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Laboratory Tests of Thermoplastic Piping Assemblies Subjected to Water Hammer and Intermittent Hot Water Flow

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Final Report

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FOREWORD

This report describes the test methods used and the results of testing chlorinated polyvinyl chloride (CPVC) thermoplastic pressure piping assemblies for their resistance to water hammer (shock pressure) and intermittent hot water flow (thermal cycling). Additionally, the results of thermal cycling of two polyvinyl chloride (PVC) thermoplastic drainage stack assemblies are reported.

The work described in this report was sponsored by the Department of Housing and Urban Development and was conducted by the Center for Building Technology, National Bureau of Standards, as part of a long-range research program with the goal of improving building standards. This report, emphasizing thermoplastics, is one of several resulting from this program concerning performance characteristics and criteria for piping materials used in residential plumbing systems.

LABORATORY TESTS OF THERMOPLASTIC PIPING ASSEMBLIES SUBJECTED TO WATER HAMMER AND INTERMITTENT HOT WATER FLOW

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ABSTRACT

Evaluation procedures are described that were used at the National Bureau of Standards (NBS) for simulating the long-term effects of water hammer (shock pressure) and cyclic hot water flow (thermal cycling) on chlorinated polyvinyl chloride (CPVC) thermoplastic pressure piping assemblies. Also included are the procedures used to study the effects of thermal cycling of two (2) polyvinyl chloride (PVC) thermoplastic drainage stack assemblies. The results obtained using these test procedures are presented and, in addition, related work of other investigators is briefly reviewed.

The shock pressure results show that a fatigue life curve can be established for CPVC as a function of temperature and pressure. As the temperature is decreased, the number of shock pressure applications necessary to produce failure increases. An estimated use life of at least 50 years was indicated at the maximum test temperature of 180° F (82° C) with pressures of 150 psi (1034 kPa).

With intermittent hot water flow all test assemblies were performing satisfactorily when the test was terminated after more than 1500 cycles had been completed.

Key words: Intermittent hot water exposure tests of thermoplastic pipe; pressure shock in thermoplastic pipe; water hammer in thermoplastic pipe.

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1. INTRODUCTION

1.1 Background

The majority of the present standards for thermoplastic piping materials (as well as for other piping materials) describe the physical properties which are generally utilized for quality control purposes in the manufacture of the materials. In general, these product-oriented piping standards do not describe, under conditions of use, the functional and durability performance requirements for assemblies of pipes and fittings. It is generally understood that the product specification approach has served its purpose when ample time has been available for the accumulation of a sufficient body of satisfactory service history for feedback purposes and proof of adequacy. As indicated in Section 1.2, the study described herein involved an effort to apply the performance approach, which places an emphasis on qualitative user needs under service conditions, and on criteria and evaluation methodology for measuring the probable adequacy of systems and components by calculation or by tests simulating end-use service conditions.

Two conditions of the end-use environment which are considered to be of primary importance with respect to long-term durability of thermoplastic piping assemblies are (1) shock pressure and (2) hot-water cycling.

Shock pressure (water hammer) occurs whenever a piping system is subjected to a sudden change in flow rate and is most severe when flow is quickly terminated by a fast-acting automatic valve such as found in some water-using appliances using hot water.

The existing standards did not provide a generally-accepted performance test for evaluating the long-term effects of shock pressure and thermal cycling on the durability of thermoplastic piping assemblies. Neither was there sufficient measurement data on the service environment for such systems to permit an accurate definition of representative conditions for simulative service tests. Therefore, in order to contribute to the development of systematic performance evaluation methodology, a course was decided upon which involved a laboratory investigation in combination with a review of related work by other investigators. In this approach, tests were to be conducted on representative assemblies of thermoplastic piping for shock pressure and thermal cycling durability, rather than on individual sections of pipe and on fittings. This approach was thought to be necessary because the system performance can be affected by interactions between the pipes, fittings, supports and attachments, and by the quality of the assembled joints.

Thermoplastic piping is lighter than its metallic counterpart. This results in reduced structural loads and increased convenience in fabrication and installation of the piping system. However, this lower density as well as the greater thermal expansion of thermoplastics contributes to greater physical movements under hydraulic and thermal loadings. Because there is insufficient experience concerning the effect of these movements on the performance of thermoplastic plumbing systems, greater attention must be given to the installation details when designing such a system; e.g. possible problems associated with localized contact with the building structure and with the friction between pipe hangers and supports must be considered. It is essential that any comprehensive evaluation of thermoplastic piping assemblies must include provisions for comparison of different installation methods that might be used in the field.

1.2 Objective

As a part of the Department of Housing and Urban Development (HUD) long-range research program for improving building standards and performance evaluation methodology, a task for the National Bureau of Standards (NBS) to develop performance criteria for piping materials for use in residential plumbing systems was sponsored. The scope of the program was limited to laboratory evaluations of thermoplastic materials. The topics of primary interest included: the long-term effects of intermittent hot-water exposure (thermal cycling) on "thin wall" polyvinyl chloride (PVC) drain-waste-vent (DWV) systems and on chlorinated PVC (CPVC) water distribution piping; and the long-term effects of water hammer (shock pressure) on CPVC water distribution system piping.

The objective of the work on resistance of an assembly of pipe and fittings to intermittent exposure of hot water was to examine the effects of a simulated service exposure to this condition. The information of principal interest was the permanent change in dimensions and the continuity of leak resistance. The objective of the work on shock pressure was to examine the effects of simulated "water hammer" on an assembly of pipe and fittings, with particular attention to the ability of the assembly to withstand, without leaking, repetitive applications of shock pressure for a sufficient number of cycles to represent anticipated exposure over the planned life of a residential water distribution system.

1.3 Scope and Approach

The constraints on the study reported herein limited the laboratory investigation to selected thermoplastic materials. A review was made of related work as reported by other investigations to supplement the NBS study and to provide input to the design of the NBS experimentation. Because concern had been expressed as to the adequacy of "thin-wall" schedule 30 PVC DWV pipe and of CPVC water tubing used in some of the Operation BREAKTHROUGH housing systems, the NBS experimental work was concentrated on these types of piping.

The approach adopted for the NBS hot water test involved the exposure of representative assemblies of water piping and DWV piping to a flow of hot water of approximately 8 gpm (0.5 l/s) for 5 minutes at 1/2-hour intervals, at a temperature of about 140° F (60° C). The rationale for this was to simulate conditions produced by automatic plumbing appliances such as dishwashers and clotheswashers. It has been widely believed that the most severe exposure of residential plumbing piping to hot water occurs in the water supply pipes leading to automatic dishwashers and clotheswashers, and in the waste piping serving these appliances. The test plan provided for different techniques of attaching and supporting the piping to the building structure to simulate both good and bad installation practices. Essential measurements made to indicate the level of performance were: evidence of leaking, thermally induced deflections, and permanent changes in dimensions of position. Such measurements are direct indicators of capability of the system to maintain essential functions and characteristics, e.g. leak resistance, acoustical acceptability, and drainability.

The approach for the NBS pressure shock test involved the repetitive application of a pressure pulse, at a frequency of 6 cycles per second, on an assembly of water piping full of water at a normal pressure and maintained at a selected temperature, and continuation until either failure (leaking) occurred or for 350,000 repetitions. The rationale for this was as follows: the most severe exposure to water hammer in a residential water distribution system is assumed to occur under rapid closure of the solenoid valve in the hard-piped hot-water supply to appliances such as the automatic dishwasher. It was estimated that as many as 350,000 operations of the hot-water supply solenoid in a dishwasher could occur over the life of a plumbing system. Review of the work of other investigators, plus some preliminary tests, showed that a frequency of as much as 6 Hz (desirable to shorten the required length of the test as much as feasible) yielded a number of cycles-to-failure essentially the same as for the much lower frequencies believed typical. Tests were made at different pressures and temperatures to gain some idea of the effects of these parameters.

2. SHOCK PRESSURE TESTS

2.1 Summary of Work by Other Investigators

Three studies have been reviewed. One of the investigations [1] was concerned with the prediction of the magnitude of shock pressure and the sizing of air chambers to reduce shock pressure. The other two [2,3] were concerned with the possible effect of shock pressure on the burst strength of PVC water pipe. The three studies are discussed in the following sections.

2.1.1 Water-Hammer Theory

The classical theory estimates that maximum over-pressure (pressure rise above static line pressure) (ΔP) caused by the rapid closure of a valve in a pipe line is given by the expression

$$\Delta P = \frac{a\ \Delta V}{2.31\ g} \tag{1}$$

in which

$$a = 12 \quad \frac{KEe}{\rho\ (Ee + KDC_1)} \tag{2}$$

where:

ΔP = pressure rise due to valve closure, psi
a = shock wave velocity in pipe, ft/s
g = acceleration of gravity, ft/s^2
V = flow velocity in pipe before valve closure, ft/s
ΔV = change in flow velocity due to valve closure, ft/s
K = Bulk modulus of elasticity of water, psi
E = modulus of elasticity of the pipe material, psi
e = pipe wall thickness, in
ρ = mass density of water, slugs/ft^3
D = inside diameter of pipe, in
C_1 = a function that depends on Poisson's ratio for the pipe material and on the physical restraint of the pipe.

The maximum shock pressure will occur only if the valve closure occurs within the time period which is less than 2L/a seconds. When this closure time is greater than 10L/a seconds, destructive water-hammer pressures will not be produced. The term L represents the length of pipe in which velocity V exists before valve closure.

2.1.2 Water-Hammer Control

There are two generally accepted methods of water hammer control:

(1) Rapid closure of valves should be prevented, particularly during the last 15% of the movement.

(2) If method (1) is not practicable, shock-absorbing devices such as air chambers may be used. A chart for sizing pipe air chambers has been provided by Dawson and Kalinske [1], and manufacturers of sealed air chambers (shock arrestors) have provided sizing criteria for their products [4, 5, 6].

2.1.3 Effect of Water Hammer on PVC Pipe

(a) Tests at Johns Manville [2]. Laboratory data for PVC 1120 pipe which was pressurized for up to two years at twice its rated pressure showed greater short-time (60 to 70 seconds) rupture (burst) strength than that of new pipe as determined in accordance with ASTM D 1599. The test was planned to provide for future verifications of this effect for pressurization up through 10 years.

Cyclic pressure surge tests for nominal 2-in and 4-in PVC pipes were made at a rate of 0.38Hz from a base pressure of 50 psi (344.7 kPa). Other tests at 0.17, .017 and .0017 Hz indicated that the frequency of the pressure surges (over this frequency range) did not significantly affect the total number of surges that the pipe could withstand at a given pressure.

The effect of prolonged exposure to high static pressure before the imposition of cyclic pressure was studied, as well as exposure first to cyclic pressure and then to prolonged static pressure. These tests showed that static pressure life and cyclic pressure life were essentially independent.

Pipe that had been subjected to cyclic pressure to near predicted failure and then subjected to the quick-burst test (ASTM D 1599) showed a strength just below that expected of new, uncycled pipe, according to the investigator [2].

Tests were made of the effect of longitudinal scratches on the external surface of 1 1/2-in 160-psi (nominal) pressure-rated PVC 1120 pipe. Scratch depths of 0.005 and 0.010 inch were milled on the test specimens. Although the static pressure life was not adversely affected, there was a significant decrease in cyclic pressure life due to the scratches. This notch effect was greater than that attributable only to the reduction of the wall thickness at the scratch.

Field measurements on operating water systems containing PVC pipe were made under normal operating conditions and with pressure variations deliberately introduced by the manipulation of fire hydrants. The pressure surges introduced by the fire hydrant manipulation resulted in pressure rises ranging up to a maximum of about 100 psi (689.5 kPa) above line pressure.

Long-term pressure measurements were also made on one system over a period of 2 months. Pressure surges up to 225 psi (1551.3 kPa) were recorded 12 times, and over 228 surges to 160-169 psi (1103.2 - 1165.2 kPa) occurred. High-frequency "noise" pressure observed on the records was attributed to the operation of pressure-reducing valves in the system. Average static pressure in this system was given as 112 psi (772.2 kPa).

It was concluded that resistance to pressure surge is an important design criterion for PVC pipe, and that PVC 1120 pipe rated for 160 psig may be expected to have a life of 250,000 to one million cycles of pressure surges up to 110 psi (758.2 kPa). Surface scratches significantly reduced cyclic pressure life.

The study showed that the magnitude of water hammer surges could be estimated for PVC pipe using the traditional equations (1) and (2) with constants appropriate to the material and its mode of restraint [2].

The author [2] recommended a similar testing program for plastic pipe of other materials prior to determination of a design basis for taking surge pressure into account.

The essence of the recommended approach was as follows:
(1) A cyclic hydrostatic design stress (CDS) should be established by testing samples. CDS is defined as the extrapolated hoop stress to which the pipe can be cycled an infinite number of times. (This was stated as 1500 psi (10.3mPa) for CPVC 1120).

(2) A cyclic hydrostatic design basis (CDB) should be calculated by multiplying the CDS by a service factor.

(3) The cyclic hydrostatic design stress (CDS) should be used in the same manner as the hydrostatic design stress (HDS) in determining wall thickness required to provide a desired pressure rating for a particular pipe.

(b) Tests at B. F. Goodrich [3].

