Designation: C361M – 16

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

This standard is issued under the fixed designation C361M; 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 U.S. 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 specification is the SI companion to Specification C361. It 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:*[2]

A27/A27M Specification for Steel Castings, Carbon, for General Application

A36/A36M Specification for Carbon Structural Steel

A82/A82M Specification for Steel Wire, Plain, for Concrete Reinforcement (Withdrawn 2013)[3]

A185/A185M Specification for Steel Welded Wire Reinforcement, Plain, for Concrete (Withdrawn 2013)[3]

A283/A283M Specification for Low and Intermediate Tensile Strength Carbon Steel Plates

A496/A496M Specification for Steel Wire, Deformed, for Concrete Reinforcement (Withdrawn 2013)[3]

A497/A497M Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete (Withdrawn 2013)[3]

A575 Specification for Steel Bars, Carbon, Merchant Quality, M-Grades

A576 Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality

A615/A615M Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

A675/A675M Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties

A1008/A1008M Specification for Steel, Sheet, Cold-Rolled, Carbon, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy with Improved Formability, Solution Hardened, and Bake Hardenable

A1011/A1011M Specification for Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy with Improved Formability, and Ultra-High Strength

C31/C31M Practice for Making and Curing Concrete Test Specimens in the Field

C33/C33M Specification for Concrete Aggregates

C39/C39M Test Method for Compressive Strength of Cylindrical Concrete Specimens

C150/C150M Specification for Portland Cement

C260/C260M Specification for Air-Entraining Admixtures for Concrete

C309 Specification for Liquid Membrane-Forming Compounds for Curing Concrete

C497M Test Methods for Concrete Pipe, Manhole Sections, or Tile (Metric)

C595/C595M Specification for Blended Hydraulic Cements

C618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

C822 Terminology Relating to Concrete Pipe and Related Products

C1602/C1602M Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete

C1619 Specification for Elastomeric Seals for Joining Concrete Structures

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))

D4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table

[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] The last approved version of this historical standard is referenced on www.astm.org.

D4254 Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density

2.2 *Other Standard:*

ACI Code 318 Standard Building Code Requirements for Reinforced Concrete[4]

AISI-C1012[5]

3. Terminology

3.1 *Definitions*—For definitions of terms relating to concrete pipe, see Terminology C822.

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 and Table 2 for the above hydrostatic heads combined with external loadings of 1.5, 3.0, 4.5, and 6.0 m (designated *A*, *B*, *C*, and *D* in Table 1 and Table 2) 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 Table 2 and Appendix X1, detailed design calculations shall be made. The design criteria for Table 1 and Table 2 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 C150/C150M.

6.2.1.2 *Blended Hydraulic Cement*—Blended cement shall conform to the requirements of Specification C595/C595M 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 C618.

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,

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 C33/C33M, 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 C260/C260M. 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 A82/A82M, Specification A496/A496M, or of wire reinforcement conforming to Specification A185/A185M or Specification A497/A497M, or of bars of Grade 300 steel conforming to Specification A615/A615M.

6.6 *Steel for Joint Rings:*

6.6.1 Steel strips for bell rings less than 6 mm thick shall conform to Grade SS30 of Specification A1011/A1011M or Grade Designation 1012 of Specification A575. Steel that meets the requirements of AISI-C1012 for chemical components will be acceptable provided it conforms to Grade SS30 of Specification A1011/A1011M 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 A36/A36M, or to Grade A of Specification A283/A283M, or to Grade Designation 1012 of Specification A576, or to Grade 50 of Specification A675/A675M. Steel that meets the requirements of AISI-C1012 for chemical components will be acceptable provided it conforms to Specification A36/A36M or to Specification A283/A283M in other respects.

6.7 *Steel Castings for Fittings*—Steel castings for fittings shall conform to Grade 70-36, Normalized, of Specification A27/A27M.

6.8 *Steel Plates and Sheets for Specials and Fittings*—Steel plates for specials and fittings shall conform to Specification A36/A36M or to Grade B or C of Specification A283/A283M or Grade SS30 or SS33 of Specification A1011/A1011M or Grade SS30 of Specification A1008/A1008M.

6.9 *Rubber Gaskets:*

6.9.1 *Composition and Properties*—All rubber gaskets shall comply with Specification C1619 in terms of material and

[4] Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333-9094, http://www.concrete.org.

[5] Available from the American Iron and Steel Institute (AISI), 1140 Connecticut Ave. NW, Suite 705, Washington D.C. 20036, http://www.steel.org.

TABLE 1 Design Requirements for Reinforced Concrete Low-Head Pressure Pipe [300 to 3650 mm Diameter], Concrete Design Strength 34.5 MPa (except as noted) Steel Reinforced Yield Strength 276 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.

NOTE 3—An "s" in place of a steel area indicates the pipe class is a special design requiring stirrup reinforcement. Stirrups may be eliminated by changing wall thickness, main reinforcement, concrete strength, or a combination thereof.

NOTE 4—The boldfaced value denotes 41.4 MPa concrete strength required.

Circumferential reinforcement, mm^2/linear m of pipe[A, 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	170	250	220	250	250	320	280	320	290	390	350	390	350	460	410	290	200	230	160	460	370		
B-75	210	170	310	240	390	320	390	320	500	420	500	420	610	540	610	540	740	650	440	280	340	210	740	440		
C-75	280	220	420	310	540	430	540	430	690	570	690	570	870	730	870	730	1060	890	590	350	450	250	1060	590		
D-75	360	270	540	390	700	540	700	540	910	730	910	730	1150	950	1150	950	1430	1170	750	440	560	300	1430	750		
A-150	220	220	280	270	350	320	520	520	430	390	610	610	510	480	690	690	600	550	390	300	330	250	780	780		
B-150	270	230	380	320	480	420	520	520	600	530	610	610	740	660	740	690	880	780	540	370	430	300	880	780		
C-150	340	280	500	390	630	520	630	520	800	680	800	680	990	860	990	860	1190	1030	690	450	540	340	1190	780		
D-150	420	330	620	470	790	640	790	640	1020	840	1020	840	1280	1070	1280	1070	1570	1310	850	530	650	390	1570	850		
A-225	340	340	430	430	520	520	...	...	600	600	...	...	690	690	...	...	770	770	490	400	430	350	...	...		
B-225	340	340	460	430	580	520	...	...	710	640	...	...	860	780	...	...	1020	920	640	470	520	390	...	...		
C-225	400	340	570	470	720	620	...	...	910	790	...	...	1110	980	...	...	1330	1170	790	550	630	440	...	...		
D-225	480	390	700	550	880	730	...	...	1130	950	...	...	1400	1200	...	...	1710	1440	940	630	730	480	...	...		
A-300	490	490	610	610	730	730	...	...	860	860	...	...	980	980	...	...	1100	1100	590	500	590	510	...	...		
B-300	490	490	610	610	730	730	...	...	860	860	...	...	980	980	...	...	1160	1100	740	570	620	480	...	...		
C-300	490	490	650	610	820	730	...	...	1020	900	...	...	1240	1110	...	...	1470	1310	880	650	720	530	...	...		
D-300	540	490	770	620	980	820	...	...	1240	1050	...	...	1530	1320	...	...	1850	1580	1040	730	820	570	...	...		
A-375	650	650	820	820	980	980	...	...	1140	1140	...	...	1310	1310	...	...	1470	1470	790	680	780	690	...	...		
B-375	650	650	820	820	980	980	...	...	1140	1140	...	...	1310	1310	...	...	1470	1470	830	670	810	660	...	...		
C-375	650	650	820	820	980	980	...	...	1140	1140	...	...	1360	1310	...	...	1610	1470	980	750	830	640	...	...		
D-375	650	650	850	820	1070	980	...	...	1350	1160	...	...	1650	1450	...	...	1990	1720	1140	830	910	670	...	...		

