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Standard Specification for Ductile Iron Gravity Sewer Pipe[1]

This standard is issued under the fixed designation A 746; 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.

~~1.3The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.~~

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]

D 2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D~~2847~~~~Classification of Soils for Engineering Purposes (Unified Soil Classification System)~~

~~D~~ 3282 Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes

E 8 Test Methods for Tension Testing of Metallic Materials

E 23 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:Symbols:*~~ 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)

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[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, 25 West 43rd Street, 4th Floor, New York, NY 10036.~~

[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 the American Society of Civil Engineers,1801 Alexander Bell Drive, Reston, VA 20191.~~

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

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 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)
3.1.22 Δ*X*—design deflection, in. (mm),

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

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.

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 C 111/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 ~~an asphaltic~~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 C 104/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.

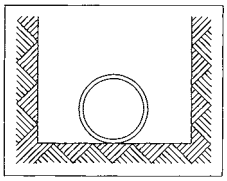
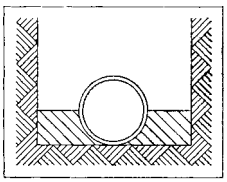
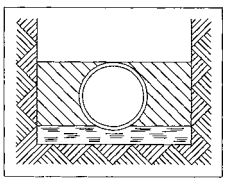
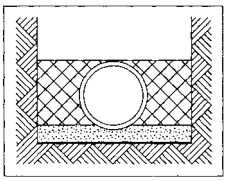
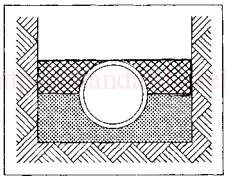
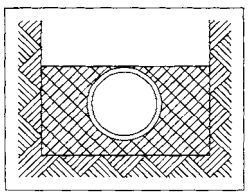
7. Pipe Design

~~7.1This section covers the design of ductile iron pipe for trench loads.~~

~~7.2*Determining the Total Calculated Thickness and Standard Thickness*:~~

~~7.2.1~~

7.1 *Step 1*—Design for trench load.

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 D 2487), 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.

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)

7.1.1 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.

7.2~~1~~.2 Determine the standard laying condition from the descriptions in Table 3 and select the appropriate table for diameter-thickness ratios from ~~Tables 7-11~~Tables 7-12. Each table lists diameter-thickness ratios calculated for both bending and deflection over a range of trench loads.

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.

