RECLAMATION

Managing Water in the West

Report DSO-09-01

Physical Properties of Plastic Pipe Used in Reclamation Toe Drains

Dam Safety Technology Development Program

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

September 2009

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
30-09-09	Research	n/a

4. TITLE AND SUBTITLE	
Physical Properties of Plastic Pipe Used in Reclamation Toe Drains	**5a. CONTRACT NUMBER** n/a
	5b. GRANT NUMBER n/a
	5c. PROGRAM ELEMENT NUMBER n/a
6. AUTHOR(S) Jay Swihart and Mark Pabst	**5d. PROJECT NUMBER** n/a
	5e. TASK NUMBER n/a
	5f. WORK UNIT NUMBER n/a
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Department of the Interior Bureau of Reclamation Technical Service Center Material Engineering and Research Laboratory	**8. PERFORMING ORGANIZATION REPORT NUMBER** n/a
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of the Interior Bureau of Reclamation Dam Safety Office	**10. SPONSOR/MONITOR'S ACRONYM(S)** DSO
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) DSO-09-01

12. DISTRIBUTION/AVAILABILITY STATEMENT
No restrictions

13. SUPPLEMENTARY NOTES
n/a

14. ABSTRACT
A significant number of plastic pipes have either collapsed or suffered some other type of poor performance in toe drains of embankment dams. To better understand the comparative strength relationships between different plastic pipe types, a laboratory study was undertaken with an emphasis on perforated pipe. A variety of material types, pipe sizes, and perforated versus non-perforated pipes were load tested. This report presents those results as well as recommendations on preferred plastic pipe for use in toe drain applications.

15. SUBJECT TERMS
plastic pipe, strength, perforated pipe, toe drains, embankment dams, pipe stiffness

16. SECURITY CLASSIFICATION OF: None			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Jay Swihart
a. REPORT	**b. ABSTRACT**	**a. THIS PAGE**		91	**19b. TELEPHONE NUMBER** *(Include area code)* (303) 445-2397

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Report DSO-09-01

Physical Properties of Plastic Pipe Used in Reclamation Toe Drains

Prepared by

Jay Swihart
Mark Pabst

Dam Safety Technology Development Program

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Civil Engineering Services Division
Materials Engineering and Research Laboratory
Denver, Colorado

September 2009

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

BUREAU OF RECLAMATION
Dam Safety Technology Development Program
Materials Engineering and Research Laboratory, 86-68180

DSO-09-01

Physical Properties of Plastic Pipe Used in Reclamation Toe Drains

Prepared: Jay Swihart
Materials Engineering and Research Laboratory, 86-68180

Checked: Mark Pabst
Embankment Dams and Geotechnical Engineering Group 3, 86-68313

Technical Approval: Bill Engemoen
Embankment Dams and Geotechnical Engineering Group 3, 86-68313

Peer Review: Bill Kepler
Manager, Materials Engineering and Research Laboratory, 86-68180

9/16/09
Date

REVISIONS					
Date	Description	Prepared	Checked	Technical Approval	Peer Review

Acronyms

CMP	corrugated metal pipe
DR	dimension ratio
DWV	drain waste vent
HDPE	high density polyethylene
POA	percent open area
PS	pipe stiffness
psi	pounds per square inch
PVC	polyvinyl chloride
Reclamation	Bureau of Reclamation
SCR	stress crack resistance
SDR	standard dimension ratio

Contents

Tables

Table | Page

Figures

Figure | Page

Appendices

Appendix

Executive Summary

In the 1980s, the Bureau of Reclamation (Reclamation) began using perforated plastic pipe for toe drains in dams. Corrugated high density polyethylene (HDPE) has been used most often, but other plastic pipe options include corrugated polyvinyl chloride (PVC), solid-wall PVC, and solid-wall HDPE. In 1999, Reclamation began video inspection of toe drains and found that about one-half of our plastic toe drains suffered from areas of serious deformation or collapse (Cooper, 2005). Concerns included whether all types of plastic pipe had sufficient strength and whether perforation patterns led to premature failure.

This study compares the strength and failure modes of perforated and non-perforated plastic pipe. Six types of plastic pipe were tested for pipe stiffness, ultimate strength, and mode of failure to determine suitability for use in toe drains. The six types of pipe evaluated include:

Single-wall corrugated HDPE drainpipe
Double-wall corrugated HDPE drainpipe
Double-wall corrugated PVC drainpipe
Solid-wall HDPE pressure pipe
Solid-wall PVC pressure pipe
Solid-wall PVC drainpipe[1]

Pipe strengths for perforated and non-perforated pipe were compared to published values. Pipe diameters ranged from 6 to 24 inches (although larger diameters are also commonly used). The manufacturer's standard perforation patterns were selected for testing.

Conclusions

1. All the pipe exceeded the manufacturer's published values for pipe stiffness.

2. For corrugated pipe, the perforated pipe was just as strong as the non-perforated pipe. The reason for this high retained strength is that corrugated pipe gets its strength from the corrugation ribs, while the perforations are located in the corrugation valleys.

[1] For this report, solid-wall PVC drainpipe is non-pressurized drain-waste-vent (DWV) pipe, not to be confused with Reclamation terminology for perforated toe drainpipe for embankment dams.

3. For solid-wall pipe, the perforated pipe was significantly weaker than the non-perforated pipe. The strength reduction was directly proportional to the percent open area (POA). Solid-wall PVC pipe (drainpipe and pressure pipe) showed a 2.5 percent decrease in pipe stiffness for every 1 percent open area. Solid-wall HDPE pipe lost more strength, with a 15.0 percent decrease in pipe stiffness for every 1 percent open area.

4. *Mode of Failure* – For all pipe tested, the presence and location of perforations had no influence on the mode or location of the pipe failure.

5. Both corrugated pipe options (HDPE and PVC) have significantly less strength (lower pipe stiffness) than both the solid-wall pressure pipe options (HDPE and PVC).

6. Lower strength corrugated plastic pipe relies greatly on support from the compacted backfill to resist deformation. Therefore, proper compaction and backfill support are critical for corrugated pipe.

7. *Brittleness* – Although not originally part of this study, brittleness proved to be an issue for some of the larger-diameter double-wall corrugated PVC pipe. This brittle behavior appears similar to field damage issues seen with thin-walled PVC pipe.

8. *Perforations* – Because of flow characteristics through perforations, fewer large holes are preferred for high-flow applications, while numerous slots (or smaller holes) are acceptable for low-flow applications.

9. *Joints* – All pipe manufacturers offer some type of satisfactory joint, with some joints easier to assemble and more robust than others. Since joints for perforated pipe need not be watertight, some manufacturers also offer a “soil-tight” joint that is appropriate for drainage applications.

10. *Recommendations* – Toe drains are critical to the safe operation of embankment dams. Toe drains frequently have deep burial where they would be difficult to access or replace. Trouble-free operation is essential, and small additional costs at the time of construction are easily justified. Proper installation of plastic pipe should be verified with closed circuit television inspection. Pipe recommendations for critical toe drain applications are shown in table ES-1.

Table ES-1.—Pipe recommendations for toe drains – advantages and disadvantages

Product	Type		Advantage	Disadvantage	Recommended
HDPE	Solid		Strong, welded joints, flexibility of perforation size and type	Highest cost, special ordered, or hand-drilled after-market addition of perforations	Highly
	Corrugated	Single	Economical	Poor historic performance, weak	No
		Double	Economical, successful applications, large perforation sizes	Low strength, careful installation required	Moderately
PVC	Solid	Well screen	Strong	Small perforation aperture	Moderately
		Drainpipe	Economical	Weak, brittle	No
	Corrugated	Double	Economical	Weak, brittle	No

1.0 Background – Introduction

Up until about 1980, Reclamation used clay, concrete, and corrugated metal pipe (CMP) pipe for toe drains in dams. Each of these pipe options has known performance issues such as corrosion, cracking, and joint separation. Therefore, Reclamation switched to perforated plastic pipe for toe drains. Corrugated HDPE has been used most often, but other plastic pipe options include corrugated PVC, solid-wall PVC, and solid-wall HDPE. An extensive video inspection program was initiated in 1999 that revealed problems with all types of pipe. While the poor performance of the older clay, concrete, and CMP pipe was already known, the poor performance of the newer plastic pipe installations was unexpected. About one-half of all toe drains constructed with plastic pipe showed localized areas of excessive deformation or failure (collapse) (see figure 1-1). Design concerns included whether all types of plastic pipe had sufficient strength and whether some perforation patterns led to premature failure. While strength properties of non-perforated plastic pipe are well known and available from a variety of sources, the strengths of perforated pipe are generally not published or need to be confirmed. This study was undertaken to better understand the comparative strength relationships between different types of plastic pipe. This study also satisfies the research identified in the *Technical Manual: Plastic Pipe Used in Embankment Dams* (Federal Emergency Management Agency, 2007).

Figure 1-1.—Collapse of corrugated plastic pipe toe drain.

1.1 Corrugated HDPE Pipe

AASHTO standards cover both Class C pipe (single-wall corrugated) and Class S pipe (double-wall, corrugated exterior with smooth interior). AASHTO M-252 (3- through 10-inch-diameter pipe) has lower strength requirements for single-wall pipe than for double-wall pipe. AASHTO M-294 (12- through 48-inch-diameter pipe) has the same strength requirements for both single-wall and double-wall pipe. Most cases of distressed HDPE pipe have been the corrugated single-wall pipe (6- to 18-inch diameter). More recent installations have used double-wall corrugated HDPE pipe and have performed much better. The HDPE pipe failures have been attributed to equipment damage and stress cracking. Stress cracking is a failure mechanism that develops over time at stresses less than the yield strength. Starting in 2000, AASHTO M294 (12-inch and larger) has required a resin with better stress crack resistance (SCR). AASHTO M252 (smaller diameters) still uses the older (less expensive) resin because pipe manufacturers claim that stress cracking has not been as issue for these smaller pipes. Because of its low pipe stiffness, proper installation of corrugated HDPE pipe is essential and requires extra attention during backfill to ensure good support under the haunches. Otherwise, the pipe will deflect excessively and concentrate stresses at the crown, invert, or springline. These stress concentrations can lead to premature failure, especially if the pipe resin does not have sufficient SCR. Single-wall pipe will also lose strength if stretched when installed with trenching equipment. ASTM F-405 and F-667 also cover single-wall corrugated HDPE pipe, but this standard has lower physical properties than the AASHTO standard and is more appropriate for more shallow burial such as agricultural drainage.

1.2 Corrugated PVC Pipe

Over the years, corrugated PVC pipe has been manufactured in both single-wall and double-wall configurations. Reclamation has used small amounts of single-wall pipe in the past with mixed results. Today, only double-wall corrugated PVC pipe is widely available and generally has slightly higher strength (pipe stiffness) than double-wall corrugated HDPE.

1.3 Solid-Wall HDPE Pipe

Solid-wall HDPE pipe is commonly used as pressure pipe for natural gas and water delivery. The HDPE resin is weaker than PVC resin, requiring thicker pipe walls for equivalent strength, resulting in a higher cost per linear foot. Joints are welded and quite strong. Perforations (drilled holes) must be special ordered from the manufacturer (minimum order about 1,000 linear feet) or drilled by hand after market. The resins used for pressure applications have good SCR.

1.4 Solid-Wall PVC Pipe

Solid-wall PVC pipe is commonly used for pressure applications in diameters up to about 24 inches. In larger diameters, PVC becomes less cost competitive. PVC pipe is available in a wide range of wall thicknesses and strengths (pipe stiffness). PVC pipe is routinely perforated (slotted) and used as well screen. This same slotted pipe can also be used for toe drains. Slotting is done at the factory, and slots are available in a wide range of slot widths and POA. However solid-wall PVC pipe has sometimes performed poorly in heavy earthwork construction operations. These problems have mostly been with thinner-walled Schedule 40 pipe, while thicker-walled Schedule 80 pipe has performed better. For this reason, some designers are reluctant to specify PVC pipe for toe drain applications.

2.0 Pipe for Testing

Available options for each type of perforated plastic pipe are listed in table 2-1, including diameters, pipe stiffness (strength), perforation options, POA, etc.

This study compares the strength and failure modes of perforated versus non-perforated plastic pipe. Six types of plastic pipe were tested for pipe stiffness, ultimate strength, and mode of failure to determine suitability for use in toe drains. Pipe with the manufacturers "standard" perforation patterns were selected for testing. Pipe diameters ranged from 6 to 24 inches, although larger pipe is also used in toe drains. Table 2-2 contains a complete list of the pipe tested. The six types of pipe evaluated are shown in appendix A and include:

Single-wall corrugated HDPE drainpipe
Double-wall corrugated HDPE drainpipe
Solid-wall HDPE pressure pipe
Double-wall corrugated PVC drainpipe
Solid wall PVC pressure pipe
Solid-wall PVC drainpipe

Table 2-1.—Perforated pipe options – 6-inch through 24-inch diameter

	HDPE solid-wall[1]	**HDPE corrugated single-wall**	**HDPE corrugated double-wall**	**PVC corrugated double-wall**	**PVC solid-wall well screen**	**PVC solid-wall drainpipe**
Sizes	3” to 24”	3” to 48”	4” to 60”	6” to 36”	2” to 17.4”	3” to 6”
Pipe stiffness (pounds per square inch)	[2]6” ≈ 6 to 716 12” ≈ 6 to 716 18” ≈ 6 to 175 24” ≈ 6 to 89	6” = 35 12” = 50 18” = 40 24” = 34 36” = 22 48” = 18	6” = 50 12” = 50 18” = 40 24” = 34 36” = 22 48” = 18 60” = 14	6” = 46 12” = 46 18” = 46 24” = 46 36” = 46	6” = 112, 224, 452 12” = 112, 224, 452 17.4” = 452	6” = 46
Dimension ratio DR[3]	6” = 7 to 32.5 12” = 11 to 32.5 18” = 17 to 32.5 24” = 21 to 32.5	---	---	---	6” = 17, 21, 26 12” = 17, 21, 26 17.4” = 17	35
Perforations	Holes[4] ¼” to 1¼” diameter	6” = slots 12” = holes 18” = holes 24” = holes	6” = slots 12” = holes 18” = holes 24” = holes	6” = slots 12” = slots 18” = slots 24” = holes	Slots[5] 6” = 0.016 to 0.085 12” = 0.025 to 0.125 17.4” = 0.040 to 0.125	Holes
Open area (in²/ft)	6” = 0.79 to 19.6 12” = 0.79 to 19.6 18” = 0.79-19.6 24” = 0.79-19.6	6” = 0.94 12” = 1.41 18” = 1.41 24” = 1.88	6” = 0.94 12” = 1.41 18” = 1.41 24” = 1.88	Standard = 2.0 Full = 4.0	6” = 8.2 to 43.0 12” = 30.0 to 110.1 17.4” = 52.8 to 127.8	6” = 0.94
Standards	ASTM F-714	AASHTO M-252 M-294	AASHTO M-252 M-294	ASTM F-758 ASTM F-679 AASHTO M-304M	ASTM F-480 ASTM D-3034	ASTM F-758 ASTM D-3034

[1] Perforated pipe must be special ordered for solid-wall HDPE pipe.
[2] ASTM F-714 lists range of pipe stiffness values for each dimension ratio. Ranges are quite wide (order or magnitude).
[3] DR = Outside diameter / wall thickness.
[4] Standard perforation pattern is four rows of holes on 3-inch centers.
[5] Well screen is fully slotted with 0.25-inch spacing between slots.

Table 2-2.—Samples for testing – manufacturer's published data

Type of pipe	Diameter (inches)	Dimension ratio	Pressure class (psi)	Pipe stiffness (psi)	Perforations	Rows and slot length	Open area (in²/lin ft)	Open area POA %	Supplier	Manu-facturer
HDPE solid-wall	12"	SDR 11	160	358	Non-perforated				Expert Piping Supply	WL Plastics[1]
	12"	SDR 11			Drilled 3/8"holes	6 rows at 2" sp	1.41	0.3		
HDPE corrugated single-wall	12"			50	Non-perforated				ADS	ADS
	18"			40	Non-perforated					
	12"				3/8" holes	6 rows	1.41	0.3		
	18"				3/8" holes	6 rows	1.41	0.2		
HDPE corrugated double-wall	6"			50	Non-perforated				ADS	ADS
	12"			50	Non-perforated					
	18"			40	Non-perforated					
	24"			34	Non-perforated					
	6"				1/8" slots	6 rows	0.94	0.4		
	12"				3/8" holes	6 rows	1.41	0.3		
	18"				3/8" holes	6 rows	1.41	0.2		
	24"				3/8" holes	8 rows	1.88	0.2		
PVC corrugated double-wall	6"			46	Non-perforated				Contech	Contech
	12"			46	Non-perforated					
	18"			46	Non-perforated					
	24"			46	Non-perforated					
	6"				Standard slots	2 rows	2.0	0.9		
	12"				Standard slots	2 rows	2.0	0.4		
	18"				Standard slots	2 rows	2.0	0.3		
	24"				3/8" holes	2 rows	2.0	0.2		
	6"				Fully slotted	4 rows	4.0	1.8		
PVC solid-wall well screen	6"	SDR 26	160	112	Non-perforated				Expert Piping Supply	Certainteed
	6"	SDR 21	200	224	Non-perforated					
	12"	SDR 21	200	224	Non-perforated					
	6"	SDR 26			0.016" slots	6 at 1.78"	[2]8.2	3.6		
	6"	SDR 21			0.016" slots	6 at 1.78"	[2]8.2	3.6		
	12"	SDR 21			0.025"slots	8 at 3.125"	[2]30.0	6.6		
PVC solid-wall drainpipe	6"	SDR 35		46	Non-perforated				Expert Piping Supply	North American
	6"	SDR 35	120		½" holes	2 rows	0.94	0.4		

[1] WL Plastics, 12"IPS, DR11, PE-349-08, ASTM F-714, Lot # B3-33M06R-C4-05-08-01.
[2] 0.25-inch slot spacing.

3.0 Test Program

Samples of perforated and non-perforated pipe were obtained from pipe suppliers with the manufacturers “standard” perforation pattern. The only exception was the solid-wall HDPE pipe in which factory perforated pipe is only available by special order at quantities starting around 1,000 linear feet. Therefore, for this study, solid-wall HDPE pipe was hand-perforated by drilling six rows of 3/8-inch diameter holes on 2-inch centers.

Pipe samples were tested in accordance with ASTM D 2412 “Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading.” In accordance with ASTM, the test specimen length was 12 inches for the 6- and 12-inch diameter pipe, and one pipe diameter for larger pipe (18 inches long for 18-inch diameter pipe, and 24 inches long for 24-inch diameter pipe). The tests were run at a crosshead speed of 0.5 inch per minute. Three specimens were tested for each pipe sample at orientations of 0, 90, and 45 degrees. For 0 degrees, the specimen was oriented with the manufacturer identification stamp located on top (at the crown). The second specimen was rotated 90 degrees, placing the identification stamp at the springline. The third specimen was rotated 45 degrees, placing the identification stamp halfway between the top (crown) and the springline.

After determining the pipe stiffness at 5 percent deflection, the test speed was increased to 2 inches per minute for 6- and 12-inch diameter pipe and to 4 inches per minute for 18- and 24-inch diameter pipe. All specimens were loaded to ultimate failure, with the maximum load and deflection recorded. Failure (test end point) was defined either as wall rupture or negative slope on the load-deflection curve. If neither of these failure events occurred, failure was defined as 50 percent deflection, which generally corresponded to the point of minimum slope on the load-deflection curve. Typical plots (load versus deflection) illustrating the three failure events (test end points) are included in appendix B.

3.1 Mode of Failure

All the pipe ultimately failed by collapsing in one of four failure modes (shapes):

1. Heart – Crown (top) of pipe collapses, eventually contacting the pipe invert
2. Inverted heart – Invert collapses upward, eventually contacting pipe crown
3. Binocular – Crown and invert collapse inward toward each other
4. Pancake – Pipe buckles (bends) at springline and collapses flat

Photos of the four failure modes (shapes) are shown in appendix A.