TABLE 1 *Continued*

Circumferential reinforcement, mm^2/linear m of pipe[A, 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	530	490	340	230	320	220	250	170	530	410	610	570	400	270	350	240	290	200	610	450
B-75	880	790	530	340	490	310	370	220	880	490	1020	950	630	400	540	340	440	270	1020	540
C-75	1260	1110	720	440	660	400	490	280	1260	660	1490	1360	870	530	730	440	580	330	1490	730
D-75	1750	1470	920	550	840	490	600	330	1750	840	**1940**	1850	1120	670	930	540	720	400	**1940**	930
A-150	680	640	450	350	430	330	350	270	870	870	780	740	520	400	470	360	400	310	950	950
B-150	1030	940	640	450	600	420	470	320	1030	870	1190	1120	750	520	660	460	550	380	1190	950
C-150	1420	1260	830	550	770	500	580	370	1420	870	1660	1530	980	650	840	550	680	440	1660	950
D-150	1900	1630	1030	650	940	600	700	430	1900	940	**2110**	2020	1230	780	1040	660	820	510	**2110**	1040
A-225	860	860	560	460	530	440	470	390	...	...	950	950	640	520	580	470	520	430	...	...
B-225	1180	1100	750	560	700	520	570	420	...	...	1360	1290	870	640	770	570	650	480	...	...
C-225	1570	1410	940	660	870	610	680	470	...	...	1830	1700	1100	770	950	670	790	550	...	...
D-225	2060	1780	1130	760	1040	700	800	520	...	...	**2280**	2190	1340	900	1150	770	930	610	...	...
A-300	1220	1220	670	570	660	560	660	560	...	...	1340	1340	760	640	730	620	730	620	...	...
B-300	1340	1250	860	670	810	630	690	540	...	...	1530	1460	990	760	890	690	760	590	...	...
C-300	1730	1570	1040	760	980	720	780	570	...	...	2000	1870	1220	890	1070	780	900	660	...	...
D-300	2210	1930	1240	870	1150	810	890	620	...	...	**2450**	2360	1460	1020	1260	880	1030	720	...	...
A-375	1630	1630	870	760	870	760	870	760	...	...	1800	1800	960	830	960	840	960	840	...	...
B-375	1630	1630	970	780	920	740	900	730	...	...	1800	1800	1110	890	1000	800	990	800	...	...
C-375	1880	1720	1150	870	1080	820	930	710	...	...	2170	2040	1330	1010	1180	900	1020	780	...	...
D-375	2360	2090	1340	980	1250	910	990	720	...	...	**2620**	2530	1570	1140	1370	990	1140	830	...	...

TABLE 1 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[A, 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	670	460	320	380	260	330	220	670	490	490	340	420	290	360	240	530	530	520	360	450	310	390	270	570	570	
B-75	1130	740	480	600	380	490	300	1130	600	790	510	650	410	540	330	790	650	850	540	710	450	590	370	850	710	
C-75	1650	1030	640	800	480	640	370	1650	800	1090	680	870	530	710	420	1090	870	1160	720	940	570	780	460	1160	940	
D-75	**2150**	1330	800	1010	600	800	450	**2150**	1010	1410	860	1100	650	880	500	1410	1100	1500	910	1190	710	970	550	1500	1190	
A-150	850	590	450	510	390	440	340	1040	1040	630	480	550	420	480	370	1130	1130	670	510	590	450	530	400	1210	1210	
B-150	1320	870	610	720	500	610	420	1320	1040	930	650	780	540	660	460	1130	1130	990	690	840	580	730	500	1210	1210	
C-150	1840	1150	760	920	610	760	490	1840	1040	1220	810	1000	660	830	540	1220	1130	1300	860	1080	710	910	590	1300	1210	
D-150	**2330**	1450	930	1130	720	910	570	**2330**	1130	1540	990	1230	780	1000	620	1540	1230	1630	1050	1330	840	1100	680	1630	1330	
A-225	1040	720	580	630	510	570	460	...	...	770	620	680	550	620	500	...	...	810	650	730	590	670	540	...	...	
B-225	1500	1000	740	840	620	720	530	...	...	1070	780	910	670	790	580	...	...	1130	830	980	720	860	630	...	...	
C-225	2030	1280	890	1040	730	870	610	...	...	1360	950	1130	790	950	660	...	...	1440	1000	1210	850	1040	720	...	...	
D-225	**2520**	1580	1060	1250	840	1030	680	...	...	1670	1120	1350	910	1130	750	...	...	1760	1180	1460	980	1230	820	...	...	
A-300	1470	860	720	800	670	790	670	...	...	910	760	860	730	860	730	...	...	960	800	930	780	930	780	...	...	
B-300	1690	1130	870	960	740	840	650	...	...	1200	920	1040	800	910	710	...	...	1270	980	1120	860	990	770	...	...	
C-300	2210	1400	1020	1160	850	990	720	...	...	1490	1080	1250	920	1080	790	...	...	1580	1150	1350	980	1170	850	...	...	
D-300	**2700**	1700	1180	1370	960	1140	800	...	...	1800	1250	1480	1040	1250	870	...	...	1900	1320	1590	1110	1360	950	...	...	
A-375	1960	1050	910	1050	910	1050	910	...	...	1140	980	1140	980	1140	990	...	...	1230	1060	1230	1060	1230	1060	...	...	
B-375	1960	1260	1000	1090	870	1090	870	...	...	1340	1060	1180	940	1180	950	...	...	1420	1120	1270	1010	1270	1020	...	...	
C-375	2400	1530	1150	1280	970	1110	850	...	...	1620	1220	1380	1050	1210	920	...	...	1720	1290	1480	1120	1300	990	...	...	
D-375	**2890**	1820	1310	1480	1080	1250	910	...	...	1920	1390	1600	1160	1370	990	...	...	2030	1460	1720	1250	1490	1080	...	...	

TABLE 1 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[A, 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	480	330	430	290	610	610	620	420	530	360	480	330	650	650	670	460	570	390	520	350	700	700
B-75	930	600	760	480	650	400	930	760	1010	650	830	530	740	460	1010	830	1100	710	890	560	790	490	1100	890
C-75	1280	790	1020	620	850	500	1280	1020	1380	860	1110	680	970	580	1380	1110	1510	940	1190	720	1040	630	1510	1190
D-75	1650	1000	1290	770	1060	610	1650	1290	1790	1080	1410	840	1210	710	1790	1410	1950	1190	1500	890	1300	760	1950	1500
A-150	720	550	630	480	570	430	1300	1300	780	590	690	520	640	480	1380	1380	840	640	730	550	680	510	1470	1470
B-150	1080	750	910	630	790	540	1300	1300	1170	810	990	680	890	610	1380	1380	1270	880	1050	720	950	650	1470	1470
C-150	1420	940	1160	760	990	640	1420	1300	1540	1020	1260	830	1120	730	1540	1380	1670	1100	1350	890	1200	780	1670	1470
D-150	1790	1150	1420	910	1190	750	1790	1420	1930	1240	1550	990	1360	850	1930	1550	2100	1350	1650	1050	1460	920	2100	1650
A-225	880	710	780	630	710	580	...	...	950	760	850	680	790	640	...	...	1020	810	900	720	840	680	...	...
B-225	1230	900	1050	770	930	680	...	...	1330	970	1140	840	1040	760	...	...	1430	1050	1210	890	1110	810	...	...
C-225	1570	1090	1300	910	1130	780	...	...	1690	1180	1410	990	1270	880	...	...	1830	1270	1510	1050	1360	940	...	...
D-225	1930	1300	1560	1050	1330	880	...	...	2080	1390	1700	1140	1500	1000	...	...	2260	1510	1810	1210	1610	1070	...	...
A-300	1040	860	1000	840	1000	840	...	...	1110	930	1070	890	1060	890	...	...	1190	990	1130	940	1130	950	...	...
B-300	1380	1060	1200	920	1070	830	...	...	1490	1140	1300	1000	1190	920	...	...	1600	1220	1380	1050	1270	970	...	...
C-300	1720	1240	1440	1050	1270	920	...	...	1850	1340	1570	1140	1420	1030	...	...	1990	1440	1670	1210	1520	1100	...	...
D-300	2070	1440	1700	1190	1470	1020	...	...	2230	1550	1850	1290	1650	1150	...	...	2410	1670	1960	1370	1760	1230	...	...
A-375	1320	1130	1320	1130	1310	1140	...	...	1410	1200	1410	1210	1400	1210	...	...	1500	1280	1500	1280	1490	1280	...	...
B-375	1540	1210	1360	1090	1360	1090	...	...	1650	1300	1460	1160	1450	1160	...	...	1780	1400	1550	1230	1550	1230	...	...
C-375	1860	1400	1590	1200	1410	1060	...	...	2010	1500	1720	1300	1570	1180	...	...	2160	1610	1830	1370	1670	1260	...	...
D-375	2220	1590	1840	1330	1600	1160	...	...	2380	1710	2000	1450	1800	1300	...	...	2570	1840	2120	1530	1920	1390	...	...

