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MEMORANDUM **Public Works Transportation**

DATE: FEBRUARY 14, 2004

TO: MAG Specifications and Details Committee

FROM: David E. Fern, Transportation Operations Manager

SUBJECT: Proposed Revision to MAG Specification Section 735 (C)

PURPOSE: 1. Reduce the required cement content for Reinforced Concrete Pipe to conform with ASTM C-76 requirements.

DISCUSSION: MAG Specification Section 735.2 requires Reinforced Concrete Pipe (RCP) quality as manufactured and tested in conformance with the requirements of ASTM C-76 "except as modified herein". The proposed revision to MAG Specification Section 735.4 (C) would read as follows:

> **(C) Mixture: The proportion of portland cement or combination of portland cement and Pozzolanic material in the mixture shall not be less ~~and~~ than ~~564~~ 470 lbs. per cubic yard of concrete.**

MAG Specification Section 735.7 establishes the tests and basis for acceptance, including reference to ASTM C-76.

The current mixture requirement under MAG Specification Section 735.4 (C) requires that all Reinforced Concrete Pipe be proportioned with portland cement or a combination of portland cement and Pozzolanic material in a mixture not less than 564 lbs. per cubic yard of concrete. ASTM C-76 requires only 470 lbs. per cubic yard unless mix designs with a lower cementitious materials content demonstrate that the quality of performance of the pipe meet the requirements of C76-03.

c: File

Designation: C 76 – 03

Standard Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe[1]

This standard is issued under the fixed designation C 76; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers reinforced concrete pipe intended to be used for the conveyance of sewage, industrial wastes, and storm water, and for the construction of culverts.

1.2 A complete metric companion to Specification C 76 has been developed—C 76M; therefore, no metric equivalents are presented in this specification.

NOTE 1—This specification is a manufacturing and purchase specification only, and does not include requirements for bedding, backfill, or the relationship between field load condition and the strength classification of pipe. However, experience has shown that the successful performance of this product depends upon the proper selection of the class of pipe, type of bedding and backfill, and care that installation conforms to the construction specifications. The owner of the reinforced concrete pipe specified herein is cautioned that he must correlate the field requirements with the class of pipe specified and provide inspection at the construction site.

NOTE 2—Attention is called to the specification for reinforced concrete D-load culvert, storm drain, and sewer pipe (Specification C 655).

2. Referenced Documents

2.1 *ASTM Standards:*

A 82 Specification for Steel Wire, Plain, for Concrete Reinforcement[2]

A 185 Specification for Steel Welded Wire Reinforcement, Plain, for Concrete[2]

A 496 Specification for Steel Wire, Deformed, for Concrete Reinforcement[2]

A 497 Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete[2]

A 615/A 615M Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement[2]

C 33 Specification for Concrete Aggregates[3]

C 150 Specification for Portland Cement[4]

C 309 Specification for Liquid Membrane-Forming Compounds for Curing Concrete[3]

C 497 Test Methods for Concrete Pipe, Manhole Sections, or Tile[5]

C 595 Specification for Blended Hydraulic Cements[4]

C 618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete[3]

C 655 Specification for Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe[5]

C 822 Terminology Relating to Concrete Pipe and Related Products[5]

C 989 Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars[3]

C 1116 Specification for Fiber-Reinforced Concrete and Shotcrete[3]

C 1157 Performance Specification for Hydraulic Concrete[4]

3. Terminology

3.1 *Definitions*—For definitions of terms relating to concrete pipe, see Terminology C 822.

4. Classification

4.1 Pipe manufactured in accordance with this specification shall be of five classes identified as Class I, Class II, Class III, Class IV, and Class V. The corresponding strength requirements are prescribed in Tables 1-5.

5. Basis of Acceptance

5.1 Unless otherwise designated by the owner at the time of, or before placing an order, two separate and alternative bases of acceptance are permitted as follows:

5.1.1 *Acceptance on the Basis of Plant Load-Bearing Tests, Material Tests, and Inspection of Manufactured Pipe for Visual Defects and Imperfections*—Acceptability of the pipe in all diameters and classes produced in accordance with 7.1 or 7.2 shall be determined by the results of the three-edge bearing tests as defined in 11.3.1; by such material tests as are required in 6.1, 6.2, and 6.4; by absorption tests on selected samples of

[1] This specification is under the jurisdiction of ASTM Committee C13 on Concrete Pipe and is the direct responsibility of Subcommittee C13.02 on Reinforced Sewer and Culvert Pipe.

Current edition approved May 10, 2003. Published August 2003. Originally approved in 1930. Last previous edition approved in 2002 as C 76–02.

[2] *Annual Book of ASTM Standards*, Vol 01.04.

[3] *Annual Book of ASTM Standards*, Vol 04.02.

[4] *Annual Book of ASTM Standards*, Vol 04.01.

[5] *Annual Book of ASTM Standards*, Vol 04.05.

TABLE 1 Design Requirements for Class I Reinforced Concrete Pipe[A]

NOTE 1—See Section 5 for basis of acceptance specified by the owner.

The strength test requirements in pounds-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pounds-force per linear foot per foot of diameter) to produce a 0.01-in. crack, or the D-loads to produce the 0.01-in. crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce a 0.01-in. crack	800
D-load to produce the ultimate load	1200

Internal Designated Diameter, in.	Reinforcement, in.²/linear ft of pipe wall								
	Wall A					Wall B			
	Concrete Strength, 4000 psi					Concrete Strength, 4000 psi			
	Wall Thickness, in.	Circular Reinforcement[B]		Elliptical Reinforcement[C]		Wall Thickness, in.	Circular Reinforcement[B]		Elliptical Reinforcement[C]	
		Inner Cage	Outer Cage				Inner Cage	Outer Cage		
60	5	0.25	0.15	0.28		6	0.21	0.13	0.23	
66	5½	0.30	0.18	0.33		6½	0.25	0.15	0.28	
72	6	0.35	0.21	0.39		7	0.29	0.17	0.32	
78	6½	0.40	0.24	0.44		7½	0.32	0.19	0.36	
84	7	0.45	0.27	0.50		8	0.37	0.22	0.41	
90	7½	0.49	0.29	0.54		8½	0.41	0.25	0.46	
96	8	0.54	0.32	0.60		9	0.46	0.28	0.51	
	Concrete Strength, 5000 psi									
102	8½	0.63	0.38	Inner Circular Plus Elliptical	0.25 0.38	9½	0.54	0.32	Inner Circular Plus Elliptical	0.22 0.32
108	9	0.68	0.41	Inner Circular Plus Elliptical	0.27 0.41	10	0.61	0.37	Inner Circular Plus Elliptical	0.24 0.37
114	[A]	...	...	...	...	[A]	...	...	...	...
120	[A]	...	...	...	...	[A]	...	...	...	...
126	[A]	...	...	...	...	[A]	...	...	...	...
132	[A]	...	...	...	...	[A]	...	...	...	...
138	[A]	...	...	...	...	[A]	...	...	...	...
144	[A]	...	...	...	...	[A]	...	...	...	...

[A] For modified or special designs see 7.2 or with the permission of the owner utilize the provisions of Specification C 655. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe over 96 in. in diameter shall have two circular cages or an inner circular plus one elliptical cage.

[B] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in either of the following manners:
An inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table,
An inner and outer cage plus quadrant mats in accordance with Fig. 1, or
An inner and outer cage plus an elliptical cage in accordance with Fig. 2.

[C] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

concrete from the wall of the pipe; and by visual inspection of the finished pipe to determine its conformance with the accepted design and its freedom from defects.

5.1.2 *Acceptance on the Basis of Material Tests and Inspection of Manufactured Pipe for Defects and Imperfections*—Acceptability of the pipe in all diameters and classes produced in accordance with 7.1 or 7.2 shall be determined by the results of such material tests as are required in 6.1, 6.2, and 6.4; by crushing tests on concrete cores or cured concrete cylinders; by absorption tests on selected samples from the wall of the pipe; and by inspection of the finished pipe including amount and placement of reinforcement to determine its conformance with the accepted design and its freedom from defects.

5.1.3 When agreed upon by the owner and manufacturer, any portion or any combination of the tests itemized in 5.1.1 or 5.1.2 may form the basis of acceptance.

5.2 *Age for Acceptance*—Pipe shall be considered ready for acceptance when it conforms to the requirements as indicated by the specified tests.

6. Materials

6.1 The aggregate shall be so sized, graded, proportioned, and mixed with such proportions of Portland cement, blended hydraulic cement, or Portland cement and supplementary cementing materials, or admixtures, if used, or a combination thereof, and water to produce a homogenous concrete mixture of such quality that the pipe will conform to the test and design requirements of the specification. In no case, however, shall the proportion of Portland cement, blended hydraulic cement, or a combination of Portland cement and supplementary cementing materials be less than 470 lb/yd^3.

6.2 *Cementitious materials*:

6.2.1 *Cement*—Cement shall conform to the requirements of Specification C 150, or shall be portland blast-furnace slag cement, or slag modified portland cement, or portland-pozzolan cement conforming to the requirements of Specification C 595, except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash.

TABLE 2 Design Requirements for Class II Reinforced Concrete Pipe[A]

Note 1—See Section 5 for basis of acceptance specified by the owner.

The strength test requirements in pounds-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pounds-force per linear foot per foot of diameter) to produce a 0.01-in. crack, or the D-loads to produce the 0.01-in. crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce a 0.01-in. crack	1000
D-load to produce the ultimate load	1500

Internal Designated Diameter, in.	Reinforcement, in.²/linear ft of pipe wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 4000 psi				Concrete Strength, 4000 psi				Concrete Strength, 4000 psi			
	Wall Thickness, in.	Circular Reinforcement[B]		Elliptical Reinforcement[C]	Wall Thickness, in.	Circular Reinforcement[B]		Elliptical Reinforcement[C]	Wall Thickness, in.	Circular Reinforcement[C]		Elliptical Reinforcement[D]
		Inner Cage	Outer Cage			Inner Cage	Outer Cage			Inner Cage	Outer Cage	
12	1¾	0.07[B]	...	...	2	0.07[B]	...	...	2¾	0.07[B]	...	...
15	1⅞	0.07[B]	...	...	2¼	0.07[B]	...	...	3	0.07[B]	...	...
18	2	0.07[B]	...	0.07[B]	2½	0.07[B]	...	0.07[B]	3¼	0.07[B]	...	0.07[B]
21	2¼	0.12	...	0.10	2¾	0.07[B]	...	0.07[B]	3½	0.07[B]	...	0.07[B]
24	2½	0.13	...	0.11	3	0.07[B]	...	0.07[B]	3¾	0.07[B]	...	0.07[B]
27	2⅝	0.15	...	0.13	3¼	0.13	...	0.11	4	0.07[B]	...	0.07[B]
30	2¾	0.15	...	0.14	3½	0.14	...	0.12	4¼	0.07[B]	...	0.07[B]
33	2⅞	0.16	...	0.15	3¾	0.15	...	0.13	4½	0.07[B]	...	0.07[B]
36	3	0.14	0.08	0.15	4[E]	0.12	0.07	0.13	4¾[E]	0.07	0.07	0.08
42	3½	0.16	0.10	0.18	4½	0.15	0.09	0.17	5¼	0.10	0.07	0.11
48	4	0.21	0.13	0.23	5	0.18	0.11	0.20	5¾	0.14	0.08	0.15
54	4½	0.25	0.15	0.28	5½	0.22	0.13	0.24	6¼	0.17	0.10	0.19
60	5	0.30	0.18	0.33	6	0.25	0.15	0.28	6¾	0.22	0.13	0.24
66	5½	0.35	0.21	0.39	6½	0.31	0.19	0.34	7¼	0.25	0.15	0.28
72	6	0.41	0.25	0.45	7	0.35	0.21	0.39	7¾	0.30	0.18	0.33
78	6½	0.46	0.28	0.51	7½	0.40	0.24	0.44	8¼	0.35	0.21	0.39
84	7	0.51	0.31	0.57	8	0.46	0.28	0.51	8¾	0.41	0.25	0.46
90	7½	0.57	0.34	0.63	8½	0.51	0.31	0.57	9¼	0.48	0.29	0.53
96	8	0.62	0.37	0.69	9	0.57	0.34	0.63	9¾	0.55	0.33	0.61
	Concrete Strength, 5000 psi											
102	8½	0.76	0.46	Inner Circular Plus Elliptical 0.30 / 0.46	9½	0.68	0.41	Inner Circular Plus Elliptical 0.27 / 0.41	10¼	0.62	0.37	Inner Circular Plus Elliptical 0.25 / 0.37
108	9	0.85	0.51	Inner Circular Plus Elliptical 0.34 / 0.51	10	0.76	0.46	Inner Circular Plus Elliptical 0.30 / 0.46	10¾	0.70	0.42	Inner Circular Plus Elliptical 0.28 / 0.42
114	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...
120	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...
126	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...
132	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...
138	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...
144	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...

[A] For modified or special designs see 7.2 or with the permission of the owner utilize the provisions of Specification C 655. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe over 96 in. in diameter shall have two circular cages or an inner circular plus one elliptical cage.

[B] For these classes and sizes, the minimum practical steel reinforcement is specified. The actual ultimate strength is greater than the minimum strength specified for nonreinforced pipe of equivalent diameters.

[C] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in either of the following manners:
An inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table,
An inner and outer cage plus quadrant mats in accordance with Fig. 1 , or
An inner and outer cage plus an elliptical cage in accordance with Fig. 2.

[D] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

[E] As an alternative, single cage reinforcement may be used. The reinforcement area in square in. per linear foot shall be 0.20 for wall B and 0.16 for wall C.

6.2.2 *Ground Granulated Blast-Furnace Slag (GGBFS)*—GGBFS shall conform to the requirements of Grade 100 or 120 of Specification C 989.

6.2.3 *Fly Ash*—Fly ash shall conform to the requirements of Class F or Class C of Specification C 618.

6.2.4 *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in the concrete shall be one of the following:

6.2.4.1 Portland cement only,

6.2.4.2 Portland blast furnace slag cement only,

6.2.4.3 Portland pozzolan cement only, or

6.2.4.4 A combination of portland cement and fly ash.

6.2.5 *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in the concrete shall be one of the following:

6.2.5.1 Portland cement only,

TABLE 3 Design Requirements for Class III Reinforced Concrete Pipe[A]

NOTE 1—See Section 5 for basis of acceptance specified by the owner.

