Designation: C 507 – 02

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

This standard is issued under the fixed designation C 507; 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 elliptically shaped concrete pipe to be used for the conveyance of sewage, industrial wastes, and storm water, and for the construction of culverts.

1.2 Pipe designed for placement with the major axis horizontal shall be designated as "Horizontal Elliptical Pipe." Pipe designed for placement with the major axis vertical shall be designated as "Vertical Elliptical Pipe."

1.3 A complete metric companion to this specification has been developed—C 507M; 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 the 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.

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 822 Terminology Relating to Concrete Pipe and Related Products[5]
C 1116 Specification for Fiber-Reinforced Concrete and Shotcrete[3]

3. Terminology

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

4. Classification

4.1 Pipe manufactured according to this specification shall be of five classes each for horizontal elliptical and vertical elliptical pipe with identification as follows:

Horizontal Elliptical Pipe	Vertical Elliptical Pipe
Class HE-A	Class VE-II
Class HE-I	Class VE-III
Class HE-II	Class VE-IV
Class HE-III	Class VE-V
Class HE-IV	Class VE-VI

4.2 The strength requirements for horizontal elliptical pipe are prescribed in Table 1 and for vertical elliptical pipe are prescribed in Table 2.

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 shall be permitted as follows:

5.1.1 *Acceptance on Basis of Plant Load Bearing Tests, Material Tests, and Inspection of the Complete Product*

[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.

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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 04.01.

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

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TABLE 1 Design Requirements for Horizontal Elliptical (HE) Pipe[A]

NOTE 1—The test load in pounds per linear foot equals D-load × inside span in feet.

NOTE 2—Single cage reinforcement, providing tension steel at the top, bottom, and springline, shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be 112 % of the tabulated inner cage area.

NOTE 3—An inner and outer cage plus quadrant mats shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be in accordance with Fig. 1.

NOTE 4—An inner and outer cage plus a middle cage shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be in accordance with Fig. 2.

Designated Diameter, Equivalent Round Size, in.	Designated Rise, in. × Span, in.	Minimum Wall Thickness, in.	Reinforcement, in.²/linear ft									
			Class HE-A		Class HE-I		Class HE-II		Class HE-III		Class HE-IV	
			D-Loads									
			0.01 = 600 Ult = 900		0.01 = 800 Ult = 1200		0.01 = 1000 Ult = 1500		0.01 = 1350 Ult = 2000		0.01 = 2000 Ult = 3000	
			In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage
18	14 × 23	2¾	0.08	. . .	0.11	. . .	0.14	. . .	0.19	. . .	0.27	. . .
24	19 × 30	3¼	0.11	. . .	0.15	. . .	0.19	. . .	0.26	. . .	0.39	. . .
27	22 × 34	3½	0.14	. . .	0.18	. . .	0.23	. . .	0.31	. . .	0.46	. . .
30	24 × 38	3¾	0.10	0.10	0.13	0.13	0.17	0.17	0.23	0.23	0.34	0.34
33	27 × 42	3¾	0.12	0.12	0.17	0.17	0.21	0.21	0.28	0.28	0.41	0.41
36	29 × 45	4½	0.11	0.11	0.15	0.15	0.19	0.19	0.26	0.26	0.39	0.39
39	32 × 49	4¾	0.13	0.13	0.17	0.17	0.21	0.21	0.29	0.29	0.44	0.44
42	34 × 53	5	0.15	0.15	0.20	0.20	0.24	0.24	0.33	0.33	0.50	0.50
48	38 × 60	5½	0.17	0.17	0.23	0.23	0.28	0.28	0.39	0.39	. . .	. .
54	43 × 68	6	0.20	0.20	0.27	0.27	0.34	0.34	0.45	0.45	. . .	. . ..
60	48 × 76	6½	0.24	0.24	0.32	0.32	0.40	0.40	0.53	0.53	. . .	. . .
66	53 × 83	7	0.27	0.27	0.36	0.36	0.45	0.45	0.61	0.61	. . .	. . .
72	58 × 91	7½	0.31	0.31	0.41	0.41	0.52	0.52	0.70	0.70	. . .	. . .
78	63 × 98	8	0.34	0.34	0.45	0.45	0.56	0.56	0.78	0.78	. . .	. . .
84	68 × 106	8½	0.38	0.38	0.50	0.50	0.63	0.63	0.88	0.88	. . .	. . .
90	72 × 113	9	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
96	77 × 121	9½	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
102	82 × 128	9¾	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
108	87 × 136	10	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
114	92 × 143	10½	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
120	97 × 151	11	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
132	106 × 166	12	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
144	116 × 180	13	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Concrete strength[B], psi			4000		4000		4000		18 to 66 in. 4000		4000	
									72 to 84 in. 5000			

[A] For sizes and loads beyond those shown in this table, pipe designs are available that make use of one or a combination of the following: shear steel, multiple cages, or thicker walls in accordance with the provisions of 7.3.