TABLE 1 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[A, 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	710	480	610	410	560	380	740	740	740	510	640	440	600	400	780	780	780	530	690	460	640	430	820	820
B-75	1140	730	940	590	840	520	1140	940	1190	760	990	630	890	560	1190	990	1240	790	1040	660	940	590	1240	1040
C-75	1580	980	1270	770	1120	670	1580	1270	1650	1030	1340	820	1200	720	1650	1340	1730	1070	1420	870	1270	770	1730	1420
D-75	2030	1240	1590	950	1400	820	2030	1590	2120	1290	1690	1010	1490	880	2120	1690	2210	1350	1790	1070	1590	930	2210	1790
A-150	890	670	780	590	730	550	1560	1560	930	700	830	620	770	580	1640	1640	980	730	870	660	820	620	1730	1730
B-150	1320	910	1110	760	1010	690	1560	1560	1370	950	1170	810	1070	730	1640	1640	1430	990	1230	850	1130	770	1730	1730
C-150	1740	1150	1430	940	1280	840	1740	1560	1820	1210	1520	1000	1370	890	1820	1640	1910	1260	1600	1050	1450	950	1910	1730
D-150	2190	1410	1760	1120	1560	980	2190	1760	2290	1470	1860	1180	1660	1050	2290	1860	2380	1530	1960	1250	1760	1110	2380	1960
A-225	1070	850	950	760	900	720	...	...	1120	890	1010	800	950	760	...	...	1170	930	1060	850	1010	800	...	...
B-225	1490	1090	1280	940	1170	860	...	...	1550	1140	1340	990	1240	910	...	...	1620	1180	1410	1030	1310	960	...	...
C-225	1910	1330	1600	1110	1450	1000	...	...	2000	1390	1690	1170	1540	1070	...	...	2090	1450	1780	1240	1630	1130	...	...
D-225	2350	1580	1920	1280	1720	1150	...	...	2460	1640	2030	1360	1830	1220	...	...	2560	1710	2140	1430	1940	1290	...	...
A-300	1250	1030	1200	1000	1200	1000	...	...	1310	1080	1270	1050	1270	1050	...	...	1370	1130	1340	1110	1340	1110	...	...
B-300	1670	1270	1450	1110	1340	1030	...	...	1740	1320	1520	1170	1420	1090	...	...	1810	1380	1600	1220	1490	1150	...	...
C-300	2080	1500	1760	1280	1610	1170	...	...	2180	1570	1860	1350	1710	1240	...	...	2270	1640	1970	1420	1810	1310	...	...
D-300	2520	1750	2080	1450	1880	1310	...	...	2620	1820	2200	1530	2000	1390	...	...	2740	1900	2320	1610	2110	1470	...	...
A-375	1590	1350	1580	1360	1580	1360	...	...	1680	1420	1670	1430	1670	1430	...	...	1770	1500	1760	1500	1760	1500	...	...
B-375	1850	1450	1640	1300	1640	1300	...	...	1920	1510	1730	1370	1730	1370	...	...	2000	1570	1820	1440	1820	1450	...	...
C-375	2260	1680	1930	1450	1780	1340	...	...	2360	1760	2040	1530	1890	1420	...	...	2460	1830	2150	1610	2000	1500	...	...
D-375	2680	1920	2250	1620	2040	1480	...	...	2800	2000	2370	1710	2170	1560	...	...	2910	2080	2500	1800	2290	1650	...	...

TABLE 1 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[A, 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	840	570	740	500	690	460	860	860	880	600	780	530	730	490	900	900	920	620	820	550	770	520	940	940
B-75	1310	840	1110	700	1010	630	1310	1110	1360	870	1160	740	1060	670	1360	1160	1410	910	1220	770	1120	700	1410	1220
C-75	1840	1140	1520	930	1370	820	1840	1520	1910	1190	1610	980	1450	870	1910	1610	1990	1240	1690	1030	1530	920	1990	1690
D-75	2350	1430	1920	1150	1700	1000	2350	1920	2450	1490	2020	1210	1800	1060	2450	2020	2540	1550	2120	1270	1900	1120	2540	2120
A-150	1040	780	940	700	880	660	1820	1820	1090	810	990	730	930	690	1900	1900	1140	850	1040	770	980	730	1990	1990
B-150	1510	1040	1300	900	1200	830	1820	1820	1560	1080	1370	940	1260	870	1900	1900	1620	1120	1430	990	1330	910	1990	1990
C-150	2030	1340	1710	1120	1560	1020	2030	1820	2110	1390	1800	1180	1650	1070	2110	1900	2200	1450	1890	1240	1730	1130	2200	1990
D-150	2530	1620	2100	1340	1890	1190	2530	2100	2630	1690	2210	1400	1990	1260	2630	2210	2740	1750	2310	1470	2100	1330	2740	2310
A-225	1250	990	1140	900	1080	860	...	...	1300	1030	1190	940	1140	900	...	...	1360	1070	1250	990	1200	940	...	...
B-225	1710	1250	1500	1100	1390	1020	...	...	1770	1290	1570	1150	1460	1070	...	...	1840	1340	1640	1200	1540	1120	...	...
C-225	2220	1540	1900	1320	1750	1210	...	...	2310	1600	2000	1380	1840	1270	...	...	2400	1660	2100	1450	1940	1340	...	...
D-225	2720	1820	2280	1530	2070	1380	...	...	2820	1890	2400	1600	2190	1460	...	...	2930	1960	2510	1680	2300	1530	...	...
A-300	1460	1200	1410	1160	1400	1160	...	...	1520	1250	1470	1210	1470	1210	...	...	1580	1300	1540	1270	1540	1270	...	...
B-300	1910	1450	1700	1300	1590	1220	...	...	1980	1510	1770	1360	1670	1280	...	...	2050	1560	1850	1420	1750	1340	...	...
C-300	2410	1740	2100	1520	1940	1400	...	...	2510	1810	2200	1590	2040	1470	...	...	2610	1880	2300	1660	2140	1550	...	...
D-300	2900	2010	2470	1720	2260	1570	...	...	3010	2090	2590	1800	2380	1650	...	...	3130	2170	2710	1890	2500	1740	...	...
A-375	1860	1570	1860	1580	1850	1580	...	...	1950	1640	1950	1650	1940	1650	...	...	2040	1720	2040	1720	2030	1720	...	...
B-375	2110	1660	1920	1510	1910	1520	...	...	2190	1720	2010	1590	2000	1590	...	...	2270	1780	2100	1660	2100	1660	...	...
C-375	2610	1940	2290	1710	2130	1600	...	...	2710	2010	2400	1790	2240	1680	...	...	2820	2090	2510	1870	2350	1760	...	...
D-375	3090	2210	2660	1910	2450	1760	...	...	3210	2290	2790	2000	2570	1850	...	...	3330	2380	2920	2090	2700	1940	...	...