Three test arrangements were used. Tests were made on 1-inch schedule 40 PVC, 2-inch SDR 17.6 PVC and 1-inch schedule 40 stainless steel piping. An air-operated ball valve, located at the downstream end of the test piping, was used to stop the flow. A pressure transducer immediately upstream of the ball valve was used to measure the pressure. In two of the test arrangements a closed system containing a pump was used, with the desired test flow velocity determined by an appropriate orifice in the line located downstream of the ball valve. In the third test arrangement, the water was taken from the building water-distribution system and flow rate was controlled by adjustment of a ball valve upstream of the test piping. Records of pressure versus time were made by means of both a recording oscillograph and an oscilloscope with a photographic attachment.

Measured shock pressures were compared with theory; the agreement was best in the closed system. Possibly the greater scatter in the data from the system connected to the building supply was caused by variations in the building supply pressure during the flow period. In all three tests, a theoretical overpressure equation which was similar to equations (1) and (2), was shown to be a satisfactory means of predicting the maximum over-pressure (providing the flow velocity, the pipe diameter and wall thickness, and the pipe material are known). Analysis of sample records in the report indicated a frequency of reflected surge pressure ranging, in most cases, from 2 to 5 Hz and a frequency of the "Noise" superimposed on the primary surge ranging from 30 to 50 Hz.

Statements and recommendations concerning limiting water velocities in thermoplastic piping systems included the following [3]:

1. The maximum safe water velocity in a thermoplastic piping system depends on the specific details of the system and the operating conditions. In general, 5 feet per second is considered to be safe. Higher velocities may be used in cases where the operating characteristics of valves and pumps are known to be such that sudden changes in flow velocity will be controlled to yield overpressures less than the theoretical maximum. The total pressure in the system at any time (static pressure during flow plus the overpressure from surge or water hammer) should not exceed 150 percent of the pressure rating of the system.

2. The pressure rating of PVC pipe should be 1.4 times the maximum operating pressure. This provides a safety factor of 2.8 based on long-term hydrostatic strength, which is adequate to account for water hammer and surges for velocities of 5 ft/s or less.

3. The factors recommended for PVC may not be appropriate for other materials.

4. Long-term hydrostatic strength was not decreased by exposure to 2000 cycles of water hammer or 2000 cycles of surge pressure.

5. Surge pressures in PVC pipe computed from theory were less than 50% of the values computed for cast iron or asbestos cement pipe.

2.2 Apparatus and Procedure - NBS Test

2.2.1 Introduction

This section describes the test procedure used in the NBS experimental study on the resistance of chlorinated polyvinyl chloride (CPVC) thermoplastic piping to pressure shock similar to that produced in a domestic water-distribution system. The review described in Section 2.1 was helpful in establishing the frequency of the cyclic pressure applications, and in establishing the need for reproducible, programmed pressure pattern.

Currently, the design method for thermoplastic piping systems is based on using a hydrostatic design stress obtained by applying a service factor to the long-term hydrostatic strength. The hydrostatic design stress is intended to provide a service life under a continuously applied internal hydrostatic pressure with a high degree of certainty that the pipe will not fail. This method provides only the service factor as the means for assuring that the system will withstand the action of water hammer, which produces high internal pressure for very short time periods. Although no standard method of testing for water hammer strength currently exists, water hammer can occur in many systems during their service life, and this phenomenon should be considered in the design of the system.

In a residential potable water distribution system, the most severe water hammer occurs in the hard-piped hot water supply pipe to the dishwasher when the solenoid valve in the dishwasher suddenly stops the flow of hot water. At the instant when this occurs, the hot water supply line is subjected to a momentary overpressure. This pressure "spike" will then propagate through the line and may recur as repetitive "reflected shocks" with successively decreasing intensity until stabilizing at the prevailing static pressure. The severity and frequency of these shock waves will depend upon the mechanical action of the solenoid in the particular dishwasher (or other automatic appliance), on the length of the affected piping, the pipe material, and on the use of the machine. Other pressure spikes, probably not as severe as those caused by the dishwasher, may occur elsewhere in the distribution system from the clotheswasher and from the rapid closure of faucets. However, the shock pressure produced by the valve action in the clotheswasher is reduced, since the clotheswasher generally is connected to the system by means of a rubber hose which can flex with the shock waves. Because of differences in elasticity in the basic materials, the maximum pressure for a given set of initial conditions (such as flow velocity and rate of valve closure) will be less in thermoplastic pipe than that produced in copper or steel pipe of the same length. The particular design of a solenoid valve can affect the effective rate of closure and hence the maximum pressure produced. The service life of a domestic water distribution system subjected to water hammer is based on the system's ability to withstand a large number of pressure spikes at a representative hot water temperature and on its ability to withstand a normal hydrostatic pressure for a long time period. Assuming a maximum of six primary pressure surges (peak spikes) per dishwasher cycle and a maximum use of the dishwasher of three times a day, the distribution system could see as many as 328,500 primary pressure surges in a 50-year period.

2.2.2 Water Hammer Evaluation Test

(a) Scope

Because no standard test method existed for the evaluation of water hammer resistance in pressure piping systems, a procedure was developed by which water hammer could be simulated in a representative system.

The primary element in this simulation is the loading program. Since the procedure required the generation of several different pre-selected magnitudes of peak pressure, a critical parameter is the duration (or period) of the pressure spike. Based on test data from another study of water hammer performed on polyvinyl chloride (PVC) pipe [3], a close relative of CPVC, the duration for the NBS test was selected as 0.16 seconds. As previously mentioned, under normal service conditions the initial spike is the most severe, as subsequent, reflected spikes are reduced in magnitude (with an increased time duration) due to the inherent damping in the pipe system.

The time between pressure pulses (or frequency) is also important. Under actual service conditions this can vary considerably. Initial testing of a specimen using a rapid cyclic pulse produced failure at a very low number of cycles. The frequency was then decreased to one pulse every half-second. This produced an increase in the number of pulses to failure by several orders of magnitude. A subsequent decrease in frequency to one pulse per second did not produce any noticeable change in the number of pulses required to produce failure. Therefore, in order to achieve a large number of pulses in a reasonable length of time, the frequency of pulse was chosen as 2 per second. The limiting number of primary pulses was taken to be 350,000, since this is a conservative estimate of the maximum number of severe pulses that might occur in a 50-year time span in residential water-distribution piping systems.

(b) Test Specimens

The test specimens were fabricated by joining together two 7-foot 10 1/2-inch sections (2.4m) of nominal 1/2-inch CPVC pipe (tubing) with a 90° elbow to form an L-shaped section. Transition fittings and couplings were then cemented to each open end of the two pipes. The final resulting length of each leg was 8 feet (2.44m) (see figure 1). A solvent cement jointing technique was used as recommended by the manufacturer of the materials. A total of sixty-five specimens were fabricated in two sets, consisting of one group of five and six groups of ten, and were air-cured in the laboratory for a minimum of seven days prior to testing. The specimens were then divided into four test sets and each set was tested at a different temperature over a range of different peak pressures.

(c) Test Procedure

The thermoplastic pipe specimens were tested in a thermal chamber constructed specifically for these tests and shown in figures 1 and 2. The chamber was an L-shaped box with internal dimensions of 15 x 27 x 108 inches (38 x 68.6 x 274 cm) in each leg. The faces of the chamber consisted of 1/2-inch (1.3 cm) plywood covered with 3-inch (7.6 cm)-thick sheets of foam insulation. Access to the interior was provided by attaching the facings on the inside of the L to the box with "suit case" type latches. Six nominal 2 x 4-inch timbers (2 x 4) were nailed to the sides of the chamber in each leg with a spacing of 16 inches (40.6 cm). The specimens were attached to the 2 x 4 every 32 inches (81.3 cm) starting from the elbow, as recommended by the manufacturer. Heating of each leg within the chamber was provided by wrapping an electric heating element around an eight-foot section of nominal 6-inch-diameter cast iron pipe. The cast iron pipe was attached to the 2 x 4 on the side away from the specimens.

Pressure was supplied to the specimens by means of a single-stroke piston pump connected to one end of the specimen. The pump was controlled by a closed-loop electro-hydraulic test machine. A pressure transducer was connected to the other end of the specimen for pressure monitoring. Three thermocouples were used during the test to monitor the temperature of the specimen. One was attached to the elbow fitting and the other two were attached to the pipe in the center of each leg. Thermostats connected to the heating elements maintained the required test temperature. The test temperatures were 75°, 120°, 140°, and 180° F (24°, 49°, 60°, and 82° C, respectively).

The closed-loop electro-hydraulic test machine was programmed to generate a predetermined maximum pressure "spike" having the appropriate magnitude, duration, and frequency. Since the volume of water in the specimen was essentially a constant before failure, a significant change in this volume was used to indicate that

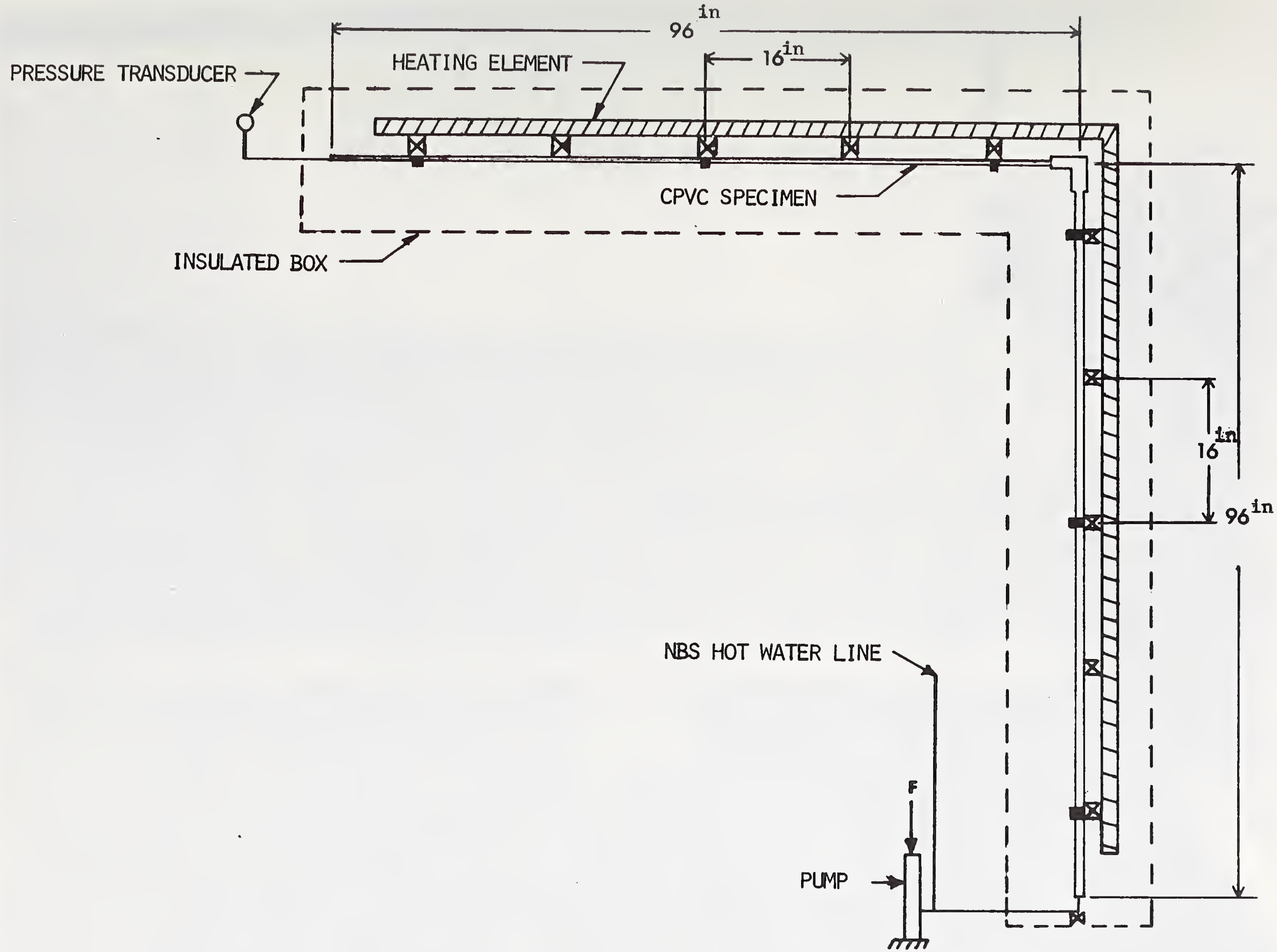

Figure 1. Schematic of Test Setup for Water Hammer.

