum 3
[D] Maximum 5 % deflection is recommended for flexible linings such as asphaltic and plastic.

mm) in height. When required in the purchaser's specifications, initials not exceeding four in number shall be cast or stamped on the pipe. All required markings shall be clear and legible, and all cast or metal stamped marks shall be on or near the bell.

## 20. Weighing Pipe

20.1 Each pipe shall be weighed before the application of any lining or coating other than the asphaltic coating and the weight shown on the outside or inside of the bell or spigot end.

## 21. Keywords

21.1 ductile iron sewer pipe; elongation; laying conditions; mechanical properties; tensile strength; yield strength

**TABLE 11 Diameter-Thickness Ratios for Laying Condition Type 5**

NOTE 1—$E' = 700$ psi[A] $K_b = 0.128$ $K_x = 0.085$

| Trench Load $P_v$, psi[A] | | | | Trench Load $P_v$, psi[A] | | | |
|---|---|---|---|---|---|---|---|
| Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ | Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t$[B] or $D/t_1$ |
| 30.21 | 16.78 | 27.96 | 150 | 38.28 | 23.08 | 38.47 | 90 |
| 30.34 | 16.81 | 28.02 | 149 | 38.49 | 23.36 | 38.93 | 89 |
| 30.48 | 16.85 | 28.08 | 148 | 38.71 | 23.65 | 39.41 | 88 |
| 30.61 | 16.89 | 28.14 | 147 | 38.93 | 23.95 | 39.91 | 87 |
| 30.74 | 16.92 | 28.20 | 146 | 39.17 | 24.27 | 40.44 | 86 |
| 30.87 | 16.96 | 28.27 | 145 | 39.41 | 24.60 | 41.00 | 85 |
| 30.99 | 17.00 | 28.34 | 144 | 39.67 | 24.95 | 41.58 | 84 |
| 31.12 | 17.04 | 28.40 | 143 | 39.94 | 25.31 | 42.19 | 83 |
| 31.25 | 17.09 | 28.48 | 142 | 40.22 | 25.70 | 42.83 | 82 |
| 31.38 | 17.13 | 28.55 | 141 | 40.51 | 26.10 | 43.50 | 81 |
| 31.50 | 17.17 | 28.62 | 140 | 40.82 | 26.52 | 44.21 | 80 |
| 31.63 | 17.22 | 28.70 | 139 | 41.14 | 26.97 | 44.95 | 79 |
| 31.76 | 17.27 | 28.78 | 138 | 41.48 | 27.44 | 45.73 | 78 |
| 31.88 | 17.32 | 28.86 | 137 | 41.84 | 27.93 | 46.56 | 77 |
| 32.01 | 17.37 | 28.94 | 136 | 42.21 | 28.46 | 47.43 | 76 |
| 32.13 | 17.42 | 29.03 | 135 | 42.60 | 29.01 | 48.34 | 75 |
| 32.25 | 17.47 | 29.12 | 134 | 43.02 | 29.59 | 49.31 | 74 |
| 32.38 | 17.53 | 29.21 | 133 | 43.45 | 30.20 | 50.33 | 73 |
| 32.50 | 17.58 | 29.30 | 132 | 43.92 | 30.85 | 51.41 | 72 |
| 32.62 | 17.64 | 29.40 | 131 | 44.40 | 31.53 | 52.56 | 71 |
| 32.75 | 17.70 | 29.50 | 130 | 44.91 | 32.26 | 53.77 | 70 |
| 32.87 | 17.76 | 29.61 | 129 | 45.46 | 33.03 | 55.05 | 69 |
| 32.99 | 17.83 | 29.71 | 128 | 46.03 | 33.85 | 56.41 | 68 |
| 33.11 | 17.89 | 29.82 | 127 | 46.64 | 34.71 | 57.85 | 67 |
| 33.23 | 17.96 | 29.94 | 126 | 47.28 | 35.63 | 59.39 | 66 |
| 33.35 | 18.03 | 30.05 | 125 | 47.96 | 36.61 | 61.02 | 65 |
| 33.47 | 18.11 | 30.18 | 124 | 48.68 | 37.65 | 62.76 | 64 |
| 33.59 | 18.18 | 30.30 | 123 | 49.44 | 38.77 | 64.61 | 63 |
| 33.71 | 18.26 | 30.43 | 122 | 50.25 | 39.95 | 66.58 | 62 |
| 33.83 | 18.34 | 30.56 | 121 | 51.11 | 41.21 | 68.69 | 61 |
| 33.95 | 18.42 | 30.70 | 120 | 52.02 | 42.57 | 70.94 | 60 |
| 34.07 | 18.51 | 30.85 | 119 | 52.99 | 44.01 | 73.36 | 59 |
| 34.19 | 18.60 | 30.99 | 118 | 54.02 | 45.56 | 75.94 | 58 |
| 34.31 | 18.69 | 31.15 | 117 | 55.12 | 47.23 | 78.71 | 57 |
| 34.43 | 18.78 | 31.31 | 116 | 56.28 | 49.01 | 81.69 | 56 |
| 34.55 | 18.88 | 31.47 | 115 | 57.53 | 50.93 | 84.89 | 55 |
| 34.68 | 18.98 | 31.64 | 114 | 58.86 | 53.00 | 88.34 | 54 |
| 34.80 | 19.09 | 31.82 | 113 | 60.28 | 55.23 | 92.05 | 53 |
| 34.92 | 19.20 | 32.00 | 112 | 61.79 | 57.64 | 96.07 | 52 |
| 35.05 | 19.31 | 32.19 | 111 | 63.41 | 60.25 | 100.41 | 51 |
| 35.17 | 19.43 | 32.39 | 110 | 65.14 | 63.07 | 105.12 | 50 |
| 35.30 | 19.55 | 32.59 | 109 | 67.00 | 66.13 | 110.22 | 49 |
| 35.43 | 19.68 | 32.80 | 108 | 68.99 | 69.46 | 115.77 | 48 |
| 35.56 | 19.81 | 33.02 | 107 | 71.12 | 73.09 | 121.81 | 47 |
| 35.69 | 19.95 | 33.25 | 106 | 73.41 | 77.04 | 128.40 | 46 |
| 35.83 | 20.09 | 33.48 | 105 | 75.88 | 81.36 | 135.61 | 45 |
| 35.96 | 20.24 | 33.73 | 104 | 78.54 | 86.10 | 143.49 | 44 |
| 36.10 | 20.39 | 33.99 | 103 | 81.40 | 91.29 | 152.15 | 43 |
| 36.25 | 20.55 | 34.25 | 102 | 84.50 | 97.01 | 161.68 | 42 |
| 36.39 | 20.72 | 34.53 | 101 | 87.85 | 103.31 | 172.18 | 41 |
| 36.54 | 20.89 | 34.82 | 100 | 91.47 | 110.27 | 183.78 | 40 |
| 36.69 | 21.07 | 35.12 | 99 | 95.40 | 117.98 | 196.64 | 39 |
| 36.85 | 21.26 | 35.43 | 98 | 99.67 | 126.56 | 210.93 | 38 |
| 37.01 | 21.45 | 35.76 | 97 | 104.32 | 136.11 | 226.84 | 37 |
| 37.17 | 21.66 | 36.10 | 96 | 109.40 | 146.78 | 244.63 | 36 |
| 37.34 | 21.87 | 36.45 | 95 | 114.94 | 158.75 | 264.58 | 35 |
| 37.52 | 22.09 | 36.82 | 94 | 121.02 | 172.21 | 287.01 | 34 |
| 37.70 | 22.32 | 37.20 | 93 | 127.69 | 187.41 | 312.34 | 33 |