The strength test requirements in pounds-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test l expressed in pounds-force per linear foot per foot of diameter) to produce a 0.01-in. crack, or the D-loads to produce the 0.01-in. crack and the ultin load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce a 0.01-in. crack	1350
D-load to produce the ultimate load	2000

Internal Designated Diameter, in.	Reinforcement, in.²/linear ft of pipe wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 4000 psi				Concrete Strength, 4000 psi				Concrete Strength, 4000 psi			
	Wall Thicknesses, in.	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement[C]	Wall Thicknesses, in.	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement[C]	Wall Thicknesses, in.	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement
12	1¾	0.07[D]	...	...	2	0.07[D]	...	...	2¾	0.07[D]	...	...
15	1⅞	0.07[D]	...	...	2¼	0.07[D]	...	...	3	0.07[D]	...	...
18	2	0.07[D]	...	0.07[D]	2½	0.07[D]	...	0.07[D]	3¼	0.07[D]	...	0.07[D]
21	2¼	0.14	...	0.11	2¾	0.07[D]	...	0.07[D]	3½	0.07[D]	...	0.07[D]
24	2½	0.17	...	0.14	3	0.07[D]	...	0.07[D]	3¾	0.07	...	0.07[D]
27	2⅝	0.18	...	0.16	3¼	0.16	...	0.14	4	0.08	...	0.07[D]
30	2¾	0.19	...	0.18	3½	0.18	...	0.15	4¼	0.10	...	0.08
33	2⅞	0.21	...	0.20	3¾	0.20	...	0.17	4½	0.12	...	0.10
36	3	0.21	0.13	0.23	4[E]	0.17	0.10	0.19	4¾[E]	0.08	0.07	0.09
42	3½	0.25	0.15	0.28	4½	0.21	0.13	0.23	5¼	0.12	0.07	0.13
48	4	0.32	0.19	0.35	5	0.24	0.14	0.27	5¾	0.16	0.10	0.18
54	4½	0.38	0.23	0.42	5½	0.29	0.17	0.32	6¼	0.21	0.13	0.23
60	5	0.44	0.26	0.49	6	0.34	0.20	0.38	6¾	0.25	0.15	0.28
66	5½	0.50	0.30	0.55	6½	0.41	0.25	0.46	7¼	0.31	0.19	0.34
72	6	0.57	0.34	0.63	7	0.49	0.29	0.54	7¾	0.36	0.22	0.40
	Concrete Strength, 5000 psi											
78	6½	0.64	0.38	0.71	7½	0.57	0.34	0.63	8¼	0.42	0.25	0.47
84	7	0.72	0.43	0.80	8	0.64	0.38	0.71	8¾	0.50	0.30	0.56
					Concrete Strength, 5000 psi				Concrete Strength, 5000 psi			
90	7½	0.81	0.49	0.90	8½	0.69	0.41	0.77	9¼	0.59	0.35	0.66
96	8	0.93	0.56	1.03	9	0.76	0.46	0.84	9¾	0.70	0.42	Inner Circular 0.2 Plus Elliptical 0.4
102	8½	1.03	0.62	Inner Circular 0.41 Plus Elliptical 0.62	9½	0.90	0.54	Inner Circular 0.36 Plus Elliptical 0.54	10¼	0.83	0.50	Inner Circular 0.3 Plus Elliptical 0.5
108	9	1.22	0.73	Inner Circular 0.49 Plus Elliptical 0.73	10	1.08	0.65	Inner Circular 0.43 Plus Elliptical 0.65	10¾	0.99	0.59	Inner Circular 0.4 Plus Elliptical 0.5
114	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...
120	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...
126	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...
132	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...
138	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...
144	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...

[A] For modified or special designs see 7.2 or with the permission of the owner utilize the provisions of Specification C 655. Steel areas may be interpolated between thos shown for variations in diameter, loading, or wall thickness. Pipe over 96 in. in diameter shall have two circular cages or an inner circular plus one elliptical cage.

[B] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in either of the following manners

An inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table,

An inner and outer cage plus quadrant mats in accordance with Fig. 1, or

An inner and outer cage plus an elliptical cage in accordance with Fig. 2.

[C] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

[D] For these classes and sizes, the minimum practical steel reinforcement is specified. The actual ultimate strength is greater than the minimum strength specified fo reinforced pipe of equivalent diameters.

[E] As an alternative, single cage reinforcement may be used. The reinforcement area in square in. per linear foot shall be 0.30 for wall B and 0.20 for wall C.

TABLE 4 Design Requirements for Class IV Reinforced Concrete Pipe[A]

NOTE 1—See Section 5 for basis of acceptance specified by the owner.

The strength test requirements in pounds-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pounds-force per linear foot per foot of diameter) to produce a 0.01-in. crack, or the D-loads to produce the 0.01-in. crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce a 0.01-in. crack	2000
D-load to produce the ultimate load	3000

Internal Designated Diameter, in.	Reinforcement, in.²/linear ft of pipe wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 5000 psi				Concrete Strength, 4000 psi				Concrete Strength, 4000 psi			
	Wall Thickness, in.	Circular Reinforcement[B]		Elliptical Reinforcement[C]	Wall Thickness, in.	Circular Reinforcement[B]		Elliptical Reinforcement[C]	Wall Thickness, in.	Circular Reinforcement[B]		Elliptical Reinforcement[C]
		Inner Cage	Outer Cage			Inner Cage	Outer Cage			Inner Cage	Outer Cage	
12	1¾	0.15	...	...	2	0.07	...	...	2¾	0.07[D]	...	...
15	1⅞	0.16	...	...	2¼	0.10	...	...	3	0.07[D]	...	...
18	2	0.17	...	0.15	2½	0.14	...	0.11	3¼	0.07[D]	...	0.07[D]
21	2¼	0.23	...	0.21	2¾	0.20	...	0.17	3½	0.07[D]	...	0.07[D]
24	2½	0.29	...	0.27	3	0.27	...	0.23	3¾	0.07	0.07	0.08
27	2⅝	0.33	...	0.31	3¼	0.31	...	0.25	4	0.08	0.07	0.09
30	2¾	0.38	...	0.35	3½	0.35	...	0.28	4¼	0.09	0.07	0.10
33	[A]	...	...	...	3¾	0.27	0.16	0.30	4½	0.11	0.07	0.12
36	[A]	...	...	...	4	0.30	0.18	0.33	4¾	0.14	0.08	0.15
42	[A]	...	...	...	4½	0.35	0.21	0.39	5¼	0.20	0.12	0.22
48	[A]	...	...	...	5	0.42	0.25	0.47	5¾	0.26	0.16	0.29
54	[A]	...	...	...	5½	0.50	0.30	0.55	6¼	0.34	0.20	0.38
					Concrete Strength, 5000 psi							
60	[A]	...	...	...	6	0.59	0.35	0.66	6¾	0.41	0.25	0.46
66	[A]	...	...	...	6½	0.69	0.41	0.77	7¼	0.51	0.31	0.57
									Concrete Strength, 5000 psi			
72	[A]	...	...	...	7	0.79	0.47	0.88	7¾	0.61	0.37	0.68
78	[A]	...	...	...	[A]	...	...	...	8¼	0.71	0.43	0.79
84	[A]	...	...	...	[A]	...	...	...	8¾	0.85	0.51	0.94
90	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
96	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
102	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
108	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
114	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
120	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
126	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
132	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
138	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
144	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...

[A] For modified or special designs see 7.2 or with the permission of the owner utilize the provisions of Specification C 655. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe over 96 in. in diameter shall have two circular cages or an inner circular plus one elliptical cage.

[B] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in either of the following manners:

An inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table,

An inner and outer cage plus quadrant mats in accordance with Fig. 1, or

An inner and outer cage plus an elliptical cage in accordance with Fig. 2.

For Wall C, in sizes 24 to 33 in., a single circular cage with an area not less than the sum of the specified inner and outer circular reinforcement areas.

[C] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

[D] For these classes and sizes, the minimum practical steel reinforcement is specified.

6.2.5.2 Portland blast furnace slag cement only,

6.2.5.3 Slag modified portland cement only,

6.2.5.4 Portland pozzolan cement only,

6.2.5.5 Hydraulic cement conforming to Specification C 1157,

6.2.5.6 A combination of portland cement or hydraulic cement and ground granulated blast-furnace slag, or

6.2.5.7 A combination of portland cement or hydraulic cement and fly ash.

6.3 *Aggregates*—Aggregates shall conform to Specification C 33 except that the requirement for gradation shall not apply.

6.4 *Admixtures and Blends*—Admixtures and blends may be used with the approval of the owner.

6.5 *Steel Reinforcement*—Reinforcement shall consist of wire conforming to Specification A 82 or Specification A 496 or of wire fabric conforming to Specification A 185 or Specification A 497 or of bars of Grade 40 steel conforming to Specification A 615/A 615M.

6.6 *Synthetic Fibers*— Collated fibrillated virgin polypropylene fibers may be used, at the manufacturer's option, in concrete pipe as a nonstructural manufacturing material. Only

TABLE 5 Design Requirements for Class V Reinforced Concrete Pipe[A]

NOTE 1—See Section 5 for basis of acceptance specified by the owner.

The strength test requirements in pounds-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test lo expressed in pounds-force per linear foot per foot of diameter) to produce a 0.01-in. crack, or the D-loads to produce the 0.01-in. crack and the ultima load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce a 0.01-in. crack	3000
D-load to produce the ultimate load	3750

Internal Designated Diameter, in.	Reinforcement, in.²/linear ft of pipe wall										
	Wall A				Wall B				Wall C		
	Concrete Strength, 6000 psi				Concrete Strength, 6000 psi				Concrete Strength, 6000 psi		
	Wall Thickness, in.	Circular Reinforcement[B]		Elliptical Reinforcement[C]	Wall Thickness, in.	Circular Reinforcement[B]		Elliptical Reinforcement[C]	Wall Thickness, in.	Circular Reinforcement[B]		Elliptical Reinforcement[C]
		Inner Cage	Outer Cage			Inner Cage	Outer Cage			Inner Cage	Outer Cage	
12	A	...	...	...	2	0.10	...	...	2¾	0.07[D]	...	...
15	A	...	...	...	2¼	0.14	...	...	3	0.07[D]	...	...
18	A	...	...	...	2½	0.19	...	0.16	3¼	0.10	...	...
21	A	...	...	...	2¾	0.24	...	0.21	3½	0.10	...	...
24	A	...	...	...	3	0.30	...	0.24	3¾	0.12	0.07	0.13
27	A	...	...	...	3¼	0.38	0.23	0.42	4	0.14	0.08	0.16
30	A	...	...	...	3½	0.41	0.25	0.46	4¼	0.18	0.11	0.20
33	A	...	...	...	3¾	0.46	0.28	0.51	4½	0.23	0.14	0.25
36	A	...	...	...	4	0.50	0.30	0.56	4¾	0.27	0.16	0.30
42	A	...	...	...	4½	0.60	0.36	0.67	5¼	0.36	0.22	0.40
48	A	...	...	...	5	0.73	0.44	0.81	5¾	0.47	0.28	0.52
54	A	...	...	...	A	...	...	...	6¼	0.58	0.35	0.64
60	A	...	...	...	A	...	...	...	6¾	0.70	0.42	0.78
66	A	...	...	...	A	...	...	...	7¼	0.84	0.50	0.93
72	A	...	...	...	A	...	...	...	7¾	0.99	0.59	1.10
78	A	...	...	...	A	...	...	...	A	...	...	...
84	A	...	...	...	A	...	...	...	A	...	...	...
90	A	...	...	...	A	...	...	...	A	...	...	...
96	A	...	...	...	A	...	...	...	A	...	...	...
102	A	...	...	...	A	...	...	...	A	...	...	...
108	A	...	...	...	A	...	...	...	A	...	...	...
114	A	...	...	...	A	...	...	...	A	...	...	...
120	A	...	...	...	A	...	...	...	A	...	...	...
126	A	...	...	...	A	...	...	...	A	...	...	...
132	A	...	...	...	A	...	...	...	A	...	...	...
138	A	...	...	...	A	...	...	...	A	...	...	...
144	A	...	...	...	A	...	...	...	A	...	...	...

[A] For modified or special designs see 7.2 or with the permission of the owner utilize the provisions of Specification C 655. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe over 96 in. in diameter shall have two circular cages or an inner circular plus one elliptical cage.

[B] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in either of the following manners:

An inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table,

An inner and outer cage plus quadrant mats in accordance with Fig. 1, or

An inner and outer cage plus an elliptical cage in accordance with Fig. 2.

[C] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

[D] For these classes and sizes, the minimum practical steel reinforcement is specified.

Type III synthetic fibers designed and manufactured specifically for use in concrete and conforming to the requirements of Specification C 1116 shall be accepted.

7. Design

7.1 *Design Tables*—The diameter, wall thickness, compressive strength of the concrete, and the area of the circumferential reinforcement shall be as prescribed for Classes I to V in Tables 1-5, except as provided in 7.2.

7.1.1 The reinforcement as presented in the tables herein allows single circular cage reinforcement, or separate inner and outer circular cage reinforcement or a combination thereof. Footnotes to the tables are intended to clarify tabulated requirements or provide acceptable alternative reinforcement designs, either of which are applicable and binding as if they were contained in the body of the specification.

7.2 *Modified and Special Designs*:

7.2.1 If permitted by the owner the manufacturer may request approval by the owner of modified designs that differ from the designs in 7.1; or special designs for sizes and loads beyond those shown in Tables 1-5, 7.1, or special designs for pipe sizes that do not have steel reinforcement areas shown in Tables 1-5 of 7.1.

7.2.2 Such modified or special designs shall be based on rational or empirical evaluations of the ultimate strength and cracking behavior of the pipe and shall fully describe to the owner any deviations from the requirements of 7.1. The descriptions of modified or special designs shall include the wall thickness, the concrete strength, and the area, type, placement, number of layers, and strength of the steel reinforcement.

7.2.3 The manufacturer shall submit to the owner proof of adequacy of the proposed modified or special design. Such proof may comprise the submission of certified three-edge-bearing tests already made, which are acceptable to the owner or, if such three-edge-bearing tests are not available or acceptable, the manufacturer may be required to perform proof tests on sizes and classes selected by the owner to demonstrate the adequacy of the proposed design.

7.2.4 Such pipe must meet all of the test and performance requirements specified by the owner in accordance with Section 5.

7.3 *Area*—In this specification, when the word area is not described by adjectives, such as cross-section or single wire, it shall be understood to be the cross-sectional area of reinforcement per unit lengths of pipe.

8. Reinforcement

8.1 *Circumferential Reinforcement*—A line of circumferential reinforcement for any given total area may be composed of two layers for pipe with wall thicknesses of less than 7 in. or three layers for pipe with wall thicknesses of 7 in. or greater. The layers shall not be separated by more than the thickness of one longitudinal plus ¼ in. The multiple layers shall be fastened together to form a single cage. All other specification requirements such as laps, welds, and tolerances of placement in the wall of the pipe, etc., shall apply to this method of fabricating a line of reinforcement.

