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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)

[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.
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[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.

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 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_1—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)

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.

3.1.22 ΔX—design deflection, in. (mm),

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

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.

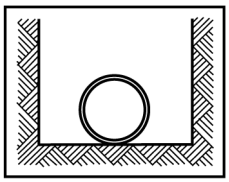
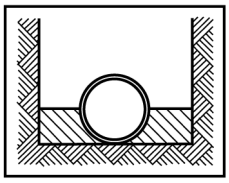
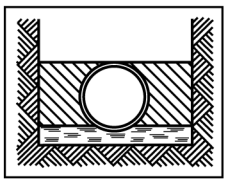
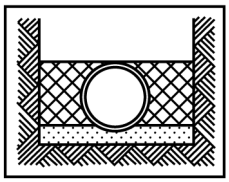
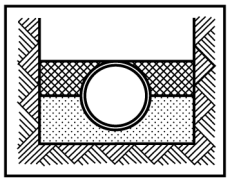
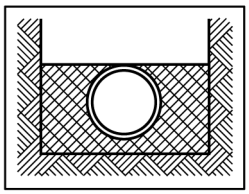
6. Coating and Lining

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.

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.

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 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)

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.

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.

7.1.2 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.

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.

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.

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.

7.7.5.1 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 Δ_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:*

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

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

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

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.

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

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

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.