4.0 Test Results

Key results are summarized in table 4-1 below. Individual test results are tabulated in tables 4-2 through 4-4. Test photos are included in appendix A, and load-deflection plots are in included in appendix B. Tables 4-5 through 4-7 compare the measured pipe stiffness for perforated and non-perforated pipe to the manufacturer's published values. See equation 1 for the calculation of pipe stiffness. Finally, the reduction in pipe stiffness versus POA is tabulated in tables 4-8 through 4-10.

Table 4-1.—Key test results – pipe stiffness

Pipe type		Pipe stiffness		Average percent difference
		Published value	Test value (range)	
Corrugated HDPE	Non-perforated	34 – 50 psi[1]	41 – 62 psi	+14 %
	Perforated		41 – 58 psi	+13 %
Corrugated PVC	Non-perforated	46 psi	55 – 61 psi	+25 %
	Perforated		53 – 64 psi	+24 %
Solid-wall PVC	Non-perforated	46 – 224 psi	61 – 400 psi	+38 %
	Perforated		60 – 352 psi	+24 %
Solid-wall HDPE	Non-perforated	358 psi	487 psi	+36 %
	Perforated		465 psi	+30 %

[1] Pounds per square inch.

Table 4-2.—Test results – corrugated PVC pipe

Lab No.	Pipe ID	Published PS (psi)	Tested PS (psi)	Load at failure (lb/ft)	Deflection at failure (%)	Comments	Failure mode
962	6" PVC Corrugated Double-wall Non-perf.	46	50.4 57.4 56.6 54.8 avg.	680 675 675 677 avg.	36.7 35.0 36.7 36.1 avg.		Pancake — Pancake
957	6" PVC Corrugated Double-wall Perforated	[1]46	52.4 56.9 56.0 55.1 avg.	665 660 625 650 avg.	36.7 38.3 34.2 36.4 avg.		Pancake — —
958	6" PVC Corrugated Double-wall Double-perf.	[1]46	54.2 56.9 52.8 54.6 avg.	655 645 625 642 avg.	35.8 34.2 36.7 35.5 avg.		Pancake Pancake —
961	12" PVC Corrugated Double-wall Non-perf.	46	56.3 57.9 58.5 57.6 avg.	1160 1170 1180 1170 avg.	32.9 36.3 37.9 35.7 avg.	Linear separation	Pancake — Pancake
956	12" PVC Corrugated Double-wall Perforated	[1]46	55.5 52.6 51.2 53.1 avg.	1020 1064 1036 1040 avg.	29.2 35.0 31.7 32.0 avg.		Pancake Pancake —
960	18" PVC Corrugated Double-wall Non-perf.	46	55.9 56.7 56.6 56.4 avg.	1755 1798 1770 1774 avg.	28.9 31.9 30.0 30.3		Pancake Pancake Pancake
955	18" PVC Corrugated Double-wall Perforated	[1]46	58.7 58.9 57.8 58.5 avg.	1839 1791 1772 1801 avg.	29.9 avg. 27.6 29.2 28.9 avg.	 Cracked[2] Cracked[2]	Inverted heart Pancake Pancake
959	24" PVC Corrugated Double-wall Non-perf.	46	57.8 61.9 62.4 60.7 avg.	2206 2352 2236 2265 avg.	22.8 28.3 31.0 27.4 avg.	Shattered at top[3] Shattered at bottom Shattered at 45°[3]	Heart Inverted heart Pancake
954	24" PVC Corrugated Double-wall Perforated	[1]46	64.4 62.0 64.2 63.5 avg.	1985 1864 2178 2009 avg.	15.3 13.1 18.8 15.7 avg.	 Shattered at 90°[3]	Binocular Binocular Binocular

[1] Published data for non-perforated pipe – perforated pipe reportedly has same strength.
[2] External corrugations cracked.
[3] Shattered at mold mark. Pipe has two mold marks.

Table 4-3.—Test results – corrugated HDPE pipe

Lab No.	Pipe ID	Published PS (psi)	Tested PS (psi)	Load at failure (lb/ft)	Deflection at failure (%)	Comments	Failure mode
970	6” HDPE Corrugated Double-wall Non-perf.	50	59.9 59.9 61.4 60.4 avg.	520 540 545 535 avg.	46.7 48.3 48.3 47.8 avg.		Heart Binocular Heart
966	6” HDPE Corrugated Double-wall Perforated	[1]50	57.0 56.1 58.5 57.2 avg.	490 600 535 542 avg.	45.0 50.0 50.0 48.3 avg.		Pancake Binocular Pancake
969	12” HDPE Corrugated Double-wall Non-perf.	50	59.3 56.5 57.3 57.7 avg.	1030 1040 990 1020 avg.	33.3 33.3 31.7 32.8 avg.		Binocular Binocular Heart
965	12” HDPE Corrugated Double-wall Perforated	[1]50	53.7 52.8 52.3 52.9 avg.	950 870 870 897 avg.	31.7 24.6 26.7 27.7 avg.		Inverted heart Inverted heart/binocular Binocular
974	12” HDPE Corrugated Single-wall Non-perf.	50	61.4 62.5 60.5 61.5 avg.	980 1040 1000 1007 avg.	36.7 45.8 41.7 41.4 avg.		Heart Heart Binocular
972	12” HDPE Corrugated Single-wall Perforated	[1]50	58.3 57.3 59.3 58.3 avg.	970 1036 1030 1012 avg.	39.2 41.7 45.8 42.2 avg.	Split at top perforation	Pancake Heart Pancake
968	18” HDPE Corrugated Double-wall Non-perf.	40	41.8 40.4 40.9 41.0 avg.	1279 1236 1244 1253 avg.	37.6 33.3 33.7 34.9 avg.		Heart Inverted heart Heart
964	18” HDPE Corrugated Double-wall Perforated	[1]40	45.2 44.1 45.0 44.8 avg.	1335 1303 1315 1318 avg.	24.0 22.0 24.4 23.5 avg.		Binocular Binocular Binocular
973	18” HDPE Corrugated Single-wall Non-perf.	40	41.3 44.0 40.5 41.9 avg.	1263 1307 1311 1294 avg.	37.4 37.5 41.8 38.9 avg.		Pancake Pancake Pancake
971	18” HDPE Corrugated Single-wall Perforated	[1]40	44.1 39.9 46.1 43.4 avg.	1234 1208 1167 1203 avg.	34.2 34.9 32.8 34.0 avg.		Binocular Binocular Binocular
967	24” HDPE Corrugated Double-wall Non-perf.	34	40.2 40.4 41.2 40.6 avg.	1808 1584 1731 1708 avg.	40.5 29.9 39.0 36.5 avg.		Inverted heart Pancake Inverted Heart
963	24” HDPE Corrugated Double-wall Perforated	[1]34	40.9 42.1 41.0 41.3 avg.	1778 1616 1706 1700 avg.	40.0 30.3 36.2 35.5 avg.		Binocular Inverted heart Heart

[1] Published data for non-perforated pipe – perforated pipe reportedly has same strength.

Table 4-4.—Test results – solid-wall PVC and HDPE pipe

Lab No.	Pipe ID	Published PS (psi)	Tested PS (psi)	Load at failure (lb/ft)	Deflection at failure (%)	Comments	Failure mode
976	6” PVC Class 160	112	139 139 140 139 avg.	2250 2275 2450 2325 avg.	50 50 50 50 avg.		Pancake Pancake Pancake
979	6” PVC Well screen Class 160	[1]112	122 118 121 120 avg.	1975 2015 1985 1992 avg.	50 50 50 50 avg.		Pancake Pancake —
977	6” PVC Class 200	224	263 260 263 262 avg.	3675 3975 3940 3863 avg.	50 50 50 50 avg.		Pancake Pancake Pancake
980	6” PVC Well screen Class 200	[1]224	236 222 233 230 avg.	3175 3200 3365 3247 avg.	50 50 50 50 avg.		Pancake Pancake Pancake
982	6” PVC Drainpipe SDR 35	46	60 62 60 61 avg.	1160 1152 1240 1184 avg.	50 50 50 50 avg.		Pancake Pancake Pancake
983	6” PVC Perforated Drainpipe SDR 35	[1]46	67 58 56 60 avg.	1140 1140 1160 1147 avg.	50 50 50 50 avg.		Pancake Pancake Pancake
978	12” PVC Class 200	224	398 396 406 400 avg.	9,883 9,774 10,617 10,091 avg.	50 50 50 50 avg.		Pancake Pancake Pancake
981	12” PVC Well screen Class 200	[1]224	341 357 357 352 avg.	8317 8728 8494 8513 avg.	50 50 50 50 avg.		Pancake Pancake Pancake
984	12” HDPE SDR 11	358	480 484 498 487 avg.	14,996 15,271 14,464 14,910 avg.	50 50 50 50 avg.		Pancake Pancake Pancake
985	12” HDPE SDR 11 Drilled holes	[1]358	464 467 463 465 avg.	15,076 14,345 13,909 14,443 avg.	50 50 50 50 avg.		Pancake Pancake Pancake

[1] Published pipe stiffness for non-perforated pipe – perforated pipe expected to have lower strength.

Table 4-5.—Comparison of pipe stiffness – non-perforated versus perforated PVC corrugated double-wall pipe

	Non-perf. pipe stiffness (psi)				Perforated pipe stiffness (psi)		
Pipe ID	**Published**	**Tested**	**% diff**	**Pipe ID**	**Published**	**Tested**	**% diff**
6” PVC Corrugated Double-wall Non-perf. (#962)	46	54.8	+19.1	6” PVC Corrugated Double-wall Perforated (#957)	46	55.1	+19.8
				6” PVC Corrugated Double-wall Double-perf. (#958)	46	54.6	+18.7
12” PVC Corrugated Double-wall Non-perf. (#961)	46	57.6	+25.2	12” PVC Corrugated Double-wall Perforated (#956)	46	53.1	+15.4
18” PVC Corrugated Double-wall Non-perf. (#960)	46	56.4	+22.6	18” PVC Corrugated Double-wall Perforated (#955)	46	58.5	+27.2
24” PVC Corrugated Double-wall Non-perf. (#959)	46	60.7	+32.0	24” PVC Corrugated Double-wall Perforated (#954)	46	63.5	+38.0
Average (range)	46	57.4	+24.7 (19 to 32)	Average (range)	46	57.0	+23.8 (15 to 38)

Table 4-6.—Comparison of pipe stiffness – non-perforated versus perforated HDPE corrugated pipe (double-wall and single-wall)

	Non-perforated pipe stiffness (psi)				Perforated pipe stiffness (psi)		
Pipe ID	**Published**	**Tested**	**% diff**	**Pipe ID**	**Published**	**Tested**	**% diff**
6" HDPE Corrugated Double-wall Non-perf. (#970)	50	60.4	+20.8	6" HDPE Corrugated Double-wall Perforated (#966)	50	57.2	+14.4
12" HDPE Corrugated Double-wall Non-perf. (#969	50	57.7	+15.4	12" HDPE Corrugated Double-wall Perforated (#965)	50	52.9	+5.8
12" HDPE Corrugated Single-wall Non-perf. (#974)	50	61.5	+23.0	12" HDPE Corrugated Single-wall Perforated (#972)	50	58.3	+16.6
18" HDPE Corrugated Double-wall Non-perf. (#968)	40	41.0	+2.5	18" HDPE Corrugated Double-wall Perforated (#964)	40	44.8	+12.0
18" HDPE Corrugated Single-wall Non-perf. (#973)	40	41.9	+4.8	18" HDPE Corrugated Single-wall Perforated (#971)	40	43.4	+8.5
24" HDPE Corrugated Double-wall Non-perf. (#967)	34	40.6	+19.4	24" HDPE Corrugated Double-wall Perforated (#963)	34	41.3	+21.4
Average (range)			+14.3 (3 to 23)				+13.1 (6 to 21)

Table 4-7.—Comparison of pipe stiffness – non-perforated versus perforated – solid-wall PVC and solid-wall HDPE pipe

	Non-perforated pipe stiffness (psi)				Perforated pipe stiffness (psi)		
Pipe ID	**Published**	**Tested**	**% diff**	**Pipe ID**	**Published**	**Tested**	**% diff**
6” PVC Class 160 (#976)	112	139	+24.1	6” PVC Well screen Class 160 (#979)	112	120	+7.1
6” PVC Class 200 (#977)	224	262	+17.0	6” PVC Well screen Class 200 (#980)	224	230	+2.7
6” PVC Drainpipe SDR 35 (#982)	46	61	+32.6	6” PVC Perforated Drainpipe SDR 35 (#983)	46	60	+30.4
12” PVC Class 200 (#978)	224	400	+78.6	12” PVC Well screen Class 200 (#981)	224	352	+57.1
12” HDPE SDR 11 (#984)	358	487	+36.0	12” HDPE SDR 11 Drilled holes (#985)	358	465	+29.9
Average (range)			+37.7 (17 to 79)				+25.4 (3 to 57)

Table 4-8.—POA versus loss of pipe stiffness – PVC corrugated double-wall pipe

Pipe ID	Pipe stiffness (psi)			Strength loss (%)	POA
	Published	Non-perforated	Perforated		
6” PVC Corrugated Double-wall (#962, 957)	46	54.8	55.1	+0.5	0.9
6” PVC Corrugated Double-wall (962, 958*)	46	54.8	54.6	-0.4	1.8
12” PVC Corrugated Double-wall (#961, 956)	46	57.6	53.1	-7.8	0.4
18” PVC Corrugated Double-wall (#960, 955)	46	56.4	58.5	+3.7	0.3
24” PVC Corrugated Double-wall (#959, 954)	46	60.7	63.5	+4.6	0.2
Average				+0.1 ± 4.9	

Table 4-9.—POA versus loss of pipe stiffness – HDPE corrugated pipe (double-wall and single-wall)

	Pipe stiffness (psi)				
Pipe ID	**Published**	**Non-perforated**	**Perforated**	**Strength loss (%)**	**POA**
6” HDPE Corrugated Double-wall (#970, 966)	50	60.4	57.2	-5.3	0.4
12” HDPE Corrugated Double-wall (#969, 965)	50	57.7	52.9	-8.3	0.3
12” HDPE Corrugated Single-wall (#974, 972)	50	61.5	58.3	-5.2	0.3
18” HDPE Corrugated Double-wall (#968, 964)	40	41.0	44.8	+9.2	0.2
18” HDPE Corrugated Single-wall (#973, 971)	40	41.9	43.4	+3.6	0.2
24” HDPE Corrugated Double-wall (#967, 963)	34	40.6	41.3	+1.7	0.2
Average				-0.7 ± 0.7	

Table 4-10.—POA versus loss of pipe stiffness – solid-wall PVC and solid-wall HDPE pipe

	Pipe stiffness (psi)				
Pipe ID	**Published**	**Non-Perforated**	**Perforated**	**Strength loss (%)**	**POA**
6” PVC Class 160 (Nos. 976, 979)	112	139	120	-13.7	3.6
6” PVC Class 200 (Nos. 977, 980)	224	262	230	-12.2	3.6
12” PVC Class 200 (Nos. 978, 981)	224	400	352	-12.0	6.6
6” PVC SDR 35 (Nos. 982, 983)	46	61	60	-1.6	0.4
12” HDPE SDR 11 (Nos. 984, 985)	358	487	465	-4.5	0.3
Average				-8.8 ± 5.4	

5.0 Discussion

5.1 Published Values

Tables 4-5 through 4-7 show that all pipe exceeded the manufacturers published values for pipe stiffness. This includes corrugated and solid-wall pipe, single-wall and double-wall pipe, PVC and HDPE pipe, and perforated and non-perforated pipe.

5.2 Effect of Perforations on Pipe Stiffness of Corrugated Pipe

For corrugated pipe (tables 4-8 and 4-9), the perforated pipe is just as strong statistically as non-perforated pipe (perhaps 1 percent weaker). Results are plotted on figures 5-1 and 5-2 and show no correlation between POA and Pipe Stiffness. In many cases, the perforated pipe actually tested higher than the non-perforated pipe, indicating that differences are due more to lot variations than to the perforations. The reason for this high retained strength is that the perforations are located in the corrugation valleys (which contribute very little pipe strength) rather than in the corrugation ribs (which contribute most of the pipe strength).

5.3 Effect of Perforations on Pipe Stiffness of Solid-Wall Pipe

For solid-wall pipe, the perforated pipe is significantly weaker than non-perforated pipe (table 4-10), and the strength reduction is proportional to the POA. The plot of POA versus loss of strength (pipe stiffness) is shown on figures 5-3 and 5-4. Solid-wall PVC pipe demonstrates a 2.5 percent decrease in pipe stiffness for every 1 percent open area. Solid-wall HDPE pipe lost more strength, with a 15.0 percent decrease in pipe stiffness for every 1 percent open area. These strength reduction numbers are based on a limited number of tests on samples often taken from different lots, but can be used as a good first approximation.

5.4 Mode of Failure

For both solid-wall and corrugated pipe, the presence of perforations did not influence the mode or location of pipe failure. Some samples did rupture along the factory mold marks, but none ruptured at the perforations.

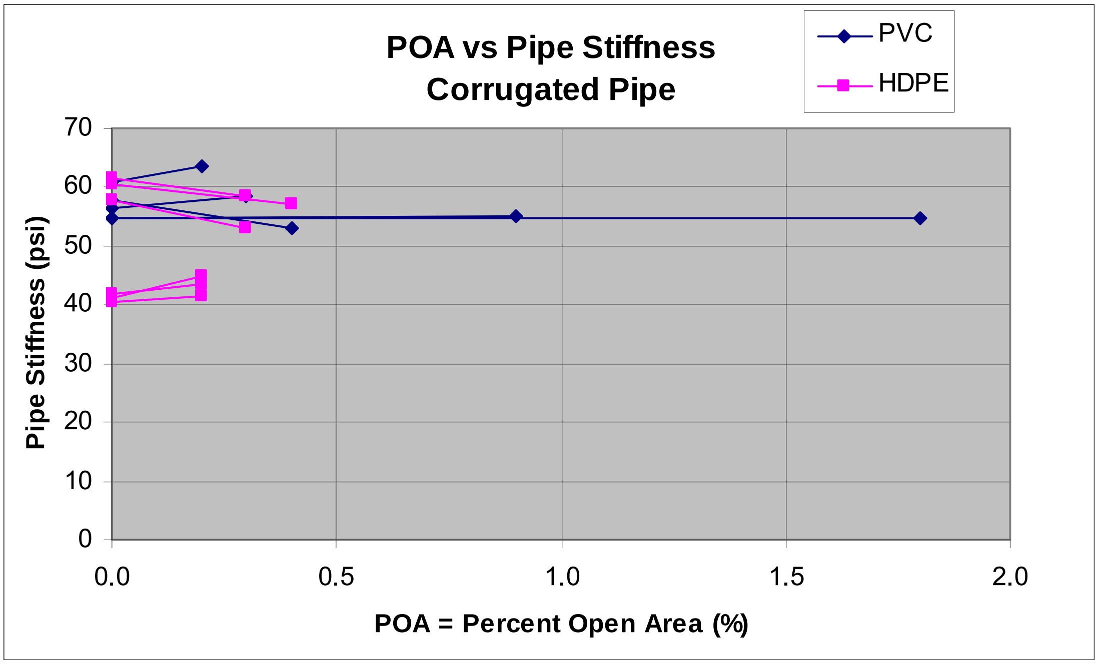


Figure 5-1.—For corrugated pipe, the perforated pipe is equal in strength (statistically) to non-perforated pipe (POA = 0.0).

