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MECHANICAL PROPERTIES OF PVC WELL SCREEN AND CASING

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16. ABSTRACT

Tensile, collapse, and stiffness tests were run on two manufacturers' Schedule 80 and Class 200, 8- and 12-inch-diameter specimens of PVC (polyvinyl chloride) well casing; well screen; flush-fit threaded joints; and flush-fit, solvent-welded, slip-fit joints. Watertightness tests were also run on the flush-fit threaded joints. The solvent-welded, slip-fit tensile specimens were cured in both air and water at temperatures ranging from 32 °F to 100 °F, with cure times before testing ranging from 2 minutes to 21 days. Special test apparatus were developed for both the tensile and the collapse tests. The results indicate that strengths of most PVC components are adequate for deeper installations than originally considered. However, deficiencies include problems with collapse due to grout pressure, low hydrostatic pressure capability of flush threaded joints, and low tensile strengths of some joint systems.

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INTRODUCTION

The use of plastic components for small-diameter (6-in and less) wells is widely accepted, while for larger diameter wells, stainless steel is the traditional material of choice because of its time-proven strength, corrosion resistance, and reliability. However, because of the cost of stainless steel and the Bureau of Reclamation's trend toward construction of temporary wells for testing and dewatering, the need exists for low-cost, easily adaptable materials for medium-diameter (8- to 12-in) wells.

PVC (polyvinyl chloride) appears especially promising because of its availability, corrosion resistance, low cost, ease of handling, and proven success in smaller diameters. However, because of the general lack of standards and mechanical data concerning PVC well components, the increasingly widespread use of various types of wells in new and often difficult environments, and recent structural failures in PVC well components, Reclamation has a critical need for research on the mechanical properties of PVC well components to provide reliable data for well design.

Review of the literature showed that tensile strength data are available for small-diameter (1- through 8-in) PVC well casing and for certain joint systems in those same diameters, but no tensile strength data are available for larger diameter PVC well casing, any size of PVC well screen, or the joint systems commonly used by Reclamation (Kurt and Pate, 1981). Also, it was not known whether these larger diameter specimens would demonstrate the tensile strength of 7,000 lb/in^2 found for smaller specimens. It was suspected that temperature gradients present during manufacture of these thick-walled specimens might substantially reduce their tensile strength.

Furthermore, both experimental and theoretical data were available for collapse strength of PVC well casing up to 6 inches in diameter, but no information was available for larger sizes of PVC well casing or for any size of joints or screen.

Finally, there were serious doubts and no data concerning the watertightness of threaded joints on large-diameter pipe. Threaded joints are not normally used on PVC pipe over 3 inches in diameter because of these concerns.

This program was undertaken to determine the tensile strength and hydraulic collapse strength of 8- and 12-inch-diameter PVC well casing and slotted well screen, and to determine the watertightness, tensile strength, and hydraulic collapse strength of similarly sized PVC joint systems used by Reclamation.

Because of the large number of variables considered (i.e., two manufacturers; two diameters; two pressure classes; and four components including casing, screen, slip-fit joints, and flush-thread joints), these tests were not intended to statistically determine the physical properties for all components and permutations listed. Instead, this study attempted to identify certain trends of interest to Reclamation. Although many tests employed only a single specimen for each permutation, sufficient tests were performed on duplicate or similar specimens to identify those trends.

SUMMARY OF RESULTS

The research results confirm that PVC casing and well screen are highly suitable for many well applications and that strengths of most components are adequate for deeper installations than originally considered. The results also show that the collapse strength of most components can be accurately predicted by simple stiffness tests; however, there are still concerns about collapse at elevated grouting temperatures that were not addressed. Shortcomings of PVC well components include low pressure ratings of flush threaded joints and low tensile strengths for some joint systems. These problems should be investigated further.

CONCLUSIONS

Tensile Strength

Dumbbell tensile specimens cut from the casing walls demonstrated the expected strength of 7,000 lb/in^2 with no variations between diameters, wall thicknesses, or manufacturers.

Samples from two manufacturers of slotted well screen demonstrated the expected tensile strength of 7,000 lb/in^2; therefore, no significant internal stresses were added during the slotting operation.

Tensile strengths varied widely for threaded joints and for solvent-welded joints cured at room temperature. This suggests that significant internal stresses can be introduced during either manufacture or assembly. Therefore, a factor of safety of 2.0 should be used during design as these components may not demonstrate the expected tensile strength of 7,000 lb/in^2.

Solvent-welded, slip-fit joints cured under water at room temperature demonstrated ultimate tensile strengths equivalent to specimens cured in air at room temperatures. Curing specimens under water apparently has no effect on their ultimate tensile strength; however, it was found to retard the rate of cure.

Solvent-welded, slip-fit joints assembled and cured at 30 °F, 47 °F, and 100 °F demonstrated tensile strengths significantly lower than those of similar joints cured at room temperature, suggesting that significant internal stresses were added during assembly at these temperatures.

As expected, the rate of cure of solvent-welded, slip-fit joints decreases with decreasing temperature.

Collapse Strength

The modified Tomishenko equation can be used to conservatively predict the collapse strength of unmodified casing.

Flush thread joints and solvent-welded, slip-fit joints demonstrated the same collapse strength as unmodified casing.

Slotted well screen with 10-percent open area demonstrated a collapse strength of approximately 75 percent of that of unmodified casing.

Parallel plate pipe stiffness can easily and accurately be used to predict collapse strength for casing, screen, and solvent-welded joints, but not for threaded joints.

Concerns about collapse strength at elevated temperatures which can occur during grouting were not addressed and need to be investigated further.

Watertightness

Neither of the two manufacturers' threaded joint designs proved to be watertight to the manufacturers' rated pressures (200 and 250 lb/in^2), and the joints often leaked at atmospheric pressure (zero gauge pressure) or slightly higher. Teflon paste improved watertightness up to a maximum of 80 lb/in^2, but still not to the rated pressures. Recent improvements in the industry thread designs should be investigated further.

TEST PROCEDURES

Test specimens were supplied at cost by two manufacturers. All specimens were manufactured from Class 12454-B PVC in accordance with ASTM: D 1784, "Standard Specification for Rigid Polyvinyl Chloride Compounds." Both suppliers provided two pressure classes (Schedule 80 and Class 200) for both their 8-inch and 12-inch products.

Only flush-fit joints (constant inside and outside diameter) are currently used for Reclamation wells because of the many disadvantages of other joint systems. External couplings with nonuniform outside diameters necessitate a larger borehole and complicate installation of the gravel pack. Couplings with nonuniform inside diameters reduce hydraulic efficiency (increase pumping costs) and obstruct the insertion of equipment into the well.

The two types of flush-fit joints used by Reclamation are the solvent-welded, slip-fit joint and the threaded joint (fig. 1). Solvent-welded, slip-fit joints are an industry standard for PVC pipe. These joints have the time-proven advantages of high tensile strength, watertightness, low cost, and standardized design; however, they are susceptible to contamination during field assembly, cannot be disassembled, and require time for joint strength development prior to installation. Also, no information was available on the rate of joint strength development for these large-diameter joints, the effect of cure temperature, or the effect of curing joints in water rather than in air.

The advantages of the threaded joint are the ease and rate of assembly and disassembly. If a problem arises and the string of casing and/or screen needs to be removed from the well, the string can be easily disassembled by unthreading the joints. Furthermore, joints can be assembled during any type of weather and the string then immediately lowered into the hole, increasing dramatically the rate of assembly.

Tensile Tests

Dumbbell tensile specimens were cut from the walls of both manufacturers' well casings and tested in accordance with ASTM: D 638, "Tensile Properties of Plastics." Typical test specimens are shown in figure 2.

Full-scale tensile tests on 8- and 12-inch-diameter specimens were run according to ASTM: D 2105, "Longitudinal Tensile Properties of Reinforced Thermosetting Plastic Pipe and Tube."

Special grips (figs. 3 and 4) were designed and fabricated for testing these large-diameter specimens. The grips fit inside the specimen, and when tightened sufficiently (approximately 2,000 ft-lbf), embed themselves in the pipe wall. The external compression band prevents the PVC specimen from deforming outward and ensures intimate contact between the serrated grips and the pipe wall. Specimens were extended at 0.5 in/min in a universal tester. Testing was quite labor intensive, and each test cycle (setup, testing, and teardown) required two laborers and approximately 4 man-hours. Approximately one-half of these tensile tests were performed by Reclamation, while the remainder were contracted out to Hauser Laboratories of Boulder, Colorado.