**TABLE 11** *Continued*

| Trench Load $P_v$, psi[A] | | | | Trench Load $P_v$, psi[A] | | | |
|---|---|---|---|---|---|---|---|
| Bending Stress Design | Deflection Check | | $D/t$[B] or $D/t_1$ | Bending Stress Design | Deflection Check | | $D/t$[B] or $D/t_1$ |
| | 3 %[C] max | 5 %[D] max | | | 3 %[C] max | 5 %[D] max | |
| 37.89 | 22.56 | 37.61 | 92 | 135.03 | 204.63 | 341.04 | 32 |
| 38.08 | 22.82 | 38.03 | 91 | 143.14 | 224.22 | 373.70 | 31 |
| | | | | 152.11 | 246.61 | 411.02 | 30 |

[A] 1 psi = 6.894757 kPa.
[B] The $D/t$ 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 $D/t$ should be used.
[C] Maximum 3 % deflection is recommended for rigid or semirigid linings such as cement mortar.
[D] Maximum 5 % deflection is recommended for flexible linings such as asphaltic and plastic.

**TABLE 12 Diameter-Thickness Ratios for Laying Condition Type "Deep Bury"**

NOTE 1—$E'$ = 1500 psi[A] $K_b$ = 0.128 $K_x$ = 0.085

| Trench Load $P_v$, psi[A] | | | | Trench Load $P_v$, psi[A] | | | |
|---|---|---|---|---|---|---|---|
| Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t^B$ or $D/t_1$ | Bending Stress Design | Deflection Check 3 %[C] max | Deflection Check 5 %[D] max | $D/t^B$ or $D/t_1$ |
| 40.42 | 34.00 | 56.67 | 150 | 57.14 | 40.30 | 67.17 | 90 |
| 40.71 | 34.04 | 56.73 | 149 | 57.4 | 40.58 | 67.63 | 89 |
| 41.00 | 34.07 | 56.79 | 148 | 57.66 | 40.87 | 68.12 | 88 |
| 41.29 | 34.11 | 56.85 | 147 | 57.92 | 41.17 | 68.62 | 87 |
| 41.57 | 34.15 | 56.91 | 146 | 58.19 | 41.49 | 69.15 | 86 |
| 41.86 | 34.19 | 56.98 | 145 | 58.46 | 41.82 | 69.70 | 85 |
| 42.16 | 34.23 | 57.04 | 144 | 58.73 | 42.17 | 70.28 | 84 |
| 42.45 | 34.27 | 57.11 | 143 | 59.01 | 42.54 | 70.89 | 83 |
| 42.74 | 34.31 | 57.18 | 142 | 59.29 | 42.92 | 71.53 | 82 |
| 43.03 | 34.35 | 57.25 | 141 | 59.58 | 43.32 | 72.21 | 81 |
| 43.32 | 34.40 | 57.33 | 140 | 59.88 | 43.75 | 72.91 | 80 |
| 43.62 | 34.44 | 57.40 | 139 | 60.18 | 44.19 | 73.66 | 79 |
| 43.91 | 34.49 | 57.48 | 138 | 60.49 | 44.66 | 74.44 | 78 |
| 44.20 | 34.54 | 57.57 | 137 | 60.81 | 45.16 | 75.26 | 77 |
| 44.50 | 34.59 | 57.65 | 136 | 61.15 | 45.68 | 76.13 | 76 |
| 44.79 | 34.64 | 57.74 | 135 | 61.49 | 46.23 | 77.05 | 75 |
| 45.08 | 34.69 | 57.82 | 134 | 61.85 | 46.81 | 78.02 | 74 |
| 45.38 | 34.75 | 57.92 | 133 | 62.22 | 47.42 | 79.04 | 73 |
| 45.67 | 34.81 | 58.01 | 132 | 62.61 | 48.07 | 80.12 | 72 |