TABLE 1 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[A, 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	1020	690	910	610	850	570	1020	980	1110	750	1000	670	940	630	1210	810	1100	730	1040	690
B-75	1550	1000	1340	850	1230	770	1550	1340	1660	1060	1460	920	1340	840	1780	1140	1580	1000	1460	920
C-75	2210	1370	1860	1140	1690	1020	2210	1860	2370	1470	2020	1240	1840	1110	2500	1550	2170	1330	1990	1200
D-75	2830	1720	2340	1400	2100	1240	2830	2340	3020	1840	2550	1530	2300	1360	**3150**	**1920**	2760	1660	2520	1490
A-150	1260	930	1140	850	1080	800	2080	2080	1370	1010	1250	920	1190	870	1480	1080	1360	1000	1300	950
B-150	1790	1230	1570	1080	1450	1000	2080	2080	1910	1320	1700	1170	1580	1090	2040	1400	1830	1260	1720	1180
C-150	2430	1600	2080	1360	1900	1240	2430	2080	2600	1710	2260	1480	2070	1350	2750	1810	2420	1580	2230	1460
D-150	3040	1940	2550	1620	2310	1460	3040	2550	3250	2070	2770	1760	2530	1600	**3400**	**2180**	3000	1910	2760	1740
A-225	1500	1180	1370	1080	1310	1030	...	...	1620	1270	1500	1170	1430	1120	1750	1360	1630	1270	1560	1210
B-225	2020	1470	1790	1310	1680	1220	...	...	2160	1570	1940	1410	1820	1330	2300	1670	2090	1520	1980	1440
C-225	2660	1830	2310	1590	2120	1460	...	...	2840	1960	2490	1720	2310	1590	3000	2070	2670	1840	2480	1710
D-225	3250	2160	2770	1840	2520	1680	...	...	3470	2310	3000	2000	2760	1830	**3650**	**2440**	3240	2160	3000	1990
A-300	1740	1420	1610	1320	1610	1320	...	...	1880	1530	1750	1430	1750	1430	2020	1630	1890	1530	1890	1530
B-300	2260	1710	2020	1540	1900	1450	...	...	2410	1820	2190	1660	2070	1570	2560	1940	2350	1790	2230	1700
C-300	2880	2070	2530	1820	2350	1690	...	...	3080	2200	2730	1960	2540	1830	3250	2330	2920	2100	2740	1970
D-300	3470	2390	2980	2070	2740	1900	...	...	3700	2550	3230	2240	2990	2070	**3890**	**2690**	3490	2410	3240	2240
A-375	2130	1790	2130	1790	2130	1790	...	...	2310	1930	2310	1940	2310	1940	2500	2080	2490	2080	2490	2080
B-375	2490	1950	2260	1780	2190	1730	...	...	2660	2080	2430	1910	2370	1870	2830	2210	2610	2050	2560	2010
C-375	3110	2300	2750	2050	2570	1910	...	...	3320	2450	2970	2210	2780	2070	3510	2590	3170	2360	2990	2230
D-375	3690	2620	3200	2290	2960	2120	...	...	3930	2790	3470	2480	3220	2310	**4150**	**2960**	3730	2660	3490	2490

TABLE 1 *Continued*

Circumferential reinforcement, mm^2/linear m of pipe[A, B]																						
Internal Designated Dia, mm	2250				2400				2550				2700				3050		3350		3650	
Type of Reinforcement	Circular				Circular				Circular				Circular				Circular		Circular		Circular	
Wall Thickness, mm	188		200		200		213		213		225		225		238		254		279		305	
Layers of Reinforcement	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer
Class																						
A-75	1310	880	1250	830	1410	940	1360	900	1520	1010	1470	970	1640	1080	1580	1040	1880	1240	2140	1400	2420	1570
B-75	1900	1210	1790	1140	2020	1290	1920	1220	2160	1370	2050	1300	2290	1460	2190	1390	2580	1640	2890	1830	3210	2030
C-75	2640	1630	2460	1520	2780	1720	2610	1610	2930	1820	2770	1710	3090	1910	2930	1810	3420	2120	3770	2330	4140	2560
D-75	**3360**	**2050**	3190	1930	**3580**	**2180**	3410	2060	**3790**	**2310**	**3570**	**2160**	**3980**	**2420**	**3750**	**2280**	S	S	S	S	S	S
A-150	1590	1160	1530	1120	1710	1240	1650	1200	1830	1330	1780	1290	1960	1420	1910	1370	2240	1600	2520	1790	2830	1990
B-150	2170	1490	2060	1420	2310	1590	2210	1510	2460	1680	2360	1610	2610	1780	2510	1710	2920	1990	3260	2210	3610	2440
C-150	2900	1910	2720	1790	3060	2010	2890	1900	3220	2120	3060	2010	3390	2230	3230	2120	3750	2460	4130	2710	4530	2960
D-150	**3620**	**2320**	3440	2190	**3850**	**2460**	3670	2340	**4080**	**2610**	**3860**	**2460**	**4270**	**2740**	**4050**	**2590**	S	S	S	S	S	S
A-225	1880	1450	1810	1400	2010	1550	1950	1500	2150	1650	2090	1600	2290	1750	2230	1710	2600	1960	2910	2190	3250	2420
B-225	2450	1780	2340	1700	2600	1880	2500	1810	2760	2000	2660	1920	2930	2110	2830	2040	3270	2350	3640	2600	4020	2860
C-225	3160	2180	2990	2060	3340	2300	3170	2190	3520	2420	3350	2310	3700	2550	3540	2440	4090	2810	4500	3080	4920	3370
D-225	**3880**	**2590**	3690	2450	**4120**	**2750**	3940	2620	**4370**	**2910**	**4140**	**2760**	**4570**	**3050**	**4350**	**2900**	S	S	S	S	S	S
A-300	2160	1740	2100	1690	2310	1850	2250	1800	2470	1970	2400	1920	2630	2090	2560	2040	2960	2330	3310	2590	3670	2850
B-300	2730	2060	2620	1980	2900	2180	2790	2110	3070	2310	2970	2230	3250	2440	3150	2370	3630	2710	4020	2990	4430	3280
C-300	3430	2460	3260	2340	3620	2590	3450	2480	3810	2730	3650	2620	4010	2870	3850	2760	4430	3160	4860	3470	5320	3780
D-300	**4140**	**2860**	3950	2720	**4400**	**3030**	4210	2900	**4660**	**3210**	**4430**	**3060**	**4880**	**3360**	**4660**	**3210**	S	S	S	S	S	S
A-375	2680	2220	2680	2220	2860	2360	2860	2370	3050	2510	3050	2510	3230	2650	3230	2650	3600	2930	3980	3210	4350	3490
B-375	3010	2350	2900	2260	3190	2490	3080	2410	3380	2630	3280	2550	3580	2770	3470	2700	3980	3070	4410	3380	4850	3700
C-375	3700	2740	3530	2620	3900	2890	3740	2770	4110	3040	3950	2920	4330	3190	4170	3080	4770	3520	5240	3850	5720	4200
D-375	**4410**	**3140**	4210	2990	**4670**	**3320**	4810	3180	**4950**	**3510**	**4730**	**3360**	**5190**	**3680**	**4970**	**3530**	S	S	S	S	S	S

[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 Design Requirements for Reinforced Concrete Low-Head Pressure Pipe [300 to 3650 mm Diameter], Concrete Design Strength 34.5 MPa (except as noted) Steel Reinforcement Yield Strength 414 Mpa

NOTE 1—See Appendix for specific installation conditions and design criteria conditions required in conjunction with the use of Table 2.