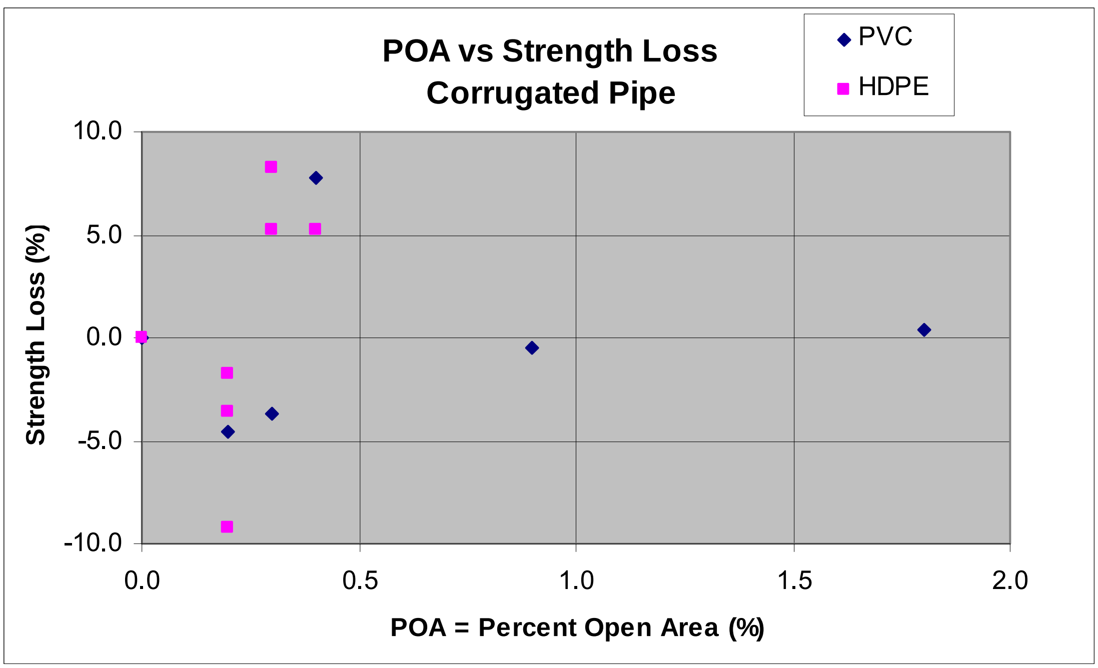


Figure 5-2.—For corrugated pipe, no correlation between POA and change in pipe stiffness.

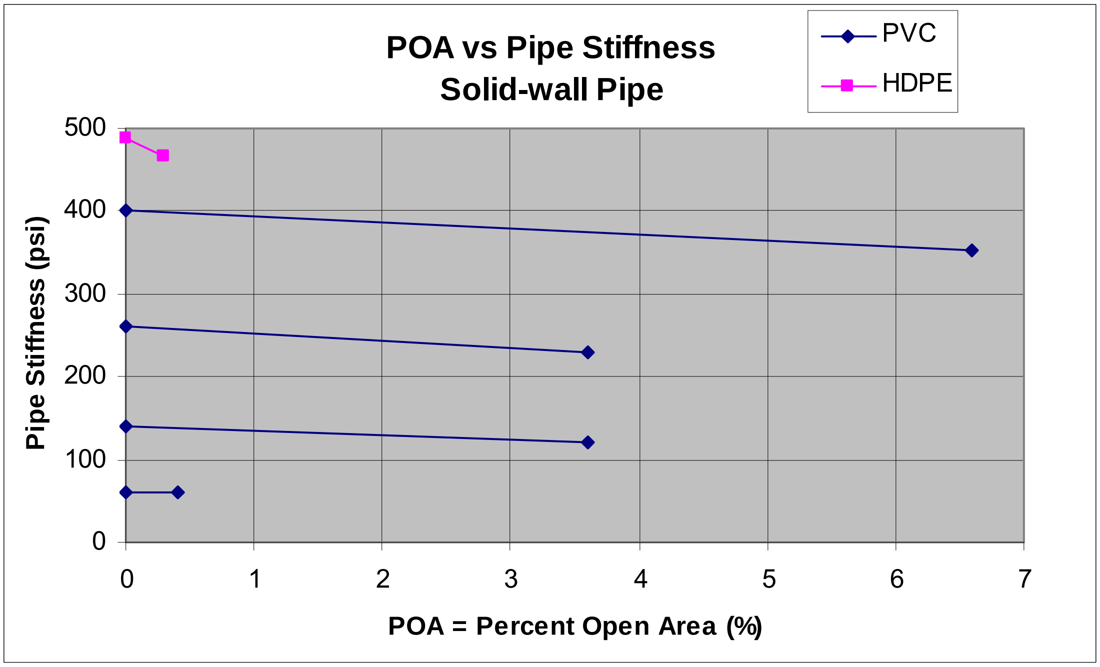


Figure 5-3.—For solid-wall pipe, all the perforated pipe showed lower strength than non-perforated pipe.

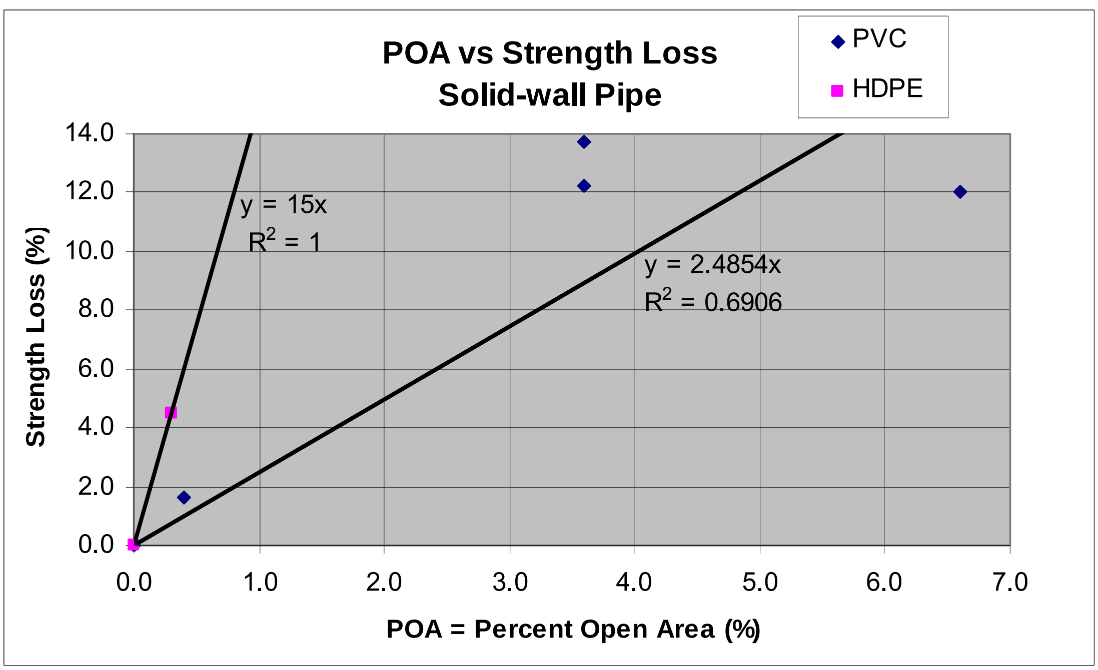


Figure 5-4.—Loss of pipe strength (pipe stiffness) is directly proportional to POA. Sampling from different lots accounts for the low correlation of PVC pipe.

5.5 Pipe Recovery

After testing to near-total collapse (80 to 90 percent deflection), all types of pipe re-rounded significantly when unloaded. The pipe would typically re-round about 50 percent within 1 hour and re-round 70 to 80 percent overnight. Of course, buried pipe cannot re-round unless uncovered; however, this recovery demonstrates the flexibility of plastic pipe.

5.6 Brittleness

Although not originally part of this study, brittleness proved to be an issue for some kinds of plastic pipe. During this study, several specimens of the double-wall corrugated PVC pipe (especially the larger diameters) demonstrated brittle failure either when tested beyond 50 percent deflection or when accidentally dropped or impacted during handling. None of the other pipe options demonstrated this degree of brittle behavior. This brittle behavior is similar to the field damage issues seen with thin-walled PVC pipe.

5.7 Perforations – Slots Versus Holes

Plastic pipe is perforated in two ways: slots and holes. Slots are openings that are much longer than wide and are typically cut with a saw. Holes are circular and typically drilled. Perforation size (aperture) must be small enough to prevent soil particles from passing through the opening and entering the pipe. The critical dimension is diameter for holes and width for slots. For the same amount of open area, fewer larger holes will experience more flow than more numerous smaller holes or slots (figure 5-5). Additionally, larger perforations are less prone to clogging by algae or iron ochre. Therefore, large holes are preferred for applications with high flows, while slots (or smaller holes) are acceptable for lower flow applications.

5.8 Joints

All pipe manufacturers offer some type of satisfactory watertight joint, with some joints easier to assemble and more robust than others. Since joints for perforated pipe need not be watertight, some manufacturers also offer a “soil-tight” joint that is appropriate for drainage applications.

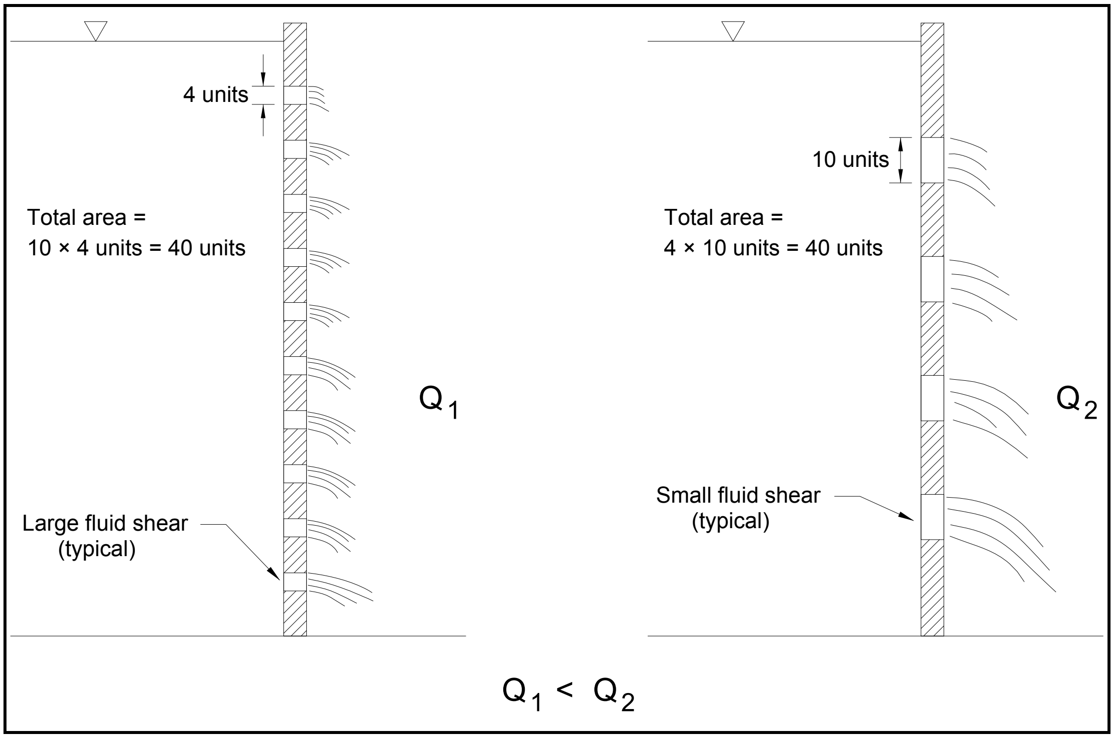


Figure 5-5.—More flow occurs with fewer large perforations compared to many small perforations.

5.9 Solid-Wall PVC Pressure Pipe

Solid-wall PVC pressure pipe is available in a wide range of wall thicknesses with high pipe stiffness. SDR 26 (pressure class 160 pounds per square inch [psi]) and SDR 21 (pressure class 200 psi) were included in this study. The pipe exceeded the manufacturer's minimum values for pipe stiffness. The failure mode was "pancake" with no areas of negative slope on the load-deflection curve. The pipe remained flexible with no brittle failures. The perforated pipe consisted of slotted well screen with slots distributed evenly around the pipe circumference. The pipe is available in a wide variety of slot widths and open areas. The decrease in pipe stiffness was proportional to 2.6 times the POA.

5.10 Solid-Wall PVC Drainpipe

Solid-wall PVC drainpipe is only available in SDR 35 (pressure class 120 psi) with a pipe stiffness of 46 psi. The perforations consisted of drilled holes located at ±120 degrees (measured from pipe crown). The pipe can also be installed in the inverted orientation, with drilled holes at ±60 degrees. The failure mode was "pancake" with no areas of negative slope and no brittle failures. The decrease in pipe stiffness was proportional to 2.5 times the POA.

5.11 Solid-Wall HDPE Pressure Pipe

Only a single size of this pipe was included in the study (12-inch diameter, SDR 11, pressure class 160 psi). The perforations were hand-drilled and consisted of six equally spaced rows of 3/8-inch holes on 2-inch centers (POA = 0.3 percent). Perforated pipe must be hand-drilled or special ordered from the manufacturer. Options for factory perforation patterns are shown in appendix C. The decrease in pipe stiffness was proportional to 15.0 times the POA.

5.12 Double-Wall Corrugated PVC Drainpipe

Double-wall corrugated PVC drainpipe consists of a corrugated exterior with a smooth interior. This is a relatively new pipe option that Reclamation has not used to date. The perforations consist of slots in smaller pipe and holes in larger pipe (24-inch diameter and larger). The two rows of perforations are located at ±120 degrees from the crown. The pipe can also be installed in the inverted orientation with perforations at ± 60 degrees from the crown. This type of pipe seemed quite brittle, as the larger-diameter pipe often failed (shattered) at the mold mark. Also, one pipe specimen fractured and had to be discarded when accidently dropped during handling. Perforated pipe was nearly as strong as non-perforated pipe (no statistical difference).

5.13 Double-Wall Corrugated HDPE Drainpipe

Double-wall corrugated HDPE drainpipe is the most commonly used pipe option for Reclamation toe drains. It is only available with limited POA (0.2 to 0.4 percent). Smaller diameter pipe is available with slotted perforations (1/8-inch slots), while larger pipe is only available with drilled perforations (typically 3/8-inch holes). Some designers have concerns about the low pipe stiffness of this option. Perforated pipe was nearly as strong as non-perforated pipe (no statistical difference).

5.14 Single-Wall Corrugated HDPE Drainpipe

Reclamation commonly used this pipe option for toe drains prior to introduction of the double-wall corrugated HDPE pipe. Reclamation still uses this pipe option for agricultural drains in irrigated fields. Smaller diameters are available with slotted perforations (typically 1/8-inch slots), while larger diameters are available with drilled perforations (3/8-inch diameter). This option is only available with limited POA (0.2 to 0.4 percent). Again, some designers have concerns about the low pipe stiffness of this option. Perforated pipe was just as strong as non-perforated pipe (no statistical difference).

5.15 Installation – Pipe Stiffness and Soil Modulus

Pipe stiffness is calculated at 5 percent deflection *(equation 1)* and is a function of the polymers modulus of elasticity and the pipe wall configuration (solid-wall versus corrugated). For solid-wall pipe, the wall configuration is described by the dimension ratio *(equation 2)*. The Modified Iowa Formula *(equation 3)* combines pipe stiffness with soil modulus to calculate long-term deflection. For thin-walled pipe, soil modulus is typically much larger than pipe stiffness, emphasizing the fact that **thin-walled plastic pipe relies greatly on support from the compacted backfill to resist deformation and to perform properly**.

$$PS = \frac{F}{L\,d} = \frac{6.71\,EI}{r^3} = \frac{4.47\;E}{(DR-1)^3} \qquad \textit{(equation 1)}$$

$$DR = D/t \qquad \textit{(equation 2)}$$

$$d = \frac{D_L\,K\,P\,D}{0.149\,PS + 0.061\,E'} \qquad \textit{(equation 3)}$$

Where:
- d = deflection (inches)
- D = diameter (inches)
- D_L = deflection lag factor
- DR = dimension ratio
- E = modulus of elasticity (psi)
- E' = soil modulus (psi)
- F = force (lbs)
- I = moment of inertia of pipe wall cross section per unit length (in^3)
- K = bedding constant
- L = length of specimen (inches)
- P = soil prism load (psi)
- PS = pipe stiffness (psi)
- r = pipe radius (inches)
- t = wall thickness (inches)

5.16 Recommendations

Toe drains are critical to the safe operation of embankment dams. Toe drains frequently have deep burial where they would be difficult to access or replace. Trouble-free operation is critical, and small additional costs at the time of construction for the "best" pipe materials are easily justified. Test results are summarized for discussion in table 5-1.

Table 5-1.—Summary of test results

Pipe material	Wall construction		Type	Diameter (inches)	Pressure class (psi)	SDR	Wall thickness (inches)	Perforation size (inches)*	Perforation type	Rows	Open area (in^2/lin ft)	Open area (POA %)	Pipe strength (psi)	Remarks
HDPE	Solid		Non-perforated	12	160	11	1.159						487.0	
			Perforated	12	160	11	1.159	0.375	Holes	6	1.41	0.3	465.0	Note 1.
	Corrugated	Single wall	Non-perforated	12									61.5	
				18									41.9	
			Perforated	12				0.374	Holes	6	1.41	0.3	58.3	Note 2.
				18				0.375	Holes	6	1.41	0.2	43.4	
		Double wall	Non-perforated	6									60.4	
				12									57.7	
				18									41.0	
				24									40.6	
			Perforated	6				0.125	0.875" slots	6	0.94	0.4	57.2	
				12				0.375	Holes	6	1.41	0.3	52.9	
				18				0.375	Holes	6	1.41	0.2	44.8	
				24				0.375	Holes	8	1.88	0.2	41.3	
PVC	Solid	Pressure	Non-perforated	6	160	26	0.255						139.0	
				6	200	21	0.316						262.0	
				12	200	21	0.606						400.0	
			Well screen	6	160	26	0.255	0.016	1.780" slots	6	8.2	3.6	120.0	
				6	200	21	0.316	0.016	1.780" slots	6	8.2	3.6	230.0	slots only
				12	200	21	0.606	0.025	3.125" slots	8	30	6.6	352.0	
		Drainpipe	Non-perforated	6	120	35							61.0	
			Perforated	6	120	35		0.500	Holes	2	0.94	0.4	60.0	
	Corrugated	Double wall	Non-perforated	6									54.8	Brittle
				12									57.6	
				18									56.4	
				24									60.7	
			Perforated	6				0.031	1.038" slots	2	2	0.9	55.1	
										4	4	1.8	54.6	
				12				0.051	1.687" slots	2	2	0.4	53.1	
				18				0.051	2.250" slots	2	2	0.3	58.5	
				24				0.375	Holes	2	2	0.2	63.5	

*For slot perforation, measurement given is for slot width.

Notes:
1. Holes drilled after market.
2. Resin issue historic poor performance.

6.0 Conclusions

1. All the pipe exceeded the manufacturer's published values for pipe stiffness.

2. For corrugated pipe, the perforated pipe was just as strong as the non-perforated pipe. The reason for this high retained strength is that corrugated pipe gets its strength from the corrugation ribs, while the perforations are located in the corrugation valleys, which contribute very little strength.

3. For solid-wall pipe, the perforated pipe was weaker than the non-perforated pipe. The strength reduction was directly proportional to the POA. Solid-wall PVC pipe (drainpipe and pressure pipe) showed a 2.5 percent decrease in pipe stiffness for every 1 percent open area. Solid-wall HDPE pipe lost more strength, with a 15.0 percent decrease in pipe stiffness for every 1 percent open area.

4. *Mode of Failure* – For all pipe tested, the presence and location of perforations had no influence on the mode or location of the pipe failure. Some samples failed (ruptured) along the factory mold marks, but none failed at the perforations.

