Designation: C 361M – 99

METRIC

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

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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 375 kPa.

1.2 This metric specification is the equivalent to Specification C 361 and is compatible in technical content.

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:*

A 27/A 27M Specification for Steel Castings, Carbon, for General Application[2]
A 36/A 36M Specification for Carbon Structural Steel[3]
A 82 Specification for Steel Wire, Plain, for Concrete Reinforcement[3]
A 185 Specification for Steel Welded Wire, Fabric, Plain, for Concrete Reinforcement[3]
A 283/A 283M Specification for Low and Intermediate Tensile Strength Carbon Steel Plates[3]
A 496 Specification for Steel Wire, Deformed, for Concrete Reinforcement[3]
A 497 Specification for Steel Welded Wire Fabric, Deformed, for Concrete Reinforcement[3]
A 570/A 570M Specification for Steel, Sheet and Strip, Carbon, Hot-Rolled, Structural Quality[4]
A 575 Specification for Steel Bars, Carbon, Merchant Quality, M-Grades[5]
A 576 Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality[5]
A 611 Specification for Steel, Sheet, Carbon, Cold-Rolled, Structural Quality[4]
A 615/A 615M Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement[3]
A 675/A 675M Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality; Mechanical Properties[5]
C 31 Practice for Making and Curing Concrete Test Specimens in the Field[6]
C 33 Specification for Concrete Aggregates[6]
C 39 Test Method for Compressive Strength of Cylindrical Concrete Specimens[6]
C 150 Specification for Portland Cement[7]
C 260 Specification for Air-Entraining Admixtures for Concrete[6]
C 309 Specification for Liquid Membrane-Forming Compounds for Curing Concrete[6]
C 497M Test Methods for Concrete Pipe, Manhole Sections, or Tile (Metric)[8]
C 595 Specification for Blended Hydraulic Cements[7]
C 618 Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete[6]
C 822 Terminology Relating to Concrete Pipe and Related Products[8]
D 395 Test Methods for Rubber Property—Compression Set[9]
D 412 Test Methods for Vulcanized Rubber and Thermoplastic Rubbers and Thermoplastic Elastomers-Tension[9]
D 471 Test Method for Rubber Property—Effect of Liquids[9]
D 573 Test Method for Rubber–Deterioration in an Air Oven[9]
D 698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))[10]

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[1] This specification is under the jurisdiction of ASTM Committee C-13 on Concrete Pipe and is the direct responsibility of Subcommittee C13.04 on Low Head Pressure Pipe.

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[2] *Annual Book of ASTM Standards*, Vol 01.02.
[3] *Annual Book of ASTM Standards*, Vol 01.04.
[4] *Annual Book of ASTM Standards*, Vol 01.03.
[5] *Annual Book of ASTM Standards*, Vol 01.05.
[6] *Annual Book of ASTM Standards*, Vol 04.02.
[7] *Annual Book of ASTM Standards*, Vol 04.01.
[8] *Annual Book of ASTM Standards*, Vol 04.05.
[9] *Annual Book of ASTM Standards*, Vol 09.01.
[10] *Annual Book of ASTM Standards*, Vol 04.08.

D 1149 Test Method for Rubber Deterioration—Surface Ozone Cracking in a Chamber[9]
D 2240 Test Method for Rubber Property—Durometer Hardness[9]
D 4253 Test Method for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table[10]
D 4254 Test Method for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density[10]

2.2 *Other Standard:*
ACI Code 318 Standard Building Code Requirements for Reinforced Concrete[11]
AISI-C1012[12]

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 75, 150, 225, 300, and 375 kPa measured to the centerline of the pipe. Designs are provided in Table 1 for the above hydrostatic heads combined with external loadings of 1.5, 3.0, 4.5, and 6.0 (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 should 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 may be 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 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 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 may 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 300 steel conforming to Specification A 615/A 615M.

6.6 *Steel for Joint Rings*:

6.6.1 Steel strips for bell rings less than 6 mm 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 6 mm 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 283M in 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 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*:

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

[12] Available from the Iron and Steel Institute, 1133 15th St., NW, Washington, DC 20005.

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 ±0.4 mm 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 physical requirements (see also Test Methods D 412):

Tensile strength, min, MPa	16
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, MPa	10
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 (96 h at 70°C)	
Decrease in tensile strength	20
Decrease in elongation	40
Liquid immersion, max, % volume change	
Oil, in ASTM #3 (70 h at 100°C)	80
Water absorption	15
Ozone resistance, 72 h exposure in 50 PPHM ozone concentration at 40°C	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 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 21°C 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 may 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, mm	Maximum Laying Length of Pipe, m
300 to 375	3.66
450	4.27
525 to 600	4.88
675 to 750	5.49
825 to 900	6.10
975 and larger	7.32

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 75 and 150-kPa head classes only and only in pipe 450 to 1800 mm in diameter, inclusive. All pipe with a wall thickness of less than 82 mm 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 82 mm 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 900 mm and less with wall thicknesses equal to or greater than 82 mm, a single circular cage may be accepted if the steel area is equal to or greater than the least area shown for a single circular cage for the 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, mm	Minimum Cover, mm	Maximum Cover, mm
1125 and less	19	25
1200 through 1500	19	29
1575 through 1725	19	32
1800 through 2700	25	38

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 13 mm or more than 25 mm 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 950 mm^2/linear m of pipe may be composed of two layers of reinforcement, and cage areas greater than 1910 mm^2/linear m of pipe may be composed of three layers. The layers shall not be separated by more than the thickness of one longitudinal plus 6 mm. 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 cage supported by longitudinal bars that extend the full length of the pipe. The minimum concrete cover for longitudinal steel shall be 13 mm, except that the longitudinal bars or rods may extend 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 1050 mm 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 may 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 may extend 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 280 MPa based on the nominal cross-sectional area of the bar or wire. Lapped welds shall have a minimum lap of 50 mm. The spacing center-to-center of adjacent rings of circumferential reinforcement in a cage shall not exceed 100 mm. The continuity of the circumferential reinforcing steel shall not be destroyed during the manufacture of the pipe.

8. Joints

8.1 Joints may 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 may bear during closure will extend not less than 19 mm 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 5 mm and width sufficient to provide for adequate embedment in the pipe. It shall be flared at one end and may be 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 may bear during the closure will extend not less than 25 mm 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 5 mm for gaskets of 17-mm diameter or less, and 6 mm for gaskets greater than 17-mm 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 The rubber gaskets shall be solid gaskets of circular cross section and 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 40 % 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 40 % 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 13 mm in diameter and ± 1 % for gaskets of 25-mm diameter and larger. The allowable percentage tolerance shall vary linearly between ±3 % and ±1 % for gasket diameters between 13 and 25 mm.

