Designation: C 361 – 05

Standard Specification for Reinforced Concrete Low-Head Pressure Pipe[1]

This standard is issued under the fixed designation C 361; 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 construction of pressure pipelines with low internal hydrostatic heads generally not exceeding 125 ft.

1.2 A complete metric companion to Specification C 361 has been developed—C 361M; therefore, no metric equivalents are presented in this specification.

NOTE 1—Field tests on completed portions of the pipeline are not covered by this specification for the manufacture of the pipe but should be included in specifications for pipe laying.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 27/A 27M Specification for Steel Castings, Carbon, for General Application
A 36/A 36M Specification for Carbon Structural Steel
A 82/A 82M Specification for Steel Wire, Plain, for Concrete Reinforcement
A 185/A 185M Specification for Steel Welded Wire Reinforcement, Plain, for Concrete
A 283/A 283M Specification for Low and Intermediate Tensile Strength Carbon Steel Plates
A 496/A 496M Specification for Steel Wire, Deformed, for Concrete Reinforcement
A 497/A 497M Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete
A 570/A 570M Specification for Steel, Sheet and Strip, Carbon, Hot-Rolled[3]
A 575 Specification for Steel Bars, Carbon, Merchant Quality, M-Grades
A 576 Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality
A 611 Specification for Structural Steel, Sheet, Carbon, Cold-Rolled[3]
A 615/A 615M Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
A 675/A 675M Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties
C 31/C 31M Practice for Making and Curing Concrete Test Specimens in the Field
C 33 Specification for Concrete Aggregates
C 39/C 39M Test Method for Compressive Strength of Cylindrical Concrete Specimens
C 150 Specification for Portland Cement
C 260 Specification for Air-Entraining Admixtures for Concrete
C 309 Specification for Liquid Membrane-Forming Compounds for Curing Concrete
C 497 Test Methods for Concrete Pipe, Manhole Sections, or Tile
C 595 Specification for Blended Hydraulic Cements
C 618 Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
C 822 Terminology Relating to Concrete Pipe and Related Products
D 395 Test Methods for Rubber Property—Compression Set
D 412 Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension
D 471 Test Method for Rubber Property—Effect of Liquids
D 573 Test Method for Rubber—Deterioration in an Air Oven

[1] This specification is under the jurisdiction of ASTM Committee C13 on Concrete Pipe and is the direct responsibility of Subcommittee C13.04 on Low Head Pressure 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.

[3] Withdrawn.

D 698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3(600 kN-m/m^3))
D 1149 Test Method for Rubber Deterioration—Surface Ozone Cracking in a Chamber
D 2240 Test Method for Rubber Property—Durometer Hardness
D 4253 Test Method for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
D 4254 Test Method for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density

2.2 *Other Standards:*
ACI Code 318 Standard Building Code Requirements for Reinforced Concrete[4]
AISI-C 1012[5]

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 for hydrostatic heads of 25, 50, 75, 100, and 125 ft measured to the centerline of the pipe. Designs are provided in Table 1 for the above hydrostatic heads combined with external loadings of 5, 10, 15, and 20 ft (designated *A*, *B*, *C*, and *D* in Table 1) of earth cover over the top of the pipe under specific installation conditions. The specific installation conditions are covered in Appendix X1. Where the hydrostatic head, external loadings, and installation conditions vary from those given in Table 1 and Appendix X1, detailed design calculations shall be made. The design criteria for Table 1 are presented in Appendix X2.

5. Basis of Acceptance

5.1 Acceptability of the pipe in all diameters and classes shall be determined by the results of such material tests as are required in 6.2 through 6.9 by crushing tests on cured concrete cylinders, by hydrostatic pressure tests on units of the pipe, by joint leakage tests, and by inspection during or after manufacture to determine whether the pipe conforms to this specification as to design and freedom from defects.

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 *Reinforced Concrete*—The reinforced concrete shall consist of portland cement, mineral aggregates, and water, in which steel has been embedded in such a manner that the steel and concrete act together. Fly ash or pozzolan is not prohibited when used as a partial cement replacement; see 9.1.