8.1.1 Where one line of circular reinforcement is used, it shall be placed from 35 to 50 % of the wall thickness from the inner surface of the pipe, except that for wall thicknesses less than 2½ in., the protective cover of the concrete over the circumferential reinforcement in the wall of the pipe shall be ¾ in.

8.1.2 In pipe having two lines of circular reinforcement, each line shall be so placed that the protective covering of concrete over the circumferential reinforcement in the wall of the pipe shall be 1 in.

8.1.3 In pipe having elliptical reinforcement with wall thicknesses 2½ in. or greater, the reinforcement in the wall of the pipe shall be so placed that the protective covering of concrete over the circumferential reinforcement shall be 1 in. from the inner surface of the pipe at the vertical diameter and 1 in. from the outer surface of the pipe at the horizontal diameter. In pipe having elliptical reinforcement with wall thicknesses less than 2½ in., the protective covering of the concrete shall be ¾ in. at the vertical and horizontal diameters.

8.1.4 The location of the reinforcement shall be subject to the permissible variations in dimensions given in 12.5.

8.1.5 The spacing center to center of circumferential reinforcement in a cage shall not exceed 4 in. for pipe up to and including pipe having a 4-in. wall thickness nor exceed the wall thickness for larger pipe, and shall in no case exceed 6 in.

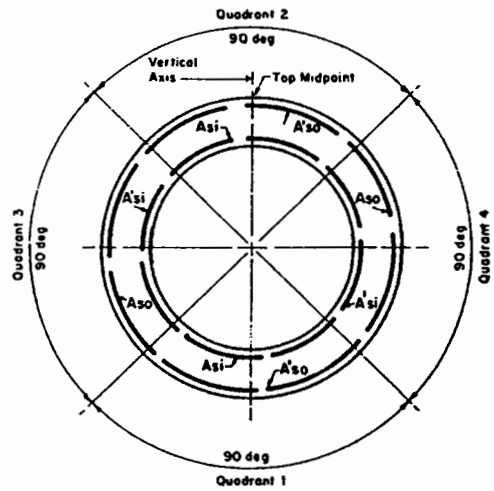
8.1.6 Where the wall reinforcement does not extend into the joint, the maximum longitudinal distance to the last circumferential from the inside shoulder of the bell or the shoulder of the spigot shall be 3 in. except that if this distance exceeds one-half the wall thickness, the pipe wall shall contain at least a total reinforcement area of the minimum specified area per linear foot times the laying length of the pipe section. The minimum cover on the last circumferential near the spigot shoulder shall be ½ in.

8.1.6.1 Where reinforcement is in the bell or spigot the minimum end cover on the last circumferential shall be ½ in. in the bell or ¼ in. in the spigot.

8.1.7 The continuity of the circumferential reinforcing steel shall not be destroyed during the manufacture of the pipe, except that when agreed upon by the owner, lift eyes or holes may be provided in each pipe for the purpose of handling.

8.1.8 If splices are not welded, the reinforcement shall be lapped not less than 20 diameters for deformed bars and deformed cold-worked wire, and 40 diameters for plain bars and cold-drawn wire. In addition, where lapped cages of welded-wire fabric are used without welding, the lap shall contain a longitudinal wire.

8.1.8.1 When splices are welded and are not lapped to the minimum requirements above, pull tests of representative specimens shall develop at least 50 % of the minimum specified strength of the steel, and there shall be a minimum lap of 2 in. For butt-welded splices in bars or wire, permitted only with helically wound cages, pull tests of representative specimens shall develop at least 75 % of the minimum specified strength of the steel.



NOTE 1—The total reinforcement area (Asi) of the inner cage plus the quadrant mat in Quadrants 1 and 2 shall not be less than that specified for the inner cage in Tables 1-5.

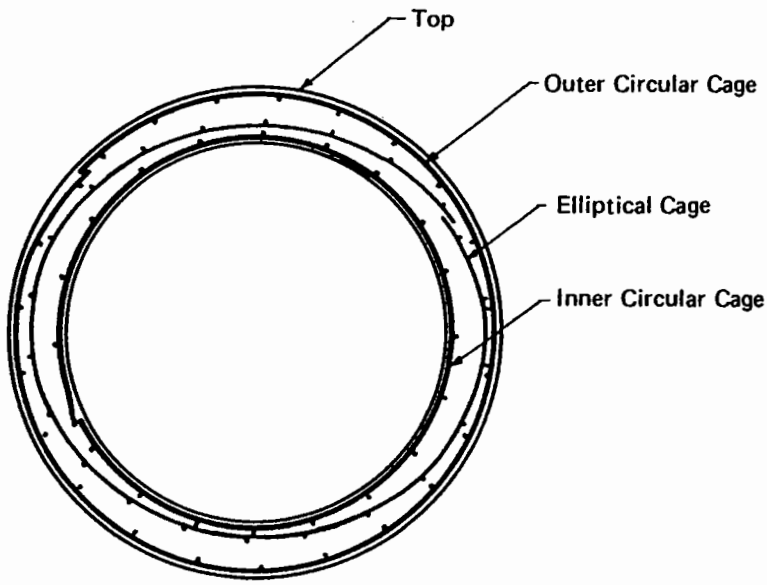
NOTE 2—The total reinforcement area (Aso) of the outer cage plus the quadrant mat in Quadrants 3 and 4 shall not be less than that specified for the outer cage in Tables 1-5.

NOTE 3—The reinforcement area (A'si) of the inner cage in Quadrants 3 and 4 shall be not less than 25 % of that specified for the inner cage in Tables 1-5.

NOTE 4—The reinforcement area (A'so) of the outer cage in Quadrants 1 and 2 shall be not less than 25 % of that specified for the outer cage in Tables 1-5.

NOTE 5—If the reinforcement area (A'so) of the outer cage in Quadrants 1 or 2 is less than 50 % of that specified for the outer cage in Tables 1-5, the quadrant mats used for the outer cage in Quadrants 3 and 4 shall extend into Quadrant 1 and 2 not less than a distance equal to the wall thickness as specified in Tables 1-5.

FIG. 1 Quadrant Reinforcement



NOTE 1—The total reinforcement area of the inner circular cage and the elliptical cage shall not be less than that specified for the inner cage in Table 1-5.

NOTE 2—The total reinforcement area of the outer circular cage and the elliptical cage shall not be less than that specified for the outer cage in Table 1-5.

FIG. 2 Triple Cage Reinforcement

8.2 *Longitudinal Reinforcement*—Each line of circumferential reinforcement shall be assembled into a cage that shall contain sufficient longitudinal bars or members, to maintain the reinforcement in shape and in position within the form to comply with permissible variations in 8.1. The exposure of the ends of longitudinals, stirrups, or spacers that have been used to position the cages during the placement of the concrete shall not be a cause for rejection.

8.3 *Joint Reinforcement*—The length of the joint as used herein means the inside length of the bell or the outside length of the spigot from the shoulder to the end of the pipe section. The end distances or cover on the end circumferential shall apply to any point on the circumference of the pipe or joint. When convoluted reinforcement is used, these distances and reinforcement areas shall be taken from the points on the convolutions closest to the end of the pipe section. Unless otherwise permitted by the owner, the following requirements for joint reinforcement shall apply.

8.3.1 *Joint Reinforcement for Non-Rubber Gasket Joints*:

8.3.1.1 For pipe 36 in. and larger in diameter, either the bell or spigot shall contain circumferential reinforcement. This reinforcement shall be an extension of a wall cage, or may be a separate cage of at least the area per foot of that specified for the outer cage or one-half of that specified for single cage wall reinforcement, whichever is less.

8.3.1.2 Where bells or spigots require reinforcement, the maximum end cover on the last circumferential shall be one-half the length of the joint or 3 in., whichever is less.

8.3.2 *Joint Reinforcement for Rubber Gasket Joints*:

8.3.2.1 For pipe 12 in. and larger in diameter, the bell ends shall contain circumferential reinforcement. This reinforcement shall be an extension of the outer cage or a single wall cage, whichever is less, or may be a separate cage of at least the same area per foot with longitudinals as required in 8.2. If a separate cage is used, the cage shall extend into the pipe with the last circumferential wire at least one in. past the inside shoulder where the pipe barrel meets the bell of the joint.

8.3.2.2 Where bells require reinforcement, the maximum end cover on the last circumferential shall be 2 in.

9. Joints

9.1 The joints shall be of such design and the ends of the concrete pipe sections so formed that the pipe can be laid together to make a continuous line of pipe compatible with the permissible variations given in Section 12.

10. Manufacture

10.1 *Mixture*—The aggregates shall be sized, graded, proportioned, and mixed with such proportions of cementitious materials and water as will produce a homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. All concrete shall have a water-cementitious materials ratio not exceeding 0.53 by weight. Cementitious materials shall be as specified in 6.2 and shall be added to the mix in a proportion not less than 470 lb/yd^3 unless mix designs with a lower cementitious materials content demonstrate that the quality and performance of the pipe meet the requirements of this specification.

10.2 *Curing*—Pipe shall be subjected to any one of the methods of curing described in 10.2.1 to 10.2.4 or to any other method or combination of methods approved by the owner, that will give satisfactory results. The pipe shall be cured for a sufficient length of time so that the specified D-load is obtained when acceptance is based on 5.1.1 or so that the concrete will develop the specified compressive strength at 28 days or less when acceptance is based on 5.1.2.

10.2.1 *Steam Curing*—Pipe may be placed in a curing chamber, free of outside drafts, and cured in a moist atmosphere maintained by the injection of steam for such time and such temperature as may be needed to enable the pipe to meet the strength requirements. The curing chamber shall be so constructed as to allow full circulation of steam around the entire pipe.

10.2.2 *Water Curing*—Concrete pipe may be water-cured by covering with water saturated material or by a system of perforated pipes, mechanical sprinklers, porous hose, or by any other approved method that will keep the pipe moist during the specified curing period.

10.2.3 The manufacturer may, at his option, combine the methods described in 10.2.1 to 10.2.4 provided the required concrete compressive strength is attained.

10.2.4 A sealing membrane conforming to the requirements of Specification C 309 may be applied and should be left intact until the required strength requirements are met. The concrete at the time of application shall be within 10°F of the atmospheric temperature. All surfaces shall be kept moist prior to the application of the compounds and shall be damp when the compound is applied.

11. Physical Requirements

11.1 *Test Specimens*—The specified number of pipe required for the tests shall be furnished without charge by the manufacturer and shall be selected at random by the owner, and shall be pipe that would not otherwise be rejected under this specification. The selection shall be made at the point or points designated by the owner when placing the order.

11.2 *Number and Type of Test Required for Various Delivery Schedules*:

11.2.1 *Preliminary Tests for Extended Delivery Schedules*—An owner of pipe, whose needs require shipments at intervals over extended periods of time, shall be entitled to such tests, preliminary to delivery of pipe, as are required by the type of basis of acceptance specified by the owner in Section 5, of not more than three sections of pipe covering each size in which he is interested.

11.2.2 *Additional Tests*— After the preliminary tests described in 11.2.1, an owner shall be entitled to additional tests at such times as the owner may deem necessary, provided that the total number of pipe tested (including preliminary tests) shall not exceed one pipe or 1 %, whichever is the greater, of each size of pipe delivered.

11.3 *External Load Crushing Strength*:

11.3.1 The load to produce a 0.01-in. crack or the ultimate load, as determined by the three-edge-bearing method as described in the Test Methods C 497 shall be not less than that prescribed in Tables 1-5 for each respective class of pipe. Pipe that support the prescribed load to produce the 0.01–in. crack and do not show a wider crack shall be considered to have met that test requirement. It is not a requirement of this speciifcation that the pipe be cracked or loaded to failure during these tests. Pipe that have been tested only to the formation of a 0.01-in. crack and that meet the 0.01-in. crack load requirements shall be accepted for use. Three-edge-bearing test to ultimate load is not required for any class of pipe 60 in. or less in diameter listed in Tables 1-5 provided all other requirements of this specification are met.

NOTE 3—As used in this specification, the 0.01-in. crack is a test criterion for pipe tested in the three-edge-bearing test and is not intended as an indication of overstressed or failed pipe under installed conditions.

11.3.2 *Retests of Pipe Not Meeting the External Load Crushing Strength Requirements*—Pipe shall be considered as meeting the strength requirements when all test specimens conform to the strength requirements. Should any of the test specimens fail to meet the strength requirements, the manufacturer shall be allowed a retest on two additional specimens for each specimen that failed, and the pipe shall be acceptable only when all of the retest specimens meet the strength requirements.

CONCRETE TESTING

11.4 *Type of Specimen*— Compression tests determining concrete compressive strength may be made on either standard rodded concrete cylinders or concrete cylinders compacted and cured in like manner as the pipe, or on cores drilled from the pipe.

11.5 *Compression Testing of Cylinders*:

11.5.1 *Cylinder Production*—Cylinders shall be prepared in accordance with Section 11 of Test Methods C 497.

11.5.2 *Number of Cylinders*—Prepare no fewer than five test cylinders from a group (one day's production) of pipe sections.

11.5.3 *Acceptability on the Basis of Cylinder Test Results*:

11.5.3.1 When the compressive strengths of all cylinders tested for a group are equal to or greater than the required concrete strength, the compressive strength of concrete in the group of pipe sections shall be accepted.

11.5.3.2 When the average compressive strength of all cylinders tested is equal to or greater than the required concrete strength, and not more than 10 % of the cylinders tested have a compressive strength less than the required concrete strength, and no cylinder tested has a compressive strength less than 80 % of the required concrete strength, then the group shall be accepted.

11.5.3.3 When the compressive strength of the cylinders tested does not conform to the acceptance criteria stated in 11.5.3.1 or 11.5.3.2, the acceptability of the group shall be determined in accordance with the provisions of 11.6.

11.6 *Compression Testing of Cores*:

11.6.1 *Obtaining Cores*— Cores shall be obtained and prepared in accordance with Section 6 of Test Methods C 497.

11.6.2 *Number of Cores*— One core shall be taken from a pipe section selected at random from each day's production run of a single concrete strength.

11.7 *Acceptability on the Basis of Core Test Results*:

11.7.1 When the compressive strength of a core tested for a group of pipe sections is equal to or greater than the required concrete strength, the compressive strength of the concrete for the group is acceptable.