| 45.96 | 34.86 | 58.11 | 131 | 63.01 | 48.76 | 81.26 | 71 |
| 46.26 | 34.92 | 58.21 | 130 | 63.44 | 49.48 | 82.47 | 70 |
| 46.55 | 34.99 | 58.31 | 129 | 63.88 | 50.25 | 83.76 | 69 |
| 46.84 | 35.05 | 58.42 | 128 | 64.35 | 51.07 | 85.12 | 68 |
| 47.13 | 35.12 | 58.53 | 127 | 64.85 | 51.94 | 86.56 | 67 |
| 47.42 | 35.19 | 58.64 | 126 | 65.37 | 52.86 | 88.09 | 66 |
| 47.71 | 35.26 | 58.76 | 125 | 65.92 | 53.84 | 89.73 | 65 |
| 48.00 | 35.33 | 58.88 | 124 | 66.51 | 54.88 | 91.46 | 64 |
| 48.29 | 35.40 | 59.01 | 123 | 67.13 | 55.99 | 93.31 | 63 |
| 48.58 | 35.48 | 59.14 | 122 | 67.79 | 57.17 | 95.29 | 62 |
| 48.86 | 35.56 | 59.27 | 121 | 68.49 | 58.44 | 97.40 | 61 |
| 49.15 | 35.65 | 59.41 | 120 | 69.24 | 59.79 | 99.65 | 60 |
| 49.43 | 35.73 | 59.55 | 119 | 70.03 | 61.24 | 102.06 | 59 |
| 49.72 | 35.82 | 59.70 | 118 | 70.89 | 62.79 | 104.64 | 58 |
| 50.00 | 35.91 | 59.85 | 117 | 71.8 | 64.45 | 107.42 | 57 |
| 50.28 | 36.01 | 60.01 | 116 | 72.77 | 66.24 | 110.39 | 56 |
| 50.56 | 36.11 | 60.18 | 115 | 73.82 | 68.16 | 113.59 | 55 |
| 50.84 | 36.21 | 60.35 | 114 | 74.94 | 70.23 | 117.04 | 54 |
| 51.12 | 36.31 | 60.52 | 113 | 76.14 | 72.46 | 120.76 | 53 |
| 51.39 | 36.42 | 60.71 | 112 | 77.44 | 74.86 | 124.77 | 52 |
| 51.66 | 36.54 | 60.89 | 111 | 78.83 | 77.47 | 129.12 | 51 |
| 51.94 | 36.65 | 61.09 | 110 | 80.33 | 80.29 | 133.82 | 50 |
| 52.21 | 36.78 | 61.29 | 109 | 81.95 | 83.36 | 138.93 | 49 |
| 52.48 | 36.90 | 61.51 | 108 | 83.69 | 86.69 | 144.48 | 48 |
| 52.74 | 37.04 | 61.73 | 107 | 85.58 | 90.31 | 150.52 | 47 |
| 53.01 | 37.17 | 61.95 | 106 | 87.62 | 94.26 | 157.11 | 46 |
| 53.28 | 37.31 | 62.19 | 105 | 89.82 | 98.59 | 164.31 | 45 |
| 53.54 | 37.46 | 62.44 | 104 | 92.22 | 103.32 | 172.20 | 44 |
| 53.80 | 37.62 | 62.69 | 103 | 94.81 | 108.52 | 180.86 | 43 |
| 54.06 | 37.78 | 62.96 | 102 | 97.63 | 114.23 | 190.38 | 42 |
| 54.32 | 37.94 | 63.24 | 101 | 100.7 | 120.53 | 200.88 | 41 |
| 54.58 | 38.11 | 63.52 | 100 | 104.03 | 127.49 | 212.49 | 40 |
| 54.84 | 38.29 | 63.82 | 99 | 107.68 | 135.21 | 225.35 | 39 |
| 55.09 | 38.48 | 64.14 | 98 | 111.66 | 143.78 | 239.63 | 38 |
| 55.35 | 38.68 | 64.46 | 97 | 116.01 | 153.33 | 255.55 | 37 |
| 55.61 | 38.88 | 64.80 | 96 | 120.78 | 164.00 | 273.34 | 36 |
| 55.86 | 39.09 | 65.16 | 95 | 126.02 | 175.97 | 293.28 | 35 |
| 56.12 | 39.31 | 65.52 | 94 | 131.79 | 189.43 | 315.72 | 34 |
| 56.37 | 39.55 | 65.91 | 93 | 138.15 | 204.63 | 341.05 | 33 |