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-D Chesignck 3 %[C] max	Deflection-D Chesignck 5 %[D] max	D/t^B or D/t_1	Bending Stress Design	Deflection-D Chesignck 3 %[C] max	Deflection-D Chesignck 5 %[D] max	D/t^B or D/t_1
5.17	3.89	6.48	150	8.86	7.12	11.87	100
5.17	3.89	6.48	150	10.37	8.85	14.74	90
5.21	3.91	6.52	149	8.99	7.26	12.11	99
5.21	3.91	6.52	149	10.55	9.06	15.11	89
5.26	3.94	6.57	148	9.13	7.41	12.35	98
5.26	3.94	6.57	148	10.74	9.29	15.48	88
5.30	3.97	6.62	147	9.27	7.57	12.61	97
5.30	3.97	6.62	147	10.93	9.53	15.88	87
5.35	4.00	6.67	146	9.41	7.73	12.88	96
5.35	4.00	6.67	146	11.13	9.78	16.30	86
5.40	4.03	6.72	145	9.56	7.89	13.15	95
5.40	4.03	6.72	145	11.34	10.04	16.73	85
5.45	4.06	6.77	144	9.71	8.07	13.45	94
5.45	4.06	6.77	144	11.55	10.31	17.19	84
5.49	4.09	6.82	143	9.87	8.25	13.75	93
5.49	4.09	6.82	143	11.78	10.60	17.67	83
5.54	4.13	6.88	142	10.03	8.44	14.07	92
5.54	4.13	6.88	142	12.01	10.90	18.17	82
5.59	4.16	6.94	141	10.20	8.64	14.40	91
5.59	4.16	6.94	141	12.25	11.22	18.70	81
5.65	4.20	6.99	140	10.37	8.85	14.74	90
5.65	4.20	6.99	140	12.50	11.56	19.26	80
5.70	4.23	7.05	139	10.55	9.06	15.11	89
5.70	4.23	7.05	139	12.76	11.91	19.85	79
5.75	4.27	7.12	138	10.74	9.29	15.48	88
5.75	4.27	7.12	138	13.03	12.28	20.46	78
5.80	4.31	7.18	137	10.93	9.53	15.88	87
5.80	4.31	7.18	137	13.31	12.67	21.11	77
5.86	4.35	7.25	136	11.13	9.78	16.30	86
5.86	4.35	7.25	136	13.60	13.08	21.79	76
5.91	4.39	7.31	135	11.34	10.04	16.73	85
5.91	4.39	7.31	135	13.91	13.51	22.52	75
5.97	4.43	7.38	134	11.55	10.31	17.19	84
5.97	4.43	7.38	134	14.23	13.97	23.28	74
6.03	4.47	7.46	133	11.78	10.60	17.67	83
6.03	4.47	7.46	133	14.56	14.45	24.08	73
6.09	4.52	7.53	132	12.01	10.90	18.17	82
6.09	4.52	7.53	132	14.91	14.96	24.93	72
6.15	4.56	7.61	131	12.25	11.22	18.70	81
6.15	4.56	7.61	131	15.27	15.50	25.83	71
6.21	4.61	7.69	130	12.50	11.56	19.26	80
6.21	4.61	7.69	130	15.65	16.07	26.78	70
6.27	4.66	7.77	129	12.76	11.91	19.85	79
6.27	4.66	7.77	129	16.05	16.68	27.79	69
6.33	4.71	7.85	128	13.03	12.28	20.46	78
6.33	4.71	7.85	128	16.46	17.32	28.86	68
6.40	4.76	7.94	127	13.31	12.67	21.11	77
6.40	4.76	7.94	127	16.89	18.00	30.00	67
6.46	4.82	8.03	126	13.60	13.08	21.79	76
6.46	4.82	8.03	126	17.35	18.73	31.21	66
6.53	4.87	8.12	125	13.91	13.51	22.52	75
6.53	4.87	8.12	125	17.83	19.50	32.49	65
6.60	4.93	8.22	124	14.23	13.97	23.28	74
6.60	4.93	8.22	124	18.33	20.32	33.86	64
6.67	4.99	8.32	123	14.56	14.45	24.08	73
6.67	4.99	8.32	123	18.85	21.19	35.32	63
6.74	5.05	8.42	122	14.91	14.96	24.93	72
6.74	5.05	8.42	122	19.40	22.12	36.87	62
6.82	5.11	8.52	121	15.27	15.50	25.83	71
6.82	5.11	8.52	121	19.98	23.12	38.53	61
6.89	5.18	8.63	120	15.65	16.07	26.78	70

TABLE 2 *Continued*

Trench Load P_v, psi[A]				Trench Load P_v, psi[A]			
