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January 1979

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CYCLIC PRESSURE TESTS

**of Direct Tapped
C-900 PVC Pipe**

for

**UNI-BELL PLASTIC PIPE ASSOCIATION
2655 Villa Creek Drive, Suite 150
Dallas, Texas 75234**

by

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**HYDRAULICS AND HYDROLOGY SERIES
UWRL/H-81/03**

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November 1979

ABSTRACT

Performance testing of direct-tapped PVC pressure pipe was conducted at the Utah Water Research Laboratory to verify and document its capabilities under cyclic pressure conditions.

Twelve samples of nominal six-inch diameter, pressure class 150 PVC pipe, manufactured to satisfy the requirements of AWWA Standard C900, were obtained from four Uni-Bell Member producers. Five pipe samples were tapped and fitted with 3/4 inch corporation stops under a line pressure of 80 ± 5 psi. Another five pipe samples were tapped and fitted with one-inch corporation stops under a pressure of 150 psi. Only corporation stops complying with AWWA Standard C800 were used. The remaining two pipe samples were not tapped, for use as controls.

All twelve pipe samples were subjected to 1.5 million pressure cycles ranging from 100 to 200 psi. A continuous record of the pressure cycles was kept and a red dye was added to the water in the test pipes so that even the smallest amount of leakage could easily be detected.

These cyclic tests represent an extreme condition that pressure class 150 psi, C900 PVC pressure pipe, would rarely be subjected to in service. To reach 1.5 million pressure surges, the pipe would need to be in service 171 years if such surges occurred once every hour on the average. A nearly instantaneous 5.7 fps flow velocity change would be needed to increment the internal pressure by 100 psi. This velocity change would occur, for example, if a flow rate of 525 gpm were stopped by complete closure of a valve in a nominal six-inch diameter PVC pipe line.

No leakage or seepage developed around any of the threaded corporation stops during the testing through 1.5 million cycles of pressures varying from 100 to 200 psi at two second intervals.

INTRODUCTION

This report describes the results of subjecting 12 samples of Pressure Class 150, C-900 PVC pipe to 1.5 million cycles of pressure changes from 100 psi to 200 psi during a period of 2 seconds for each cycle. Ten of these test pipes were tapped under pressure and fitted with corporation stops; five with 3/4 inch stops and five with 1 inch stops. These tests replicate earlier tests in which the pipe was carried through 1.0 million cycles of pressure change. The results of the previous testing are contained in a report "Cyclic Pressure Test" dated May 1979.

In tapping the pipes involved in the previous testing, it was not possible to cut and thread the newly cut hole as is standard practice, because the rod which held the end caps in place passed through the center of the pipe and the Mueller cutter-tap would have extended beyond the center of the pipe. Therefore, the Mueller tapping tool had to be withdrawn, the cutting head removed, and the tool reinserted without the cutting head as a guide in completing the tapping of the pipe. Because of this major modification of the tapping procedure from the usual "straight through cutting and tapping," as well as various equipment problems, this second series of testing was begun. For these replication tests two special end caps were fabricated to allow proper "straight-through" cutting and tapping and additional automatic controls were added to the test equipment.

During these tests no leakage occurred in any of the pipe during the 1.5 million cycles of pressure fluctuations. This report describes the latter cyclic pressure tests and the modifications that were made to the cyclic testing equipment.

Tapping of Pipes

Several 4 ft lengths of Pressure Class 150, C-900 PVC pipe were supplied by all current Uni-Bell member manufacturers of C-900 PVC pipe. Five of these pipes were tapped with a 3/4 inch hole and a 3/4 inch corporation stop installed and five of these pipes were tapped with a 1 inch hole and a 1 inch corporation stop installed. Only AWWA tapered thread corporation stops, as specified in AWWA C-800, were used. This tapping operation was conducted at the Utah Water Research Laboratory (UWRL) by a plastic pipe distributor from Salt Lake City using the Mueller tool designed for this procedure.