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 may bear 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 may bear during closure will extend not less than 19 mm 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 may 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*—If permitted by the owner, manufacturers may 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 with the proportions of cementitious material 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 material 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 330 kg/m ^{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 25 MPa. 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 25 MPa. Pipe shall be protected from temperatures below 5°C from the time the concrete is placed until the curing period is completed. Curing may be by any other 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 22°C in any 1 h; nor shall the ambient temperature exceed 37°C during the 2 h immediately following concrete placement. At no time shall the ambient temperature exceed 66°C. Following the periods of steam curing, the pipe shall be protected from rapid drops in temperature, which may injure the pipe.

9.2.2 *Water Curing*— Concrete in pipe may 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 6°C of the atmospheric temperature. If the membrane is damaged, it shall be repaired immediately with additional compound.

10. Physical Requirements

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 may 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 may 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 that the cylinders may 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 of Test Methods C 497M may 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 150 by 300-mm concrete test cylinders. Where the strength of 150 by 300-mm concrete test cylinders exceeds the capacity of the normal field testing machine (900 kN), 75 by 150-mm test cylinders will be permitted with correction for size of cylinder.

10.4 *Hydrostatic Tests*:

10.4.1 *Hydrostatic Testing of Pipe*—Hydrostatic tests on pipe shall be made in accordance with the provisions of Test Methods C 497M. Before the test pressure is applied, the pipe may be allowed, at the option of the manufacturer, to stand under reduced pressure, but not for more than 48 h. Acceptance hydrostatic tests shall be made to 120 % of the specified internal working pressure for which the pipe is designed. The pipe shall withstand the percentage of working pressure prescribed above for at least 20 min without cracking and with no leakage appearing on the exterior surface. Moisture appearing on the surface of the pipe in the form of patches or beads adhering to the surface will not be considered as leakage. Slow-forming beads of water that result in minor dripping which can be proven to seal and dry up upon retesting under the prescribed test pressure will be considered acceptable.

10.4.2 *Hydrostatic Testing of Rubber Gasket Joints*—Hydrostatic pressure tests on joints shall be made on joints assembled of two sections of pipe, properly connected in accordance with the joint design. Suitable bulkheads may be provided with the pipe adjacent to and on either side of the joint, or the manufacturer may bulkhead the outer ends of joined pipe sections and conduct hydrostatic tests on both the pipe and pipe joint concurrently. No mortar or concrete coatings, fillings, or packings shall be placed prior to watertightness tests. After the pipe sections are fitted together with the rubber gasket or gaskets in place, the watertightness of the joints shall be tested under hydrostatic heads of 120 % of the pressure for which the pipe is designed, and there shall be no water leakage through the rubber gasket joint. On completion of the above straight alignment tests, the assembly shall be loaded to cause maximum joint annular space to occur. The load shall be applied such that a minimum differential load across the non-bulkheaded joint of 26.3 KN per mm of diameter is obtained or concrete to concrete contact occurs. The assembly shall then be retested as set forth in 10.4.1 and 10.4.2.

10.4.3 *Retests of Pipe or Pipe Joints Not Meeting the Hydrostatic Test Requirements*—In the event that a pipe or pipe joint fails the required tests, the manufacturer shall have the right to test two other sections of the pipe selected by the owner from the same period's run from which the original was selected. If these two pipe successfully pass the test, the remainder of the pipe in that period's run will be accepted. If either of these pipe fails, the remainder in that period's run will not be accepted until each pipe has satisfactorily passed this test.

10.5 *Rubber Gasket Compound*:

10.5.1 *Test Methods*— Laboratory tests to determine the physical properties of the rubber gaskets to be furnished under this specification shall be performed on test specimens taken from the finished rubber product, except that at the option of the pipe manufacturer specimens may be furnished in accordance with the appropriate ASTM method.

10.5.1.1 *Tensile Strength and Elongation*—Test Methods D 412.

10.5.1.2 *Hardness*—Test Method D 2240 (with the exception of the Summary of Test Methods Section). The determination shall be taken directly on the gasket. The presser foot shall be applied on areas that are 6 mm or greater in thickness. If 6 mm or greater in thickness is not available in the gasket, thinner samples may be piled up to obtain this thickness.

10.5.1.3 *Compression Set*— The Compression Set under Constant Deflection in Air Method of Test Methods D 395. The specimens shall be a 13-mm long section of gasket with a minimum diameter of 13 mm, deflected axially. Test conditions shall be 22 h at 70°C.

10.5.1.4 *Accelerated Aging*—Test Method D 573. Test conditions shall be 96 h at 70°C.

10.5.1.5 *Water Absorption*— Test Method D 471. Use distilled water for the standard test liquid. When a 25-mm wide test specimen cannot be obtained, use the greatest width obtainable from the test sample. Test conditions shall be 48 h at 70°C.

10.5.1.6 *Splices*—If a splice is used in the manufacture of the gasket, the strength shall be such that the gasket shall withstand 100 % elongation over the part of the gasket that includes the splice with no visible separation of the splice. While in the stretched position, the gasket shall be rotated in the spliced area a minimum of 180° in each direction in order to inspect for separation. Any portion of the splice shall be capable of passing a bend test without visible separation. The bend test for circular gaskets is defined as wrapping the portion of the unstretched gasket containing the splice a minimum of 180° and a maximum of 270° around a rod of a diameter equal to the cross section diameter of the gasket.

10.5.1.7 *Ozone Resistance*— Determine the resistance to ozone in accordance with Test Method D 1149. Specimens shall be the test specimen of the finished gasket cross-section. Conduct test for 72 h in 50 PPHM with specimens stressed to 20 % extension.

10.5.2 *Test Reports*— The manufacturer shall, if required, furnish certified copies of test reports of the rubber compound used in all rubber gaskets.

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

11. Permissible Variations

11.1 *Internal Diameter*—Permissible variations in internal diameter shall be as prescribed in Table 2. In order to obtain continuity of the interior surfaces of the pipeline, the maximum offset at the joints shall not exceed 0.75 % of the internal diameter of the pipe.

11.2 *Wall Thickness*— The wall thickness shall not be less than that intended in the design by more than 5 % at any point.

11.3 *Length of Two Opposite Sides*—Variations in laying lengths (see L in Figs. 1 and Figs. 2 of Test Methods C 497M) of two opposite sides of pipe shall not be more than 10 mm/m of diameter, with a maximum of 16 mm in any length of pipe, except where beveled-end pipe for laying on curves is specified by the owner.