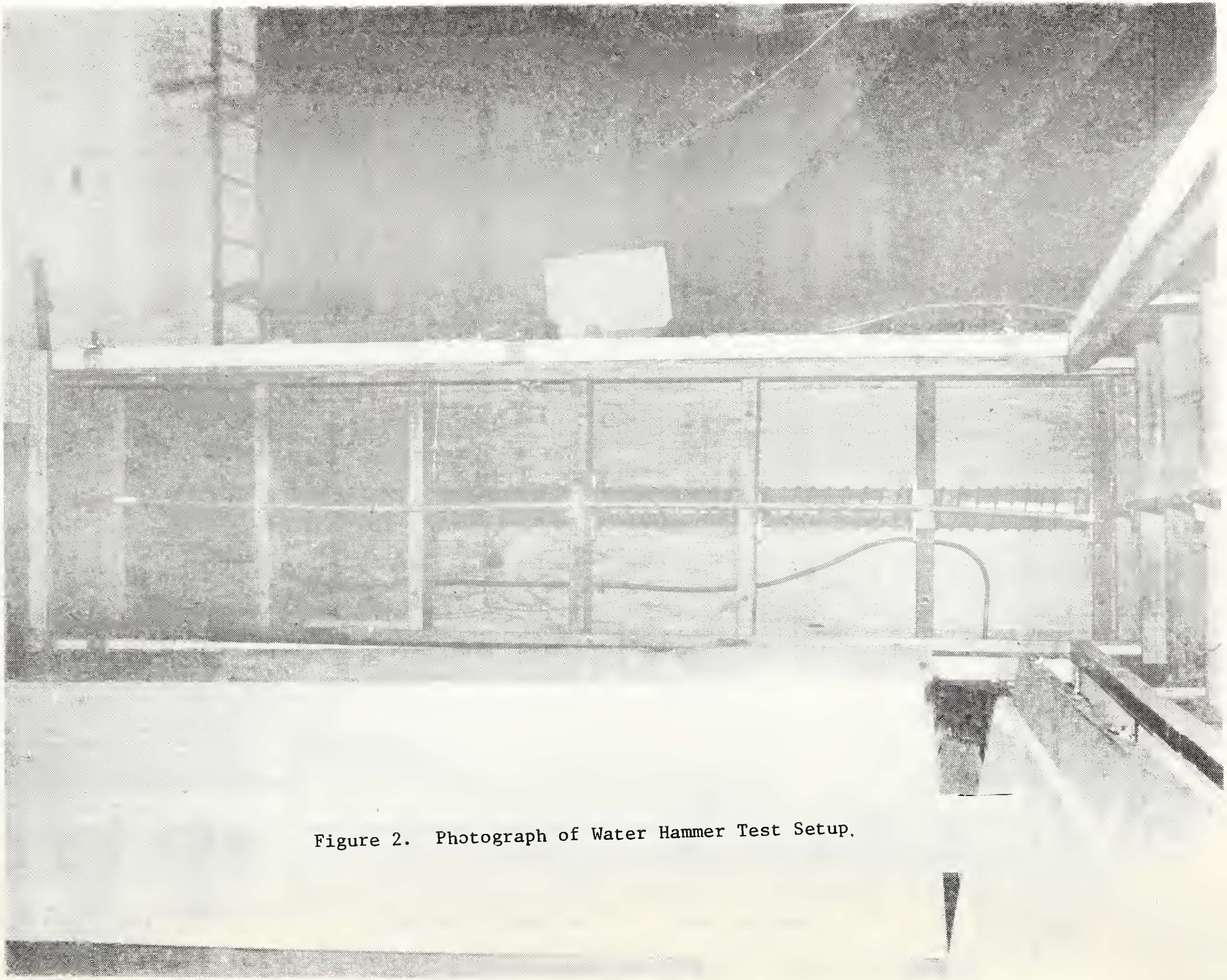

Figure 2. Photograph of Water Hammer Test Setup.

failure had occurred. This change in volume occurred when water was lost due to change in order to maintain the programmed maximum pressure. The position of the piston was monitored to determine when the volume of water had changed, and to indicate when a specimen had failed. This sudden change in position was programmed to stop the test. The specimen was initially filled with water from the NBS hot water supply and the flow was maintained through the test specimen as the thermal chamber was heated until the temperature stabilized, as indicated by the thermocouples. The flow was then terminated and the surface temperature of the pipe was monitored until it stabilized at the required test temperature. The test temperature was maintained with $\pm$ 5° F ($\pm$ 2.8° C) during the test. Next the programmed pressure in the specimen was increased to the maximum test pressure for that specimen. The loading program was then initiated and the number of pulses counted until either failure occurred or 350,000 pulses occurred without failure.

2.3 Results and Discussion

The results of the NBS simulated water hammer test to ascertain the effect of water hammer on chlorinated polyvinyl chloride for the four test temperatures are presented in figures 3, 4, 5, and 6. Because of variability factors in the specimens, a range in the number of pulses to failure was obtained for a given test pressure. This range was fairly narrow at high pressures and broadened as the pressure decreased. This is illustrated in the figures, where the solid circles represent the minimum and maximum number of pulses for failure at a given pressure level. The triangle represents the average. The region of the curve to the right, where a large number of pulses were necessary for failure, is not well defined, as a very large number of tests would have been required. Hence, the curves shown in the figures represent estimates in this region, based on the limited number of test results. Most failures in the destructive tests, with the exception of those at zero pulse (failure with one application of the indicated pressure), were due to fatigue of the elbow. This fatigue produced a small pin hole in the throat of the elbow, as shown in figure 7.

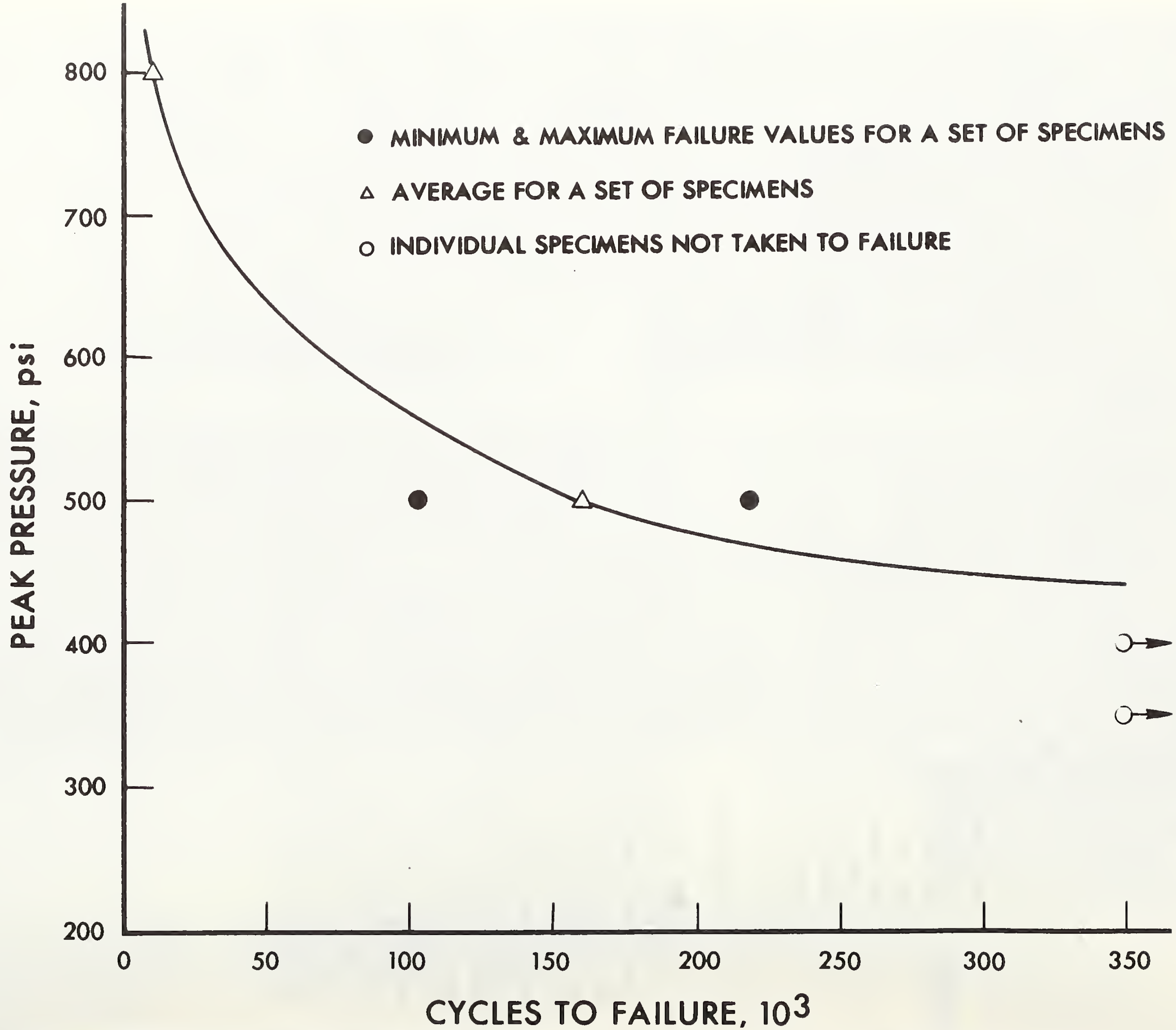

Figure 3. Peak Pressure Vs. No. of Cycles to Failure at Test Temperature of 75° F (24° C).

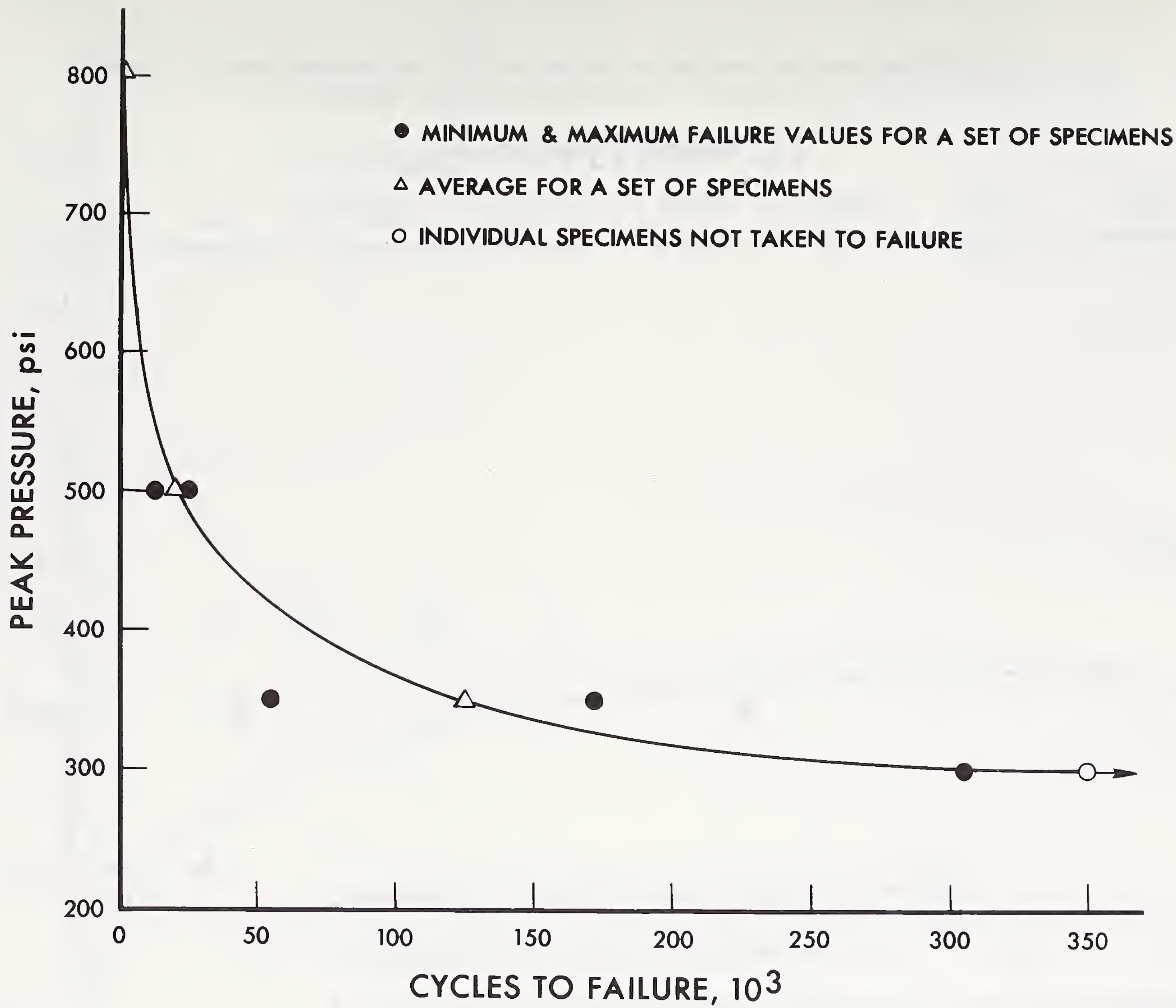

Figure 4. Peak Pressure Vs. No. of Cycles to Failure at Test Temperature of 120° F (49° C).