6.2 *Cementitious Materials*:

6.2.1 *Cement*:

6.2.1.1 *Portland Cement*—Portland cement shall conform to the requirements of Specification C 150.

6.2.1.2 *Blended Cement*—Blended cement shall conform to the requirements of Specification C 595 for Type IS portland blast furnace slag cement or Type IP portland pozzolan cement, except that the pozzolan constituent in the Type IP portland pozzolan cement shall not exceed 20 % by weight.

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

6.2.3 *Allowable 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, or

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 or pozzolan is between 5 and 20 % by weight of total cementitious material (portland cement plus fly ash or pozzolan).

6.3 *Aggregates*—Aggregates shall conform to Specification C 33, except that the requirements for grading are waived.

6.4 *Admixtures*—Admixtures, except for air-entraining agents, shall not be added to the concrete unless permitted by the owner. At the option of the manufacturer, or if specified by the owner, the concrete in precast concrete pipe placed by the cast-and-vibrated method shall contain an air-entraining agent conforming to Specification C 260. The amount of air-entraining agent used shall be such as will affect the entrainment of not more than 3 % air by volume of concrete as discharged from the mixer.

6.5 *Steel Reinforcement*—Reinforcement shall consist of wire conforming to Specification A 82, 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 *Steel for Joint Rings*:

6.6.1 Steel strips for bell rings less than ¼ in. thick shall conform to Grade 30 of Specification A 570/A 570M or Grade Designation 1012 of Specification A 575. Steel that meets the requirements of AISI-C1012 for chemical components will be acceptable provided it conforms to Grade 30 of Specification A 570/A 570M in other respects.

6.6.2 Steel plate for bell rings ¼ in. or more in thickness and special shapes for spigot joint rings shall conform to Specification A 36/A 36M, or to Grade A of Specification A 283/A 283M, or to Grade Designation 1012 of Specification A 576, or to Grade 50 of Specification A 675/A 675M. Steel that meets the requirements of AISI-C1012 for chemical components will be acceptable provided it conforms to Specification A 36/A 36M or to Specification A 283/A 283Min other respects.

6.7 *Steel Castings for Fittings*—Steel castings for fittings shall conform to Grade 70-36, Normalized, of Specification A 27/A 27M.

6.8 *Steel Plates and Sheets for Specials and Fittings*—Steel plates for specials and fittings shall conform to Specification A 36/A 36M or to Grade B or C of Specification

[4] Available from the American Concrete Institute, 38800 Country Club Dr., Farmington Hills, MI 48331.

[5] Available from American Iron and Steel Institute, 1140 Connecticut Ave., Suite 705, Washington D.C. 20036.

A 283/A 283M or Grade 30 or 33 of Specification A 570/A 570M or Grade B of Specification A 611.

6.9 *Rubber Gaskets*:

6.9.1 *Composition and Properties*—All rubber gaskets shall be extruded or molded and cured in such a manner that any cross section will be dense, homogeneous, and free of porosity, blisters, pitting, and other imperfections. The gaskets shall be of a solid circular cross section and shall be extruded or molded to the specified size within a diametrical tolerance of $\pm 1/64$ in. or ±1.5 % of the diameter, whichever is larger. The basic polymer shall be natural rubber, synthetic rubber, or a blend of both. The properties enumerated below shall be determined in accordance with 10.5.

6.9.1.1 *Standard Gasket Requirements*—The compound shall meet the following for physical requirements (see also Test Methods D 412):

Tensile strength, min, psi	2300
Elongation at break, min, %	425
Shore durometer hardness, nominal:	
Min	40[A]
Max	60[A]
Compression set, max, % of original deflection	20
Accelerated aging, max, % of original	
Decrease in tensile strength	15
Decrease in elongation	20
Liquid immersion, max, % weight increase	
Water absorption	5
Ozone resistance	no visible cracking in accordance with Test Method D 1149

[A] Allowable variation ±5 from manufacturers' specified nominal hardness.