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.

NOTE 3—An "s" in place of a steel area indicates the pipe class is a special design requiring stirrup reinforcement. Stirrups may be eliminated by changing wall thickness, main reinforcement, concrete strength, or a combination thereof.

NOTE 4—The boldfaced value denotes 41.4 MPa concrete strength required.

Circumferential reinforcement, mm^2/linear m of pipe[A, 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	100	100	130	130	170	150	250	250	210	190	290	290	260	230	330	330	300	280	190	130	160	110	370	370		
B-75	140	110	200	160	260	220	260	250	330	280	330	290	410	360	410	360	490	430	290	180	230	140	490	370		
C-75	190	140	280	210	360	290	360	290	460	380	460	380	580	490	580	490	700	590	400	240	300	170	700	400		
D-75	240	180	360	260	470	360	470	360	610	490	610	490	770	630	770	630	950	780	500	290	370	200	950	500		
A-150	220	220	270	270	320	320	520	520	380	380	610	610	430	430	690	690	490	490	280	210	280	210	780	780		
B-150	220	220	270	270	320	320	520	520	400	380	610	610	490	440	690	690	590	520	360	250	290	200	780	780		
C-150	230	220	330	270	420	350	520	520	530	450	610	610	660	570	690	690	800	690	460	300	360	230	800	780		
D-150	280	220	410	310	530	420	530	520	680	560	680	610	850	720	850	720	1050	870	570	360	430	260	1050	780		
A-225	340	340	430	430	520	520	...	...	600	600	...	...	690	690	...	...	770	770	430	350	430	350	...	...		
B-225	340	340	430	430	520	520	...	...	600	600	...	...	690	690	...	...	770	770	440	330	440	330	...	...		
C-225	340	340	430	430	520	520	...	...	610	600	...	...	740	690	...	...	890	780	520	370	460	320	...	...		
D-225	340	340	470	430	590	520	...	...	750	630	...	...	930	800	...	...	1140	960	630	420	490	320	...	...		
A-300	490	490	610	610	730	730	...	...	860	860	...	...	980	980	...	...	1100	1100	590	500	590	510	...	...		
B-300	490	490	610	610	730	730	...	...	860	860	...	...	980	980	...	...	1100	1100	620	480	620	480	...	...		
C-300	490	490	610	610	730	730	...	...	860	860	...	...	980	980	...	...	1100	1100	630	470	630	470	...	...		
D-300	490	490	610	610	730	730	...	...	860	860	...	...	1020	980	...	...	1230	1100	690	490	650	450	...	...		
A-375	650	650	820	820	980	980	...	...	1140	1140	...	...	1310	1310	...	...	1470	1470	790	680	780	690	...	...		
B-375	650	650	820	820	980	980	...	...	1140	1140	...	...	1310	1310	...	...	1470	1470	810	660	810	660	...	...		
C-375	650	650	820	820	980	980	...	...	1140	1140	...	...	1310	1310	...	...	1470	1470	830	640	830	640	...	...		
D-375	650	650	820	820	980	980	...	...	1140	1140	...	...	1310	1310	...	...	1470	1470	850	620	850	620	...	...		

TABLE 2 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[A, 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	350	330	230	160	210	150	170	110	410	410	400	380	260	180	230	160	200	130	450	450
B-75	580	520	350	220	330	210	250	150	580	410	680	630	420	270	360	230	290	180	680	450
C-75	840	740	480	290	440	270	320	180	840	440	1000	900	580	350	490	290	380	220	1000	490
D-75	1160	980	620	360	560	330	400	220	1160	560	**1290**	1230	740	450	620	360	480	270	**1290**	620
A-150	540	540	310	230	310	230	310	230	870	870	590	590	350	260	340	260	340	260	950	950
B-150	690	630	430	300	400	280	320	220	870	870	790	750	500	350	440	300	360	250	950	950
C-150	950	840	550	360	510	340	390	250	950	870	1110	1020	650	430	560	370	450	290	1110	950
D-150	1270	1080	680	440	630	400	470	280	1270	870	**1410**	1350	820	520	690	440	550	340	**1410**	950
A-225	860	860	470	390	470	390	470	390	...	...	950	950	520	420	520	420	520	430	...	...
B-225	860	860	500	370	490	370	490	370	...	...	950	950	580	430	540	400	540	400	...	...
C-225	1050	940	620	440	580	410	510	350	...	...	1220	1130	730	510	640	450	560	390	...	...
D-225	1370	1190	750	510	700	470	530	350	...	...	**1520**	1460	890	600	760	510	620	410	...	...
A-300	1220	1220	660	560	660	560	660	560	...	...	1340	1340	730	610	730	620	730	620	...	...
B-300	1220	1220	690	530	690	530	690	540	...	...	1340	1340	760	590	760	590	760	590	...	...
C-300	1220	1220	710	520	700	520	710	520	...	...	1340	1340	810	590	780	570	780	570	...	...
D-300	1470	1290	820	580	770	540	720	500	...	...	**1630**	1570	970	680	840	590	790	550	...	...
A-375	1630	1630	870	760	870	760	870	760	...	...	1800	1800	960	830	960	840	960	840	...	...
B-375	1630	1630	910	730	900	730	900	730	...	...	1800	1800	1000	800	1000	800	990	800	...	...
C-375	1630	1630	930	700	930	710	930	710	...	...	1800	1800	1020	770	1020	780	1020	780	...	...
D-375	1690	1630	950	690	950	690	950	690	...	...	**1800**	1800	1050	760	1040	760	1040	760	...	...

TABLE 2 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[A, 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	440	310	210	250	180	220	150	490	490	330	230	280	190	240	160	530	530	350	240	300	210	260	180	570	570	
B-75	760	500	320	400	250	330	200	760	490	530	340	430	270	360	220	530	530	560	360	470	300	400	240	570	570	
C-75	1100	680	420	530	320	430	250	1100	530	730	450	580	350	470	280	730	580	770	480	630	380	520	310	770	630	
D-75	**1430**	890	540	680	400	530	300	**1430**	680	940	570	740	440	590	340	940	740	1000	600	800	470	650	370	1000	800	
A-150	650	390	300	370	280	370	280	1040	1040	420	320	400	300	400	300	1130	1130	440	340	430	330	430	330	1210	1210	
B-150	880	580	400	480	330	400	280	1040	1040	620	430	520	360	440	300	1130	1130	660	460	560	390	480	330	1210	1210	
C-150	1230	770	510	610	400	500	330	1230	1040	820	540	670	440	550	360	1130	1130	870	570	720	470	610	390	1210	1210	
D-150	**1550**	970	620	750	480	610	380	**1550**	1040	1030	660	820	520	670	420	1130	1130	1090	700	880	560	730	460	1210	1210	
A-225	1030	570	460	570	460	570	460	...	...	620	500	620	500	620	500	...	...	670	540	670	540	670	540	...	...	
B-225	1030	670	490	590	440	590	440	...	...	710	520	640	480	640	480	...	...	750	550	690	510	690	510	...	...	
C-225	1350	850	590	690	480	610	420	...	...	900	630	750	520	660	460	...	...	960	670	810	560	710	490	...	...	
D-225	**1680**	1050	700	830	560	680	450	...	...	1110	750	900	600	750	500	...	...	1180	790	970	650	820	540	...	...	
A-300	1470	800	670	800	670	790	670	...	...	860	720	860	730	860	730	...	...	930	780	930	780	930	780	...	...	
B-300	1470	830	640	830	640	830	640	...	...	900	690	900	690	900	690	...	...	970	740	970	740	970	750	...	...	
C-300	1470	940	680	850	620	850	620	...	...	990	720	920	670	920	670	...	...	1050	760	990	720	990	720	...	...	
D-300	**1800**	1130	790	910	640	860	600	...	...	1200	830	980	690	940	650	...	...	1270	880	1060	740	1010	700	...	...	
A-375	1960	1050	910	1050	910	1050	910	...	...	1140	980	1140	980	1140	990	...	...	1230	1060	1230	1060	1230	1060	...	...	
B-375	1960	1090	870	1090	870	1090	870	...	...	1180	940	1180	940	1180	950	...	...	1280	1010	1270	1010	1270	1020	...	...	
C-375	1960	1120	840	1110	850	1110	850	...	...	1210	910	1210	920	1210	920	...	...	1310	980	1300	980	1300	990	...	...	
D-375	**1960**	1210	870	1140	820	1140	820	...	...	1280	920	1230	890	1230	890	...	...	1360	980	1330	960	1330	960	...	...	