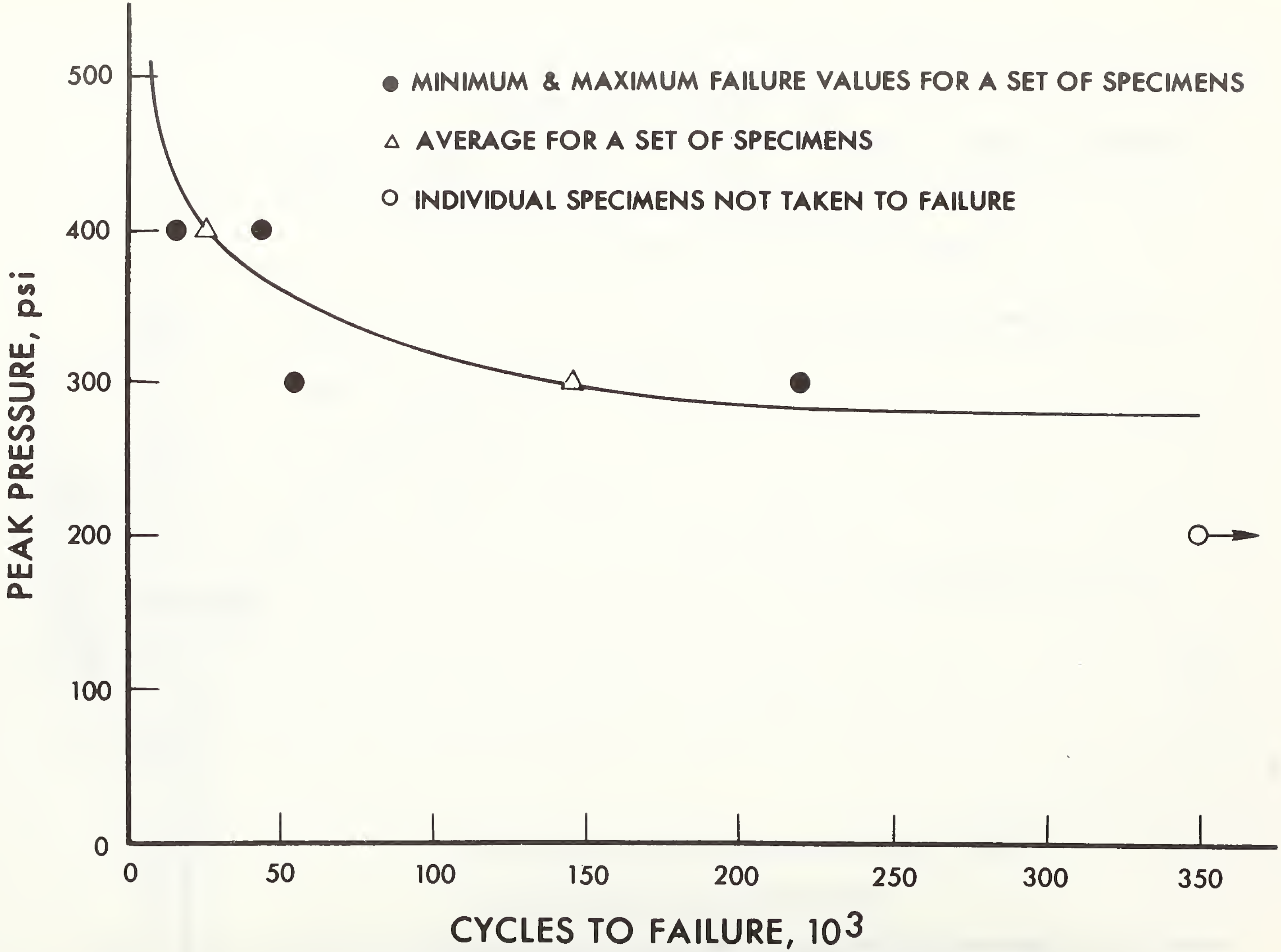

Figure 5. Peak Pressure Vs. No. of Cycles to Failure at Test Temperature of 140° F (60° C).

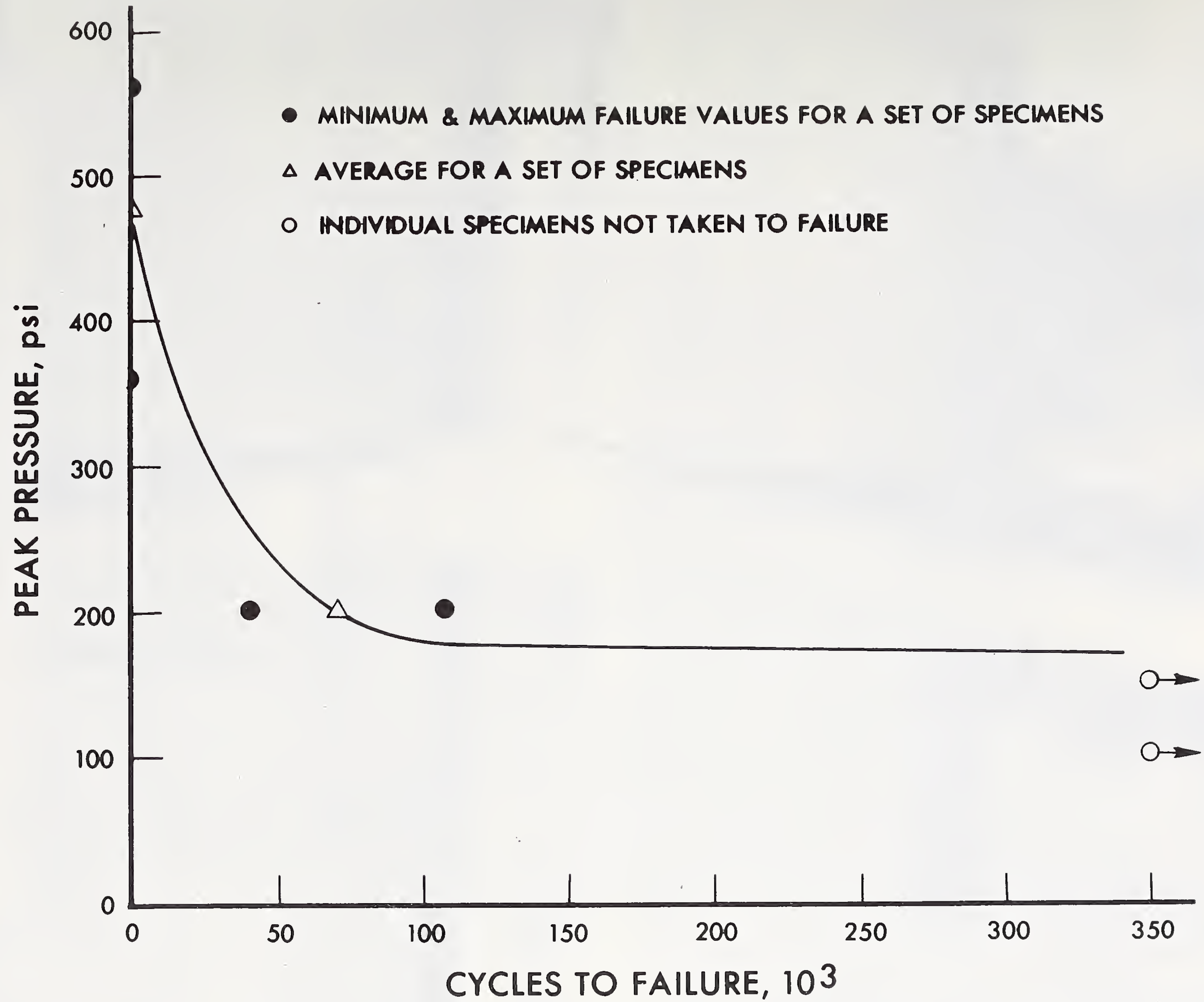

Figure 6. Peak Pressure Vs. No. of Cycles to Failure at Test Temperature of 180° F (82° C).

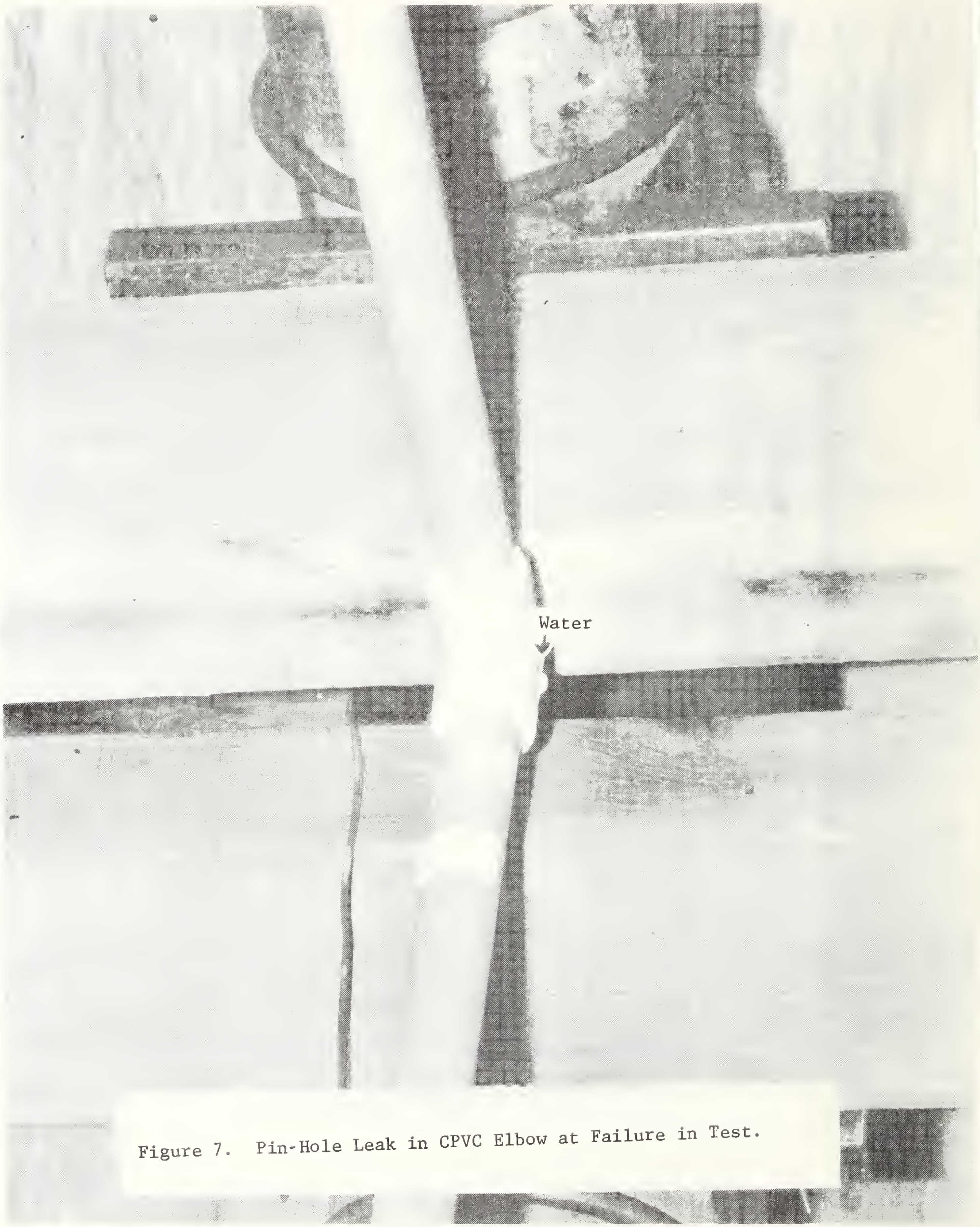

Figure 7. Pin-Hole Leak in CPVC Elbow at Failure in Test.

3. INTERMITTENT HOT WATER EXPOSURE TESTS

3.1 Summary of Work by Other Investigators

A report [7] on tests of deflection of horizontal thermoplastic pipe from alternate hot-and-cold water loading was reviewed. Also, an elevated temperature cycling test for a vertical assembly of DWV pipe and fittings (British Standard BSS 4514 [8]) was reviewed. These reports provided ideas useful in deciding upon the experimental design for the NBS test and provided meaningful supplemental information.

3.1.1 The Deflection of Thermoplastic Pipe Resulting from Thermal Cycling [7].

The significant features of the testing procedure used and the important findings [7] are as follows:

> An apparatus was used that provided for alternating exposure of nominally horizontal 20-foot lengths of pipe to hot and cold water. Supports were placed at 3- and 4-foot intervals. A slope of 1/4 in/ft was provided in the test pipes. The following thermal loading cycle was provided:
>
> 2 min with 180° F water at 7 1/2 gpm
> 2 min with no flow
> 6 min with 60° - 75° F water at 15 gpm
> 2 min with no flow (Deflection measurements were made during this time. Preliminary tests with measurements made at one-minute intervals during the first 10 minutes of the cycle showed that the most meaningful deflection was that remaining after completion of each cycle).

Tests results were shown from 1 1/2-inch sch 40 GEON 85092 PVC; 1 1/2-inch sch 40 ABS; 1 1/2-inch SDR 17, 21 and 26 GEON PVC; and 1 1/2-inch sch 40 PVC of compounds with hydrostatic design temperature values of 158°, 160° and 169° F.

The method compared deflection as affected by the heat deflection temperature of the material (ASTM D 648), by the material's flexural modulus (ASTM D 790), by the pipe-wall thickness, and by the support spacing. It was suggested that by projection of the test results, the probable deflection at 73,000 cycles (which was considered equivalent to 50 years of service at 4 cycles per day) could be predicted.

For the purposes of the study [7], a deflection between supports (at mid-span) after 73,000 cycles not exceeding d/4 inches was considered permissible, where the elevation difference between adjacent supports is "d" inches. This limit provided assurance against the development of "zero" or "negative" slope.

Transient temperature profiles were computed across the wall of 1 1/2-inch sch 40 PVC pipe for various times of exposure of the inside surface temperatures and were compared with experimental measurements, with good agreement [7]. The outside surface temperatures at 2-min and 5-min exposure were shown as approximately 142° and 148° F, respectively. The results showed that the principal factors affecting the deflection of PVC pipe were heat deflection temperature (as defined by ASTM D 648), support-spacing, and wall thickness; deflection was less with the greater wall thicknesses and higher heat deflection temperatures, and more with the greater support spacings. It was concluded that PVC DWV pipe made from material with a high heat deflection temperature will withstand long-term exposure to thermal cycling without excessive deflection. ABS pipe showed slightly less deflection than PVC.