Reclamation's tests were performed on a hydraulically operated 400,000-pound universal tester (fig. 5). Because the crosshead velocity cannot be directly controlled on a hydraulically driven machine, the load rate was selected such that the calculated crosshead velocity in the elastic range would be as close to 0.5 in/min as possible. The actual calculated crosshead velocity ranged from 0.3 to 1.0 in/min. These variations did not adversely affect the results.

The Hauser tests were performed on a 60,000-pound, screw-driven universal tester. Some uncertainty existed as to the desired crosshead velocity, and the actual test velocity ranged from 0.05 to 0.5 in/min with the majority of the tests at 0.2 in/min. These variations also had no adverse effects on the results.

Full-scale tensile tests were performed on samples of well screen and threaded joints from both manufacturers to confirm the strength of the extruded PVC as determined by the dumbbell tests and to identify any stress concentrations produced by the machining operation. The results from these tests are shown in table 1.

Full-scale tensile tests were performed on solvent-welded, slip-fit joints to determine the effect of cure time and cure environment on joint strength. The cure environments examined were air at 100 °F, 75 °F, 50 °F, and 30 °F, and water at 70 °F, 50 °F, and 30 °F. The cure time before testing ranged from 2 minutes to 60 days. The specific cure times and environments are shown in tables 2 and 3.

The solvent-welded, slip-fit joints were assembled according to ASTM: D 2855, "Standard Practice for Making Solvent-Cement Joints With PVC Pipe and Fittings." To ensure a clean joint, special care was taken to wash and dry each specimen thoroughly before assembly. The specimens and the solvent cement were also conditioned before assembly for a minimum of 24 hours at the specified cure temperature. A thin coat of PVC primer was then applied to both halves of the joint, followed immediately by a thicker coat of PVC cement. The two halves were then immediately forced together with the assistance of a 1,000-pound-capacity hydraulic lift. The joint was held in place for a minimum of 2 minutes before removal from the hydraulic lift. The PVC cement was recommended and supplied by the manufacturers. For Manufacturer A, the cement was WELD-ON No. 705, medium-bodied cement for PVC. For Manufacturer B, the cement was WELD-ON No. 711, heavy-bodied cement. Since neither manufacturer expressed a primer preference, WELD-ON No. P-70 PVC primer was used on all slip-fit joints.

Collapse Tests

Collapse tests were run according to ASTM: D 2924, "External Pressure, Resistance of Reinforced Thermosetting Resin Pipe," modified as discussed below. These tests were performed to determine the allowable external hydrostatic pressure that various specimens could withstand before collapsing. This type of failure most often occurs in a field installation during the grouting operation where the density of the cement grout on the outside of the casing is higher than the density of the water or air on the inside. This situation is aggravated by the grout's heat of hydration since thermoplastics lose strength at elevated temperatures (National Water Well Association, 1980).

The specimen was enclosed in a pressure vessel (figs. 6 and 7) and the outside of the specimen pressurized while the inside remained at atmospheric pressure. The pressure was increased at a rate of 60 $lb/in^2/min$ until the specimen collapsed. For the well screen specimens, a 20-mil PVC flexible membrane liner was cemented onto the exterior of the specimen (figs. 8 and 9). This thin membrane allowed sufficient pressure to build up around the specimen for collapse, but did not increase the specimen strength. The appendix shows photographs taken at 10-second intervals of a typical collapse test. Video recordings were also made of some tests.

Modifications. - The ASTM method specifies that the specimen length-to-diameter ratio should be at least 10 to avoid end effects. However, our pressure vessel was only 5 feet long, giving ratios of 7.5 and 5.0 for 8- and 12-inch-diameter specimens, respectively. Furthermore, the inside of the test specimen was not filled with water, nor was a monometer tube used to monitor changes in the specimen volume. Better results were obtained by eliminating the end caps and visually monitoring the pipe profile for collapse (see appendix). In addition, a pressure gauge was positioned inside the specimen for simultaneous monitoring of the test pressure. A Plexiglas safety shield was placed in front of the specimen to protect the operator.

The pressurized fluid on the outside of the test specimen was water. Because of small leaks around the test apparatus O-rings, the hand pump acquired for this testing could not provide sufficient water pressure to collapse the test specimens. Therefore, as shown in figure 6, a high-pressure accumulator tank was used as an air/water interface, with air pressure supplied by a 15-liter bottle of compressed air. With the addition of a high-pressure, steel-braided hose (rated to 5,000 lb/in^2) between the air supply cylinder and the accumulator tank, all safety concerns were satisfied.

Watertightness Tests

Watertightness tests were run on the threaded joints provided by both manufacturers. Both ends of each threaded joint were sealed with a solvent-welded, slip-fit end cap that had been drilled and tapped for a 1/4-inch fitting. The test apparatus is shown in figure 10. After torquing the threaded joint to approximately 200 ft-lbf, the specimen was filled with water, bled of air, and pressurized with the hydraulic hand pump. The pressure was increased until the joint began leaking, and this pressure was recorded as the failure point. Each manufacturer supplied both Schedule 80 and Class 200 flush-fit, threaded joints for both 8- and 12-inch well casing. Both manufacturers' threaded joints had square threads formed by a lathing operation. The two manufacturers' thread designs appeared almost identical but differed slightly in that one manufacturer used a double thread (two threads per inch) while the other used a single thread (four threads per inch).

RESULTS AND DISCUSSION

Tensile Strength

The tensile test results are tabulated in tables 1 through 3 and summarized in table 4.

Tests on the dumbbell specimens showed a tensile strength of approximately 7,100 lb/in^2 with no significant variations between manufacturers, diameters, or wall thicknesses. This agrees with the accepted minimum value of 7,000 lb/in^2 for PVC cell classification 12454-B.

Full-size tensile tests on both manufacturers' samples of slotted well screen and on flush thread joints from Manufacturer A revealed tensile strengths of 7,000 and 7,100 lb/in^2, respectively, essentially the same as those of the dumbbell specimens. However, samples of flush thread joints from Manufacturer B showed very low tensile strength (approximately 3,400 lb/in^2). Examination of these failed test specimens from Manufacturer B showed that the female half of the joint usually failed, even though the male half always had the smaller cross-sectional area. This suggests that significant internal stresses can be introduced into these joints, either from the machining operation during manufacture or from torquing during assembly.

Manufacturer B slip-fit specimens showed ultimate tensile strength of approximately 6,800 lb/in^2, and no differences were detected between samples cured in air at 75 °F, water at 70 °F, and water at 58 °F. However, Manufacturer A specimens cured in air or water at 75 °F showed a tensile strength of only 5,900 lb/in^2, again suggesting that internal stresses were added during either manufacture or joint formation. Samples from both manufacturers, cured in air at 30 °F, 40 °F, and 100 °F, all showed significantly lower tensile strength than similar samples cured at room temperature, showing that additional internal stresses were introduced during joint formation and curing at these temperatures. These results indicate that a factor of safety of 2.0 should be used during design to accommodate the variations in joint tensile strength.

Figure 11 shows tensile strength versus time for various cure conditions. As expected, the four air-cure curves show that the cure rate decreases at lower temperatures. The single water-cure curve indicates that curing specimens under water also retards the cure rate; however, as already stated, underwater curing apparently has no effect on the ultimate tensile strength.

Collapse Strength

The results of the collapse tests are summarized in table 5. The theoretical collapse strengths were predicted using a modified Tomishenko equation (National Water Well Association, 1980).

$$Pc = \frac{2E}{(1-u^2)} \frac{1}{(DR-1)^3} \quad (1)$$

where:

Pc = Collapse strength (lb/in^2)
E = Young's modulus = 400,000 lb/in^2*
u = Poisson's ratio = 0.36*
DR = Dimension ratio = Ratio of average outside diameter to average wall thickness (dimensionless)

* = Values for Class 12454-B PVC from ASTM: D 1784.