In order to allow this tapping and installation of corporation stops to occur while the pipes were under pressure, the end caps were restrained with a pair of 3/4" steel plates (30" square) and connected with four, 3/4 inch rods. With this arrangement the pipe being tapped was not subjected to any axial stress. The photograph in Figure 1 shows these restrained end caps and the pipe being tapped.

Modifications to Equipment

Shut-down of the equipment occurred during the previous testing when the water level in the small make-up water reservoir dropped below a level switch that shut-off the equipment completely. As end cap leakage increased during the latter portion of the previous tests it became necessary to hand refill this make-up water reservoir 3 or 4 times a day to prevent the reservoir running dry. This occurred despite the fact that a larger capacity tank was added to the original equipment. It was decided to make this refilling operation automatic, as one modification to the cyclic test equipment.

Automatic Make-up Water

To automatically have the equipment maintain a safe level of water in the make-up water reservoir, two additional level switches were installed in the reservoir in addition to the level switch that shut-off the equipment. When the water level in the reservoir dropped to the elevation of the lower of these two additional switches, a small capacity all bronze gear pump was turned on and the reservoirs refilled. When the water in the make-up reservoir reached the elevation of the upper level switch, this small pump was shut-off. These two level switches were located 5 inches above and 5 inches below the mid elevation of the make-up reservoir tank. To prevent leakage back through the pump when it was not in operation, a check valve was placed in the line of the make-up water supply. The photo in Figure 2 shows this make-up water pump.

Automatic Centering of Pressurizing Piston

The cyclic pressure from the test equipment was achieved by driving a piston within a brass cylinder back and forth a complete stroke for each pressure cycle. The driver consists of an air cylinder equipped with a piston and solenoid valves whose opening and closing are electronically controlled to achieve the desired driving speed. As the water piston is driving to one side the pipes connected to that end of the cylinder are pressurized to their highest pressure, while those pipes connected to the other side of the cylinder are at the low portion of the pressure cycle.

During the previous cyclic tests, particularly toward the end of the 1.0 million cycles, a slow gradual movement of the piston toward one side or the other was experienced. This movement required periodic hand adjustment. To achieve this adjustment, two of the valves used to fill the system had to be opened

simultaneously during the right time of the cycle to allow water from the side of the cylinder with the largest displacement of the piston to flow into the side toward which the movement was occurring. This adjustment was easily accomplished by hand while the equipment was in operation over a couple of cycles. However, it did require periodic checking to ensure that the piston was operating near the middle of its cylinder. When the piston became very badly positioned, the full range of pressure was not achieved in the pipes being tested, as well as an excessive hammering noise occurred as the piston struck the end of its cylinder.

To eliminate the need to manually adjust the piston to its mid position, a cam was attached to the shaft of the cylinder with electronic circuitry to detect whenever the piston moved beyond a preset limit from its center. An additional small line was plumbed between the two sides of the water cylinder containing two solenoid valves. Whenever the piston drifted more than the preset amount to one side or the other of its center, these solenoid valves were opened for a small fraction of a second to allow a small amount of water to flow from the side of the cylinder with the excessive volume of water into the side with the lesser volume of water. Thus the piston's position of operation was automatically maintained within preset limits. The photo in Figure 3 shows these automatic positioning add-ons.

Continuous Recording of Pressure Cycles

A continuous record of the pressure cycles was obtained throughout the entire test. A line tapped into an end cap of one pipe took the water with the varying pressure to a PACE transducer. The output signal from the transducer was directed to a RUSTRAK recorder. The recorder has the capability of very slow strip chart movements in the order of a fraction of an inch per hour. It records by

burning a small dot on the recording paper approximately each 1.5 seconds as a rocker arm presses the recording mechanism in contrast with the recording paper. This slow moving recorder was not designed to record, nor is it capable of recording, the actual pressure function that varies from 100 psi to 200 psi in 2 seconds time. It gives only one or possibly two dots over this period and, depending upon when the dot is made with respect to the varying function pressure, the dot may occur anywhere within the 100 psi to 200 psi range. Furthermore, during the fraction of a second that the scribe is against the paper and not free to move, the pressure change is significant. While not visible to the eye, the recording mechanism is forced to operate in a jerky fashion. However, as a record of the complete cyclic performance of the testing over a long period of time the data randomly placed within the upper and lower bounds provide an ideal record. Parts of this record are shown on Figure 4.