6.9.1.2 *Oil Resistant Gasket Requirements*— The compound shall contain not less than 50 % by volume oil resistant polymer and shall meet the following physical requirements:

Tensile strength, min, psi	1500
Elongation at break, min, %	350
Shore durometer hardness, nominal:	
Min	40[A]
Max	60[A]
Durometer aging, max, increase	15
Compression set, max, % of original deflection	20
Accelerated aging, max, % of original	
Decrease in tensile strength	20
Decrease in elongation	40
Liquid immersion, max, % volume change:	
Oil, in ASTM #3 (70 h at 212°F)	80
Water absorption	15
Ozone resistance, 72 h exposure in 50 PPHM ozone concentration at 104°F	no visible cracking in accordance with Test Method D 1149

[A] Allowable variation ±5 from manufacturers specified nominal hardness.

6.9.1.3 *Durometer Hardness*—The shore durometer hardness shall be in the range of from 35 to 50 for concrete spigots and 35 to 65 for steel spigots where the range includes the allowable variation as given in 6.9.1.1 and 6.9.1.2.

6.9.2 *Storage*—All rubber shall be stored in as cool a place as practicable, preferably at 70°F or less, and in no case shall the rubber for joints be exposed to the direct rays of the sun for more than 72 h.

6.10 *Gasket Lubricants*:

6.10.1 Where the joint design utilizing a rubber gasket dictates the use of a lubricant to facilitate assembly, the lubricant composition shall have no detrimental effect on the performance of the gasket and joint due to prolonged exposure.

6.10.2 *Storage*—The lubricant shall be stored in accordance with the lubricant manufacturer's recommended temperature range.

6.10.3 *Certification*—When requested by the owner, the manufacturer shall furnish written certification that the joint lubricant conforms to all requirements of this specification for the specific gaskets supplied.

6.10.4 *Marking*—The following information shall be clearly marked on each container of lubricant.

6.10.4.1 Name of lubricant manufacturer.

6.10.4.2 Usable temperature range for application and storage.

6.10.4.3 Shelf life.

6.10.4.4 Lot or batch number.

7. Design

7.1 *Design Tables*—The diameter, wall thickness, compressive strength of the concrete, and the area of circumferential reinforcement shall be as prescribed for the classes of combined hydrostatic head and external loading given in Table 1 subject to the provisions of 7.2, 7.4, 7.5, 10.3, 11.1, 11.2, and 11.5.

7.2 *Modified and Special Design*—Manufacturers shall submit to the owner, for approval prior to manufacture, detailed designs for loading or installation conditions other than those shown in Table 1. Such pipe must meet all of the tests and performance requirements specified by the owner in accordance with Section 5.

7.3 *Laying Lengths*—The maximum laying lengths of pipe units that will be acceptable are as follows and are subject to the provisions of 11.4:

Internal Diameter of Pipe, in.	Maximum Laying Length of Pipe, ft
12 to 15	12
18	14
21 to 24	16
27 to 30	18
33 to 36	20
39 and larger	24

7.4 *Placement of Reinforcement*—The circumferential reinforcement shall be a single-cage circular, double-cage circular, or elliptical cage as shown in Table 1. Elliptical reinforcement will be permitted for 25 and 50-ft head classes only and only in pipe 18 to 72 in. in diameter, inclusive. All pipe with a wall thickness of less than 3¼ in. shall be reinforced with either a circular cage or a single elliptical cage of steel as provided in Table 1. All pipe with wall thickness of 3¼ in. and greater shall be reinforced with either two separate cages or a single elliptical cage of steel as provided in Table 1, except that for pipe sizes 36 in. and less with wall thicknesses equal to or greater than 3¼ in., a single circular cage is not prohibited if the steel area is equal to or greater than the least area shown for a single circular cage for that particular class of pipe. The areas of circumferential reinforcement shown in Table 1 are the design requirements for each of the wall thicknesses shown in the table. Where single-cage circular reinforcement is used, the center-line of the reinforcement shall be placed from 40 to 50 % of the wall thickness from the inner surface of the pipe, provided that the minimum concrete cover specified below shall be maintained. Where two separated circular cages of reinforcement are used, the inner and outer cages shall be placed so that the concrete cover, measured radially, over the circumferential reinforcement will be as follows:

Pipe Diameter, in.	Minimum Cover, in.	Maximum Cover, in.
45 and less	¾	1
48 through 60	¾	1⅛
63 through 69	¾	1¼
72 through 108	1	1½

7.4.1 These limits on minimum and maximum cover are applicable to elliptical steel at the horizontal and vertical axes of the pipe. The circumferential reinforcement at each end of the pipe unit shall consist of one complete coil or ring in which the end is lapped or welded as prescribed in 7.6. The clear distance of the end coil or ring shall not be less than ½ in. or more than 1 in. from the end of the pipe unit, except this requirement does not apply to the inner layer of circumferential reinforcement in joints utilizing steel bell and spigot rings, provided that the clear distance restrictions will not apply for a distance of 20 bar diameters measured circumferentially from the end of the lap or weld.

7.4.2 A cage of circumferential reinforcement with Table 1 areas greater than 0.45 in.^{2}/linear ft of pipe shall be composed of one or two layers of reinforcement, and cage areas greater than 0.90 in.^{2}/linear ft of pipe shall be composed of one, two, or three layers. The layers shall not be separated by more than the thickness of one longitudinal plus ¼ in. The layers shall be fastened together to form a single rigid cage. Where inner and outer cages are used, the minimum clear spacing between the two cage systems shall be 0.25 times the wall thickness. All other specification requirements such as laps, welds, concrete cover, and tolerances of placement in the wall of the pipe, etc., shall apply to this method for fabrication of a cage of reinforcement.

7.5 *Longitudinal Reinforcement*—Each layer of circumferential reinforcement shall be assembled into a rigid cage supported by longitudinal bars that extend the full length of the pipe. The minimum concrete cover for longitudinal steel shall be ½ in. except that the longitudinal bars or rods are not prohibited from extending to either or both ends of the pipe unit to form supports for holding the circumferential cage in proper position. Not less than four longitudinal bars at approximately equal spacing shall be provided for each cage, and additional bars shall be provided as necessary so that the circumferential spacing between longitudinal bars shall not exceed 42 in. in any cage. Where the pipe joint construction requires the use of a bell, the minimum number of longitudinal bars shall be provided in the bell and shall be continuous bars or spliced to the main longitudinal bars. The circumferential bars of each cage shall be spaced and supported by welding or tying each hoop to the longitudinal bars. Spacer bars, chairs, or other methods shall be provided to maintain the reinforcement cage or cages in proper position within the forms during the placement and consolidation of the concrete. The spacer bars or chairs are not prohibited from extending to the finished concrete surfaces of the pipe.

7.6 *Laps, Welds, and Spacing*—If the 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. Lapped or butt welded splices shall develop a tensile strength of not less than 40 000 psi based on the nominal cross-sectional area of the bar or wire. Lapped welds shall have a minimum lap of 2 in. The spacing center-to-center of adjacent rings of circumferential reinforcement in a cage shall not exceed 4 in. The continuity of the circumferential reinforcing steel shall not be destroyed during the manufacture of the pipe.

8. Joints

8.1 Joints shall utilize steel joint rings, steel bells and concrete spigots, or be formed entirely of concrete. Joint assemblies shall be so formed and accurately manufactured that when the pipes are drawn together the pipe shall form a continuous watertight conduit with a smooth and uniform interior surface and shall provide for slight movements of any pipe unit in the pipeline due to expansion, contraction, settlement, or lateral displacement. The rubber gasket shall be the sole element of the joint depended upon to provide watertightness. The joint shall be so designed that the gaskets will not be required to support the weight of the pipe, but will keep the joint tight under all normal conditions of service. The ends of the pipe shall be in planes at right angles to the longitudinal centerline of the pipe, except where bevel-end pipe for deflections up to 5° is specified or indicated for bends.