[B] Concrete strength for designs with reinforcement tabulated. For modified or special designs, see 7.3.

—Acceptability of the pipe in all sizes and classes produced in accordance with 7.1 or 7.2 shall be determined by the results of the three-edge-bearing tests for either the load to produce a 0.01-in. crack or, at the option of the owner, the load to produce the 0.01-in. crack and the ultimate load; by such material tests as are required in accordance with 6.1, 6.2, and 6.4; by absorption tests on selected samples from the wall of the pipe; and by inspection of the finished pipe to determine its conformance with the design prescribed in this specification and its freedom from defects.

5.1.2 *Acceptance on Basis of Material Tests and Inspection of the Complete Product*—Acceptability of the pipe in all sizes 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 accordance with 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 design prescribed in this specification and its freedom from defects.

5.1.3 When agreed upon by the owner and the 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 they conform 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 homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. In no case, however, shall the proportion of portland cement, blended hydraulic cement, or a combination of portland cement and supplementary

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TABLE 2 Design Requirements for Vertical Elliptical Pipe[A]

NOTE 1—Test load in pounds per linear foot equals D-load × inside span in feet.

NOTE 2—An inner and outer cage plus quadrant mats shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be in accordance with Fig. 3.

NOTE 3—Single cage reinforcement, providing tension steel at the top, bottom, and springline, shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be 112 % of the tabulated inner cage area.

NOTE 4—An inner and outer cage plus a middle cage shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be in accordance with Fig. 4.

Designated Diameter, Equivalent Round Size, in.	Designated Rise, in. × Span, in.	Minimum Wall Thickness, in.	Reinforcement, in.^{2}/linear ft									
			Class VE-II		Class VE-III		Class VE-IV		Class VE-V		Class VE-VI	
			D-Loads									
			0.01 = 1000 Ult = 1500		0.01 = 1350 Ult = 2000		0.01 = 2000 Ult = 3000		0.01 = 3000 Ult = 3750		0.01 = 4000 Ult = 5000	
			In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage
36	45 × 29	4½	0.08	0.05	0.11	0.07	0.16	0.10	0.23	0.14	0.31	0.19
39	49 × 32	4¾	0.09	0.05	0.12	0.07	0.18	0.11	0.26	0.16	0.35	0.21
42	53 × 34	5	0.10	0.06	0.13	0.08	0.20	0.12	0.29	0.17	0.38	0.23
48	60 × 38	5½	0.11	0.07	0.15	0.09	0.22	0.13	0.33	0.20	0.44	0.26
54	68 × 43	6	0.13	0.08	0.18	0.11	0.27	0.16	0.40	0.24	0.53	0.32
60	76 × 48	6½	0.16	0.10	0.21	0.13	0.31	0.19	0.47	0.28	. . .	. . .
66	83 × 53	7	0.18	0.11	0.25	0.15	0.36	0.22	0.55	0.33	. . .	. . .
72	91 × 58	7½	0.21	0.13	0.28	0.17	0.41	0.25	. . .	. . .	. . .	. . .
78	98 × 63	8	0.23	0.14	0.31	0.19	0.47	0.28	. . .	. . .	. . .	. . .
84	106 × 68	8½	0.26	0.16	0.35	0.21	0.53	0.32	. . .	. . .	. . .	. . .
90	113 × 72	9	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
96	121 × 77	9½	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
102	128 × 82	9¾	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
108	136 × 87	10	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
114	143 × 92	10½	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
120	151 × 97	11	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
132	166 × 106	12	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
144	180 × 116	13	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Concrete strength[B], psi			4000		4000		4000		5000		6000	

[A] For sizes and loads beyond those shown in this table, pipe designs are available which make use of one or a combination of the following: shear steel, multiple cages, or thicker walls in accordance with the provisions of 7.3.