3.1.2 Elevated Temperature Cycling Test for Vertical Assembly of DWV Pipe and Fittings

British Standard BS4514: 1969 [8] contains a requirement and a test for "elevated temperature cycling" of hot and cold water through a vertical assembly of PVC DWV pipe and fittings.

BS4514 requires that there be no leaks during the test, that after 2500 cycles the assembly shall withstand being filled with water to 150 mm (5.9 in) above the waste inlet without leaking, and that the assembly accept the passage of a ball with a diameter 6 mm (1/4 in) less than the nominal diameter of the system being tested.

The test installation consists of a horizontal waste pipe branch and a soil pipe, fittings, and an expansion joint. Alternately hot and cold water is passed into the assembly through a 0.6 m (23.6 in) minimum length of straight waste pipe branch according to the following schedule for 2500 cycles:

(1) 35 ± 3 litres (7 1/2 gallons) water at a temperature of 91 ± 9° C (160 ± 2° F) over a period of 90 s to 95 s. The water temperature shall be measured at the point of entry into the stack.
(2) Rest and drain period of 60 s to 70 s.
(3) 35 ± 3 litres (7 1/2 gallons) of cold water (no temperature specified) over a period of 90 s to 95 s.
(4) Rest and drain period of not less than 60 s.
During the test the ambient temperatures shall be 17 ± 5° C (63 ± 9° F).

It was stated in BS4514 that the test* is to be carried out for each formulation used and when any change is made in compositon or method of manufacture of pipe or fittings.

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* A test to be made for each specified "type" or category of product, but not required subsequently in routine production of the same product. If significant variations are introduced, another type test is required.

3.2 Apparatus, Measurements and Procedure - NBS Test

The design of the apparatus and of the procedure for the NBS intermittent hot water exposure tests benefitted from the review of codes, trade information and References 7 and 8.

3.2.1 Test Specimens

The piping materials subject to the intermittent thermal loading test were of PVC and CPVC thermoplastics. The fixture traps, trap arms and drainage stacks were of PVC. Trap arms were nominal 1 1/2-inch Schedule 40, and drainage stacks were nominal 4-inch Schedule 30. The water piping was of nominal 1/2-inch CPVC (tubing size).

Two methods of attachment of the PVC drainage stacks were utilized:

1. Longitudinal motion restrained at both ends.
2. Longitudinal motion not restrained (through the use of an expansion joint).

The length of the 1 1/2-inch trap arms in the drainage system test was on the order of 3 feet, 6 inch (1.07 m), the maximum allowed by many codes for hydraulic and pneumatic reasons. The drainage piping components of the test assembly were designed in a fashion similar to that described in BS 4514-1969 [8].

Four different methods of attachment of the simple water pressure piping specimen to the simulated building construction (floor joists at right angles to the pipe) were utilized:

1. One end restrained and the other end not restrained, and supported with non-restraining clamps at 32-inch (81cm) centers.
2. Both ends restrained and supported with restraining clamps at 32-inch (81cm) centers.
3. Both ends restrained and supported with non-restraining clamps at 32-inch centers.
4. Both ends restrained and supported with non-restraining clamps at 32-inch (81cm) centers. Additionally, a nominal 1-foot (30.5cm) 90° offset was provided at the mid-point.

According to industry recommendations, methods 2 and 3 are improper and methods 1 and 4 are acceptable methods of installation.

All piping test systems were installed by qualified practicing plumbers, following the industry-recommended procedures for making joints.

3.2.2 Test Apparatus

The general configuration of the intermittent hot-water exposure test system is depicted schematically in Figure 8. During flow, water was pumped from a holding tank of approximately 30-gallon (114 liters) capacity to a nominal 52-gallon (197-liter) capacity household-type electric water heater forcing hot water through a CPVC thermoplastic pressure piping test loop which discharged into one of two PVC thermoplastic trap arms. Then, the water was returned to the holding tank through the PVC test drainage stack which received the trap arm discharge. The nominal flow rate of 8 gpm (0.51 L/s) for 5 minutes produced a volume of discharge less than the rated capacity of the water heater during any one flow cycle. Each flow cycle was controlled through a set of electrical solenoid valves so that the water flow direction could be reversed in the CPVC test loop with discharge into a different PVC trap arm and drainage stack. The relatively short distances between the water heater and the solenoid valves made it necessary to install a small thermal expansion tank of 2 1/4-gallon (8 1/2-L) capacity in order to limit excessive pressure buildup during the "no flow" condition wnen thermal expansion of the water occurred during heating. Flow rate was controlled by a throttle valve and a 1-inch circuit setter (a calibrated flow rate measurement device with provisions for flow restriction) installed between the pump and water heater, and was measured through the use of a 1 1/2-inch venturi. Although the thermal expansion tank served the secondary function of limiting water hammer, additonal water hammer control was achieved through the use of a vertically piped air chamber (see figure 8). Pressure regulation was maintained with a pressure reducing valve.

A detailed layout of the CPVC test loop is presented in figure 9 with the individual CPVC tests outlined in further detail in figures 10a, 10b, 10c, and 10d. The capped stubs shown in (a) and (b) of figure 9 served the purpose of simulating the fittings and branch piping which would normally be installed in water-distributing systems. These stubs were omitted from figure 10a for clarity.

3.2.3 Measurements

All measurements of water pressure, water temperature, and pipe displacement were made using manual reading methods with standard pressure and temperature gages, mercury-in-glass thermometers, rulers, calipers, and scales. Surface temperatures were recorded by direct reading of standard bi-metallic maximum/minimum surface thermometers. The load cell measurement data were automatically recorded on magnetic tape for subsequent data reduction, calculation, and plotting by the use of computerized techniques.

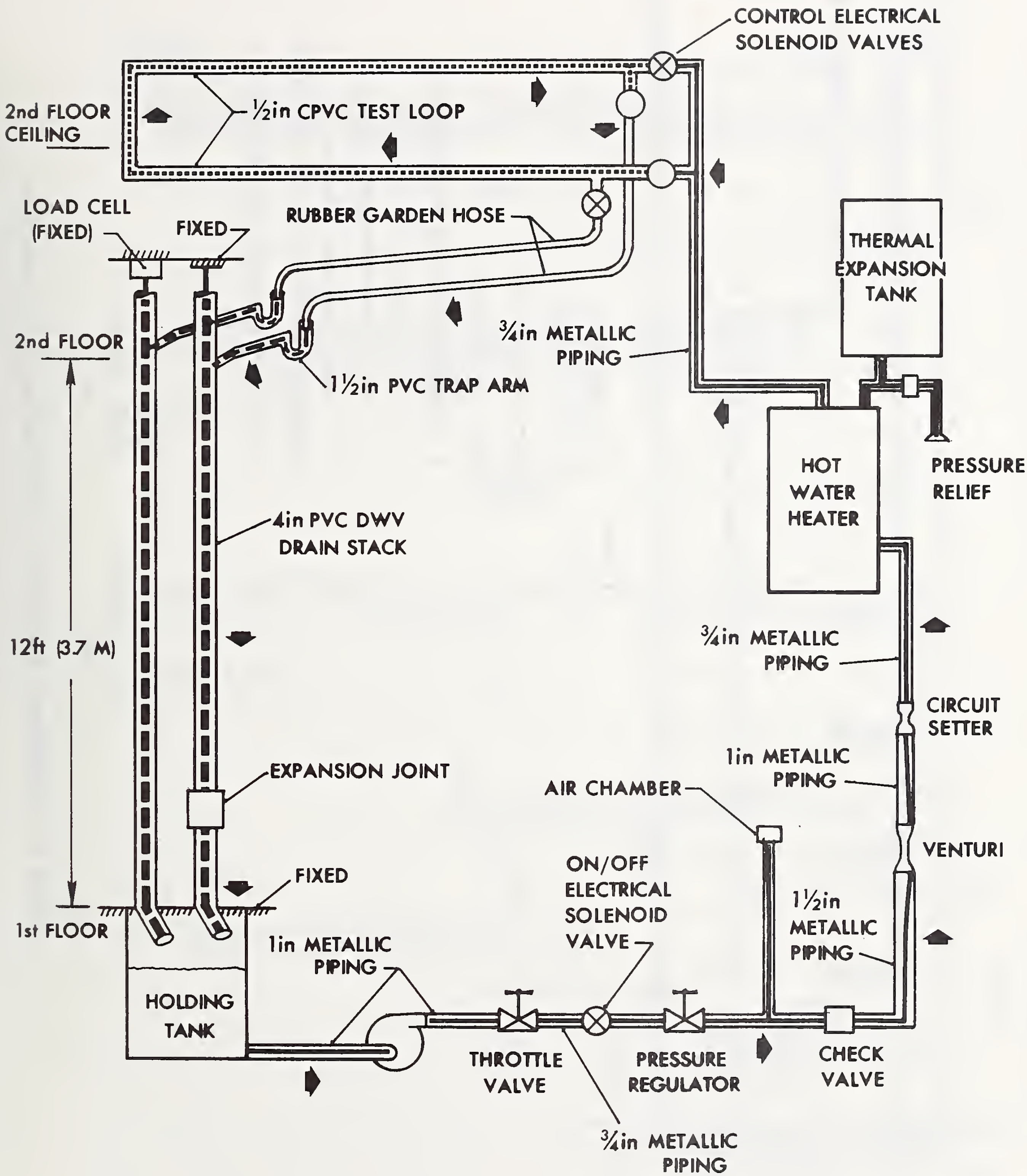

Figure 8. Intermittent Hot Water Exposure Test Schematic.

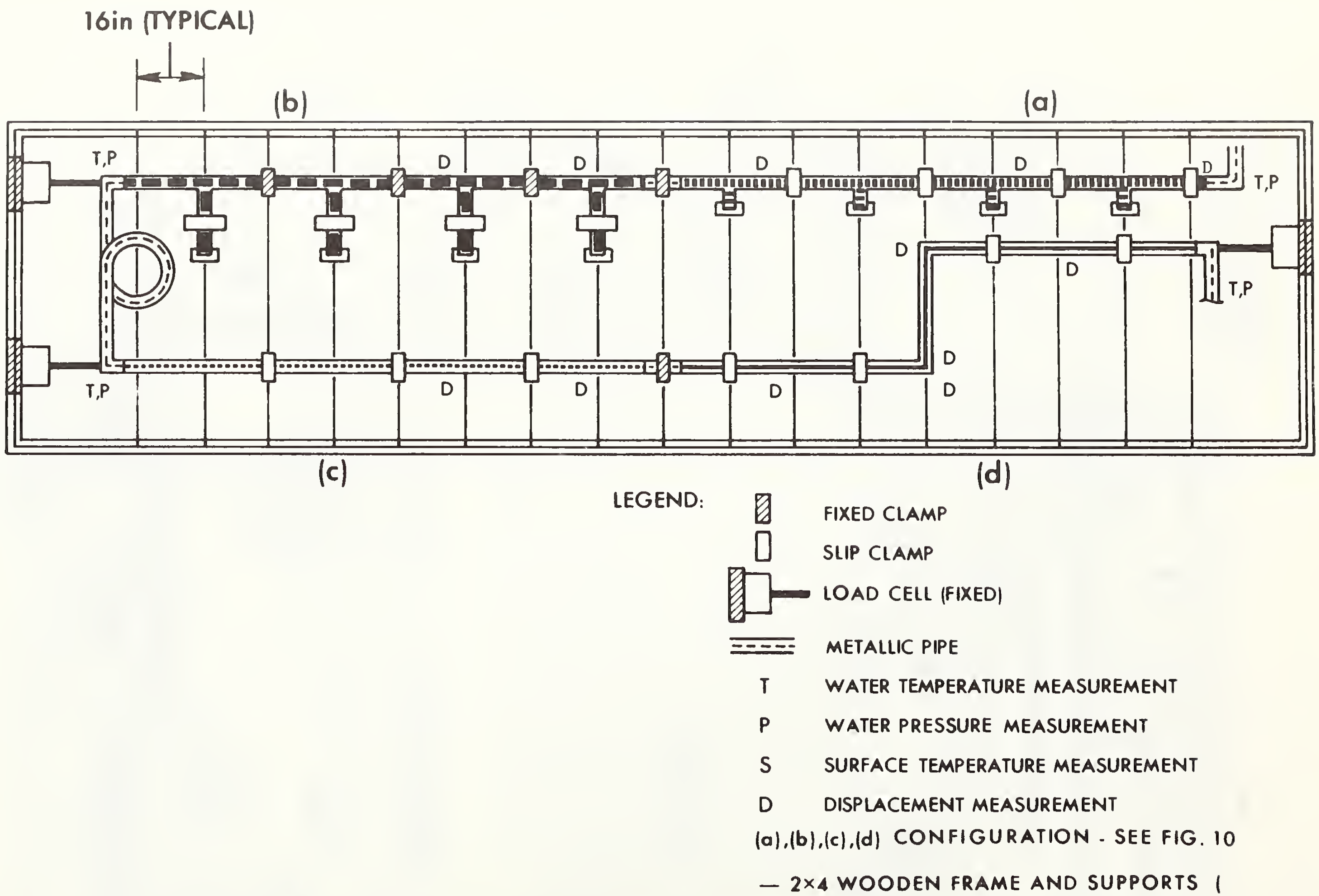

Figure 9. Measurement Locations in CPVC Thermoplastic Test Loop.