TABLE 2 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[A, 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	380	260	320	220	280	190	610	610	410	280	350	240	320	220	650	650	450	310	380	260	350	230	700	700
B-75	620	400	510	320	430	270	620	610	670	430	560	350	490	310	670	650	730	470	590	370	530	330	730	700
C-75	850	530	680	410	570	330	850	680	920	570	740	450	650	390	920	740	1000	620	790	480	700	420	1000	790
D-75	1100	670	860	510	700	410	1100	860	1190	720	940	560	810	470	1190	940	1300	790	1000	600	870	510	1300	1000
A-150	480	370	460	350	460	350	1300	1300	520	390	490	370	490	370	1380	1380	560	420	520	400	520	400	1470	1470
B-150	720	500	600	420	530	360	1300	1300	780	540	660	450	590	410	1380	1380	840	580	700	480	630	430	1470	1470
C-150	950	630	770	510	660	430	1300	1300	1020	680	840	550	750	490	1380	1380	1110	740	900	590	800	520	1470	1470
D-150	1190	770	950	600	790	500	1300	1300	1290	830	1030	660	900	570	1380	1380	1400	900	1100	700	970	610	1470	1470
A-225	720	570	710	580	710	580	...	...	770	610	760	610	760	610	...	...	810	650	810	650	810	650	...	...
B-225	820	600	740	550	740	550	...	...	890	650	790	580	790	580	...	...	960	700	840	620	840	620	...	...
C-225	1050	730	870	610	760	530	...	...	1130	780	940	660	850	590	...	...	1220	850	1000	700	900	630	...	...
D-225	1290	860	1040	700	890	590	...	...	1390	930	1130	760	1000	670	...	...	1500	1010	1210	810	1070	720	...	...
A-300	1000	830	1000	840	1000	840	...	...	1070	890	1070	890	1060	890	...	...	1140	940	1130	940	1130	950	...	...
B-300	1040	790	1040	800	1040	800	...	...	1110	850	1110	850	1110	850	...	...	1180	900	1180	900	1170	900	...	...
C-300	1140	830	1060	770	1060	770	...	...	1230	890	1130	820	1130	820	...	...	1330	960	1200	870	1200	870	...	...
D-300	1380	960	1130	790	1080	750	...	...	1490	1030	1230	860	1150	800	...	...	1610	1120	1310	910	1220	850	...	...
A-375	1320	1130	1320	1130	1310	1140	...	...	1410	1200	1410	1210	1400	1210	...	...	1500	1280	1500	1280	1490	1280	...	...
B-375	1370	1080	1360	1090	1360	1090	...	...	1460	1150	1460	1160	1450	1160	...	...	1550	1220	1550	1230	1550	1230	...	...
C-375	1400	1050	1400	1050	1390	1060	...	...	1500	1120	1490	1120	1490	1120	...	...	1590	1190	1580	1190	1580	1190	...	...
D-375	1480	1060	1420	1030	1420	1030	...	...	1590	1140	1520	1100	1520	1100	...	...	1710	1230	1610	1160	1610	1170	...	...

TABLE 2 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[A, 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	470	320	400	270	370	250	740	740	500	340	430	290	400	270	780	780	520	360	460	310	420	290	820	820
B-75	760	490	630	400	560	350	760	740	790	510	660	420	590	370	790	780	820	530	690	440	630	390	820	820
C-75	1050	650	840	520	750	450	1050	840	1100	680	900	550	800	480	1100	900	1150	720	950	580	850	510	1150	950
D-75	1360	830	1060	640	930	550	1360	1060	1410	860	1130	670	990	580	1410	1130	1480	900	1190	710	1060	620	1480	1190
A-150	590	440	560	420	560	420	1560	1560	620	470	590	440	590	440	1640	1640	650	490	620	460	620	460	1730	1730
B-150	880	610	740	510	670	460	1560	1560	910	630	780	540	710	490	1640	1640	950	660	820	560	750	520	1730	1730
C-150	1160	770	950	630	860	560	1560	1560	1220	800	1010	660	910	590	1640	1640	1270	840	1070	700	970	630	1730	1730
D-150	1460	940	1170	750	1040	650	1560	1560	1530	980	1240	790	1110	700	1640	1640	1590	1020	1310	830	1170	740	1730	1730
A-225	860	690	860	690	860	690	...	...	910	720	910	730	910	730	...	...	960	760	960	760	960	760	...	...
B-225	1000	730	890	660	890	660	...	...	1040	760	940	690	940	690	...	...	1080	790	990	730	990	730	...	...
C-225	1280	890	1060	740	970	670	...	...	1330	930	1130	780	1030	710	...	...	1390	970	1190	830	1090	750	...	...
D-225	1570	1050	1280	860	1150	760	...	...	1640	1100	1350	910	1220	810	...	...	1710	1140	1430	950	1290	860	...	...
A-300	1200	1000	1200	1000	1200	1000	...	...	1270	1050	1270	1050	1270	1050	...	...	1340	1100	1340	1110	1340	1110	...	...
B-300	1250	950	1250	950	1240	960	...	...	1320	1000	1310	1010	1310	1010	...	...	1390	1060	1380	1060	1380	1060	...	...
C-300	1390	1000	1270	930	1270	930	...	...	1450	1050	1350	980	1350	980	...	...	1510	1090	1420	1030	1420	1030	...	...
D-300	1680	1160	1390	970	1300	900	...	...	1750	1210	1470	1020	1370	950	...	...	1820	1270	1540	1080	1440	1000	...	...
A-375	1590	1350	1580	1360	1580	1360	...	...	1680	1420	1670	1430	1670	1430	...	...	1770	1500	1760	1500	1760	1500	...	...
B-375	1650	1290	1640	1300	1640	1300	...	...	1740	1370	1730	1370	1730	1370	...	...	1830	1440	1820	1440	1820	1450	...	...
C-375	1680	1260	1680	1260	1680	1260	...	...	1780	1330	1770	1330	1770	1330	...	...	1870	1390	1870	1400	1870	1400	...	...
D-375	1790	1280	1710	1230	1710	1230	...	...	1860	1330	1800	1300	1800	1300	...	...	1940	1390	1900	1370	1900	1370	...	...