[B] Concrete strength for designs with reinforcement tabulated. For modified or special designs, see 7.3.

cementing materials be less than 470 lb/yd^3.

6.2 *Cementitious Materials*:

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.

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

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, or

6.2.3.4 A combination of portland 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 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 *Size and Shape*—The standard sizes of elliptical pipe shall be as listed in Table 1 and Table 2. The internal shape for each size pipe shall be defined by the internal dimensions shown in Fig. 5, subject to the permissible variations of 12.1.

7.2 *Design Tables*—The wall thickness, compressive strength of concrete, and the area of circumferential reinforcement shall be as prescribed in Table 1 and Table 2, subject to the provisions of 7.3 and Sections 11 and 12.

7.2.1 Footnotes to the tables herein are intended to be amplifications of the tabulated requirements and are to be considered applicable and binding as if they were contained in the body of the specification.

7.3 *Modified and Special Designs*:

7.3.1 If permitted by the owner, the manufacturer may request approval by the owner of modified designs which differ from the designs in this Section 7; or special designs for sizes and loads beyond those shown in Table 1 and Table 2; or

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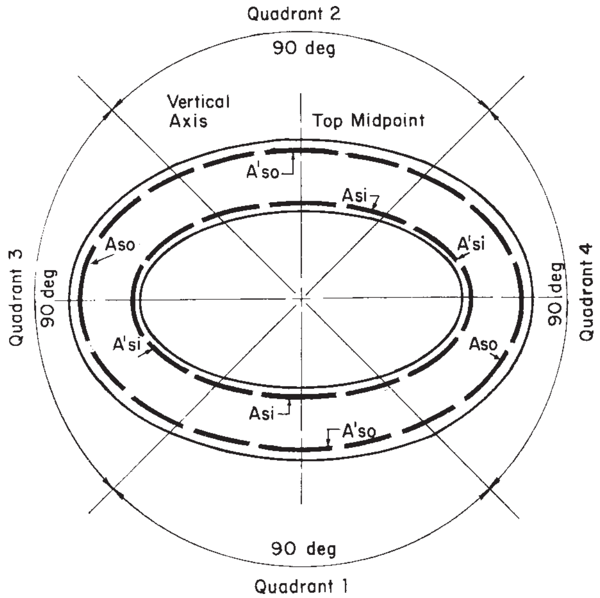


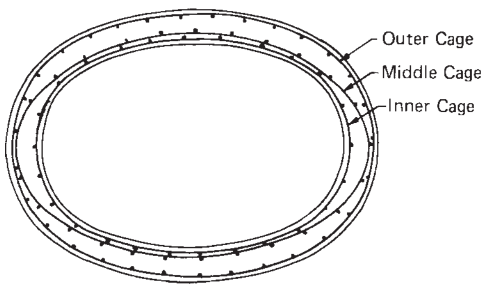
NOTE 1—The total reinforcement area (Asi) of the inner cage plus the quadrant mat in Quadrants 1 and 2 shall not be less than that specified for the inner cage in Table 1.

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 Table 1.

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 Table 1.

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 Table 1.

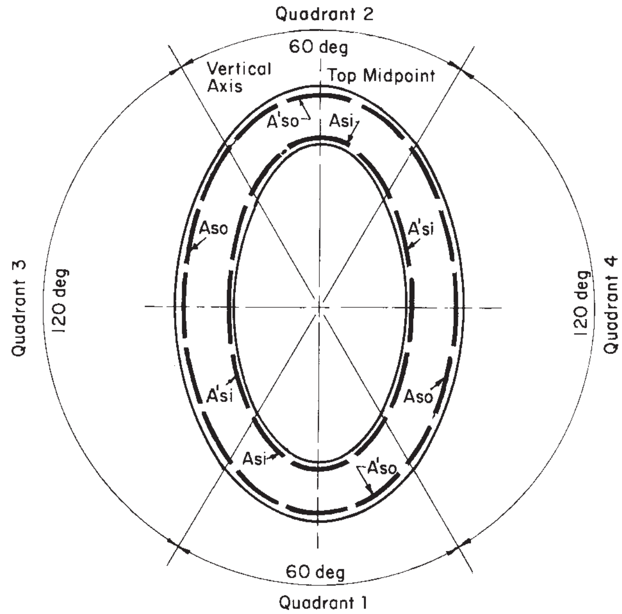
FIG. 1 Quadrant Reinforcement, Horizontal Elliptical Pipe



NOTE 1—The total reinforcement area of the inner cage plus the middle cage shall not be less than that specified for the inner cage in Table 1.