5. Both corrugated pipe options (HDPE and PVC) have significantly less strength (lower pipe stiffness) than both the solid-wall pressure pipe options (HDPE and PVC).

6. Pipe deflection is a function of both pipe stiffness and soil modulus. For corrugated pipe, soil modulus is typically much larger than pipe stiffness, emphasizing the fact that thin-walled plastic pipe relies greatly on support from the compacted backfill to resist deformation. Therefore, proper compaction and backfill support are critical for corrugated pipe.

7. *Brittleness* – Although not originally part of this study, brittleness proved to be an issue for some of the larger-diameter double-wall corrugated PVC pipe. This brittle behavior is probably related to some of the construction damage issues seen with thin-walled PVC pipe in the field.

8. *Perforations* – Because of flow characteristics, fewer large holes are preferred for high-flow applications, while numerous slots (or smaller holes) are acceptable for low-flow applications.

9. *Joints* – All pipe manufacturers offer some type of satisfactory watertight joint. Some joints are easier to assemble and more robust than others. Since joints for perforated pipe need not be watertight, some manufacturers also offer a “soil-tight” joint that is appropriate for drainage applications.

10. *Recommendations* – Toe drains are critical to the safe operation of embankment dams. Toe drains frequently have deep burial where they would be difficult to access or replace. Long-term, trouble-free operation is essential, and small additional costs at the time of construction are easily justified. Proper installation of plastic pipe should be verified with closed circuit television inspection. Therefore, pipe recommendations for critical toe drain applications are shown in table 6-1.

Table 6-1.—Pipe recommendations for toe drains – advantages and disadvantages

Product	**Type**		**Advantage**	**Disadvantage**	**Recommended**
HDPE	Solid		Strong, welded joints, flexibility of perforation size and type	Highest cost, special ordered, or hand-drilled after-market addition of perforations	Highly
	Corrugated	Single	Economical	Poor historic performance, weak	No
		Double	Economical, successful applications, large perforation sizes	Low strength, careful installation required	Moderately
PVC	Solid	Well screen	Strong	Small perforation aperture	Moderately
		Drainpipe	Economical	Weak, brittle	No
	Corrugated	Double	Economical	Weak, brittle	No

7.0 References

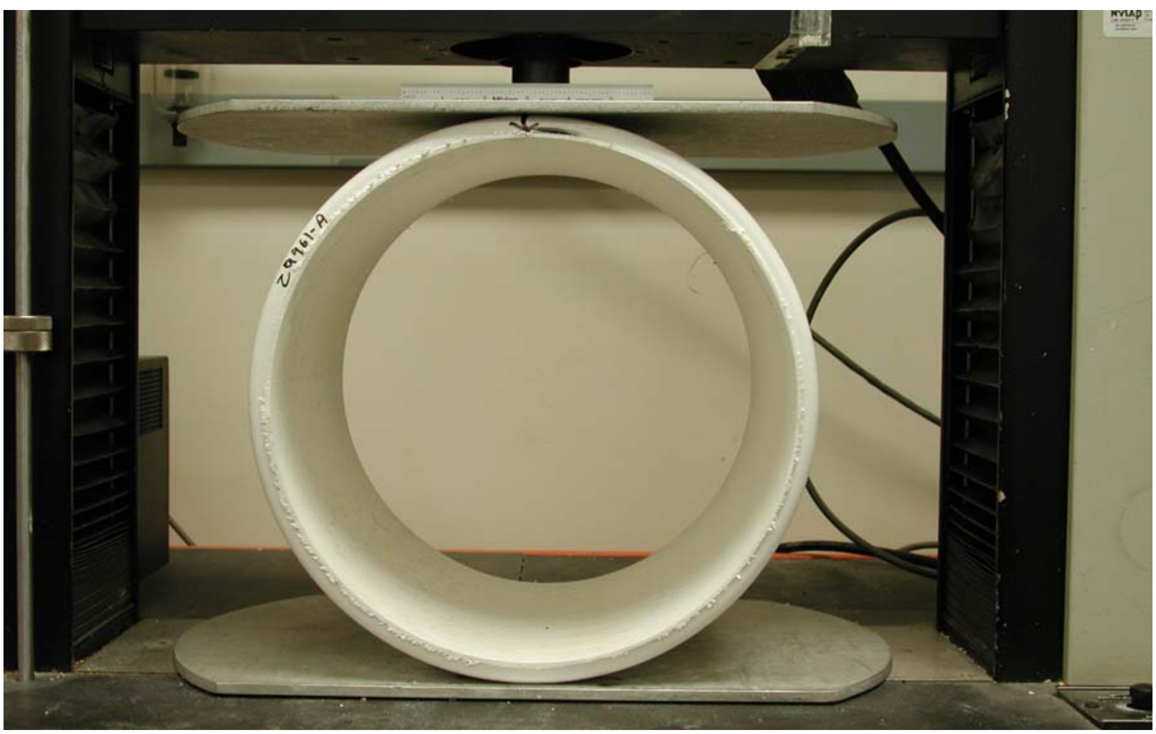
Cooper, Chuck R. "Closed Circuit Television Inspection of Outlet Works and Spillway Conduits and Toe Drains." Association of State Dam Safety Officials Annual Conference. 2005.

Federal Emergency Management Agency. *Technical Manual: Plastic Pipe Used in Embankment Dams*. FEMA P-676. November 2007.

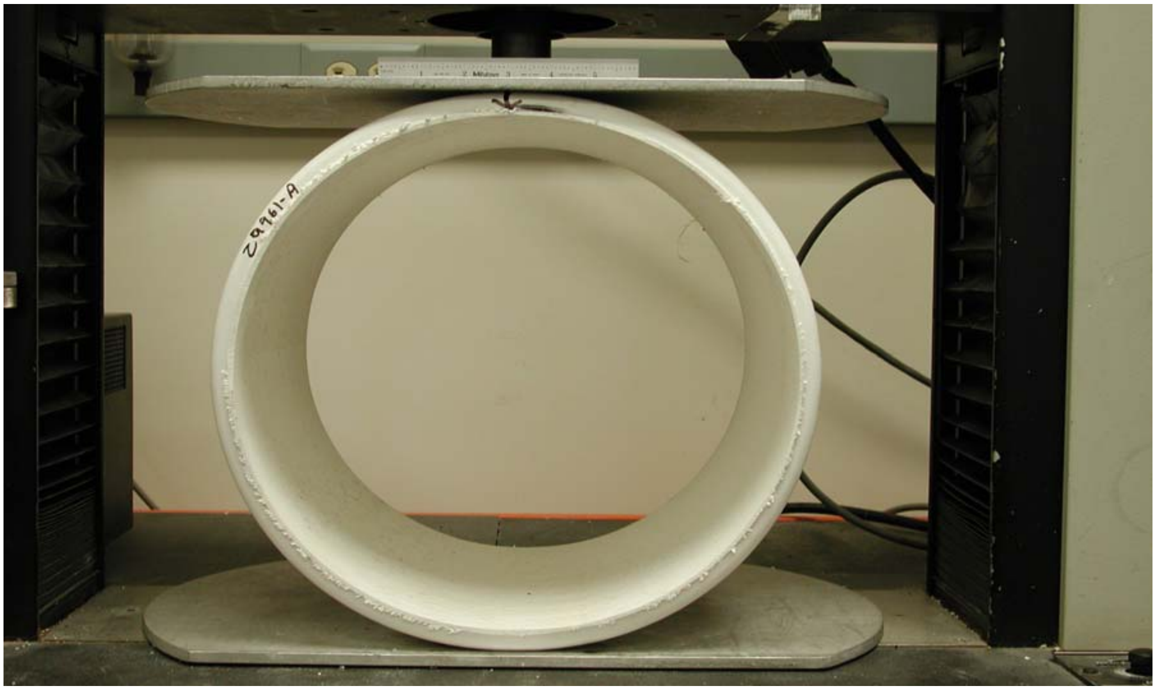
Appendix A

Photographs – Pipe Testing

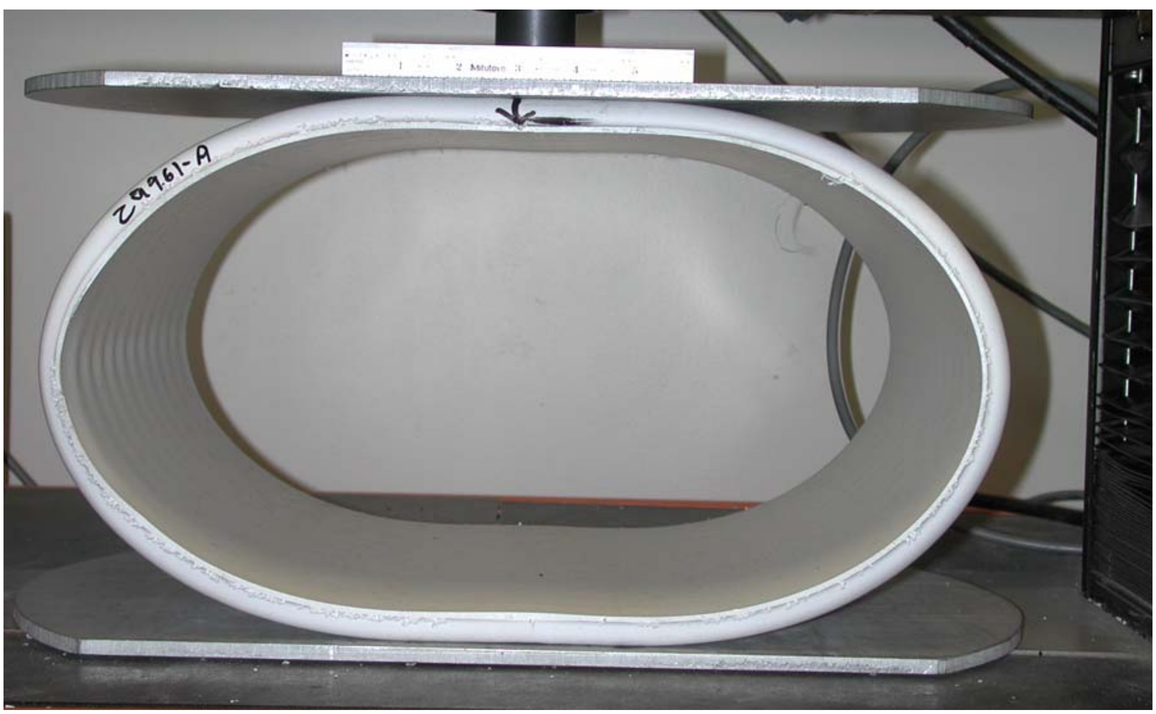
Photograph 1.—Corrugated double-wall PVC pipe, 6-, 12-, 18-, and 24-inch diameter.



Photograph 2.—Double-wall PVC pipe at 0 (zero) percent deflection.



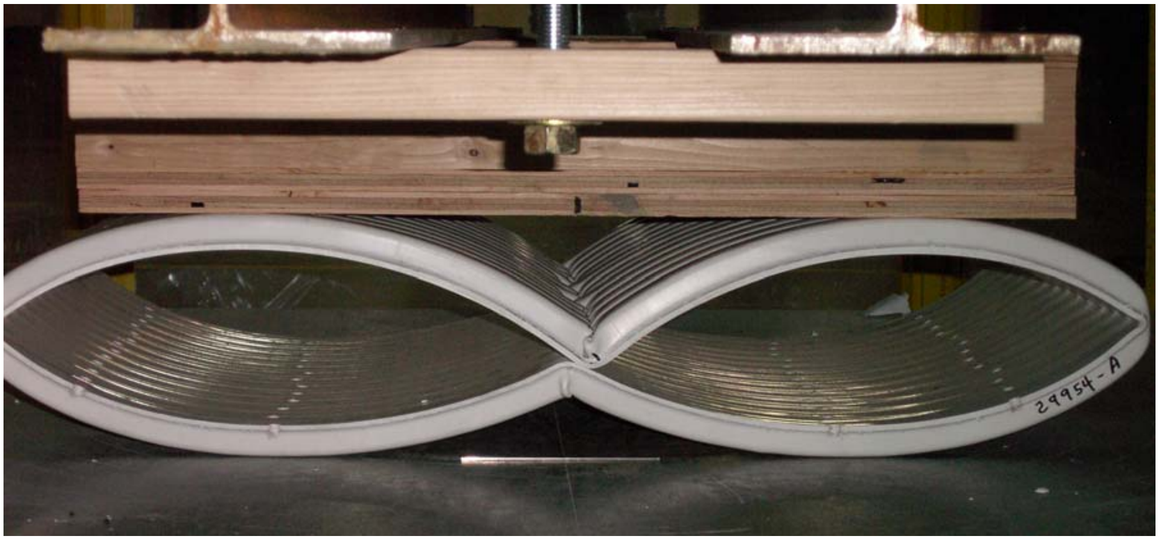
Photograph 3.—5 percent deflection.



Photograph 4.—50 percent deflection.

Photograph 5.—Pancake failure mode.

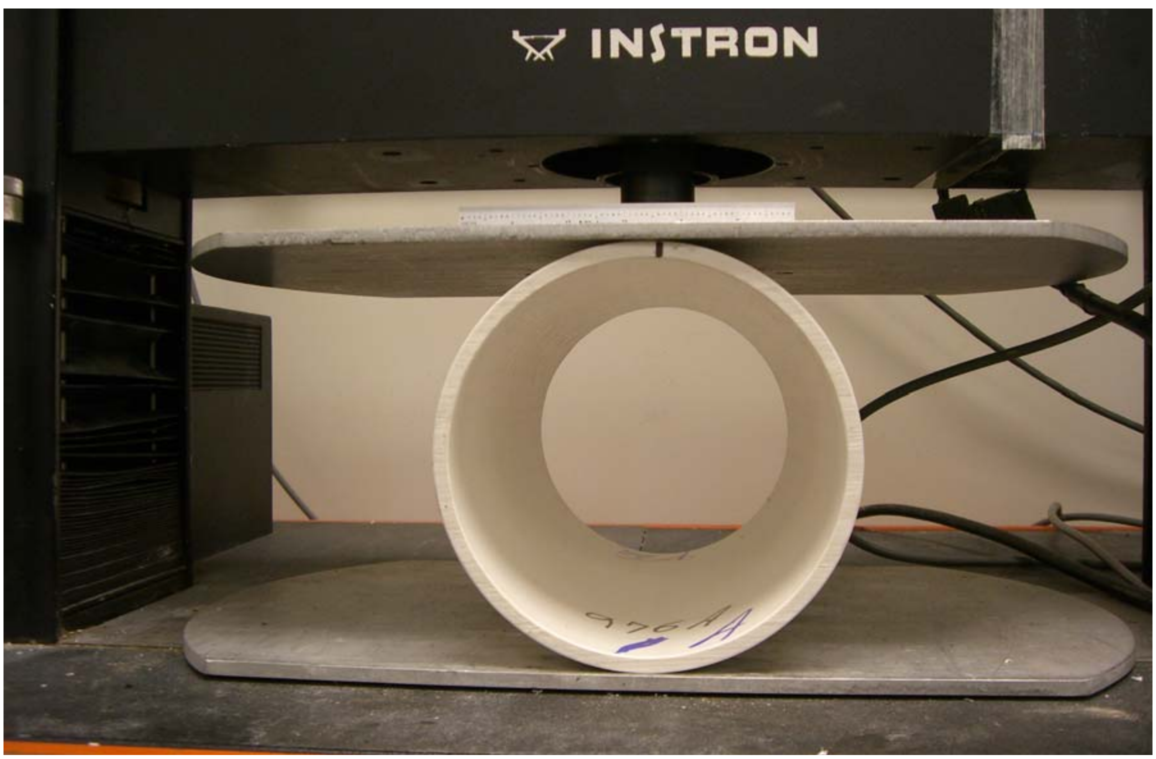
Photograph 6.—Shattered pipe wall with inverted heart failure mode.



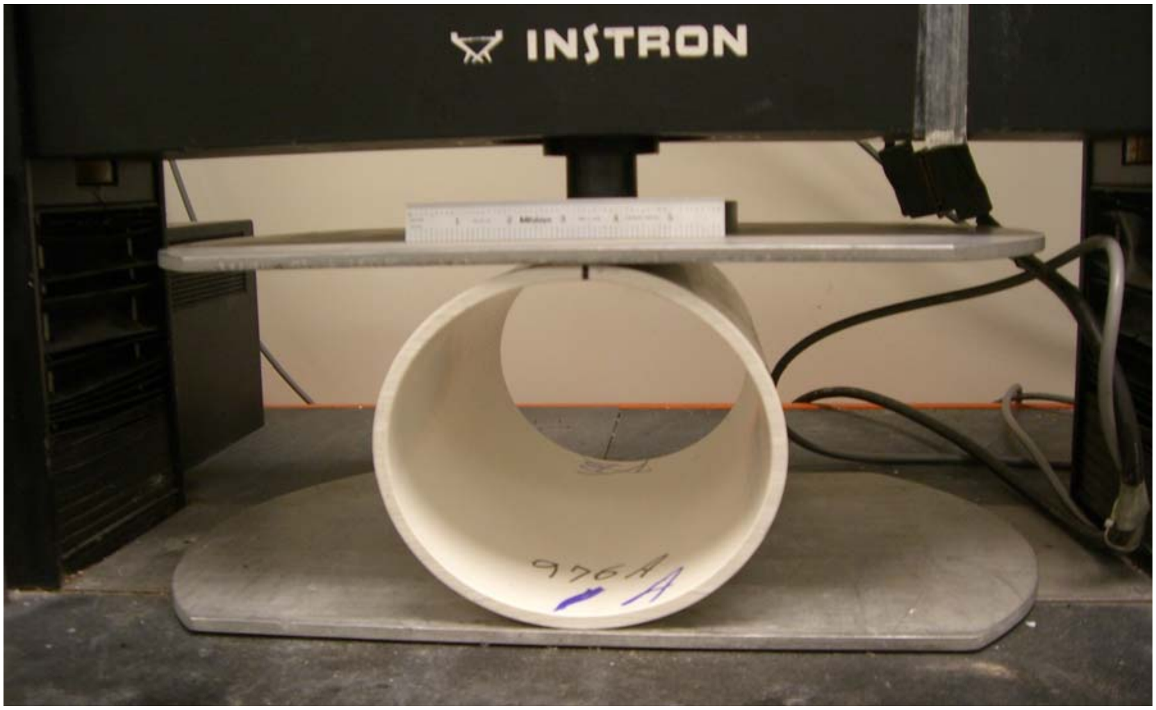
Photograph 7.—Binocular failure mode.

Photograph 8.—Pancake failure mode with shattered pipe wall.

Photograph 9.—PVC solid-wall drainpipe and pressure pipe in 6- and 12-inch diameters.