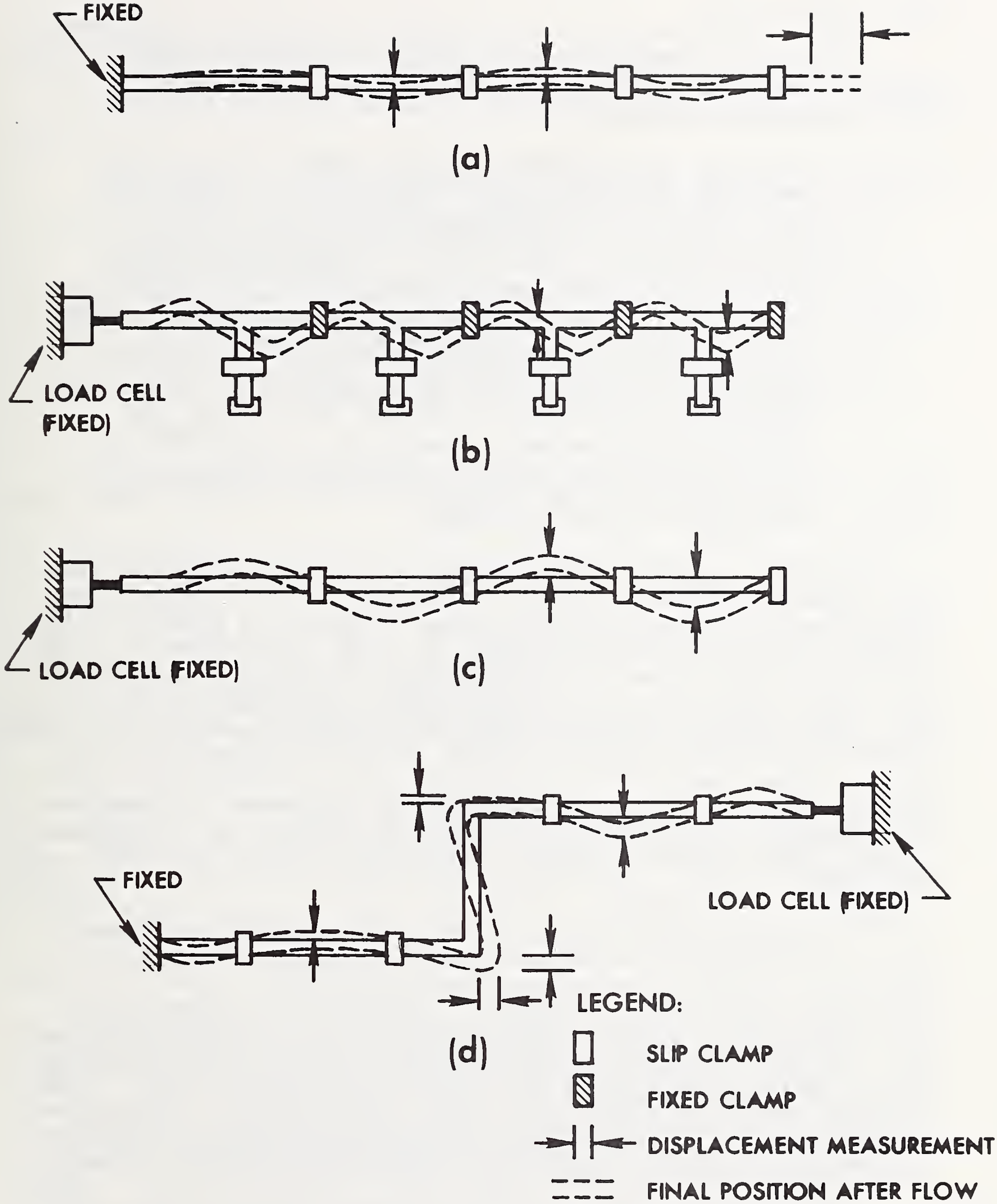

Figure 10. CPVC Thermoplastic Test Configurations.

3.2.4 Test Procedure

The apparatus provided for intermittent repetitive thermal loading of the water tubing and the drainage piping. The loading cycle is described as follows:

a. Hot water flow at 8 gpm (0.5 L/s) average for 5 minutes clockwise through the water loop at 120° to 144° F (49° to 62° C) with discharge into the first drain stack.
b. 25 minute dwell or cooling pause with no water flow.
c. Hot water flow at 8 gpm (0.5 L/s) average for 5 minutes counterclockwise through the water loop at 120° to 144° F (29° to 62° C) with discharge into the second drain stack.
d. 25 minute dwell or cooling pause with no water flow.
e. Repeat of a, b, c, and d above for a total of over 1500 exposures to hot water flow in the water loop, and over 750 exposures to hot water flow in each drain stack. The reason for twice as many exposures of the water loop as of the drain stacks was that alternately each drain stack was idle as the other was exposed to the hot water discharged from the water loop.

The above loading cycle was chosen as a compromise between the normal homeowner appliance hot water usage cycle and the necessity to subject the test system to as many cycles as reasonable in a short time period. It was felt that the 5-minute hot water flow followed by a 25-minute pause was reasonably representative of the conditions in the hot water supply line serving a clothes washer or a dishwasher. The 25-minute pause allowed for some cooling, but not down to ambient temperature. The flow direction in the water loop was reversed with each cycle in order to subject each of the four pressure-pipe test components to the same temperature and pressure conditions, on the average. In addition, this arrangement provided for the test of two drainage systems during the same period--one with expansion device and the other with rigid attachment.

It should be noted that the water in the pressure pipe assembly did not cool completely to the normal ambient temperature of 78° F (26° C) but did cool to an average temperature of 125° F (52° C). Also, although the water heater thermostat was adjusted to a temperature of 180° F (82° C) due to the control limitations of the thermostat and the time required to reheat the water returned to the heater after passing through the test system, the actual water temperature delivered to the test pipes was in the range of 144° F (62° C). This water temperature is near to the 140° F (60° C) which is normally experienced in the home and specified as the upper limit in the HUD Minimum Property Standards.

The significance of the relatively small amount of cooling down is that this test did not simulate conditions of thermal cycling, but rather intermittent hot water exposure with limited cool-down (at least in the water loop). Had the constraints permitted, the test could have been extended to include alternating hot and cold-water exposure of the drainage stack, and greater cool-down of the hot-water loop between hot-water flows.

Locations of key measurement stations are shown in figures 8, 9, and 10.

Measurements or observations were made of the following parameters:

- Water and pipe-surface temperatures at a number of points.
- Internal pressures at the entrance and exit of the water pipe testing loop.
- Longitudinal forces generated by the pipes at their restraint points. (Reported as the compressive stresses in the pipes).
- Longitudinal movements at unrestrained ends.
- Lateral movements at midpoint between points of attachment of pipes restrained at ends or intermediate points.
- Leakage.

The measurements were classified as either static or dynamic. The general operating procedure for making the tests is described as follows:

1. Within one minute of the beginning of hot water flow, all selected static readings were manually recorded on data log sheets.
2. Within one minute of the end of hot water flow, the readings taken in (1.) above were repeated, but these readings were classified as the dynamic set.
3. All measurement readings were typed in to a computer for placement on magnetic tape and for subsequent data reduction and display.

Because of the length of time required to make a complete set of measurements in the manner described, only partial sets of data could be taken at any one selected "cycle time"; however, 35 sets of partial data were recorded over the duration of the test. Additionally, a full set of "before test" data and a full set of "end-of-test" data were recorded.

3.3 Results and Discussion

The relatively small number of exposure cycles (1500 for the water piping and 750 for the DWV) made before the test was stopped probably does not represent a sufficiently long period of service exposure. Also, the inadequate capacity of the water heater resulted in poor control of the temperature of the water in contact with the test piping and in the necessity to average successive measurements obtained at significantly different exposure temperatures for the purposes of the analysis. For these reasons, there is not a satisfactory degree of confidence in conclusions that might be drawn from the data.

3.3.1 Water Piping

Table 1 summarizes the average of the longitudinal and lateral motions, pressure drops and temperatures measured in the water piping during several "typical" cycles. These typical cycles were chosen based on the availability of required data from the partial data sets.

For the pressure pipe assembly that was fixed at one end only (figure 10a) the typical dynamic elongation was +.24* in (6mm) or + 0.18%. If a numerical approximation is applied to the assembly which was fixed at both ends and slip-clamped (figure 10c), a typical dynamic elongation of + .1 in (2.5mm) or + 0.08% is indicated. Indicated permanent elongation for the two assemblies (figures 10a and 10c) varied between -.2% to +.11% respectively and +.6% to +.05% respectively, with the final values at the end of the test of -.01% and +.05% respectively.

Figure 11 illustrates the compressive stress** buildup and decay within the three noted assemblies of 1/2-inch nominal CPVC pressure piping which were subjected to an 8 gpm (0.5 L/s) flow of 150° F (60° C) water for 5 minutes. The conditions of each test assembly at the time of maximum stress are summarized in table 2. The data used in the development of figure 11 and table 2 were obtained by averaging the information attained from four individual tests using automatic recording techniques for the stress information and manual recording for other data.

3.3.2 Drain-Waste-Vent Piping

Table 3 summarizes the average of the longitudinal and lateral motions (see figure 8), water temperatures, and flow rate, and pipe surface temperatures measured during several hot water flow cycles of 5-minute duration through 1 1/2-in nominal Schedule 40 PVC trap arms and 4-in nominal Schedule 30 PVC DWV stacks. The particular cycles chosen for use in the development of table 3 were based on the availability of the required data from the partial data sets.

Because of uncertainty in the accuracy of the surface temperature measurements, caution should be exercised in making precise comparisons of absolute values, particularly of values taken at different points. The data indicated lower maximum surface temperatures at the branch than at the mid-point of the stack. This seeming inconsistency may be attributable in part to (a) difference in diameter and wall thickness of branch and stack, and (b) possible difference in proximity of flowing water to temperature sensor for the branch (horizontal) and the stack (vertical).

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* A (-) sign indicates a shortening and a (+) sign indicates a lengthening of the test pipe.

** The stress was calculated as an average obtained by dividing the measured longitudinal force by the cross-sectional area of the stack pipe wall.

TABLE 1. TYPICAL 1/2-INCH CPVC WATER PIPE TEST DATA TAKEN DURING 5-MINUTE FLOW OF HOT WATER AT A RATE OF 8.1 gpm (0.51 L/s)

PARAMETER	TEST CONFIGURATION			
	FIXED ONE END (FIGURE 10a)	FIXED CLAMPED (FIGURE 10b)	SLIP CLAMPED (FIGURE 10c)	OFFSET (FIGURE 10d)
TEMPERATURE OF PIPE INTERIOR BEFORE FLOW	105°F (40.5°C)	105°F (40.5°C)	105°F (40.5°C)	105°F (40.5°C)
WATER TEMPERATURE DURING CW* FLOW	139°F (59.4°C)	140°F (60°C)	145°F (62.8°C)	148°F (64.4°C)
MINIMUM PIPE SURFACE TEMPERATURE	73°F (22.8°C)	73°F (22.8°C)	73°F (22.8°C)	73°F (22.8°C)
MAXIMUM PIPE SURFACE TEMPERATURE	118°F (47.8°C)	116°F (46.7°C)	111°F (43.9°C)	108°F (77.8°C)
WATER PRESSURE+ DURING CCW* FLOW	59PSI (.41MPa)	49PSI (.33MPa)	35PSI (.24MPa)	21PSI (.14MPa)
WATER PRESSURE+ DURING CW* FLOW	22PSI (.15MPa)	35PSI (.24MPa)	49PSI (.34MPa)	61PSI (.42MPa)
PRESSURE DROP THROUGH TEST SECTION (AVERAGE)	11.8PSI(.08MPa)	11.8PSI (.08MPa)	12.2PSI (.08MPa)	13.3PSI (.09MPa)
LONGITUDINAL POSITION CHANGE	.24 in. (6.0mm)	-0-	-0-	.26 in. (6.5mm)***
LATERAL POSITION CHANGE	.02 in. (.5mm)	**	.37 in. (9.5mm)	.04 in. (1.05mm)

+ Mean pressures measured within the indicated configuration, obtained by averaging the inlet and outlet pressures for each configuration during flow.

* "CW" indicates clockwise flow in the test loop, and "CCW" counterclockwise flow.

** Measurements taken were not usable due to being measured incorrectly at the Nodal Points.

*** Longitudinal position change for the offset configuration is expressed as the vector sum of the measured changes in the "Z" shaped portion of the offset.