8.2 Joints utilizing collars instead of bells cast as an integral part with the pipe barrel shall comply with the requirements for bell-and-spigot joints given in 8.4.1 through 8.4.8. The collar shall be flared at each end to facilitate entrance of the gasket when closing the joint. The straight section between the flares at either end shall be a true cylinder of such length that at the position of normal joint closure, the parallel surfaces upon which the gasket bears during closure will extend not less than ¾ in. away from the edges of the gasket. Each end of the pipe shall have a groove formed on its outer surface of suitable dimensions to contain a circular rubber gasket.

8.3 Joints utilizing steel bell-and-spigot rings shall comply with the requirements for bell-and-spigot joints given in 8.4.1, 8.4.3, and 8.4.5. The bell ring shall have a minimum thickness of 3/16 in. and width sufficient to provide for adequate embedment in the pipe. It shall be flared at one end and is not prohibited from being tapered at the other end. The remainder of the bell ring shall be a true cylinder of such length that at the position of normal joint closure, the parallel surface upon which the gasket bears during the closure will extend not less than 1 in. away from the edge of the gasket. The spigot ring shall be formed from a specially shaped section of steel with a groove of suitable dimensions to contain a circular rubber gasket. The difference in circumference of the inside of the bell ring and the outside of the spigot ring shall not exceed 3/16 in. for gaskets of 21/32-in. diameter or less, and ¼ in. for gaskets greater than 21/32-in. diameter.

8.4 In pipe utilizing bell-and-spigot joints, the joint shall be designed and manufactured so that the spigot and gasket will readily enter the bell of the pipe. In all-concrete joints the manufacturer shall provide sufficient reinforcement in the bell to resist the hydrostatic, hydrodynamic, and gasket pressures.

The shape and dimensions of the joint shall be such as to provide the minimum requirements given in 8.4.1 through 8.4.8.

8.4.1 For design pressures greater than 25 feet-head, the rubber gaskets shall be solid gaskets of circular cross section. For design pressures greater than or equal to 25 feet-head, the gaskets shall be solid gaskets of circular or non-circular cross section. All gaskets shall be confined in an annular space formed by shoulders on the bell and spigot or in a groove in the spigot of the pipe so that movement of the pipe or hydrostatic and hydrodynamic pressure cannot displace the gasket. When the joint is assembled, the gasket shall be compressed to form a watertight seal.

8.4.2 In joints that utilize spigot grooves, the volume of the annular space provided for the gasket, with the engaged joint at normal joint closure in concentric position, and neglecting ellipticity of the bell and spigot, shall be not less than the design volume of the gasket furnished. The cross-sectional area of the annular space shall be calculated for minimum bell diameter, maximum spigot diameter, minimum width of groove at surface of spigot, and minimum depth of groove. The volume of the annular space shall be calculated considering the centroid of the cross-sectional area to be at the midpoint between the inside bell surface and the surface of the groove on which the gasket is seated at the centerline of the groove.

8.4.3 In joints that utilize spigot grooves, if the average volume of the gasket furnished is less than 75 % of the volume of the annular space in which the gasket is to be contained with the engaged joint at normal joint closure in concentric position, the gasket shall not be stretched more than 20 % of its unstretched length when seated on the spigot or not more than 30 % if the design volume of the gasket is 75 % or more of the volume of the annular space. For determining the volume of the annular space, the cross-sectional area of the annular space shall be calculated for average bell diameter, average spigot diameter, average width of groove at surface of spigot, and average depth of groove. The volume of the annular space shall be calculated considering the centroid of the cross-sectional area to be at the midpoint between the inside bell surface and the surface of the groove on which the gasket is seated at the centerline of the groove. It is further specified that when the design volume of the gasket is less than 75 % of the volume of the annular space, as calculated above, the gasket shall be of such diameter that when the outer surface of the spigot and the inner surface of the bell come into contact at some point in their periphery, the deformation in the gasket shall not exceed 50 % at the point of contact nor be less than 15 % at any point. If the design volume of the gasket is 75 % or more of the volume of the annular space, the deformation of the gasket, as prescribed above, shall not exceed 50 % nor be less than 15 %. When determining the maximum percent deformation of the gasket, the maximum groove width, the minimum depth of groove, and the stretched gasket diameter shall be used and calculations made at the centerline of the groove. When determining the minimum percent deformation of the gasket, the minimum groove width, the maximum bell diameter, the minimum spigot diameter, the maximum depth of groove, and the stretched gasket diameter shall be used and calculations made at the centerline of the groove. For gasket deformation calculations, stretched gasket diameter shall be determined as being the design diameter of the gasket divided by the square root of $(1 + x)$ where x equals the design percent of gasket stretch divided by 100.

