



Designation: C 655 – 02

Standard Specification for Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe¹

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 Reinforcement²
- A 185 Specification for Steel Welded Wire Reinforcement, Plain, for Concrete²
- A 496 Specification for Steel Wire, Deformed, for Concrete Reinforcement²
- A 497 Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete²
- A 615/A 615M Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement²
- C 33 Specification for Concrete Aggregates³
- C 150 Specification for Portland Cement⁴

- C 497 Test Methods for Concrete Pipe, Manhole Sections, or Tile⁵
- C 595 Specification for Blended Hydraulic Cements⁴
- C 618 Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete³
- C 822 Terminology Relating to Concrete Pipe and Related Products⁵
- C 989 Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars³
- C 1116 Specification for Fiber-Reinforced Concrete and Shotcrete³
- E 105 Practice for Probability Sampling of Materials⁶

3. Terminology

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

4. Basis of Acceptance

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

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

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

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

4.2 *Age for Acceptance*—Pipe shall be considered ready for 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.

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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.

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 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.

6.2 *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/yd³ 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 2½ in. or greater, and ¾ in. for wall thicknesses less than 2½ in., 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 $\pm 1.5\%$ from the design diameter. The internal diameter of 27 to 144-in. pipe shall vary not more than $\pm 1\%$ or $\frac{3}{8}$ 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 $\pm 10\%$ of the wall thickness or $\pm \frac{5}{8}$ 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 $\frac{5}{8}$ 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 $\frac{1}{4}$ in. for all sizes through 24-in. internal diameter, and not more than $\frac{1}{8}$ in./ft of internal diameter for all larger sizes, with a maximum of $\frac{5}{8}$ in. in any pipe through 84-in. internal diameter, and a maximum of $\frac{3}{4}$ 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 $\frac{1}{8}$ in./ft with a maximum of $\frac{1}{2}$ 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 $\frac{3}{16}$ 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 and to ultimate strength and the results recorded. Compute the values

in 9.1.1 and 9.1.2 for both the 0.01-in. crack and the ultimate strength.

9.1.1 Compute the estimated standard deviation, s , by Eq 1 or Eq 2, which equations yield identical values.

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

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

where:

X_i = observed value of the load to produce the 0.01-in. crack (and the load to develop the ultimate strength),

\bar{X} = average (arithmetic mean) of the values of X_i , and

n = number of observed values.

9.1.2 Compute the minimum allowable arithmetic mean, X_s , by Eq 3. In Eq 3, the value of the estimated standard deviation, s , shall be as calculated by Eq 1 or Eq 2 or equal to $0.07L$, whichever is greater.

$$X_s = L + 1.07 s \quad (3)$$

where:

L = specification limit (specified D-load).

9.1.3 The pipe design shall be acceptable if the arithmetic mean \bar{X} for the 0.01-in. crack and ultimate strength is equal to or greater than the computed values of X_s , and if all the tested specimens meet or exceed the specification limit.

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

10. Acceptance of Pipe by Load Testing

10.1 Lot Sampling—When the acceptance is to be in accordance with 4.1.1, randomly select from the lot a sample of the size listed in Table 2 and test each specimen to the 0.01-in. crack. When all specimen test strengths are greater than the minimum design strength D-load, the lot shall be accepted. When one or more specimen test strengths are less than the minimum design strength D-load, the values for \bar{X} and s shall be computed and substituted into the applicable equation given in Table 2. When the arithmetic mean \bar{X} is equal to or greater than the computed value of X_s , the lot of pipe shall be acceptable. When the arithmetic mean \bar{X} is less than the computed value of X_s , the lot of pipe shall be rejected for that design strength D-load strength.

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.

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)

10.3 *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 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. 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 the 0.01-in. crack D-load designated in 5.1.2 followed by the

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 be installed with a particular axis of orientation shall be clearly marked during the process of manufacturing or immediately thereafter on the inside and outside of opposite walls on the vertical axis or shall be designated by location of lift holes.

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

18. Keywords

18.1 concrete pipe—reinforced; culvert; D load; sewer pipe; 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 \bar{X} and s must be computed (see Note X1.1):

\bar{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 size of the numbers so they can be computed more readily on a desk calculator.

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
$\Sigma X_i = 2090$	$\Sigma X_i^2 = 887\,450$

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

$$= 4\,368\,100 \quad (\text{X1.3})$$

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

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

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

X1.8 The standard deviation, s , shall be computed by either Eq 1 or Eq 2. Since Eq 2 is a simpler form for computation, this 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:

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

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

The required minimum allowable arithmetic mean \bar{X}_s is computed by Eq X1.3:

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

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

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

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

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.

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