11.4 *Length of Pipe*— The underrun or overrun 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.

11.5 *Area of Reinforcement*—The area of steel reinforcement shall be not less than 97 % of the design steel area of each cage ring. Steel areas greater than those required in the design shall not be cause for rejection.

11.6 The average diameter of any bell or spigot shall be within the minimum and maximum limits used in Section 8 (except 8.3 for design of the joint). The average diameter of a bell will be determined by taking the average of four equally spaced diametric measurements. The average spigot diameter will be determined by dividing the measured circumference by 3.1416.

11.6.1 An additional tolerance referred to as "inspection" tolerance is allowed during inspection of completed pipe units. This tolerance quantitatively is two times the minimum design joint clearance. The minimum design joint clearance is one half of the difference between the maximum design spigot diameter and the minimum design bell diameter. This "inspection" tolerance shall be apportioned to the bell and to the spigot in a ratio elected by the manufacturer. This tolerance, when applied, defines the minimum acceptable bell diameter on any pipe unit, measured diametrically, to be the minimum design bell diameter minus that part of the "inspection" tolerance apportioned to the bell. Similarly, the maximum acceptable spigot diameter on any pipe unit, measured diametrically, is defined to be the maximum design spigot diameter plus that part of the "inspection" tolerance apportioned to the spigot.

12. Workmanship, Finish, and Appearance

12.1 Pipe shall be substantially free of fractures, excessive surface crazing, pits, air holes, laitance, excessive brush marks, and interior surface roughness.

13. Repairs

13.1 Pipe may be repaired if made necessary because of imperfections in manufacture or damage during handling, and will be considered acceptable if, in the opinion of the owner, the defects do not subject the pipe unit to rejection as specified in Section 15, and the repairs are sound and properly finished and cured. Air holes in the gasket-bearing area may be repaired. Such fillings shall be kept moist under wet burlap for at least 48 h. Hydrostatic testing of repaired pipe may be required if deemed necessary by the owner, and such testing shall be at no additional cost to the owner.

14. Inspection

14.1 The quality of all 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 or on account of any of the following:

15.1.1 Defects that indicate imperfect mixing and molding,

15.1.2 Surface defects indicating honeycombed or open texture, that would adversely affect the performance of the pipe, and

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

16. Product Marking

16.1 The following shall be legibly marked on the interior surface of the pipe:

16.1.1 Specification designation, class, and size as indicated in Table 1.

16.1.2 Date of manufacture,

16.1.3 Name or trademark of the manufacturer, and

16.1.4 One end of each section of pipe with elliptical reinforcement shall be clearly marked, during the process of manufacturing or immediately thereafter, on the inside and the outside of opposite walls along the minor axes of the elliptical reinforcing. Markings shall be indented on the pipe section or painted thereon with waterproof paint.

TABLE 1 Design Requirements for Reinforced Concrete Low-Head Pressure Pipe[A] [300 to 2700 mm Diameter], Concrete Design Strength 31 MPa

NOTE 1—See Appendix for specific installation conditions and design criteria conditions required in conjunction with the use of Table 1.

NOTE 2—Designations A, B, C, and D, for class of pipe, denote 1.5, 3.0, 4.5, and 6.0 m of earth cover over top of pipe. Figures 75, Figures 150, Figures 225, etc. for class of pipe, denote hydrostatic pressure heads in kilopascals measured to centerline of pipe.

Circumferential reinforcement, mm^2/linear m of pipe[B]

Internal Designated Dia, mm	300		375		450				525				600				675							
Type of Reinforcement	Circular		Circular		Circular		Elliptical		Circular		Elliptical		Circular		Elliptical		Circular						Elliptical	
Wall Thickness, mm	50	75	50	75	57	75	57	75	60	75	60	75	63	75	63	75	66	79	82		107		66	82
Layers of Reinforcement	Single	Single	Single	Single	Single	Single	Single	Single	Single	Single	Single	Single	Single	Single	Single	Single	Single	Single	Inner	Outer	Inner	Outer	Single	Single
Class																								
A-75	140	120	200	160	250	220	250	250	310	270	290	290	370	330	330	330	430	390	290	190	220	150	370	370
B-75	200	150	300	220	370	300	370	250	480	400	440	310	590	510	520	400	720	610	440	250	320	170	600	440
C-75	260	190	400	290	510	400	500	310	670	540	610	420	840	700	730	530	1030	840	590	310	420	190	840	590
D-75	330	230	520	350	660	500	650	390	880	690	800	520	1130	910	960	680	...	1110	740	370	510	220	1120	740
A-150	220	220	290	270	360	330	520	520	440	400	610	610	520	480	700	700	600	560	410	320	340	260	780	780
B-150	270	230	390	320	480	420	520	520	610	530	610	610	740	660	700	700	890	780	560	370	430	280	780	780
C-150	330	260	500	380	620	510	610	520	800	670	730	610	990	850	860	700	1200	1010	710	430	530	300	980	780
D-150	400	300	610	440	770	610	750	520	1010	820	920	620	1280	1060	1090	790	...	1280	860	490	620	330	1260	860
A-225	350	350	440	440	520	520	...	...	610	610	...	...	690	690	...	...	780	780	540	440	450	370	...	...
B-225	350	350	480	440	600	530	...	...	740	660	...	...	890	810	...	...	1050	950	690	500	550	390	...	...
C-225	410	350	590	470	730	620	...	...	930	800	...	...	1140	1000	...	...	1360	1180	830	550	640	410	...	...
D-225	480	380	710	540	880	720	...	...	1140	950	...	...	1430	1210	...	...	...	1440	980	610	730	440	...	...
A-300	490	490	620	620	740	740	...	...	860	860	...	...	980	980	...	...	1100	1100	660	570	600	500	...	...
B-300	490	490	620	620	740	740	...	...	870	860	...	...	1040	980	...	...	1220	1120	810	620	660	510	...	...
C-300	490	490	680	620	840	740	...	...	1060	930	...	...	1280	1150	...	...	1530	1350	950	680	750	530	...	...
D-300	550	490	800	630	1000	840	...	...	1270	1080	...	...	1580	1360	...	...	...	1610	1100	740	840	550	...	...
A-375	660	660	830	830	990	990	...	...	1150	1150	...	...	1310	1310	...	...	1480	1480	800	680	800	680	...	...
B-375	660	660	830	830	990	990	...	...	1150	1150	...	...	1310	1310	...	...	1480	1480	940	750	820	660	...	...
C-375	660	660	830	830	990	990	...	...	1190	1150	...	...	1430	1310	...	...	1700	1510	1080	800	860	640	...	...
D-375	660	660	890	830	1110	990	...	...	1400	1210	...	...	1730	1500	...	...	...	1780	1230	860	950	660	...	...