Problems did develop with the recorder that could be traced to it not being designed for full scale deflection over such a short time period. The problem was that the scribe would get hung up at a given position. The original recorder used was replaced by a second one after a few weeks of operation, but the same difficulties were encountered. Finally, by clipping off the end of the needle that showed the position of the pressure reading much of the difficulty with sticking at a given location was eliminated. In the process of attempting to adjust the recorder so that the scribe did not stick at a given position, the range of movement and the rate at which the strip chart moved were adjusted periodically. Initially, the scribe swing was adjusted to be over nearly the entire width of the recording paper, but after a few days of operation was reduced to about $\frac{2}{3}$ of the width of the paper when the record showed numerous times when the scribe hung up. The first part of the record on Figure 4 reveals the sticking of

the scribe, as well as adjustments made to the range of movement. The last part of the record displayed in Figure 4 is the record from the termination of the 1,500,000 cycles of pressure surges.

History of Testing

The pipes were tapped on August 29 and August 30, 1979. On August 29, five of the pipes were tapped and 3/4 inch corporation stops were installed. On August 30, 1979 the 1 inch corporation stops were installed in 5 other pipes. The 3/4 inch taps were done under the water supply pressure at the UWRL, which varied ± 5 psi about 80 psi during the tapping operation. The tapping of the 1" diameter holes was done by pressurizing the pipes to 150 psi during the tapping process. Table 1 shows the manufacturer's pipes that were tapped.

Table 1. Pipes used for cyclic tests*

Pipe No.	Size of tap (inches)	Manufacturer
1	3/4	A
2	3/4	B
3	3/4	C
4	3/4	D
5	3/4	C
6	1	A
8	1	C
9	1	D
10	1	B
11	No tap	D
12	No tap	B
13	1	A

*All pipe was 6" diameter AWWA C-900, Pressure Class 150, PVC pipe manufactured by Uni-Bell member companies.

After being tapped the pipes were placed in the test bed and pressurized to 150 psi. The pipes tapped on August 29 were pressurized before 5 p.m. of that afternoon and the pipes tapped on August 30 were under pressure by noon of that day.

The actual cyclic testing did not begin until Sept. 11 at 12 noon. The delay between the time the pipes were tapped and the beginning of the testing resulted from the observation that the bronze gear pump allowed a small seepage back flow when not in operation and, therefore, a check valve was ordered and installed in that make-up water supply line. Also the technicians needed time to test the piston centering electronics.

The cyclic testing continued without need for any manual adjustments beyond attempts at preventing the recorder scribe from sticking and the frequency of inspection of the operation was gradually decreased from several times a day to once a day or less. Then just after noon on Saturday, Sept. 22, upon visiting the site the equipment had stopped. A fuse in the electronic timer had blown. Upon replacement of the fuse the timer mechanism did not go back into operation. The technician responsible for the design and construction of this timer mechanism was not at home and, therefore, it was necessary to leave the equipment out of operation until Monday morning, Sept. 24, at 9 a.m. While the exact time when the equipment stopped cycling the pressure could not be determined, from the strip chart of pressure record the time can be estimated at about 9 a.m. Sept. 22. Thus the testing was stopped for about 48 hours from Sept. 22 to Sept. 24. During this time all pipes were maintained under the 150 psi mean pressure. In starting the equipment up it was discovered that the gear pump had been connected backward into the line and was thus attempting to take water from the

make-up water supply, but the check valve in the line prevented this. Obviously after a short time of operation it became hot enough to place a sufficiently heavy load on the motor driving it to blow the fuse.