11.7.2 If the compressive strength of the core tested is less than the required concrete strength, two additional cores shall be taken from that pipe section and tested. Concrete represented by these three core tests shall be considered acceptable

if: *(1)* the average of the three core strengths is equal to at least 85 % of the required strength and *(2)* no single core is less than 75 % of the required strength.

11.7.3 If the compressive strength of the three cores does not meet the requirements of 11.7.2, the pipe from which the cores were taken shall be rejected. Two pipe sections from the remainder of the group shall be selected at random and cored and tested for conformance with either 11.7.1 or 11.7.2. If both pipe sections meet the core strength requirements of either 11.7.1 or 11.7.2, the remainder of the group shall be acceptable. If both pipe do not meet the test strength requirement, the remainder of the group shall be either rejected or, at the option of the manufacturer, each pipe section of the remaining group shall be cored and accepted individually and any of the pipe sections that have core strengths less than the requirements of 11.7.1 or 11.7.2 shall be rejected.

11.8 *Plugging Core Holes*—Core holes shall be plugged and sealed by the manufacturer in a manner such that the pipe section will meet all of the requirements of this specification. Pipe sections so plugged and sealed shall be considered satisfactory for use.

11.9 *Absorption*—The absorption of a sample from the wall of the pipe, as determined in accordance with Test Methods C 497, shall not exceed 9 % of the dry mass for Method A or 8.5 % for Method B. Each Method A sample shall have a minimum mass of 1.0 kg, shall be free of visible cracks, and shall represent the full wall thickness of the pipe. When the initial absorption sample from a pipe fails to conform to this specification, the absorption test shall be made on another sample from the same pipe and the results of the retest shall be substituted for the original test results.

11.10 *Retests of Pipe*— When not more than 20 % of the concrete specimens fail to pass the requirements of this specification, the manufacturer may cull the project stock and may eliminate whatever quantity of pipe desired and shall mark those pipe so that they will not be shipped. The required tests shall be made on the balance of the order and the pipe shall be accepted if they conform to the requirements of this specification.

11.11 *Test Equipment*— Every manufacturer furnishing pipe under this specification shall furnish all facilities and personnel necessary to carry out the tests described in Test Methods C 497.

12. Permissible Variations

12.1 *Internal Diameter*—The internal diameter of 12 to 24-in. pipe shall vary not more than ±1.5 % from the design diameter. The internal diameter of 27-in. and larger pipe shall not vary from the design diameter by more than ± 1 % of the design diameter or ±⅜ in., whichever is greater.

12.2 *Wall Thickness*— The wall thickness shall not vary more than shown in the design or specified wall by more than ±5 % or 3/16 in., whichever is greater. A specified wall thickness more than required in the design is not cause for rejection. Pipe having localized variations in wall thickness exceeding those specified above shall be accepted if the three-edge-bearing strength and minimum steel cover requirements are met.

12.3 *Length of Two Opposite Sides*—Variations in the laying length of two opposite sides of the pipe shall not be more than ¼ in. for all sizes through 24-in. internal diameter, and not more than ⅛ in./ft for all sizes larger with a maximum of ⅝ in. in any length of pipe through 84-in. internal diameter and a maximum of ¾ in. for 90-in. internal diameter or larger except where beveled end pipe for laying on curves is specified by the owner.

12.4 *Length of Pipe*— The underrun in length of a section of pipe shall not be more than ⅛ in./ft. with a maximum of ½ in in any length of pipe. Regardless of the underrun or overrun in any section of the pipe, the end cover requirements of Sections 8 and 12 shall apply.

12.5 *Position or Area of Reinforcement*:

12.5.1 *Position*—The maximum variation in the position of the reinforcement shall be ± 10 % of the wall thickness or ±½ in., whichever is greater. Pipe having variations in the position of the reinforcement exceeding those specified above shall be accepted if the three-edge-bearing strength requirements obtained on a representative specimen are met. In no case, however, shall the cover over the circumferential reinforcement be less than ¼ in. as measured to the end of the spigot or ½ in. as measured to any other surface. The preceding minimum cover limitations do not apply to mating surfaces of nonrubber gasket joints or gasket grooves in rubber gasket joints. If convoluted reinforcement is used, the convoluted circumferential end wire may be at the end surface of the joint providing the alternate convolutions have at least 1 in. cover from the end surface of the joint.

12.5.2 *Area of Reinforcement*—Reinforcement will be considered as meeting the design requirements if the area, computed on the basis of nominal area of the wire or bars used, equals or exceeds the requirements of 7.1 or 7.2. Actual area of the reinforcing used may vary from the nominal area according to permissible variations of the standard specifications for the reinforcing. When inner cage and outer cage reinforcing is used, the inner cage nominal area may vary to the lower limit of 85 % of the elliptical nominal area and the outer cage nominal area may vary to the lower limit of 51 % of the elliptical nominal area provided that the total nominal area of the inner cage plus the outer cage shall not vary beyond the lower limit of 140 % of the elliptical nominal area.

13. Repairs

13.1 Pipe may be repaired, if necessary, because of imperfections in manufacture or damage during handling and will be acceptable if, in the opinion of the owner, the repaired pipe conforms to the requirements of this specification.

14. Inspection

14.1 The quality of materials, the process of manufacture, and the finished pipe shall be subject to inspection and approval by the owner.

15. Rejection

15.1 Pipe shall be subject to rejection on account of failure to conform to any of the specification requirements. Individual sections of pipe may be rejected because of any of the following:

15.1.1 Fractures or cracks passing through the wall, except a single end crack that does not exceed the depth of the joint.

15.1.2 Defects that indicate proportioning, mixing, and molding not in compliance with 10.1 or surface defects indicating honeycombed or open texture that would adversely affect the function of the pipe.

15.1.3 The ends of the pipe are not normal to the walls and center line of the pipe, within the limits of variations given in 12.3 and 12.4.

15.1.4 Damaged or cracked ends where such damage would prevent making a satisfactory joint.

15.1.5 Any continuous crack having a surface width of 0.01 in. or more and extending for a length of 12 in. or more, regardless of position in the wall of the pipe.

16. Marking

16.1 The following information shall be legibly marked on each section of pipe:

16.1.1 The pipe class and specification designation,

16.1.2 The date of manufacture,

16.1.3 The name or trademark of the manufacturer, and

16.1.4 Identification of plant.

16.2 One end of each section of pipe with elliptical or quadrant reinforcement shall be clearly marked during the process of manufacturing or immediately thereafter, on the inside and the outside of opposite walls along the minor axis of the elliptical reinforcing or along the vertical axis for quadrant reinforcing.

16.3 Markings shall be indented on the pipe section or painted thereon with waterproof paint.

17. Keywords

17.1 circular pipe; culvert; D-load; pipe; reinforced concrete; sewer pipe; storm drain

Designation: C 655 – 02

Standard Specification for Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe[1]

This standard is issued under the fixed designation C 655; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers reinforced concrete pipe designed for specific D-loads and intended to be used for the conveyance of sewage, industrial wastes, and storm water and for the construction of culverts.

1.2 A complete metric companion to Specification C 655 has been developed—Specification C 655M; therefore, no metric equivalents are presented in this specification.

NOTE 1—Experience has shown that the successful performance of this product depends upon the proper selection of the pipe strength, the type of bedding and backfill, the care that the installation conforms to the construction specifications, and provision for adequate inspection at the construction site. This specification does not include requirements for bedding, backfill, the relationship between field load conditions and the strength designation of pipe, or durability under unusual environmental conditions. These requirements should be included in the project specification.

2. Referenced Documents

2.1 *ASTM Standards:*

A 82 Specification for Steel Wire, Plain, for Concrete Reinforcement[2]

A 185 Specification for Steel Welded Wire Reinforcement, Plain, for Concrete[2]

A 496 Specification for Steel Wire, Deformed, for Concrete Reinforcement[2]

A 497 Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete[2]

A 615/A 615M Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement[2]

C 33 Specification for Concrete Aggregates[3]

C 150 Specification for Portland Cement[4]

C 497 Test Methods for Concrete Pipe, Manhole Sec or Tile[5]

C 595 Specification for Blended Hydraulic Cements[4]

C 618 Specification for Fly Ash and Raw or Cal Natural Pozzolan for Use as a Mineral Admixtu Concrete[3]

C 822 Terminology Relating to Concrete Pipe and Re Products[5]

C 989 Specification for Ground Granulated Blast-Fur Slag for Use in Concrete and Mortars[3]

C 1116 Specification for Fiber-Reinforced Concrete Shotcrete[3]

E 105 Practice for Probability Sampling of Materials[6]

3. Terminology

3.1 *Definitions*—For definitions of terms relating to c crete pipe, see Terminology C 822.

4. Basis of Acceptance

4.1 The acceptability of the pipe design shall be determi in accordance with Section 9. After the pipe design has b accepted, or if the pipe design has been accepted previously accordance with Section 9, the owner may select and h applied the basis of acceptance described in either 4.1.1 4.1.2. Unless designated by the owner at the time of, or bef placing an order, either basis of acceptance shall be permitt

4.1.1 *Acceptance on the Basis of Pipe Load and Mate Tests and Inspection of Manufactured Pipe for Defe* —Determine in accordance with Sections 5, 6, 8, and 10.

NOTE 2—It is necessary that samples be selected at random. guidance see Practice E 105.

4.1.2 *Acceptance on the Basis of Concrete Compression a Materials Tests and Inspection of Manufactured Pipe Defects*—Determine in accordance with Sections 5, 6, 8 a 11.

4.2 *Age for Acceptance*—Pipe shall be considered ready acceptance when they conform to the requirements.

[1] This specification is under the jurisdiction of ASTM Committee C13 on Concrete Pipe and is the direct responsibility of Subcommittee C13.07 on Acceptance Specifications and Precast Concrete Box Sections.

Current edition approved July 10, 2002. Published October 2002. Originally published as C 655–70T. Last previous edition C 655–00.

[2] *Annual Book of ASTM Standards*, Vol 01.04.

[3] *Annual Book of ASTM Standards*, Vol 04.02.

[4] *Annual Book of ASTM Standards*, Vol 04.01.

[5] *Annual Book of ASTM Standards*, Vol 04.05.

[6] *Annual Book of ASTM Standards*, Vol 14.02.

5. Design and Manufacturing Data

5.1 The manufacturer shall provide the following information regarding the pipe unless waived by the owner:

5.1.1 Basis of acceptance.

5.1.2 Pipe design strength.

5.1.3 *Physical Characteristics*—Diameter, wall thickness, laying length, and joint details.

5.1.4 Design concrete strength; minimum f'_c equals 4000 psi.

5.1.5 Admixtures.

5.1.6 *Reinforcement*:

5.1.6.1 Type of reinforcement, applicable reinforcement specification, and grade.

5.1.6.2 Placement, placement tolerances, diameter, spacing and cross-sectional area of circumferential, longitudinal, and special reinforcement.

5.1.7 Manufacturing and curing process.

6. Materials and Manufacture

6.1 *Materials*:

6.1.1 *Reinforced Concrete*—The reinforced concrete shall consist of cementitious materials, mineral aggregates, and water, in which steel has been embedded in such a manner that the steel and concrete act together.

6.1.2 *Cementitious Materials*:

6.1.2.1 *Cement*—Cement shall conform to the requirements for portland cement of Specification C 150 or shall be portland blast-furnace slag cement or portland-pozzolan cement conforming to the requirements of Specification C 595, except that the pozzolan constituent in the Type IP portland pozzolan cement shall be fly ash.

6.1.2.2 *Fly Ash*—Fly ash shall conform to the requirements of Specification C 618, Class F or Class C.

6.1.2.3 *Ground Granulated Blast-Furnace Slag (GGBFS)*—GGBFS shall conform to the requirements of Grade 100 or 120 of Specification C 989.

6.1.2.4 *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in the cement shall be one of the following:

(1) Portland cement only,

(2) Portland blast furnace slag cement only,

(3) Portland pozzolan cement only,

(4) A combination of portland cement and fly ash, or

(5) A combination of portland cement and ground granulated blast-furnace slag.

6.1.3 *Aggregates*—Aggregates shall conform to the requirements of Specification C 33, except that the requirement for gradation shall not apply.

6.1.4 *Admixtures and Blends*—Admixtures and blends shall be allowed to be used unless prohibited by the owner.

6.1.5 *Steel Reinforcement*—Reinforcement shall consist of steel conforming to Specification A 82 or Specification A 496, of wire fabric conforming to Specification A 185 or Specification A 497, or of bars of Grade 40 steel conforming to Specification A 615/A 615M.

6.2 *Manufacture*:

6.2.1 *Mixture*—The aggregates shall be sized, graded, proportioned, and mixed with such proportions of cementitious materials and water as will produce a homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. All concrete shall have a water-cementitious materials ratio not exceeding 0.53 by weight. Cementitious materials shall be as specified in 6.1 and shall be added to the mix in a proportion not less than 470 lb/yd^3 unless mix designs with a lower cementitious material content demonstrate that the quality and performance of the pipe meet the requirements of this specification.

6.2.2 *Reinforcement*:

6.2.2.1 *Placement*—Reinforcement shall be placed as indicated in 5.1.6.2, subject to the tolerances given in 8.2.2. Minimum design protective cover of concrete over the circumferential reinforcement in the barrel of the pipe shall be 1 in. for wall thicknesses of 2½in. or greater, and ¾ in. for wall thicknesses less than 2½in., subject to the tolerances given in 8.2.2.

6.2.2.2 *Splices*—The strength of the pipe shall not be adversely affected by the splice.

6.2.2.3 *Spacing*—The spacing center-to-center of adjacent rings of circumferential reinforcement in a cage shall not exceed 4 in. for pipe with a wall thickness up to and including 4 in. and shall not exceed the wall thickness or 6 in., whichever is smaller, for larger pipe.

6.2.3 *Joints*—The joints shall be of such design and the ends of the concrete pipe sections so formed that when the sections are laid together they will make a continuous line of pipe with a smooth interior free of appreciable irregularities in the flow line, all compatible with the permissible variations given in Section 8.

6.2.4 *Lift Holes*—When agreed upon by the owner, lift eyes or holes shall be allowed to be provided in each pipe for the purpose of handling.

6.3 *Synthetic Fibers*— Collated fibrillated virgin polypropylene fibers shall be allowed to be used, at the manufacturer's option, in concrete pipe as a nonstructural manufacturing material. Only Type III synthetic fibers designed and manufactured specifically for use in concrete and conforming to the requirements of Specification C 1116 shall be accepted.