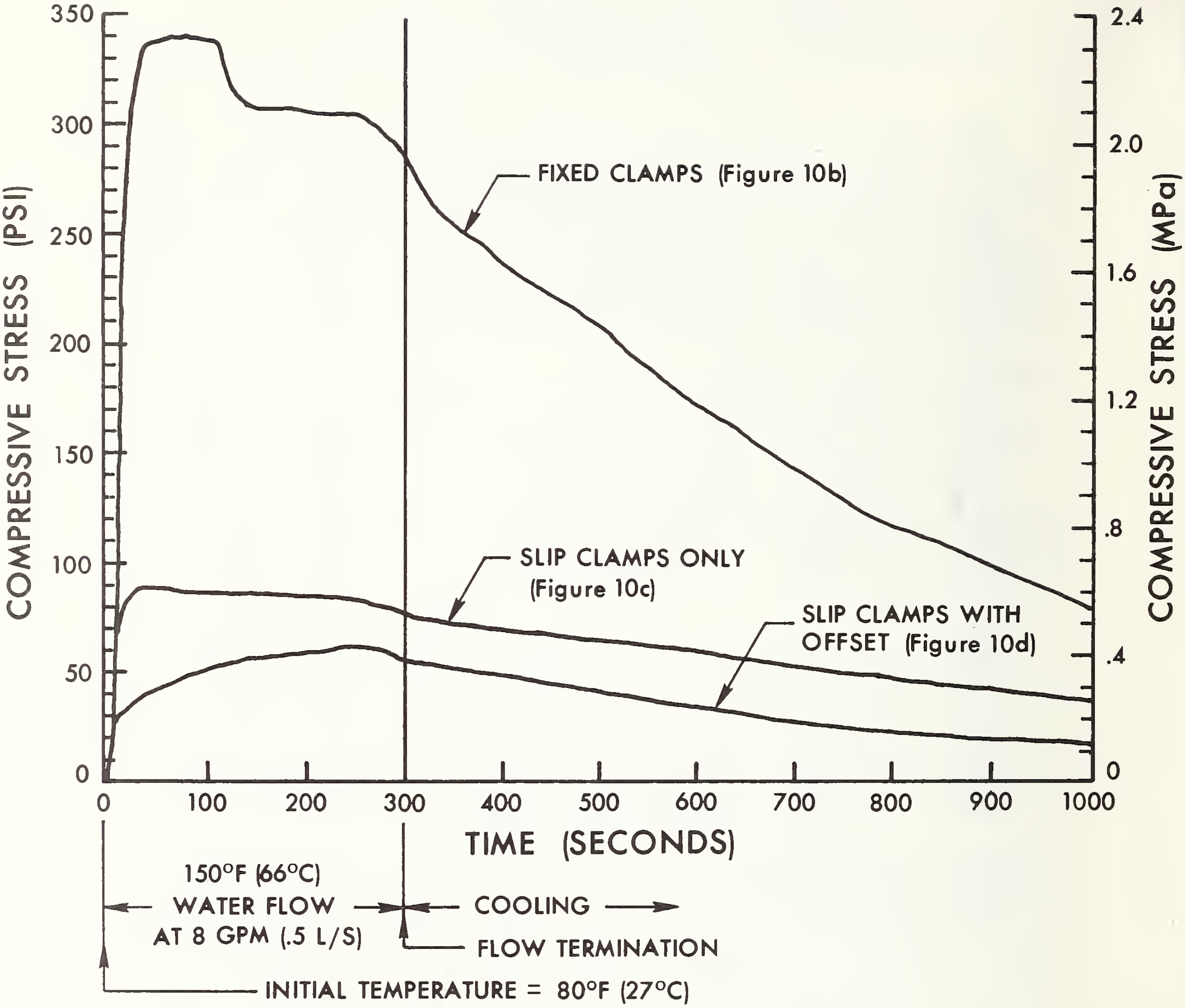

Figure 11. Hot Water Flow Stress Characteristics for Different Mounting Configurations of 1/2 Inch CPVC Pressure Pipe.

TABLE 2. SUMMARY OF TYPICAL COMPRESSIVE STRESSES AND DEFLECTIONS FOR 1/2-INCH CPVC ASSEMBLIES DURING 5-MINUTE FLOW OF HOT WATER (66° C) AT A RATE OF 8.1 gpm (0.51 L/s)

ASSEMBLY	TIME OF MAXIMUM STRESS (seconds)	MAXIMUM STRESS	MAXIMUM LONGITUDINAL LOAD	DEFLECTION
FIXED CLAMP (FIGURE 10b)	80 sec	340.7 PSI (2.35 MPa)	45.7 lb (20.7 kg.)	0.63 in (16mm)
SLIP CLAMP ONLY (FIGURE 10c)	40 sec	88.6 PSI (0.61 MPa)	11.9 lb (5.4 Kg.)	0.56 in (14.2mm)
SLIP CLAMP WITH OFFSET (FIGURE 10d)	270 sec	61.1 PSI (0.42 MPa)	8.2 lb (3.7 Kg.)	0.10 in (2.5mm) LONGITUDINAL 0.11 in (2.8mm) LATERAL

TABLE 3. TYPICAL 4-INCH PVC DWV PIPE TEST DATA TAKEN DURING 5-MINUTE FLOW OF HOT WATER AT A RATE OF 8.1 gpm (0.51 L/s)

PARAMETER	ASSEMBLY WITH SLIP EXPANSION JOINT IN STACK			ASSEMBLY FIXED AT BOTH ENDS OF STACK		
	AT BRANCH	AT MID-POINT of STACK	AT LOWER END OF STACK	AT BRANCH	AT MID-POINT OF STACK	AT LOWER END OF STACK
INTERIOR TEMPERATURE BEFORE FLOW	---	---	73°F (22.8°C)	---	---	73°F (22.8°C)
MAXIMUM WATER TEMPERATURE DURING FLOW	---	---	148°F (64.4°C)	---	---	142°F (61.1°C)
MINIMUM SURFACE TEMPERATURE	72°F (22.2°C)	71°F (21.7°C)	68°F (20°C)	72°F (22.2°C)	70°F (21.1°C)	68°F (20°C)
MAXIMUM SURFACE TEMPERATURE	116°F (46.7°C)	130°F (54.4°C)	105°F (40.6°C)	117°F (47.2°C)	125°F (51.7°C)	101°F (38.3°C)
LONGITUDINAL POSITION CHANGE 1/	---	---	.06 in (1.5mm)	---	---	- 0 -
LATERAL POSITION CHANGE 1/	0.16 in (4.0mm)	0.08 in (2.0mm)	---	0.12 in (3.0mm)	0.16 in (4.0mm)	-----

1/ Maximum change measured during test run.

The longitudinal expansion measured in the stack with the expansion joint was only 0.06 in (1.5 mm). This indicates that the average temperature within the wall of the stack pipe did not rise to a value anywhere near the temperature of the hot water. This is also indicated by the fact that the measured maximum surface temperatures were significantly below the temperature of the hot water.

The lateral change in position measured at the mid-point of the stack was less for the stack with the expansion joint than for the stack fixed at both ends, as expected (0.08 in/2.0 mm and 0.16 in/4.0 mm, respectively). The small deflection of the stack with the expansion joint, in combination with a non-uniform temperature gradient through the pipe wall results in deflections of those small magnitudes. The small disturbances would not significantly affect the functional performance of drainage stacks.

The lateral deflections measured in the branches (0.16 in/4.0 mm and 0.12 in/3.0 mm) were not sufficiently large to affect essential functional capability of the branches.

Figure 12 illustrates the stress buildup and decay within a 12-foot (3.66mm) length of nominal 4-inch Schedule 30 PVC drainage pipe fixed at both ends and subjected to an 8 gpm (.5 L/s) flow of 145° F (63° C) water for 5 minutes. The initial pipe surface temperature was 75° F (24° C), and the maximum surface temperature reached was in the range of 125° to 130° F (52° to 55° C). The maximum stress occurred about 250 seconds after the beginning of hot water flow and was equal to 71.7 psi (0.49MPa). This corresponds to a maximum longitudinal load of 145.2 pounds (65.9kg) which was transmitted to the restraint devices, one of which was the load cell attached to the test frame. The maximum lateral pipe deflection in this run was 0.14 in (3.6mm) at the mid-point; however, the pipe returned to its original position after cooling.

The data on permanent change in length of the stack with the expansion joint are not considered reliable. Values corresponding to a shortening of 0.05 to 0.20% were obtained, but consistency between successive measurements was lacking. The reason for this is not clear. In any event, the measured values do not indicate a change of more than 1/4 in (6.1 mm) per 10-ft story. Permanent changes in length of this magnitude could be accommodated by generally accepted good practice in design and installation.

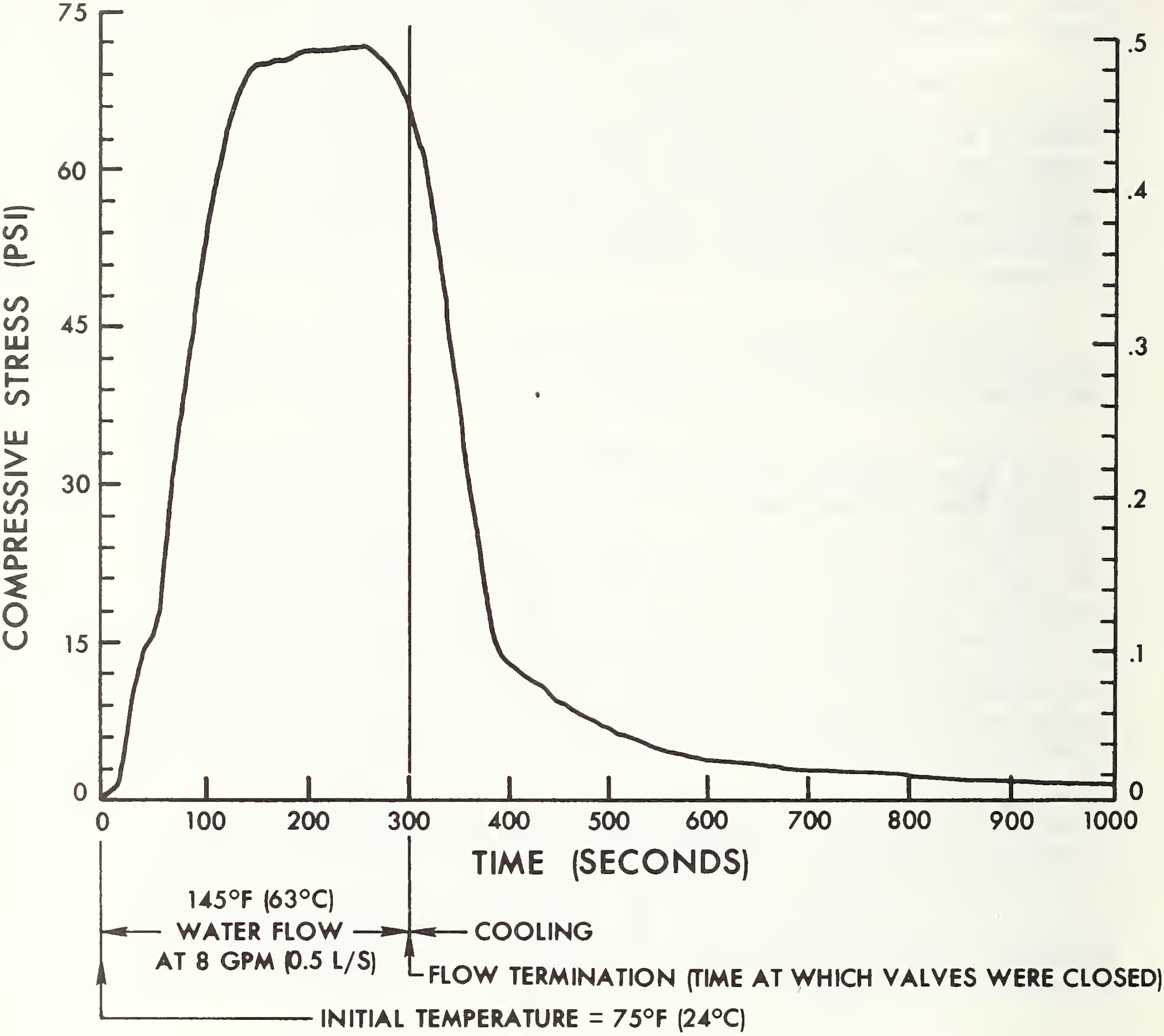

Figure 12. Hot Water Flow Stress Characteristics of 4-Inch PVC (Thin-Wall) Drainage Pipe Fixed at Both Ends.

4. CONCLUSIONS

4.1 Intermittent Exposure to Hot Water

The intermittent hot water flow tests were terminated after approximately 1500 cycles (pressure pipe) and 750 cycles (drainage pipe). Because of the relatively small number of cycles, it is not clear whether long-term dimensional stability had been fully attained, nor could realistic extrapolations be made. The conclusions presented here are, therefore, based on the state of the test assemblies when the test was terminated and do not necessarily reflect conditions which might have occurred with a completely representative life-cycle test.

Based on the data obtained, thermal expansion and associated lateral deflections, as well as permanent dimensional changes, were not considered excessive. Changes of these magnitudes can be accommodated by generally accepted good practice in design and installation, and do not imply any significant effects on essential hydraulic performance.

4.1.1 CPVC Pressure Piping

The following statements and conclusions can be made from the analysis in terms of leak resistance, thermal deflections and permanent dimensional changes:

1. The performance of the CPVC hot water supply piping was satisfactory from the standpoint of thermal deflection and permanent change in length. The typical lateral deflection observed for the improper installation, fixed at both ends, was 0.37 in (9.5 mm) in a span of 36 in. This might be considered excessive. However, with recommended installation methods, the comparable lateral deflection did not exceed 0.04 in (1.0 mm), an insignificant amount. Longitudinal movement at the unrestrained ends of the recommended installations was typically about 1/4 in. The amount of movement can readily be accommodated in generally accepted good installation practice.

   However, because the average temperatures in the pipe wall were considerably lower than the water temperature, thermal expansion was correspondingly lower than if the pipe wall had been heated to the temperature of the water.