**TABLE 12** *Continued*

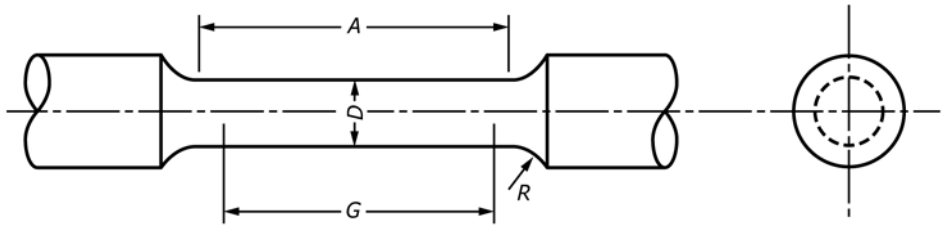
| Trench Load $P_v$, psi[A] | | | | Trench Load $P_v$, psi[A] | | | |
|---|---|---|---|---|---|---|---|
| Bending Stress Design | Deflection Check | | $D/t$[B] or $D/t_1$ | Bending Stress Design | Deflection Check | | $D/t$[B] or $D/t_1$ |
| | 3 %[C] max | 5 %[D] max | | | 3 %[C] max | 5 %[D] max | |
| 56.63 | 39.79 | 66.31 | 92 | 145.18 | 221.85 | 369.75 | 32 |
| 56.88 | 40.04 | 66.73 | 91 | 152.97 | 241.44 | 402.41 | 31 |
| | | | | 161.63 | 263.84 | 439.73 | 30 |

[A] 1 psi = 6.894757 kPa.
[B] The $D/t$ 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 $D/t$ should be used.
[C] Maximum 3 % deflection is recommended for rigid or semirigid linings such as cement mortar.
[D] Maximum 5 % deflection is recommended for flexible linings such as asphaltic and plastic.

NOTE 1—The reduced section (*A*) may have a gradual taper from the ends toward the center with the ends not more than 0.005 in. [11] (0.13 min) larger in diameter than the center on the standard specimen and not more than 0.003 in. (0.08 mm) larger in diameter than the center on the small size specimens.

NOTE 2—If desired, on the small size specimens the length of the reduced section may be increased to accommodate an extensometer. However, reference marks for the measurement of elongation should nevertheless be spaced at the indicated gage length (*G*).

NOTE 3—The gage length and fillets shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial. If the ends are to be held in grips it is desirable, if possible to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips.

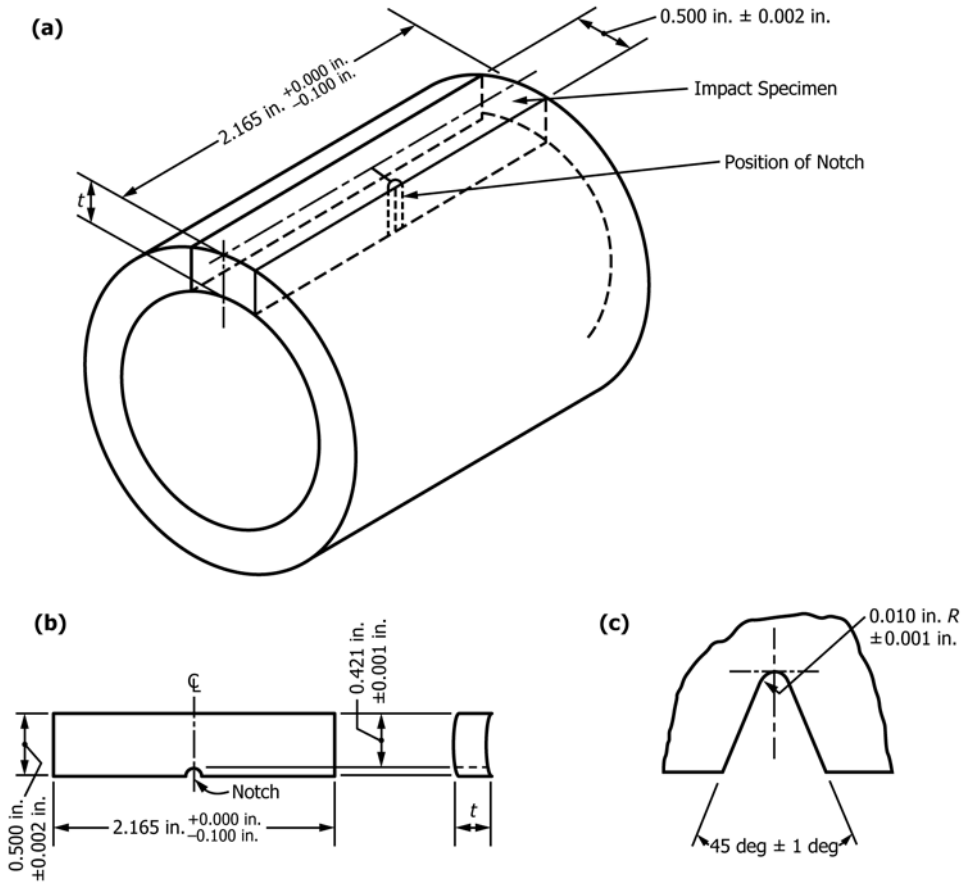



| Dimension | Standard Specimen 0.50–in | | Small-Size Specimens Proportional to Standard | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | (12.7–mm) Round | | 0.350-in. (8.89-mm) Round | | 0.250-in. (6.35-mm) Round | | 0.175-in. (4.45-mm) Round | | 0.125-in. (3.18-mm) Round | |
| | Dimensions, in. (mm) | | | | | | | | | |
| *G* | 2.000 ± 0.005 | (50.80 ± 0.13) | 1.400 ± 0.005 | (35.56 ± 0.13) | 1.000 ± 0.005 | (25.40 ± 0.13) | 0.700 ± 0.005 | (12.78 ± 0.13) | 0.500 ± 0.005 | (12.70 ± 0.13) |
| *D* | 0.500 ± 0.010 | (12.70 ± 0.25) | 0.350 ± 0.007 | (8.89 ± 0.18) | 0.250 ± 0.005 | (6.35 ± 0.13) | 0.175 ± 0.005 | (4.44 ± 0.13) | 0.125 ± 0.005 | (3.18 ± 0.13) |
| *R*, min | ⅜ | (9.5) | ¼ | (6.4) | 3⁄16 | (4.8) | 3⁄32 | (2.4) | 3⁄32 | (2.4) |
| *A*, min | 2¼ | (57.2) | 1¾ | (44.4) | 1¼ | (31.8) | ¾ | (19) | ⅝ | (15.9) |
| *T*[A] | 0.71 and greater | (18.0) | 0.50 to 0.70 | (12.2 to 17.8) | 0.35 to 0.49 | (8.9 to 12.4) | 0.25 to 0.34 | (6.4 to 8.6) | 0.18 to 0.24 | (4.6 to 6.1) |