NOTE 2—The total reinforcement area of the outer cage plus the middle cage shall not be less than that specified for the outer cage in Table 1.

FIG. 2 Horizontal Elliptical Pipe



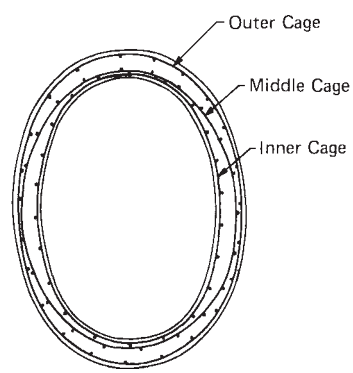
NOTE 1—The total reinforcement area (Asi) of the inner cage plus the quadrant mat in Quadrants 1 and 2 shall not be less than that specified for the inner cage in Table 2.

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 Table 2.

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 Table 2.

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 Table 2.

FIG. 3 Quadrant Reinforcement, Vertical Elliptical Pipe



NOTE 1—The total reinforcement area of the inner cage plus the middle cage shall not be less than that specified for the inner cage in Table 2.

NOTE 2—The total reinforcement area of the outer cage plus the middle cage shall not be less than that specified for the outer cage in Table 2.

FIG. 4 Vertical Elliptical Pipe

special designs for pipe sizes that do not have steel reinforcement areas shown in Table 1 and Table 2.

7.3.2 Such modified and special designs shall be based on rational or empirical evaluations of the ultimate strength and cracking behavior of pipe and shall fully describe to the owner any deviations from the requirements of this section. 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.

7.3.3 The manufacturer shall submit to the owner proof of the adequacy of the proposed modified and 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.

7.3.4 Such pipe shall meet all of the test and performance

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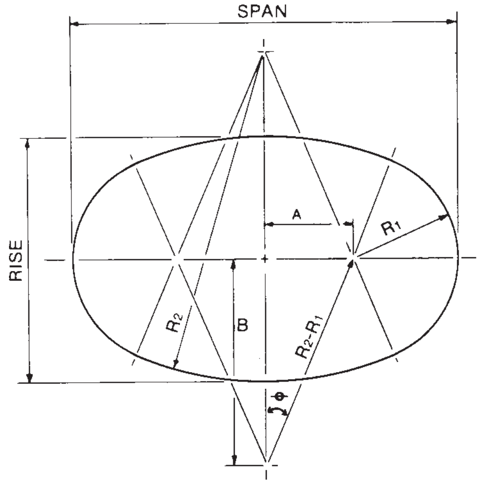

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Approximate Equivalent Round Size, in. K	Full Flow Water Area, ft^3	Rise, in.	Span, in.	*A*, in.	*B*, in.	R_1, in.	R_2, in.	θ Degrees
18	1.83	14¼	22¾	5⅜	12⅞	6	20	22.6
24	3.28	19¼	30¼	6⅞	16⅝	8¼	26¼	22.6
27	4.12	21½	34	7¾	18½	9¼	29¼	22.6
30	5.10	24	37¾	8⅝	20¾	10¼	32¾	22.6
33	6.33	26¾	42	9½	22⅞	11½	36¼	22.6
36	7.36	28¾	45½	10½	24⅞	12¼	39¼	22.6
39	8.78	31½	49½	11¼	27	13½	42¾	22.6
42	10.2	34	53¼	12⅛	29	14½	46	22.6
48	12.9	38¼	60	13½	32⅜	16½	51½	22.6
54	16.7	43½	68	15¼	36¾	18¾	58½	22.6
60	20.5	48¼	75½	17	40⅞	20¾	65	22.6
66	24.8	53	83	18¾	45	22¾	71½	22.6
72	29.4	57¾	90½	20½	49⅛	24¾	78	22.6
78	34.6	62¾	98	22	53⅛	27	84½	22.6
84	40.1	67½	105½	23¾	57	29	90¾	22.6
90	46.1	72½	113	25½	61	31	97¼	22.6
96	52.4	77¼	120½	27	65⅛	33¼	103¾	22.6
102	59.1	82	128	28¾	69	35¼	110	22.6
108	66.4	87	135½	30¼	72¾	37½	116¼	22.6
114	73.9	91¾	143	32	76⅞	39½	122¾	22.6
120	82.1	96¾	150¾	33⅞	80⅞	41½	129¼	22.7
132	99.2	106½	165½	37	88¾	45¾	142	22.6
144	118	116	180¾	40⅜	96¾	50	154¾	22.6

NOTE 1—Rise, span, and radii are fixed; other dimensions and angles are calculated.