Table 5 shows that the actual collapse strengths of the well casing, the solvent-welded slip-fit joints, and the flush thread joints are all slightly higher (an average of 11 percent) than their theoretical strengths. The Tomishenko equation may be slightly conservative, or this result may be due to end effects since our 5-foot test vessel produced slenderness ratios (length/diameter) of slightly less than 10. Regardless, it appears that the well casing, the solvent-welded slip-fit joints, and the threaded joints all possess about the same collapse strength, which can be conservatively predicted from the modified Tomishenko equation.

As expected, the slotted well screen demonstrated a collapse strength lower than that demonstrated by an unmodified length of casing. Specifically, the 10-percent open area of the slotted specimens resulted in a 25-percent reduction in collapse strength.

Parallel plate stiffness tests were run on the well casing, well screen, and joints in accordance with ASTM: D 2412, "External Loading Properties of Plastic Pipe by Parallel-plate Loading." These tests were run to check the theoretical correlation between pipe stiffness and collapse strength. Theoretically, the pipe stiffness (lb/in^2) should be:

$$PS = \frac{4.474\ E}{(DR-1)^3} \quad (2)$$

Combining equations 1 and 2 yields a theoretical relationship between pipe stiffness and collapse strength:

$$Pc = \frac{0.447\ (PS)}{(1-u^2)} \quad (3)$$

And, since u = 0.36 for PVC,

$$Pc = 0.51\ PS \quad (4)$$

Table 6 compares the stiffness as determined by parallel plate testing to the experimental collapse strength. These results are plotted in figure 12 and agree closely with the relationship predicted by equation 4.

This relationship is quite useful because a parallel plate stiffness test can be run in less than half an hour on standard laboratory equipment, while the collapse test requires about 4 man-hours and some very specialized equipment.

Watertightness

The results of the watertightness tests for the threaded joints are presented in table 7. These square threaded joints would not withstand pressures nearly as high as the rated pressures of the casings. Both Teflon tape and Teflon paste were used on the threads of some of the specimens to improve the watertightness; however, even these specimens were not watertight to their rated pressure. This is partially due to the out-of-roundness typical of these larger diameter PVC pipes; however, even with perfectly round pipe, it does not appear that watertight joints can be obtained using these square threads.

ASTM recently approved a threaded joint standard (ASTM: F 480) which requires an O-ring gasket. This standard along with computerized machining operations currently being perfected by the manufacturers should improve the watertightness of these threaded joints.

BIBLIOGRAPHY

Kurt, Carl E., and W. Denney Pate, *Tensile Strength of PVC and ABS Well Casing Joints*, American Society of Civil Engineers, vol. 107, No. IR2, June 1981.

National Water Well Association, *Manual on the Selection and Installation of Thermoplastic Water Well Casing*, A Joint Project of the National Water Well Association and the Plastic Pipe Institute, October 1, 1980.

American Society for Testing and Materials, *Annual Book of ASTM Standards*, vols. 8.01 and 8.04, 1987.

Table 1. - Tensile strength of PVC well casing and components.

Type of specimen	Mfr.	Diam. (in)	Pressure category	Load (kips)	Area (in^2)	Stress (lb/in^2)	Testing lab
Dumbbell	A	8	Sched 80	2.95	0.41	7,200	USBR*
Dumbbell	A	8	Sched 80	2.98	0.41	7,300	USBR
Dumbbell	A	8	Sched 80	2.85	0.41	7,000	USBR
Dumbbell	B	8	Class 200	2.48	0.34	7,300	USBR
Dumbbell	B	8	Class 200	2.37	0.35	6,900	USBR
Dumbbell	B	8	Class 200	2.30	0.33	7,000	USBR
Dumbbell	B	12	Class 200	3.50	0.50	7,000	USBR
Dumbbell	B	12	Class 200	3.55	0.49	7,200	USBR
Dumbbell	B	12	Class 200	3.42	0.47	7,300	USBR
Screen	A	8	Class 200	23.6	3.2	7,400	USBR
Screen	A	8	Class 200	23.8	3.2	7,400	USBR
Screen	A	8	Sched 80	31.5	5.0	6,300	USBR
Screen	A	8	Sched 80	31.7	5.0	6,300	USBR
Screen	B	8	Class 200	23.0	3.0	7,600	Hauser
Screen	B	8	Sched 80	27.6	4.1	6,700	Hauser
Threaded	A	8	Class 200	25.4	3.6	7,100	USBR
Threaded	A	8	Class 200	24.7	3.6	6,900	USBR
Threaded	A	8	Class 200	22.9	3.6	6,400	Hauser
Threaded	A	8	Sched 80	36.6	4.8	7,600	USBR
Threaded	A	8	Sched 80	35.5	4.8	7,400	USBR
Threaded	A	8	Sched 80	34.8	4.8	7,300	USBR
Threaded	B	8	Class 200	19.7	5.1	3,900	Hauser
Threaded	B	8	Class 200	16.6	5.1	3,300	Hauser
Threaded	B	12	Class 200	27.7	9.5	2,900	Hauser

*Bureau of Reclamation

Note: These tests were not intended to statistically determine the tensile capabilities of all the components and permutations listed. However, these results do indicate certain trends as discussed in the narrative.

Table 2. - Tensile tests on solvent-welded slip-fit joints - Reclamation tests.

Mfr.	Diam. (in)	Pressure category	Cure time	Cure condition	Load (kips)	Stress (lb/in^2)	Mode of failure
A	8	Class 200	17 days	Air @ 75 °F	37.8	6,500	Tension
A	8	Class 200	17 days	Air @ 75 °F	38.7	6,700	Tension
A	8	Sched 80	2 min	Air @ 75 °F	1.0		Shear
A	8	Sched 80	30 min	Air @ 75 °F	2.9		Shear
A	8	Sched 80	60 min	Air @ 75 °F	4.9		Shear
A	8	Sched 80	4 hrs	Air @ 75 °F	14.0		Shear
A	8	Sched 80	8 hrs	Air @ 75 °F	12.0		Shear
A	8	Sched 80	23 hrs	Air @ 75 °F	23.6		Shear
A	8	Sched 80	48 hrs	Air @ 75 °F	41.1	6,000	Tension
A	8	Sched 80	5 days	Air @ 75 °F	37.7	5,400	Tension
A	8	Sched 80	5 days	Air @ 75 °F	36.4	5,300	Tension
A	8	Sched 80	21 days	Air @ 75 °F	43.8	6,300	Tension
A	8	Sched 80	2 hrs	Air @ 100 °F	14.1		Shear
A	8	Sched 80	4 hrs	Air @ 100 °F	16.7		Shear
A	8	Sched 80	8 hrs	Air @ 100 °F	22.0		Shear
A	8	Sched 80	24 hrs	Air @ 100 °F	32.1		Shear
A	8	Sched 80	48 hrs	Air @ 100 °F	34.0	4,900	Tension
A	8	Sched 80	9 days	Air @ 100 °F	27.2	3,900	Tension
A	8	Sched 80	16 days	Air @ 100 °F	27.0	3,900	Tension
A	8	Sched 80	4 hrs	Air @ 47 °F	13.5		Shear
A	8	Sched 80	24 hrs	Air @ 47 °F	18.2		Shear
A	8	Sched 80	48 hrs	Air @ 47 °F	21.0		Shear
A	8	Sched 80	4 days	Air @ 47 °F	20.0		Shear
A	8	Sched 80	9 days	Air @ 47 °F	27.7	4,000	Tension
A	8	Sched 80	16 days	Air @ 47 °F	31.5	4,600	Tension
A	8	Sched 80	7 days	H_2O @ 32 °F	18.0		Shear
A	8	Sched 80	7 days	H_2O @ 47 °F	19.0		Shear
A	8	Sched 80	7 days	H_2O @ 70 °F	37.5	5,400	Tension

Water-cured specimens were air cured for 3 minutes before immersion. All temperatures are ±5 °F and all times are ±10 percent.

Stress at failure was calculated from the following cross-sectional areas:

Manufacturer A 8-inch Sched 80	Area = 6.9 in^2
Manufacturer A 8-inch Class 200	Area = 5.8 in^2
Manufacturer B 8-inch Sched 80	Area = 6.4 in^2
Manufacturer B 8-inch Class 200	Area = 4.8 in^2

Note: These tests were not intended to statistically determine the tensile capabilities of all the components and permutations listed. However, these results do indicate certain trends as discussed in the narrative.