[A] Thickness of the section from the wall of the pipe from which the tension specimen is to be machined.

**FIG. 1 Tension Test Specimen**

NOTE 1—$t$ = pipe-wall thickness.




| Test Specimen Detail | | Notch Detail | |
|---|---|---|---|
| in. | mm | in. | mm |
| –0.100 | –2.54 | 0.100 | 2.54 |
| +0.000 | +0.00 | 0.421 | 10.69 |
| 0.001 | 0.03 | 0.500 | 12.70 |
| 0.002 | 0.05 | 2.165 | 54.99 |
| 0.010 | 0.25 | | |

**FIG. 2 Impact Test Specimen**

**TABLE 13 Pipe Selection Table (Cement-Lined Pipe)**

NOTE 1—Ring deflection limited to 3 %, minimum safety factor of 2.

NOTE 2—Earth load ($P_e$) of 120 pcf.

| Pipe Size, in. | Pressure Class | Nominal Thickness, in. | Laying Condition | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Type 1 | Type 2 | Type 3 | Type 4 | Type 5 | Deep Bury |
| | | | Maximum Depth of Cover, ft[A] | | | | | |
| 3 | 350 | 0.25 | 78 | 88 | 99 | [B] | [B] | [B] |
| 4 | 350 | 0.25 | 53 | 61 | 69 | 85 | [B] | [B] |
| 6 | 350 | 0.25 | 26 | 31 | 37 | 47 | 65 | 85 |
| 8 | 350 | 0.25 | 16 | 20 | 25 | 34 | 50 | 73 |
| 10 | 350 | 0.26 | 11[C] | 15 | 19 | 28 | 45 | 67 |
| 12 | 350 | 0.28 | 10[C] | 15 | 19 | 28 | 44 | 67 |
| 14 | 250 | 0.28 | [D] | 11[C] | 15 | 23 | 36 | 56 |
| | 300 | 0.30 | | 13 | 17 | 26 | 42 | 62 |
| | 350 | 0.31 | | 14 | 19 | 27 | 44 | 66 |
| 16 | 250 | 0.30 | [D] | 11[C] | 15 | 24 | 34 | 55 |
| | 300 | 0.32 | | 13 | 17 | 26 | 39 | 59 |
| | 350 | 0.34 | | 15 | 20 | 28 | 44 | 65 |
| 18 | 250 | 0.31 | [D] | 10[C] | 14 | 22 | 31 | 51 |
| | 300 | 0.34 | | 13 | 17 | 26 | 36 | 57 |
| | 350 | 0.36 | | 15 | 19 | 28 | 41 | 62 |
| 20 | 250 | 0.33 | [D] | 10[C] | 14 | 22 | 30 | 50 |
| | 300 | 0.36 | | 13 | 17 | 26 | 35 | 55 |
| | 350 | 0.38 | | 15 | 19 | 28 | 38 | 59 |
| 24 | 200 | 0.33 | [D] | 8[C] | 12 | 17 | 25 | 45 |
| | 250 | 0.37 | | 11 | 15 | 20 | 29 | 49 |
| | 300 | 0.40 | | 13 | 17 | 24 | 32 | 53 |
| | 350 | 0.43 | | 15 | 19 | 28 | 37 | 57 |
| 30 | 150 | 0.34 | [D] | . . . | 9 | 14 | 22 | 42 |
| | 200 | 0.38 | | 8[C] | 12 | 16 | 24 | 45 |
| | 250 | 0.42 | | 11 | 15 | 19 | 27 | 47 |
| | 300 | 0.45 | | 12 | 16 | 21 | 29 | 50 |
| | 350 | 0.49 | | 15 | 19 | 25 | 33 | 54 |
| 36 | 150 | 0.38 | [D] | . . . | 9 | 14 | 21 | 42 |
| | 200 | 0.42 | | 8[C] | 12 | 15 | 23 | 44 |
| | 250 | 0.47 | | 10 | 14 | 18 | 25 | 46 |
| | 300 | 0.51 | | 12 | 16 | 20 | 28 | 49 |
| | 350 | 0.56 | | 15 | 19 | 24 | 32 | 53 |
| 42 | 150 | 0.41 | [D] | . . . | 9 | 13 | 20 | 41 |
| | 200 | 0.47 | | 8 | 12 | 15 | 22 | 43 |
| | 250 | 0.52 | | 10 | 14 | 17 | 25 | 45 |
| | 300 | 0.57 | | 12 | 16 | 20 | 27 | 48 |
| | 350 | 0.63 | | 15 | 19 | 23 | 32 | 52 |
| 48 | 150 | 0.46 | [D] | . . . | 9 | 13 | 20 | 41 |
| | 200 | 0.52 | | 8 | 11 | 15 | 22 | 43 |
| | 250 | 0.58 | | 10 | 13 | 17 | 24 | 45 |
| | 300 | 0.64 | | 12 | 15 | 19 | 27 | 48 |
| | 350 | 0.70 | | 15 | 18 | 22 | 30 | 51 |
| 54 | 150 | 0.51 | [D] | . . . | 9 | 13 | 20 | 41 |
| | 200 | 0.58 | | 8 | 11 | 14 | 22 | 42 |
| | 250 | 0.65 | | 10 | 13 | 16 | 24 | 45 |
| | 300 | 0.72 | | 13 | 15 | 19 | 27 | 47 |
| | 350 | 0.79 | | 15 | 18 | 22 | 30 | 51 |
| 60 | 150 | 0.54 | [D] | 5[C] | 9 | 13 | 20 | 41 |
| | 200 | 0.61 | | 8 | 11 | 14 | 22 | 42 |
| | 250 | 0.68 | | 10 | 13 | 16 | 24 | 44 |
| | 300 | 0.76 | | 13 | 15 | 19 | 26 | 47 |
| | 350 | 0.83 | | 15 | 18 | 22 | 30 | 50 |
| 64 | 150 | 0.56 | [D] | 5[C] | 9 | 13 | 20 | 41 |
| | 200 | 0.64 | | 8 | 11 | 14 | 21 | 42 |
| | 250 | 0.72 | | 10 | 13 | 16 | 24 | 44 |
| | 300 | 0.80 | | 12 | 15 | 19 | 26 | 47 |
| | 350 | 0.87 | | 15 | 17 | 21 | 29 | 50 |