FIG. 5 Cross-Sectional Shape of Elliptical Pipe

requirements specified by the owner in accordance with Section 5.

7.4 *Area*—In this specification, when the word area is not described by adjectives, such as cross-sectional 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 reinforcement is used, it shall be placed so that the cover of the concrete over the circumferential reinforcement at the vertical and horizontal diameters of the pipe is 1 in. from the inside and outside surfaces of the pipe, except 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 Where two lines of reinforcement of elliptical shape corresponding to the contour of the pipe are used, each line shall be so placed that the covering of concrete over the reinforcement is 1 in.

8.1.3 The location of the reinforcement shall be subject to the permissible variations in dimensions given in 11.5. Requirements for placement and protective covering of the

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concrete from the inner or outer surface of the pipe do not apply to that portion of a cage which is flared so as to extend into the bell or reduced in diameter so as to extend into the spigot.

8.1.4 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.

8.1.5 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.

8.1.6 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.

8.1.6.1 When splices are welded and are not lapped to the minimum requirements in 8.1.6, 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.

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 rigidly 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*—In all pipe 36 in. or larger in diameter, either the bell or the spigot of the joint shall contain circumferential reinforcement.

8.3.1 For single-cage pipe, joint reinforcement shall be at least equal in area to that required for an equivalent length of pipe wall.

8.3.2 For double-cage and triple-cage pipe, joint reinforcement shall be at least equal in area to that required for an equivalent length of the outer circular cage if placed in the bell, or at least equal in area to that required for an equivalent length of the inner circular cage if placed in the spigot.

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 from 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 10.2.1-10.2.4, providing 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, 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 the pipe delivered.

11.3 *External Load Crushing Strength*:

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11.3.1 The load required to produce a 0.01-in. crack or the ultimate load as determined by the three-edge-bearing method described in Test Methods C 497 shall be not less than that prescribed in Table 1 and Table 2 for each respective class of pipe. 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.

NOTE 2—As used in this specification, the 0.01-in. crack is a test criterion for pipe tested in a 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 Test Method A or 8.5 % for Test Method B. Each Test 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 Dimensions*—The internal dimensions of the elliptical pipe shall not vary more than ± 2 % from the internal dimensions shown in Fig. 5. The variation shall normally be determined by measuring the major and minor axes of the pipe. Where measurements at other points are necessary, the lengths so measured shall not depart from those shown in Fig. 5 by more than ± 2 %.

12.2 *Wall Thickness*—The wall thickness shall not vary more than shown in the design or specified wall by more than

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± 5 % or 3⁄16 in., whichever is greater. A specified wall thickness that is 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. internal diameter, with a maximum of ¼ in. for all sizes through 24-in. internal equivalent diameter, and not more than ⅛ in./ft of internal equivalent diameter for all sizes larger with a maximum of ⅝ in. in any length of pipe through 84-in. internal equivalent diameter, and a maximum of ¾ in. for 90-in. internal equivalent 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 be not more than ⅛ in./ft with a maximum of ½ in. in any length of pipe.

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 or ±½ in., whichever is the greater. Pipe having variations in the position of 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 ½ in. The preceding minimum cover limitation does not apply to the mating surfaces 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 7.2 or 7.3. Actual area of the reinforcing used may vary from the nominal area according to permissible variations of the standard specifications for the reinforcing.

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 the following:

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

15.1.2 Defects that indicate 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, and

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. Product Marking

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

16.1.1 Pipe class and specification designation,

16.1.2 Date of manufacture,

16.1.3 Name or trademark of the manufacturer, and

16.1.4 Identification of plant.

16.2 Pipe with quadrant reinforcement shall be marked with the letter "Q."

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

17. Keywords

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

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