Table 3. - Tensile tests on solvent-welded slip-fit joints - Hauser Laboratory tests.

Mfr.	Diam. (in)	Pressure category	Cure time	Cure condition	Load (kips)	Stress (lb/in^2)	Mode of failure
B	8	Class 200	2 min	Air @ 75 °F	0.8		Shear
B	8	Class 200	10 min	Air @ 75 °F	2.6		Shear
B	8	Class 200	30 min	Air @ 75 °F	7.6		Shear
B	8	Class 200	2 hrs	Air @ 75 °F	14.0		Shear
B	8	Class 200	8 hrs	Air @ 75 °F	16.9		Shear
B	8	Class 200	24 hrs	Air @ 75 °F	21.9		Shear
B	8	Class 200	4 days	Air @ 75 °F	32.0	6,700	Tension
B	8	Class 200	16 days	Air @ 75 °F	30.5	6,400	Tension
B	8	Class 200	60 days	Air @ 75 °F	31.6	6,600	Tension
B	8	Class 200	5 days	Air @ 30 °F	15.8		Shear
B	8	Class 200	10 days	Air @ 30 °F	12.2		Shear
B	8	Class 200	20 days	Air @ 30 °F	21.8		Shear
B	8	Class 200	40 days	Air @ 30 °F	24.4	5,100	Tension
B	8	Class 200	5 days	H_2O @ 58 °F	19.6		Shear
B	8	Class 200	10 days	H_2O @ 58 °F	22.3		Shear
B	8	Class 200	20 days	H_2O @ 58 °F	34.0	7,100	Tension
B	8	Class 200	40 days	H_2O @ 58 °F	34.8	7,200	Tension
B	8	Class 200	5 days	H_2O @ 70 °F	34.1	7,100	Tension
B	8	Class 200	10 days	H_2O @ 70 °F	30.8	6,400	Tension
B	8	Class 200	20 days	H_2O @ 70 °F	32.8	6,800	Tension
B	8	Class 200	40 days	H_2O @ 70 °F	34.7	7,200	Tension
B	8	Sched 80	7 days	Air @ 75 °F	39.5	6,000	Tension
A	8	Sched 80	7 days	Air @ 75 °F	23.4		Shear
A	8	Sched 80	14 days	Air @ 75 °F	39.0	5,700	Tension
A	8	Sched 80	14 days	Air @ 75 °F	37.4	5,400	Tension
B	12	Class 200	30 min	Air @ 75 °F	2.0		Shear
A	12	Sched 80	30 min	Air @ 75 °F	2.0		Shear

Water-cured specimens were air cured for 3 minutes before immersion. All temperatures are ±5 °F and all times are ±10 percent.

Stress at failure was calculated from the following cross-sectional areas:

Manufacturer A 8-inch Sched 80	Area = 6.9 in^2
Manufacturer A 8-inch Class 200	Area = 5.8 in^2
Manufacturer B 8-inch Sched 80	Area = 6.4 in^2
Manufacturer B 8-inch Class 200	Area = 4.8 in^2

Note: These tests were not intended to statistically determine the tensile capabilities of all the components and permutations listed. However, these results do indicate certain trends as discussed in the narrative.

Table 4. - Summary of tensile tests.

Test specimen	Tensile strength (lb/in^2) Range	Average
Dumbbell (Manufacturers A and B)	6,900 - 7,300	7,100 ± 100
Well Screen (Manufacturers A and B)	6,300 - 7,600	7,000 ± 600
Manufacturer B Threaded	2,900 - 3,900	3,400 ± 500
Manufacturer A Threaded	6,400 - 7,600	7,100 ± 400
Manufacturer A Slip-Fit		
Air @ 75 °F	5,300 - 6,700	5,900 ± 500
H_2O @ 70 °F	5,400	
Air @ 100 °F	3,900 - 4,900	4,300 ± 500
Air @ 47 °F	4,000 - 4,600	
Manufacturer B Slip-Fit		
Air @ 75 °F	6,000 - 6,700	
H_2O @ 70 °F	6,400 - 7,200	6,800 ± 400
H_2O @ 58 °F	7,100 - 7,200	
Air @ 30 °F	5,100	5,100

Note: These tests were not intended to statistically determine the tensile capabilities of all the components and permutations listed. However, these results do indicate certain trends as discussed in the narrative.

Table 5A. - Collapse strength of PVC well casing and joints.

Type of sample	Mfr.	Diam. (in)	Pressure category	Theoretical strength (lb/in^2)	Actual strength (lb/in^2)	Percent of theoretical
Casing	B	8	Class 200	138	155	112
Slip-Fit	B	8	Class 200	138	160	116
Slip-Fit	B	8	Sched 80	247	280	113
Slip-Fit	B	12	Class 200	128	150	117
Slip-Fit	B	12	Sched 80	212	260	123
Slip-Fit	A	8	Class 200	152	175	115
Slip-Fit	A	8	Sched 80	257	275	107
Slip-Fit	A	12	Class 200	150	155	103
Slip-Fit	A	12	Class 200	150	150	100
Slip-Fit	A	12	Sched 80	205	245	120
Slip-Fit	A	12	Sched 80	205	230	112
Slip-Fit	A	12	Sched 80	205	225	110
Threaded	B	8	Class 200	138	140	101
Threaded	B	8	Class 200	138	145	105
Threaded	B	8	Sched 80	247	295	119
Threaded	B	12	Class 200	128	145	113
Threaded	B	12	Sched 80	212	250	118
Threaded	A	8	Class 200	152	160	105
Threaded	A	8	Sched 80	257	260	101
Threaded	A	12	Sched 80	205	220	107
						Average = 111%

Note: These tests were not intended to statistically determine the collapse strength of all the components and permutations listed. However, these results do indicate certain trends as discussed in the narrative.

Table 5B. - Collapse strength of PVC well screen.

Type of sample	Mfr.	Diam. (in)	Pressure category	Casing strength* (lb/in^2)	Screen strength (lb/in^2)	Percent of casing strength
Screen	B	8	Class 200	150	115	77
Screen	B	8	Sched 80	288	210	73
Screen	B	12	Class 200	148	115	78
Screen	B	12	Sched 80	255	190	75
Screen	A	8	Class 200	168	130	77
Screen	A	8	Sched 80	268	215	80
Screen	A	12	Class 200	153	100	65
Screen	A	12	Class 200	153	115	75
Screen	A	12	Class 200	153	110	72
Screen	A	12	Sched 80	230	165	72
					Average =	74%

* Casing strengths are averages calculated from table 5A.

Note: These tests were not intended to statistically determine the collapse strength of all the components and permutations listed. However, these results do indicate certain trends as discussed in the narrative.

Table 6. - Collapse strength vs. pipe stiffness.

Type of sample	Mfr.	Diam. (in)	Pressure category	Collapse strength (lb/in^2)	Pipe stiffness (lb/in^2)	Ratio of collapse/ stiffness
Casing	B	8	Sched 80	280	551	0.51
Screen	B	8	Sched 80	210	433	0.49
Screen	A	8	Sched 80	215	433	0.50
Casing	B	8	Class 200	150	287	0.52
Screen	B	8	Class 200	115	234	0.49
Screen	A	8	Class 200	130	258	0.50
Casing	B	12	Sched 80	255	449	0.57
Screen	B	12	Sched 80	190	363	0.52
Casing	B	12	Class 200	150	273	0.55
Screen	B	12	Class 200	115	226	0.51
Screen	A	12	Class 200	108	226	0.48

Note: These tests were not intended to statistically determine the collapse strength of all the components and permutations listed. However, these results do indicate certain trends as discussed in the narrative.

Table 7. - Watertightness of threaded joints.

Mfr.	Diam. (in)	Pressure category	Leakage pressure* (lb/in^2)	Joint compound
A	8	Class 200	80	Teflon
A	8	Class 200	80	Teflon
A	8	Class 200	50	Teflon
A	12	Sched 80	25	None
B	8	Class 200	20	None
B	8	Sched 80	0	None
B	12	Class 200	10	None
B	12	Sched 80	0	None

*Pressure at which leakage was first observed

Note: These tests were not intended to statistically determine the precise leakage pressure for each class of joint. These tests merely indicate that these flush-thread joints have very low leakage pressures.