The only other problem of significance encountered during the testing occurred 3 or 4 days before completing the 1.5 million cycles of pressure surges. At this time it was noted that the automatic centering of the piston was no longer capable of maintaining the piston at the center and there was a gradual shifting of its movement outward that required manual assistance in bringing the piston back to its center. This tendency to drift beyond the capacity of the adjustment to keep it centered gradually became worse until it required manual adjustment on a 2-3 hour interval. Rather than visiting the site every 2-3 hours during the night, the tests were shut-off October 13 at 8:20 p.m.

The technicians were requested to add an additional potentiometer into the circuit to allow adjustment of the small time interval that the solenoid valves stayed open. As originally designed, the only control was in adjusting when these valves were open with respect to the position of the piston. The original open-time was only a small fraction of a second. Because of other commitments these adjustments to the centering circuitry could not be completed until October 17.

The tendency of the piston to drift must be associated with wear within the seal between the piston and cylinder in such a manner as to allow water to more easily escape by the seal in one direction than the other.

With the added control, the piston centering circuitry was manually adjusted until it had about 50 % excessive capacity needed to maintain the piston centered. The

tests were completed October 21, taking the 12 test samples of C-900 PVC pipe through 1.5 million cycles of pressure surges from 100 to 200 psi. Not one of these pipes developed any seepage loss from the taps or elsewhere.

Observations

In reporting this second series of cyclic tests some observations seem appropriate.

1. Not only is 1.5 million cycles of pressure from 100 to 200 psi a severe test of the pipes durability, but also it is a severe test of the equipment. For instance, the silicon rubber seal between the end caps, washer and rods developed leakage in two cases, one of which became large enough that it was necessary to replace it. Evidently the 2.5 million cycles have wore the piston or cylinder sufficiently that some parts will need to be replaced before additional testing. A better design of cyclic testing equipment would eliminate movement of contacting parts.

2. In examining the 1/4 inch steel end caps following the testing, fatigue cracking was very evident around the entire circumference of the 1 inch drilled hole in the caps. The end caps would obviously have failed if subjected to many more cycles of pressure surges. Figure 7 shows the permanent indentations caused by the fatiguing of the center portion of the end caps. An inside view of the caps shows eight to ten large cracks emanating from the hole cut for the center rod. These fatigue cracks extend on the inside face from 1/2 to 5/6 of the distance through the 1/4 inch plate steel. In no instance, however, did these cracks extend completely through the steel. Not only did the end caps themselves contain such fatigue cracks, but the washers on the outside of the caps showed the same type of cracking.

3. The author noted that visual observation indicated significantly more movement, for each pressure surge, between the caps and the pipes toward the end of the 1.5 million cycles than at the beginning of these cyclic tests. He speculated about the cause and wondered if perhaps the large number of cycles of strain had altered the material properties, such as the modulus of elasticity of the plastic. The explanation for this observed phenomena is now apparent. It was the end caps themselves that were deflecting more as the fatigue cracks extended deeper through the 1/4 inch steel. An approximate analysis of the stress in these end caps indicates their failure was inevitable.

Design of end caps needs to ensure they are sufficiently thick near the anchor bolts to be structurally sound. Furthermore, since the lengths of the pipes will be reduced as they are pressurized and the anchor bolts will stretch, a sufficient base of rubber is needed in the seal to accommodate the movement between the pipes and the end caps. Otherwise gasket wear will occur. A less satisfactory solution involves periodic lubrication of the gasket seal to prevent excessive wear.