TABLE 1 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[B]																				
Internal Designated Dia, mm	750										825									
Type of Reinforcement	Circular								Elliptical		Circular								Elliptical	
Wall Thickness, mm	69	79	82		88		119		69	88	72	79	82		94		119		72	94
Layers of Reinforcement	Single	Single	Inner	Outer	Inner	Outer	Inner	Outer	Single	Single	Single	Single	Inner	Outer	Inner	Outer	Inner	Outer	Single	Single
Class																				
A-75	510	470	340	230	320	210	240	160	420	410	580	540	400	270	340	230	280	190	460	450
B-75	860	760	530	310	490	280	350	180	690	490	1010	920	640	380	540	310	420	220	780	540
C-75	1250	1060	720	390	650	350	450	210	970	650	...	1320	870	490	720	380	540	260	1100	720
D-75	...	1430	930	480	830	420	560	240	1300	830	...	...	1140	610	910	470	670	300	1540	910
A-150	690	650	480	370	450	350	360	280	870	870	780	750	550	420	490	380	410	320	960	960
B-150	1050	950	670	450	620	410	470	300	870	870	1210	1120	790	530	680	450	550	360	960	960
C-150	1440	1250	860	530	780	480	570	330	1120	870	...	1520	1020	630	860	520	670	390	1250	960
D-150	...	1620	1060	620	960	550	670	360	1450	960	...	...	1280	750	1050	600	790	430	1690	1050
A-225	880	870	620	510	590	480	490	390	...	...	990	950	700	580	630	520	550	440	...	...
B-225	1230	1130	810	590	750	550	590	430	...	...	1420	1330	940	680	820	590	680	490	...	...
C-225	1630	1440	990	670	910	610	690	450	...	...	...	1730	1170	780	990	670	800	520	...	...
D-225	...	1810	1190	750	1090	680	790	470	...	...	...	...	1420	900	1180	740	920	560	...	...
A-300	1230	1230	760	650	720	620	670	560	...	...	1350	1350	860	730	780	650	740	610	...	...
B-300	1420	1320	950	730	890	680	710	550	...	...	1620	1530	1090	830	960	740	810	620	...	...
C-300	1810	1620	1130	800	1050	740	810	570	...	...	...	1930	1310	930	1130	810	930	650	...	...
D-300	...	1990	1320	890	1210	810	910	590	...	...	...	...	1600	1040	1320	880	1050	690	...	...
A-375	1640	1640	900	770	900	740	880	760	...	...	1810	1810	1010	880	980	830	980	830	...	...
B-375	1640	1640	1090	870	1020	820	910	730	...	...	1830	1810	1240	990	1110	880	1000	810	...	...
C-375	2000	1810	1260	940	1180	880	940	700	...	...	...	2140	1460	1080	1280	950	1060	790	...	...
D-375	...	2180	1460	1020	1340	940	1030	710	...	...	...	...	1740	1190	1460	1020	1180	820		...

TABLE 1 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[B]																									
Internal Designated Dia, mm	900									975[C]								1050							
Type of Reinforcement	Circular							Elliptical		Circular						Elliptical		Circular						Elliptical	
Wall Thickness, mm	79	82		100		125		79	100	88		107		132		88	107	94		113		138		94	113
Layers of Reinforcement	Single	Inner	Outer	Inner	Outer	Inner	Outer	Single	Single	Inner	Outer	Inner	Outer	Inner	Outer	Single	Single	Inner	Outer	Inner	Outer	Inner	Outer	Single	Single
Class																									
A-75	630	460	310	370	250	310	210	490	490	480	330	400	270	340	220	530	530	510	350	430	290	370	250	580	580
B-75	1100	750	450	580	340	460	250	800	580	800	480	630	360	500	280	800	630	840	510	670	390	540	300	840	670
C-75	...	1050	590	780	420	600	300	1110	780	1100	630	840	450	660	330	1100	840	1170	660	910	500	720	370	1170	910
D-75	...	1370	750	990	510	740	350	1480	990	1440	790	1060	550	810	390	1440	1060	1550	840	1150	600	900	430	1550	1150
A-150	860	620	480	520	410	450	350	1040	1040	660	500	560	430	490	380	1130	1130	690	530	600	460	530	410	1220	1220
B-150	1330	920	620	730	490	600	390	1040	1040	970	650	790	520	650	430	1130	1130	1010	690	840	560	700	460	1220	1220
C-150	...	1200	750	930	570	740	440	1270	1040	1260	790	990	610	800	480	1260	1130	1330	840	1070	660	880	530	1330	1220
D-150	...	1560	900	1140	660	880	480	1680	1140	1630	950	1210	710	960	530	1630	1210	1710	1010	1310	770	1050	590	1710	1310
A-225	1080	790	650	680	560	590	480	...	...	830	680	720	600	640	520	...	...	880	720	770	640	690	560	...	...
B-225	1550	1080	780	880	640	740	540	...	...	1140	820	940	680	800	580	...	...	1190	860	1000	730	860	630	...	...
C-225	...	1360	910	1080	720	880	580	...	...	1430	960	1150	770	950	630	...	...	1500	1010	1230	830	1040	680	...	...
D-225	...	1720	1060	1280	810	1020	620	...	...	1790	1110	1360	860	1100	680	...	...	1880	1180	1470	930	1200	740	...	...
A-300	1470	960	820	830	690	800	670	...	...	1010	860	890	730	870	720	...	...	1060	900	940	780	940	780	...	...
B-300	1770	1240	950	1040	790	890	680	...	...	1310	1000	1100	840	950	730	...	...	1370	1050	1170	900	1020	790	...	...
C-300	...	1550	1070	1220	870	1020	720	...	...	1620	1130	1300	930	1100	780	...	...	1710	1190	1400	990	1190	840	...	...
D-300	...	1870	1220	1420	950	1150	760	...	...	1950	1280	1540	1020	1250	830	...	...	2090	1350	1650	1090	1360	900	...	...
A-375	1970	1130	990	1070	900	1060	910	...	...	1180	1010	1160	970	1150	980	...	...	1250	1050	1240	1060	1240	1060	...	...
B-375	1990	1410	1110	1190	950	1100	870	...	...	1480	1170	1260	1010	1180	950	...	...	1570	1230	1340	1070	1280	1020	...	...
C-375	...	1710	1240	1370	1020	1160	860	...	...	1790	1300	1460	1090	1250	930	...	...	1880	1370	1580	1160	1350	1000	...	...
D-375	...	2080	1380	1590	1100	1290	900	...	...	2160	1440	1690	1170	1400	980	...	...	2260	1550	1810	1260	1520	1060	...	...