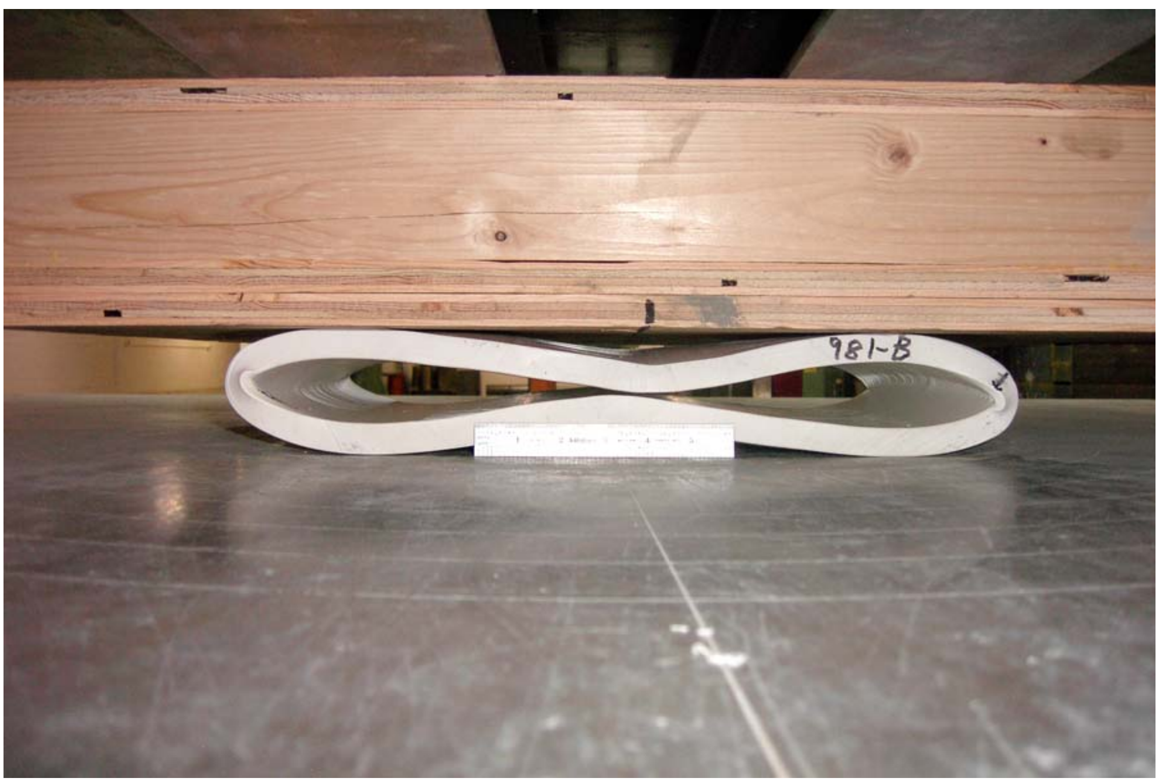
Photograph 10.—Test begins at 0 (zero) percent deflection.



Photograph 11.—Pipe stiffness determined at 5 percent deflection.

Photograph 12.—50 percent deflection.

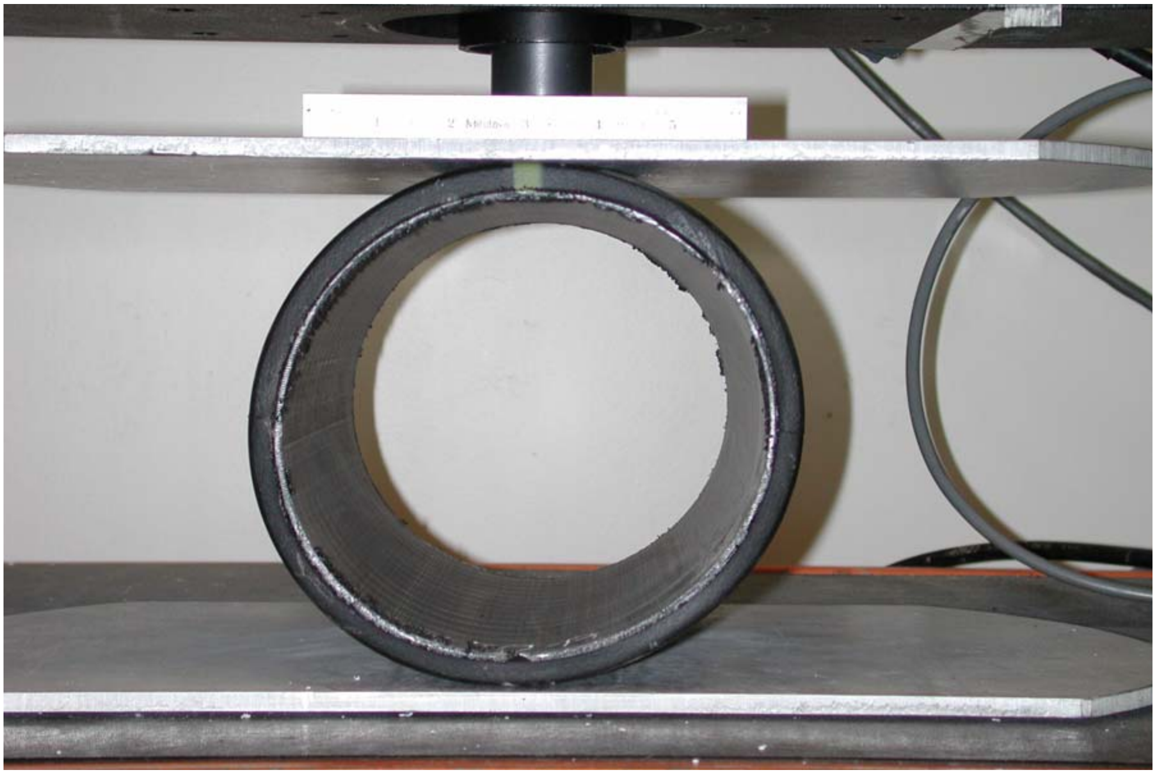
Photograph 13.—Pancake failure mode for thin-walled PVC drainpipe.



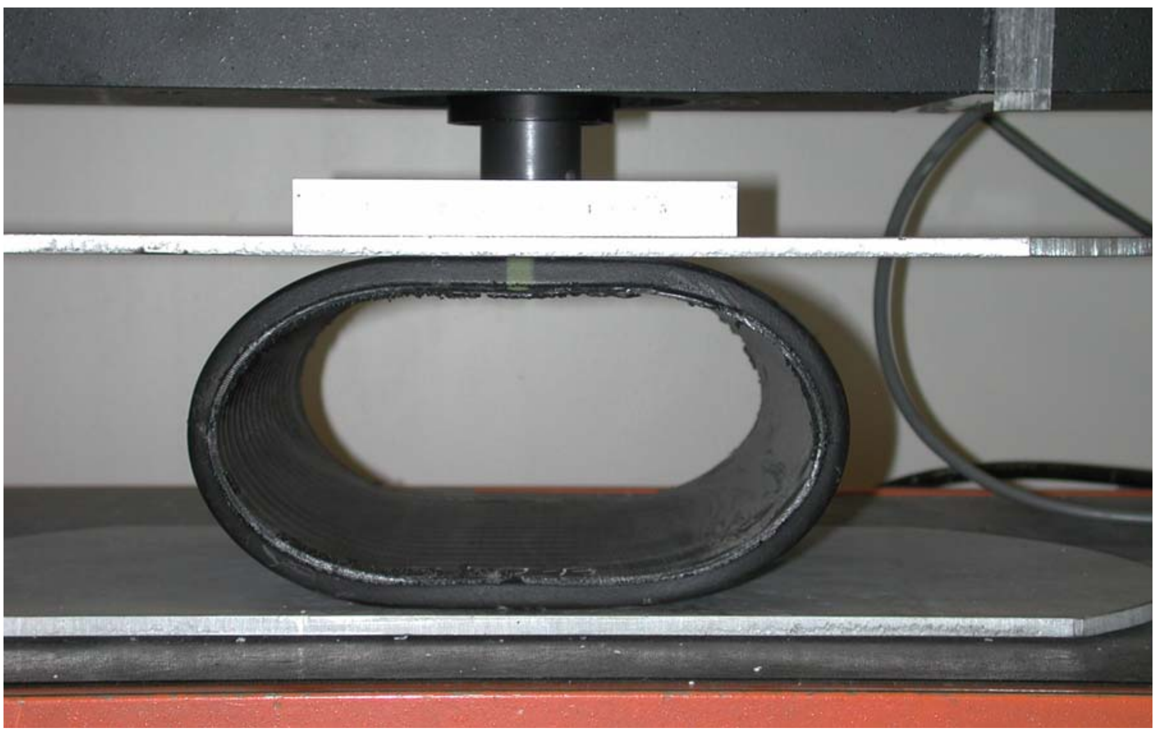
Photograph 14.—Pancake failure mode for sample of PVC pressure pipe.

Photograph 15.—Samples of HDPE perforated and non-perforated double-wall corrugated drainpipe, including 6-, 12-, 18-, and 24-inch diameter.

Photograph 16.—Double-wall HDPE pipe at 0 (zero) percent deflection.



Photograph 17.—HDPE double-wall corrugated drainpipe at 5 percent deflection.



Photograph 18.—HDPE pipe at maximum load – buckling of pipe wall at approximately 40 percent deflection.

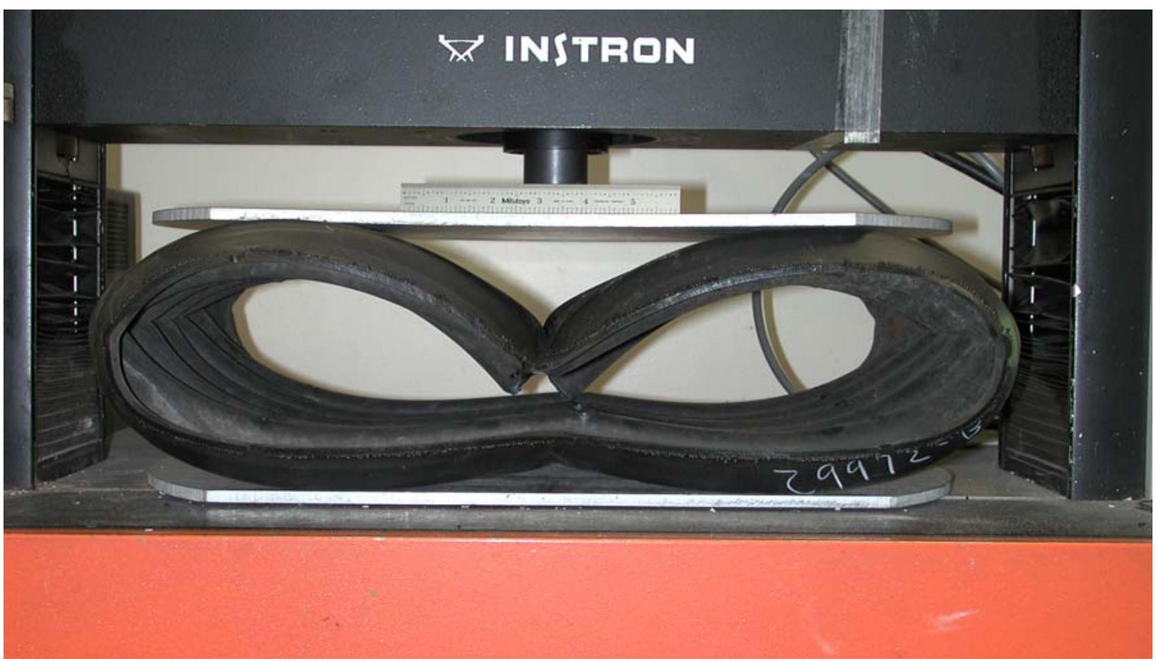
Photograph 19.—“Heart” failure mode.

Photograph 20.—“Binocular” failure mode.

Photograph 21.—Samples of single-wall corrugated HDPE drainpipe include 12- and 18-inch diameter (perforated and non-perforated).

Photograph 22.—12-inch diameter sample loaded in the test machine and ready for testing.

Photograph 23.—Pipe walls begin to buckle at approximately 40 percent deflection (maximum load).



Photograph 24.—Single-wall HDPE pipe with heart-shaped failure mode and rupture of pipe wall.

Photograph 25.—Single-wall HDPE pipe – “binocular” failure mode.

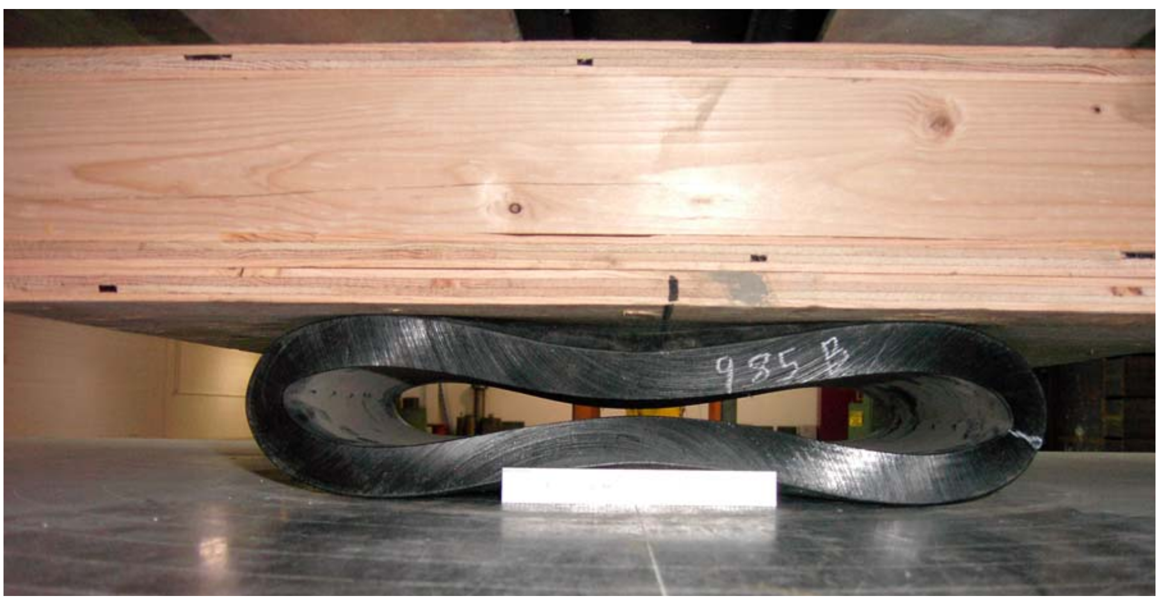
Photograph 26.—Single-wall pipe – “inverted heart” failure mode.

Photograph 27.—Pancake failure mode.

Photograph 28.—Samples of perforated and non-perforated 12-inch diameter solid-wall HDPE pressure pipe. Perforations consist of four rows of 3/8-inch holes on 2-inch centers.

Photograph 29.—HDPE solid-wall ready for testing.

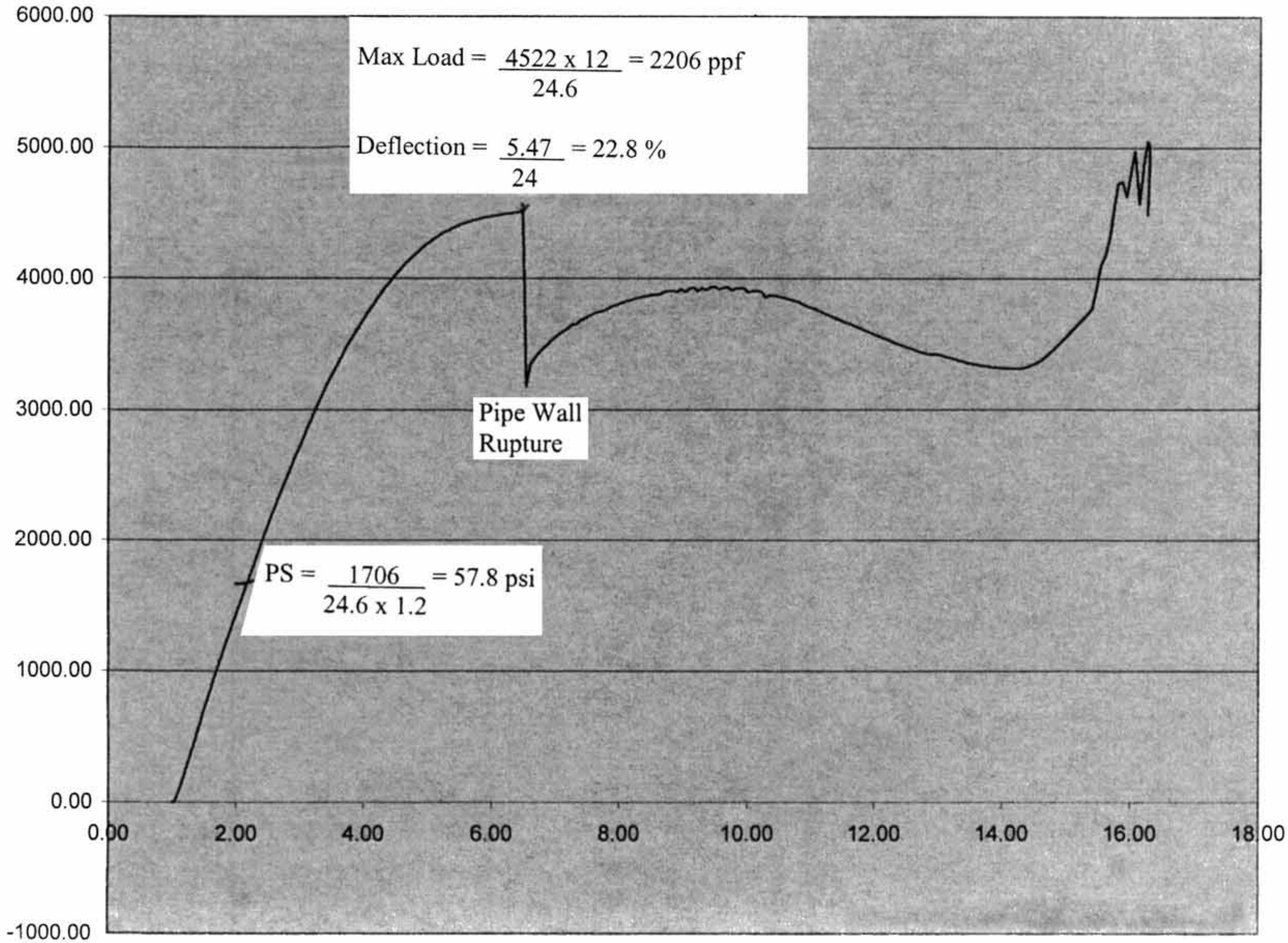
Photograph 30.—Pipe at 5 percent deflection.



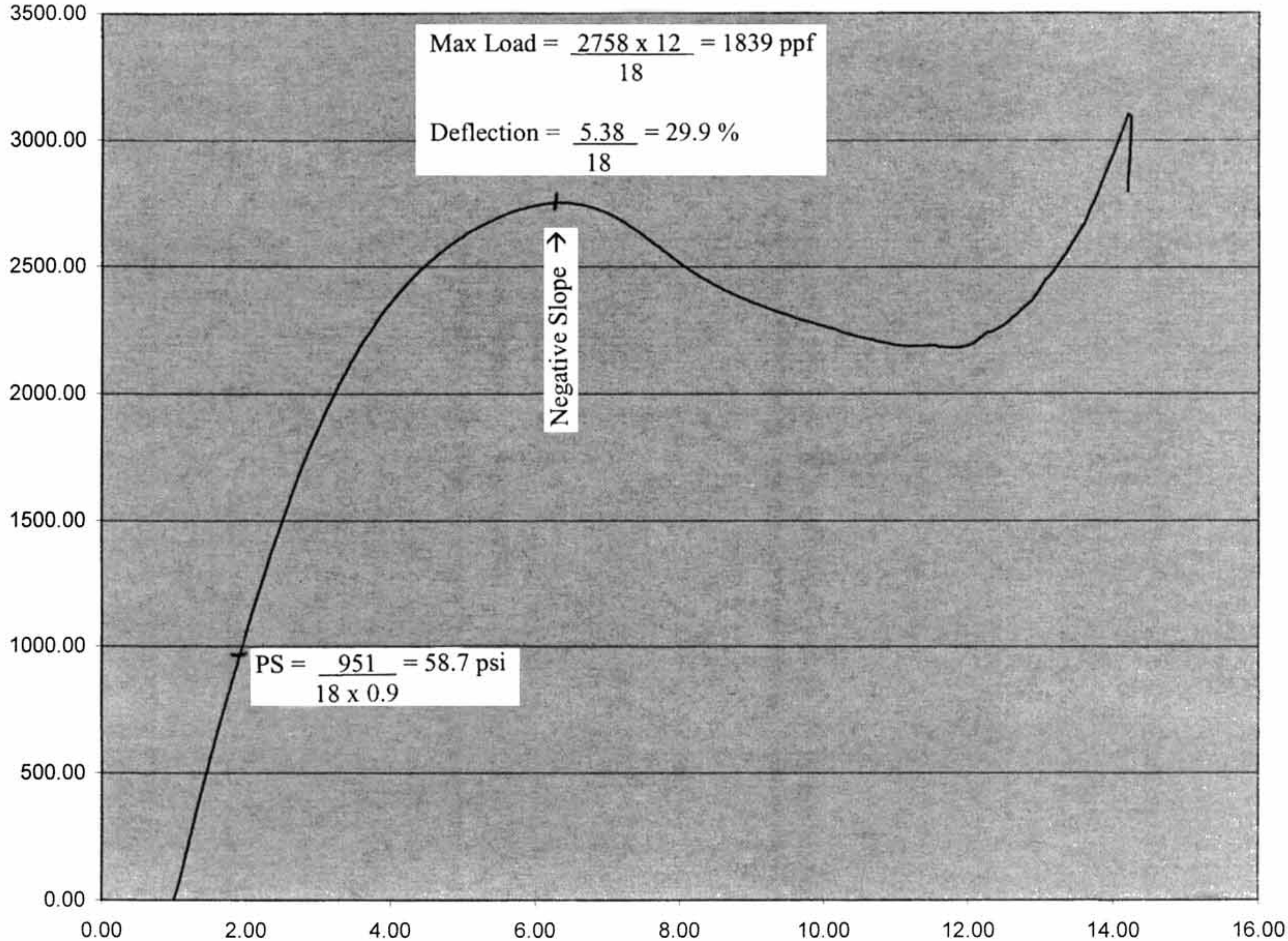
Photograph 31.—Pancake failure mode – slightly binocular.