7. Physical Requirements

7.1 *Strength*—The design strength designation of the pipe shall be the D-load to produce the 0.01-in. crack when tested in accordance with Test Methods C 497. The relationship of ultimate strength D-load to the design strength D-load shall be determined using a factor of 1.5 for design strength designations up to 2000 lbf/ft·ft of diameter, a factor varying in linear proportions from 1.5 to 1.25 for design strength designations from 2000 through 3000, and a factor of 1.25 for design strength designations in excess of 3000.

NOTE 3—As used in this specification, the 0.01-in. crack is a test criterion for pipe tested in three-edge bearing test and is not intended as an indication of overstressed or failed pipe under installed conditions.

NOTE 4—Ultimate strength of concrete pipe in the buried condition is dependent on varying soil bedding factors and varying failure modes and shall not necessarily have a relationship to the ultimate strength as defined under three-edge bearing conditions.

7.2 *Test Equipment and Facilities*—The manufacturer shall furnish without charge all samples, facilities, and personnel necessary to carry out the tests required by this specification.

7.3 *Pipe Load Tests*— The tests for crushing strength, when required, shall be made in accordance with Test Methods C 497. When alternative methods of load testing are specified, tests shall be made in accordance with the alternative requirements.

8. Dimensions and Permissible Variations

8.1 *Standard Diameters*—Pipe shall be manufactured in the standard inside diameters listed in Table 1.

NOTE 5—Diameters other than those shown in Table 1 and diameters larger than 144 in. are possibly available. When such sizes are required, the owner should contact the manufacturers in the area.

8.2 *Design Tolerances*—Except as specified in this section, all permissible design tolerances shall be given in Section 5.

8.2.1 *Diameter Tolerances*—The internal diameter of 12 to 24-in. pipe shall vary not more than ±1.5 % from the design diameter. The internal diameter of 27 to 144-in. pipe shall vary not more than ±1 % or 3/8 in., whichever is greater, from the design diameter.

8.2.2 *Reinforcement Placement Tolerances*—The maximum variation in the nominal position of the reinforcement shall be ±10 % of the wall thickness or ±5/8 in., whichever is greater. Pipe having variations in the position of the reinforcement exceeding those specified above shall be accepted if the three-edge-bearing strength requirements obtained on a representative sample are met. In no case, however, shall the cover over the circumferential reinforcement be less than 5/8 in.

8.2.3 *Length of Two Opposite Sides*—Variations in the laying length of two opposite sides of pipe shall not be more than 1/4 in. for all sizes through 24-in. internal diameter, and not more than 1/8 in./ft of internal diameter for all larger sizes, with a maximum of 5/8in. in any pipe through 84-in. internal diameter, and a maximum of 3/4 in. for 90-in. internal diameter or larger, except where beveled-end pipe for laying on curves is specified by the owner.

8.2.4 *Length of Pipe*—The underrun in length of a section of pipe shall not be more than 1/8 in./ft with a maximum of 1/2 in. in any length of pipe.

8.2.5 *Wall Thickness Tolerances*—The wall thickness shall be not less than the nominal specified in the design given in 5.1.3 by more than 5 % or 3/16 in., whichever is greater. A wall thickness more than that required in the design is not a cause for rejection, except that such pipe shall not be used for the tests required in 7.3.

9. Acceptance of Design

9.1 *Acceptance by Tests of Specimens*—Three to five representative specimens, or special test pipe that are shorter than standard production pipe, as agreed upon by the owner and manufacturer, shall be tested to the 0.01-in. crack a ultimate strength and the results recorded. Compute the in 9.1.1 and 9.1.2 for both the 0.01-in. crack and the ul strength.

9.1.1 Compute the estimated standard deviation, s, by or Eq 2, which equations yield identical values.

$$s = \sqrt{[\Sigma(X_i - \bar{X})^2]/(n-1)}$$

$$s = \sqrt{[\Sigma X_i^2 - (\Sigma X_i)^2/n]/(n-1)}$$

where:

X_i = observed value of the load to produce the 0.0 crack (and the load to develop the ultimate stren
X = average (arithmetic mean) of the values of X_i, a
n = number of observed values.

9.1.2 Compute the minimum allowable arithmetic mea by Eq 3. In Eq 3, the value of the estimated standard devia s, shall be as calculated by Eq 1 or Eq 2 or equal to 0. whichever is greater.

$$X_s = L + 1.07\,s$$

where:

L = specification limit (specified D-load).

9.1.3 The pipe design shall be acceptable if the arithm mean X for the 0.01-in. crack and ultimate strength is equ or greater than the computed values of X_s, and if all the te specimens meet or exceed the specification limit.

9.2 *Alternative Acceptance Method*—The manufact shall be allowed to request approval of designs based empirical evaluations of the strength of the pipe including, not limited to, designs based on interpolation between desi approved in accordance with 9.1, or designs evaluated on basis of tests other than the three-edge-bearing test meth Acceptance of design tests need not be performed for e contract or order.

10. Acceptance of Pipe by Load Testing

10.1 *Lot Sampling*—When the acceptance is to be in acc dance with 4.1.1, randomly select from the lot a sample of size listed in Table 2 and test each specimen to the 0.01- crack. When all specimen test strengths are greater than minimum design strength D-load, the lot shall be accept When one or more specimen test strengths are less than minimum design strength D-load, the values for X and s sh be computed and substituted into the applicable equation giv in Table 2. When the arithmetic mean X is equal to or grea than the computed value of X_s, the lot of pipe shall acceptable. When the arithmetic mean X is less than t computed value of X_s, the lot of pipe shall be rejected for th design strength D-load strength.

TABLE 1 Standard Designated Inside Diameter, in.

12	24	36	60	84	108	132
15	27	42	66	90	114	138
18	30	48	72	96	120	144
21	33	54	78	102	126	

TABLE 2 Sample Size

Lot Size	Sample Size	Equation	Equation Number
0 to 300	3	$\bar{X}_s = L + 1.08\,s$	(4)
301 to 500	4	$\bar{X}_s = L + 1.09\,s$	(5)
501 to 800	5	$\bar{X}_s = L + 1.10\,s$	(6)
801 to 1300	7	$\bar{X}_s = L + 1.16\,s$	(7)

10.2 *Use of Design Test Pipe*—When the pipe tested in Section 9 were selected at random from a production lot, the test data may be used in the acceptance analysis of that lot.

10.3 *Use of Pipe Tested to 0.01-in. Crack*—Pipe that have been tested only to the formation of the 0.01-in. crack and that meet the design strength requirements shall be acceptable for use. All pipe that test less than the design strength shall be removed from the lot and marked so that they will not be shipped.

11. Acceptance of Pipe by Concrete Compression Testing

CONCRETE TESTING

11.1 *Type of Specimen*—Compression tests for determining concrete compressive strength shall be allowed to be made on either concrete cylinders or on cores drilled from the pipe.

11.2 *Compression Testing of Cylinders*:

11.2.1 *Cylinder Production*—Cylinders shall be prepared in accordance with the Cylinder Strength Test Method of Test Methods C 497.

11.2.2 *Number of Cylinders*—Prepare not fewer than three test cylinders from each concrete mix used within a group (one day's production) of pipe sections.

11.2.3 *Acceptability on the Basis of Cylinder Test Results*:

11.2.3.1 When the compressive strengths of all cylinders tested for a group are equal to or greater than the design concrete strength, the compressive strength of concrete in the group of pipe sections shall be accepted.

11.2.3.2 When the average compressive strength of all cylinders tested is equal to or greater than the design concrete strength, not more than 10 % of the cylinders tested have a compressive strength less than the design concrete strength, and no cylinder tested has a compressive strength less than 80 % of the design concrete strength, then the group shall be accepted.

11.2.3.3 When the compressive strength of the cylinders tested does not conform to the acceptance criteria stated in 11.2.3.1 or 11.2.3.2, the acceptability of the group shall be determined in accordance with the provisions of 11.3.

11.3 *Compression Testing of Cores*:

11.3.1 *Obtaining Cores*—Cores shall be obtained, prepared, and tested in accordance with the Core Strength Test Method of Test Methods C 497.

11.3.2 *Number of Cores*—Three cores shall be cut from sections selected at random from each day's production run of a single concrete strength.

11.4 *Acceptability on the Basis of Core Test Results*:

11.4.1 The compressive strength of the concrete, as defined in 11.1, for each group of pipe sections is acceptable when the concrete compressive test strength, defined as the average of three cores taken at random from the subject group, is equal to or greater than 85 % of the required strength of the concrete with no one core less than 75 % of the required strength.

11.4.2 If the compressive strength of the three cores does not meet the requirements of 11.3.3.1, the sections from which cores were taken shall be rejected. Two pipe sections from the remainder of the group shall be selected at random and one core shall be taken from each. If both cores have a strength equal to or greater than 85 % of the required strength of the concrete, the remainder of the group is acceptable. If the compressive strength of either of the two cores tested is less than 85 % of the required strength of the concrete, the remainder of the group of pipe sections shall be rejected or, at the option of the manufacturer, each pipe section of the entire group shall be cored and accepted individually, and any of these pipe sections that have cores with less than 85 % of the required strength of the concrete shall be rejected.

11.5 *Plugging Core Holes*—Core holes shall be plugged and sealed by the manufacturer in a manner such that the pipe section will meet all of the requirements of this specification. Pipe sections so plugged and sealed shall be considered satisfactory for use.

11.6 *Retests of Pipe*—When not more than 20 % of the concrete specimens fail to pass the requirements of this specification, the manufacturer may cull the project stock and may eliminate whatever quantity of pipe desired. The manufacturer shall mark those pipe so that they will not be shipped. The required tests shall be made on the balance of the order and the pipe shall be accepted if they conform to the requirements of this specification.

12. Inspection

12.1 The quality of materials, process of manufacture, and the finished pipe shall be subject to inspection by the owner.

13. Rejection

13.1 Pipe shall be subject to rejection for failure to conform to any of the specification requirements. Individual sections of pipe shall be allowed to be rejected because of any of the following:

13.1.1 Fractures or cracks passing through the wall, except for a single end crack that does not exceed the depth of the joint.

13.1.2 Defects that indicate mixing and molding, not in compliance with 6.2.

13.1.3 The ends of the pipe are not normal to the walls and center line of the pipe, within the limits of variations given in 8.2.3.

13.1.4 Damaged ends where such damage would prevent making a satisfactory joint.

13.1.5 Surface defects that indicate honeycombed or open texture that would adversely affect the function of the pipe.

13.2 The exposure of the ends of longitudinals, stirrups, or spacers that have been used to position the cages during the placement of the concrete is not a cause for rejection.

14. Disposition of a Rejected Lot

14.1 A lot of pipe which fails to meet the criteria for acceptability shall be allowed to be utilized in accordance with a procedure mutually agreed upon by the manufacturer and the owner. The procedure shall demonstrate improvement in the lot, statistically calculate a reduced D-load strength for the lot, or develop an acceptable disposition. The manufacturer shall bear all expenses incurred by the procedure.

15. Repairs

15.1 Pipe shall be repaired, if necessary, because of imperfections in manufacture, damage during handling, or pipes that

have been cored for testing, and will be acceptable if, in the opinion of the owner, the repairs are sound and properly finished and cured and the repaired pipe conforms to the requirements of this specification.

16. Certification

16.1 When agreed upon in writing by the owner and the manufacturer, a certification shall be made the basis of acceptance. This shall consist of a copy of the manufacturer's test report or a statement by the manufacturer, accompanied by a copy of the test results, that the pipe has been sampled, tested, and inspected in accordance with the provisions of Section 4. Each certification so furnished shall be signed by an authorized agent of the manufacturer.

17. Product Marking

17.1 The following information shall be legibly marked on each section of pipe:

17.1.1 The pipe design strength shall be indicated by 0.01-in. crack D-load designated in 5.1.2 followed by capital letter D and specification designation,

17.1.2 Date of manufacture,

17.1.3 Name or trademark of the manufacturer,

17.1.4 Plant identification, and

17.1.5 One end of each section of pipe designed to installed with a particular axis of orientation shall be cle marked during the process of manufacturing or immediat thereafter on the inside and outside of opposite walls on vertical axis or shall be designated by location of lift hole

17.2 Markings shall be indented on the pipe section painted thereon with waterproof paint.

18. Keywords

18.1 concrete pipe—reinforced; culvert; D load; sewer pi storm drains; three edge bearing strength

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE CALCULATION

X1.1 As required by 10.1, the acceptability of a lot of 520 sections of 54-in. designated inside diameter pipe will be determined in accordance with 4.1.1. The design strength (0.01 in. crack) D-load is specified as 1250 lbf/linear ft per foot of designated inside diameter (1250 D pipe).

X1.2 From the lot, randomly select a sample of five specimens ($n = 5$) each 6 ft long as shown in Table 2.

X1.3 Test the pipe and record the observed values of X_i in pounds-force which produce the 0.01-in. crack: 48 000, 32 500, 43 000, 45 000, and 40 500.

X1.4 Since in this example X_i is in pounds-force, convert the specification limit L (design strength D-load) to pounds by multiplying the D-load times the designated inside diameter in feet times the pipe length in feet, or

$$L = 1250 \times (54/12) \times 6 = 33\,750 \text{ lbf} \quad \text{(X1.1)}$$

X1.5 Since an observed value of the test loads (X_i = 32 500) is less than the specification limit ($L = 33\,750$), compliance with the acceptability criteria must be determined in accordance with Section 10.

X1.6 The following values for X and s must be computed (see Note X1.1):

X = average (arithmetic mean) of the observed values X_i, and
s = estimated standard deviation.

NOTE X1.1—The observed values of pipe strengths will be divided by 100 to simplify the computations in accordance with the recommendation made in Section 25 of *ASTM STP 15-C*.[7] The effect is to reduce the si of the numbers so they can be computed more readily on a desk calculat

X1.7 Calculate the values for $\bar{X}$ as follows:

X_i	X_i^2
480	230 400
325	105 625
430	184 900
450	202 500
405	164 025
$\Sigma X_i = 2090$	$\Sigma X_i^2 = 887\,450$

$$(\Sigma X_i)^2 = (2090)^2 \quad \text{(X1.}$$

$$= 4\,368\,100 \quad \text{(X1.}$$

$$\bar{X} = (\Sigma X_i/n) \times 100$$

$$\bar{X} = (2090/5) \times 100$$

$$\bar{X} = 41\,800 \text{ lbf}$$

X1.8 The standard deviation, s, shall be computed by eithe Eq 1 or Eq 2. Since Eq 2 is a simpler form for computation, thi will be used.

$$s = \sqrt{[\Sigma X_i^2 - (\Sigma X_i)^2/n]/(n-1)} \quad \text{(X1.4}$$

$$s = \sqrt{(887\,450 - 4\,368\,100/5)/(5-1)}$$

$$s = \sqrt{3458}$$

$$s = 58.8$$

X1.9 Multiply by 100 to obtain total pounds-force:

$$s = 58.8 \times 100 \quad \text{(X1.5}$$

$$s = 5880 \text{ lbf}$$

[7] *Manual on Quality Control of Materials, ASTM STP 15C*, ASTM, Januar 1951, Section 25.