[A] These pipes are adequate for depths of cover from 2.5 ft up to the maximum shown including an allowance for a single H-20 truck with 1.5 impact factor unless noted.
[B] Calculated maximum depth of cover exceeds 100 ft.
[C] Minimum allowable depth of cover is 3 ft.
[D] For pipe 14 in. and larger, consideration should be given to the use of laying conditions other than Type 1.

**TABLE 14 Pipe Selection Table (Pipe with Flexible Lining)**

NOTE 1—Examples of flexible linings include polyethylene, epoxy, asphaltic, etc.

NOTE 2—Ring deflection limited to 5 %, minimum safety factor of 2.

NOTE 3—Earth load ($P_e$) of 120 pcf.

| Pipe Size, in. | Pressure Class | Nominal Thickness, in. | Laying Condition | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Type 1 | Type 2 | Type 3 | Type 4 | Type 5 | Deep Bury |
| | | | Maximum Depth of Cover, ft[A] | | | | | |
| 3 | 350 | 0.25 | 78 | 88 | 99 | [B] | [B] | [B] |
| 4 | 350 | 0.25 | 53 | 61 | 69 | 85 | [B] | [B] |
| 6 | 350 | 0.25 | 26 | 31 | 37 | 47 | 65 | 85 |
| 8 | 350 | 0.25 | 16 | 20 | 25 | 34 | 50 | 73 |
| 10 | 350 | 0.26 | 11[C] | 15 | 19 | 28 | 45 | 67 |
| 12 | 350 | 0.28 | 10[C] | 15 | 19 | 28 | 44 | 67 |
| 14 | 250 | 0.28 | [D] | 11[C] | 15 | 23 | 41 | 59 |
| | 300 | 0.30 | | 13 | 17 | 26 | 43 | 64 |
| | 350 | 0.31 | | 14 | 19 | 27 | 44 | 66 |
| 16 | 250 | 0.30 | [D] | 11[C] | 15 | 24 | 41 | 60 |
| | 300 | 0.32 | | 13 | 17 | 26 | 43 | 64 |
| | 350 | 0.34 | | 15 | 20 | 28 | 45 | 68 |
| 18 | 250 | 0.31 | [D] | 10 [C] | 14 | 23 | 40 | 58 |
| | 300 | 0.34 | | 13 | 17 | 26 | 43 | 64 |
| | 350 | 0.36 | | 15 | 19 | 28 | 45 | 67 |
| 20 | 250 | 0.33 | [D] | 10[C] | 14 | 23 | 40 | 58 |
| | 300 | 0.36 | | 13 | 17 | 26 | 43 | 64 |
| | 350 | 0.38 | | 15 | 19 | 28 | 44 | 67 |
| 24 | 200 | 0.33 | [D] | 8[C] | 12 | 20 | 37 | 50 |
| | 250 | 0.37 | | 11 | 15 | 23 | 41 | 59 |
| | 300 | 0.40 | | 13 | 17 | 26 | 43 | 64 |
| | 350 | 0.43 | | 15 | 19 | 28 | 45 | 67 |
| 30 | 150 | 0.34 | [D] | . . . | 9 | 17 | 33 | 42 |
| | 200 | 0.38 | | 8[C] | 12 | 20 | 37 | 52 |
| | 250 | 0.42 | | 11 | 15 | 23 | 40 | 59 |
| | 300 | 0.45 | | 12 | 16 | 25 | 42 | 63 |
| | 350 | 0.49 | | 15 | 19 | 28 | 44 | 67 |
| 36 | 150 | 0.38 | [D] | . . . | 9 | 17 | 33 | 42 |
| | 200 | 0.42 | | 8[C] | 12 | 20 | 37 | 51 |
| | 250 | 0.47 | | 10 | 14 | 23 | 40 | 59 |
| | 300 | 0.51 | | 12 | 17 | 25 | 42 | 63 |
| | 350 | 0.56 | | 15 | 19 | 28 | 45 | 67 |
| 42 | 150 | 0.41 | [D] | . . . | 9 | 16 | 32 | 41 |
| | 200 | 0.47 | | 8 | 12 | 20 | 37 | 52 |
| | 250 | 0.52 | | 10 | 14 | 23 | 40 | 58 |
| | 300 | 0.57 | | 12 | 17 | 25 | 42 | 63 |
| | 350 | 0.63 | | 15 | 19 | 28 | 45 | 67 |
| 48 | 150 | 0.46 | [D] | . . . | 9 | 17 | 33 | 42 |
| | 200 | 0.52 | | 8 | 12 | 20 | 37 | 51 |
| | 250 | 0.58 | | 10 | 14 | 23 | 40 | 58 |
| | 300 | 0.64 | | 12 | 17 | 25 | 42 | 63 |
| | 350 | 0.70 | | 15 | 19 | 28 | 44 | 67 |
| 54 | 150 | 0.51 | [D] | . . . | 9 | 17 | 33 | 42 |
| | 200 | 0.58 | | 8 | 12 | 20 | 37 | 51 |
| | 250 | 0.65 | | 10 | 14 | 23 | 40 | 58 |
| | 300 | 0.72 | | 13 | 17 | 25 | 42 | 64 |
| | 350 | 0.79 | | 15 | 19 | 28 | 45 | 67 |
| 60 | 150 | 0.54 | [D] | 5[C] | 9 | 17 | 33 | 42 |
| | 200 | 0.61 | | 8 | 12 | 20 | 37 | 51 |
| | 250 | 0.68 | | 10 | 14 | 23 | 40 | 58 |
| | 300 | 0.76 | | 13 | 17 | 25 | 43 | 64 |
| | 350 | 0.83 | | 15 | 19 | 28 | 45 | 67 |
| 64 | 150 | 0.56 | [D] | 5[C] | 9 | 17 | 33 | 42 |
| | 200 | 0.64 | | 8 | 12 | 20 | 36 | 52 |
| | 250 | 0.72 | | 10 | 14 | 23 | 40 | 59 |
| | 300 | 0.80 | | 13 | 17 | 26 | 43 | 64 |
| | 350 | 0.87 | | 15 | 19 | 28 | 45 | 67 |