Bending Stress Design	Deflection D Chesignck 3 %[C] max	Deflection D Chesignck 5 %[D] max	D/t^B or D/t_1	Bending Stress Design	Deflection D Chesignck 3 %[C] max	Deflection D Chesignck 5 %[D] max	D/t^B or D/t_1
6.89	5.18	8.63	120	20.59	24.18	40.30	60
6.91	5.25	8.74	119	16.05	16.68	27.79	69
6.97	5.25	8.74	119	21.23	25.32	42.20	59
7.05	5.32	8.86	118	16.46	17.32	28.86	68
7.05	5.32	8.86	118	21.91	26.54	44.23	58
7.13	5.39	8.98	117	16.89	18.00	30.00	67
7.13	5.39	8.98	117	22.63	27.85	46.42	57
7.21	5.46	9.11	116	17.35	18.73	31.21	66
7.21	5.46	9.11	116	23.38	29.26	48.76	56
7.29	5.54	9.24	115	17.83	19.50	32.49	65
7.29	5.54	9.24	115	24.18	30.77	51.28	55
7.38	5.62	9.37	114	18.33	20.32	33.86	64
7.38	5.62	9.37	114	25.02	32.39	53.99	54
7.47	5.71	9.51	113	18.85	21.19	35.32	63
7.47	5.71	9.51	113	25.92	34.15	56.92	53
7.56	5.79	9.65	112	19.40	22.12	36.87	62
7.56	5.79	9.65	112	26.86	36.05	60.08	52
7.65	5.88	9.80	111	19.98	23.12	38.53	61
7.65	5.88	9.80	111	27.87	38.10	63.50	51
7.75	5.97	9.96	110	20.59	24.18	40.30	60
7.75	5.97	9.96	110	28.94	40.32	67.20	50
7.85	6.07	10.12	109	21.23	25.32	42.20	59
7.85	6.07	10.12	109	30.07	42.73	71.22	49
7.95	6.17	10.20	108	21.91	26.54	44.23	58
7.95	6.17	10.28	108	31.28	45.35	75.58	48
8.05	6.27	10.46	107	22.63	27.85	46.42	57
8.05	6.27	10.46	107	32.57	48.20	80.34	47
8.16	6.38	10.63	106	23.38	29.26	48.76	56
8.16	6.38	10.63	106	33.95	51.31	85.52	46
8.27	6.49	10.82	105	24.18	30.77	51.28	55
8.27	6.49	10.82	105	35.42	54.72	91.19	45
8.38	6.61	11.01	104	25.02	32.39	53.99	54
8.38	6.61	11.01	104	37.00	58.44	97.40	44
8.49	6.73	11.22	103	25.92	34.15	56.92	53
8.49	6.73	11.22	103	38.69	62.53	104.22	43
8.61	6.86	11.43	102	26.86	36.05	60.08	52
8.61	6.86	11.43	102	40.50	67.03	111.71	42
8.74	6.99	11.64	101	27.87	38.10	63.50	51
8.74	6.99	11.64	101	42.46	71.99	119.98	41
28.94	40.32	67.20	50	46.84	83.54	139.23	39
8.86	7.12	11.87	100	44.56	77.47	129.11	40
30.07	42.73	71.22	49	49.30	90.28	150.47	38
8.99	7.26	12.11	99	46.84	83.54	139.23	39
31.28	45.35	75.58	48	51.96	97.80	163.00	37
9.13	7.41	12.35	98	49.30	90.28	150.47	38
32.57	48.20	80.34	47	54.86	106.20	177.00	36
9.27	7.57	12.61	97	51.96	97.80	163.00	37
33.95	51.31	85.52	46				
9.41	7.73	12.88	96	54.86	106.20	177.00	36
35.42	54.72	91.19	45	58.02	115.62	192.70	35
9.56	7.89	13.15	95	58.02	115.62	192.70	35
37.00	58.44	97.40	44	61.46	126.21	210.36	34
9.71	8.07	13.45	94	61.46	126.21	210.36	34
38.69	62.53	104.22	43	65.23	138.18	230.29	33
9.87	8.25	13.75	93	65.23	138.18	230.29	33
40.50	67.03	111.71	42	69.36	151.73	252.88	32
10.03	8.44	14.07	92	69.36	151.73	252.88	32
42.46	71.99	119.98	41	73.92	167.15	278.58	31
10.20	8.64	14.40	91	73.92	167.15	278.58	31
				78.94	184.77	307.96	30
44.56	77.47	129.11	40				