The required minimum allowable arithmetic mean X_s is computed by Eq X1.3:

$$\bar{X}_s = L + 1.10\,s \quad \text{(X1.6)}$$

$$\bar{X}_s = 33\,750 + 1.10 \times 5880$$

$$\bar{X}_s = 40\,218 \text{ lbf}$$

Since the actual X of 41 800 lbf is greater than the required minimum allowable X_s of 40 218 lbf, the lot of pipe is acceptable.

X1.10 *ASTM STP 15 D*[8] is a valuable source of information regarding statistical procedures and simplified computational methods.

[8] *Manual on Presentation of Data and Control Chart Analysis, ASTM STP 15D*, ASTM, 1976.

Designation: C 822 – 04

Standard Terminology Relating to Concrete Pipe and Related Products[1]

This standard is issued under the fixed designation C 822; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Referenced Documents

1.1 *ASTM Standards:* [2]

C 497 Test Methods for Concrete Pipe, Manhole Sections, or Tile

2. Terminology

absorption—the increase in weight of concrete resulting from the penetration of water into the concrete.

absorption test—a test made to determine the absorption of concrete.

admixture—a material other than water, aggregates, cement and fibre reinforcing used as an ingredient of concrete and added to the batch immediately before or during its mixture.

annular space—the space between the inner surface of the female end and the outer surface of the male end of an assembled pipe joint.

bell—see **female end of pipe.**

blend—a combining of various cementitious materials.

box section—a concrete pipe with a rectangular cross section.

box section bottom slab—lower horizontal portion of a box section in the installed condition.

box section top slab—upper horizontal portion of a box section in the installed condition.

box section wall—vertical sides of a box section in the installed condition.

cage—an assembled unit of steel reinforcement consisting of circumferential and longitudinal bars or wires.

circular reinforcement—a circular-shaped line of reinforcement.

circumferential reinforcement—reinforcement that is approximately perpendicular to the longitudinal axis of the concrete pipe.

combined sewer—a pipeline intended to convey sewage storm water.

compression test—a test made on a concrete specimen determine the compressive strength.

compressive strength—the maximum resistance of a concr specimen to axial compressive loading; or the specif resistance used in design calculations.

concrete—a homogeneous mixture of portland cement, f aggregate, coarse aggregate, and water. The mixture n also contain admixtures, or other cementitious materials, both.

core—a cylinder of concrete obtained from concrete by me of a core drill.

crown—the top or highest point of the internal surface of transverse cross section of a pipe.

culvert—a pipeline intended to convey water under a highw railroad, canal, or similar facility.

cylinder (test)—a cast cylindrical specimen of concrete.

design strength—the minimum acceptable 0.01-in. (0.3-m crack D-load.

designated size—the dimensional name for a particular si that may or may not be equal to or related to the dimensio used for design purposes or of the manufactured product

distribution reinforcement—reinforcement, typically runni 90° to the main or circumferential reinforcement, intended disperse concentrated loads to larger areas of a structu member.

D-load—the supporting strength of a pipe loaded und three-edge-bearing test conditions expressed in pounds p linear foot per foot of inside diameter or horizontal span, expressed in newtons per linear metre per millimetre inside diameter or horizontal span.

D-load, 0.01-in. (0.3-mm) crack—the maximum three-edg bearing test load supported by a concrete pipe before a crac having a width of 0.01 in. (0.3 mm) occurs, measured close intervals, throughout a continuous length of 1 ft (30 mm) or more measured parallel to the longitudinal axis pipe barrel expressed as D-load.

D-load ultimate *(Du)*—the maximum three-edge-bearing te load supported by a pipe, expressed as D-load.

drain tile—pipe for collecting and conveying surface an subsurface water from an area.

[1] This terminology is under the jurisdiction of ASTM Committee C13 on Concrete Pipe and are the direct responsibility of Subcommittee C13.10 on Correlation and Editorial.

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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.

elliptical reinforcement—a line of reinforcement in the approximate shape of an ellipse.

exfiltration—the volume of pipeline flow leaving a sewer and its connections into the soil from pipe, joints, connections, and appurtenances.

external load-crushing strength test—a test of the pipe in which external crushing forces are exerted in specified directions and locations on a specified length of pipe.

external sealing bands—flexible wrappings that are applied to the outside of a concrete pipe, box section, or manhole section joint intended to control the movement of fluids or solids through the joint.

female end of pipe (bell, socket, groove, modified groove)—that portion of the end of the pipe, regardless of its shape or dimensions, which overlaps a portion of the end of the adjoining pipe.

flow line—a line formed by the inverts of pipe.

gradation—the distribution of particles of granular material among standard sizes usually expressed in terms of cumulative percentages larger or smaller than each of a series of sieve openings.

grade rings—precast concrete rings used for vertical adjustment at the top of a manhole to set manhole casting to proper grade.

groove—see **female end of pipe.**

handling reinforcement—reinforcement intended to reduce the risk of collapse of the pipe or section during handling or storage prior to and during final placement.

hydrostatic pressure—the pressure exerted by water at rest.

hydrostatic test—a test of the ability of a pipe or its joint to withstand internal hydrostatic pressure.

infiltration—the volume of groundwater entering a sewer and its connections from the soil through pipe, joints, connections, or appurtenances.

inflow—the volume of any kind of water entering a sewer and its connections from outside sources not including those sources described under "infiltration."

invert—the bottom or lowest point of the internal surface of the transverse cross section of a pipe.

irrigation pipe—pipe intended for the distribution of irrigation water by pumping or gravity.

joint—a connection of two pipe, manhole, or box section ends, made either with or without the use of additional parts and/or materials.

joint leakage test—test procedure, utilizing water pressure, air pressure or a vacuum, intended to determine the acceptability of an individual joint relative to leakage.

joint reinforcement—reinforcement, in or near the joint, intended to enhance the structural characteristics of the joint area of a concrete pipe or box section.

joint test apparatus—sealing device used on the inside of the pipe to isolate a single pipe joint so that it can be tested for leakage without filling the entire pipe with compressed air or water. See joint acceptance test.

layer of reinforcement—circumferential reinforcement that is one bar or wire in thickness.

lift hole—a small hole cast or drilled in the wall of the pipe or section for inserting a bolt, loop of cable or other device used in handling the pipe or section.

line of reinforcement—circumferential reinforcement comprised of one or more layers.

longitudinal reinforcement—reinforcement, in a concrete pipe or box section, running parallel to the intended flow.

lot—an assemblage of concrete pipe, all being of like size, material, and strength designation, manufactured by the same process. The lot size may differ from the quantity designated in the contract or order.

low-pressure air test—testing procedure, utilizing compressed air, intended to determine the acceptability of a pipe section, joint, or pipeline.

male end of pipe (spigot, tongue, modified tongue)—that portion of the end of the pipe, regardless of its shape or dimensions, which is overlapped by a portion of the end of the adjoining pipe.

manhole—a precast concrete structure for vertical access to a pipeline or other closed structure.

manhole base—a concrete slab foundation and the bottom manhole riser section or a bottom manhole riser section with a connected concrete slab.

manhole base section—precast concrete slab foundation and the bottom manhole riser section, or the bottom riser section with precast monolithic or integral slab. A monolithic base section is cast as a single unit. An integral base section is made into a single unit by interconnecting precast manhole components such as a riser section and base slab.

manhole reducer section—a concrete section used as a transition between different diameter manhole riser sections.

manhole riser section—a concrete section used to construct a manhole exclusive of the base, reducers, and top section.

manhole top—the concrete slab top or conical top used to reduce the manhole riser diameter to that of the desired access hole.

manufacturer—the group, corporation, partnership, or individual that manufactures or supplies a product.

mat reinforcement— see **quadrant mat.**

material tests—the quality and property tests of component materials.

modified design—a concrete pipe design changed from a standard design.

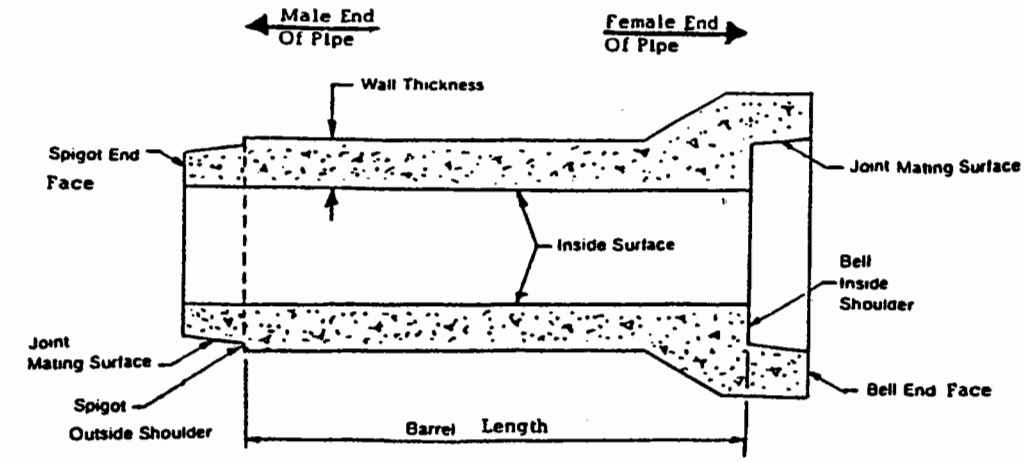
modified groove—see **female end of pipe.**

modified tongue—see **male end of pipe.**

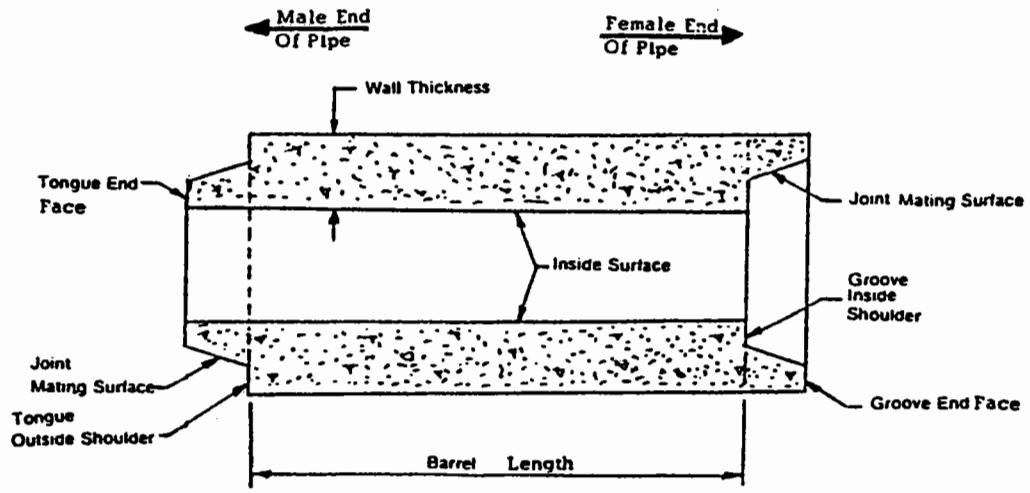
negative air pressure (vacuum) test—test procedure utilizing air at a pressure less than atmospheric pressure, intended to determine the acceptability of a pipe section or multiple pipe sections, or an installed pipeline or manhole before or after backfill.

nonreinforced pipe—concrete pipe designed without reinforcement.

O-ring gasket—a solid gasket of circular cross section.
owner—the public agency or authority, group, corporation, partnership, or individual that specifies products or services for use on a project that it presently or eventually will own or administrate.
permeability—that property which permits movement of a liquid through the pores and interstices of the concrete.
permeability test—a test to determine the movement of a liquid through concrete under a hydraulic or pressure gradient.
pipe—a tube or elongated hollow concrete structure intended to transmit flow between locations.
pipe diameter—the inside diameter of a concrete pipe.
pipe section—a single pipe.
pipeline—pipe sections joined together.
plant tests—the quality assurance tests performed prior to delivery as a basis of acceptance.
preformed flexible joint sealant—pliable material, formed into a defined cross section, that is applied to the surface of a pipe, box section, or manhole section joint, intended to control the movement of fluids or solids through the joint.
quadrant mat—additional tension zone circumferential reinforcement secured to a layer of reinforcement in the concrete pipe wall.
reinforced concrete pipe—a pipe structure comprised of concrete and steel reinforcement. Such reinforcement is comprised of steel wire, welded wire fabric, or bars, of known strength, formed into a cage and positioned in the concrete wall in a specific location in such a manner that the two materials act together to resist stresses.
reinforcement—steel in the form of continuous wire, welded wire fabric, or bars embedded in concrete in such a manner that the above referenced concrete and steel act together to resist stresses.
resilient connector—a flexible connection for joining pipe to structures capable of being deformed and deflected w rupture or leakage.
rubber gasket—rubber formed and used as a seal in co pipe joints.
sample—the number of specimens drawn from a lot.
sewage (wastewater)—the spent water of a community is a combination of liquid and water-carried wastes.
sewer—a pipeline intended to convey sewage.
special design—a concrete pipe design for sizes, load service conditions not covered by a standard design.
specimen—an individual unit on which a test can be m
spigot—see **male end of pipe.**
splice (reinforcement)—junction of two sections of pa reinforcement intended to provide continuity and to tra forces between the two sections.
springline—the points on the internal surface of the transv cross section of a pipe intersected by the line of maxim horizontal dimension; or in box sections, the mid-height the internal vertical wall.
standard design—a published and proven concrete p design.
storm drain—a pipeline intended to convey storm water.
storm sewer—a pipeline intended to convey storm water.
storm water—precipitation run-off.
three-edge-bearing method—a method for applying the lo to a pipe in an external load-crushing strength test.
tongue—see **male end of pipe.**
ultimate strength—the maximum three edge bearing test lo supported by a pipe.
wall (pipe)—the structural element composed of concrete concrete and steel between the inside and outside surfaces a concrete pipe.
watertight—will restrain the passage of water to not exceed specified limit.



Bell and Spigot Pipe



Tongue and Groove Pipe

NOTE 1—This is a schematic drawing which only defines nomenclature, and cannot be used for joint designs.
NOTE 2—Laying length is not shown and shall be as recommended by the pipe manufacturer when developing a pipe layout for field installations.
NOTE 3—The length of pipe used in the calculations for three-edge bearing strength test results is defined as laying length in the Calculations Section of Test Methods C 497[2] and may not equal field laying length.