TABLE 2 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[A, 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	560	380	490	330	460	310	860	860	580	400	520	350	480	330	900	900	610	420	550	370	510	340	940	940
B-75	870	560	740	470	670	420	870	860	910	580	780	490	710	440	910	900	940	600	810	520	750	470	940	940
C-75	1220	760	1020	620	910	550	1220	1020	1280	790	1070	650	970	580	1280	1070	1330	830	1130	690	1020	620	1330	1130
D-75	1570	960	1280	760	1140	670	1570	1280	1630	990	1340	810	1200	710	1630	1340	1690	1030	1410	850	1270	750	1690	1410
A-150	690	520	650	490	650	490	1820	1820	730	540	680	510	680	510	1900	1900	760	560	710	530	710	530	1990	1990
B-150	1000	700	870	600	800	550	1820	1820	1040	720	910	630	840	580	1900	1900	1080	750	950	660	880	610	1990	1990
C-150	1350	890	1140	750	1040	680	1820	1820	1410	930	1200	790	1100	710	1900	1900	1460	970	1260	830	1160	750	1990	1990
D-150	1690	1080	1400	890	1260	790	1820	1820	1760	1130	1470	940	1330	840	1900	1900	1820	1170	1540	980	1400	880	1990	1990
A-225	1010	800	1010	800	1010	800	...	...	1060	830	1060	840	1060	840	...	...	1110	870	1110	870	1110	870	...	...
B-225	1140	830	1040	760	1040	760	...	...	1180	860	1090	800	1090	800	...	...	1230	890	1140	840	1140	840	...	...
C-225	1480	1020	1270	880	1160	810	...	...	1540	1070	1330	920	1230	850	...	...	1600	1110	1400	970	1290	890	...	...
D-225	1810	1210	1520	1020	1380	920	...	...	1880	1260	1600	1070	1460	970	...	...	1950	1310	1670	1120	1530	1020	...	...
A-300	1410	1160	1410	1160	1400	1160	...	...	1480	1210	1470	1210	1470	1210	...	...	1550	1260	1540	1270	1540	1270	...	...
B-300	1460	1110	1450	1110	1450	1110	...	...	1530	1160	1520	1160	1520	1170	...	...	1600	1210	1590	1220	1590	1220	...	...
C-300	1610	1160	1490	1080	1490	1080	...	...	1670	1200	1560	1130	1560	1130	...	...	1740	1250	1630	1180	1630	1180	...	...
D-300	1930	1340	1650	1150	1510	1050	...	...	2010	1390	1730	1200	1590	1100	...	...	2090	1450	1810	1260	1670	1160	...	...
A-375	1860	1570	1860	1580	1850	1580	...	...	1950	1640	1950	1650	1940	1650	...	...	2040	1720	2040	1720	2030	1720	...	...
B-375	1920	1510	1920	1510	1910	1520	...	...	2010	1580	2010	1590	2000	1590	...	...	2100	1650	2100	1660	2100	1660	...	...
C-375	1970	1460	1960	1470	1960	1470	...	...	2060	1530	2060	1540	2060	1540	...	...	2160	1600	2150	1610	2150	1610	...	...
D-375	2060	1470	1990	1440	1990	1440	...	...	2140	1530	2090	1500	2090	1500	...	...	2220	1590	2190	1570	2190	1570	...	...

TABLE 2 *Continued*

Circumferential reinforcement, mm²/linear m of pipe[A, 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	680	460	610	410	570	380	980	980	740	500	670	450	630	420	800	540	730	490	690	460
B-75	1040	660	890	570	820	510	1040	980	1110	710	970	610	900	560	1180	760	1050	670	980	610
C-75	1470	910	1240	760	1120	680	1470	1240	1580	980	1350	820	1230	740	1670	1030	1440	880	1320	800
D-75	1890	1140	1560	930	1400	830	1890	1560	2020	1220	1700	1020	1540	910	**2100**	**1280**	1840	1110	1680	990
A-150	840	620	760	560	750	550	2080	2080	910	670	830	610	810	600	980	720	910	670	870	640
B-150	1190	820	1040	720	970	660	2080	2080	1270	880	1130	780	1050	720	1360	940	1220	840	1150	780
C-150	1620	1070	1390	910	1270	830	2080	2080	1740	1140	1500	980	1380	900	1830	1200	1610	1050	1490	970
D-150	2030	1290	1700	1080	1540	970	2080	2080	2160	1380	1850	1180	1690	1060	**2270**	**1450**	2000	1270	1840	1160
A-225	1160	910	1160	910	1160	910	...	...	1260	980	1260	980	1260	980	1360	1050	1360	1050	1360	1050
B-225	1350	980	1200	870	1190	870	...	...	1440	1050	1290	940	1290	940	1530	1110	1400	1010	1400	1010
C-225	1770	1220	1540	1060	1420	980	...	...	1890	1300	1660	1150	1540	1060	2000	1380	1780	1230	1660	1140
D-225	2170	1440	1840	1230	1680	1120	...	...	2600	1540	2000	1330	1840	1220	**2430**	**1620**	2160	1440	2000	1330
A-300	1620	1320	1610	1320	1610	1320	...	...	1750	1420	1750	1430	1750	1430	1890	1530	1890	1530	1890	1530
B-300	1670	1270	1660	1270	1660	1270	...	...	1810	1370	1800	1370	1800	1370	1950	1470	1940	1480	1940	1480
C-300	1920	1380	1710	1230	1710	1230	...	...	2050	1470	1850	1330	1850	1330	2170	1550	1990	1430	1990	1430
D-300	2550	1590	1990	1380	1830	1270	...	...	3100	1700	2160	1490	1990	1380	**2620**	**1800**	2330	1610	2160	1490
A-375	2130	1790	2130	1790	2130	1790	...	...	2310	1930	2310	1940	2310	1940	2500	2080	2490	2080	2490	2080
B-375	2200	1720	2190	1730	2190	1730	...	...	2380	1860	2380	1870	2370	1870	2570	2010	2560	2010	2560	2010
C-375	2260	1660	2250	1670	2250	1670	...	...	2470	1780	2440	1810	2430	1810	2670	1910	2620	1950	2620	1950
D-375	2960	1750	2280	1640	2280	1640	...	...	3600	1860	2480	1770	2480	1770	**2890**	**1970**	2680	1890	2670	1910

TABLE 2 *Continued*

Circumferential reinforcement, mm^2/linear m of pipe[A, B]																						
Internal Designated Dia, mm	2250				2400				2550				2700				3050		3350		3650	
Type of Reinforcement	Circular				Circular				Circular				Circular				Circular		Circular		Circular	
Wall Thickness, mm	188		200		200		213		213		225		225		238		254		279		305	
Layers of Reinforcement	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer
Class																						
A-75	870	580	830	560	940	630	900	600	1010	670	980	650	1090	720	1050	700	1250	820	1430	930	1610	1050
B-75	1270	810	1190	760	1350	860	1280	810	1440	920	1370	870	1530	970	1460	930	1720	1090	1920	1220	2140	1350
C-75	1760	1090	1640	1010	1850	1150	1740	1070	1950	1210	1850	1140	2060	1280	1950	1200	2280	1410	2510	1560	2760	1710
D-75	**2240**	**1370**	2120	1280	**2380**	**1450**	2270	1370	**2530**	**1540**	**2380**	**1440**	**2650**	**1620**	**2500**	**1520**	S	S	S	S	S	S
A-150	1060	770	1020	750	1140	830	1100	800	1220	890	1180	860	1310	940	1270	920	1490	1070	1680	1190	1890	1330
B-150	1450	1000	1380	950	1540	1060	1470	1010	1640	1120	1570	1070	1740	1190	1670	1140	1950	1330	2170	1470	2410	1630
C-150	1930	1270	1820	1190	2040	1340	1930	1260	2150	1410	2040	1340	2260	1490	2160	1410	2500	1640	2750	1800	3020	1980
D-150	**2410**	**1550**	2330	1460	**2560**	**1640**	2800	1560	**2720**	**1740**	**2570**	**1640**	**2850**	**1820**	**2700**	**1720**	S	S	S	S	S	S
A-225	1460	1130	1460	1130	1560	1200	1560	1200	1660	1270	1660	1270	1760	1340	1760	1340	1960	1480	2160	1620	2370	1760
B-225	1630	1180	1560	1130	1740	1260	1660	1210	1840	1330	1770	1280	1950	1410	1880	1360	2180	1570	2430	1730	2680	1900
C-225	2110	1450	1990	1370	2220	1530	2110	1460	2340	1610	2240	1540	2470	1700	2360	1630	2720	1870	3000	2060	3330	2250
D-225	**2590**	**1730**	2890	1640	**2750**	**1830**	3470	1740	**3020**	**1940**	**2760**	**1840**	**3260**	**2030**	**2900**	**1930**	S	S	S	S	S	S
A-300	2030	1630	2030	1640	2170	1740	2170	1740	2310	1840	2310	1850	2450	1950	2450	1950	2730	2150	3020	2360	3300	2560
B-300	2090	1580	2090	1580	2230	1680	2230	1680	2370	1780	2370	1780	2510	1890	2510	1890	2800	2090	3080	2290	3400	2470
C-300	2290	1640	2170	1560	2440	1730	2300	1650	2590	1820	2430	1740	2750	1910	2570	1840	3070	2110	3420	2310	3780	2520
D-300	**2820**	**1910**	3460	1810	**3100**	**2020**	4140	1930	**3600**	**2140**	**2980**	**2040**	**3880**	**2240**	**3170**	**2140**	S	S	S	S	S	S
A-375	2680	2220	2680	2220	2860	2360	2860	2370	3050	2510	3050	2510	3230	2650	3230	2650	3600	2930	3980	3210	4370	3470
B-375	2750	2150	2750	2150	2940	2290	2940	2290	3130	2420	3120	2430	3330	2550	3310	2570	3740	2790	4160	3030	4570	3270
C-375	2870	2030	2830	2070	3070	2160	3030	2190	3270	2280	3240	2320	3480	2400	3440	2440	3890	2650	4300	2890	4720	3120
D-375	**3100**	**2090**	4020	1990	**3600**	**2220**	4810	2120	**4170**	**2340**	**3410**	**2250**	**4510**	**2460**	**3680**	**2370**	S	S	S	S	S	S