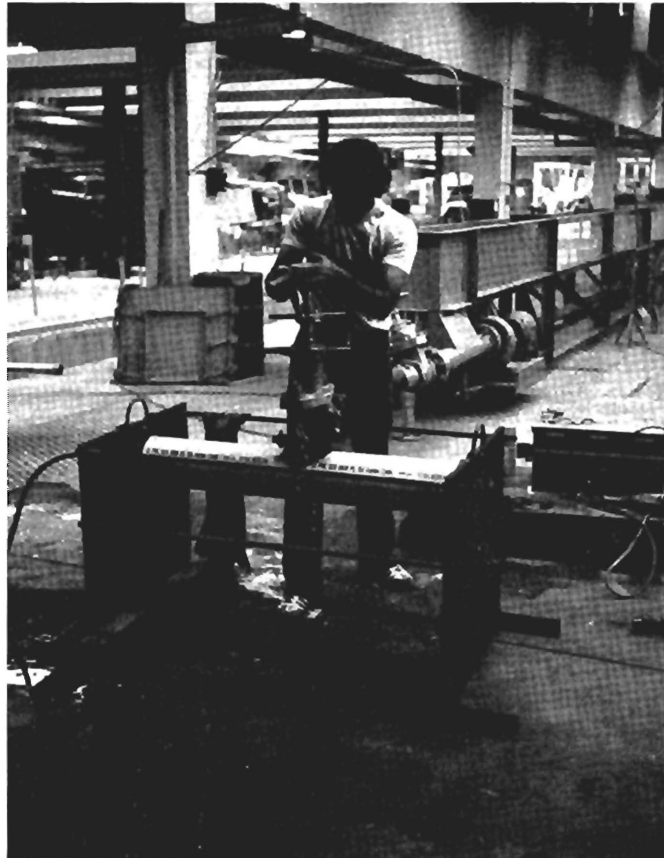


Figure 1. Photograph of one specimen of pipe being tapped in preparation for testing through 1.5 million cycles of pressure changes from 100 to 200 psi at 30 cycles per minute. The Mueller tapping device allows the hole to be cut and threaded in one operation and then the corporation stop inserted while the water in the pipe is under pressure.

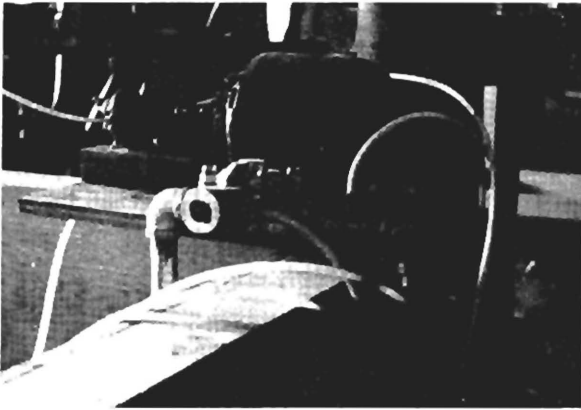


Fig. 2. Small pump that added water to system whenever the make-up supply level dropped below level switch in tank.

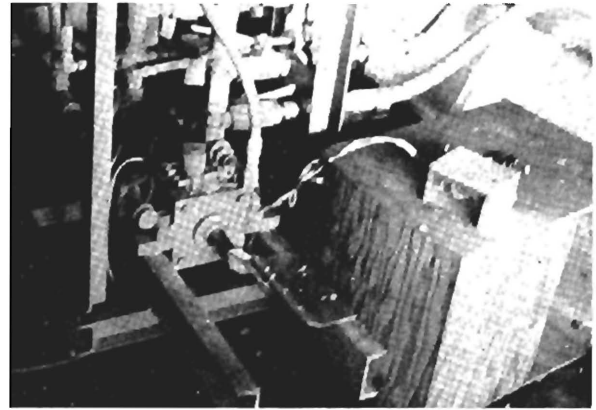


Fig. 3. Pressurizing water cylinder showing automatic piston centering cam attached to end of shaft.