[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.

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 ~~Design~~ Check 3 %[C] max	Deflection ~~Design~~ Check 5 %[D] max	D/t[B] or D/t_1	Bending Stress Design	Deflection ~~Design~~ Check 3 %[C] max	Deflection ~~Design~~ Check 5 %[D] max	D/t[B] or D/t_1
~~7.42~~	~~6.61~~	~~11.02~~	~~150~~	~~12.01~~	~~9.94~~	~~16.57~~	~~100~~
7.42	6.61	11.02	150	13.68	11.71	19.52	90
~~7.48~~	~~6.64~~	~~11.06~~	~~149~~	~~12.16~~	~~10.09~~	~~16.81~~	~~99~~
7.48	6.64	11.06	149	13.88	11.94	19.89	89
~~7.54~~	~~6.67~~	~~11.11~~	~~148~~	~~12.31~~	~~10.24~~	~~17.06~~	~~98~~
7.54	6.67	11.11	148	14.08	12.17	20.28	88
~~7.61~~	~~6.70~~	~~11.16~~	~~147~~	~~12.46~~	~~10.40~~	~~17.33~~	~~97~~
7.61	6.70	11.16	147	14.30	12.42	20.69	87
~~7.67~~	~~6.73~~	~~11.21~~	~~146~~	~~12.62~~	~~10.56~~	~~17.60~~	~~96~~
7.67	6.73	11.21	146	14.51	12.67	21.12	86
~~7.74~~	~~6.76~~	~~11.27~~	~~15~~	~~12.79~~	~~10.73~~	~~17.89~~	~~95~~
7.74	6.76	11.27	145	14.74	12.94	21.57	85
~~7.80~~	~~6.79~~	~~11.32~~	~~144~~	~~12.96~~	~~10.91~~	~~18.19~~	~~94~~
7.80	6.79	11.32	144	14.97	13.22	22.04	84
~~7.87~~	~~6.83~~	~~11.38~~	~~143~~	~~13.13~~	~~11.10~~	~~18.50~~	~~93~~
7.87	6.83	11.38	143	15.21	13.52	22.53	83
~~7.94~~	~~6.86~~	~~11.43~~	~~142~~	~~13.31~~	~~11.29~~	~~18.82~~	~~92~~
7.94	6.86	11.43	142	15.46	13.83	23.05	82
~~8.01~~	~~6.89~~	~~11.49~~	~~141~~	~~13.49~~	~~11.50~~	~~19.17~~	~~91~~
8.01	6.89	11.49	141	15.72	14.16	23.60	81
~~8.08~~	~~6.93~~	~~11.55~~	~~140~~	~~13.68~~	~~11.71~~	~~19.52~~	~~90~~
8.08	6.93	11.55	140	15.99	14.50	24.17	80
~~8.15~~	~~6.97~~	~~11.61~~	~~139~~	~~13.88~~	~~11.94~~	~~19.89~~	~~89~~
8.15	6.97	11.61	139	16.28	14.86	24.77	79
~~8.22~~	~~7.01~~	~~11.68~~	~~138~~	~~14.08~~	~~12.17~~	~~20.28~~	~~88~~
8.22	7.01	11.68	138	16.57	15.24	25.40	78
~~8.29~~	~~7.05~~	~~11.74~~	~~137~~	~~14.30~~	~~12.42~~	~~20.69~~	~~87~~
8.29	7.05	11.74	137	16.87	15.64	26.07	77
~~8.37~~	~~7.09~~	~~11.81~~	~~135~~	~~14.51~~	~~12.67~~	~~21.12~~	~~86~~
8.37	7.09	11.81	136	17.19	16.06	26.77	76
~~8.44~~	~~7.13~~	~~11.88~~	~~135~~	~~14.74~~	~~12.94~~	~~21.57~~	~~85~~
8.44	7.13	11.88	135	17.52	16.51	27.52	75
~~8.52~~	~~7.17~~	~~11.95~~	~~134~~	~~14.97~~	~~13.22~~	~~22.04~~	~~84~~
8.52	7.17	11.95	134	17.86	16.98	28.30	74
~~8.59~~	~~7.22~~	~~12.03~~	~~133~~	~~15.21~~	~~13.52~~	~~22.53~~	~~83~~
8.59	7.22	12.03	133	18.22	17.48	29.13	73
~~8.67~~	~~7.26~~	~~12.10~~	~~132~~	~~15.46~~	~~13.83~~	~~23.05~~	~~82~~
8.67	7.26	12.10	132	18.59	18.00	30.00	72
~~8.75~~	~~7.31~~	~~12.18~~	~~131~~	~~15.72~~	~~14.16~~	~~23.60~~	~~81~~
8.75	7.31	12.18	131	18.98	18.56	30.93	71
~~8.83~~	~~7.36~~	~~12.26~~	~~130~~	~~15.99~~	~~14.50~~	~~24.17~~	~~80~~
8.83	7.36	12.26	130	19.39	19.14	31.91	70
~~8.91~~	~~7.41~~	~~12.35~~	~~129~~	~~16.28~~	~~14.86~~	~~24.77~~	~~79~~
8.91	7.41	12.35	129	19.82	19.77	32.95	69
~~8.99~~	~~7.46~~	~~12.43~~	~~128~~	~~16.57~~	~~15.24~~	~~25.40~~	~~78~~
8.99	7.46	12.43	128	20.27	20.43	34.05	68
~~9.07~~	~~7.51~~	~~12.52~~	~~127~~	~~16.87~~	~~15.64~~	~~26.07~~	~~77~~
9.07	7.51	12.52	127	20.73	21.13	35.22	67
~~9.16~~	~~7.57~~	~~12.62~~	~~126~~	~~17.19~~	~~16.06~~	~~26.77~~	~~76~~
9.16	7.57	12.62	126	21.23	21.87	36.46	66
~~9.25~~	~~7.63~~	~~12.71~~	~~125~~	~~17.52~~	~~16.51~~	~~27.52~~	~~75~~
9.25	7.63	12.71	125	21.74	22.67	37.78	65
~~9.33~~	~~7.69~~	~~12.81~~	~~124~~	~~17.86~~	~~16.98~~	~~28.30~~	~~74~~
9.33	7.69	12.81	124	22.28	23.51	39.18	64
~~9.42~~	~~7.75~~	~~12.91~~	~~123~~	~~18.22~~	~~17.48~~	~~29.13~~	~~73~~
9.42	7.75	12.91	123	22.85	24.41	40.68	63
~~9.51~~	~~7.81~~	~~13.02~~	~~122~~	~~18.59~~	~~18.00~~	~~30.00~~	~~72~~
9.51	7.81	13.02	122	23.45	25.37	42.28	62
~~9.60~~	~~7.87~~	~~13.12~~	~~121~~	~~18.98~~	~~18.56~~	~~30.93~~	~~71~~
9.60	7.87	13.12	121	24.07	26.39	43.99	61
~~9.70~~	~~7.94~~	~~13.24~~	~~120~~	~~19.39~~	~~19.14~~	~~31.91~~	~~70~~