[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.

manufacture. 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.

6.9.1.1 *Standard Gasket Requirements*—All rubber gaskets shall meet the dimensions, tolerances, and physical requirements of Specification C1619, Class A.

6.9.1.2 *Oil Resistant Gasket Requirements*—All rubber gaskets shall meet the dimensions, tolerances, and physical requirements of Specification C1619, Class B.

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 ±5 from the manufacturer's specified hardness, provided the actual hardness is within the limits of 35 to 65.

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.

6.11 *Mixing Water*—Water used in the production of concrete shall be potable or non-potable water that meets the requirements of Specification C1602/C1602M.

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, 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 and Table 2. 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 and Table 2. 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 and Table 2, except that for pipe sizes 900 mm and less with wall thicknesses equal to or greater than 82 mm, 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 the particular class of pipe. The areas of circumferential reinforcement shown in Table 1 and Table 2 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 The steel areas in Table 1 and Table 2 for inner and outer reinforcement are based on a single layer of reinforcement for that steel area. A line of reinforcement may be composed of more than one layer. However, this requires a special design in accordance with 7.2 and Appendix X2. If more than one layer of reinforcement is used, 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 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 used in the barrel of the pipe 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 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 reinforcement 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 the specified yield strength of the bars or wires spliced 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 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 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 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 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 For design pressures greater than 75 kilopascals, the rubber gaskets shall be solid gaskets of circular cross section. For design pressures less than or equal to 75 kilopascals, 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 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 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 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*—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 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 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 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 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 C309. 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 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 compressive strength as specified in 10.3.3. Compression tests of such cylinders shall be made in accordance with Test Method C39/C39M.

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 C31/C31M, 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 of Test Methods C497M 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 C497M. Before the test pressure is applied, the pipe shall 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. To minimize the stress in the pipe wall due to the weights of pipe and water during the hydrostatic test, it is not prohibited to

support the pipe on two longitudinal line bearings in planes each separated from the vertical centerline of the pipe section by 15 degrees.

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 shall be provided with the pipe adjacent to and on either side of the joint, or the manufacturer shall 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 water-tightness 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 *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 3. 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 C497M) 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

TABLE 3 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

(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 It is not prohibited for pipe to 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 shall be repaired. Such fillings shall be kept moist under wet burlap for at least 48 h. Hydrostatic testing of repaired pipe shall 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 It is not prohibited for pipe to 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 and Table 2.

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.

APPENDIXES

(Nonmandatory Information)

X1. FIELD INSTALLATION PROCEDURE

X1.1 The class of pipe given in Table 1 and Table 2 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.

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,

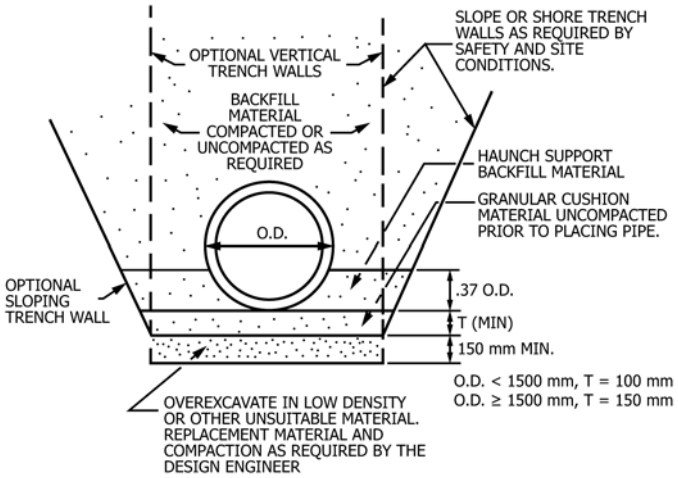

FIG. X1.1 Pipe Bedding

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 D698.

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 D4253 and D4254.

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 TABLES 1 AND 2

X2.1 The designs for reinforced concrete low-head pressure pipe presented in Table 1 and Table 2 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. The reinforcement areas shown in Table 1 and Table 2 were obtained by converting the corresponding values in $in.^2/ft$ units from Tables 1 and 2 in Specification C361 to metric units.

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:

$$w_e = 1992 + 384(H_e/OD)$$

where:

H_e = earth cover over top of pipe, m,
OD = outside diameter of pipe, m, and
max w_e = 2688 kg/m^3.

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

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

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 for earth, water, and live loads and 45° for pipe dead load. Pressure distributions and the analysis of stresses in the pipe wall are based on theory.[6]

X2.4 *Design Requirements*—Reinforced low-head concrete pressure pipe is designed for flexure, crack width control, diagonal tension (shear), and radial tension using methods found in AASHTO LRFD Bridge Design Specifications. The pipe is analyzed for three load conditions, and the reinforcing steel requirement is established based on the steel area needed to satisfy all three of these conditions.

Load Cond. I — Internal pressure only
Load Cond. II — Earth load, pipe weight, and water weight with no internal pressure
Load Cond. III — External and internal loads acting concurrently

Load factors used for design are:
Flexure, for internal pressure — 1.5
Flexure, for dead and earth loads — 1.6 except 1.0 for compressive thrust
Shear, for all loads — 1.3

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

Capacity reduction factors used for design are:
Φf = strength reduction factor for flexure — 0.95
Φv = strength reduction factor for shear and radial tension — 0.9

Table 1 and Table 2 were developed using concrete strength of 35.4 MPa, and steel reinforcing yield strengths of 276 MPa and 414 MPa, respectively. Bolded areas in the tables are based on concrete strength of 41.4 MPa when required by shear analysis.

Pipe fabricated with reinforcement areas shown in Table 1 and Table 2 must be specified with respective material requirements of minimum concrete and reinforcement strengths shown.

X2.4.1 For Load Cond. I, 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 3, 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 Circumferential reinforcement to resist cracking of the concrete, diagonal tension (shear), and radial tension reinforcement (stirrups) shall be determined by methods in C361, Appendix X2 in in.^{2}/ft units and results converted to metric units. 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:

D = designated size given in Table 3.

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} ≤ $0.37\sqrt{f'_c}$