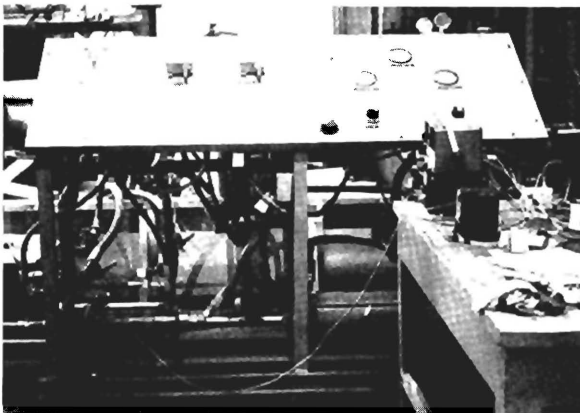


Fig. 5. Cyclic test equipment.

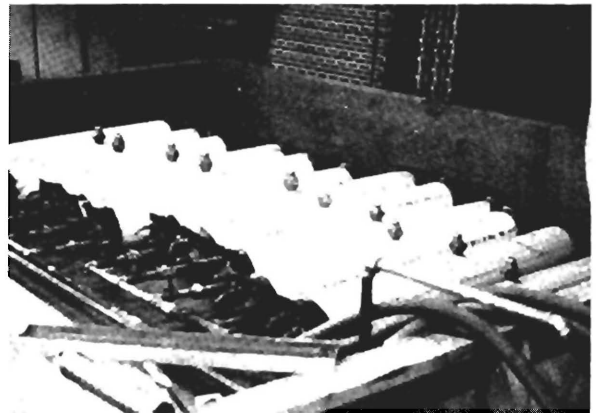


Fig. 6. Pipes under cyclic pressure tests.