8.4.4 In joints that utilize shoulders on the bell and spigot to confine the gasket, the gasket shall not be stretched more than 20 % of its unstretched length when seated on the spigot. It is further specified that the gasket shall be of such diameter that when the outer surface of the spigot and the inner surface of the bell come into contact at some point in their periphery, the deformation in the gasket shall not exceed 50 % at the point of contact nor be less than 15 % at any point. When determining the maximum percent deformation of the gasket, the minimum depth of shoulders and the stretched gasket diameter shall be used. When determining the minimum percent deformation of the gasket, the maximum depth of shoulders, the maximum bell diameter, the minimum spigot diameter, and the stretched gasket diameter shall be used. For gasket deformation calculations, the stretched diameter shall be determined as described for joints that utilize spigot grooves.

8.4.5 Each gasket shall be manufactured to provide the volume of rubber required by the pipe manufacturer's joint design with a tolerance of ±3 % for gaskets up to and including ½ in. in diameter and ±1 % for gaskets of 1-in. diameter and larger. The allowable percentage tolerance shall vary linearly between ±3 % and ±1 % for gasket diameters between ½ and 1 in.

8.4.6 The tolerances permitted in the construction of the joint shall be those stated in the pipe manufacturer's design as approved.

8.4.7 The taper on all surfaces of the bells and spigots, on which the rubber gasket bears during closure of the joint and at any degree of partial closure, except within the gasket groove, shall form an angle of not more than 2° with the longitudinal axis of the pipe. The joint shall be so designed and manufactured that at the position of normal joint closure, the parallel surfaces upon which the gasket bears during closure will extend not less than ¾ in. away from the edges of the gasket.

8.4.8 The surfaces of the bell and spigot in contact with the gasket, and adjacent surfaces that come in contact with the gasket within a joint movement range, shall be free from airholes, chipped or spalled concrete, laitance, or other defects. The inside surface of the bell adjacent to the bell face shall be flared to facilitate joining the pipe sections without damaging or displacing the gasket.

8.5 *Alternative Joint Designs*—It is not prohibited for the manufacturer to submit to the owner, detailed designs for joints and gaskets other than those described in Section 8. Design submissions shall include joint geometry, tolerances, gasket characteristics, proposed plant tests, gasket splice bend tests, and such other information as required by the owner to evaluate the joint design for field performance. Joints and gaskets of alternate joint designs shall meet all test requirements of this specification and shall maintain at least 15 % deformation of the rubber gasket when out-of-roundness and off-center position of the joint is considered. Alternative joint designs shall be acceptable provided the designs are approved by the owner prior to manufacture and provided the test pipe comply with the specified tests.

9. Materials and Manufacture

9.1 *Concrete Mixture*—The aggregates shall be graded, proportioned, and thoroughly mixed in a batch mixer with the proportions of cementitious materials and water that will produce a workable, uniform, homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. Batching shall be accomplished by weighing. If the concrete materials are weighed accumulatively, the cementitious materials shall be weighed before the other ingredients. Cementitious materials shall be as specified in 6.2 and shall be added to the mix in a proportion not less than 564 lb/yd ^{3}.

9.1.1 *Placement of Concrete*—The transporting and placement of concrete shall be by methods that will prevent separation of the concrete materials and the displacement of the reinforcement steel from its proper position in the form.