Appendix B

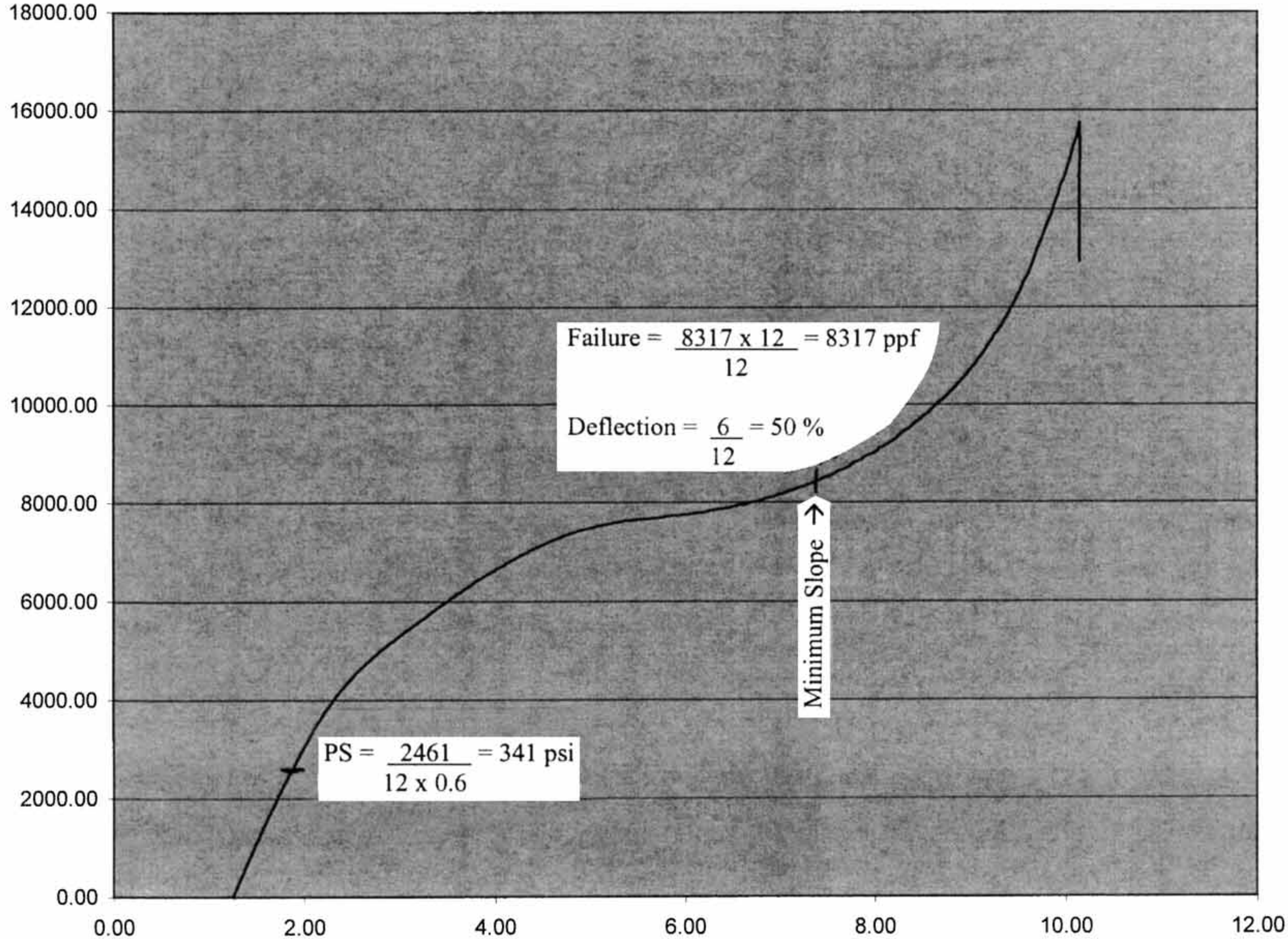
Data Plots – Load versus Deflection



Sample 954A – 24-inch PVC Corrugated Non-Perforated - Pipe Stiffness (PS) calculated at 5 % deflection. Failure by pipe wall rupture at 22.8 % deflection.



Sample 955A – 18-inch PVC Corrugated Perforated - Pipe Stiffness (PS) calculated at 5% deflection. Failure at negative slope on load-deflection curve (29.9% deflection).



Sample 981A – 12-inch PVC Slotted Well Screen - Pipe Stiffness (PS) calculated at 5 % deflection. Failure defined as 50 percent deflection which roughly corresponds to minimum slope on the load-deflection curve.

Appendix C

Manufacturer Data Sheets

CONTECH
CONSTRUCTION PRODUCTS INC.

A-2000 Perforated Pipe

The Exceptional Subdrainage System

Designed for Better Performance

Quality design and preferred materials selection make CONTECH® A-2000™ perforated pipe the designer's first choice for subsurface drainage materials. A-2000 double-wall PVC pipe will give you confidence in your drainage system's long-term performance capabilities.

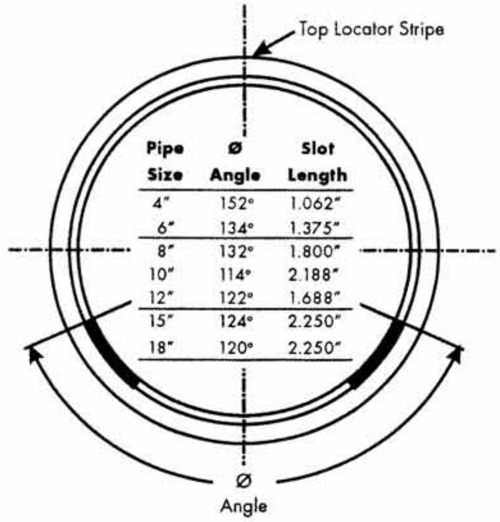
Benefits by Design

- 46 psi pipe stiffness for assured deep trench performance or H-20 wheel loads at shallow covers.
- Glossy smooth (Manning's n = .009) interior for greater flow, flatter installation grades, smaller diameter requirements and less interior silting.
- Higher beam strength than HDPE underdrains for improved alignment and grade control during installation.
- Lightweight, long lengths with positive O-ring gasketed bell-spigot joints result in fast, easy, economical installation.
- Manufactured only from virgin, low-filler cell class PVC resin (12454 per ASTM D1784) for maximum durability.
- Straightness allows uniform slot positioning.
- Complete line of fittings for uniform quality and more efficient placement.

National Standards

Economical CONTECH A-2000 subdrainage pipe, available in 4" through 18" diameters in 12'-6" lengths and 21" through 36" diameters in standard 13'-0" lengths, conforms to the requirements of ASTM F949, ASTM F794, and AASHTO M304M.

Slot geometry and placement provide a minimum of 1.90 square inches/lineal foot opening for each diameter. 20'-0" lengths of 4" and 6" are available on special order.

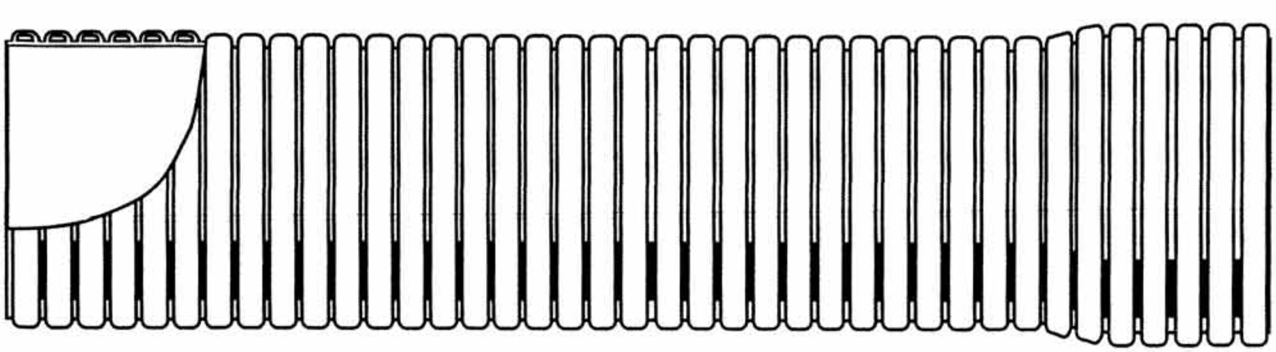


Pipe Size	Ø Angle	Slot Length
4"	152°	1.062"
6"	134°	1.375"
8"	132°	1.800"
10"	114°	2.188"
12"	122°	1.688"
15"	124°	2.250"
18"	120°	2.250"

Perforation Dimensions

Pipe Size	Slot Length	Slot Width	Slot Centers	Open Area*
4"	1-1/16"	.031"	.413"	1.90
6"	1-3/8"	.031"	.516"	1.98
8"	1-3/4"	.031"	.689"	1.90
10"	2-3/16"	.031"	.826"	1.98
12"	1-11/16"	.051"	1.033"	2.00
15"	2-1/4"	.051"	1.377"	2.00
18"	2-1/4"	.051"	1.377"	2.00

* *Open area is square inches per lineal foot of underdrain pipe.*
Note: *21" through 36" is available with 3/8" diameter holes for open area specified by engineer.*

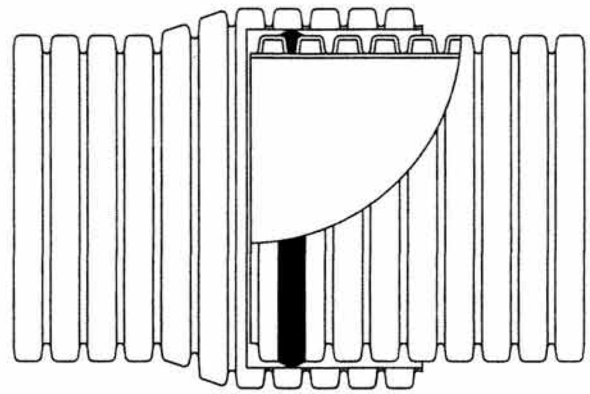


A-2000 Perforated Pipe

Better Performance by Design

Filter Performance

In soils or aggregates containing migratory fines, high-quality geotextile wraps are proven to be effective in protecting against inflow reductions and interior silting. For best performance, the selected geotextile must have high resistance to blinding and clogging, while preventing significant passage of fines.



8" thru 36" is also available in fully-perforated pipe.

For more information, call one of CONTECH's Regional offices or Plastic Pipe Specialists located in the following cities:

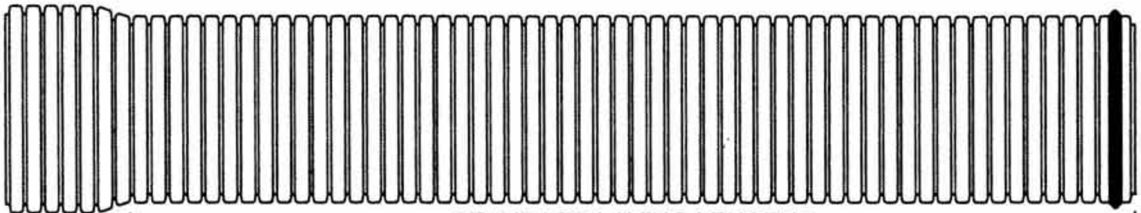
Arkansas (North Little Rock) 72115	501/758-1985
California (San Bernardino) 92408	909/885-8800
Colorado (Denver) 80033	303/431-8999
Florida (Pinellas Park) 33781	727/544-8811
Georgia (Atlanta) 30071	770/409-0814
Illinois (Chicago) 60523	630/573-1110
Indiana (Indianapolis) 46250	317/842-7766
Iowa (Johnston) 50131	515/331-2517
Kansas (Kansas City) 66210	913/906-9200
Louisiana (Baton Rouge) 70767	225/749-1001
Massachusetts (Palmer) 01069	410/740-8490
Michigan (Clinton Township) 48036	586/469-4240
Michigan (Dewitt)	517/669-5760
Michigan (Zeeland) 49464	616/748-6258
Missouri (St. Louis) 63105	314/862-7300
North Carolina (Rocky Mount) 27803	252/212-5408
Ohio (Eaton) 45320	937/456-1009
Ohio (Middletown) 45044	513/425-2393
Tennessee (Germantown)	901/848-2773
Texas (Houston) 77014	281/893-6012
Texas (Dallas) 75062	972/659-0828

Visit our web site: www.contech-cpi.com

CONTECH CONSTRUCTION PRODUCTS INC.

BRO-A2000PP-1 6/03

A-2000 PERFORATED PVC DRAINAGE PIPE



STANDARD LAYING LENGTHS
4" thru 10" Diameters = 12' - 6"
12" thru 36" Diameters = 13' - 0"
21" thru 36" Diameters = 20' - 0"

Nominal Diameters (in.)	Average O.D. (Spigot) (in.)	Average O.D. (Bell) (in.)	Average I.D. (in.)	Pipe Stiffness (lbs/in/in)	Standard Perforation Open Area per foot (SQIN)	Fully Perforated Open Area per foot (SQIN)
4	4.3	4.8	3.9	46	1.92	
6	6.4	7.0	5.9	46	1.99	
8	8.6	9.4	7.9	46	1.90	3.80
10	10.8	11.7	9.8	46	1.98	3.96
12	12.8	13.9	11.7	46	2.00	4.00
15	15.7	16.9	14.3	46	2.00	4.00
18	19.2	20.6	17.6	46	2.00	4.00
21	22.6	24.6	20.7	46	* 2.70	5.40
24	25.6	27.9	23.5	46	* 2.70	5.40
30	32.2	35.1	29.5	46	* 2.20	4.40
36	38.7	42.3	35.5	46	* 2.00	4.00

* Open Area based upon 3/8"Ø round holes

SPECIFICATION

Scope:

This specification includes materials, test methods and installation requirements for 4 to 36-inch diameter polyvinyl chloride (PVC) corrugated pipe with a smooth interior. The requirements of this specification are intended to provide perforated pipe and fittings suitable for underground use in non-pressure applications such as sub-drainage and underdrains.

Pipe:

PVC corrugated pipe with a smooth interior shall conform to the requirements of ASTM Designation F949 & F794 Dual Wall Corrugated Profile (DWCP) Pipe . Pipe and fittings shall be homogeneous throughout and free from visible cracks, holes, foreign inclusions or other injurious defects. Pipe shall be manufactured to 46 psi stiffness when tested in accordance with ASTM Test Method D2412. There shall be no evidence of splitting, cracking or breaking when the pipe is tested per ASTM Test Method D2412 and F949 section 7.5. The pipe shall be made of PVC compound having a minimum cell classification of 12454B as defined in ASTM Specification D1784.

Fittings:

All fittings for PVC corrugated sewer pipe with a smooth interior shall conform to ASTM F949, Section 5.2.3 or F794, Section 7.2.4. To insure compatibility, the pipe manufacturer shall provide all fittings.

Joints:

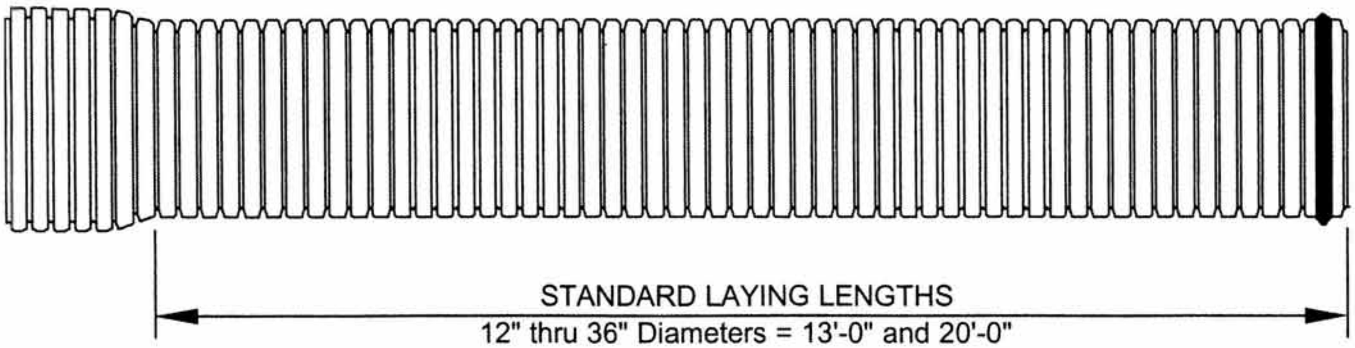
All joints shall be made with integrally-formed bell and spigot gasketed connections. Elastomeric seals (gaskets) shall meet the requirements of ASTM Designation F477.

Perforations:

For slotted, standard perforated pipe, the perforation dimensions shall be in accordance with ASTM F949 table 5 and section 7.9. Instead of slots, round holes (min. 1/4" Ø) may be used for 15"-36" diameter pipe.

10/24/03

A-2000 PVC DRAINAGE PIPE



Nominal Diameters (in.)	Average O.D. (Spigot) (in.)	Average O.D. (Bell) (in.)	Average I.D. (in.)	Pipe Stiffness (lbs/in/in)	Minimum Flattening (%)
12	12.8	13.9	11.7	46	40
15	15.7	16.9	14.3	46	40
18	19.2	20.6	17.6	46	40
21	22.6	24.6	20.7	46	40
24	25.6	27.9	23.5	46	40
30	32.2	35.1	29.5	46	40
36	38.7	42.3	35.5	46	40

SPECIFICATION

Scope:

This specification includes materials, test methods and installation requirements for 12 to 36-inch diameter polyvinyl chloride (PVC) corrugated pipe with a smooth interior. The requirements of this specification are intended to provide pipe and fittings suitable for underground use in non-pressure applications such as sanitary sewers, storm sewers, drainage and underdrains.

Pipe:

PVC corrugated pipe with a smooth interior shall conform to the requirements of ASTM Designation F949 and F794. Pipe and fittings shall be homogeneous throughout and free from visible cracks, holes, foreign inclusions or other injurious defects. Pipe shall be manufactured to 46 psi stiffness when tested in accordance with ASTM Test Method D2412. There shall be no evidence of splitting, cracking or breaking when the pipe is tested per ASTM Test Method D2412 in accordance with ASTM F949 section 7.5 and ASTM F794 section 8.5. The pipe shall be made of PVC compound having a minimum cell classification of 12454B as defined in ASTM Specification D1784.