TABLE 2 *Continued*

Trench Load P_v, psi[A]				Trench Load P_v, psi[A]			
Bending Stress Design	Deflection Design Check 3 %[C] max	Deflection Design Check 5 %[D] max	D/t[B] or D/t_1	Bending Stress Design	Deflection Design Check 3 %[C] max	Deflection Design Check 5 %[D] max	D/t[B] or D/t_1
9.70	7.94	13.24	120	24.74	27.49	45.81	60
9.79	8.01	13.35	119	19.82	19.77	32.95	69
9.79	8.01	13.35	119	25.43	28.66	47.76	59
9.89	8.08	13.47	118	20.27	20.43	34.05	68
9.89	8.08	13.47	118	26.17	29.91	49.86	58
9.99	8.16	13.60	117	20.73	21.13	35.22	67
9.99	8.16	13.60	117	26.95	31.26	52.10	57
10.09	8.23	13.72	116	21.23	21.87	36.46	66
10.09	8.23	13.72	116	27.77	32.71	54.51	56
10.19	8.31	13.86	115	21.74	22.67	37.78	65
10.19	8.31	13.86	115	28.64	34.26	57.10	55
10.29	8.40	13.99	114	22.28	23.51	39.18	64
10.29	8.40	13.99	114	29.56	35.93	59.89	54
10.40	8.48	14.14	113	22.85	24.41	40.68	63
10.40	8.48	14.14	113	30.53	37.74	62.90	53
10.51	8.57	14.29	112	23.45	25.37	42.28	62
10.51	8.57	14.29	112	31.57	39.69	66.15	52
10.62	8.66	14.44	111	24.07	26.39	43.99	61
10.62	8.66	14.44	111	32.67	41.80	69.67	51
10.73	8.76	14.60	110	24.74	27.49	45.81	60
10.73	8.76	14.60	110	33.84	44.09	73.48	50
10.84	8.86	14.76	109	25.43	28.66	47.76	59
10.84	8.86	14.76	109	35.08	46.56	77.61	49
10.96	8.96	14.93	108	26.17	29.91	49.86	58
10.96	8.96	14.93	108	36.41	49.26	82.10	48
11.08	9.07	15.11	107	26.95	31.26	52.10	57
11.08	9.07	15.11	107	37.83	52.19	86.99	47
11.21	9.18	15.30	106	27.77	32.71	54.521	56
11.21	9.18	15.30	106	39.34	55.40	92.33	46
11.33	9.29	15.49	105	28.64	34.26	57.10	55
11.33	9.29	15.49	105	40.96	58.89	98.16	45
11.46	9.41	15.69	104	29.56	35.93	59.89	54
11.46	9.41	15.69	104	42.70	62.73	104.54	44
11.59	9.54	15.89	103	30.53	37.74	62.90	53
11.59	9.54	15.89	103	44.57	66.93	111.55	43
11.73	9.67	16.11	102	31.57	39.69	66.15	52
11.73	9.67	16.11	102	46.57	71.56	119.26	42
11.87	9.80	16.33	101	32.67	41.80	69.67	51
11.87	9.80	16.33	101	48.73	76.66	127.76	41
33.84	44.09	73.48	50	51.06	82.29	137.16	40
12.01	9.94	16.57	100	51.06	82.29	137.16	40
35.08	46.56	77.61	49	53.57	88.54	147.57	39
12.16	10.09	16.81	99	53.57	88.54	147.57	39
36.41	49.26	82.10	48	56.30	95.48	159.13	38
12.31	10.24	17.06	98	56.30	95.48	159.13	38
37.83	52.19	86.99	47	59.25	103.21	172.02	37
12.46	10.40	17.33	97	59.25	103.21	172.02	37
39.34	55.40	92.33	46	62.46	111.85	186.42	36
12.62	10.56	17.60	96	62.46	111.85	186.42	36
40.96	58.89	98.16	45	65.96	121.54	202.56	35
12.79	10.73	17.89	95	65.96	121.54	202.56	35
42.70	62.73	104.54	44	69.79	132.44	220.73	34
12.96	10.91	18.19	94	69.79	132.44	220.73	34
44.57	66.93	111.55	43	73.98	144.74	241.23	33
13.13	11.10	18.50	93	73.98	144.74	241.23	33
46.57	71.56	119.26	42	78.57	158.68	264.46	32
13.31	11.29	18.82	92	78.57	158.68	264.46	32
48.73	76.66	127.76	41	83.64	174.54	290.90	31
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.