9.2 *Curing of Pipe*—The method and extent of curing shall be established by testing not less than five cylinders cured in the same manner as the pipe until they have attained an average strength of 3600 psi. After a satisfactory curing method and period have been established, they shall not be changed without approval of the owner. If required by the owner, each day's run of pipe shall be cured until a companionate test cylinder cured in the same manner as the pipe has attained a strength of 3600 psi. Pipe shall be protected from temperatures below 40°F from the time the concrete is placed until the curing period is completed. Curing shall be by any method or combination of methods described below or by any other method approved by the owner.

9.2.1 *Steam Curing*—After the pipe has been cast, it shall be placed in an enclosure of such nature as to protect the pipe from outside drafts and to allow full circulation of saturated vapor around the inside and outside of the pipe. The rise in the ambient temperature shall not exceed 40°F in any 1 h; nor shall the ambient temperature exceed 100°F during the 2 h immediately following concrete placement. At no time shall the ambient temperature exceed 150°F. Following the periods of steam curing, the pipe shall be protected from rapid drops in temperature which are capable of injuring the pipe.

9.2.2 *Water Curing*—Concrete in pipe shall be water-cured by any method that will keep the pipe moist during the curing period.

9.2.3 *Membrane Curing*—The sealing compound used for membrane curing shall conform to the requirements of Specification C 309. The pipe surfaces shall be kept moist prior to application of the compound, and at the time of application the surfaces shall be moist and the temperature of the concrete shall be within 10°F of the atmospheric temperature. If the membrane is damaged, it shall be repaired immediately with additional compound.

10. Physical Properties

10.1 *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. Pipe units that satisfactorily pass the required tests shall be acceptable for use.

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

10.2.1 *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 in Section 5, of not more than three sections of pipe covering each size in which he is interested. The strength of concrete shall be determined from test cylinders made from the concrete used in making the pipe as provided in 10.3.

10.2.2 *Additional Tests for Extended Delivery Schedules*—After the preliminary tests described in 10.2.1 an owner shall be entitled to additional tests in such numbers and at such times as he may deem necessary, provided that the total number of pipe shall not exceed 1 % of each size and class of pipe manufactured in each test period, except that at least one hydrostatic and joint leakage test shall be made for each size and class.

10.2.3 *Length of Test Period*—For the purpose of testing the pipe units, the length of the test period will be set at the number of days the plant of the pipe manufacturer is normally operated in a calendar week. The test period will include any shutdown of the plant that does not exceed a 24-h period due to failure of the plant or equipment. The length of the test period shall be reduced, at the discretion of the owner if there is a significant change in the materials used in the pipe, in the mix proportions, or in the production procedures or by numerous shutdowns of the plant due to failures of the plant or equipment. The length of the test period shall be increased at the discretion of the owner when results of tests for successive periods indicate that the manufacturer's operations are productive of uniformly acceptable pipe.

10.3 *Concrete Strength*:

10.3.1 *Compressive Strength*—Compression tests for satisfying the design concrete strength shall be made on cured concrete cylinders. The concrete shall have a minimum crushing strength as specified in 10.3.3. Compression tests of such cylinders shall be made in accordance with Test Method C 39.

10.3.2 *Number of Compression Tests*—At least five standard test cylinders shall be prepared from each day's production of concrete. Test cylinders shall be prepared in conformance with Practice C 31, except it is not prohibited that cylinders be prepared by methods comparable to those used to consolidate and cure concrete in the actual pipe manufactured, or for concrete of a consistency too stiff for compaction by rodding or internal vibration, the alternative method described in the cylinder strength test method section of Test Methods C 497 shall be used.

10.3.3 *Compression Test Requirements*— The average 28-day compressive strength of all cylinders tested shall be equal to or greater than the design strength of the concrete. Not more than 10 % of the cylinders tested shall fall below the design strength. In no case shall any cylinder tested fall below 80 % of the specified design strength. These compressive strength requirements refer to standard 6 by 12-in. concrete test