Fittings:

All fittings for PVC corrugated sewer pipe with a smooth interior shall conform to ASTM F949, Section 5.2.3 or F794, Section 7.2.4. To insure compatibility, the pipe manufacturer shall provide all fittings.

Joints:

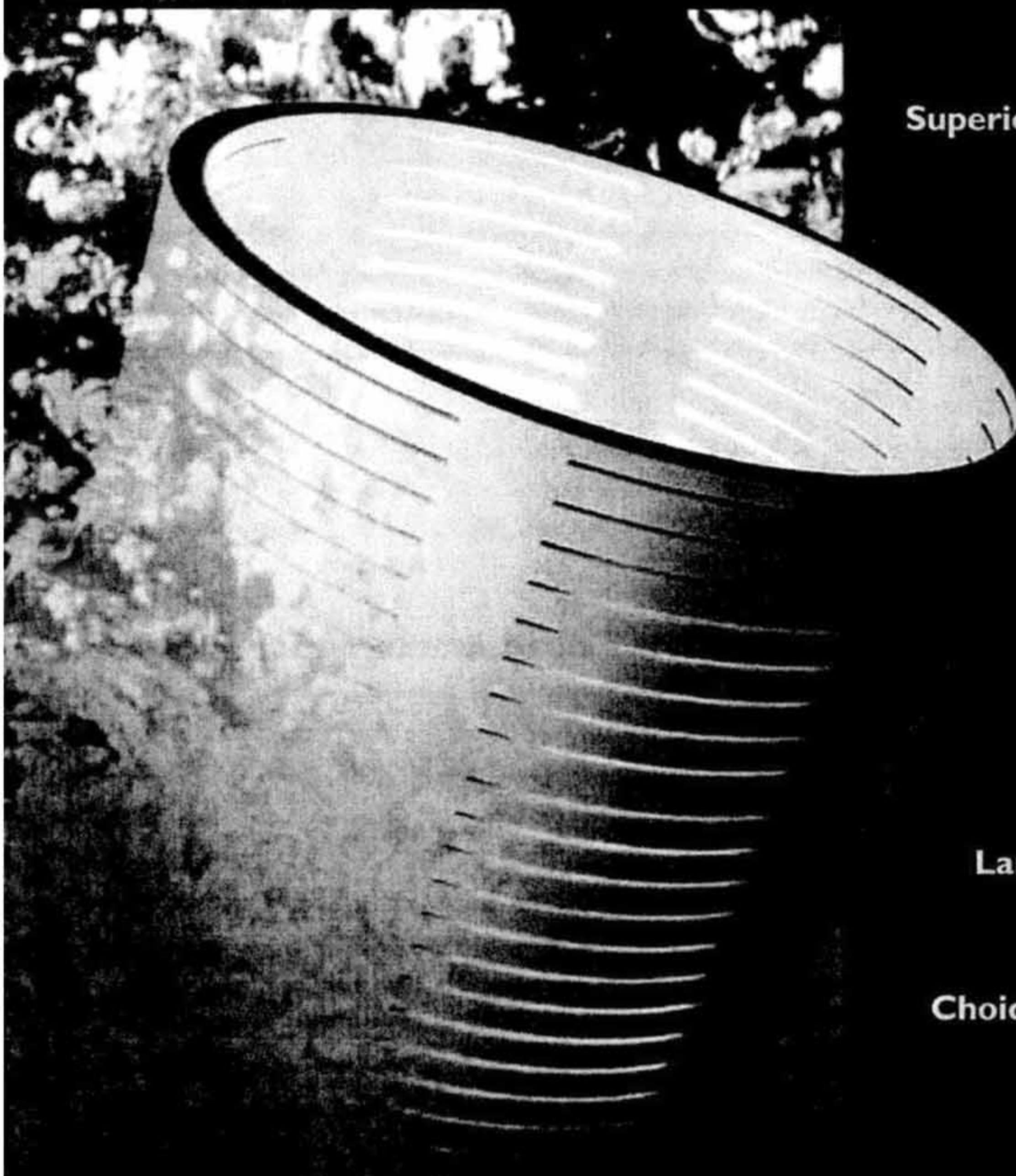
All joints shall be made with integrally-formed bell and spigot gasketed connections. The manufacturer shall provide documentation showing no leakage when gasketed pipe joints are tested in accordance with ASTM Test Method D3212. Elastomeric seals (gaskets) shall meet the requirements of ASTM Designation F477.

10/24/03

CertainTeed

Slotted PVC Well Casing

High Performance



Superior flow performance

Corrosion resistant

Large selection of slot configurations

Choice of joining systems

CertainTeed

Quality made certain. Satisfaction guaranteed.

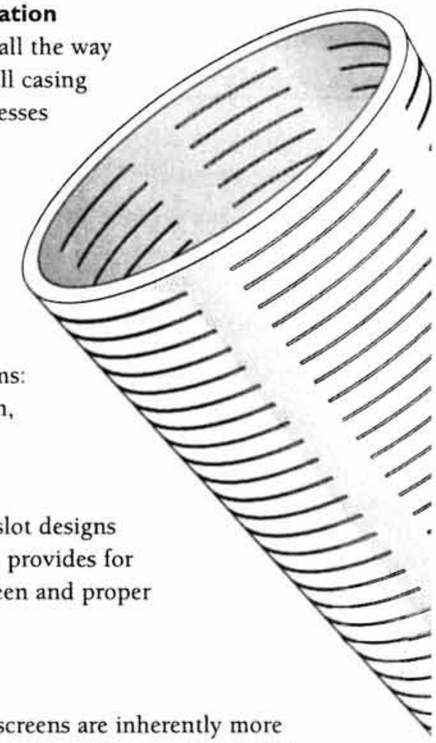
The CertainTeed Advantage

CertainTeed – the name that contractors have come to associate with the industry's broadest line of high-quality PVC well products – is also the industry leader in high performance slotted well casing. Using new manufacturing technology, slotted casing can now be produced with open areas and efficiencies that rival those of other screens, often at a fraction of the cost. Combine PVC screens with PVC well casing for the ultimate corrosion-resistant, low-maintenance water well!

A Size and Joining System for Every Application

Slotted casing can be produced in sizes from 2" all the way up to the largest commercially available PVC well casing product (17.4" O.D.), in a variety of wall thicknesses and strengths to suit virtually all applications:

- Domestic
- Irrigation
- Municipal
- Aquifer Storage and Recovery
- Environmental



CertainTeed also offers a choice of joining systems: traditional solvent-weld or the contractor-proven, all-weather Certa-Lok™ mechanical joint.

Slot Width Selection

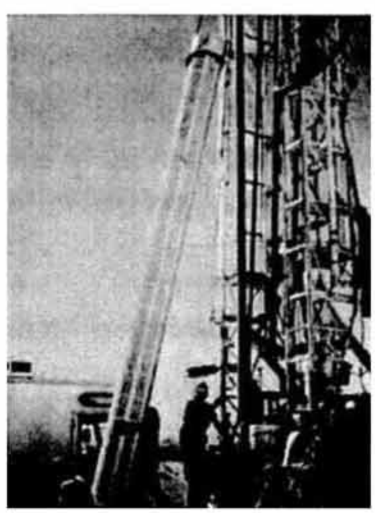
A wide selection of precision-machined factory slot designs (.010"-.125") with closely spaced inlet openings provides for uniform development over the length of the screen and proper stabilization of the gravel pack.

Long Life

Well rehabilitation costs are minimized, as PVC screens are inherently more resistant than conventional steel products to clogging and encrustation. PVC also outperforms stainless steel in highly corrosive environments, at a fraction of the cost. All screens are manufactured from PVC casing that is listed by NSF International as safe for use with potable water.

Single Source for All Your Well Product Needs

No more unloading, local-machining, and repackaging required. With CertainTeed, the industry's best slotted casing is shipped ready to use – no field fabrication required – along with your other PVC well product needs, including solid casing, drop pipe for submersible pumps, and a variety of fittings.



Underdrain Pipe

Slotted PVC casing is also ideal for use as underdrain pipe. Applications include, but are not limited to:

- Leachate collection systems for solid waste landfills
- Drainage and dewatering applications
- Mining heap leach projects

PVC underdrain pipe is supplied with precision-machined slots, which provide greater intake capacity and continuous, clog-resistant drainage of fluids, as compared to standard round-hole perforated pipe. Slotted underdrain reduces entrance velocity into the pipe, thereby reducing the possibility that solids will be carried into the system. Slot rows can generally be positioned symmetrically or asymmetrically around the pipe circumference, depending upon the application. Outside diameters are generally the same for PVC and non-corrugated polyethylene (HDPE) pipe. However, the HDPE pipe must be extruded with a thicker wall (and therefore a reduced cross-sectional flow area) to obtain a comparable stiffness rating.

Slotted PVC and Underdrain Pipe Specifications

This chart illustrates standard manufacturing capabilities only. Not all products shown are routinely stocked – call for availability.
Slot configurations not included on this chart are covered under CertainTeed's non-standard product warranty.

NOM. SIZE	NOM. O.D.	NO. OF ROWS	CLASS	MIN. WALL THICKNESS	JOINT AVAILABILITY	O.D. OPEN AREA, SQ. INCHES PER FOOT OF SCREEN (.25" SLOT SPACING) SLOT WIDTH INCHES 0.010	0.013	0.016	0.020	0.025	0.032	0.040	0.050	0.085	0.100	0.125
2"	2.375	4	SCH40	0.154	SW	2.4	3.1	3.7	4.6	5.6	7.0					
3"	3.500	4	SCH40	0.216	SW	2.6	3.4	4.1	5.0	6.2	7.7					
4"	4.500	4	SDR26	0.173	SW											
			SDR21	0.214	SW	3.0	3.9	4.8	8.0	9.7	12.2	14.8	18.2	27.2		
			SCH40	0.237	SW,CLIB											
4 1/2"	4.950	4	SDR26	0.190	SW,CLIB											
			SCH40	0.248	SW,CLIB	3.0*	4.5*	5.4*	9.2	11.3	14.1	17.1	21.0	31.5		
			SDR17	0.291	SW,CLIB											
5"	5.563	4	SDR26	0.214	SW											
			SDR21**	0.265	SW,CLIB		4.5*	5.4*	10.0	12.3	15.4	18.7	23.0	34.4		
			SDR17	0.327	SW,CLIB											
			SCH80	0.375	CLIB											
6"	6.625	6	SDR26	0.255	SW											
			SCH40	0.280	SW,CLIB											
			SDR21	0.316	SW,CLIB			8.2*	12.6	15.4	19.2	23.4	28.7	43.0		
			SDR17	0.390	SW,CLIB											
6 1/4"	6.900	6	DR27.6	0.250	SW											
6 1/8"			SDR21	0.329	SW,CLIB				12.6*	15.4	19.2	23.4	28.7	43.0		
6.9"O.D.			SDR17	0.406	SW,CLIB											
8"	8.625	6	SDR26	0.332	SW											
			SDR21	0.410	SW				14.2*	20.3	25.4	30.8	37.9	56.7	63.8	74.6
			SDR17	0.508	CLIB											
10"	10.750	6	SDR26	0.413	SW											
			SDR21	0.511	SW					22.5*	28.1	34.1	41.9	62.7	70.7	82.5
			SDR17	0.632	CL											
12"	12.750	8	SDR26	0.490	SW											
			SDR21	0.606	SW					30.0*	37.4	45.5	55.9	83.7	94.2	110.1
			SDR17	0.750	CL											
14"	14.000	8	SCH40	0.437	SW					32.9*	41.1	49.9	61.3	91.8	103.4	120.7
			SDR17	0.823	CL											
16"	16.000	10	SCH40	0.500	SW					36.3	45.3	55.1	67.6	101.2	114.0	133.1
		10	SDR26	0.616	SW,CL											
		8	SDR21	0.762	CL					31.0	38.7	47.0	57.7	86.4	97.3	113.6
		8	SDR17	0.941	CL						43.5	52.8	64.9	97.2	109.4	127.8
17.4" O.D.	17.400	8	SDR17	1.024	CL							52.8	64.9	97.2	109.4	127.8

KEY: SW = Solvent Weld Belled End, CL = Certa-Lok (w/coupling), CLIB = Certa-Lok Integral Bell
* = Not available in SDR17 or SCH80
** = Equivalent to SCH40

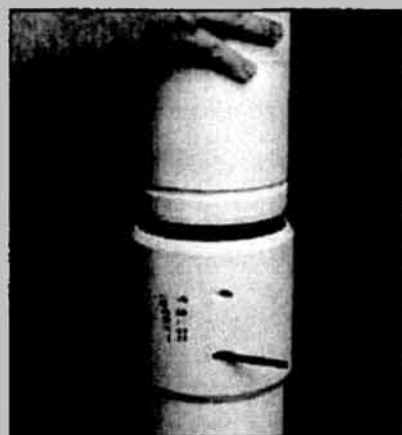
Notes:
1. As a general rule, Flow Rating (GPM/ft) in a gravel-packed well = O.D. Open Area (in^2/ft)* (.50 blockage factor)* (.31 conversion factor) at an entrance velocity of 0.1 fps.
2. Open area percentage varies from 2% to over 20%, depending upon casing size and slot width.
3. CertainTeed can supply a detailed Engineering Specification for any of the products shown, or for special made-to-order products.
4. Slots can often be lengthened on thick-wall products to provide additional I.D. penetration; revised specifications showing increased open area are available upon request.
5. Standard slot spacing = .25". Smaller and wider spacing is available - wider spacing is generally recommended for slot widths of .100" and above.
6. Specifications subject to change. Standard manufacturing tolerances apply.
7. All dimensions are in inches.

Our Slots Pay Off Three Ways!

CertainTeed solid and slotted casing is available with a joining system to suit all of your needs:

Traditional Solvent - Weld Joint – Now with a deeper bell for a stronger, more durable bond. Available in sizes 2" - 16".

Sure Fit



Certa-Lok™ – Check out the Best Joint in Town. No more "glue and screw" attachments. Mechanical joint achieves full strength instantly in all weather conditions. Fast assembly and disassembly. Available in sizes 10"-17.4" O.D.

Certa-Lok™ Integral Bell Well Casing – All the advantages of the contractor-proven Certa-Lok joining system, now with a conventional belled-end joint for even faster assembly. The economical choice for all of your small-to-medium diameter well casing requirements. Available in sizes 4", 4 ½", 5", 6", 6.9" O.D., 8".

national ground water association® MEMBER

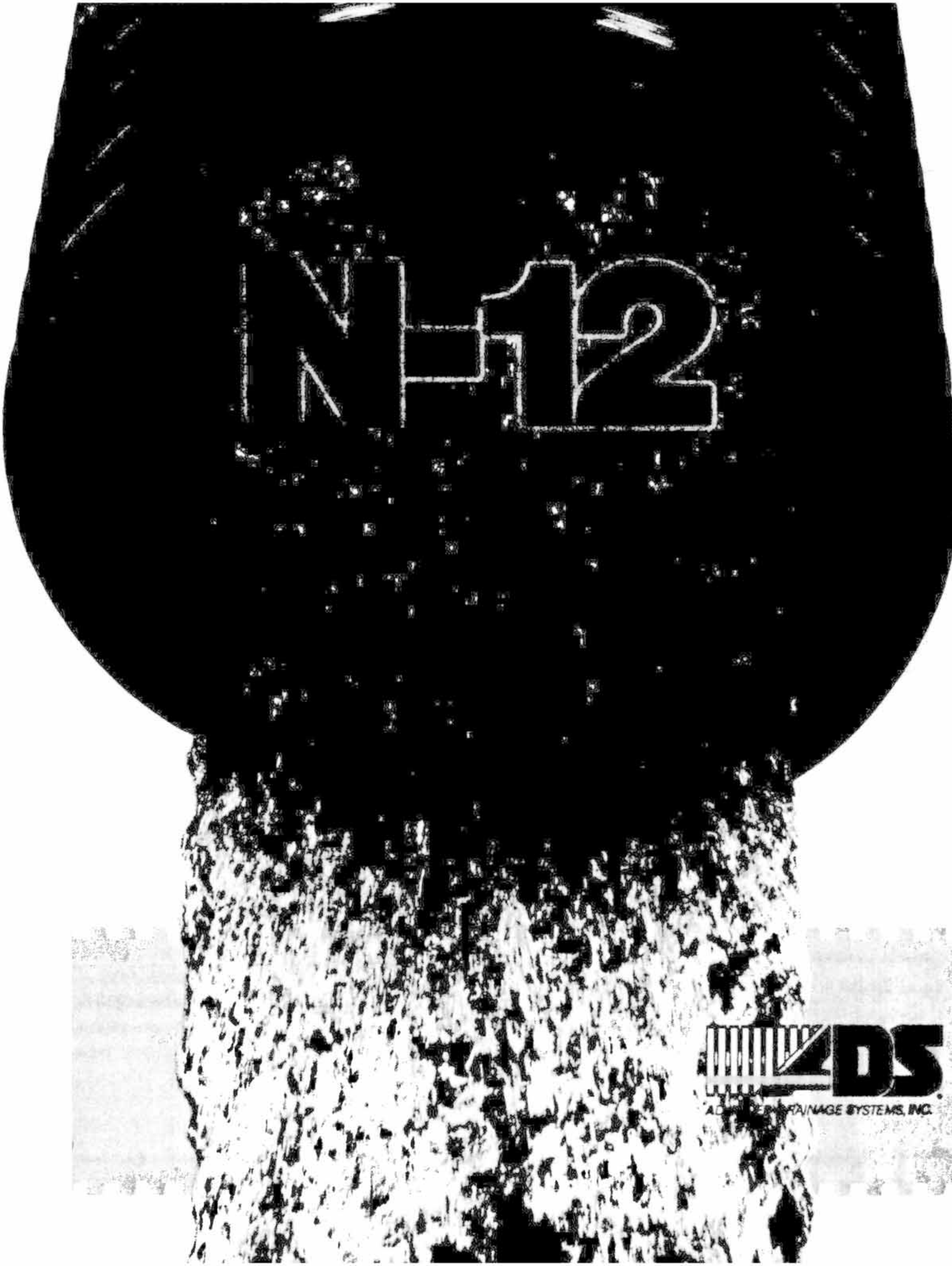
ASK ABOUT OUR OTHER CERTAINTEED PRODUCTS AND SYSTEMS:

EXTERIOR: ROOFING • SIDING • WINDOWS • FENCE • RAILING • TRIM • DECKING • FOUNDATIONS • PIPE
INTERIOR: INSULATION • WALLS • CEILINGS

CertainTeed Corporation
Pipe & Plastics Group
P.O. Box 860
Valley Forge, PA 19482

Phone: 866-CT4-PIPE
Fax: 610-254-5428
www.certainteed.com

CertainTeed


N-12
ADS

Specifications ar

Applicable Specifications and Installation Guidelines

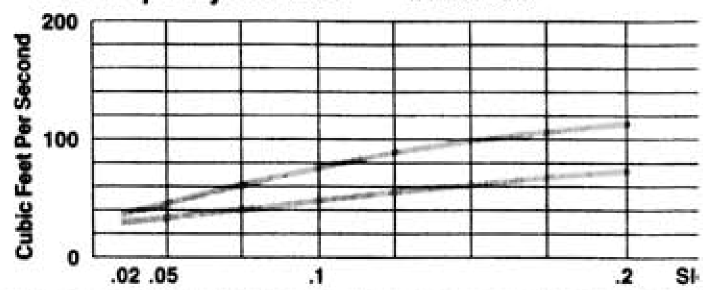
1. ASTM F 405, Standard Specification for Corrugated Polyethylene Pipe and Fittings.
2. ASTM F 667, Standard Specification for Large Diameter Corrugated Polyethylene Pipe and Fittings.
3. AASHTO M 252, Standard Specification for Polyethylene Corrugated Drainage Pipe.
4. AASHTO M 294, Standard Specification for Corrugated Polyethylene Pipe, 12″ to 36″ diameter.
5. ASTM D 2321, Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity Flow Applications.