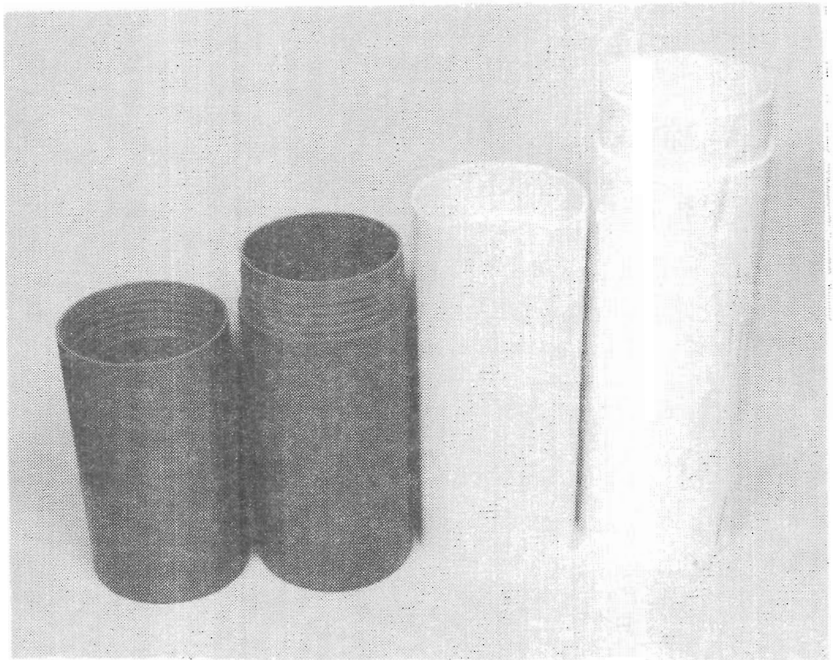

Figure 1. - The two types of flush-fit joints tested were the solvent-welded, slip-fit joint and the threaded joint.

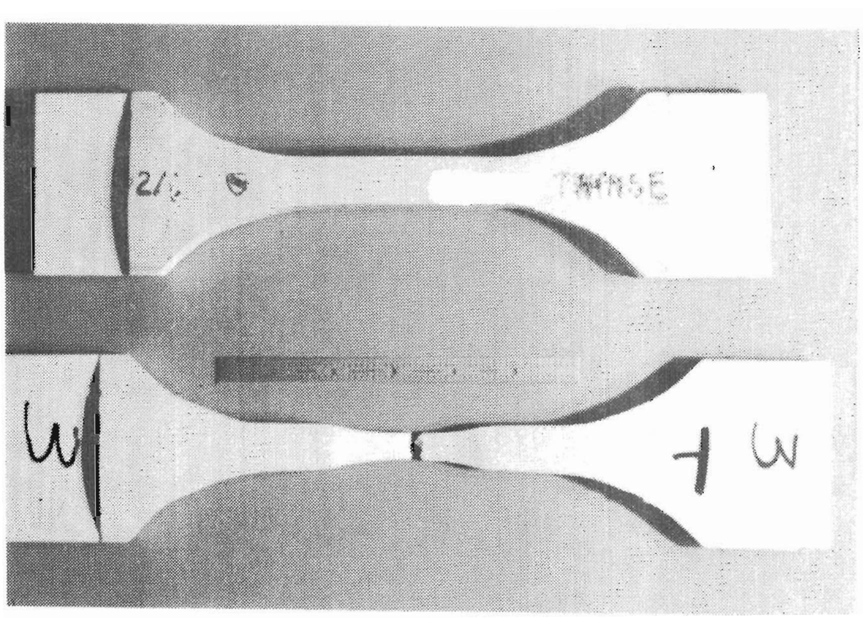

Figure 2. - Dumbbell tensile specimens were machined from the well casing walls.

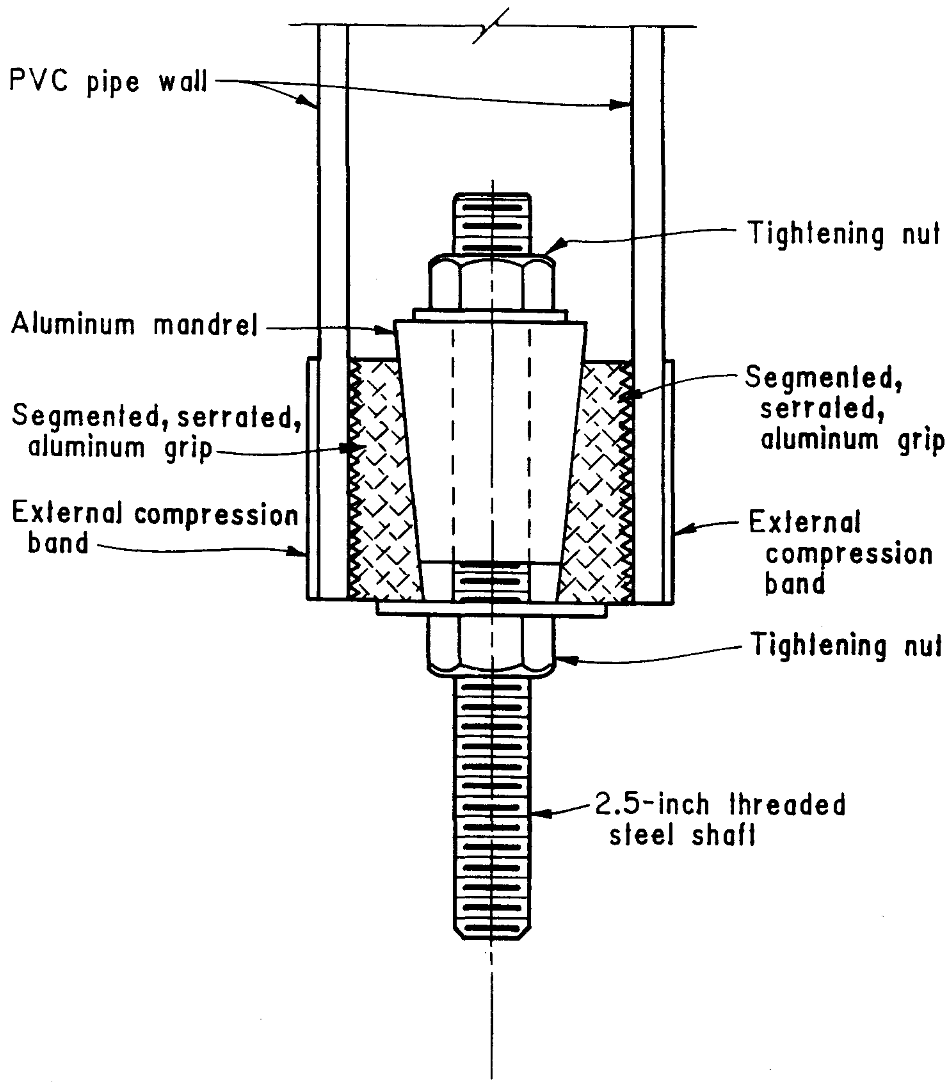

Figure 3. - Special tensile grips were designed and fabricated for full-scale testing of 8- and 12-inch-diameter specimens.

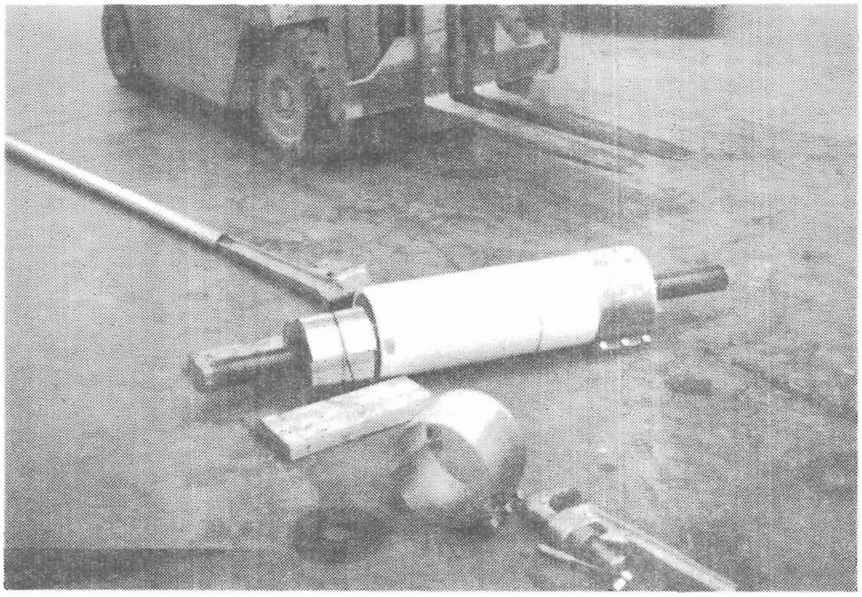

Figure 4. - Two 36-inch pipe wrenches with 8-foot cheater bars, a forklift, and strong backs were required to adequately torque the tensile grips.