FIG. 1 Pipe Nomenclature

Designation: C 1417 – 02

Standard Specification for Manufacture of Reinforced Concrete Sewer, Storm Drain, and Culvert Pipe for Direct Design[1]

This standard is issued under the fixed designation C 1417; 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 the manufacture and acceptance of precast concrete pipe designed to conform to the owner's design requirements and to ASCE 15-93 or an equivalent design specification.

1.2 This specification is the companion to SI Specification C 1417M; therefore, no SI equivalents are presented in this specification.

2. Referenced Documents

2.1 *ASTM Standards:*

A 82 Specification for Steel Wire, Plain, for Concrete Reinforcement[2]

A 185 Specification for Steel Welded Wire Reinforcement, Plain, for Concrete[2]

A 496 Specification for Steel Wire, Deformed, for Concrete Reinforcement[2]

A 497 Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete[2]

A 615/A 615M Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement[2]

C 33 Specification for Concrete Aggregates[3]

C 76 Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe[4]

C 150 Specification for Portland Cement[2]

C 497 Test Methods for Concrete Pipe, Manhole Sections, or Tile[4]

C 595 Specification for Blended Hydraulic Cements (Metric)[2]

C 618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete[3]

C 655 Specification for Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe[4]

C 822 Terminology Relating to Concrete Pipe and Related Products[4]

2.2 *Other Standards:*

ASCE 15-93 Standard Practice for the Direct Design of Buried Precast Reinforced Concrete Pipe Using Standard Installations (SIDD)[5]

ACI 318 Building Code Requirements for Reinforced Concrete[6]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms relating to concrete pipe, see Terminology C 822.

3.1.2 *group of pipe sections, n*—each day's production run of pipe sections of a single concrete strength for a specific project.

3.1.3 *lot of pipe sections, n*—total of the number of groups of pipe sections of a single concrete strength produced for a specific project.

3.1.4 *running average, n*—average concrete compressive strength of all groups of pipe sections of a single concrete strength produced for a specific project, generally determined as each group is tested.

4. Basis of Acceptance of Design

4.1 *Manufacturing Design Data*—The manufacturer shall submit the following manufacturing design data for the concrete pipe to the owner for approval.

4.1.1 Pipe wall thickness.

4.1.2 Concrete strength.

4.1.3 *Reinforcement*:

4.1.3.1 Specification,

4.1.3.2 Reinforcement Type 1, 2, or 3, where:

Type 1: Smooth wire or plain bars
Type 2: Welded smooth wire fabric, 8 in. maximum spacing of longitudinals

[1] This specification is under the jurisdiction of ASTM Committee C13 on Concrete Pipe and is the direct responsibility of Subcommittee C13.05 on Least Cost Analysis.

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[2] *Annual Book of ASTM Standards*, Vol 01.04.

[3] *Annual Book of ASTM Standards*, Vol 04.02.

[4] *Annual Book of ASTM Standards*, Vol 04.05.

[5] Available from American Society of Civil Engineers, 345 E. 45th Street, New York, NY 10017–2398.

[6] Available from American Concrete Institute, P.O. Box 19150, Detroit, MI 48219.

Type 3: Welded deformed wire fabric, deformed wire, deformed bars, or any reinforcement with stirrups, anchored thereto

4.1.3.3 Design yield strength,

4.1.3.4 Placement and design concrete cover,

4.1.3.5 Cross-sectional diameters,

4.1.3.6 Spacing,

4.1.3.7 Cross-sectional area,

4.1.3.8 Description of longitudinal members, and

4.1.3.9 If stirrups are used, developable stirrup design stress, stirrup shape, placement, and anchorage details.

4.1.4 Design factors and the assumed orientation angle.

4.1.5 Pipe laying length and joint information.

4.2 Approval of the manufacturing design data shall be based on its conformance to the owner's design requirements and to ASCE 15-93 or to an equivalent design specification.

5. Basis of Acceptance of Concrete Pipe

5.1 Acceptance of pipe shall be on the basis of concrete compression tests, materials tests, conformance to the manufacturing design data, conformance to this specification, and inspection of manufactured pipe for defects.

5.2 When mutually agreed in writing by the owner and the manufacturer, a certification may be made the basis of acceptance of the concrete pipe. This certification shall consist of a statement by the manufacturer that the concrete pipe conforms to the manufacturing design data and to this specification, and that the concrete and materials have been sampled and tested and conform to this specification.

5.3 *Age for Acceptance*—Pipe shall be considered ready for acceptance when they conform to the requirements of this specification.

6. Material

6.1 *Reinforced Concrete*—The reinforced concrete shall consist of cementitious materials; mineral aggregates; admixtures, if used; and water in which steel has been embedded in such a manner that the steel and concrete act together.

6.2 *Cementitious Material*:

6.2.1 *Cement*—Cement shall conform to the requirements for portland cement of Specification C 150 or shall be portland blast-furnace slag cement or portland-pozzolan cement conforming to the requirements of Specification C 595, except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash and shall not exceed 25 % by weight.

6.2.2 *Fly Ash or Pozzolan*—Fly ash or pozzolan shall conform to the requirements of Specification C 618, Class F or Class C.

6.2.3 *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in the concrete shall be one of the following:

6.2.3.1 Portland cement only.

6.2.3.2 Portland blast furnace slag cement only.

6.2.3.3 Portland pozzolan cement only.

6.2.3.4 A combination of portland cement and fly ash or pozzolan, wherein the proportion of fly ash is between 5 and 25 % by weight (mass) of total cementitious material (portland cement plus fly ash).

6.3 *Aggregates*—Aggregates shall conform to the requirements of Specification C 33, except that the requirement for gradation shall not apply.

6.4 *Admixtures*—Admixtures and blends may be used with the approval of the owner.

6.5 *Steel Reinforcement*—Reinforcement shall consist of wire conforming to Specifications A 82 or A 496, of wire fabric conforming to Specifications A 185 or A 497, or of bars conforming to Specification A 615/A 615M.

7. Joints

7.1 The joints shall be designed and the ends of the concrete pipe sections shall be formed so that the sections can be laid together to make a continuous line of pipe, compatible with the permissible variations given in Section 15.

8. Manufacture

8.1 *Concrete*—The aggregates shall be sized, graded, proportioned, and mixed with cementitious material and water and admixtures, if any, to produce a concrete mixture of such quality that the pipe will conform to the design requirements of this specification. The water-cementitious material ratio of all concrete shall be 0.53, or less, by weight. Minimum concrete strength shall be 4000 psi.

8.2 *Finish*—Pipe shall be substantially free of fractures, large or deep cracks, and surface roughness. The ends of the pipe shall be normal to walls and center line of the pipe, within the limits of variations given in Section 15.

9. Circumferential Reinforcement

9.1 A line of circumferential reinforcement for any given total area may be composed of up to two layers for pipe with wall thicknesses of less than 7 in. or three layers for pipe with wall thickness of 7 in. or greater. The layers shall not be separated by more than the thickness of one longitudinal plus ¼ in. The multiple layers shall be fastened together to form a single cage. If the multiple layers of a cage contain circumferential splices, the individual layers shall be rotated so that the splices are staggered. All other specification requirements, such as laps, welds, tolerances of placement in the wall of the pipe, and so forth, shall apply to this method of fabricating a line of reinforcement. The design shall be based on the centroid of the layers.

9.2 Reinforcement placement and concrete cover shall conform to the approved manufacturing data. The nominal concrete cover over the circumferential reinforcement shall not be less than 1 in. in pipe having a wall thickness of 2½ in. or greater, and shall not be less than ¾ in. in pipe having a wall thickness of less than 2½ in. The location of the reinforcement shall be subject to the permissible variations in dimensions given in Section 15. Requirements for placement and protective covering of the concrete from the inner or outer surface of the pipe do not apply to that portion of a cage that is flared so as to extend into the bell or reduced in diameter so as to extend into the spigot.

9.3 Where the wall reinforcement does not extend into the joint area, the maximum longitudinal distance to the last circumferential from the inside shoulder of the bell or the

shoulder of the spigot shall be 3 in., except that if this distance exceeds one half of the wall thickness, the pipe wall shall contain at least a total reinforcement area of the minimum specified area per linear foot times the laying length of the pipe section. The minimum cover on the last circumferential near the spigot shoulder shall be ½ in.

9.4 Where reinforcement is in the bell or spigot, the minimum end-cover on the last circumferential shall be ½ in. in the bell or ¼ in. in the spigot.

9.5 The continuity of the circumferential reinforcing steel shall be maintained during the manufacture of the pipe, except when, as agreed upon by the owner, lift eyes or holes are provided in each pipe or the pipe is converted into a manhole tee.

10. Welds, Splices, and Development of Circumferential Reinforcement

10.1 *General*:

10.1.1 When pipe are not marked to show a specific orientation in the ground, any weld to, or splice of, a circumferential shall be considered to be at the point of the maximum flexural stress.

10.1.2 When pipe are marked to show a specific orientation in the ground, any weld to, or splice of, a circumferential shall be considered to be at a distance determined by the orientation angle closer to the point of maximum flexural stress than the marking indicates.

10.1.3 Splices of smooth and deformed wire shall be welded shall meet the requirements of 10.3 and 10.4.

10.2 *Notation*:

A_{wa} = actual steel area of the individual circumferential wire, in.^{2}

A_{wr} = steel area required for the individual circumferential wire for flexure, in.^{2}, either at the splice, for splices, or at the point of maximum moment, for quadrant mat reinforcement.

d_b = diameter of reinforcing wire or bar, in.

f'_c = design compressive strength of concrete, lb/in.^{2}.

f_y = design yield strength of reinforcement, lb/in.^{2}.

F_w = embedded weld factor (see 10.4.3).

L_d = development length of reinforcing wire or bar, in.

P_t = pull test strength of wire or bar at break, lbf.

s = spacing of wire to be developed or spliced, in.

10.3 *Welds*:

10.3.1 For butt splices of circumferentials or where welds are made to circumferentials, pull tests of representative specimens of the circumferential across the finished weld shall demonstrate a strength of no less than 1.1 times the design yield strength of the circumferential except as provided in 10.4.

10.3.2 At the option of the manufacturer, a more detailed analysis may be made and the requirements of this section used instead of 10.3.1. For butt splices of circumferentials or where welds are made to circumferentials, pull tests, P_t, of representative specimens of the circumferential across the finished weld shall demonstrate a strength of no less than:

$$P_t = 1.1\, A_{wr}\, f_y \quad (1)$$

or no less than:

$$P_t = 0.5\, A_{wa}\, f_y \quad (2)$$

whichever is greater.

10.4 *Lapped Splices of Circumferential Reinforcement*:

10.4.1 Where lapped circumferentials are spliced by welding, they shall be lapped no less than 2 in. Pull tests of representative specimens shall develop no less than 0.9 times design yield strength of the circumferential.

10.4.2 At the option of the manufacturer, a more detailed analysis may be made and the requirements of 10.4.2 and 10.4.3 used instead of 10.4.1. Where lapped circumferentials are spliced by welding, they shall be lapped no less than 2 in. Pull tests, P_t, of representative specimens shall develop no less than:

$$P_t = F_w\, A_{wr}\, f_y \quad (3)$$

or not less than the strength required by Eq 2, whichever is the greater.

10.4.3 The embedded weld factor, F_w, relates the pull test strength of the non-embedded splice specimens to the strength of the splice embedded in the concrete of the pipe wall.

10.4.3.1 If the pull test break is in the wire, F_w shall be taken as 0.90.

10.4.3.2 If the pull test break is in the weld, F_w shall be taken as 0.70.

10.4.4 If lapped splices of circumferentials consisting of deformed bars #6 or less are not welded, they shall be lapped not less than L_d, where:

$$L_d = \frac{d_b f_y A_{wr}}{33\sqrt{f'_c}\, A_{wa}} \quad (4)$$

or not less than:

$$\frac{d_b f_y}{66\sqrt{f'_c}} \quad (5)$$

whichever is greater. Splices of larger than #6 bars shall meet the requirements of ACI 318–95.

10.4.5 If lapped splices of circumferentials consisting of welded smooth wire fabric or welded deformed wire fabric are not welded, the overlap measured between the outermost longitudinals on each side of the splice shall be no less than the spacing of the longitudinals plus 1 in. or L_d, where:

$$L_d = 0.27\,\frac{A_{wr} f_y}{s\sqrt{f'_c}} \quad (6)$$

whichever is greater.

10.4.6 At the option of the manufacturer, a more detailed analysis may be made and the following exception to the requirements of 10.4.5 may be applied. If the area of circumferential reinforcement is at least twice that required for flexure, the first requirement of 10.4.5 shall not apply. The overlap measured between the outermost longitudinals on each side of the splice shall be no less than that required by Eq 6, or 1 in., whichever is greater.

10.4.7 Alternative splice designs that differ from 10.4 may be submitted to the owner for approval.

10.5 *Development of Quadrant Mat Reinforcement*:

10.5.1 Circumferential quadrant mat reinforcement shall consist of welded wire fabric with 8-in. maximum cross wire spacing. When quadrant mat reinforcement is used, the area of the main cage shall be no less than 25 % of the area required

at the point of maximum moment. The quadrant mats shall extend at least 45° on each side of the point of maximum moment.

10.5.2 At the option of the manufacturer, a more detailed analysis may be made and the requirements of 10.5.3 or 10.5.4 used instead of 10.5.1.

10.5.3 When circumferential quadrant mat reinforcement consists of welded smooth wire fabric or welded deformed wire fabric, the following requirements shall apply:

10.5.3.1 The outermost longitudinals on each end of the circumferentials shall be embedded in accordance with the following requirements: *(1)* past the point where the quadrant reinforcement is no longer required by the orientation angle plus the greater of twelve circumferential wire diameters or three quarters of the wall thickness of the pipe, and *(2)* past the point of maximum flexural stress by the orientation angle plus the development length, L_d, required by Eq 6.

10.5.3.2 The mat shall contain no less than two longitudinals at a distance 1 in. greater than that determined by the orientation angle from either side of the point requiring the maximum flexural reinforcement.

10.5.3.3 The point of embedment of the outermost longitudinals of the mat shall be at least a distance determined by the orientation angle past the point where the continuing reinforcement is no less than double the area required for flexure.

10.5.4 When circumferential quadrant mat reinforcement consists of #6 or less deformed bars, the following requirements shall apply:

10.5.4.1 Circumferentials shall extend past the point where they are no longer required by the orientation angle plus the greater of twelve wire diameters or three quarters of the wall thickness of the pipe.

10.5.4.2 Circumferentials shall extend either side of the point of maximum flexural stress not less than the orientation angle plus the development length, L_d, required by Eq 4.