ADS corrugated polyethylene pipe is a flexible conduit. When properly installed, ADS pipe has excellent compressive load bearing strength. It is suitable for use under H20 and E80 live loads, or with fill heights in excess of 50 feet. To ensure maximum performance, ADS pipe should be installed in accordance with the following recommendations:

Installation Recommendations

1. Crushed stone, gravel or compacted soil backfill material should be used as the bedding and envelope material.
2. The corrugated pipe should be laid on grade, on a layer of bedding material. If native soil is used as the bedding and backfill material, it should be well compacted in six inch layers under the haunches, around the sides and above the pipe to the recommended minimum height of cover.
3. Either flexible (asphalt) or rigid (concrete) pavements may be laid as part of the minimum cover requirements.
4. Site conditions and availability of bedding materials often dictate the type of installation method used.
5. The load bearing capability of flexible conduits is dependent on the type of backfill material used and the degree of compaction achieved. Crushed stone and gravel backfill materials typically reach a compaction level of 90-95% AASHTO standard density without compaction. When native soils are used as backfill material, a compaction level of 85% is required. This is the same minimum compaction that is recommended by all drainage pipe manufacturers and can be achieved by either hand or mechanical tamping.
6. ADS recommends that N-12 pipe be installed in accordance with ASTM D 2321, Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity Flow Applications.

ADS Pipe Hydraulics 24″ Diameter



ADS Recommended Manning's "n" For Desig

Pipe Diameter	ADS Corrugated Polyethylene	*ADS-N-12 Polyethylene*
4-6-8-10-12″	.018	*.010*
15″	.018	*.010*
18″	.020	*.010*
24″	.020	*.010*
30″	.020	*.010*
36″	.020	*.010*

*ASCE Manual and Report on Engineering Practice #37

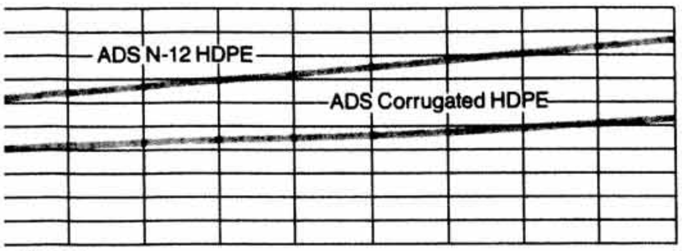
ADS N-12 Pipe Stiffness

Pipe Diameter	Minimum Pipe Stiffness Pounds/Inch/Inch
4-6-8 Inches	50
10 Inches	48
12 Inches	45
15 Inches	42
18 Inches	40
24 Inches	34
30 Inches	28
36 Inches	22

Weight Comparison Pounds/Linear Foot

Inside Diameter (inches)	ADS Corrugated HDPE Pipe	Clay or Concrete	Corrugated Metal
10″	2.0	50	9.0
12″	2.5	79	10.5
15″	3.1	103	
18″	6.6	131	
24″	13.8	217	
30″	18.0	384	
36″	22.0	524	36.0

d Technical Data



Concrete Pipe*	Corrugated Steel Pipe*
.011-.015	.022-.026
.011-.015	.022-.026
.011-.015	.022-.026
.011-015	.022-.026
.011-.015	.022-.026
.011-.015	.022-.026

Height of Cover Table for ADS Culvert Pipe

- Depth of Cover for Corrugated Polyethylene Pipe
- H20 or E80 Live Load
- Pipe Manufactured to AASHTO M-294

Diameter (inches)	Minimum Cover H20 (inches)	Minimum Cover E80 (inches)	Maximum Cover (feet)
4-6-8-10-12"	12	24	58
15"	12	24	59
18"	12	24	62
24"	12	24	61
30"	12	24	61
36"	12	24	61

Notes:

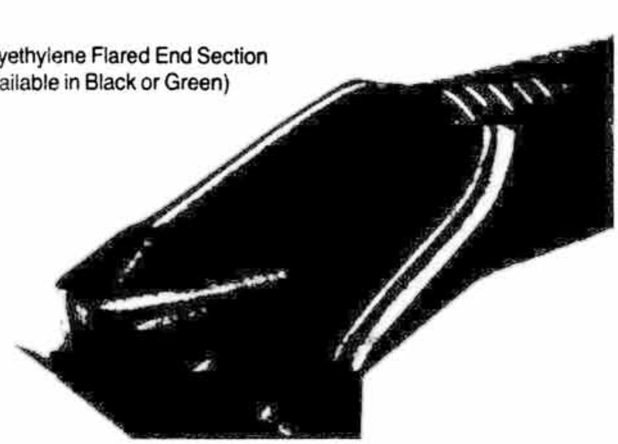
1. Cover limitations calculated using load factor design per AASHTO procedures.
2. Soil density of 100#/cu. ft. is assumed.
   Backfill around the pipe must be compacted to a density of 90% per AASHTO T-99.
4. Use reasonable care in handling and installation.
5. Cover limitations are measured from the top of the pipe.

N-12 Fabricated Tee Fitting

N-12 Fabricated Elbow Fitting

N-12 Coupler

Polyethylene Flared End Section
(Available in Black or Green)



IPS PIPE SIZES & PRESSURE RATINGS – PE3608/PE3408

WL PLASTICS

CONTACT WL PLASTICS CUSTOMER SERVICE TO CONFIRM AVAILABILITY AND FOR SIZES AND DR'S NOT SHOWN. SEE FOOTNOTES ON PAGE 2.

IPS SIZE	AVG OD	DR PR	7 267	7.3 254	9 200	11 160	13.5 128	15.5 110	17 100	19 89	21 80	26 64	32.5 51
1	1.315	Min wall	0.188	0.180	0.146	0.120							
		Avg ID	0.917	0.933	1.005	1.062							
		lb/ft	0.288	0.278	0.232	0.195							
1 1/4	1.660	Min wall	0.237	0.227	0.184	0.151							
		Avg ID	1.157	1.178	1.269	1.340							
		lb/ft	0.459	0.442	0.369	0.310							
1 1/2	1.900	Min wall	0.271	0.260	0.211	0.173							
		Avg ID	1.325	1.348	1.452	1.534							
		lb/ft	0.600	0.580	0.485	0.406							
2	2.375	Min wall	0.339	0.325	0.264	0.216	0.176	0.153	0.140				
		Avg ID	1.656	1.685	1.816	1.917	2.002	2.050	2.079				
		lb/ft	0.939	0.906	0.758	0.634	0.526	0.462	0.425				
2 ½	2.875	Min wall	0.411	0.394	0.319	0.261	0.213	0.185	0.169				
		Avg ID	2.004	2.040	2.198	2.321	2.424	2.482	2.516				
		lb/ft	1.377	1.329	1.109	0.928	0.771	0.677	0.622				
3	3.500	Min wall	0.500	0.479	0.389	0.318	0.259	0.226	0.206	0.184	0.167		
		Avg ID	2.440	2.484	2.676	2.825	2.950	3.021	3.064	3.109	3.147		
		lb/ft	2.040	1.968	1.646	1.376	1.141	1.006	0.923	0.830	0.757		
4	4.500	Min wall	0.643	0.616	0.500	0.409	0.333	0.290	0.265	0.237	0.214	0.173	0.138
		Avg ID	3.137	3.193	3.440	3.633	3.793	3.885	3.939	3.998	4.046	4.133	4.206
		lb/ft	3.372	3.253	2.720	2.275	1.887	1.660	1.526	1.374	1.247	1.018	0.819
5	5.563	Min wall	0.795	0.762	0.618	0.506	0.412	0.359	0.327	0.293	0.265	0.214	0.171
		Avg ID	3.878	3.947	4.253	4.491	4.689	4.802	4.869	4.942	5.001	5.109	5.200
		lb/ft	5.154	4.975	4.156	3.479	2.886	2.540	2.328	2.100	1.909	1.557	1.254
6	6.625	Min wall	0.946	0.908	0.736	0.602	0.491	0.427	0.390	0.349	0.315	0.255	0.204
		Avg ID	4.619	4.701	5.064	5.348	5.585	5.719	5.799	5.886	5.956	6.085	6.193
		lb/ft	7.305	7.059	5.894	4.930	4.095	3.599	3.307	2.978	2.703	2.209	1.781
7	7.125	Min wall							0.419	0.375	0.339	0.274	0.219
		Avg ID							6.236	6.330	6.406	6.544	6.660
		lb/ft							3.821	3.442	3.128	2.553	2.057
8	8.625	Min wall	1.232	1.182	0.958	0.784	0.639	0.556	0.507	0.454	0.411	0.332	0.265
		Avg ID	6.013	6.120	6.593	6.963	7.271	7.445	7.549	7.663	7.754	7.922	8.062
		lb/ft	12.385	11.963	9.988	8.359	6.939	6.100	5.597	5.044	4.591	3.744	3.012
10	10.750	Min wall	1.536	1.473	1.194	0.977	0.796	0.694	0.632	0.566	0.512	0.413	0.331
		Avg ID	7.494	7.628	8.218	8.678	9.062	9.280	9.409	9.551	9.665	9.873	10.049
		lb/ft	19.245	18.581	15.515	12.983	10.774	9.490	8.695	7.838	7.128	5.805	4.689
12	12.750	Min wall	1.821	1.747	1.417	1.159	0.944	0.823	0.750	0.671	0.607	0.490	0.392
		Avg ID	8.889	9.047	9.747	10.293	10.748	11.006	11.160	11.327	11.463	11.710	11.918
		lb/ft	27.062	26.138	21.837	18.267	15.155	13.348	12.238	11.021	10.023	8.169	6.587
14	14.000	Min wall	2.000	1.918	1.556	1.273	1.037	0.903	0.824	0.737	0.667	0.538	0.431
		Avg ID	9.760	9.934	10.702	11.302	11.801	12.085	12.254	12.438	12.587	12.858	13.087
		lb/ft	32.635	31.511	26.329	22.030	18.279	16.082	14.763	13.292	12.093	9.848	7.952

IPS SIZE	AVG OD	DR / PR	7 / 267	7.3 / 254	9 / 200	11 / 160	13.5 / 128	15.5 / 110	17 / 100	19 / 89	21 / 80	26 / 64	32.5 / 51
16	16.000	Min wall	2.286	2.192	1.778	1.455	1.185	1.032	0.941	0.842	0.762	0.615	0.492
		Avg ID	11.154	11.353	12.231	12.916	13.487	13.812	14.005	14.215	14.385	14.695	14.956
		lb/ft	42.629	41.157	34.364	28.777	23.872	21.005	19.269	17.355	15.789	12.866	10.375
18	18.000	Min wall	2.571	2.466	2.000	1.636	1.333	1.161	1.059	0.947	0.857	0.692	0.554
		Avg ID	12.549	12.773	13.760	14.531	15.173	15.538	15.755	15.992	16.183	16.532	16.826
		lb/ft	53.940	52.089	43.513	36.403	30.210	26.584	24.395	21.959	19.977	16.286	13.142
20	20.000	Min wall	2.857	2.740	2.222	1.818	1.481	1.290	1.176	1.053	0.952	0.769	0.615
		Avg ID	13.943	14.192	15.289	16.145	16.859	17.265	17.506	17.768	17.981	18.369	18.695
		lb/ft	66.599	64.307	53.715	44.947	37.294	32.820	30.102	27.129	24.658	20.109	16.211
22	22.000	Min wall	3.143	3.014	2.444	2.000	1.630	1.419	1.294	1.158	1.048	0.846	0.677
		Avg ID	15.337	15.611	16.818	17.760	18.545	18.991	19.256	19.545	19.779	20.206	20.565
		lb/ft	80.591	77.812	64.991	54.391	45.149	39.712	36.433	32.818	29.858	24.335	19.629
24	24.000	Min wall	3.429	3.288	2.667	2.182	1.778	1.548	1.412	1.263	1.143	0.923	0.738
		Avg ID	16.731	17.030	18.347	19.375	20.231	20.717	21.007	21.322	21.577	22.043	22.434
		lb/ft	95.916	92.603	77.365	64.735	53.726	47.260	43.369	39.049	35.525	28.963	23.344
26	26.000	Min wall		3.562	2.889	2.364	1.926	1.677	1.529	1.368	1.238	1.000	0.800
		Avg ID		18.449	19.876	20.989	21.917	22.444	22.758	23.099	23.375	23.880	24.304
		lb/ft		110.769	92.535	77.440	64.261	56.532	51.856	46.701	42.486	34.648	27.940
28	28.000	Min wall			3.111	2.545	2.074	1.806	1.647	1.474	1.333	1.077	0.862
		Avg ID			21.404	22.604	23.603	24.170	24.508	24.876	25.173	25.717	26.174
		lb/ft			107.312	89.785	74.522	65.563	60.154	54.189	49.266	40.187	32.421
30	30.000	Min wall			3.333	2.727	2.222	1.935	1.765	1.579	1.429	1.154	0.923
		Avg ID			22.933	24.218	25.289	25.897	26.259	26.653	26.971	27.554	28.043
		lb/ft			123.183	103.076	85.543	75.264	69.068	62.196	56.585	46.135	37.196
32	32.000	Min wall			3.556	2.909	2.370	2.065	1.882	1.684	1.524	1.231	0.985
		Avg ID			24.462	25.833	26.975	27.623	28.009	28.429	28.770	29.391	29.913
		lb/ft			140.183	117.285	97.324	85.672	78.557	70.755	64.370	52.494	42.340
34	34.000	Min wall				3.091	2.519	2.194	2.000	1.789	1.619	1.308	1.046
		Avg ID				27.447	28.661	29.350	29.760	30.206	30.568	31.228	31.782
		lb/ft				132.411	109.905	96.714	88.700	79.865	72.657	59.264	47.773
36	36.000	Min wall				3.273	2.667	2.323	2.118	1.895	1.714	1.385	1.108
		Avg ID				29.062	30.347	31.076	31.511	31.983	32.366	33.065	33.652
		lb/ft				148.454	123.208	108.424	99.457	89.571	81.446	66.444	53.581
42	42.000	Min wall					3.111	2.710	2.471	2.211	2.000	1.615	1.292
		Avg ID					35.404	36.255	36.762	37.314	37.760	38.575	39.260
		lb/ft					167.675	147.568	135.372	121.925	110.874	90.393	72.893
48	48.000	Min wall						3.097	2.824	2.526	2.286	1.846	1.477
		Avg ID						41.435	42.014	42.644	43.154	44.086	44.869
		lb/ft						192.774	176.813	159.198	144.833	118.082	95.233
54	54.000	Min wall						3.484	3.176	2.842	2.571	2.077	1.662
		Avg ID						46.641	47.266	47.975	48.549	49.597	50.478
		lb/ft						243.921	223.713	201.502	183.253	149.464	120.556

Contact WL Plastics Customer Service to confirm availability and for sizes and DR's not shown. 1. IPS sizes below 4" IPS per ASTM D3035; IPS sizes 4" IPS and larger per ASTM F714. 2. Pressure Rating (PR) is for water at 80°F and lower, and will vary for other fluids and temperatures. See WL118 Pressure Rating. 3. Avg ID – Avg OD – (2.12 x min wall), and is for flow estimation only. Actual ID will vary depending on specification dimensions and tolerances. Consult specifications or measure actual pipe ID for devices such as stiffeners that install in the pipe bore. 4. All dimensions in inches. 5. NSF-61 Certification for potable water service available on request. 6. See WL101 and WL124 for fusion, mechanical and electrofusion joining information. 7. The information in this publication does not constitute a guarantee or warranty for piping installations and cannot be guaranteed because the conditions of use are beyond our control. The user of this information assumes all risk associated with its use. Changes to this publication may occur from time to time without notice. Contact WL Plastics Corporation to determine if you have the most current edition. Copying without change permitted.

CASPER PLANT: 2075 N. Pyrite Road • P.O. Box 1120 • Mills, WY 82644 • **Customer Service: 307-472-6000** • Fax: 307-472-6200

CEDAR CITY PLANT: 4660 W. Highway 56 • P.O. Box 627 • Cedar City, UT 84721 • **Customer Service: 435-867-8908** • Fax: 435-865-2703

GILLETTE PLANT: 1301 E. Lincoln St. • Gillette, WY 82716 • **Customer Service: 307-682-5554** • Fax: 307-682-3339

BOWIE PLANT: 1110 Old Wise Road • PO Box 32 • Bowie, TX 76230 • **Customer Service: 940-872-8300** • Fax: 940-872-8304

CROSSFIELD PLANT: PO Box 860 • 1030 Western Drive • Crossfield, AB T0M 0S0 Canada • **Customer Service: 403-946-0202** • Fax: 403-946-0252

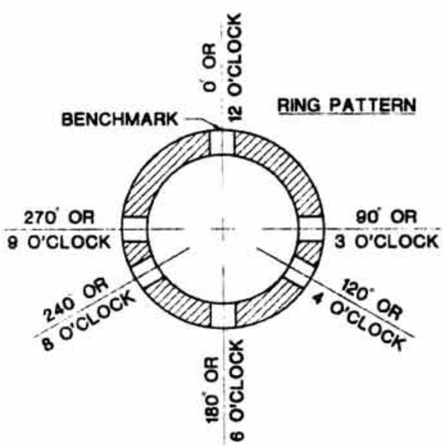
CPChem
PERFORMANCE PIPE

1900 SERIES (IPS)
STANDARD PERFORATION PATTERN

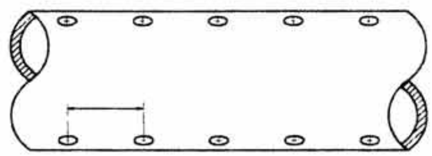
SECTION 1 - TO BE FILLED OUT BY CUSTOMER

Distributor/Branch: ________________	**Date:** ________________
Contact: ________________	**Customer PO #:** ________________
Phone/Fax: ________________	**Customer Signature:** ________________

SECTION 2 - TO BE FILLED OUT BY CUSTOMER



Fill in Hole #'s below showing positions relative to benchmark seen above (Maximum of 4 Holes - Hole #1 is the 0 degree Benchmark - fill in unwanted holes with N/A)



_____" hole spacing between ring patterns (3" to 18") in even inch increments.

*****IPS Size and SDR Capabilities**

Pipe Diameter	SDR Range
3" - 4"	SDR 7 – 17
6" – 8"	SDR 7 – 32.5
10"	SDR 9 – 32.5
12"	SDR 11 – 32.5
14" – 16"	SDR 13.5 – 32.5
18" – 20"	SDR 17 – 32.5
22" – 24"	SDR 21 – 32.5

Hole #1 →	**0 Degrees**	**Hole #2** →		**Hole #3** →		**Hole #4** →	

Pipe size: ______" (Please conform to Chart above ***) | SDR: ______" (Please conform to Chart above ***)

Hole diameter: ______" (1/4", 3/8", ½", 5/8", ¾", 7/8", 1", 1-1/8", 1-1/4") | Joint Length: ______"

SECTION 3 - FOR OFFICE USE ONLY (PRODUCTION PLANNING)

Material # ________________ Production Order #: ________________

Hole diameter		Hole Pattern	Hole Spacing		
A = 1/4"	F = 7/8"	A = 1 Hole	03 = 3"	09 = 9"	15 = 15"
B = 3/8"	G = 1"	B = 2 Holes	04 = 4"	10 = 10"	16 = 16"
C = 1/2"	H = 1-1/8"	C = 3 Holes	05 = 5"	11 = 11"	17 = 17"
D = 5/8"	I = 1-1/4"	D = 4 Holes	06 = 6"	12 = 12"	18 = 18"
E = 3/4"			07 = 7"	13 = 13"	
			08 = 8"	14 = 14"	

SALES ORDER # ________ Schedulers Signature: ________________ Date: ___ / ___ / ___

(August 2005 Edition)