2. No leaks occurred in any of the CPVC test assemblies.

3. Lateral motion of all CPVC supply piping was essentially limited to a plane which was parallel to the structure against which it was mounted. No apparent negative slope was observed in any of the CPVC test assemblies. This would be anticipated for the methods commonly used for attaching pipe to horizontal surfaces such as the lower faces of floor joists. However,

lateral deflections of the piping could produce appreciable slope changes where attached in contact with vertical or leaning surfaces.

4. The maximum compressive stresses recorded in the CPVC test assemblies are considered to be within acceptable limits (much lower than the 2,000-psi design hydrostatic (tensile). stress levels used by the industry for PVC and CPVC pipe of the type and grade tested in the present study.

4.1.2 PVC Drainage Piping

The following statements and conclusions can be made from the data analysis in terms of leaks, thermal deflections and permanent dimensional changes:

1. The performance of both PVC test assemblies was satisfactory from the standpoint of thermal deflection and permanent change in length.

2. The maximum compressive stress recorded was considered to be within acceptable limits (much lower than 2,000-psi design hydrostatic (tensile) stress levels used by the industry for PVC and CPVC pipe of the type and grade tested in the present study.

4.2 Internal Shock Pressure

The following statements can be made from the water hammer test results:

1. A fatigue life curve can be established for a given test temperature.

2. As the temperature increases, the number of pulses necessary to produce failure at a given peak pressure decreases (from approximately 160,000 pulses at 500 psi and 75° F to less than 25,000 pulses at 5000 psi and 120° F).

3. At the maximum temperature rating of 180° F (82° C) specified for this material by the manufacturer, a very large number (in excess of 350,000) of pressure surges to 150 psi (1.03 MPa) were withstood without failure.

4.3 Future Evaluation needs:

1. Performance acceptance criteria are needed for the evaluation of the long-term durability of new piping materials when subjected to pressure shock and/or the intermittent cyclic flow of hot water. Experience to date with CPVC residential hot water piping has been encouraging when the industry

recommendations on the design and installation of the piping system have been followed. A DE Journal* survey conducted in 1976 indicated that approximately 25% of the local codes now allow CPVC for hot and cold water piping.

2. Standard performance test methods are needed for evaluating the ability of new piping materials to meet essential requirements in relation to shock pressure (water hammer) and intermittent transport of hot water. The most important needs relate to methods for estimating the long-term effects of these phenomena on the ability of new piping materials to maintain essential functional performance capability.

   It is believed that test methods patterned after those described herein would be applicable as performance tests, and that the work described in this report provides a meaningful basis for development of the needed Standard Methods. In order to achieve this, the following steps should be taken:

   A. The experimental techniques, methods of measurement and statistical treatment of the data should be improved for simplicity, reproducibility and accuracy.

   B. The procedures should be tried on a wider range of materials than were used in the present study. This could be the basis for the accomplishment of the objectives of A.

   C. The results of the present study plus the results of steps A and B should be offered to the national standardizing organizations having an interest in developing performance evaluation methodology.

3. Since the series of tests described in this report was conducted, additional field service history of thermoplastic piping materials (e.g. CPVC, PB, ABS, PVC) has been accumulated and there have been changes in code acceptance of thermoplastic piping. This information should be identified and examined periodically. It would be beneficial to coordinate this systematic updating of service history and code acceptance with acceptance surveys conducted by the DE Journal.

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* Published monthly by the Construction Industry Press, Inc., 522 North State Rd., Briarcliff Manor, N.Y. 10510

5. REFERENCES

[1] Water Hammer and Noises in Water-Piping Systems - Chapter VIII of Water-Supply Piping for the Plumbing System, F. M. Dawson and A. A. Kalinske, Technical Bulletin No. 3, National Association of Master Plumbers, 1942.

[2] Performance of PVC Pipe in Water Distribution Systems; R. T. Hucks, Jr.; Modern Plastics, September, 1972.

[3] Special Report to AWWA Relative to PVC Pipe, Plastics Pipe Institute.

[4] *Water Hammer Arrestors Standard PDI-WH201, Plumbing and Drainage Institute, September, 1974.

[5] Engineered Mechanical Water Hammer Arrestors. Jay R. Smith Mfg. Co. Catalog J-70, Piscataway, New Jersey.

[6] Theory of Water Hammer and Shockstop Sizing. Wade Specification Manual 1976, Wade Division - Tyler Pipe Industries, Tyler, Texas.

[7] The Deflection of Thermoplastic Pipe Resulting from Thermal Cycling; Robert C. Wilging, paper presented at Engineered Plumbing Exposition, American Society of Plumbing Engineers, Chicago, Ill., September, 1970.

[8] Elevated Temperature Cycling Test, Appendix G of British Standard 4514: 1969, Specification for UPVC Soil and Ventilating Pipe, Fittings and Accessories, British Standards Institution, London.

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* See also: Water Hammer Arrestors. ANSI A112.26.1 - 1969 (Reaffirmed) 1975), American Society of Sanitary Engineering and the American Society of Mechanical Engineers.

6. APPENDIX

6.1 Definitions and Nomenclature

ABS: Acrylontrile-butadiene-styrene, a thermoplastic material used in drain, waste and vent piping systems and also for shallow-well water piping and for gas distribution. The minimum content of each component is: acrylontrile, 13 percent; butadiene, 5 percent; and styrene and/or substituted styrene, 15 percent.

Aging: The effect on materials of exposure to an environment for an interval of time; also, the process of exposing materials to an environment for an interval of time. (ASTM)

Code: As related to plumbing work, usually an ordinance, with any subsequent amendment thereto, or any emergency rules or regulations which a city or a governing body may adopt to control the plumbing work within its jurisdiction.

CPVC: Chlorinated poly (vinyl chloride), a thermoplastic material used for piping in hot and cold water distribution systems.

DWV System: All the sanitary drainage and vent piping inside a building or relevant portion thereof, including the building drain to its point of connection with the building sewer.

Fitting: A device used to join or to terminate sections of pipe.

Horizontal Branch: A drain pipe extending laterally from a soil or waste stack or building drain with or without vertical sections or branches, which receives the discharge from one or more fixture drains and conducts it to the soil or waste stack or to the building drain.

Pipe: A term applied generally to tubular products and materials commonly used to conduct or transport fluids or gases. In this specific nomenclature, "pipe" usually has greater wall thickness than similar products called "tube" or "tubing."

Plastic Pipe: A hollow cylinder of plastic material in which the wall thickness is usually small when compared to the diameter and in which the inside and outside walls are essentially concentric. See plastic tubing. (ASTM)

Piping: This term has a broader meaning than the term "pipe". For example, "cold water piping" includes the pipe, tube, or tubing used to conduct the cold water; the fittings used to control or regulate the rate of flow and the direction of flow. "Hot water piping" and "drainage piping" have similarly broad meanings.

Plastic Tubing: A particular size of plastic pipe in which the outside diameter is essentially the same as that of copper tubing. See plastic pipe. (ASTM)

Polybutylene Plastics: Plastics based on polymers made with butene as essentially the sole monomer. (ASTM)

Poly(vinyl chloride): A resin prepared by the polymerization of vinyl chloride with or without the addition of small amounts of other monomers. (PPI)

Poly(vinyl chloride) Plastics: Plastics made by combining poly (vinyl chloride) with colorants, fillers, plasticizers, stabilizers, lubricants, other polymers, and other compounding ingredients. Not all of these modifiers are used in pipe compounds. (PPI)

Potable Water: Water free from impurities in amount sufficient to cause disease or harmful physiological effects and conforming in its bacteriological and chemical quality to the requirements of the United States Public Health Service Drinking Water Standards or the regulations of the public health authority having jurisdiction. (NSPC)

Pressure: When expressed with reference to pipe, the force per unit area exerted by the fluid in the pipe.

Pressure Shock: A general term indicating a fluctuation in pressure (water hammer on pressure surge) within a piping system caused by a relatively abrupt increase or decrease in flow velocity. Water hammer is usually associated with a very sudden decrease of flow velocity often giving rise to high frequency "hammering" noises in pipelines of moderate length in buildings. Pressure surge is usually associated with the fluctuating pressures resulting from less sudden or severe shocks, usually with a lower frequency such as may occur in long pipelines.

Stack: The vertical main of a system of soil, waste or vent piping.

Thermoplastic (noun): A plastic which is thermoplastic in behavior. (PPI)

Thermoplastic (adjective): Capable of being repeatedly softened by increase of temperature and hardened by decrease of temperature. Note: Thermoplastic applies to those materials whose change upon heating is substantially physical. (PPI)

Trap: A fitting or device constructed in a drain so as to provide, when properly vented, a water seal for protection against the emission of noxious or explosive sewer gases, without significantly retarding the flow of sewage or waste water through it.

Trap Arm: Another name for fixture drain.

Vent: A pipe installed to provide a flow of air to or from a drainage system or element thereof so as to provide protection of trap seals from siphonage and back pressure.

Vinyl Chloride Plastics: Plastics based on resins made by the polymerization of vinyl chloride or copolymerization of vinyl chloride with other unsaturated compounds, the vinyl chloride being the greatest amount by weight. (PPI)

Water Distribution (distributing) Pipe: A pipe within the building or on the premises which conveys water from the water-service pipe to the point of usage. (NSPC)

Water Hammer: The term used to identify the hammering noises and severe shocks that may occur in a pressurized water supply system when flow is halted abruptly by the rapid closure of a valve or faucet.

Water Outlet: A discharge opening through which water is supplied to a fixture, into the atmosphere (except into an open tank which is part of the water supply system), to a boiler or heating system, or to any devices or equipment requiring water to operate but which are not part of the plumbing system. (NSPC)

Note: Definitions found in this section are to be identical with those identified by the abbreviations (ASTM), (NSPC), and (PPI). For those definitions listed but not identified by one of the abbreviations, some modifications have been made to definitions which may bave been found elsewhere in the technical literature.

(ASTM) - ASTM D 883-73a
(NSPC) - National Standard Plumbing Code 1975
(PPI) - PPI-TRI-November 1968

6.2 Units of Measure and S.I. Conversion Factors

A recent NBS document LC 1056 dated November 1974 and revised August, 1975 reaffirms, clarifies and strengthens the policy of NBS to lead in the use of the metric system. In keeping with the intent of LC 1056, the following guidelines have been adopted for this report:

1. Equations or formulas for which metric equivalents do not yet appear in the engineering literature are expressed in U.S. customary units.

2. When measurements have been reported in the literature in U.S. customary units, the equivalent values in the International System of Units (S.I.) are reported alongside enclosed in parantheses.

3. No S.I. equivalent for descriptive data not affecting calculations or results is required. For example, when nominal values of units appear as adjectives such as 3-inch pipe, 2 x 6-inch stud, and 2-oz. bottle, etc. designations expressed in customary units are acceptable.

4. Exceptions to the exclusive use of S.I. units are allowed when communication or readership would be limited by the exclusive use of S.I. units.

5. The following conversion factors from ASTM E380-74 are appropriate for units of measure that appear in this report:

   Acceleration

   1 foot per second per second = .3048 meter per second per second

   Length

   1 inch (in.) = 0.0254 meter (m)
   1 foot (ft.) = 0.3048 meter (m)

   Mass

   1 slug = the unit of mass to which 1 pound force can impart an acceleration of 1 foot per second per second
   1 pound-mass (lbm) - .4535924 kilogram

   Temperature

   1 Degree Fahrenheit (°F) = $(1.8)^{-1}$ kelvin (K) or (°K)
   Temperature Fahrenheit (°F) = (459.67 + temp. °F)/1.8 kelvins (K)

Time

1 hour (h) = 60 minutes (min.) = 3600 seconds (s)

Velocity

1 foot per second (fps) = 0.3048 meter per second (m/s)

Force

1 pound-force (lbf) = 4.448222 newtons (N)

Pressure

1 pound-force per square inch (psi) = 6894.757 pascals (Pa)
6.894757 kilopascals (kPa)
.006894757 megapascal (MPa)

1 inch of water column at 60° F = 248.84 pascals (Pa)

Volume

1 U.S. liquid gallon (gal.) = 0.003785412 meter^3 (m^3)
3.785412 liters (L)

Flow Rate

1 U.S. gallon per minute (gpm) = 0.0000630902 meter^3/second (m^3/s)
= 63.0902 centimeters^3/second (cm^3/s)
= 0.0630902 liters/second (L/s)

1 cubic foot per second (cfs) = 0.028316585 meter^3/second (m^3/s)
= 28.31685 liters/second (L/s)

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Evaluation procedures are described that were used at the National Bureau of Standards (NBS) for simulating the long-term effects of water hammer (shock pressure) and cyclic hot water flow (thermal cycling) on chlorinated polyvinyl (CPVC) thermoplastic pressure piping assemblies. Also included are the procedures used to study the effects of thermal cycling of two (2) polyvinyl chloride (PVC) thermoplastic drainage stack assemblies. The results obtained using these test procedures are presented and, in addition, related work of other investigators is briefly reviewed.

The shock pressure results show that a fatigue life curve can be established for CPVC as a function of temperature and pressure. As the temperature is decreased the number of shock pressure applications necessary to produce failure increases. An estimated use-life of at least 50 years was indicated at the maximum test temperature of 180° F (82° C) with pressures of 150 psi (1034 kPa).

With intermittent hot water flow all test assemblies were performing satisfactorily when the test was terminated after more than 1500 cycles had been completed.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Intermittent hot water exposure tests of thermoplastic pipe; pressure shock in thermoplastic pipe; water hammer in thermoplastic pipe.

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