Designation: C 655M – 04ε1

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

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

ε[1] NOTE—Editorial changes were made throughout in March 2005.

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 This specification is the metric counterpart of Specification C 655.

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:*[2]

A 82 Specification for Steel Wire, Plain, for Concrete Reinforcement

A 185 Specification for Steel Welded Wire Reinforcement, Plain, for Concrete

A 496 Specification for Steel Wire, Deformed, for Concrete Reinforcement

A 497 Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete

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

C 33 Specification for Concrete Aggregates

C 150 Specification for Portland Cement

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

C 595 Specification for Blended Hydraulic Cements

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

C 822 Terminology Relating to Concrete Pipe and Related Products

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

C 1116 Specification for Fiber-Reinforced Concrete and Shotcrete

E 105 Practice for Probability Sampling of Materials

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.

[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] 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.

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

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 27.6 MPa.

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 concrete shall be one of the following:

(1) Portland cement only,

(2) Portland blast furnace slag cement only,

(3) Slag modified Portland cement only,

(4) Portland pozzolan cement only,

(5) A combination of Portland cement and fly ash, or

(6) A combination of Portland cement and ground granulated blast-furnace slag

(7) A combination of Portland cement, ground granulated blast furnace slag (not to exceed 25% of the total cementitious weight), and fly ash (not to exceed 25% of the total cementitious weight).

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 300 steel conforming to Specifications 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 280 kg/m^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 25 mm for wall thicknesses of 63 mm or greater, and 19 mm for wall thicknesses less than 63 mm, 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 100 mm for pipe with a wall thickness up to and including 100 mm and shall not exceed the wall thickness or 150 mm, 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 0.3-mm crack when tested in accordance with Test Methods C 497M. 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 100 N/m·mm of diameter, a factor varying in linear proportion from 1.5 to 1.25 for design strength designations from 100 N/m·mm through 150 N/m·mm, and a factor of 1.25 for design strength designations in excess of 150 N/m·mm.

NOTE 3—As used in this specification, the 0.3-mm 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 497M. 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 3600 mm 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*—Permissible variations in the internal diameter are as prescribed in Table 2.

8.2.2 *Reinforcement Placement Tolerances*—The maximum variation in the nominal position of the reinforcement shall be ±10 % of the wall thickness or 16 mm, 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 16 mm.

8.2.3 *Length of Two Opposite Sides*—Variations in the laying length of two opposite sides of pipe shall not be more than 6 mm for all sizes through 600 mm internal diameter, and not more than 10 mm/m of internal diameter for all larger sizes, with a maximum of 16 mm in any pipe through 2100 mm internal diameter, and a maximum of 19 mm for 2250 mm 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 10 mm/m with a maximum of 13 mm 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 5.1.3.1 by more than 5 % or 5 mm, 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.

TABLE 1 Standard Designated Inside Diameter, mm

300	600	900	1500	2100	2700	3300
375	675	1050	1650	2250	2850	3450
450	750	1200	1800	2400	3000	3600
525	825	1350	1950	2550	3150	

TABLE 2 Permissible Variation in Internal Diameter

Designated Diameter of Pipe, mm	Permissible Variation, Internal Diameter of Pipe	
	Minimum, mm	Maximum, mm
300	300	310
375	375	390
450	450	465
525	525	545
600	600	620
675	675	695
750	750	775
825	825	850
900	900	925
1050	1050	1080
1200	1200	1230
1350	1350	1385
1500	1500	1540
1650	1650	1695
1800	1800	1850
1950	1950	2000
2100	2100	2155
2250	2250	2310
2400	2400	2465
2550	2550	2620
2700	2700	2770
2850	2850	2925
3000	3000	3080
3150	3150	3235
3300	3300	3390
3450	3450	3540
3600	3600	3695

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 0.3-mm crack and to ultimate strength and the results recorded. Compute the values in 9.1.1 and 9.1.2 for both the 0.3-mm 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.

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

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

where:

X_i = observed value of the load to produce the 0.3-mm 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, $\bar{X}_s$, 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.

$$\bar{X}_s = L + 1.07\,s \quad (3)$$

where:

L = specification limit (specified D-load).

9.1.3 The pipe design shall be acceptable if the arithmetic mean $\bar{X}$ for the 0.03-mm crack and ultimate strength is equal to or greater than the computed values of $\bar{X}_s$, 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 3 and test each specimen to the design strength. 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 of $\bar{X}$ and s shall be computed and substituted into the applicable equation given in Table 3. When the arithmetic mean $\bar{X}$ is equal to or greater than the computed value of $\bar{X}_s$, the lot of pipe shall be acceptable. When the arithmetic mean $\bar{X}$ is less than the computed value of $\bar{X}_s$, 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 10 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 0.3-mm Crack*—Pipe that have been tested only to the formation of the 0.3-mm 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 497M.

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.

TABLE 3 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)

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 and prepared in accordance with the Core Strength Test Method of Test Methods C 497M.

11.3.2 *Number of Cores*—Three cores shall be taken from a pipe section 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 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 to 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 pipe 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 0.3-mm 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 1350 mm designated inside diameter pipe will be determined in accordance with 4.1.1. The design strength (0.3-mm crack) D-load is specified as 62 N/linear metre per millimetre of inside designated diameter (62 D pipe).

X1.2 From the lot, randomly select a sample of five specimens ($n = 5$) each 1.8 m long as shown in Table 2.

X1.3 Test the pipe and record the observed values of X_i in kilonewtons which produce the 0.3-mm crack: 213.51, 144.57, 191.27, 200.17, and 180.15.

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

$$L = 62 \times 1350 \times 1.8 = 150.66 \text{ kN} \quad \text{(X1.1)}$$

X1.5 Since an observed value of the test loads ($X_i = 144.57$) is less than the specification limit ($L = 150.66$), 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:

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

s = estimated standard deviation.

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

X_i	X_i^2
213.51	45 586.52

144.57	20 900.48
191.27	36 584.21
200.17	40 068.03
180.15	32 454.02
$\Sigma X_i = 929.67$	$\Sigma X_i^2 = 175\ 593.26$

$$(\Sigma X_i)^2 = (929.67)^2 \quad \text{(X1.2)}$$

$$= 864\ 286.31$$

$$\bar{X} = (\Sigma X_i (/n \quad \text{(X1.3)}$$

$$\bar{X} = (929.67/5)$$

$$\bar{X} = 185.93\ kN$$

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.

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

$$s = \sqrt{(175\ 593.26 - 864\ 286.31/5)/(5-1)}$$

$$s = \sqrt{684.0}$$

$$s = 26.15\ kN$$

X1.9 The required minimum allowable arithmetic mean $\bar{X}_s$ is computed by Eq X1.3:

$$\bar{X}_s = L + 1.10\,s \quad \text{(X1.5)}$$

$$\bar{X}_s = 150.66 + 1.10 \times 26.15$$

$$\bar{X}_s = 179.43\ \text{kN}$$

Since the actual $\bar{X}$ of 185.93 kN is greater than the required minimum allowable $\bar{X}_s$ of 179.43 kN, the lot of pipe is acceptable.

X1.10 *ASTM STP 15 D*[3] is a valuable source of information regarding statistical procedures and simplified computational methods.

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