TABLE 1 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[B]																								
Internal Designated Dia, mm	1125[C]								1200								1275[C]							
Type of Reinforcement	Circular						Elliptical		Circular						Elliptical		Circular						Elliptical	
Wall Thickness, mm	97		119		144		97	119	104		125		144		104	125	107		132		150		107	132
Layers of Reinforcement	Inner	Outer	Inner	Outer	Inner	Outer	Single	Single	Inner	Outer	Inner	Outer	Inner	Outer	Single	Single	Inner	Outer	Inner	Outer	Inner	Outer	Single	Single
Class																								
A-75	570	390	470	320	410	270	620	620	600	410	500	340	450	300	660	660	650	440	530	360	480	320	700	700
B-75	940	570	730	430	600	340	940	730	960	590	770	460	670	380	960	770	1030	630	810	480	710	410	1030	810
C-75	1330	760	1000	550	800	410	1330	1000	1370	790	1070	590	910	480	1370	1070	1490	860	1130	620	970	520	1490	1130
D-75	1790	970	1270	670	990	490	1790	1270	1820	990	1350	720	1130	570	1820	1350	2020	1090	1430	760	1210	620	...	1430
A-150	770	590	660	500	580	450	1300	1300	800	620	700	540	640	490	1390	1390	860	660	730	560	680	520	1470	1470
B-150	1130	770	910	610	770	510	1300	1300	1160	790	960	650	850	570	1390	1390	1240	840	1000	680	900	600	1470	1470
C-150	1540	950	1170	730	970	580	1540	1300	1580	980	1250	770	1080	660	1580	1390	1710	1070	1320	820	1160	710	1710	1470
D-150	1960	1150	1440	840	1160	650	1960	1440	2040	1180	1550	900	1300	750	2040	1550	2210	1290	1630	950	1400	800	...	1630
A-225	970	790	840	690	750	610	...	...	1010	820	890	730	820	670	...	...	1070	880	940	770	870	710	...	...
B-225	1320	960	1090	790	940	680	...	...	1360	990	1150	840	1030	750	...	...	1450	1050	1200	880	1090	800	...	...
C-225	1730	1140	1350	900	1140	750	...	...	1780	1180	1430	960	1260	840	...	...	1910	1270	1510	1010	1350	900	...	...
D-225	2180	1330	1630	1020	1330	820	...	...	2220	1370	1730	1080	1480	920	...	...	2400	1480	1810	1140	1590	990	...	...
A-300	1170	990	1030	850	1000	840	...	...	1210	1030	1090	890	1070	890	...	...	1290	1090	1150	930	1140	940	...	...
B-300	1540	1160	1270	980	1110	860	...	...	1580	1190	1340	1030	1210	940	...	...	1680	1270	1400	1080	1290	990	...	...
C-300	1920	1330	1550	1080	1310	920	...	...	1970	1370	1640	1150	1440	1020	...	...	2150	1480	1720	1210	1550	1090	...	...
D-300	2360	1550	1800	1190	1490	990	...	...	2410	1590	1910	1270	1670	1100	...	...	2640	1710	2030	1330	1780	1180	...	...
A-375	1370	1170	1330	1130	1330	1130	...	...	1430	1190	1420	1200	1420	1200	...	...	1510	1270	1510	1270	1500	1280	...	...
B-375	1740	1350	1450	1160	1370	1090	...	...	1780	1400	1550	1220	1460	1160	...	...	1890	1480	1620	1280	1540	1240	...	...
C-375	2150	1550	1730	1270	1480	1100	...	...	2200	1600	1830	1340	1640	1210	...	...	2360	1710	1920	1410	1740	1280	...	...
D-375	2600	1740	1980	1370	1680	1160	...	...	2650	1780	2120	1450	1850	1280	...	...	2840	1910	2220	1540	1970	1370	...	...

TABLE 1 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[B]																								
Internal Designated Dia, mm	1350								1425[C]								1500							
Type of Reinforcement	Circular						Elliptical		Circular						Elliptical		Circular						Elliptical	
Wall Thickness, mm	113		138		157		113	138	119		144		163		119	144	125		150		169		125	150
Layers of Reinforcement	Inner	Outer	Inner	Outer	Inner	Outer	Single	Single	Inner	Outer	Inner	Outer	Inner	Outer	Single	Single	Inner	Outer	Inner	Outer	Inner	Outer	Single	Single
Class																								
A-75	680	470	570	390	520	350	740	740	710	490	600	410	550	370	780	780	760	520	650	440	590	400	820	820
B-75	1070	660	850	510	750	440	1070	850	1110	690	900	540	800	470	1110	900	1170	730	960	580	850	500	1170	960
C-75	1580	910	1200	670	1040	560	1580	1200	1650	940	1270	710	1110	600	1650	1270	1750	1010	1370	760	1190	640	1750	1370
D-75	2110	1140	1540	820	1300	660	...	1540	2180	1190	1630	870	1380	710	...	1630	2310	1270	1750	940	1490	780	...	1750
A-150	900	690	780	600	720	550	1560	1560	940	720	820	630	760	580	1650	1650	1000	760	880	670	820	620	1740	1740
B-150	1290	880	1060	720	950	640	1560	1560	1330	910	1110	760	1010	680	1650	1650	1410	960	1180	810	1070	730	1740	1740
C-150	1790	1110	1400	870	1230	750	1830	1560	1860	1160	1480	920	1310	800	1950	1650	1980	1230	1600	990	1400	860	2070	1740
D-150	2300	1340	1730	1010	1490	860	...	1770	2380	1400	1830	1070	1590	920	...	1900	2560	1490	1960	1150	1710	990	...	2050
A-225	1130	920	990	810	930	750	...	...	1170	950	1040	850	980	790	...	...	1250	1010	1110	910	1050	850	...	...
B-225	1500	1100	1270	930	1150	840	...	...	1580	1140	1330	970	1220	890	...	...	1660	1200	1410	1040	1300	950	...	...
C-225	2030	1330	1620	1070	1430	950	...	...	2100	1380	1700	1130	1520	1010	...	...	2230	1460	1820	1210	1630	1080	...	...
D-225	2500	1570	1930	1210	1690	1050	...	...	2620	1630	2050	1280	1800	1120	...	...	2780	1730	2190	1370	1930	1200	...	...
A-300	1350	1140	1210	1000	1210	1000	...	...	1410	1190	1280	1050	1270	1060	...	...	1490	1260	1350	1100	1340	1110	...	...
B-300	1740	1320	1470	1140	1360	1050	...	...	1800	1370	1560	1190	1430	1100	...	...	1900	1440	1660	1270	1520	1180	...	...
C-300	2240	1560	1820	1280	1640	1150	...	...	2320	1620	1920	1350	1740	1220	...	...	2460	1720	2060	1430	1850	1300	...	...
D-300	2740	1780	2150	1410	1890	1250	...	...	2830	1850	2260	1490	2020	1320	...	...	3000	1960	2410	1600	2160	1420	...	...
A-375	1620	1330	1600	1350	1590	1360	...	...	1710	1400	1690	1420	1680	1430	...	...	1800	1480	1790	1490	1780	1500	...	...
B-375	1960	1560	1700	1350	1640	1310	...	...	2060	1620	1780	1410	1730	1380	...	...	2170	1710	1890	1500	1830	1450	...	...
C-375	2450	1780	2050	1490	1840	1350	...	...	2580	1850	2150	1580	1950	1430	...	...	2730	1960	2290	1680	2090	1540	...	...
D-375	2950	2020	2350	1630	2100	1450	...	...	3040	2090	2470	1710	2220	1540	...	...	3260	2210	2660	1830	2380	1650	...	...