10.5.4.3 Circumferentials shall extend at least a distance determined by the orientation angle past the point where the continuing reinforcement is no less than double the area required for flexure.

10.5.4.4 Development of larger than #6 bars shall meet the requirements of ACI 318–95.

11. Stirrup Reinforcement

11.1 The number of lines of stirrups shall be sufficient to include the distance determined by calculation where V_u is less than V_c plus the distance l_θ as determined in Section 12.6.4.1 of ASCE 15-93 or as determined by the requirements of an equivalent design specification. The required number of lines of stirrups shall be equally distributed on each side of the point of maximum moment.

11.2 Stirrups used to resist radial tension shall be anchored around each circumferential of the inside cage.

11.3 When stirrups are not required for radial tension but required for shear, their longitudinal spacing shall be such that they are anchored either at every or every other inside face tension circumferential. Such spacing shall not exceed 6 in.

11.4 Stirrups intended to resist forces in the invert and crown regions shall be anchored around the inside circumferentials and anchored sufficiently in the concrete compression zone on the opposite side of the pipe wall to develop the design strength of the stirrup.

11.5 Anchorage of both ends of the stirrup shall be sufficient to develop the factored stress in the stirrup. The maximum factored tensile stress in the stirrup shall be the yield stress or the stress that can be developed by anchorage, whichever is less.

12. Longitudinal Reinforcement

12.1 Circumferential reinforcement shall be assembled into a cage containing sufficient longitudinal members to maintain the circumferential reinforcement in correct position within the pipe.

13. Joint Reinforcement

13.1 *General*—The length of the joint as used in this specification means the inside length of the bell or the outside length of the spigot from the shoulder to the end of the pipe section. The end distances or cover on the end circumferential shall apply to any point on the circumference of the pipe or joint. When convoluted reinforcement is used, these distances and reinforcement areas shall be taken from the points on the convolutions closest to the end of the pipe section. The following requirements for joint reinforcement shall apply.

13.2 *Non-Rubber Gasket Joints*:

13.2.1 For pipe less than 36 in. in diameter, neither the bell or spigot require circumferential reinforcement.

13.2.2 For pipe 36 in. and larger in diameter, either the bell or spigot shall contain circumferential reinforcement. This reinforcement shall be an extension of a wall cage or may be a separate cage of at least the area per linear foot of that specified for the outer cage or one half of that specified for single cage wall reinforcement, whichever is less.

13.2.3 Where bells or spigots require reinforcement, the maximum end cover on the last circumferential shall be one-half the length of the joint or 3 in., whichever is less.

13.3 *Rubber Gasket Joints*:

13.3.1 For pipe 12 in. and larger in diameter, the bell ends shall contain circumferential reinforcement. This reinforcement shall be an extension of the outer cage or a single wall cage, whichever is less, or it may be a separate cage of at least the same area per linear foot with longitudinals as required in Section 12. If a separate cage is used, the cage shall extend into the pipe with the last circumferential wire at least 1 in. past the inside shoulder where the pipe barrel meets the bell of the joint.

13.3.2 When bells require reinforcement, the maximum end cover on the last circumferential shall be 1½ in.

14. Physical Requirements

14.1 *Concrete Compressive Strength Testing, Type of Specimen*—Compression tests for determining concrete compressive strength may be made on either concrete cylinders or on cores drilled from the pipe.

14.2 *Acceptance by Cylinder Tests*:

14.2.1 Cylinders shall be prepared in accordance with Section 11 of Test Methods C 497.

14.2.2 *Number of Cylinders*—Prepare not less than five test cylinders from a group (one day's production) of pipe sections.

14.2.3 *Evaluation of Test Results*:

14.2.3.1 When the compressive strengths of all cylinders tested for a group are equal to or greater than the design concrete strength, the compressive strength of concrete in the group of pipe sections shall be acceptable.

14.2.3.2 When the running average compressive strength of all cylinders tested in a lot is equal to or greater than the design concrete strength, not more than 10 % of the cylinders tested have a compressive strength less than the design concrete strength, and no cylinder tested has a compressive strength less than 80 % of the design concrete strength, then the compressive strength of the concrete in the lot of pipe sections shall be acceptable.

14.2.3.3 If the concrete strength for a group does not meet the required concrete strength because of faulty cylinders or faulty production, the manufacturer may cull that group from the lot and running average. A group culled because of faulty cylinders may be accepted in accordance with the provisions of 14.2.3.4.

14.2.3.4 When the concrete compressive strength of the cylinders tested for a group or for a lot does not conform to the acceptance criteria in 14.2.3.1 or 14.2.3.2, the acceptability of the group or lot shall be determined by additional tests on cores in accordance with the provisions of 14.3.

14.3 *Acceptance by Core Tests*:

14.3.1 *Obtaining Cores*—Core specimens shall be obtained, prepared, and tested in accordance with Test Methods C 497.

14.3.2 *Number of Cores*—Three cores shall be taken from pipe sections (one core from each) selected at random from each group of pipe sections or fraction thereof of a single size from each continuous production run.

14.3.3 *Evaluation of Test Results*:

14.3.3.1 Concrete represented by these three core tests shall be considered acceptable if the average of the three core strengths is equal to or greater than 85 % of the required compressive strength and no single core is less than 75 % of the required compressive strength.

14.3.3.2 If the compressive strength of the three cores does not meet the requirements of 14.3.3.1, the sections from which the cores were taken shall be rejected. Two pipe sections from the remainder of the group shall be selected at random, and one core shall be taken from each and tested. If both cores have a strength equal to or greater than 85 % of the required strength, the remainder of the group is acceptable. If the compressive strength of either of the two cores is less than 85 % of the required strength, the remainder of the group shall be rejected or, at the option of the manufacturer, each pipe section of the remaining group shall be cored and accepted individually, and any of these pipe sections that have core strengths less than 85 % of the required strength shall be rejected.

14.3.4 *Plugging Core Holes*—Core holes shall be plugged and sealed by the manufacturer in a manner such that the pipe section will meet all the requirements of the specification. Pipe sections so plugged and sealed shall be considered acceptable for use.

15. Permissible Variations

15.1 *Pipe Diameter*—The internal diameter of 12 to 24 in. pipe shall vary not more than ±1.5 % from the design diameter. The internal diameter of 27 to 144 in. pipe shall vary not more than ±1 % or ±3/8 in., whichever is greater, from the design diameter.

15.2 *Reinforcement Area*—Reinforcement will be considered as meeting the design requirements if the area, computed on the basis of nominal area of the wire or bars used, equals or exceeds the design requirements. Actual area of the reinforcement used may vary from the nominal area in accordance with permissible variations of the standard specifications for the reinforcement.

15.3 *Reinforcement Placement*—The maximum variation in the nominal location of the reinforcement shall be ±10 % of the wall thickness. In no case, however, shall the cover over the circumferential reinforcement be less than 5/8 in.

15.4 *Length of Two Opposite Sides*—Variations in the laying length of two opposite sides of pipe shall not be more than 1/4 in. for all sizes through 24-in. internal diameter, and not more than 1/8 in./ft of internal diameter for all larger sizes, with a maximum of 5/8 in. in any pipe through 84-in. internal diameter, and a maximum of 3/4 in. for 90-in. internal diameter, or larger, except where beveled-end pipe for laying on curves is specified by the owner.

15.5 *Length of Pipe*—The underrun in length of a section of pipe shall not be more than 1/8 in./ft with a maximum of 1/2 in. in any length of pipe.

15.6 *Wall Thickness*—The wall thickness shall be not less than the nominal specified in the design by more than 5 % or 3/16 in., whichever is greater. A wall thickness more than that required in the design is not cause for rejection.

16. Inspection

16.1 The quality of materials, process of manufacture, and the finished pipe shall be subject to inspection by the owner.

16.2 *Rejection*:

16.2.1 Pipe shall be subject to rejection for failure to conform to any of the requirements of this specification. Individual sections of pipe may be rejected because of any of the following:

16.2.1.1 Fractures or cracks passing through the wall, except for a single end crack that does not exceed the depth of the joint.

16.2.1.2 Defects that indicate proportioning, mixing and molding not in compliance with 6.1, or surface defects indicating honeycombed or open texture that would adversely affect the function of the pipe.

16.2.1.3 Damaged ends when such damage would prevent making a satisfactory joint.

16.2.1.4 Any continuous crack having a surface width of 0.01 in. or more and extending for a length of 1 ft or more, regardless of position in the wall of the pipe.

16.2.1.5 The ends of the pipe are not normal to the walls and centerline of the pipe, within the limits of variations given in 15.4 and 15.5.

16.2.2 The exposure of ends of longitudinals, stirrups, or spacers that have been used to position the cages during the placement of the concrete is not cause for rejection.

16.3 *Repairs*—Pipe may be repaired, if necessary, because of imperfections in manufacture or damage during handling or if it has been cored for testing, and it will be acceptable if the

repairs are sound and the repaired pipe conforms to the requirements of this specification.

17. Marking

17.1 The following information shall be legibly marked on each pipe section with waterproof paint or indented:

17.1.1 The pipe designation shall be indicated as follows:

$$D_i\_\_\_\_T\_\_\_\_H\_\_\_\_-\_\_\_\_$$

where:

D_i = designated pipe internal diameter, in.,
T = installation type, and
H = minimum - maximum fill height, ft.

17.1.2 Date of manufacture.

17.1.3 Name or trademark of the manufacturer.

17.1.4 Plant identification.

17.1.5 One end of each section of pipe reinforced w elliptical cages, quadrant mats, or stirrups and designed to installed with a particular axis of orientation shall be legib marked during the process of manufacturing, or immediate thereafter, on the inside crown and outside top of pipe or sh have the orientation identified by the location of one or mo lift holes.

18. Keywords

18.1 concrete pipe; reinforced; culvert; sewer pipe; stor drain; direct design

APPENDIX

(Nonmandatory Information)

X1. EXPLANATORY INFORMATION

X1.1 *Scope (see Section 1)*—The concrete pipe manufacturing requirements in this standard are similar to the requirements given in Specifications C 76 and C 655. The requirements are modified to be compatible with ASCE 15-93, which specifies direct design procedures for buried concrete pipe instead of indirect procedures based on the three-edge bearing test. This specification contains manufacturing requirements, detailing requirements for reinforcement, acceptance of design, and acceptance of concrete pipe based on materials tests and visual inspection.

X1.2 *Acceptance of Concrete Pipe*:

X1.2.1 This specification has been developed as the manufacturing standard for pipe designed and installed in accordance with ASCE 15–93. Pipe designs and specifying of pipe in accordance with ASCE 15–93 is in terms of pipe reinforcement required for a height of earth cover for a pipe installed in a specific Standard installation. Consequently, the three-edge bearing test and D-load strength are not applicable.

X1.2.2 Critical items for strength characteristics are wall thickness, concrete strength, and reinforcement type, placement and area. Inspection for strength characteristics can be made by observations and measurements during manufacture or tests, or both, and observations and measurements of cores taken from randomly selected pipe sections.

X1.3 *Welds, Splices, and Development of Circumferential Reinforcement*:

X1.3.1 *General (see 10.1)*—Weld and splice strength requirements are based on the assumption that the weld or splice will occur at the location of maximum flexural stress. When the pipe is to be installed with a specific orientation that is marked on the pipe, the manufacturer may elect to determine the factored stress at a splice location and design the splice for that stress. The assumed stress at the splice location must account for misplacement (rotation) of the pipe during installation of at least the orientation angle in the direction of increasing stress.

X1.3.2 *Welds (see 10.3)*—Improper welding procedures ca damage circumferential wires or not develop adequa strength. The manufacturer will perform pull tests on represe tative specimens of circumferentials with welds to substantia the adequacy of the circumferentials after welding.

X1.3.3 *Lapped Splices of Circumferential Reinforceme (see 10.4)*— The specified minimum pull test strength of th welded lap splice of 0.9 times design yield strength is less tha 1.0 times design yield strength. This is because pull tests o wire with lapped welded splices embedded in concrete hav shown that the actual strength of the spliced wire whe embedded in concrete is substantially higher than when th spliced wire is not embedded in concrete. This is due to th elimination of the eccentricity inherent in a lapped welde splice in the standard pull test and the beneficial effect of bon to the strength of the splice embedded in concrete.

X1.3.4 Tests on welded lapped splices embedded in con crete show that the strength of the wire is more important tha the strength of the weld. Overheating of the wire while weldin may help make a strong weld but it also tends to weaken th wire. The effect of bond is also important to the strength of th embedded splice. The results of pull tests on splices nc embedded in concrete do not reflect these factors. The embed ded weld factor corrects for the embedded strength of a welde lapped splice measured in a non-embedded condition (se 10.4.3).

X1.3.5 The minimum overlap lengths for lapped splices tha are not welded is based on ACI 318–95 with modification appropriate for reinforced concrete pipe (see 10.4.4-10.4.6).

X1.3.6 *Development of Quadrant Mat Reinforcement*:

X1.3.6.1 Design studies have demonstrated that if the are of welded wire fabric quadrant mat reinforcing does not excee 75 % of the total required reinforcement at the point o maximum moment, no special analysis for the location of ma cut off points need be performed if the mat reinforcemen extends at least 45° beyond each side of the point of maximun

ment. No additional extension for orientation angle is required if the specified orientation angle is equal to or less than 10° (see 10.5.1).

X1.3.6.2 The requirements for determining cut off points for mat reinforcement that are given in these sections are based on criteria given in ACI 318–95. They are to be used when a detailed analysis of mat reinforcement cutoff points is performed by the manufacturer (see 10.5.2-10.5.4).

X1.4 *Stirrup Reinforcement (see Section 11)*—To be effective, stirrups must have sufficient anchorage at each end to develop their design tensile strength. At the inside of the pipe wall, stirrups should be anchored around the inside circumferential reinforcement. This gives positive anchorage to resist any radial tension stresses. Because of fabrication requirements of concrete pipe, it is usually not practical to anchor the outside end of stirrups to the outside circumferential reinforcement. Several proprietary stirrup configurations have been developed and tested for adequate anchorage, both in the tension zone of the pipe wall on the inside of the pipe and in the opposite side or compression side near the outside of the pipe.

X1.5 *Longitudinal Reinforcement (see Section 12)*—Except for special cases, such as where pipe is supported on piers, there are no specific requirements for a minimum amount of longitudinal reinforcement. Long-standing successful practice in the concrete pipe industry has shown that this is practical due to the limited length of typical precast concrete pipe sections.

X1.6 *Joint Reinforcement (see Section 13)*—Requirements for joint reinforcement are the same as Specification C 76.