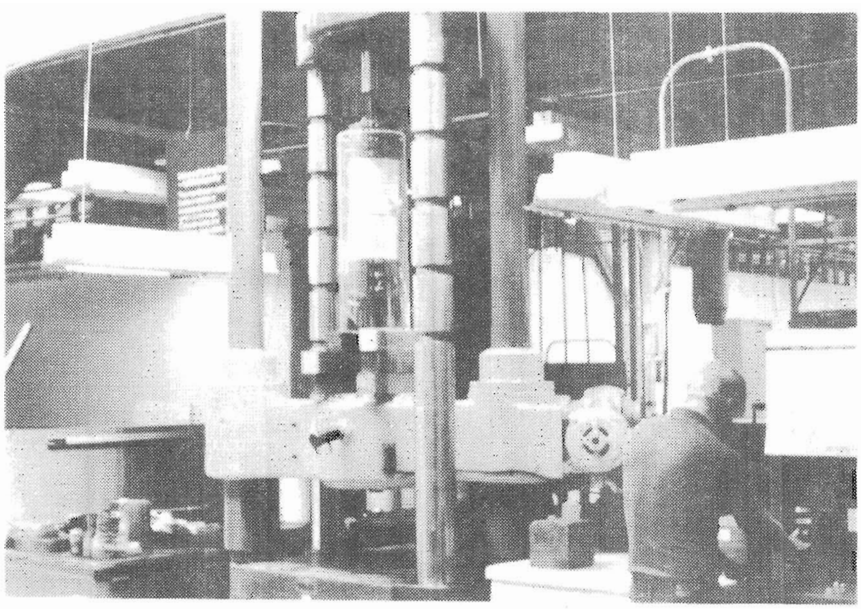

Figure 5. - Tensile tests were performed on a 400,000-pound universal tester. A Plexiglas shield protects the operator from ballistic test specimen fragments.

1...Compressed air bottle
2...High pressure hose
3...Accumulator tank (air/water interface)
4...Pressure vessel
5...Pressure gauge (mounted inside the specimen)
6...Test specimen
7...Air bleed valve

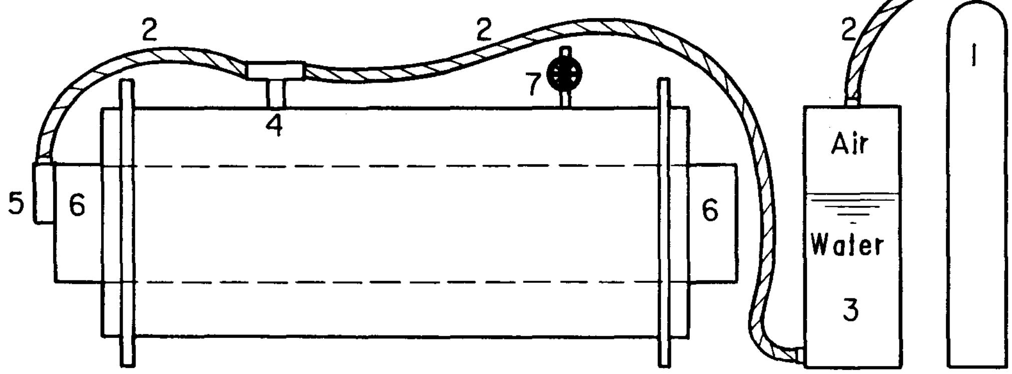

Figure 6. - Schematic of collapse test apparatus for 8- and 12-inch-diameter specimens.

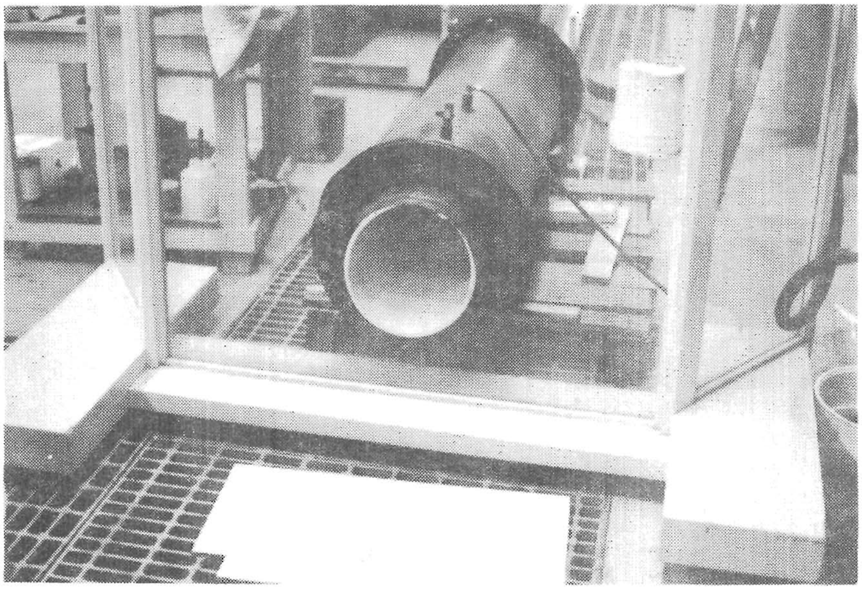

Figure 7. - A Plexiglas shield separates the operator from the collapse pressure vessel. The pressure gauge (not visible) is located inside the test specimen for simultaneous monitoring of test pressure and pipe profile.

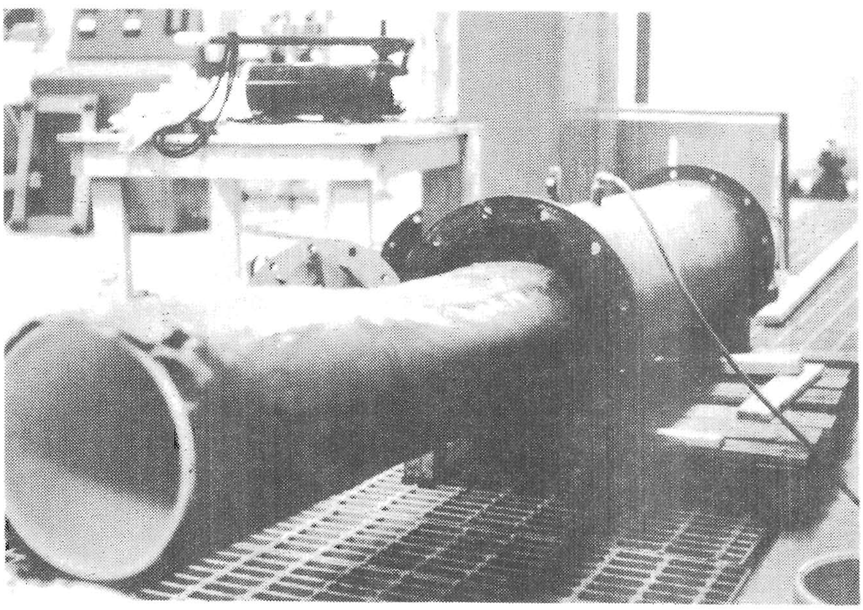

Figure 8. - The well screen specimen, wrapped with flexible membrane, is removed from the collapse pressure vessel.