[A] These pipes are adequate for depths of cover from 2.5 ft up to the maximum shown including an allowance for a single H-20 truck with 1.5 impact factor unless noted.
[B] Calculated maximum depth of cover exceeds 100 ft.
[C] Minimum allowable depth of cover is 3 ft.
[D] For pipe 14 in. and larger, consideration should be given to the use of laying conditions other than Type 1.

**TABLE 15 Standard Dimensions and Weights of Push-on Joint Ductile Iron Pipe**

| Pipe Size, in. | Pressure Class | Thickness, in. | OD,[A] in. | Weight of Barrel per ft, lb | Weight of Bell,[B] lb | 18-ft Laying Length | | 20-ft Laying Length | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Weight per Length,[C] lb | Average Weight per ft,[D] lb | Weight per Length,[C] lb | Average Weight per ft,[D] lb |
| 3 | 350 | 0.25 | 3.96 | 8.9 | 7.0 | 165 | 9.3 | 185 | 9.2 |
| 4 | 350 | 0.25 | 4.80 | 10.9 | 9.0 | 205 | 11.4 | 225 | 11.3 |
| 6 | 350 | 0.25 | 6.90 | 16.0 | 11.0 | 300 | 16.6 | 330 | 16.6 |
| 8 | 350 | 0.25 | 9.05 | 21.1 | 17.0 | 395 | 22.0 | 440 | 22.0 |
| 10 | 350 | 0.26 | 11.10 | 27.1 | 24.0 | 510 | 28.4 | 565 | 28.3 |
| 12 | 350 | 0.28 | 13.20 | 34.8 | 29.0 | 655 | 36.4 | 725 | 36.3 |
| 14 | 250 | 0.28 | 15.30 | 40.4 | 45.0 | 770 | 42.9 | 855 | 42.7 |
| | 300 | 0.30 | 15.30 | 43.3 | 45.0 | 825 | 45.8 | 910 | 45.6 |
| | 350 | 0.31 | 15.30 | 44.7 | 45.0 | 850 | 47.2 | 940 | 47.0 |
| 16 | 250 | 0.30 | 17.40 | 49.3 | 54.0 | 940 | 52.3 | 1040 | 52.0 |
| | 300 | 0.32 | 17.40 | 52.5 | 54.0 | 1000 | 55.5 | 1105 | 55.2 |
| | 350 | 0.34 | 17.40 | 55.8 | 54.0 | 1060 | 58.8 | 1170 | 58.5 |
| 18 | 250 | 0.31 | 19.50 | 57.2 | 59.0 | 1090 | 60.5 | 1205 | 60.2 |
| | 300 | 0.34 | 19.50 | 62.6 | 59.0 | 1185 | 65.9 | 1310 | 65.6 |
| | 350 | 0.36 | 19.50 | 66.2 | 59.0 | 1250 | 69.5 | 1385 | 69.2 |
| 20 | 250 | 0.33 | 21.60 | 67.5 | 74.0 | 1290 | 71.6 | 1425 | 71.2 |
| | 300 | 0.36 | 21.60 | 73.5 | 74.0 | 1395 | 77.6 | 1545 | 77.2 |
| | 350 | 0.38 | 21.60 | 77.5 | 74.0 | 1470 | 81.6 | 1625 | 81.2 |
| 24 | 200 | 0.33 | 25.80 | 80.8 | 95.0 | 1550 | 86.1 | 1710 | 85.6 |
| | 250 | 0.37 | 25.80 | 90.5 | 95.0 | 1725 | 95.8 | 1905 | 95.3 |
| | 300 | 0.40 | 25.80 | 97.7 | 95.0 | 1855 | 103.0 | 2050 | 102.5 |
| | 350 | 0.43 | 25.80 | 104.9 | 95.0 | 1985 | 110.2 | 2195 | 109.7 |
| 30 | 150 | 0.34 | 32.00 | 103.5 | 139.0 | 2000 | 111.2 | 2210 | 110.5 |
| | 200 | 0.38 | 32.00 | 115.5 | 139.0 | 2220 | 123.2 | 2450 | 122.5 |
| | 250 | 0.42 | 32.00 | 127.5 | 139.0 | 2435 | 135.2 | 2690 | 134.5 |
| | 300 | 0.45 | 32.00 | 136.5 | 139.0 | 2595 | 144.2 | 2870 | 143.5 |
| | 350 | 0.49 | 32.00 | 148.4 | 139.0 | 2810 | 156.1 | 3105 | 155.3 |
| 36 | 150 | 0.38 | 38.30 | 138.5 | 184.0 | 2675 | 148.7 | 2955 | 147.7 |