TABLE 1 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[B]																								
Internal Designated Dia, mm	1575[C]								1650								1725[C]							
Type of Reinforcement	Circular						Elliptical		Circular						Elliptical		Circular						Elliptical	
Wall Thickness, mm	132		157		175		132	157	138		163		182		138	163	144		169		188		144	169
Layers of Reinforcement	Inner	Outer	Inner	Outer	Inner	Outer	Single	Single	Inner	Outer	Inner	Outer	Inner	Outer	Single	Single	Inner	Outer	Inner	Outer	Inner	Outer	Single	Single
Class																								
A-75	790	540	680	460	630	420	860	860	830	570	720	490	670	450	900	900	920	630	800	540	730	490	960	940
B-75	1200	750	1000	600	900	530	1210	1010	1250	780	1050	640	950	560	1280	1080	1380	850	1150	700	1040	620	1380	1150
C-75	1790	1030	1410	790	1250	680	1790	1410	1840	1060	1470	830	1300	710	1860	1470	2040	1160	1630	910	1420	780	2040	1630
D-75	2360	1300	1820	980	1590	830	...	1820	2460	1350	1920	1040	1680	870	...	1920	2780	1510	2150	1150	1850	970	...	2150
A-150	1040	790	920	700	860	660	1820	1820	1090	830	970	740	910	690	1910	1910	1200	910	1070	810	990	750	2000	2000
B-150	1450	990	1230	840	1130	760	1820	1820	1500	1030	1290	880	1180	800	1910	1910	1670	1130	1420	960	1290	880	2000	2000
C-150	2040	1260	1650	1020	1470	910	2160	1820	2100	1300	1720	1070	1540	950	2270	1910	2310	1430	1880	1170	1680	1040	2370	2000
D-150	2610	1540	2060	1200	1810	1050	...	2170	2710	1600	2170	1270	1910	1100	...	2320	3030	1780	2390	1400	2110	1220	...	2470
A-225	1290	1050	1160	950	1100	890	...	...	1350	1090	1220	990	1150	930	...	...	1480	1190	1340	1080	1260	1020	...	...
B-225	1710	1240	1470	1080	1360	1000	...	...	1770	1280	1550	1130	1420	1040	...	...	1940	1410	1690	1230	1560	1140	...	...
C-225	2270	1500	1880	1250	1710	1130	...	...	2340	1570	1960	1310	1780	1190	...	...	2600	1720	2160	1430	1940	1290	...	...
D-225	2840	1770	2280	1430	2050	1270	...	...	2940	1840	2400	1500	2150	1340	...	...	3320	2060	2670	1670	2360	1470	...	...
A-300	1560	1290	1410	1160	1410	1160	...	...	1620	1340	1480	1220	1480	1220	...	...	1780	1480	1620	1330	1550	1270	...	...
B-300	1950	1490	1720	1320	1610	1230	...	...	2050	1560	1800	1380	1680	1290	...	...	2250	1710	1960	1500	1830	1400	...	...
C-300	2510	1760	2130	1490	1940	1360	...	...	2620	1820	2220	1570	2030	1430	...	...	2870	1990	2420	1710	2210	1560	...	...
D-300	3060	2030	2510	1670	2270	1500	...	...	3210	2110	2650	1750	2380	1580	...	...	3570	2330	2920	1920	2630	1730	...	...
A-375	1890	1550	1870	1570	1860	1580	...	...	1980	1630	1970	1640	1960	1650	...	...	2090	1740	2060	1710	2060	1710	...	...
B-375	2230	1760	1960	1570	1910	1530	...	...	2310	1820	2070	1640	2000	1610	...	...	2560	1990	2250	1790	2110	1680	...	...
C-375	2780	2030	2370	1740	2180	1610	...	...	2870	2090	2460	1810	2270	1680	...	...	3180	2290	2710	1980	2470	1820	...	...
D-375	3340	2270	2760	1900	2500	1740	...	...	3450	2350	2890	1990	2640	1820	...	...	3880	2630	3200	2200	2880	1990	...	...