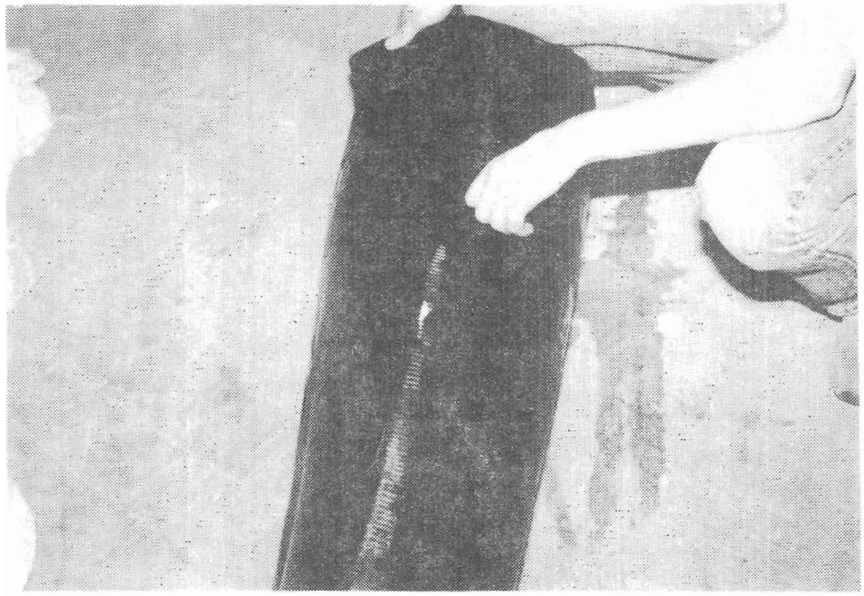

Figure 9. - The flexible membrane is removed from the well screen specimen after testing. Slotted screen with 50-mil slots and 10 percent open area was used for this study.

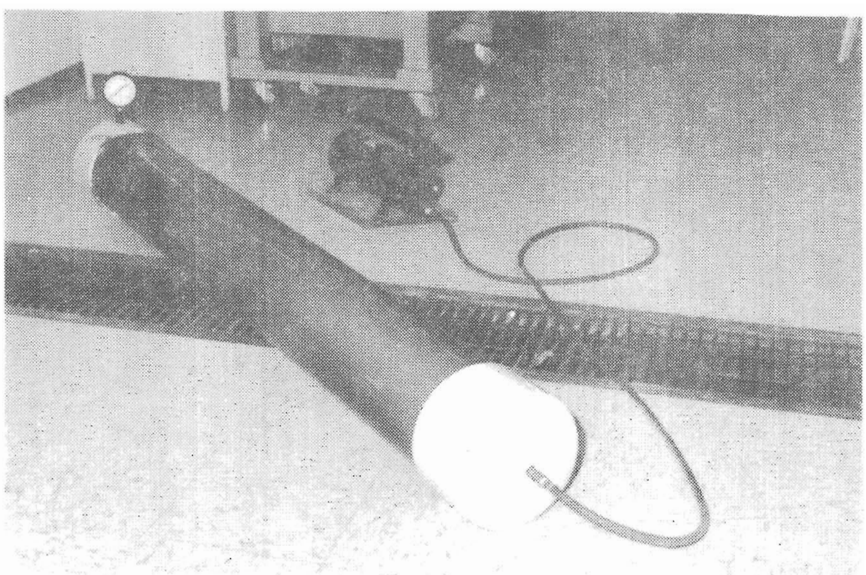

Figure 10. - Test apparatus for determining watertightness of threaded joints.

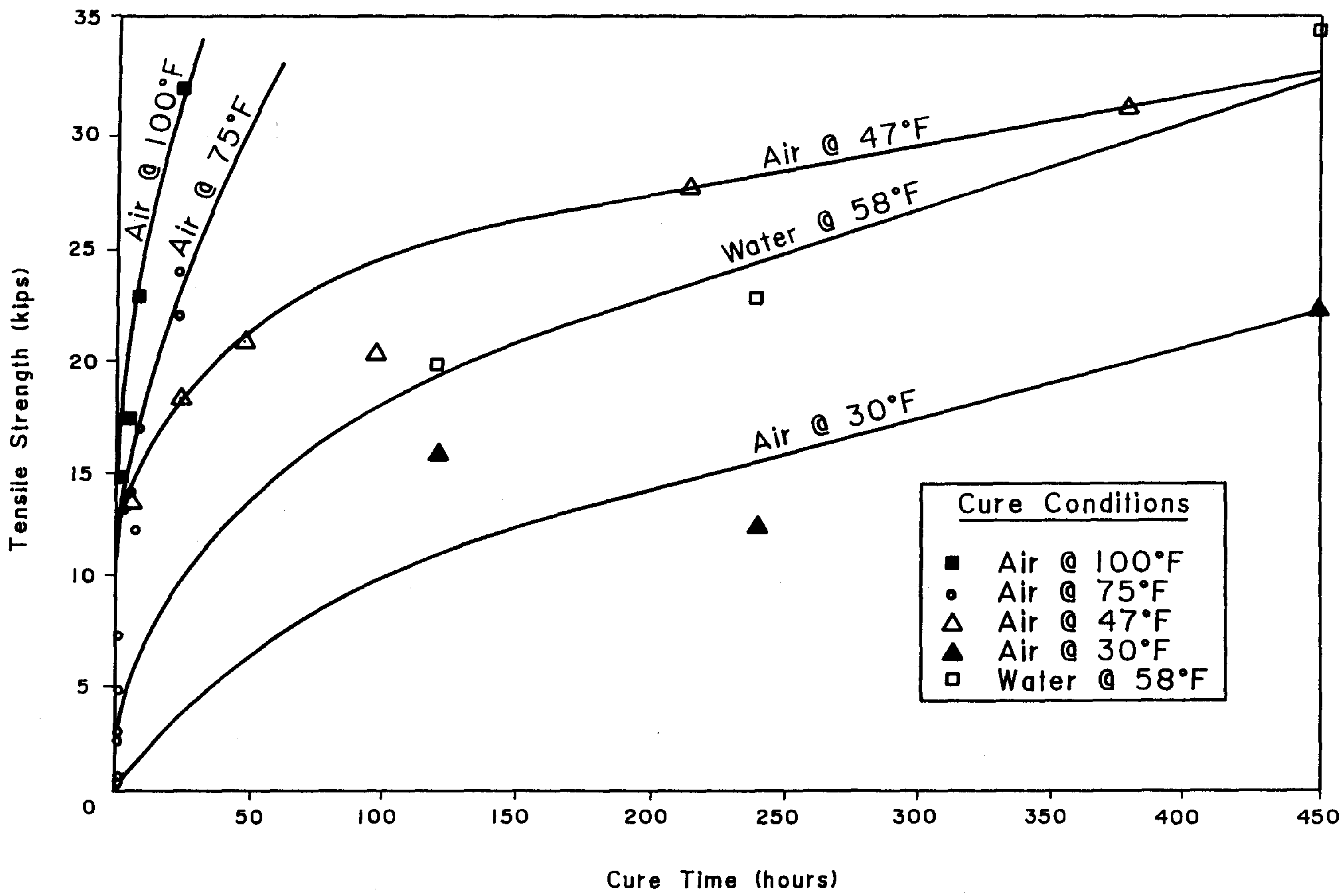

Figure 11. - Tensile strength of 8-inch-diameter, solvent-welded, slip-fit PVC joints. As expected, cure rate decreases with decreasing temperature. Although data are limited, water cure also appears to retard the cure rate.