| | 200 | 0.42 | 38.30 | 152.9 | 184.0 | 2935 | 163.1 | 3240 | 162.1 |
| | 250 | 0.47 | 38.30 | 170.9 | 184.0 | 3260 | 181.1 | 3600 | 180.1 |
| | 300 | 0.51 | 38.30 | 185.3 | 184.0 | 3520 | 195.5 | 3890 | 194.5 |
| | 350 | 0.56 | 38.30 | 203.2 | 184.0 | 3840 | 213.4 | 4250 | 212.4 |
| 42 | 150 | 0.41 | 44.50 | 173.8 | 289.0 | 3415 | 189.9 | 3765 | 188.3 |
| | 200 | 0.47 | 44.50 | 198.9 | 289.0 | 3870 | 215.0 | 4265 | 213.3 |
| | 250 | 0.52 | 44.50 | 219.9 | 289.0 | 4245 | 236.0 | 4685 | 234.3 |
| | 300 | 0.57 | 44.50 | 240.7 | 289.0 | 4620 | 256.8 | 5105 | 255.2 |
| | 350 | 0.63 | 44.50 | 265.7 | 289.0 | 5070 | 281.8 | 5605 | 280.2 |
| 48 | 150 | 0.46 | 50.80 | 222.6 | 354.0 | . . . | . . . | 4805 | 240.3 |
| | 200 | 0.52 | 50.80 | 251.3 | 354.0 | . . . | . . . | 5380 | 269.0 |
| | 250 | 0.58 | 50.80 | 280.0 | 354.0 | . . . | . . . | 5955 | 297.7 |
| | 300 | 0.64 | 50.80 | 308.6 | 354.0 | . . . | . . . | 6525 | 326.3 |
| | 350 | 0.70 | 50.80 | 337.1 | 354.0 | . . . | . . . | 7095 | 354.8 |
| 54 | 150 | 0.51 | 57.56 | 279.7 | 439.0 | . . . | . . . | 6035 | 301.7 |
| | 200 | 0.58 | 57.56 | 317.7 | 439.0 | . . . | . . . | 6795 | 339.7 |
| | 250 | 0.65 | 57.56 | 355.6 | 439.0 | . . . | . . . | 7550 | 377.5 |
| | 300 | 0.72 | 57.56 | 393.4 | 439.0 | . . . | . . . | 8305 | 415.3 |
| | 350 | 0.79 | 57.56 | 431.1 | 439.0 | . . . | . . . | 9060 | 453.1 |
| 60 | 150 | 0.54 | 61.61 | 317.0 | 588.0 | . . . | . . . | 6930 | 346.4 |
| | 200 | 0.61 | 61.61 | 357.7 | 588.0 | . . . | . . . | 7740 | 387.1 |
| | 250 | 0.68 | 61.61 | 398.3 | 588.0 | . . . | . . . | 8555 | 427.7 |
| | 300 | 0.76 | 61.61 | 444.6 | 588.0 | . . . | . . . | 9480 | 474.0 |
| | 350 | 0.83 | 61.61 | 485.0 | 588.0 | . . . | . . . | 10 290 | 514.4 |
| 64 | 150 | 0.56 | 65.67 | 350.5 | 670.0 | . . . | . . . | 7680 | 384.0 |
| | 200 | 0.64 | 65.67 | 400.1 | 670.0 | . . . | . . . | 8670 | 433.6 |
| | 250 | 0.72 | 65.67 | 449.6 | 670.0 | . . . | . . . | 9660 | 483.1 |
| | 300 | 0.80 | 65.67 | 496.9 | 670.0 | . . . | . . . | 10 650 | 532.4 |
| | 350 | 0.87 | 65.67 | 542.0 | 670.0 | . . . | . . . | 11 510 | 575.5 |

[A] Tolerance of OD of spigot end: 3–12 in., ±0.06 in.; 14–24 in., +0.05 in., –0.08 in.; 30–48 in., +0.08 in., –0.06 in.; 54–64 in., +0.04 in., –0.10 in.

[B] The bell weights shown above are adequate for 350-psi (2413-kPa) operating pressure. Bell weights vary due to differences in push-on-joint design. The manufacturer shall calculate pipe weights using standard barrel weights and weights of bells being produced.

[C] Including bell; calculated weight of pipe rounded off to nearest 5 lb.

[D] Including bell; average weight per foot based on calculated weight of pipe before rounding.