TABLE 1 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[B]																				
Internal Designated Dia, mm	1800								1950						2100					
Type of Reinforcement	Circular						Elliptical		Circular						Circular					
Wall Thickness, mm	150		175		194		150	175	163		188		207		175		200		219	
Layers of Reinforcement	Inner	Outer	Inner	Outer	Inner	Outer	Single	Single	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer
Class																				
A-75	960	650	840	560	770	520	1010	990	1030	700	910	620	850	570	1120	760	1000	670	940	620
B-75	1430	880	1200	730	1090	650	1430	1210	1510	940	1300	790	1180	710	1630	1000	1410	860	1290	780
C-75	2090	1200	1690	950	1490	820	2090	1690	2170	1250	1800	1020	1610	890	2290	1330	1930	1100	1740	980
D-75	2870	1580	2250	1210	1950	1030	...	2250	3010	1660	2420	1310	2140	1130	3200	1760	2610	1410	2300	1220
A-150	1250	940	1110	840	1040	790	2090	2090	1330	1010	1210	910	1140	860	1440	1080	1310	990	1240	930
B-150	1720	1170	1480	1010	1350	920	2090	2090	1820	1240	1600	1080	1470	1000	1940	1320	1720	1170	1600	1080
C-150	2360	1470	1950	1220	1760	1090	2480	2090	2460	1550	2090	1300	1890	1170	2610	1640	2240	1400	2050	1270
D-150	3160	1840	2500	1460	2220	1280	...	2620	3300	1940	2710	1590	2410	1400	3470	2070	2890	1710	2600	1510
A-225	1550	1240	1390	1130	1320	1070	...	...	1650	1320	1510	1210	1430	1150	1770	1410	1640	1310	1560	1250
B-225	2030	1460	1760	1280	1630	1190	...	...	2140	1550	1890	1380	1760	1280	2270	1650	2040	1480	1910	1390
C-225	2660	1770	2240	1490	2030	1350	...	...	2770	1850	2380	1600	2180	1460	2920	1950	2560	1710	2350	1580
D-225	3410	2130	2780	1740	2470	1550	...	...	3570	2240	2980	1870	2700	1680	3760	2370	3200	2020	2890	1810
A-300	1850	1550	1690	1380	1620	1320	...	...	1970	1640	1820	1480	1760	1430	2120	1750	1960	1610	1900	1530
B-300	2320	1760	2060	1570	1910	1460	...	...	2440	1860	2200	1680	2070	1590	2610	1970	2360	1810	2230	1710
C-300	2940	2070	2510	1770	2300	1630	...	...	3060	2160	2680	1890	2470	1750	3250	2290	2860	2040	2670	1890
D-300	3680	2400	3040	2020	2750	1810	...	...	3890	2550	3280	2170	2970	1960	4090	2690	3490	2320	3200	2120
A-375	2170	1800	2140	1790	2140	1790	...	...	2340	1920	2330	1930	2310	1950	2510	2080	2510	2080	2500	2090
B-375	2630	2070	2340	1860	2190	1750	...	...	2770	2190	2500	1980	2370	1890	2940	2320	2690	2140	2560	2030
C-375	3260	2360	2800	2070	2590	1900	...	...	3390	2470	2970	2200	2770	2050	3570	2630	3190	2350	2970	2210
D-375	3990	2710	3330	2290	3010	2090	...	...	4170	2840	3560	2450	3270	2260	4380	3000	3820	2640	3500	2420

TABLE 1 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[B]																
Internal Designated Dia, mm	2250				2400				2550				2700			
Type of Reinforcement	Circular				Circular				Circular				Circular			
Wall thickness, mm	188		200		200		213		213		225		225		238	
Layers of Reinforcement	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer
Class																
A-75	1200	810	1140	770	1290	870	1230	830	1380	930	1330	890	1480	1000	1420	950
B-75	1720	1060	1620	990	1830	1140	1720	1060	1940	1200	1840	1130	2070	1280	1950	1200
C-75	2390	1390	2220	1280	2520	1470	2340	1350	2660	1560	2480	1440	2790	1640	2620	1520
D-75	3290	1830	2980	1650	3430	1920	3120	1740	3550	1990	3300	1830	3700	2100	3430	1920
A-150	1550	1150	1470	1100	1660	1230	1590	1180	1760	1310	1700	1260	1880	1390	1810	1340
B-150	2060	1400	1940	1320	2190	1480	2080	1400	2320	1580	2210	1500	2450	1670	2340	1590
C-150	2730	1720	2550	1610	2870	1820	2690	1700	3010	1910	2840	1800	3180	2020	2980	1890
D-150	3590	2150	3310	1960	3740	2250	3450	2070	3900	2350	3630	2190	4070	2450	3780	2290
A-225	1890	1490	1820	1440	2030	1600	1950	1550	2150	1690	2090	1640	2290	1790	2220	1740
B-225	2400	1740	2290	1660	2560	1850	2430	1760	2700	1950	2590	1870	2850	2070	2730	1970
C-225	3050	2070	2870	1930	3230	2180	3020	2050	3380	2280	3210	2170	3550	2400	3370	2280
D-255	3920	2460	3610	2290	4090	2600	3770	2400	4240	2710	3990	2550	4410	2830	4150	2660
A-300	2250	1850	2180	1780	2400	1970	2320	1890	2550	2090	2470	2020	2700	2210	2620	2140
B-300	2760	2100	2640	2000	2920	2220	2790	2130	3070	2340	2960	2260	3260	2460	3120	2380
C-300	3400	2400	3220	2270	3580	2530	3390	2400	3740	2670	3570	2550	3940	2800	3750	2670
D-300	4230	2800	3950	2620	4410	2940	4130	2750	4580	3060	4330	2900	4770	3220	4510	3030
A-375	2700	2210	2680	2230	2880	2360	2880	2360	3060	2510	3060	2510	3230	2660	3240	2650
B-375	3100	2450	2980	2360	3300	2600	3170	2490	3470	2730	3350	2650	3650	2880	3530	2790
C-375	3730	2750	3550	2620	3950	2900	3730	2770	4130	3040	3960	2920	4330	3200	4150	3060
D-375	4540	3150	4260	2950	4740	3300	4460	3090	4920	3440	4680	3280	5130	3590	4880	3420

[A] Steel areas may be interpolated between those shown for variations in wall thickness. See 7.2 for provisions for special designs.
[B] The prescribed amounts of reinforcement do not provide any allowance for pressure surges (water hammer) in pipelines.
[C] Available in some areas.

TABLE 2 Permissible Variations in Internal Diameter

Designated Size 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
975	975	1000
1050	1050	1080
1125	1125	1155
1200	1200	1230
1275	1275	1305
1350	1350	1385
1425	1425	1460
1500	1500	1540
1575	1575	1615
1650	1650	1695
1725	1725	1770
1800	1800	1850
1950	1950	2000
2100	2100	2155
2250	2250	2310
2400	2400	2465
2550	2550	2620
2700	2700	2770

APPENDIXES

(Nonmandatory Information)

X1. FIELD INSTALLATION PROCEDURE

X1.1 The class of pipe given in Table 1 for combined external load and hydrostatic head is based on a field installation procedure at least comparable to that described below. Where the designer does not expect to attain such an installation, a detailed design analysis of the pipe should be made taking into consideration the anticipated external loading, hydrostatic head, and installation procedure. Failure to comply with the requirements herein may result in a bedding angle of less than 90° as defined in Appendix X2 and may result in excessive pipe cracking.

X1.2 The trench shall be excavated of sufficient width to achieve the specified haunch backfill compaction, and to a depth of either 100 mm or 150 mm below the bottom of the pipe, to provide for granular cushion material as shown in Fig. X1.1. The trench shall be backfilled to the bottom of the pipe with uncompacted granular cushion material meeting the physical requirements of X1.2.2. After the pipe is placed in the trench to the correct grade and alignment, additional haunch support backfill material shall be compacted in accordance with X1.2.1 or X1.2.2, depending on the type of soil used as pipe backfill material. An additional depth of 150 mm or more shall be removed if the native material in the trench is soft, low density, or unsuitable for a pipeline foundation. The additional 150 mm or more shall be compacted to the requirements of the design engineer.