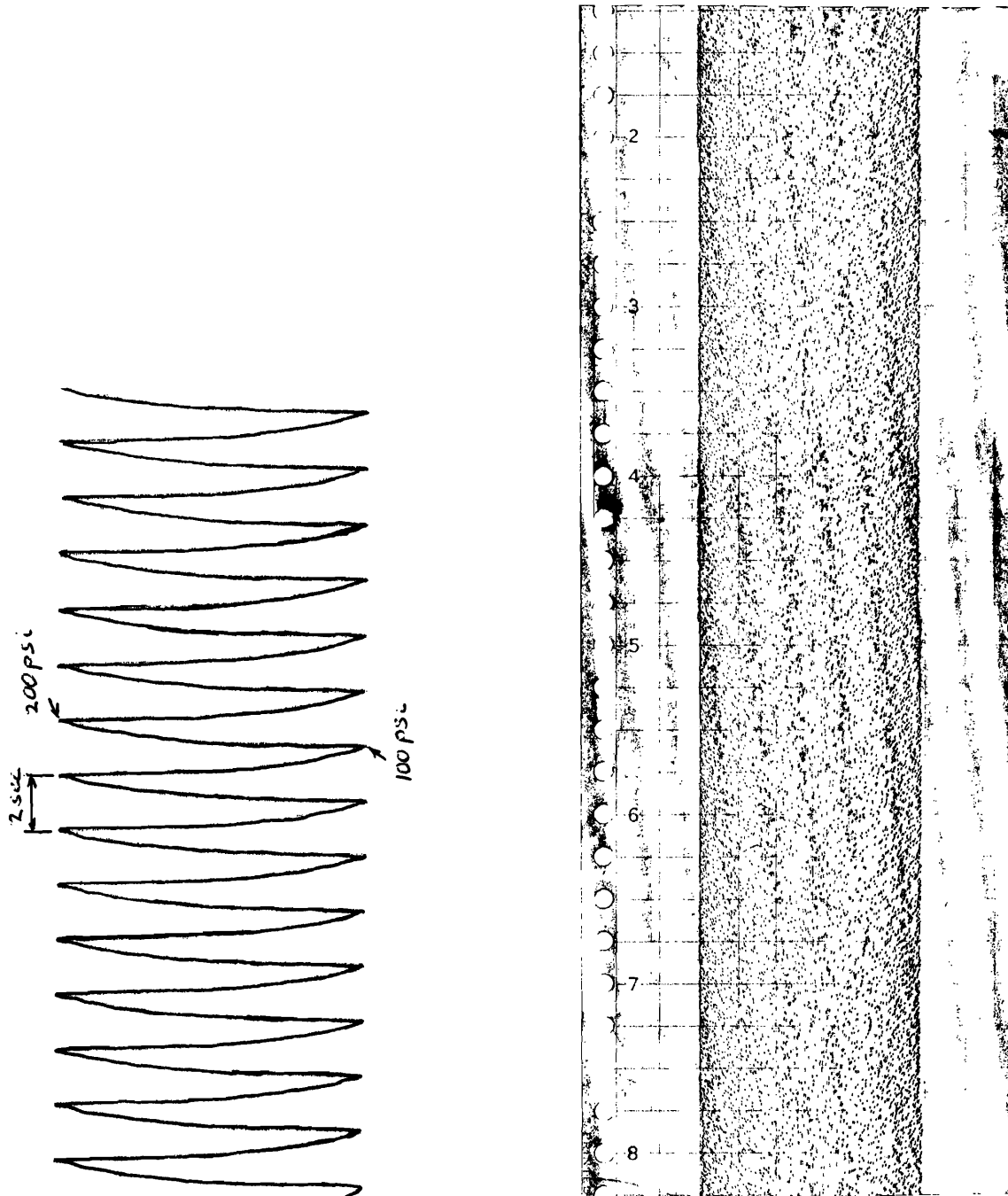


Figure 4

Samples of strip chart records of pressure fluctuation. The left record above (a) shows the pressure wave used in cycling the test pipes pressure from 100 psi to 200 psi every 2 seconds. The right record above (b) gives a small piece of the continuous record maintained throughout the entire tests to 1.5 million cycles. Each dot on this record indicates the pressure at that instance of time. Dots were read on about a 1.5 second interval.

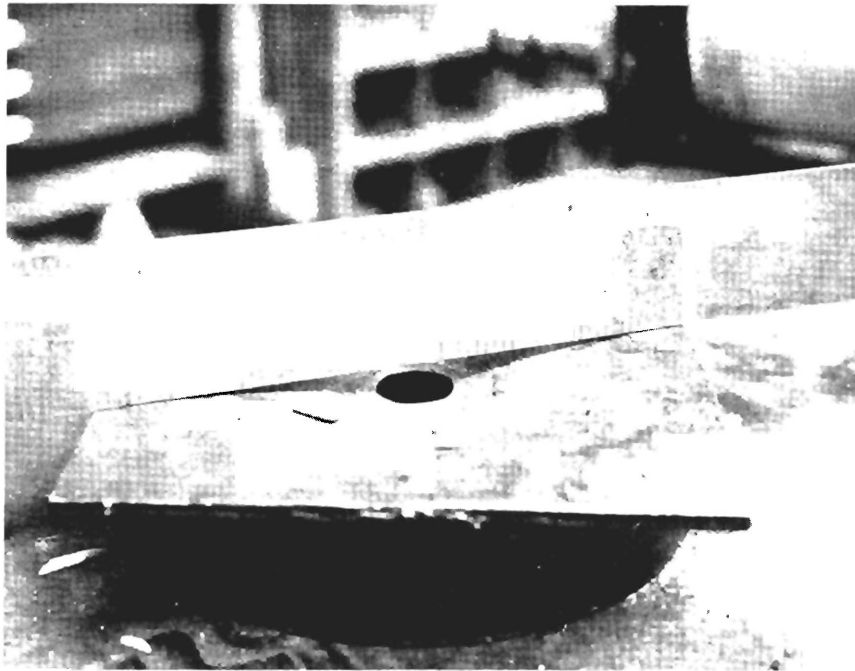


Figure 7 Photo of end cap showing the effects of fatigue on the 1/4 inch steel plate.