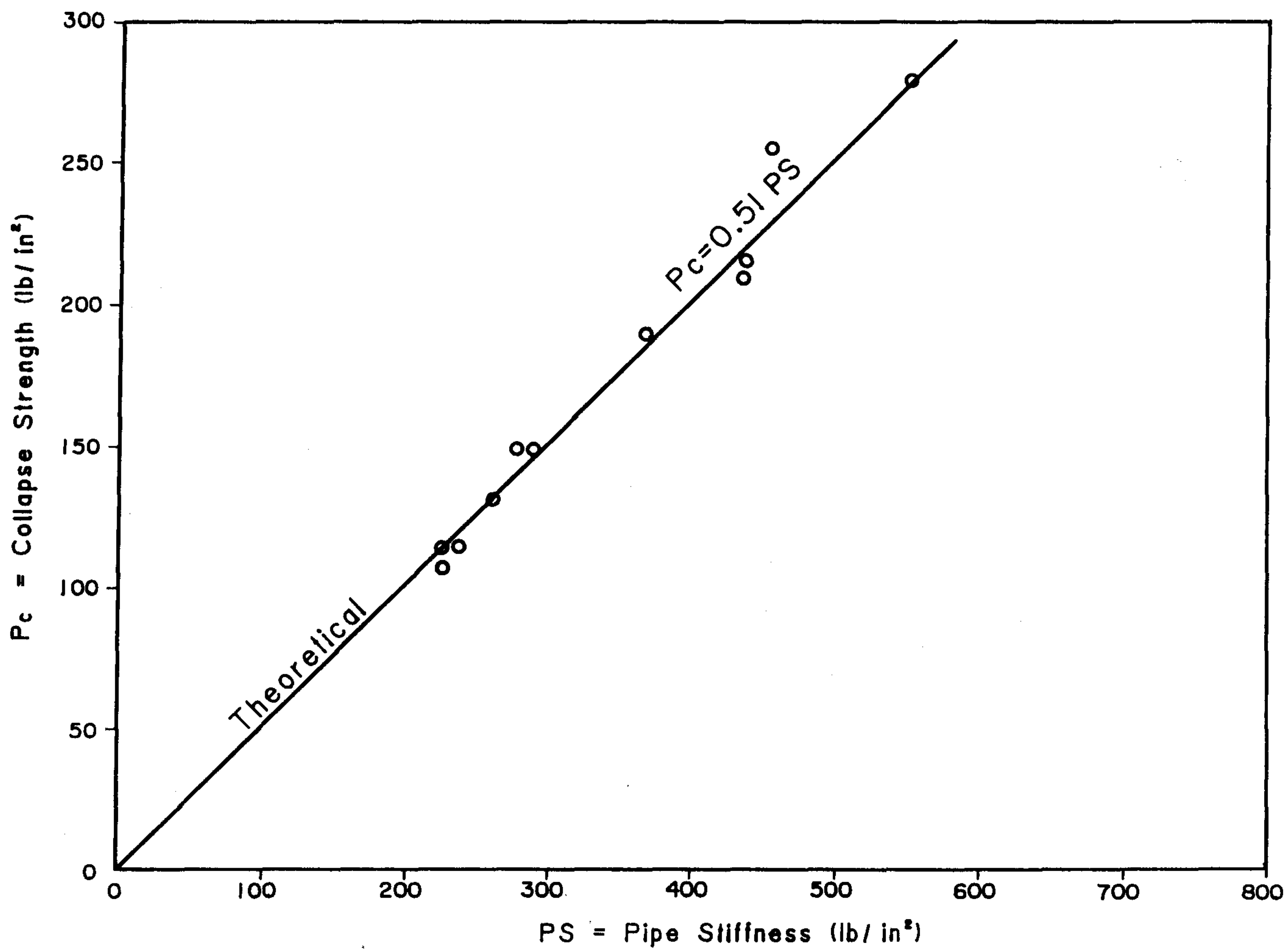

Figure 12. - Pipe stiffness vs. collapse strength for Schedule 80 and Class 200, 8- and 12-inch-diameter PVC well casing and screen. Laboratory data agree very well with the theoretical relationship.

APPENDIX

Photographs of collapse test on 8-inch-diameter PVC well screen (Camera was positioned inside test specimen.)

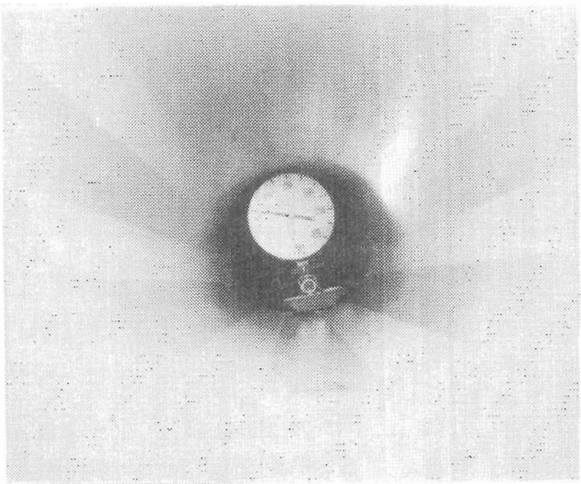

Figure A-1. - 60 lb/in^2.

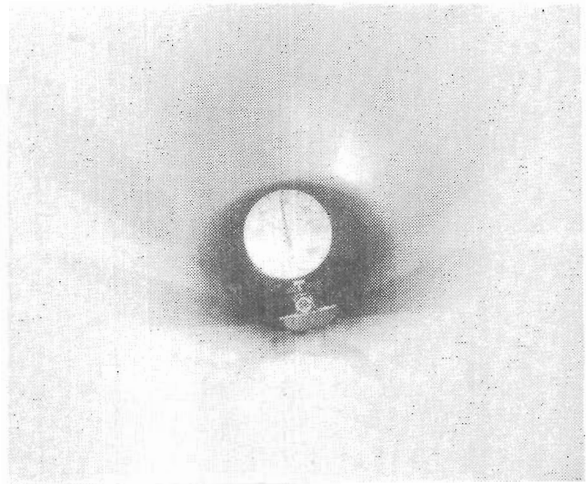

Figure A-2. - 145 lb/in^2.

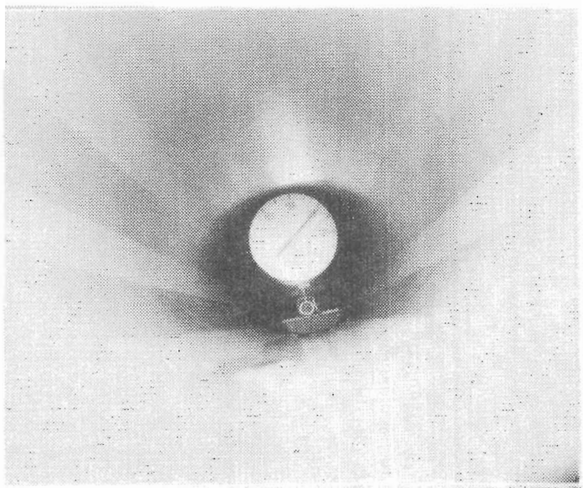

Figure A-3. - 205 lb/in^2.

Figure A-4. - Collapse, maximum pressure = 215 lb/in^2.

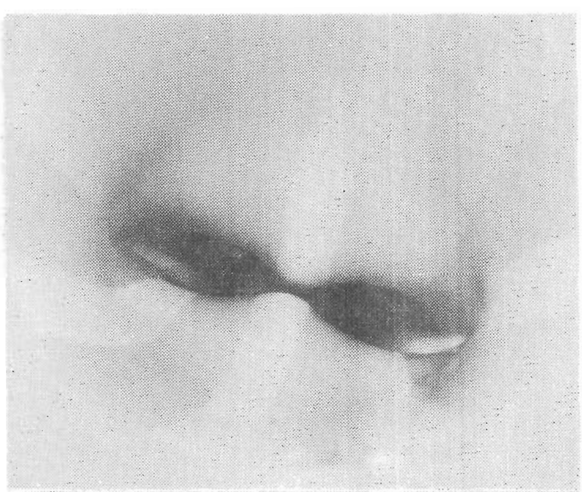

Figure A-5. - Maximum deflection.

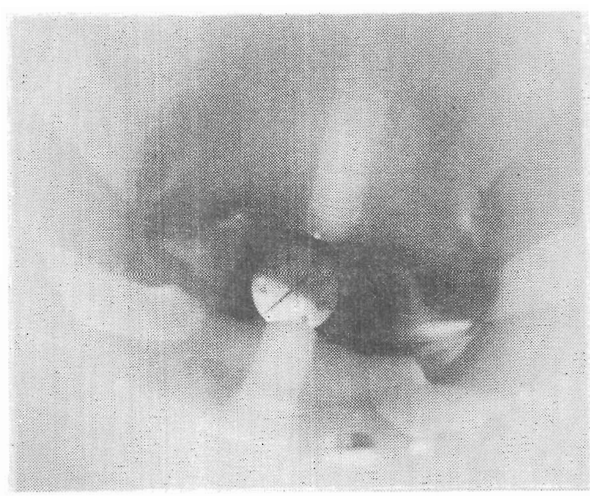

Figure A-6. - Recovery.

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-7923A, PO Box 25007, Denver Federal Center, Denver CO 80225-0007.