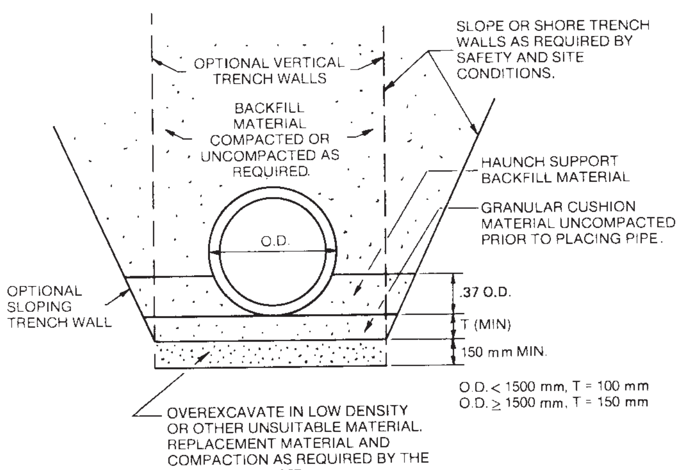

FIG. X1.1 Pipe Bedding

X1.2.1 *Cohesive Soil or Granular Soil Containing More Than 5 % Fines*—If the haunch support backfill material is a cohesive soil or is a granular soil containing more than 5 % material passing the number 200 sieve, the material shall be placed in layers not exceeding 150 mm in thickness and compacted by appropriate surface methods such as tamping, rolling, vibration, or a combination thereof. The material shall be placed from the bottom of the pipe to a height of 0.37 times the outside diameter of the pipe, shall be placed and compacted in such a manner as to completely fill the space under the haunches of the pipe, and shall be compacted throughout to a minimum of 95 % of laboratory maximum density as determined in accordance with Test Method D 698.

X1.2.2 *Granular Soil Containing 5 % Fines or Less*—If the haunch support backfill material is a cohesionless, free-draining soil (containing no more than 5 % material passing the number 200 sieve) it shall be placed a minimum depth of 0.37 times the outside diameter of the pipe and shall be compacted by saturation and internal vibration in such a manner as to completely fill the spaces under the haunches of the pipe and shall be compacted throughout to a minimum of 70 % relative density as determined in accordance with Test Methods D 4253 and D 4254.

NOTE X1.1—In order to achieve specified density, it may be necessary to provide means for draining the water utilized during vibration whenever the trenchsides and subgrade are incapable or readily absorbing the excess.

X1.2.3 The pipe backfill material in X1.2.1 and X1.2.2 shall have a maximum particle size not exceeding 19 mm and shall be graded to preclude migration of soil particles. The backfill material placed above the 0.37 outside diameter level shall be compacted or uncompacted to the requirements of the design engineer.

X2. DESIGN CRITERIA FOR TABLE 1

X2.1 The designs for reinforced concrete low-head pressure pipe presented in Table 1 are based on specific loadings, bedding, and design requirements summarized in this appendix as information for the designer in considering the suitability of the designs.

X2.2 *Loads*—This pipe is designed for dead load of the pipe itself, the earth load, the water load, and the internal pressure due to hydrostatic head calculated from the inside top of the pipe to the design gradient. The hydrostatic head defined in Table 1 is measured to the horizontal centerline of the pipe.

X2.2.1 The earth load is based on a one-metre length of the prism of earth directly over the outside diameter of the pipe. The *effective* density (mass per unit volume) of earth in kilograms per cubic metre is:

$$w_e = 1600 + 320(H_e/OD)$$

where:
H_e = earth cover over top of pipe, m,
OD = outside diameter of pipe, m, and
max w_e = 2400 kg/m^3.

The force exerted on the pipe by the prism of earth over the pipe is:

$$W = w_e H_e (OD) g / 1000, \text{ kn/linear m} \quad \text{(X2.1)}$$

where:
g = 9.81 m/s^2

NOTE X2.1—The earth load from X2.2.1 represents loose backfill over pipe in a trench of any width, as may be used for cross-country pipelines. For any other earth load design assumption selected by the engineer, the new earth load may be compared to the design earth load in kilonewtons per linear metre from X2.2.1 for the range of cover loads, A through D, within the same pressure head designation.

X2.2.2 The prescribed amounts of reinforcement do not provide any allowance for pressure surges (water hammer) in pipelines.

X2.3 *Bedding*—The bedding described in Appendix X1 is assumed to result in bearing over a 90° central angle. Pressure distributions and the analysis of stresses in the pipe wall are based on theory.[13]

X2.4 *Design Requirements*—Reinforced concrete design for combined internal and external loads is based on ACI Code 318,[14] with a concrete compressive strength of 31 MPa, reinforcing steel with a yield point strength of 276 MPa, a load factor of 1.8, and a capacity reduction factor of 1.0.

X2.4.1 The minimum steel area is calculated for hydrostatic head only. The minimum area of circular reinforcement is:

$$A_s = \frac{PD_d}{2f_s}, \text{ mm}^2/\text{m}$$

where:
P = hydrostatic pressure head, kPa,
D_d = design diameter, the average of the minimum and maximum internal diameters shown in Table 2, mm, and
f_s = 117 − 0.08P, allowable tensile stress in the reinforcement, MPa.

For elliptical reinforcement, the minimum area of reinforcement is 1.6 times that required for circular reinforcement for hydrostatic head alone.

X2.4.2 The design concrete cover is the average of the dimensions given in paragraph 7.4 of the specification for a particular range of pipe diameters. For single-layer reinforcement, the steel is assumed to be at the centerline of the cross-section.

X2.4.3 The minimum wall thickness of the pipe is:

$$t_{w\,min} = \frac{D}{12}, \text{ mm}$$

where:

[13] Olander, H. C., "Stress Analysis of Concrete Pipe," Engineering Monograph No. 6, U.S. Bureau of Reclamation, October 1950.

[14] *ACI Standard Building Code Requirements for Reinforced Concrete (ACI 318)*, American Concrete Institute, P.O. Box 19150, Detroit, MI 48219.

D = designated size given in Table 2.

The tensile stress in the concrete of the pipe wall is:

$$f_{ct} \frac{PD}{2000\ t_w}, \text{ MPa}$$

where:

t_w = design pipe wall thickness, assumed unreinforced, mm, and

f_{ct} = $\leq$ 2.3 MPa for the concrete design strength of 31 MPa shown in Table 1.